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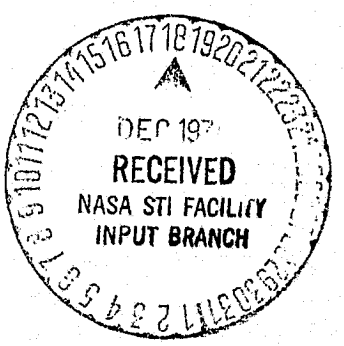
COST ESTIMATING METHODOLOGY AND TECHNIQUES FOR PREPARING INDUSTRIAL-ENGINEERING TYPE MANHOUR AND MATERIAL-BASED COST ESTIMATES

By Rodney D. Stewart
Systems Analysis and Integration Laboratory

November 1975



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16. ABSTRACT

The increasing restriction on funds available for space research, coupled with rapidly rising costs of labor, materials, energy, and services, has resulted in a need for application of the best available techniques for estimating the costs of products, goods, and services required for the research, development, production, delivery, and operation of space flight and ground support hardware. Experience has shown that accurate cost estimating can result in significant cost savings through improved planning, effective budgeting, and optimum time-oriented utilization of resources. There are many methods of developing credible, supportable, and consistent cost estimates.

This report briefly describes the various methods of cost estimating and presents in detail the method and benefits of industrial engineering type manhour and material based cost estimates as practiced in the Science and Engineering Directorate of the Marshall Space Flight Center. This document can be used as a handbook for individual estimators wishing to avail themselves of the proven techniques, methods, and computer programs which have been developed to formulate this type of cost estimate.

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COST ESTIMATING METHODOLOGY AND TECHNIQUES FOR PREPARING INDUSTRIAL-ENGINEERING TYPE MANHOUR AND MATERIAL-BASED COST ESTIMATES

I. INTRODUCTION AND BACKGROUND

Cost estimating at the Marshall Space Flight Center (MSFC) has been performed in three general functional areas. Each of the functions has consistently provided top level estimates. The method of development of estimate rationale and intermediate and lower level data has varied. Each of these estimates has its optimum purpose and place, and each is complementary of the other in the overall estimating process.

"Grounds-up" industrial engineering manhour and material based estimating techniques have traditionally been applied to estimating construction activities. In facilities programs, the procurement process requires generation of sufficient data to accommodate this methodology. By beginning with and developing through the architect-engineering phase the production of final drawings and specifications, direct material take-off and labor computations, and the development of precise estimates, are possible. Parametric or statistical techniques have been applied for total program/project costing in early phases of program development. In this method, analogies are drawn from the most similar historical experience available. This method has produced realistic planning estimates for a large number of programs, many of which have been acquired by MSFC as new program starts. Industry cost data, generated in proposals and in cost reporting under contracts are normally based on industrial manhour and material type pricing. The past several years of estimating activity to develop in-house industrial engineering type estimates for approved projects has shown that a very beneficial planning and learning experience can be gained by organizing an in-house government activity for conceptualizing, in detail, the total program parameters (cost, schedule, and performance).

The in-house Science and Engineering estimating activity has been and is still being used for the support of source evaluation activities, the estimating of changes, the preparation of procurement requests and proposals, and the performance of special trade-off studies.

Tables 1, 2, and 3 show a typical grouping of the elements of cost which normally comprise product costs. Since cost definitions and accounting systems vary, the specific cost elements listed under each cost category may vary substantially. It is not expected that every cost analysis will encompass a rigorous treatment of all of the subelements of cost, but the basic fact of the existence of these costs must be recognized in the preparation of a cost estimate. The cost estimating method described in this report assumes the availability and use of drawings, specifications, schedules, work breakdown structures, and program ground rules for a project to develop manhour, material, computer, and travel estimates of resources required to accomplish the total job.

II. METHODOLOGY

The most important aspect of making a cost estimate is the preparation of a plan which will assure that the proper information and skills will be available to provide inputs to the cost estimate. Since virtually every project is multidisciplinary in nature, it is necessary to identify organizations and/or individuals at MSFC who are qualified and capable to provide expert advice on the resources required to accomplish each part of the job. Since this expertise can very seldom be found in one place, it is necessary to form a small estimating team which will work cooperatively with the individual responsible for managing or coordinating the cost estimate. Team assignments are usually aligned with the work breakdown structure. Prior to assembling the cost estimating team for its first meeting, it is necessary to bring together as much information as possible concerning the project which will be useful in preparing the cost estimate. The following information is required before a cost estimate "kick-off" meeting can be held:

1. A schedule for the estimating activity.

2. A work breakdown structure (a typical work breakdown structure is shown in Figure 1).

TABLE 1. FACTORS AFFECTING PRODUCT COST — DIRECT COSTS

Direct Costs

1. Labor

- Engineering
- Manufacturing
- Tooling
- Quality and Reliability Assurance
- Testing
- Planning
- Tool Design
- Tool Maintenance
- Packaging
- Shipping
- Transportation

2. Materials and Subcontracts

- Raw Materials
- Partially Finished Materials (Forgings)
- Parts, Sheet Stock, Fuels and Lubricants
- Tool Materials
- Equipment and Supplies

3. Other Direct Costs

- Travel Costs
- Computer Services
- Reproduction Services
- Training Costs

TABLE 2. FACTORS AFFECTING PRODUCT COST — INDIRECT COSTS

Indirect Costs

1. Labor Burden

- Bonuses
- Health Insurance
- Paid Holidays
- Paid Vacations
- Social Security
- Supervisor' s Salary
- Pensions

2. Material Burden

- Handling
- Inventory Control
- Purchasing Costs
- Storage

3. Overhead

- Amortization
- Bid and Proposal Costs
- Claims
- Communications
- Custodial
- Depreciation
- Heating and Cooling
- Independent Research and Development
- Industrial Relations
- Insurance
- Lighting
- Maintenance
- Operating Supplies
- Power
- Rental of Buildings
- Waste Disposal
- Water

TABLE 3. FACTORS AFFECTING PRODUCT COST — OTHER COSTS

Other Costs

1. General and Administrative (G&A) Expenses
   - Administration
   - Advanced Design
   - Advertising
   - Corporate Expenses
   - Executive Salaries
   - Finance
   - Marketing
   - Personnel Department
   - Research
   - Training Department
   - Corporate Taxes

2. Fee (Profit or Earnings)
   - Return to Stockholders
   - Reinvestment
   - Capital Equipment and Tooling

3. Furnished Equipment[a]
   - Fuels and Lubricants
   - Subassemblies
   - Facilities
   - Equipment
   - Spare Parts
   - Experiments
   - Selected Services

4. Other
   - Warrantee Costs
   - Hazardous Pay
   - License Fees

a. Listed only as a "below-the-line" cost.

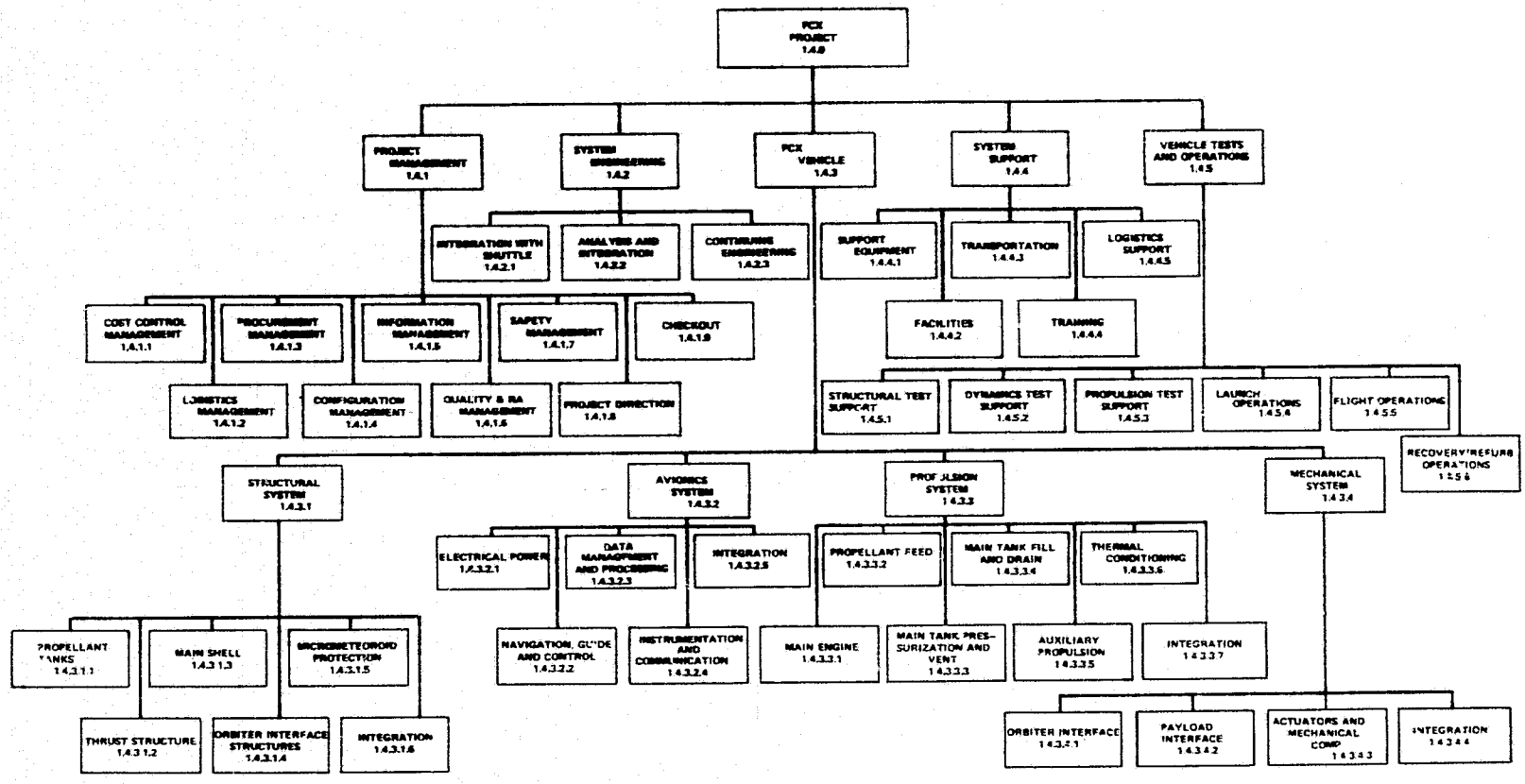


Figure 1. Typical work breakdown structure.

3. A work breakdown structure dictionary (Appendix A is a typical work breakdown structure dictionary).

4. A program schedule showing key DDT& E milestones and hardware delivery dates.

5. A make-or-buy structure showing which work elements are to be done in-house versus what elements will be performed out-of-house.

6. Drawings or sketches, and specifications for the item.

7. Programmatic ground rules concerning spares, tooling, GSE, GFE, etc.

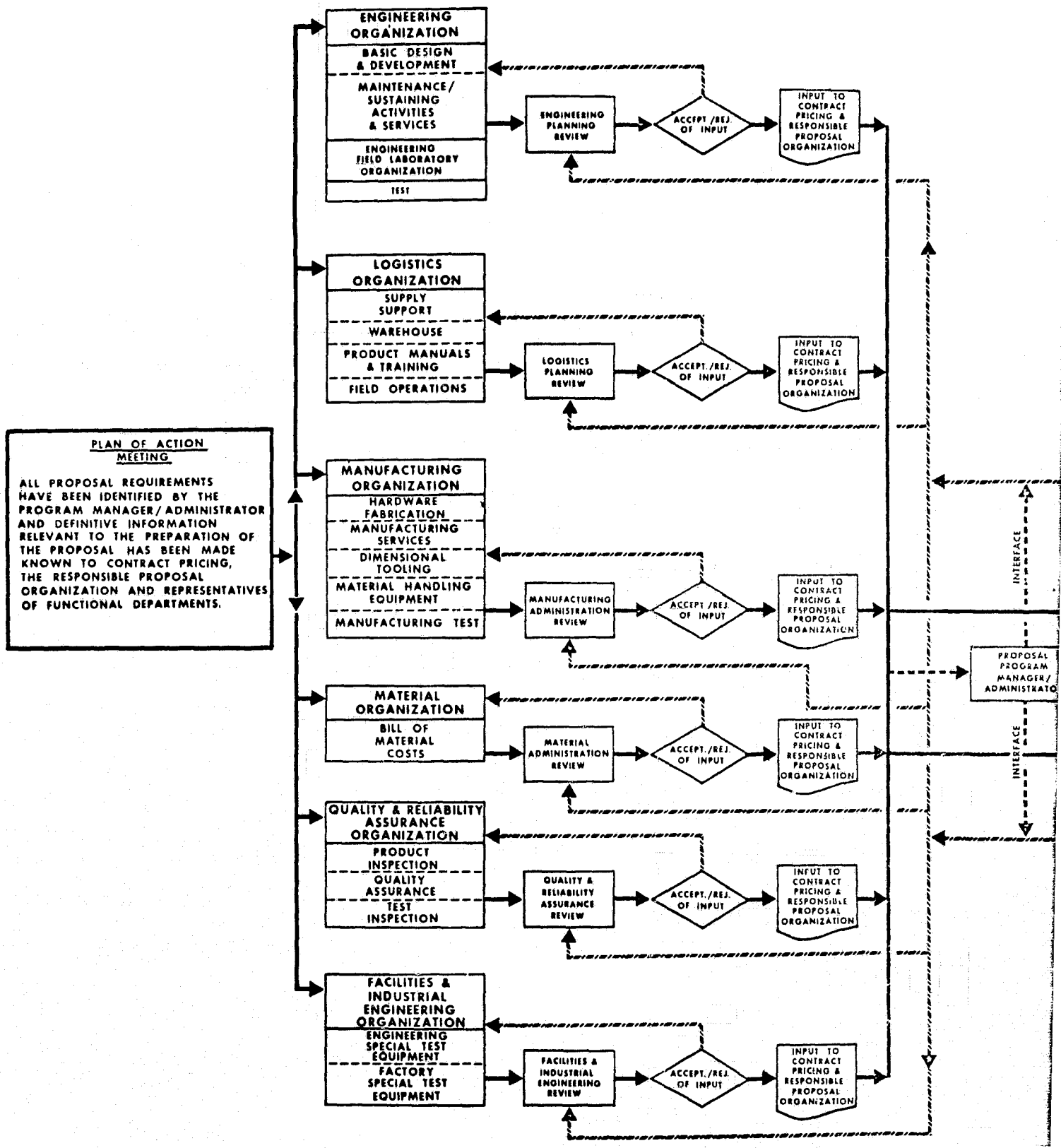
8. Cost estimate forms and instructions on how to complete them.

A kick-off meeting is then held for the purpose of implementing the estimate work statement and schedule. Participants at these meetings will include representatives of Program Office, Science and Engineering Laboratories and an estimate manager designated from the Cost Analysis Office. The objective of the initial meeting is to inform all of the concerned performing organizations of their responsibilities. Estimate input requirements are defined and target dates are fixed as to when such inputs are to be completed and submitted to the estimate manager. Subsequent meetings are held if required to clarify any open questions and to discuss other aspects of the estimate work statement when needed.

Following these meetings, a plan of action memorandum is prepared and distributed to all concerned parties which formally sets forth the established commitment dates for inputs as well as the programmatic assumptions which are to be applied.

The attached data flow charts (Figs. 2 and 3) illustrate the flow of data for industrial cost proposals and government cost estimates respectively. The functional identifications shown on the chart under the performing organizations are typical of the effort performed within the several Science and Engineering Laboratories.

Wherever feasible, the estimate is developed by the preparation of a process or manufacturing plan. All of the steps required to design, build, test, deliver, and operate the item are envisioned, and manhours or manloading are provided for each step in each work breakdown structure element. In the



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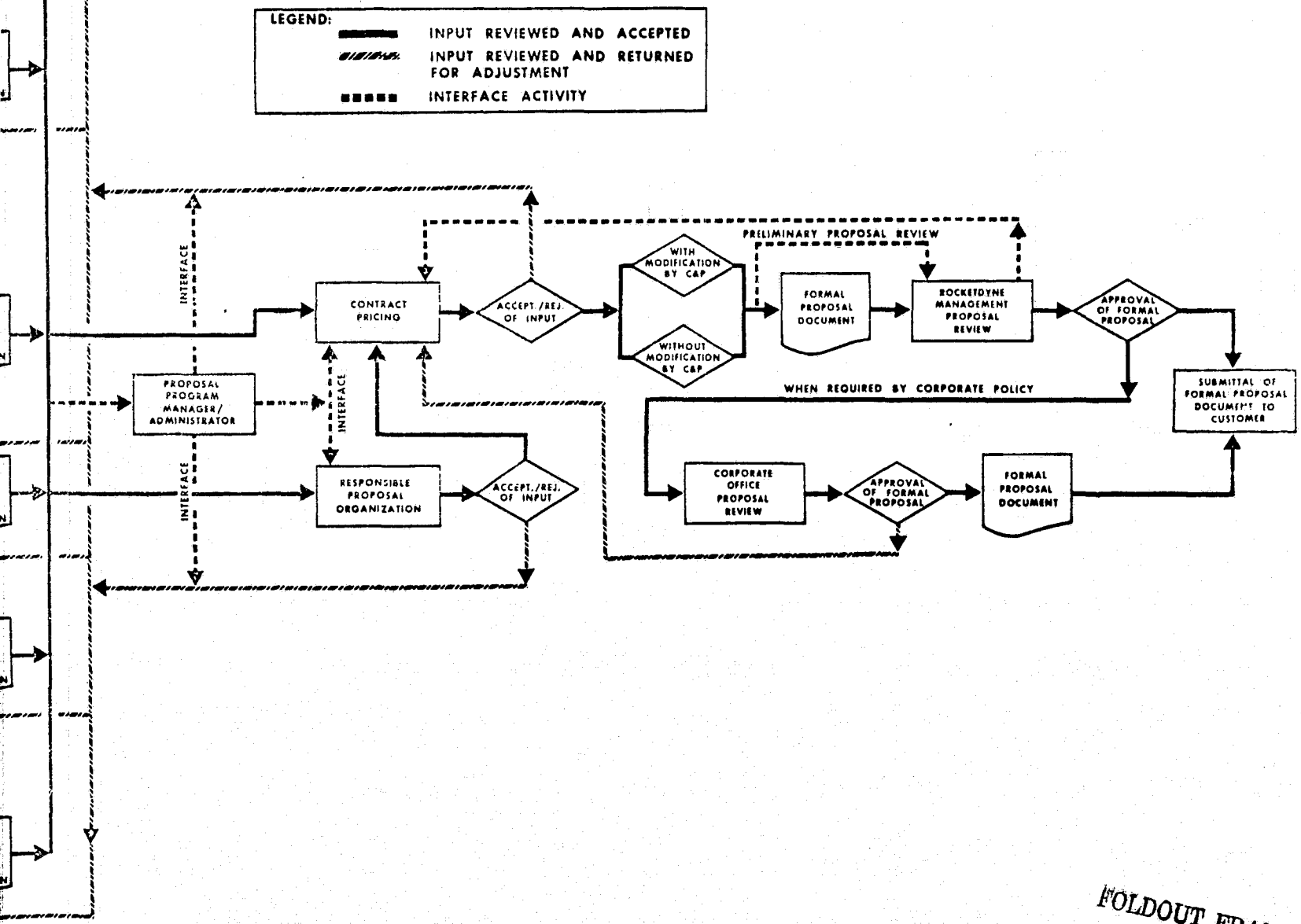

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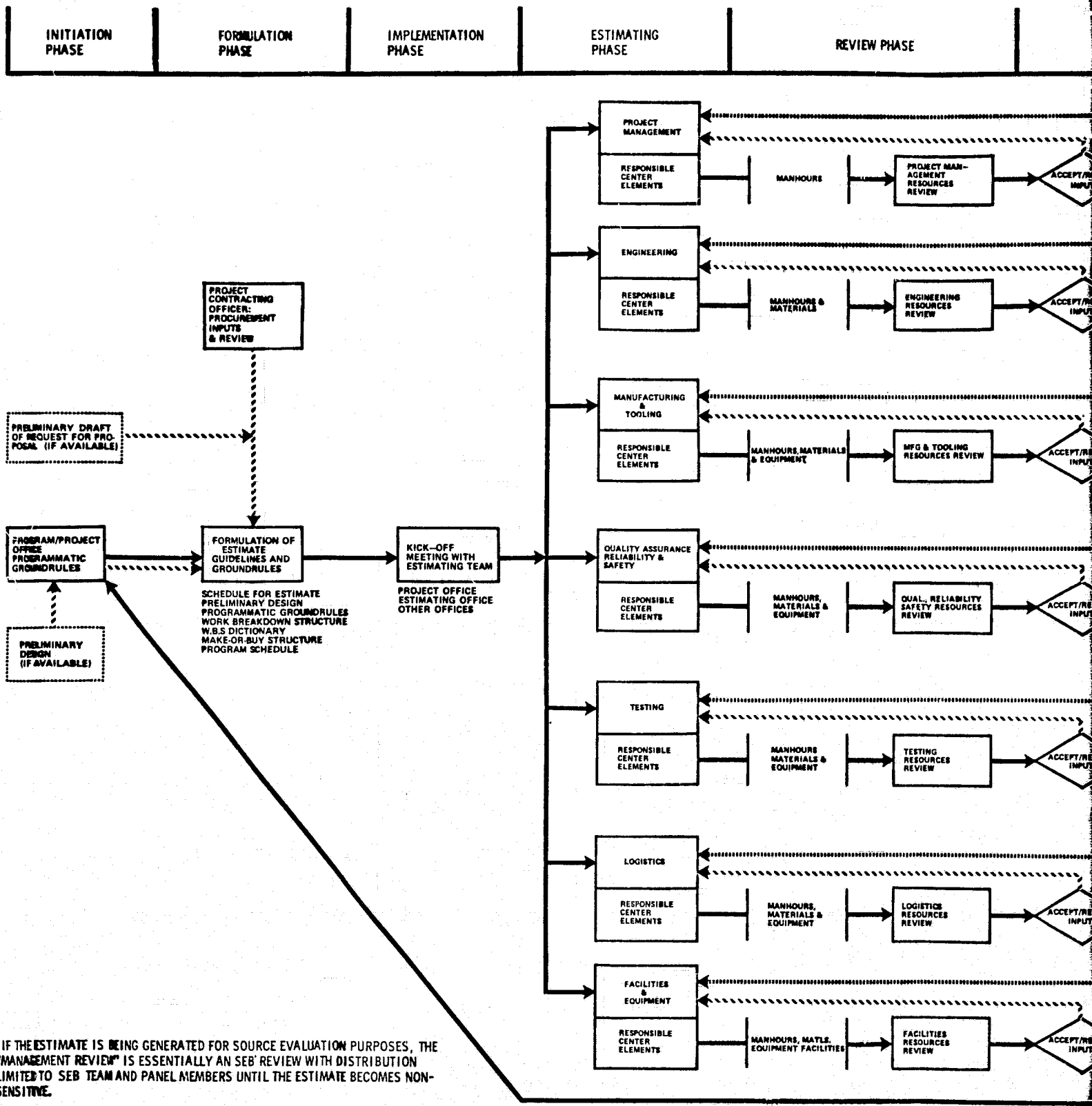
Figure 2. Typical contractor proposal data flow chart.



* IF THE ESTIMATE IS BEING GENERATED FOR SOURCE EVALUATION PURPOSES, THE "MANAGEMENT REVIEW" IS ESSENTIALLY AN SEB REVIEW WITH DISTRIBUTION LIMITED TO SEB TEAM AND PANEL MEMBERS UNTIL THE ESTIMATE BECOMES NON-SENSITIVE.

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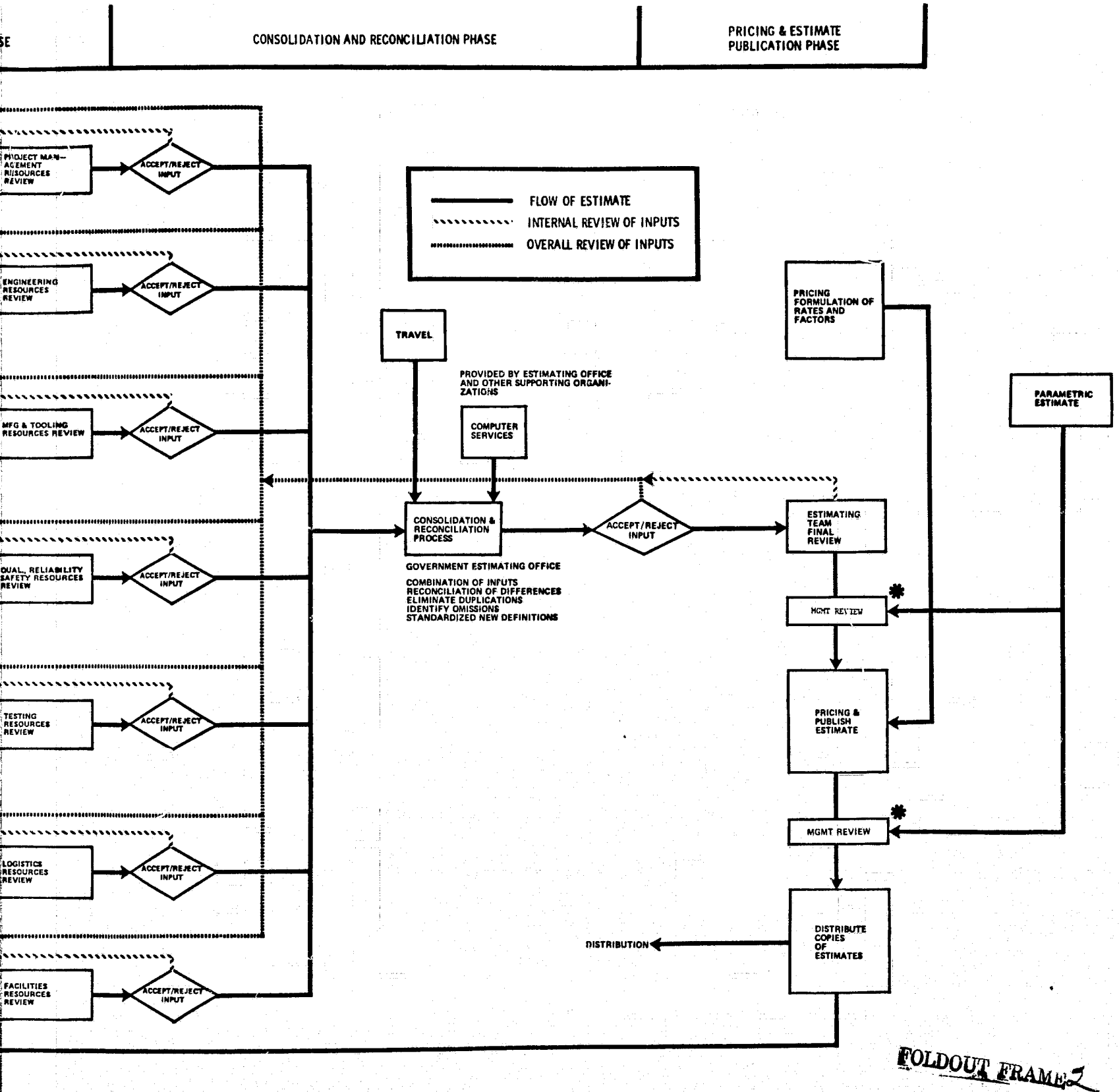


Figure 3. Flow diagram of a cost estimate.

same manner listings of required materials, supplies, and equipment are prepared and costs of these items are provided if feasible (if not, the Cost Analysis Office, working with the Procurement Office, will provide the material cost estimates). Care must be taken to include all direct charges such as travel costs, computer changes, spares, refurbishment, etc.

The preparation of "grounds-up" industrial engineering-type estimates requires extensive planning, coordination, and interface with many other MSFC organizations. In all instances support should be drawn from areas of known expertise since estimate quality depends upon the capability to accumulate the most professional expert opinion available in the required disciplines. Specific input can be obtained from the following MSFC organizations:

1. Administration and Program Support:

a. Pricing support can be obtained from the Procurement Office.

b. Information relating to available Government-owned equipment and facilities can be obtained from the Management Division, Logistics Office.

c. Specific proposed contractual provisions to be included in any resultant RFP and contract which would affect the cost or the format of the cost proposal can be obtained from the various Procurement Office Contracting Officers.

d. Packing, packaging, shipping, transportation, and logistics management requirements and costs can be obtained from the Logistics Office.

e. Facility design and construction, modification, and operations costs are provided by the Facilities Office and the Shuttle Construction Office.

2. Program Offices supply the overall program parameters for program implementation. The Program/Project Managers for MSFC programs and projects locate specific expertise within the center for estimate input. Very close coordination is required with the requiring organization in developing estimate guidelines, work breakdown structures, program assumptions, and estimate rationale for the final estimate. Very close and continuous communications have been found to be essential between the estimate manager and the program personnel to assure that omissions and redundancies are identified and eliminated during the estimate development.

3. The Science and Engineering Laboratories have provided engineers, technicians, and other experts for developing manhour and material estimates for the functional program requirements. Each estimate developed to date has required numerous interfaces with Science and Engineering Laboratory personnel in clarifying and refining guidelines, assumptions, and manhours or material estimates.

In addition to contributions of Science and Engineering Laboratories in estimate development, The Computer Services Office in Administration and Program Support provides computational capability which permits rapid computation of the total estimate from estimate inputs. This program, which is being modified and improved as innovative approaches are identified, is described in Appendix B.

A. Completing and Assembling a Cost Estimate

When all input data are received, the Cost Analysis Office prepares an initial accounting tabulation of all the inputs from the contributing laboratories and offices. Following the receipt of all inputed data, the estimate team leader or manager takes the following steps:

1. Reviews the input for areas where the input is either not in the proper work breakdown order or is nonresponsive to the estimate plan of action.

2. Reviews the input for duplications, overlapping effort, and missing items.

3. Reviews the input for adequacy of rationale and validity of techniques used by the inputing source.

4. Confirms material costs through procurement sources.

5. Calls meetings and arranges interviews as required for obtaining further information and resolution of differences.

After all inputs and backup data are reviewed and analyzed by the Cost Analysis Office, the data are assembled and completed by first computing and identifying the elements of cost by task on an overall spread sheet. This breakdown conforms with the item or task breakdown of the respective work breakdown structure items.

The priced fiscal year spreads are performed by use of the computer which stores preestablished rates and factors (Appendix B).

The summary cost sheets printed by the computer are verified for accuracy and then are collated into the formal estimate together with rationale statements, work descriptions, work flow diagrams, and drawings as appropriate. Final publication and distribution in a bound report are the responsibility of the Cost Analysis Office. The contents and format of a typical cost estimate are shown in Figure 4.

For protection against compromise of sensitive information, procedures and controls in the form of locked work areas and locked files have been established within the Cost Analysis Office. Estimates are marked "SEB Sensitive" or "For NASA Use Only," depending on the intended use. Inter-office distribution of data and final estimates are made on a handcarry basis. These procedures are spelled out in an intra-office memorandum.

Due to the diversity of functions that are associated with the separate inputting organizational elements, a complete description of each organizational discipline would be too voluminous for this report. However, Appendix C summarizes some of the fundamental steps employed in the manufacturing estimates, which best typify the depth of detail and understanding necessary to a sound estimating approach.

Appendix D provides a selection of worksheets which have been adapted for use in accomplishing the submittal of estimate input from the respective laboratories and offices. Explanatory notes and functional definitions pertinent to the preparation of the forms are also attached.

B. Follow-up and Tracking After Government Estimate Completion

For the purpose of maintaining continuity and extending the use of the Government estimate, it is planned that a continuing history be maintained on each estimate throughout the project life. Such history shall include, but not be limited to, the following:

1. Copy of the completed estimate (preproposal receipt).

2. Related backup inputs from estimators.

3. Total cost comparison analysis (Government estimate versus bidder proposals).

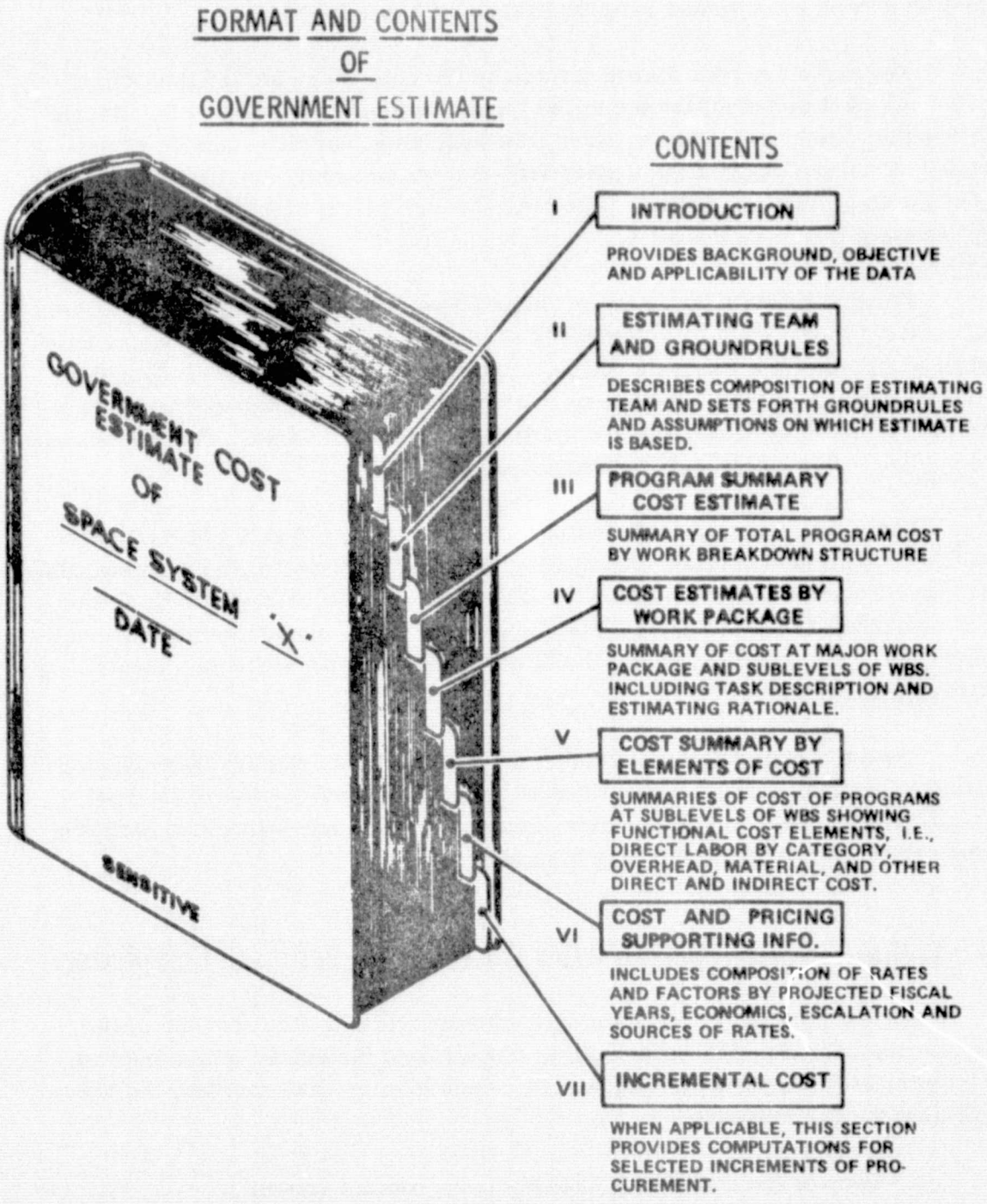


Figure 4. Format and contents of Government estimate.

4. Direct Labor, Overhead and G&A Rate comparison (Government estimate versus bidder proposals).

5. During the SEB, if pertinent changes are made to the Government estimate, a detailed record will be kept of the final updated Government estimate.

6. Comparative analysis of Most Probable Cost (Government assessment of potential bid responses to lowest work breakdown structure level).

7. Summary of the basic negotiated cost by work breakdown structure. Hours and Total Dollars.

III. ESTIMATE USES AND BENEFITS

A number of benefits of performing detailed "grounds-up" estimates have been observed and other benefits are postulated to be inherent in the estimating process as practiced in performing trial specific estimates. These observed and potential benefits are as follows.

A. Observed Benefits

1. Pre-RFP Uses.

a. Cost estimate encourages a disciplined approach to:

1. Formulation of Work Breakdown Structure.

2. Orderly, logical, and meaningful descriptions of work breakdown structure elements.

3. Layout of total program approach and plans.

b. The cost estimating activity identifies and assembles Center expertise to estimate and to support functional areas.

c. Estimates demand an analytical process in program definition and planning.

d. Estimates result in the identification of areas requiring specific treatment in subsequent RFP's.

e. Familiarity developed through planning for and making the estimate provides detail which is transferable to the source selection process.

f. The estimating process encourages and requires individuals who will be managing the program to develop a more thorough knowledge of the project being estimated.

g. A completed cost estimate aids in making Government make-or-buy decisions.

2. Source Evaluation and Selection Uses.

a. Cost estimate serves as an established baseline for comparison of proposals.

b. Estimating process forces consideration of alternatives in:

1. Scheduling of activities.

2. Funding requirements.

3. Investment analysis.

4. Make-or-buy structure.

c. Comparison of estimate with proposals identifies "buy-ins" and facilitates an in-depth restructuring if costs appear unrealistically low.

d. Development of a cost estimate establishes compatible formats for comparative analysis of proposals down to the lowest work breakdown structure level.

e. A Government estimate supports presentation to and selection by the administrator (source selection official).

f. An estimate contributes to establishing a tenable prenegotiation position.

B. Potential and Achievable Benefits

1. Negotiation Uses.

a. Government estimating process establishes a comparative baseline for in-depth evaluation of selected proposal.

b. The estimate provides a baseline for establishing Performance Measurement System (PMS) parameters.

c. Existence of a Government estimate permits rapid identification of contractor proposal/estimate variances.

d. Existence of an estimate permits elimination of extensive detailed work in areas of agreement, thereby reducing negotiation time for contractor and MSFC through rapid comparison.

e. A cost estimate provides means of determining validity, increased confidence, and realism in detailed negotiations for each element of work.

f. Preparation of a cost estimate improves basis for incentive-fee construction.

g. Use of an independent estimate assists in establishing funding levels for realistic performance.

h. The estimate provides basic understanding of proposal discrepancies and provides a means of making credible adjustments.

i. An adjusted Government estimate provides a baseline for estimating the cost of change in the programs as the programs progress.

2. Contract Management Uses. A cost estimate:

a. Establishes documented bases for:

1. PMS comparisons

2. Assessment of progress

3. Possible termination settlements

4. Estimation of changes throughout the life of the contract.

b. Quantifies alternative impacts of changes (provides a basis for programmatic cost trade-offs and decisions).

c. Structures and correlates both contractor and Government performance tracking measures.

3. Uses in Program Management. The use of a Government estimate:

a. Contributes to development of data bank (base) for better future estimates.

b. Rationalizes program planning and improves information for decision-making by:

1. Identification of possible alternatives

2. Quantification of consequences of selecting each alternative.

c. Permits increased simplicity and more meaningful presentation of data.

d. Helps police cost consciousness in program formulation and implementation.

e. Can contribute to confidence in program managers' decisions thereby fostering more aggressive management.

IV. SUMMARY AND CONCLUSIONS

The preparation of detailed industrial engineering type, manhours and materials cost estimates and the use of these estimates in trade-off studies, budgeting, source evaluation, and procurement has resulted in significant benefits to the using organization in understanding a project, in budgeting for the project, and in selecting an approach and a contractor which is most likely to be cost effective. The effort put into the preparation of cost estimates has proven to be well justified when the perceived benefits are evaluated. Adherence to the techniques described in this report, while not necessarily a guarantee of success, will enhance the using organization's ability to plan and to perform a project within its estimated resources.

APPENDIX A

TYPICAL WORK BREAKDOWN STRUCTURE DICTIONARY

1.4.0 PCX PROJECT

This overall category includes the total complex of labor, travel expenses, services, materials, tooling and equipment, facilities, prime contracting and subcontracting required for the concept selection, design, development, manufacture, assembly, testing, modification (in the case of the DDT&E vehicle), checkout, preparation to ship to KSC or WTR, transportation, preparation to launch, launch, flight operations, recovery, and refurbishment in preparation for a second launch. Subordinate element descriptions indicate specific inclusions and exclusions in this summary category.

1.4.1 PROJECT MANAGEMENT

This includes the overall administrative effort of planning, organizing, coordinating, directing, controlling, and approving which is required to accomplish the program objectives. Checking out the vehicle prior to release from the manufacturer is also included, principally because many organizational elements are involved. This element is subdivided as shown on WBS Sheet 1. These subelements are defined below:

1.4.1.1 COST CONTROL MANAGEMENT

This refers to those activities which assure the integrated planning, scheduling, budgeting, work authorization and cost accumulation of all tasks performed during the PCX program. It provides project performance planning, including preparation and maintenance of the Project Management Plan, project schedules, resource status reports and cost forecasting. Also included are the establishment of project performance criteria, the control of change parameters, and the analysis and summary of measurement data. Continuous monitoring of all functional management disciplines is provided for central direction and control of the overall project, including timely resolution of problem areas to insure that established schedules are met. Establishment, operation, and maintenance of a Management Information Center is a portion of this element. Other task elements include interface with the cognizant customer, contract and proposal administration, and visitation control.

Specific Inclusions:

1. Updating of the Work Breakdown Structure Dictionary.

2. Preparation and maintenance of a cost distribution section in the Financial Management Office coding system.

3. Monitoring of all laboratory budget allocations.

4. Maintenance of surveillance of cost accounts in order to assure reasonably accurate accrued charges.

5. Identification of technical performance measurement parameters and values, and technical achievement planning including preparation, submittal, and maintenance of a Technical Performance Report.

1.4.1.2 LOGISTICS MANAGEMENT

This element provides the effort to implement, operate, and maintain a logistics management for support of the PCX and its related ground equipment. Included in this element are the preparation and maintenance of the following documents:

1. Systems Support and Logistics Plan

2. Recommended Spare Parts List

3. Maintenance Analysis

4. Analysis of Support Requirements

Other examples of policy and procedures generated by this WBS element are:

Spares Management

Inventory Management

Repair and Overhaul Policy

Propellant and Gasses (Forecasts and Usage Reports)

Warehousing and Storage Policy

Transportation Analysis and Planning

Specific Exclusions:

Those operating functions relating to implementing policy and procedures set by Logistics Management are covered by WBS 1.4.4.5, Logistics Support.

1.4.1.3 PROCUREMENT MANAGEMENT

Management and technical control of interdivisional work, subcontractors and vendors are provided by this element. Tasks included are the providing of contractural direction to other divisions, subcontractors and vendors; authorizing subcontractor tooling and equipment; analyzing subcontractor reports; conducting subcontractor and vendor reviews; and on-site coordination and evaluation of procurements. Also, included are the maintenance of records and submission of required reports relating to the geographic dispersion of minority and small business participation in procurements.

Specific Inclusion:

Coordinate and review all vendor data, maintain vendor data specification, and maintain vendor technical data file.

Specific Exclusions:

1. Responses to vendor inquiries concerning changes to, deviation from, or interpretation of design or other requirements is included in the appropriate hardware or service element.

2. Establishment of supplier performance measurement criteria and survey of vendor facilities, and procedures to determine adequacy are included under the Management elements of Cost Control, Quality and Reliability Assurance, and Safety respectively.

1.4.1.4 CONFIGURATION MANAGEMENT

This element provides a system for defining the hardware and software configurations at any point in time throughout the project life cycle. This system provides identification of configuration baselines; and a progressive verification that the as-built configuration agrees with the current baseline or that differences are identified. Included in this element are the tasks associated with preparation, maintenance, and submittal of the following:

1. Configuration Management Plan

2. Configuration Status Accounting Report

3. Configuration Baseline Document(s)

4. As-Built Configuration Report

5. Engineering Change Proposals and Requests

Also included are establishment, implementation, and maintenance of specification formats; end-item selection criteria; and procedures for control and accounting of configuration and changes. Provisions for design support, conducting design reviews, audits and analyses and Class II change control are included in the element. Participation in configuration verification to support CEI acceptance and configuration inspection are also covered.

1.4.1.5 INFORMATION MANAGEMENT

This element refers to the overall management process and activities required to ensure proper information control. Services are provided to identify, control, and monitor the preparation of and maintain status of the documentation for the PCX project. Establishment, implementation, and maintenance of the Data Management Plan and procedures are part of this element. Monitoring and preparation of data required by the appropriate Task Agreement are included in this element together with submittal of the data as required. Acquisition of data from subcontractors and vendors is also included. Preparation, maintenance, and submittal of the Data Schedule and Status Report and Accession List are parts of this element. Establishment, operation, and maintenance of a project level information file are also included. Efforts associated with data acquisition, reproduction, and dissemination required by S&E for proper management, control, and definition of the PCX project are included in the appropriate WBS elements. Any audio-visual and photography support and training presentations are also included under the appropriate WBS elements.

1.4.1.6 QUALITY AND RELIABILITY ASSURANCE MANAGEMENT

This element covers those efforts associated with the establishment, implementation, and maintenance of a quality and reliability assurance activity in order to provide quality hardware through systematic procedures, training, analysis, review, and assessment. It includes the development and implementation of plans, requirements, procedures, and controls; design participation;

quality audits; identification and data retrieval; quality control procurement related activities; nonconformance reporting and disposition; metrology; stamp controls; laboratory test support; packaging handling and storage related activities; establishment and monitoring of a Failure Mode and Effect Analysis policy; statistical analysis; Government property control; and flight test/ground operations related activities. This element will prepare, submit, and maintain the Reliability Program Plan and the Quality Control Plan. Training of quality personnel is included under this category.

Specific Exclusions:

1. Those engineering oriented quality, reliability, and safety activities specifically included under 1.4.2.2, PCX, Analysis and Integration.

2. Implementation of the plans prepared by this element are included under 1.4.2.2, PCX, Analysis and Integration.

3. Quality control inspections are charged under the applicable hardware oriented WBS elements.

1.4.1.7 SAFETY MANAGEMENT

This element covers items required in the definition, direction, and monitoring of a safety program that will assure the development of a safe product, prevent accidents and incidents, and minimize hazards to personnel and property. Safety will be an integral part of design, development, manufacturing, testing, handling, storage, and operation. This will be accomplished through training, analysis, safety program assessments; preparation of Project Hazard Summary; development and implementation of procedures, controls, reviews, audits, safety analysis, design participation; and a Safety Plan which covers the safety program and how it will be implemented.

Specific Inclusions:

1. Safety training exercises.

2. Periodic reporting, auditing, certification, working group meetings, and accident investigation.

3. Review of all designs and procedures for compliance with established safety requirements.

Specific Exclusions:

1. Labor and materials used in the making of signs or training aids are charged to the specific hardware WBS element.

2. Implementation of safety programs and practices that can be identified with specific Level 6 WBS items.

1.4.1.8 PROJECT DIRECTION

This function integrates the Level 5 elements defined above, while providing day-to-day management direction of the PCX activities. Specifically excluded are activities of higher management and staff work. Management activities identifiable with single Level 5 Project Management elements or specific hardware items are included in those items.

1.4.1.9 CHECKOUT

Included are those quality and manufacturing operations required from the time of final assembly until the vehicle is enroute to KSC or Western Test Range.

Specific Inclusions:

1. The final acceptance tests that confirm that the PCX systems will perform in accordance with engineering documentation, that the system meets all design criteria, that all specified operating parameters are within tolerance, and that the system will interface physically and functionally with all flight and ground support equipment items are required.

2. Tool liaison and maintenance during checkout.

3. Final vehicle weighing, including preparation, maintenance, and submittal of a final vehicle weight report.

4. Data reduction and analysis.

5. Alignment.

6. Operations required to prepare the vehicle for shipment, including removal of appropriate hardware, installation of protective equipment and covers, packing, and crating.

7. Preparation of form DD-250, Materials Receiving and Inspection Report.

8. Storage of the vehicle between checkout and transportation to KSC or Western Test Range.

Specific Exclusions:

1. Final assembly is included under Integration, WBS numbers 1.4.3.1.6; 1.4.3.2.5; 1.4.3.3.7 and 1.4.3.4.4.

2. Installation of pyrotechnic devices, if any, are covered under WBS 1.5.

3. Preparations for launching at KSC or Western Test Range are covered under Launch Support.

4. Acceptance testing of hardware at Levels 5 and below before final assembly is covered under the specific hardware element.

1.4.2 SYSTEMS ENGINEERING

This summary element deals with the application of scientific and engineering endeavors toward the planning and control of a totally integrated PCX project. The work, involving more than one Level 5 WBS element, includes (1) transformation of an operational need to a description of performance parameters and a configuration through an iterative process of definition, synthesis, analysis, design, test, and evaluation; (2) integration of related technical parameters in order to assure compatibility of all physical, functional, and program interfaces in a manner that optimizes the total project definition and design; (3) integration of maintainability, producibility, and human factors into the total engineering effort; and (4) technology utilization. The three subelements as listed on WBS Sheet 1 are defined below.

Specific Inclusions:

1. An especially important requirement of Systems Engineering is materials and processes investigations that span more than one Level 6 hardware element. Facets of this area are composite materials, metals, nonmetals, processes, and compatibility of materials.

2. Provision of a traceability of significant engineering decisions and the rationale upon which the decisions were based.

3. Assurance that engineering decisions on design alternatives consider a system/cost effectiveness analysis based on merit, performance parameters, and available resources.

4. Mission concepts and analysis, including PCX/Shuttle and PCX/Payload interface trades; and PCX timelines, delta velocities, and payload placement accuracies.

5. Monitoring the conduct of the technical program.

6. Provision of a systems engineering management plan for satisfying the systems engineering objectives.

7. Preliminary Design Reviews (PDR's), Critical Design Reviews (CDR's), Flight Readiness Reviews (FRR's), and Production Configuration Audit (PCA), which pertain to combinations of two or more subsystems (for example, subsystem interface reviews).

8. Technical risk assessment to identify potential major problems. Development and maintenance of hazard tracking and reporting system.

9. Integration of test results and analyses into system design.

10. Review of specifications and procedures.

Specific Exclusions:

1. Engineering efforts (for example, Test Plans, Specifications, and Design Reviews) directed toward specific WBS elements are charged to those elements.

2. Hardware item redesign required because of problems identified during design reviews are included under the specific WBS element.

3. Materials and processes investigations relating to one Level 6 hardware item are included in that particular element.

1.4.2.1 INTEGRATION WITH SPACE SHUTTLE

This element represents that portion of systems engineering as defined in 6.2 that pertains specifically to the PCX/Shuttle interface.

Specific Inclusions:

1. Participation in system analysis, design, and test and evaluation to ensure the efficient integration of the PCX into the Space Shuttle System.

2. Activities to implement and maintain a system of integrating the PCX-to-Shuttle design.

3. Overall integration with NASA and Space Shuttle contractors.

4. Preparation, submittal, and maintenance of Interface Control Documents (ICD's) between the PCX and the Shuttle.

5. Test integration and preparation, submittal, and maintenance of the Test Plan, and instrumentation and measurement lists.

No Specific Exclusions.

1.4.2.2 PCX ANALYSIS AND INTEGRATION

This Level 5 element covers all that portion of Systems Engineering as defined in 6.2 pertaining to the PCX Vehicle and the PCX/Payload interface from preliminary design through checkout. The Level 6 elements are (1) Mission/Operations Requirements Analysis, (2) System Requirements Analysis, (3) System Verification, (4) System Requirements Control, and (5) Vehicle Integration. Details of these are:

1. Mission/Operation Requirements Analysis

A. System Mission/Operations Analysis defines the operational requirements of the PCX Systems and Ground Support Systems.

B. Ground Operations Timelines will be prepared to define the sequence and duration of the pre-flight phase events until Shuttle launch. The phases covered are pre-launch, launch, and post-launch. These timelines provide data for PCX support systems design and for reliability analysis.

C. Flight Operations Timelines define the sequence and duration of the flight phase events. These will lead to the definition of flight sequence requirements and will be utilized for reliability and failure effects analysis.

D. Contingency Analysis will be performed to define the parameters to be utilized as cues for off-nominal PCX operations and to define the actions to be taken in case of abnormalities during pre-launch and flight phases.

E. Pre-Launch PCX Systems Integrity Verification Analysis will be conducted to define the parameters and the limits of these parameters to ensure PCX Systems integrity prior to the launch of the PCX. The task will also define whether the parameters are automatically verified or verified by an observer.

F. Fleet Size Analysis — The PCX mission model, on orbit stay time and ground turn-around times, will be modeled to define the PCX fleet size required during the PCX operational phase.

G. Various other analyses that are included are consumables analysis, power profiles, payload deployment event timelines, capture analysis, launch rates, reference mission profiles, trajectory analysis, minimum duration deployment analysis, analysis of servicing satellites on-orbit, retrieval capability analysis, design reference trajectory analysis, functional flow diagrams, and abort capability analysis.

2. Systems Requirements Analysis involves the following analyses and functions:

A. Vehicle sizing analysis which is utilized in determining optimum performance.

B. Control, loads, and thermal analyses which will establish structure and subsystem requirements.

C. Identification of requirements for ground support operations, equipment, and facilities in support of the flight system.

D. Incorporation of safety, reliability, and quality requirements generated under WBS 1.4.1.6 and 1.4.1.7 into the system and end-item specifications, interface control documents, and PCX subsystem requirements handbooks, and the establishment of a requirements baseline based on these documents.

E. Consolidation of the subsystem requirements in the requirements handbooks for use by the designers and for the ensurance of compatibility of the subsystem interfaces.

F. Preparation of the technical portion of the procurement packages.

G. Preparation, submittal, and maintenance of an Engineering Program Plan providing planning and control of all engineering and development tasks.

H. Configuration trade studies and design definitions.

I. Performance of various other analyses: mass properties, induced environments, and subsystem requirements.

3. System Verification consists of the establishment of test requirements and integration, definition of requirements for a certification program, assessment of the design definition and test data to verify that the requirements have been met by the defined system. Analytical verification and certification status are also included.

4. System Requirements Control is composed of the following aspects:

A. Preparation and maintenance of the Technical Plan.

B. Engineering Change Control.

C. Support to Cost Control Management.

D. Technology Utilization.

E. Preparation and Maintenance of Specifications.

F. Preparation, coordination, and support of Interface Control Documents.

G. Procurement Specification formulation.

5. Vehicle Integration covers those efforts directed toward assembling the Level 5 hardware systems into a PCX vehicle or test article. Those overall integration endeavors outside the scope of the WBS elements 1.4.3.1.6, 14.3.2.5, 1.4.3.3.7, and 1.4.3.4.4 are included.

Specific Inclusions:

1. Provision of engineering support to manufacturing during hardware build, including assistance in performance trades.

2. Preparation, submittal, and maintenance of the PCX Pre-Launch/Post-Landing Operations Analysis document. It provides a logical functional flow of the activities of the PCX from factory through pre-launch. The analysis also includes event sheets which describe or summarize the individual events in the functional flow, and also identifies requirements for ground support equipment, handling hardware, transportation equipment, etc., to support the activities of each event. This activity relates to aspects of WBS 1.4.4.3, Transportation; 1.4.5, Vehicle Tests & Operations; and 1.4.1.9, Checkout. Also, the necessary documentation required to support each activity is identified, such as:

A. Interface Control Documents (ICD's)

B. Test and Checkout Documents

C. Composite Mechanical Schematics

D. Others, as applicable

3. Integrating Failure Mode and Effect Analysis on hardware and systems which effect launch and mission, including preparation, maintenance, and submittal of data required.

4. Implementation of the Safety Program Plan, the Reliability Program Plan, and Quality Control Plan.

5. Review of all designs and procedures for compliance with human engineering requirements.

6. Developing and maintaining the necessary training requirements for engineering, fabrication, test, procurement, reliability and quality assurance and other personnel who may have an effect upon, or who are responsible for, the determination of reliability or quality.

7. Activities to determine and control the weight of the PCX subsystems, and components, including the preparation and submittal of required mass properties reports.

8. Provide in-scope basic design maintenance for Flight Test hardware. Maintenance shall include in-scope changes identified by factory and field liaison calls and engineering evaluation in the course of checkout, launch, and flight operations.

9. Establishment and control of an Electromechanical Interference Control Plan.

10. Standards and calibration services.

Specific Exclusions:

1. Provision of ICD' s between the PCX and the Shuttle is covered under 1.4.2.1.

2. Performing parts selection and control of electronics, electrical, and mechanical parts, including preparation, maintenance and submittal of data required. This activity is covered by the individual Level 6 WBS elements.

3. Preparing, maintaining and updating equipment logs for each subsystem and system as a means of documenting its history, including preparation and submittal of the data required. This is included under each Level 6 WBS element.

1.4.2.3 CONTINUING ENGINEERING

This Level 5 subelement of Project Engineering covers all sustaining engineering support of the PCX Project after the completed PCX stage has been assembled and checked out. Sustaining tooling engineering effort is included.

Specific Inclusions:

1. Design, development, test, and analysis; tool design, fabrication, and maintenance; manufacturing of detail parts, components, assemblies, and subassemblies; support to reliability and safety; inspection; and the procurement activities to provide the lower level elements for installation and integration into the PCX.

2. Test and support articles.

3. Design and fabrication of specified models relating to this System.

4. Fabrication of spare parts in support of the test units.

5. Tooling and fabrication efforts required to install wiring harnesses, conduits, plumbing assemblies, ducting, and attachment provisions.

6. Quality control and reliability inspection, including suppliers' source inspections.

7. Fabrication, repair, and overhaul of spare parts in support of operational flights.

8. Sustaining engineering that can be identified with a single WBS element.

Specific Exclusions:

1. Checkout of the fully assembled PCX is covered by 1.4.1.9.

1.4.3 PCS VEHICLE

This summary element comprises the design, development, procurement, manufacturing, testing, quality control inspection, safety, tooling, checkout of Level 3 and lower elements, and rework required in order to produce a complete PCX with its full complement of spares. Levels 5 and 6 elements are listed on WBS Sheet 2, and defined below. Facilities are covered under WBS 1.4.4.2.

1.4.3.1 STRUCTURAL SYSTEM

This element refers to the assembled structural and aerodynamic components of the PCX, integration of the Level 6 elements together and integration of structural system into the PCX vehicle, and support of major vehicle tests and launch support. Included is the effort required to monitor the in-scope engineering design changes for producibility, to establish the incorporation points and prepare advanced planning instructions, process plans, log changes, tool orders, tool drawing for new or changed tools, the liaison and tool fabrication effort. This also covers the preventive maintenance, calibration, improvement and periodic inspection of tooling, tool control and storage, and the maintenance of tooling and planning files. Level 6 elements are listed on WBS Sheet 2.

1.4.3.1.1 PROPELLANT TANKS

This element covers the structural details and structural subassemblies of the propellant tanks. It encompasses subordinate features such as necessary frames and struts; multilayered insulation including purge bag, reflector, separator, face sheets, studs and fastener (adhesive); baffles; level sensor support structure (if required); basic tank shells; feedline support structures; manhole covers; access doors and lesser openings; attach mechanisms for wiring and other such provisions; and mounting devices for propellant lines and pumps.

Specific Inclusions:

1. Detail design and analysis, including preparation, maintenance, and submittal of drawings and Technical Studies and Analyses.

2. Tool engineering, tool manufacture and associated manufacturing aids, including preparation and maintenance of Tool and Fixture Drawings.

3. Detail manufacture and associated support activities, including quality control and the preparation and maintenance of Manufacturing Planning Data, and Manufacturing Specifications and Procedures.

4. Procurement of material and services, including supplier nonrecurring and recurring costs.

5. Joining of subordinate elements listed in previously mentioned definition.

6. Details and subassemblies for development test, qualification test, and production.

7. Development and qualification test fixtures, tests, test rigs, test set-ups and instrumentation in support of the test. Also includes the preparation, maintenance, and submittal of Test Procedures, Test Reports, and Qualification Status Reports.

8. Tool liaison and tool maintenance during production and test.

9. Subsystem models.

10. Manufacture of spares and repair parts in support of production and test.

11. Materials research and analysis.

12. Design, fabrication, and test of spare parts in support of the operational flights.

1.4.3.1.2 THRUST STRUCTURE

This Level 6 element is composed of all structural members and subassemblies comprising the interface and between the main shell and the engine. It includes fiberglass lay-ups, thrust struts, engine mounting provisions, feedline supports, actuator attach points, and mounting supports for engine fluid and electrical interface lines, cables, and couplings.

Specific Inclusions and Specific Exclusions:

Refer to 1.4.3.1.1

1.4.3.1.3 MAIN SHELL

This element is the principal structural entity upon which the propellant tanks mount. It consists of the shell structure, manipulator attach points, and support bracketry for the feed system, vent system, pressurization system, electrical cabling and avionics components, access ports, and stage-side umbilicals.

Specific Inclusions and Exclusions:

Refer to 1.4.3.1.1

Excluded are any materials bonded to the main shell for the purpose of dampening heat caused by impingement of effluent from the APS.

1.4.3.1.4 SPACE SHUTTLE INTERFACE STRUCTURES

This element covers the structural portion of the forward support cradle and the aft adapter (support skirt) situated between the PCX stage and the Space Shuttle. Excluded are electrical, propulsion, and mechanical aspects, which are included under WBS elements 1.4.3.2, 1.4.3.3, and 1.4.3.4 respectively.

Specific Inclusions and Exclusions:

1.4.3.1.5 MICROMETEOROID PROTECTION

This item is comprised of any special micrometeoroid protection that may be deemed necessary beyond that provided by the main shell and the multilayered insulation.

Specific Inclusions and Specific Exclusions:

Refer to 1.4.3.1.1

1.4.3.1.6 INTEGRATION

This element covers assembling Structural System and its subelements into the PCX Vehicle, and testing the assembled system.

Specific Inclusions:

1. Detail design and analysis, including preparation, maintenance, and submittal of installation and final assembly drawings and Technical Studies and Analyses.

2. Tool engineering, tool manufacture and associated manufacturing aids required for the installation, mating and in-process checking.

3. Fabrication and installation of simulated parts, components, or assemblies necessary to later installation or mating operations, including preparation and maintenance of Manufacturing Planning Data, and Manufacturing Specifications and Procedures.

4. Interface Alignment Documentation.

5. Inboard profile drawings.

6. Quality Assurance effort consists of performing inspection verification during installation and mating of structural assemblies, systems, and interfacing checks. Nondestructive evaluation inspection, such as X-ray, is included as is verification of cleaning process controls, and component closeout.

7. Procurement of material and services, including supplier nonrecurring and recurring costs, required to support installation.

8. Inprocess verification test of subsystems during installation.

9. Tool liaison and tool maintenance during mating and final assembly.

10. Mating of all Structural System elements.

11. Data reduction and analysis.

12. Analysis of all thermal control systems relating to the Structural System.

13. Design and development of any active thermal control systems, such as radiators, that pertain to the Structural System.

1.4.3.2 AVIONICS SYSTEM

This element refers to those electrical/electronic subsystems which provide electrical power, navigation, guidance and control, telecommunication instrumentation, data management, tracking and command, and systems integration functions to the PCX. Any required thermal conditioning relating to an Avionics Level 6 element is included in that element. It includes

the effort required to monitor the in-scope engineering design changes for producibility, to establish the incorporation points and prepare advanced planning instructions, process plans, log changes, tool orders, tool drawings for new or changed tools, the liaison and tool fabrication effort. This also covers the preventive maintenance, calibration, improvement and periodic inspection of tooling, tool control and storage, and the maintenance of tooling and planning files. Umbilical disconnects and actuators are covered under 1.4.3.4.1 and 1.4.3.4.3. Level 6 elements listed on WBS Sheet 2 are defined below.

Specific Inclusions:

1. Design, development, test, and analysis; tool design, fabrication, and maintenance; manufacturing of detail parts, components, assemblies, and subassemblies; support to reliability and safety; inspection; and the procurement activities to provide the lower level elements for installation and integration into the PCX.

2. Test and Support articles.

3. Design and fabrication of specified models relating to this system.

4. Fabrication of spare parts in support of production and test.

5. Tooling and fabrication efforts required to install wiring harnesses, conduits, plumbing assemblies, ducting attachment provisions.

6. Quality control and reliability inspection, including suppliers' source inspections.

7. Fabrication, repair, and overhaul of spare parts in support of operational flights.

8. Preparation, maintenance, and submittal of the Development Flight Instrumentation (DFI)/Data Source Definition Document.

Specific Exclusion:

Checkout of the fully assembled PCX is covered by 1.4.1.9.

1.4.3.2.1 ELECTRICAL POWER

This Level 6 element refers to those equipments which generate, condition, control, and distribute electrical power throughout the PCX. It includes fuel cells, batteries, voltage sensors, connectors, static inverters, power amplifiers, power conditioner, distribution, switching elements, and wiring. Electrical power from the PCX to the Shuttle is covered herein to the interfaces of the disconnects.

1.4.3.2.2 NAVIGATION, GUIDANCE AND CONTROL

This Level 6 element includes the star tracker, horizon sensor, inertial measuring unit, platform, gyros, accelerometer, rate stabilization system, attitude control equipment, rendezvous and docking equipment, data acquisition, teleoperation, as well as navigation, guidance and control analysis, and flight dynamics. Actuators are included under 1.4.3.4.3.

1.4.3.2.3 DATA MANAGEMENT AND PROCESSING

This Level 6 element consists of a computer, data storage, data bus, data terminals, computer operations, data processing and software.

1.4.3.2.4 INSTRUMENTATION AND COMMUNICATION

This Level 6 element covers the development and operational flight instrumentation and communication systems including establishment of detail requirements. It includes measuring equipment, signal conditioning, instrumentation sensors, digital IF units, transmitter, transponder, antennas, multiplexer, camera lights, relay assemblies, malfunction detection package, cable harnesses, rate pulse beacon, command control receivers, imaging devices (for example, TV) and transducers not readily identifiable with another Level 6 item.

1.4.3.2.5 INTEGRATION

This covers all work relating to incorporating the Avionics System Level 6 hardware elements into the PCX Vehicle, and testing the System.

Specific Inclusions:

1. Detail design and analysis, including preparation, maintenance, and submittal of installation and final assembly drawings and Technical Studies and Analyses.

2. Tool engineering, tool manufacture and associated manufacturing aids required for the installation, mating and in-process checking.

3. Fabrication and installation of simulated parts, components, or assemblies necessary to later installation or mating operations, including preparation and maintenance of Manufacturing Planning Data, and Manufacturing Specifications and Procedures.

4. Quality Assurance effort consists of performing inspection verification during installation and mating of Avionics System assemblies, electrical systems, and interfacing checks. Nondestructive evaluation inspection such as X-Ray are included as is verification of cleaning process controls, proof pressure and lead checks, component closeout, continuity and megger checks.

5. Procurement of material and service, including supplier nonrecurring and recurring costs, required to support installation.

6. In-process verification test of subsystems during installation.

7. Tool liaison and tool maintenance during mating and final assembly.

8. Mating of all Avionics System elements.

1.4.3.3 PROPULSION SYSTEM

This Level 5 summary category is comprised of those elements that provide impulse for translation and attitude control for the PCX when it is acting independently of the Shuttle. Also covered is thermal conditioning of propulsion elements. The Level 6 elements shown on WBS Sheet 2 are defined below. Actuators are covered under 1.4.3.4.3.

Specific Inclusions:

1. Design, development, test, and analysis; tool design, fabrication, and maintenance; manufacturing of detail parts, components, assemblies, and subassemblies; support to reliability and safety; inspection; and the procurement activities to provide the lower level elements for installation and integration into the PCX.

2. Test and support articles.

3. Design and fabrication of specified models relating to this system.

4. Fabrication of spare parts in support of production and test.

5. Tooling and fabrication efforts required to install wiring harnesses, conduits, plumbing assemblies, ducting, and attachment provisions.

6. Quality control and reliability inspection, including suppliers' source inspections.

7. Fabrication, repair, and overhaul of spare parts in support of operational flights.

8. Valve actuators are included.

Specific Exclusion:

Checkout of the fully assembled PCX is covered by 1.4.19.

1.4.3.3.1 MAIN ENGINE

This Level 6 item covers that device which imparts the basic thrust to the PCX Stage. Gimbals and thermal control are included. Should a two-position nozzle be adopted, it is also included in this element.

1.4.3.3.2 PROPELLANT FEED

This Level 6 element is comprised of all lines, valves, ducts, bellows, and other components that transfer the main engine oxidizer/fuel from the tanks to the main engine. Attendant thermal conditioning is excluded, being covered by Thermal Conditioning, 1.4.3.3.6.

1.4.3.3.3 MAIN TANK PRESSURIZATION AND VENT

This Level 6 element is composed of all lines, valves, ducts, bellows, and other components that take pressurization gasses from the engine to the main fuel tank, and the lines, valves, ducts, bellows, storage tank, and other components which provide pressurization gas to the fuel tanks. Also covered are those components that carry pressurization gas for dumping overboard.

1.4.3.3.4 MAIN TANK FILL AND DRAIN

This Level 6 element covers all lines, ducts, valves and other components required to fill and drain the main propellant tanks. Dumping provisions are also covered, although a major portion of the lines may remain in the Space Shuttle during PCX flights.

1.4.3.3.5 AUXILIARY PROPULSION

This Level 6 element in the Propulsion System covers the thrusters, valves, lines, and storage tanks that provide impulse for small translation and attitude control maneuvers. Also covered are materials and equipment designed to control or dampen heat caused by impingement of effluent from the APS.

1.4.3.3.6 THERMAL CONDITIONING

This Level 6 element includes all devices provided especially to control temperatures of hardware elements in the propulsion system. As an example, this covers the thermal control of the engine and propellant feed but not of the APS.

1.4.3.3.7 INTEGRATION

This element covers all work required for incorporating the Propulsion System Level 6 element into the PCX Vehicle, and testing the System.

Specific Inclusions:

1. Detail design and analysis, including preparation, maintenance, and submittal of installation and final assembly drawings and Technical Studies and Analyses.

2. Tool engineering, tool manufacture and associated manufacturing aids required for the installation, mating and in-process checking.

3. Fabrication and installation of simulated parts, components, or assemblies necessary to later installation or mating operations, including preparation and maintenance of Manufacturing Planning Data, and Manufacturing Specifications and Procedures.

4. Quality Assurance Effort consists of performing inspection verification during installation and mating of fluid systems and interfacing checks. Nondestructive evaluation inspection, such as X-Ray, is included as is verification of cleaning process controls, proof pressure and lead checks, component closeout.

5. Procurement of material and services, including supplier nonrecurring and recurring costs, required to support installation.

6. In-process verification test of subsystems during installation.

7. Tool liaison and tool maintenance during mating and final assembly.

8. Mating of all Propulsion System elements.

9. Tank cleaning.

10. Data reduction and analysis.

1.4.3.4 MECHANICAL SYSTEM

This Level 5 WBS element includes all machinery or mechanisms imparting some action to a subordinate structural member or members. Included is the effort required to monitor the in-scope engineering design changes for producibility, to establish the incorporation point, and to prepare advanced planning instructions, process plans, log changes, tool orders, tool drawing for new or changed tools, the liaison and tool fabrication effort. This also covers the preventive maintenance, calibration, improvement and periodic inspection of tooling, tool control and storage, and the maintenance of tooling and planning files. Individual components include latches, vent closing and opening devices, holding devices, actuators, and hinges. Level 6 elements are listed on WBS Sheet 2 and defined below.

Specific Inclusions:

1. Design, development, test, and analysis; tool design, fabrication and maintenance; manufacturing of detail parts, components, assemblies, and subassemblies; support to reliability and safety; inspection; and the procurement activities to provide the lower level elements for installation and integration into the PCX.

2. Test and support articles.

3. Design and fabrication of specified models relating to this system.

4. Fabrication of spare parts in support of production and test.

5. Tooling and fabrication efforts required to install wiring harnesses, conduits, plumbing assemblies, ducting, attachment provisions.

6. Quality control and reliability inspection, including suppliers' source inspections.

7. Fabrication, repair, and overhaul of spare parts in support of operational flights.

Specific Exclusions:

1. Checkout of the fully assembled PCX is covered by 1.4.1.9.

2. Valves are covered by the Propulsion System.

1.4.3.4.1 ORBITER INTERFACE

This covers all the mechanical hardware enabling the PCX to link with Shuttle and to separate from it in flight. It is limited to those items that will remain in the Shuttle during the flight of the PCX. Included is the operational docking/undocking attachment of the PCX to the Shuttle, the alignment and energy absorption subsystem, the retraction/extension support subsystem, the reentry purge subsystem, and the umbilical disconnects in the fluid/electrical interface. Hinges and mechanical devices designed to retract and extend a docking ring are included herein. A guide arm capture latch, retraction cylinder, and latch spring are also included. The tubing, tubing fittings, hoses, cables, connectors, adapters, and interface supports are excluded and are covered

under other appropriate hardware WBS elements. The orbiter-to-adapter interface hardware is excluded, and is costed as Shuttle expense.

1.4.3.4.2 PAYLOAD INTERFACE

This Level 6 element is comprised of all mechanical devices associated with attachment of the PCX to its payload. The structural entities are covered under the appropriate Structural System Level 6 element.

1.4.3.4.3 ACTUATORS AND OTHER MECHANICAL COMPONENTS

This Level 6 element covers all engine actuators and other mechanical components necessary to orient the thrust vector control of the main engine and those actuators necessary to actuate all the valves in the PCX. Related structural members are covered under 1.4.3.1. This Level 6 element also includes all mechanical devices associated with the PCX and PCX ground support equipment interfacing with the launch facility. Mechanical devices for gimballing TV cameras are also included.

1.4.3.4.4 INTEGRATION

This includes all work required to incorporate the Mechanical System Level 6 elements into the Space PCX Vehicle, and to test the system.

Specific Inclusions:

1. Detail design and analysis, including preparation, maintenance, and submittal of installation and final assembly drawings and Technical Studies and Analyses.

2. Tool engineering, tool manufacture and associated manufacturing aids required for the installation, mating and in-process checking.

3. Fabrication and installation of simulated parts, components, or assemblies necessary to later installation or mating operations, including preparation and maintenance of Manufacturing Planning Data, and Manufacturing Specifications and Procedures.

4. Quality Assurance effort consists of performing inspection verification during installation and mating of mechanical systems and interfacing checks. Nondestructive evaluation inspections, such as X-ray, are included as is verification of cleaning process controls and component closeout.

5. Procurement of material and services, including supplier non-recurring and recurring costs, required to support installation.

6. In-process verification test of subsystems during installation.

7. Tool liaison and tool maintenance during mating and final assembly.

8. Mating of all mechanical system elements.

9. Data reduction and analysis.

1.4.4 SYSTEM SUPPORT

This Level 4 summary WBS element covers miscellaneous activities not identifiable to any of the previously defined WBS elements. The five Level 5 elements are shown on WBS Sheet 1. Specifically included is that design, development testing, qualification testing, tool design, tool manufacture, tool maintenance, test hardware, procurement, manufacturing, assembly, transportation, and installation of items defined below.

1.4.4.1 SUPPORT EQUIPMENT

This Level 5 element covers Ground Support Equipment, Factory Support Equipment, Special Test Equipment, Software, and Support Equipment Integration not relatable to a single Level 6 Space PCX Vehicle item.

The Level 6 Ground Support Equipment is composed of deliverable equipment of those categories described in the following subelements:

1. Servicing Equipment is that required to supply, distribute, and condition fluids or electrical power to the PCX vehicle.

2. Handling Equipment is that required to support and handle the PCX vehicle, assemblies, and subassemblies.

3. Transportation Equipment is that required to package and/or transport the PCX vehicle, assemblies, and subassemblies.

4. Checkout Equipment is that required to verify flight systems and other GSE, provide controls and monitoring, and distribute electrical signals.

5. Auxiliary Equipment is other GSE, such as access platforms and work stands, which are not included otherwise.

The Level 6 Factory Support Equipment element covers the design and manufacture of those items of nondeliverable support equipment which satisfy unique Space PCX manufacturing test, checkout, access and handling requirements.

Specific Inclusions:

1. Test and support articles.

2. Propellant tanks multilayered insulation purge equipment.

3. Spare parts for those support equipments listed above.

4. Vehicles, equipment, and tools used to fuel, service, transport and hoist, repair overhaul, assemble, disassemble, test, inspect, or otherwise maintain the PCX vehicle and its Ground Support Equipment.

5. Installation and activation of support equipment necessary to support the ground and flight tests.

Specific Exclusions:

1. Spare parts provided for PCX hardware items.

2. Dimensional and fabrication tooling, materials handling equipment, facilities, or laboratory test fixtures.

3. System engineering integration activity, including reliability, maintainability, human engineering, and integration with the Orbiter contractor, is included in the subelements of WBS element 1.4.2.

4. Standards and calibration services are included in element 1.4.2.2.

5. The purge bag integral to the multilayered insulation is included in 1.4.3.1.1.

6. Integration effort required by WBS 1.4.2.

7. Development testing and quality testing, which is included in appropriate WBS hardware element.

1.4.4.2 FACILITIES

Facilities encompasses the activation, modification, construction, and maintenance of all buildings (including furniture), roads, utilities, equipment foundations, rail appurtenances, drainage ways, test stands, block houses, coax passages, trailers, and docks required for the administration, engineering, manufacturing, checkout, test and flight of the PCX vehicle and its related Support Equipment. Installation of tooling and Support Equipment in the buildings or on the foundations is covered under WBS 1.4.3 and 1.4.4.1.

Specific Inclusions:

1. Preproduction studies.

2. Formulation and maintenance of Facility Plan, Progress Reports, and Change Control Activities that relate to Facilities.

3. Planning of use of Facilities, including Applications Evaluation.

4. Capability Surveys.

5. Drawings depicting installation of support equipment.

6. Implementation of safety and environmental obligations.

7. Inspection of new facilities or modifications.

8. Analyzing requirements against existing facilities and planning the utilization of all facilities and facility equipment required for design, development, production, test, and checkout associated with the PCX, including preparation, maintenance, and submittal of the Facilities Plan.

9. Maintenance of real property records.

10. Coordination on facility planning and activation, including preparation, maintenance and submittal of the Facility Construction, Activities, Utilization, and Maintenance Report.

11. Activation of administration, manufacturing, and flight test facilities (where required) including Site Readiness Review. Activation includes the installation of all equipment and verification of facility-equipment-hardware interfaces.

12. Supervision and accomplishment of facility design, modification, and new construction.

Specific Exclusions:

Ancillary equipment that facilitates fabrication.

1.4.4.3 TRANSPORTATION

This element refers to the services required to transport the PCX, its subassemblies and associated ground equipment from the point where it is finally assembled through the point of barge or air debarkation to the point of ultimate use at KSC or WTR.

Specific Inclusions:

1. The effort required to provide monitoring of the PCX while in transit to the launch site.

2. Preparation and maintenance of the Transportation Plan included as a part of the Systems Support and Logistics Plan.

3. The transporter crew and incidental materials and equipment for protection of the PCX during shipment.

4. Transportation from the barge landing or airport to the test site.

Specific Exclusions:

1. In-plant transportation required during manufacturing buildup, test, and checkout is included under the specific WBS item to which it relates.

2. Protective covers, shipping containers, handling equipment, etc., are included under checkout, 1.4.1.9.

3. Shipment of manufactured details from the manufacturing site to the final assembly site are included in the element under which the item was manufactured.

4. Transportation of the PCX within the launch site is covered under the appropriate Level 5 element of Vehicle Support, 1.4.5.

1.4.4.4 TRAINING

This element refers to training services, devices, accessories, aids, equipment, and parts used to facilitate instruction through which personnel will acquire sufficient concepts, skills, cost consciousness, and attitudes to operate and maintain the PCX with maximum efficiency. This includes all endeavors associated with the design, development, and production of training equipment as well as the execution of training activities.

Specific Inclusions:

1. Instructor and personnel training, including the preparation and maintenance of the Training Plan and Training Manual, and the preparation, maintenance, and submittal of the Training Requirements Analysis.

2. Detail design and development of unique training equipment, including the preparation and maintenance of drawings.

3. Training aids (as applicable):

   a. Vertical display panels.

   b. Equipment group panels.

   c. Open frame panels.

   d. Electronic workbench panels.

   e. Animated panels.

   f. Composite panels.

   g. Charts, slides, and training manuals.

   h. Film video tape, and live video.

i. Interactive computer graphics.

j. Configurations and programmed instruction.

k. Other training aids.

4. Training in support of Flight Operations.

5. Travel allowances and per diem in connection with training exercises.

6. Maintenance and shop support of training equipment and maintenance of tooling in support of Flight Operations Phase.

Specific Exclusions:

Safety training is covered under 1.4.1.7 and quality training is in 1.4.1.6.

1.4.4.5 LOGISTICS SUPPORT

This element provides the effort to implement and operate a logistics activity for the Space PCX and its related ground equipment.

Specific Inclusions:

1. Spares handling.

2. Fabrication, maintenance, repair, and testing of spares.

3. Warehousing.

4. Inventory control.

5. Propellant and gasses handling and control.

6. Shipping and receiving.

7. Receiving inspection.

Specific Exclusions:

1. Planning and management functions are covered under 1.4.1.2, Logistics Management.

2. The spares themselves are covered under the specific hardware categories.

1.4.5 VEHICLE TESTS AND OPERATIONS

This summary element encompasses all labor, materials, and other expenses required to conduct all major tests and mission operations of a PCX Vehicle. The subordinates are shown on WBS Sheet 1 and detailed below.

Specific Inclusions:

1. Provision of engineering/technical effort required for the formulation of procedures, plans, checklists, and test reports.

2. Liaison engineering for the support of planning for system support activities.

3. Removal of protective covers installed during transportation.

4. Reassembly of PCX elements that were removed from the vehicle in preparation for transportation.

5. Tool engineering, tool manufacture, and associated manufacturing aids required for reassembly and checkout after arrival at the test or launch site.

6. Manufacturing planning data, specifications, and procedures specifying removal of equipment, reassembly, and site installation tasks.

7. Quality inspection during assembly and installation, final vehicle inspection, and inspection support to tooling fabrication and tool maintenance.

8. Materials and services required during reassembly and installation.

9. Tool liaison and maintenance.

10. Data reduction and analysis.

11. Installation of pyrotechnic devices, if any.

12. Test and operations planning, control, and wrap-up.

Specific Exclusions:

1. Final assembly drawing, which is covered by 1.4.2.2.

2. Manufacturing aids which are used in integration elements are included under 1.4.3.1.6, 1.4.3.2.5, 1.4.3.3.7, and 1.4.3.4.4.

3. Identification and activation of all facilities and support equipment required at the site are included in the appropriate subelements of WBS elements 1.4.4, System Support.

1.4.5.1 STRUCTURAL TEST SUPPORT

This Level 5 element covers all work required to prepare the structural test article for test, conduct the test, acquire data and analyze, and refurbish the hardware in preparation for follow-on tests.

Specific Inclusions:

1. Transportation of the test article to the test site.

2. Installation of test article in structural test stand.

3. Installation of strain gages.

4. Checkout and quality inspection during test.

5. Reports preparation.

Specific Exclusions:

1. Costs of manufacturing test hardware are included under 1.4.3 and 1.4.4.1.

2. Facilities expenses are included under 1.4.4.2.

3. Logistics support costs are covered under 1.4.4.5.

1.4.5.2 DYNAMICS TEST SUPPORT

This element includes all work required to prepare the structural test article for dynamics test, conduct the test, acquire data and analyze, and refurbish (if required) in preparation for further tests.

Specific Inclusions:

1. Transportation of the test article to the test site.

2. Installation of the test article in the dynamics test stand.

3. Installation of any special measuring devices, such as strain gages.

4. Quality inspection during test.

5. Reports preparation.

Specific Exclusions:

1. Test hardware and GSE are included under 1.4.3 and 1.4.4.1.

2. Facilities are included under 1.4.4.2.

3. Logistics support is included under 1.4.4.5.

1.4.5.3 PROPULSION TEST SUPPORT

Covered herein are all expenses incurred in preparing the propulsion test article for test, installation of the engine, loading of the propellants, conducting the test, gathering the data and analyzing it, and refurbishing the vehicle in preparation for flight.

Specific Inclusions:

1. Transportation of the assembled PCX from the point of manufacture to the test site.

2. Installation of the test vehicle into the test stand.

3. Quality inspection.

4. Reports preparation.

Specific Exclusions:

1. Hardware and GSE costs are included in 1.4.3 and 1.4.4.1.

2. Facilities are covered under 1.4.4.2.

3. Logistics support costs are covered under 1.4.4.5.

4. Integration of Avionics components into the Propulsion Test Vehicle after the test is included under 1.4.3.2.5.

1.4.5.4 LAUNCH OPERATIONS

This element covers all the work required to receive, assemble, install in the Orbiter, service and prepare, checkout and perform countdown for launch, and command during ascent the PCX Vehicle/Payload until control of the Orbiter/PCX system is turned over to Flight Operations. The work applies to flight tests and mission operations.

The tasks include:

1. Management of launch operations activities.

2. Data acquisition and analyses.

3. Tracking (up to Flight Operations acquisition).

4. Report preparation.

1.4.5.5 FLIGHT OPERATIONS

This element covers all the work required to control the PCX and PCX/ Payload mission operations from the end of Launch Operations through reentry and landing. The work applies to flight tests and mission operations.

The tasks include:

1. Management of flight operations activities.
2. Flight control.
3. Mission planning.
4. Data Acquisition and analyses.
5. Tracking (from Launch Operations hand-over).
6. Flight operations procedures preparation.
7. Mission evaluation.
8. Flight software.

1.4.5.6 RECOVERY/ REFURBISHMENT OPERATIONS

This element covers all the work required to recover, refurbish, and deliver to launch operations for mission recycle the PCX vehicle (and PCX payload if appropriate). The work applies to all flights of the PCX.

The tasks include:

1. Management of recovery/ refurbishment operations.
2. Demating and removal from Orbiter.
3. Handling, packaging, transportation, refurbishment and transportation to launch site.
4. Implementation of engineering modifications.

5. Post-flight and post-refurbishment checkout.

6. Post-flight safing operations.

7. Maintenance support.

8. PCX/ Payload mating and checkout.

9. Integration activities.

APPENDIX B

AUTOMATIC DATA PROCESSING FOR COST ESTIMATES PRICING AND COST ESTIMATING SYSTEM (PACE)

1.1 GENERAL SYSTEM DESCRIPTION AND PURPOSE

The Pricing and Cost Estimating System (PACE) is an automatic data processing system designed to create a total cost estimate for any project over a period of up to eight fiscal years, using government estimated manhours, material, other direct costs, and labor and overhead rates, to develop a total estimated cost.

The system is organized by subdividing each project into specific tasks to form a Work Breakdown Structure (WBS). Standard cost elements (either in manpower or dollars) are established for each WBS as follows: (1) manpower cost elements: engineering, manufacturing, tooling, quality and reliability assurance, testing, and other; (2) dollar-value cost elements: material and subcontract costs, travel, and other direct costs. These cost elements are summarized to the major WBS level and, using estimated labor rate data, potential contractors' cost estimates are calculated. These calculations can be performed at any WBS level and for eight or fewer fiscal years according to the needs of the user.

The major advantages of this computerized system include standardization of input/output formats, increased responsiveness to manpower and rate fluctuations, and a substantial reduction in manpower and time requirements of the cost estimating process. The PACE System uses less than 1 minute of actual computer time to complete an estimate, as opposed to several days necessary to manually compute a project cost estimate. Clerical work is substantially reduced by using the PACE System because the computer printer rapidly produces the finished detailed cost sheets, and no typing is required.

Attachment 1 is a flow diagram of the PACE System.

1.2 COLLECTION OF DATA

All original data are collected, verified, and prepared for input by the Cost Analysis Office.

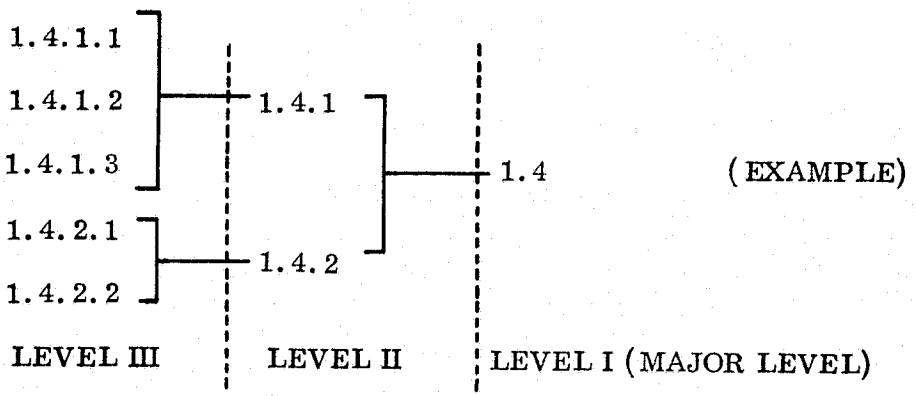
1.3 INPUT PROCEDURES

There are three types of input to the PACE System, all of which are entered into the system via standard 80-column computer cards: (1) table of contents data, (2) rate data, and (3) cost element data.

1.3.1 Table-of-Contents Data

Each table-of-contents card contains a numeric WBS level code matched to the appropriate task description as provided by the user. This table provides the organization for the total cost estimate report (see Attachment 2 and the following diagram). Also included with the table-of-contents cards is a "contractor-estimated-fee" card (see Attachment 3). The figure entered in the first two columns of this card represents a percentage of the total estimated cost (fee) that a contractor would charge for the completion of a given project. This percentage is added to the total estimated cost giving a grand total (see Attachment 4).

The WBS levels are summarized according to the following general scheme:



1.3.2 Rate Table

The rate table (see Attachments 3 and 5) contains the user-supplied labor rates (hourly, monthly, or yearly), G&A expense, and overhead per fiscal year for as many years (up to eight) as are required by the user for a given project. The table is coded for identification by project.

1.3.3 Cost Element Transactions

Each cost element transaction contains a code identifying the manpower figures as being in manhours, manmonths, or manyears, the fiscal year, the WBS code, the manpower and dollar figures for the cost element, and a code

identifying the manpower and dollar figures of the cost element as being recurring or nonrecurring costs (see Attachments 6 and 7). This data are subsequently summarized by the computer. Cost estimates are generated through a mulitplication of labor rates in the rate table by the manhour figures, adding materials, applying overhead and G&A expense, and summing the results.

1.4 OUTPUT PROCEDURES

There are two output reports produced by the PACE System: (1) a transaction list and (2) a total cost estimate report.

1.4.1 Transaction List

The transaction list prints all cost element transactions as they enter the system (see Attachment 7).

1.4.2 Total Cost Estimate Report

The total cost estimate report is the principal output of the system (see Attachment 4). The report is generated in descending order of the WBS with one page printed per WBS level. Each page contains the WBS code number, WBS name, and project name. The fiscal years and cost element totals are arranged in columns, and the cost element manhours and labor/overhead dollars are arranged in rows. A subtotal row for the columns is created, to which is added the G&A expense to result in total estimated costs for each fiscal year. The contractor fee is then added to the total estimated cost per fiscal year giving grand totals per fiscal year, as mentioned in Section 1.3.1 of this appendix.

Three versions of the total cost estimate report can be produced, with the version name being shown in the report header for easy identification. The particular versions to be produced are controlled through "Flags" being inserted into the designated card columns of one of the two header cards submitted with the cost element transactions.

The "Recurring and Nonrecurring Costs" version of the total cost estimate report (see Attachment 4) reflects the totals arrived at by using both the cost element transactions that have been identified as being recurring costs (an "R" punched in card column 80) and the cost element transactions that have been identified as being nonrecurring costs (an "N" punched in card column 80).

The totals of the "Recurring Costs Only" version are arrived at by using only the cost element transactions marked "R".

The totals of the "Nonrecurring Costs Only" version are arrived at by using only the cost element transactions marked "N".

Another feature of the PACE System used in producing the total cost estimate report(s) is the design-to-cost capability. It may be necessary to reduce (or increase) the totals of a previously calculated estimate by a determined amount to bring the totals more in line with the operating budget. This can be accomplished by inserting the appropriate design-to-cost factor into the designated card columns of one of the two cost element transaction header cards and rerunning the estimate using the same input. The desired amount of increase or decrease will be spread evenly at all levels of the WBS. The design-to-cost factor will be shown in the total cost estimate report header (see Attachment 8).

FLOW DIAGRAM

FLOW DIAGRAM

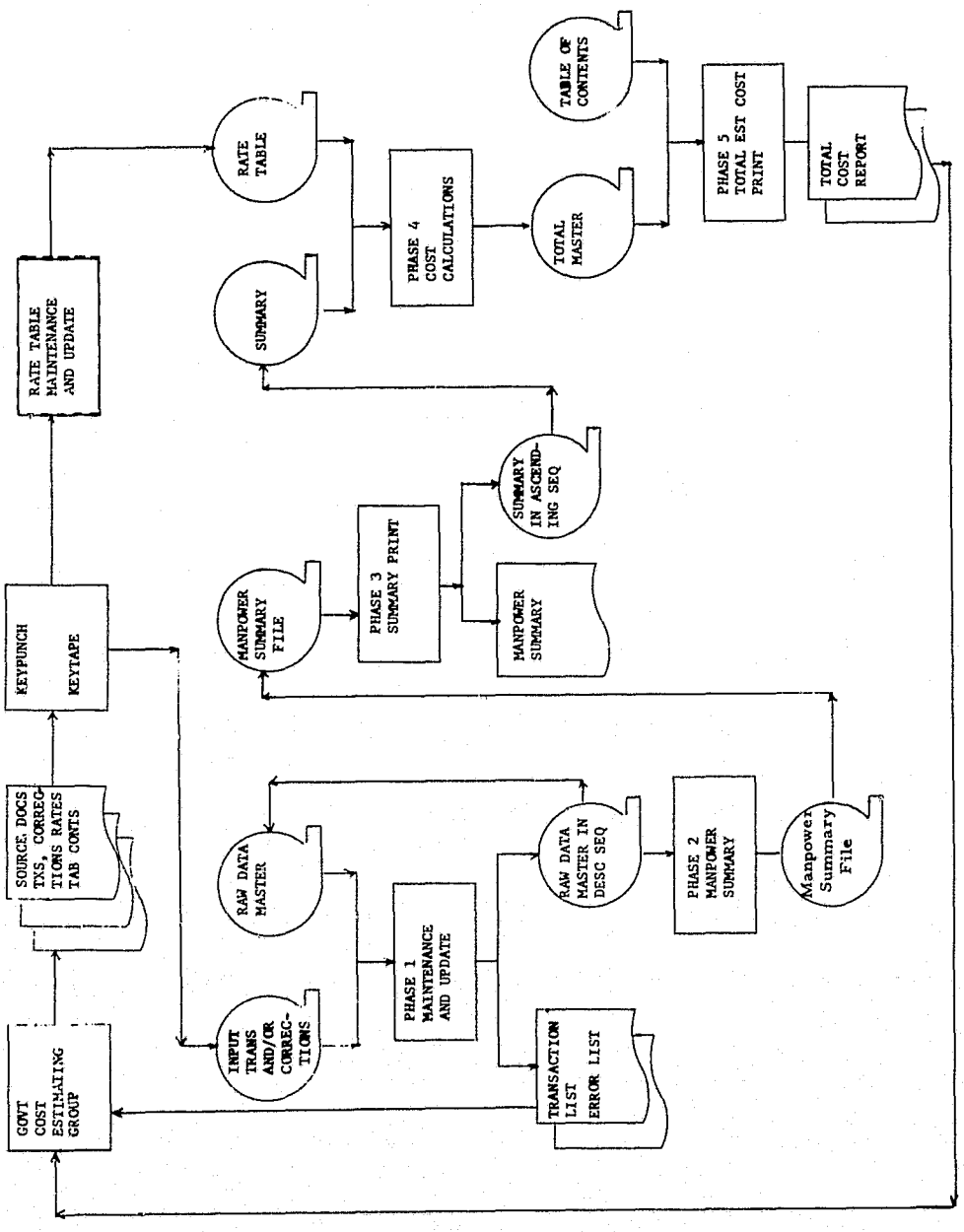


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TABLE OF CONTENTS LISTING

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RUN DECK LISTING

RUN DECK LISTING Attachment 3 Page 1 of 4

```
RUN _ MRPACE,1HNTSVA2060A,FTYSONB,N212,3,200 } RUN CARDS
RUN   MRPACE,1HNTSVA2060A,FTYSONB,N212,3,200 }
ASG,T        PUR,T,13197 . BACKUP C2100 ← TAPE ASSIGNMENT CARD
DELETE,C     PACE1B
DELETE,C     PACE1C
DELETE,C     PACE1D
DELETE,C     PACE1E
DELETE,C     PACE1F
DELETE,C     PACE1G
DELETE,C     PACE2A
DELETE,C     PACE2B
DELETE,C     PACE2C
DELETE,C     PACE3A
DELETE,C     PACE3B
DELETE,C     PACE3C
DELETE,C     PACE3D
DELETE,C     PACE4A
DELETE,C     PACE4B
DELETE,C     PACE4C
DELETE,C     PACE6B
DELETE,C     PACE7A                    CONTROL CARDS
DELETE,C     PACE7B
DELETE,C     PACE7C
ASG,T        PACE1B,F2/1/POS/2
ASG,U        PACE1C,F2/13/TRK/13
ASG,U        PACE1D,F2/1/POS/2
ASG,U        PACE1E,F2/1/POS/2
ASG,U        PACE1F,F2/1/POS/2
ASG,U        PACE1G,F2/1/POS/2
ASG,U        PACE2A,F2/13/TRK/13
ASG,U        PACE2B,F2/1/POS/2
ASG,U        PACE2C,F2/1/POS/2
ASG,U        PACE3A,F2/1/POS/2
ASG,U        PACE3B,F2/13/TRK/13
ASG,U        PACE3C,F2/1/POS/2
ASG,U        PACE3D,F2/1/POS/2
ASG,U        PACE4A,F2/1/POS/2
ASG,U        PACE4B,F2/1/POS/2
ASG,U        PACE4C,F2/1/POS/2
ASG,U        PACE6B,F2/1/POS/2
ASG,U        PACE7A,F2/1/POS/2
ASG,U        PACE7B,F2/1/POS/2
ASG,U        PACE7C,F2/1/POS/2
ASG,T        XB,F2/83/TRK/83
REWIND   PUR
ERS
COPIN    PUR.,TPFS.
FREE     PUR
PRT,T
XQT      A2060G
```

Y 1971	1974	1975	1976	1977	1978	1979	1980	1981	ET AB
EMG22771	25344	26611	27936	29338	30797	32352	33965	35674	ET AB
MEG17814	21542	22637	23789	24960	26227	27533	28934	30374	ET AB
TLG17779	22042	23155	24326	25536	26822	28166	29587	31066	ET AB
GRA20160	24518	25747	27053	28397	29818	31334	32909	34560	ET AB
TST20314	22176	23290	24442	25670	26957	28320	29741	31238	ET AB
GTH21964	25114	26362	27667	29050	30509	32045	33638	35328	ET AB

} RATE TABLE

```
MAT     8       8       8       8       8       8       8       8       8   ET AB
GA     11      11      11      11      11      11      11      11      11   ET AB
 PMD,EL
  XQT       A2060B
    01631960  C93 11                                                              H
   **EXTERNALTANKTEST
  BM7401060301          19552          139840   2400   1600          8569        407R
  BM7401060302           5000            1088    640    480           720         44R
  BY7401060303             25                       2      2           894         32R
  BM7401060304          47539                    3840   3840           399         32R
  BY7401060305                                      6                              3N
  BM7501060301          17240  32160239680      4960   3200          9999        653N
  BM7501060302           4976    1600   160     1120   1400          1170         49N
  BY7501060303             34                       4      4          1022         45N
  BM7501060304          54682                    3840   3840          1197         36R
  BY7501060305                                     12      5                         7N
  BM7601060301          11248  51904119680      6080   4320          3821        466N
  BM7601060302           3520    1920   160     1920   2520          1170         45N
  BY7601060303             34                       6      4           607         45N
  BM7601060304           2160                     320    320          1197         18N
  BY7601060305                                     15     15                        13R
  PMD,EL
  FREE        PACE1D
  FREE        PACE1E
  SYM       PACE1D
  SYM       PACE1E
  XQT       A2060C
  PMD,EL
  XQT       A2060D
  PMD,EL
  FREE        PACE3A
  SYM       PACE3A
  XQT       A2060E
  PMD,EL
  XQT       A2060F
CB
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  PMD,EL
  FREE        PACE7A
  FREE        PACE7B
  FREE        PACE7C
  SYM       PACE7A
  SYM       PACE7B
  SYM       PACE7C
  XQT       SYS$*MSFC$.ZEROFL
PACE1B
  XQT       SYS$*MSFC$.ZEROFL
PACE1C
  XQT       SYS$*MSFC$.ZEROFL
PACE1D
```

RATE TABLE (CONTD.)

← DESIGN-TO-COST FACTOR and RECURRING AND NON-RECURRING CAPABILITY

RAW DATA

CONTROL CARDS

← CONTRACTOR'S FEE RATE

TABLE OF CONTENTS DATA

CONTROL CARDS

```
XQT      SYS$*MSFC$.ZEROFL
PACE1E
XQT      SYS$*MSFC$.ZEROFL
PACE1F
XQT      SYS$*MSFC$.ZEROFL
PACE1G
XQT      SYS$*MSFC$.ZEROFL
PACE2A
XQT      SYS$*MSFC$.ZEROFL
PACE2B
XQT      SYS$*MSFC$.ZEROFL
PACE2C
XQT      SYS$*MSFC$.ZEROFL
PACE3A
XQT      SYS$*MSFC$.ZEROFL
PACE3B
XQT      SYS$*MSFC$.ZEROFL
PACE3C
XQT      SYS$*MSFC$.ZEROFL
PACE3D
XQT      SYS$*MSFC$.ZEROFL
PACE4A
XQT      SYS$*MSFC$.ZEROFL
PACE4B
XQT      SYS$*MSFC$.ZEROFL
PACE4C
XQT      SYS$*MSFC$.ZEROFL
PACE4B
XQT      SYS$*MSFC$.ZEROFL
PACE7A
XQT      SYS$*MSFC$.ZEROFL
PACE7B
XQT      SYS$*MSFC$.ZEROFL
PACE7C
XQT      SYS$*MSFC$.CHECKFL
PACE1B
XQT      SYS$*MSFC$.CHECKFL
PACE1C
XQT      SYS$*MSFC$.CHECKFL
PACE1D
XQT      SYS$*MSFC$.CHECKFL
PACE1E
XQT      SYS$*MSFC$.CHECKFL
PACE1F
XQT      SYS$*MSFC$.CHECKFL
PACE1G
XQT      SYS$*MSFC$.CHECKFL
PACE2A
XQT      SYS$*MSFC$.CHECKFL
PACE2B
XQT      SYS$*MSFC$.CHECKFL
PACE2C
XQT      SYS$*MSFC$.CHECKFL
PACE3A
XQT      SYS$*MSFC$.CHECKFL
PACE3B
XQT      SYS$*MSFC$.CHECKFL
PACE3C
```

CONTROL CARDS

```
        XQT       SYS$*MSFC$.CHECKFL
PACE3D
        XQT       SYS$*MSFC$.CHECKFL
PACE4A
        XQT       SYS$*MSFC$.CHECKFL
PACE4B
        XQT       SYS$*MSFC$.CHECKFL
PACE4C
        XQT       SYS$*MSFC$.CHECKFL
PACE6B
        XQT       SYS$*MSFC$.CHECKFL
PACE7A
        XQT       SYS$*MSFC$.CHECKFL
PACE7B
        XQT       SYS$*MSFC$.CHECKFL
PACE7C
        DELETE,C      PACE1B
        DELETE,C      PACE1C
        DELETE,C      PACE1D
        DELETE,C      PACE1E
        DELETE,C      PACE1F
        DELETE,C      PACE1G
        DELETE,C      PACE2A
        DELETE,C      PACE2B
        DELETE,C      PACE2C
        DELETE,C      PACE3A
        DELETE,C      PACE3B
        DELETE,C      PACE3C
        DELETE,C      PACE3D
        DELETE,C      PACE4A
        DELETE,C      PACE4B
        DELETE,C      PACE4C
        DELETE,C      PACE6B
        DELETE,C      PACE7A
        DELETE,C      PACE7B
        DELETE,C      PACE7C
        FIN
        FIN
```

CONTROL CARDS

TOTAL COST ESTIMATE REPORT

(Recurring and Nonrecurring)

TOTAL COST ESTIMATE REPORT

DATE 18 JUL 75 — PROJECT=PCX PROJECT — PAGE 1

WBS 1.4 — TITLE PCX PROJECT

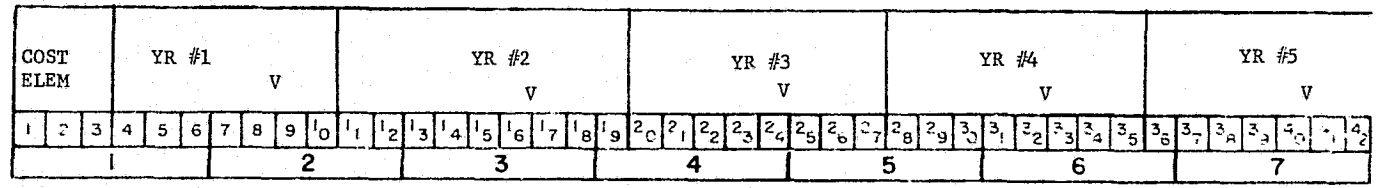
ELEMENTS OF COST		FY - 81	FY - 82	FY - 83	FY - 84	FY - 85	FY -	FY -	FY -	TOTAL
ENGR.	HOURS	394,244	718,037	712,561	427,262	160,498				2,412,602
	LABOR/OH $	11,752,419	21,404,683	21,241,443	12,736,680	4,784,445				71,919,665
MFG	HOURS	20,236	124,483	173,284	89,754	5,042				412,801
	LABOR/OH $	456,962	2,804,602	3,904,089	2,022,158	113,596				9,300,407
TOOLING	HOURS	2,830	48,424	28,357	1,176	1,176				81,163
	LABOR/OH $	43,901	1,335,305	666,273	25,143	25,143				1,735,265
Q + RA	HOURS	88,281	136,154	183,567	144,663	12,574				565,239
	LABOR/OH $	2,368,579	3,653,612	4,925,103	3,881,308	337,360				15,165,362
TEST	HOURS	38,562	127,211	199,028	186,517	80,428				631,066
	LABOR/OH $	998,891	3,331,499	5,226,504	4,892,341	2,109,626				16,552,861
OTHER	HOURS	37,853	63,136	59,412	41,296	64,643				266,304
	LABOR/OH $	1,362,708	2,271,603	2,138,832	1,486,656	2,327,148				9,586,944
TOTALS	HOURS	583,726	1,217,209	1,356,209	890,668	324,361				4,369,175
	LABOR/OH $	16,981,955	34,500,701	38,036,244	25,044,286	9,697,318				124,260,504
MATERIAL + SUBCON.		10,951,191	28,288,665	34,307,090	5,657,036	2,945,050				82,148,992
MATERIAL OVERHEAD		547,560	1,414,433	1,715,355	282,852	147,253				4,107,451
TRAVEL		17,033	32,312	37,447	30,722	18,159				135,643
OTHER		792,441	1,134,343	1,163,022	1,079,022	568,136				4,706,964
SUBTOTAL EST. COST		29,290,180	66,390,454	75,259,158	32,093,918	13,375,916				215,359,554
G + A EXPENSE		3,514,813	7,842,854	9,031,799	3,851,270	1,605,110				25,843,146
TOTAL EST. COST		32,804,921	73,181,308	84,290,957	35,945,188	14,981,026				241,202,700

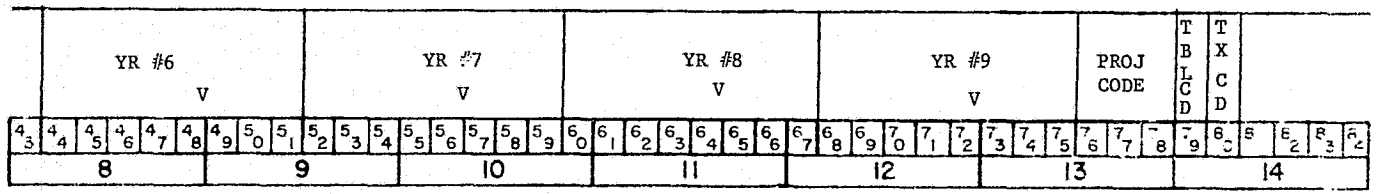
RATE TABLE FORMAT SHEET

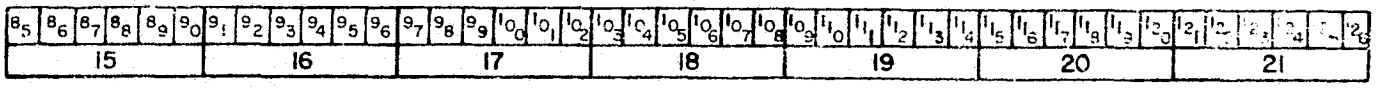
Attachment 5

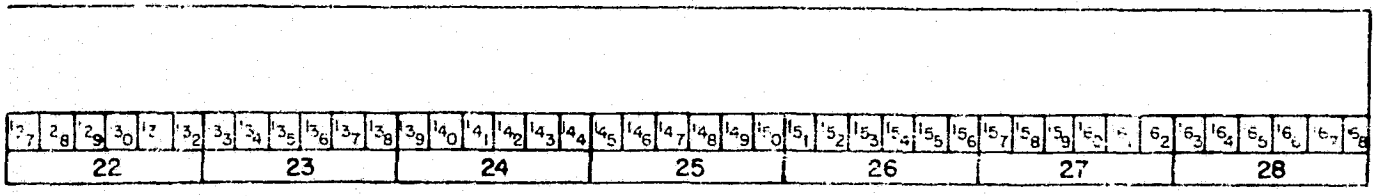
RATE TABLE FORMAT

COMPUTER RECORD DESIGN FORMAT	TYPE RECORD: RATE TABLE FORMAT	NUMBER OF: CHAR- 80	WDS-
RUN TITLE: Cost Calculations	DESIGNED BY: J. Jackson	DATE:	
RUN NUMBER: Pace 04	CHECKED BY	DATE:	









CSC FORM NO. PU-45-66

RUN DATA INPUT SHEET

WBS NUMBER:	COMPUTER INPUT AND WORKSHEET (Base Data) PACE SYSTEM (Pricing And Cost Estimating)	DATE:	PAGE OF
WBS TITLE:	PROJECT NAME:	PREPARED BY:	

T.C. (1)	M.C. (2)	FY	WORK BREAKDOWN STRUCTURE CODE	MANPOWER						DOLLARS			
				ENGINEERING	MANUFACTURING	TOOLING	QUAL. & REL. ASSURANCE	TESTING	OTHER (3)	MATERIAL $	TRAVEL $	OTHER DIRECT $ (4)	(5)
1	2	3	4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20	21 22 23 24 25 26 27	28 29 30 31 32 33 34	35 36 37 38 39 40	41 42 43 44 45 46	47 48 49 50 51 52	53 54 55 56 57 58	59 60 61 62 63 64 65 66	67 68 69 70 71 72	73 74 75 76 77 78 79	80

LEGEND:

(1) TC = Transaction Code: B = Build, C = Change, D = Delete

(2) MC = Manpower Code: H = Manhour, M = Montns, Y = Manyears

(3) OTHER: Mgmt., Transp. Eqpt., Support, Training, Logistics, Facility Planning

(4) OTHER DIRECT: Computer Chg. Engr. Supplies and Materials

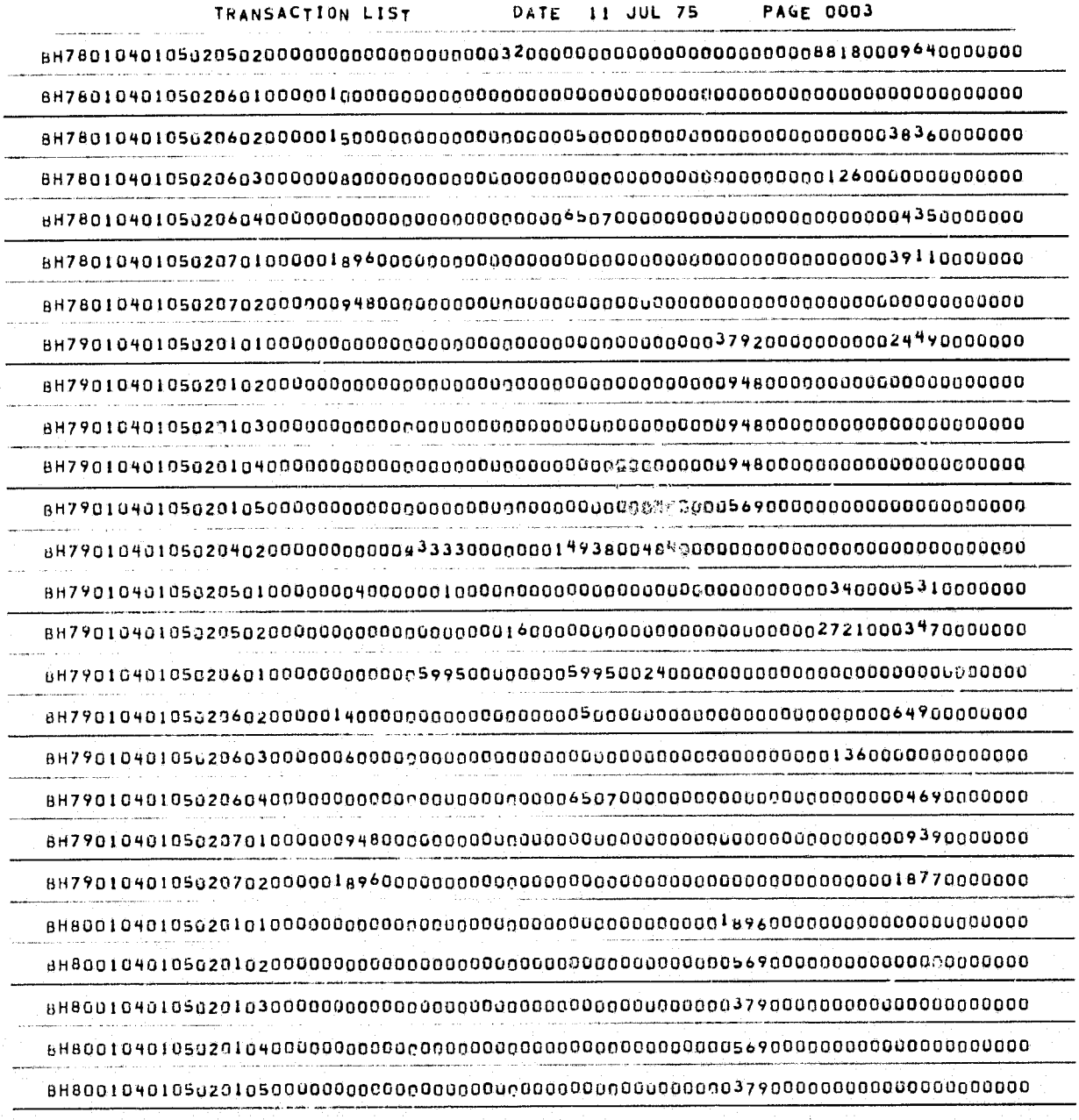
(5) R = Recurring, N = Non-Recurring

MSFC - Form 514 (April 1976)

TRANSACTION LIST!

Attachment 7

TRANSACTION LIST DATE 11 JUL 75 PAGE 0003



DESIGN-TO-COST ESTIMATE

Attachment 8

DESIGN-TO-COST ESTIMATE

DATE 22 JUL 75 PROJECT-PCX PROJECT DESIGN-TO-COST FACTOR = 0.82 PAGE 1

WBS 1.4 TITLE PCX PROJECT

ELEMENTS OF COST		FY - 81	FY - 82	FY - 83	FY - 84	FY - 85	FY -	FY -	FY -	TOTAL
ENGR.	HOURS	323,266	588,774	584,283	350,337	131,593				1,978,253
	LABOR/OH $	9,636,559	17,551,353	17,417,476	10,443,546	3,922,787				58,971,721
MFG	HOURS	16,592	102,070	142,086	73,592	4,133				338,473
	LABOR/OH $	373,818	2,299,637	3,201,198	1,658,028	93,116				7,625,797
TOOLING	HOURS	1,663	39,703	23,250	964	964				66,544
	LABOR/OH $	35,555	848,850	497,085	20,610	20,610				1,422,710
G + A	HOURS	72,342	111,635	150,511	118,612	10,310				463,450
	LABOR/OH $	1,942,009	2,995,167	4,038,210	3,182,360	276,617				12,434,363
TEST	HOURS	31,223	104,142	163,196	152,935	65,947				517,443
	LABOR/OH $	818,979	2,731,645	4,280,631	4,011,485	1,729,790				13,572,530
OTHER	HOURS	31,031	51,737	48,711	33,857	52,999				218,335
	LABOR/OH $	1,117,116	1,862,532	1,753,596	1,218,852	1,907,964				7,860,060
TOT LAB	HOURS	476,157	998,061	1,112,037	730,297	265,946				3,582,498
	LABOR/OH $	12,924,036	28,289,184	31,188,196	20,534,881	7,950,884				101,887,181
MATERIAL + SUBCON.		8,979,933	23,196,691	28,131	1,638,760	2,414,939				67,362,129
MATERIAL OVERHEAD		448,997	1,159,835	1,406,590	231,938	120,747				3,368,107
TRAVEL		13,935	26,488	30,692	25,184	14,883				111,182
OTHER		649,793	905,552	953,664	884,785	465,862				5,859,656
SUBTOTAL EST. COST		24,016,694	53,577,750	61,710,948	26,315,548	10,967,315				176,588,255
G + A EXPENSE		2,882,003	6,429,330	7,405,314	3,157,866	1,316,073				21,190,591
TOTAL EST. COST		26,898,697	60,007,080	69,116,262	29,473,414	12,283,393				197,778,846

APPENDIX C

STEPS REQUIRED TO DEVELOP A MANUFACTURING ESTIMATE

Estimating for the manufacturing elements of a project should, as a minimum, involve the following basic steps:

1. Management:

   a. Define the Management structure for Manufacturing Operations.

   b. Define Manufacturing Operations participation in the generation of overall program schedule.

   c. Establish Manufacturing processes and flow plan.

   d. Verify the availability of tools, processes and labor skills to meet the Manufacturing schedule.

   e. Define criteria for Make or Buy.

   f. List major assemblies and/or tools to be subcontracted.

2. Manufacturing Technology and Processes:

   a. Identify the processes required for implementation of the design in areas such as: joining, forming, machining, electrical fabrication finishing, thermal protection, fabrication, etc.

   b. Identify the major tools required and numbers of each. Prepare an estimate of tooling cost and specify which tools are Government furnished and which are contractor furnished.

   c. Prepare summary listing of Mock-ups and Breadboard requirements.

   d. Correlate tooling and manufacturing requirements to dovetail with total program schedules.

3. Assembly Sequence and Operations:

   a. Correlate the phasing of components and subassemblies into the assembly sequence.

b. Define the skill mix and the ratio of support personnel to production personnel.

c. Estimate certification and training requirements.

d. Compile special requirements, i.e., transportation, protection and packaging of raw materials, in process materials and parts, components, major assemblies, spares, test materials, and off-site requirements.

APPENDIX D

INSTRUCTIONS REGARDING COMPLETION OF WORKSHEETS

A separate set of worksheets must be used for each Work Breakdown Structure (WBS) element. Tooling labor applicable to a given WBS must be listed separate from other types of labor, i.e., labor needed to fabricate flight hardware. This requires the use of MSFC Form No. 441, titled Estimating Worksheet/ Labor, Exhibit #1.

Tooling materials applicable to a given WBS must also be listed separate from other types of materials, i.e., material used in fabrication of flight hardware and avionics. This requires the use of a separate MSFC Form No. 441-1, titled Estimating Worksheet/Materials, Exhibit #2.

The heading on all Worksheet forms must be completed listing the date prepared, name of individual preparing worksheet and office or laboratory involved. If worksheet is being used for tooling check yes; check no if not being used for tooling. The applicable WBS number and title must be filled in.

The various offices and laboratories are requested to complete the worksheets giving as much detail as possible and completing only those blocks, i.e., Eng., Mfg., Q/A Rel., that are applicable to your office and/or laboratory.

ATTACHMENTS:

Exhibit #1, MSFC Form No. 441
Exhibit #2, MSFC Form No. 441-1
Exhibit #3, MSFC Form No. 441-2
Exhibit #4, MSFC Form No. 441-3
Exhibit #5, Functional Definitions

MSFC Form 441 Estimating Worksheet/ Labor

Exhibit No. 1 is used to record the various tasks and the manhours required to perform those tasks. Rationale used in arriving at manhours should be included on this form. If not enough room is provided for rationale, a supplementary sheet may be attached.

DATE: _____ TOOLING ☐ YES ☐ NO

PREP BY: _____

OFFICE/LAB: _____ WBS _____ TITLE _____

MANHOURS
ESTIMATING WORKSHEET/LABOR

QTY.	DESCRIPTION OF TASK	ENGR.	MFG.	Q/A REL	TEST	OTHER	RATIONALE
	TOTAL						

MSFC - Form 441 (August 1974)

Exhibit No. 1

MSFC Form 411-1 (August 1974) Estimating Worksheet/ Material

Exhibit No. 2 is for purchased materials used in fabrication. If the drawing number is known it must be included. This form is intended for listing all material (raw and/or purchased finished) for each WBS.

The source and basis used in arriving at cost should be included on this form. If there isn't enough room a supplementary sheet may be added.

DATE: _____ TOOLING ☐ YES ☐ NO

PREP BY: _____

OFFICE/LAB: _____ WBS _____ TITLE _____

ESTIMATING WORKSHEET/MATERIAL

ITEM	DRAWING NO, TYPE & SIZE, MATERIAL DESCRIPTION	QTY.	PURCHASED MATERIALS		SOURCE AND BASIS
			UNIT COST	TOTAL	
	TOTAL				

Exhibit No. 2

A&PS-Form No. 256-3 Other Direct Cost

Exhibit No. 3 is for Other Direct Cost as defined in Exhibit No. 5. This Exhibit is intended to show the information that will be included upon completion by EL-02.

The information desired from the various offices and laboratories includes number of trips, duration of trip, point of origin and destination, and number of days a rental car would be needed. If computer time is required, the type of computer, i.e., UNIVAC 1108, and the total number of hours should be shown on this form.

Costing of travel, computer and other (miscellaneous) will be done by EL-02.

DATE: _____

PREP BY: _____

OFFICE/LAB: _____ WBS _____ TITLE _____

TRAVEL AND OTHER DIRECT $
WORKSHEET

TRAVEL		OTHER DIRECT $	COMPUTER HRS	RATIONALE
TRIPS	DAYS PER DIEM			

MSFC - Form 411-3 (August 1974)

Exhibit No. 3

MSFC Form 441-3 (August 1974) Summary Cost Data

Exhibit No. 4 is used for spreading of manhours over the appropriate fiscal year. Manpower spread for a given WBS should reflect those manhours required to accomplish the work task in that particular WBS by fiscal year.

Provisions have also been made on this form to spread the materials cost by fiscal year for the same WBS.

Travel and Other Direct Costs at the bottom of this form are as defined in Exhibit No. 5 Functional Definitions.

DATE: _____

PREP BY: _____

OFFICE/LAB: _____

SUMMARY COST DATA
GOV. FISCAL YEAR SPREAD

WBS _____ TITLE _____

FISCAL YEAR	75	76	77	78	79	80	81	82	83	TOTAL
ENGR. MANHOURS										
MFG MANHOURS										
TOOLING MANHOURS (ENGR. AND MFG & QUAL)										
QUAL & REL MANHOURS										
TESTING MANHOURS										
OTHER MANHOURS										
TOTAL MANHOURS										
MATERIAL & SUBCONTRACT $										
TRAVEL TRIPS										
TRAVEL DAYS PER DIEM										
OTHER DIRECT COSTS $										
COMPUTER HOURS										

MSFC - Form 441-3 (August 1974)

Exhibit No. 4

EXHIBIT No. 5

FUNCTIONAL DEFINITIONS

Engineering — The study, analysis, design, development, evaluation and redesign for specified subdivisions of work. 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.

Manufacturing — Time expended on, or chargeable to, such operations as fabrication, processing, subassembly, final assembly, reworking, modification, experimental production, and installation of parts and equipment (including Government furnished equipment). This includes all effort on those parts that — because of their strength, configuration, or weight characteristics — are design controlled for the performance of the basic mission. Included are direct manhours expended in the preparation and processing of material of any kind (metal, plastic, glass, cloth, etc.). Preparation and processing includes but is not limited to all flashing operations, annealing, heat treating, baking, refrigeration, anodizing, plating, painting and preflight or pretest and production services operations (prior to final acceptance of each unit). Fabrication (the construction of detail parts from raw materials) includes the hours expended in the cutting, molding, forming, stretching, and blanking operations performed on materials of any kind — metal, wood, plastic, cloth, tubing, etc. — to make individual parts. Experimental hours spent in construction of mock-up models, test articles, testing, reworking during the test program, etc. should be considered as direct manufacturing manhours, as should machine setup time when performed by the operator of the machine.

Tooling — The planning, design, fabrication, assembly, installation, modification, maintenance, and rework of all tools, dies, jigs, fixtures, gauges, handling equipment, work platforms, and test equipment and Special Test Equipment (STE) in support of the manufacturing process. Includes time expended in the determination of tool and STE records, establishing make-or-buy plans and manufacturing plans on components and equipment, scheduling and controlling all tool and STE orders, and programming and preparation of tapes for all numerically controlled machine parts. Also includes preparation of templates and patterns, and form block manufacture.

Quality and Reliability Assurance — All efforts prescribed by the proposed contractual reliability and quality program plans for the project except for portions of effort which are distinguished by these plans as being overall project

effort rather than functional reliability or quality effort; e.g., design review may be prescribed by the reliability program plan, but the plan may prescribe that all design review activity except that performed by the reliability organization should be charged as an overall engineering cost rather than a reliability and quality assurance cost. Reliability and quality assurance costs should be derived from specific task requirements in the reliability and quality program plans. Typical tasks include receiving inspection, in-process and final inspection of tools, parts, and subassemblies of complete assemblies; and reliability testing and failure report reviewing.

Test — Time expended in the performance of tests on all components, assemblies, subsystems, and systems to determine operational characteristics and compatibility with the overall system and its intended operational/nonoperational environment. Such tests include design feasibility tests, design verification tests, reliability tests, etc.; and tests on parts, systems, and integrated systems to verify the unconditional suitability in meeting the criteria for intended usage. These tests are conducted on hardware or final designs that have been produced, inspected, and assembled by established methods. Also includes tests performed by two or more associate contractors to substantiate the feasibility, development, qualification, or acceptance of interface and/or interface system compatibility. Time expended in test planning and scheduling, data reduction, and report preparation should also be included in this category.

Other -- Includes program peculiar functional definitions that are direct labor and are not covered in engineering, manufacturing, tooling, quality and reliability assurance, and test. An example would be program management that will be charged as direct labor to the program.

Materials

Includes the cost of raw materials and parts that are required in the performance of the work.

Other Direct Costs

Includes the cost of travel, per diem, automatic data processing, reproduction of printed materials, and other items applicable to the WBS and not specifically identified with other specific direct and indirect categories of cost.

APPENDIX E

EXCERPTS FROM APPLICABLE REGULATIONS

C.2

NASA Procurement Regulations place specific requirements on the Center with respect to cost estimates and proposal evaluation. The following are excerpts from Part 3, Subpart 8 of those regulations which are relevant to the cost estimating function:

I. Requirements in NASA Regulations for Preparation of Independent Estimates

3.802-1 "Knowledge of the product or service, and its use is essential to sound pricing. Before soliciting quotations, every contracting officer should develop, where feasible, an estimate of the proper price level of value of the product or service to be purchased. Such estimates may be based on a physical inspection of the product and review of such items as drawings, specifications and for the delivery requirements must necessarily rest with requirements and technical groups."

3.801-2(d) "Pricing based on cost analysis involves, among other things, an appraisal of estimates of costs expected to be incurred in the future. The accounting projection of trends based on cost or pricing data, together with any known changes therein, is only one method of conducting this appraisal — others being:"

(i) An engineering appraisal of the need for the estimated labor and material costs and of tooling and facilities, and the reasonableness of scrap and spoilage factors, and

(ii) The preparation of independent estimates by competent technical personnel.

3.807-2 Requirement for Price or Cost Analysis Para. (b) (1):
"...Price analysis may be accomplished in various ways including the following:

(v) the comparison of proposed prices with estimates of cost independently developed by personnel with the Procurement Office;" and

Paragraph (c) (3)
"...the evaluations that should be made where the necessary data are available, are comparisons of a contractor's or offeror's current estimated costs with:

(iii) current cost estimates from other possible sources;"

II. Requirements in NASA Regulations for Team Approach to Cost Estimating

3.801-2(a) & (b) "The contracting officer shall avail himself of all appropriate organizational tools such as the advice of specialists in the fields of contracting, finance, law, contract audit, engineering, and price analysis;"

"To the extent services of specialists are utilized in the negotiation of contracts, the contracting officer must coordinate a team of experts, requesting advice from them, evaluating their counsel, and availing himself of their skills."

III. Requirements in Source Evaluation Board Manual

NHB 5103.6 — NASA Source Evaluation Board Manual

Chapter 2: Evaluation Factors and Criteria

Paragraph 200-3. "In making the selection, the official considers all pertinent factors; ... what it will probably actually cost the Government.."

"Getting the proposed work done properly is always important, and so is the forecast cost of it. The likely cost is not necessarily the proposers' estimate of costs; rather it is our assessment of what would likely ensue..."

Paragraph 202-1 "The principal aims of the SEB in the analysis of costs are to advise the Source Selection Official concerning (a) the validity of costs as proposed; (b) the probable cost to the Government of accepting each proposal in the competitive range; (c) the probable difference among the proposers, including those due to differences in business methods and operating procedures and practices; and (d) its level of confidence in its analyses and projections regarding costs as they pertain to each fully evaluated proposal."

APPENDIX F

GLOSSARY
DEFINITION OF TERMS

GLOSSARY

Contract Change Estimate	An estimate developed independent of the contractors' proposal submitted in response to a change directed pursuant to the "changes" clause of an on-going contract.
Cost Data Bank	A compilation of logically derived rates of cost developed from candidate aerospace contractors for improving rough order of magnitude estimating.
Data Bank	The systematic accumulation and storage of historical cost and performance data for quick and easy retrieval in the form desired for estimate development.
Data Base	The identification and accumulation of a group of data which may serve as a source of information for construction of a data bank.
Design to Cost	Design-to-cost is a process utilizing unit cost goals as thresholds for managers and as design parameters for engineers. The dollar value for each goal represents what the Government has established as an amount it can afford (i.e., is willing and able) to pay for a unit of equipment or major subsystem which meets established and measureable performance requirements at a specified production quantity and rate during a specified period of time.

Estimate Coordinator	Person(s) within the organizational entities of MSFC responsible for providing estimate input which coordinates and communicates all estimate instructions to the individuals within his organization.
Estimate Assumptions	The establishment and documentation of a basis for quantifying those areas between given or known conditions and those areas where complete program definition is not available.
Estimate Groundrules	The identification and documentation of the parameters, both technical and administrative, applicable to the project being estimated.
Estimate Handbook	A collection of uniform multipliers, such as unit cost per unit of resource and a detailed description of a methodology to be applied to the estimating process.
Estimate Input	The preparation and delivery of data including the assessment and quantification of all materials, services, travel, and cost associated therewith, in a form suitable for developing a total program/project estimate.
Estimate Manager	The designated individual within the Government Cost Estimating Office responsible for coordinating, developing, and publishing the Government estimate.
Estimate Rationale	The documented basis for assessing labor, material, and other activities and costing for both individual components and the complete estimate.

Estimating Worksheets	Standardized formats developed for preparation and accumulation of estimate input. These worksheets are developed by the Cost Estimating Office Manager and established compatibility with other estimate formats of computations.
Estimate Types	
(1) Grounds-Up Estimates (Also called "Grass-Roots," "Bottoms-Up," "Industrial Engineering type," "Building-Block" or "Built-Up" estimates)	An independent Government "grounds-up" estimate is an estimate made by the Government of the most probable costs of contracting with industry for a given product, service, or mission based on the use of detailed, direct, and/or statistical estimates of the labor, materials, and equipment required to accomplish each element of work. The technique entails the examination of separate items of work at a low level of the work breakdown structure with estimates developed for the functional costs of engineering, manufacturing, quality assurance and reliability testing and tooling. These estimates employ a mutually agreed upon labor rate structure for each skill and for each fiscal year covered by the project being estimated to develop labor costs. Total costs are derived by summing labor material, and subcontract costs for all elements and adding other direct changes overhead, general and administrative expenses, and fee.
(2) Parametric Estimates	The parametric cost estimating technique predicts costs by means of explanatory variables such as performance characteristics, physical characteristics, and characteristics relevant to the development process as derived from experience

Parametric Estimates (Concluded)	on logically related systems. The statistical technique of regression analysis is often used to derive the relationships between two or more meaningful variables such as total dollar costs of development and weight. The expression of cost in terms of any physical or performance characteristic is called a cost estimating relationship (CER). The cost data derived from one or more CERs is used as the basis for developing a parametric cost estimate for an entire system. This technique may also be used to develop manhour and material estimates.
(3) Detail Estimate	This technique entails the estimating of separate items of work to the lowest level of the Work Breakdown Structure (Work Package Task) by functional costs of Engineering, Manufacturing, Quality Control, etc., which are in turn broken down by labor, material, and other elements of cost for each item.
(4) Direct Estimate	This technique entails the estimating of the manhours and materials required to perform a specific element of the WBS and generally are made at a summary level. Direct estimates are based on the professional judgement and experience of the individual(s) making the estimate. The validity of the estimate for the most part is dependent on the professional qualifications of the estimator.
(5) Statistical Estimate	Statistical estimates are obtained by projecting known quantities from an existing data base and adjusting the results by judgemental factors to create a comparable situation. This technique is most useful when analyzing proposals for follow-on effort or for estimates to

Statistical Estimate (Concluded)	complete. Careful consideration should be given to the consistency of assumptions from one program to another.
(6) Rough Order of Magnitude	The assessment of overall program cost by generally sizing the job to be done in gross terms.
Investment Analysis	The assessment of funding requirements to assure optimum utilization of program financial resources by determining funding levels for specific increments of performance.
Kick-Off Meeting	The initial meeting of representatives of the Program Office, estimate manager and estimate coordinators to establish estimate guidelines, ground-rules, schedules, and other estimate parameters.
Most Probable Cost	The assessment of all program requirements to arrive at the most probable cost for total program completion based either upon optimum program development or a specific contractor approach described in a proposal for project procurement.
Plan of Action Memorandum	The documented agreements reached in the kick-off meeting.
Performance Measurement System (PMS)	Contractor measuring and reporting system of cost, schedule, and performance criteria. Timely visibility of the contract baseline, changes, planned versus actual experience, and variance analysis are provided.
Work Breakdown Structure (WBS)	A subdivision of work required to achieve an objective which is structured successively into systems, subsystems, components, tasks, subtasks, and work packages.

Preliminary estimate	The initial compilation of estimate input and publication of a complete program estimate based upon a single set of assumptions. This preliminary estimate may then be updated during program/ project refinement to reflect the final estimate for program management throughout the contract performance phase.
Strawman Estimate	A "strawman" estimate is a preliminary estimate made for the purpose of computer checkout, for comparison with budgetary figures, or for developing proportions of costs to be allocated to elements of cost and/or elements of work in a "design-to-cost" situation. This type of estimate is used for verifying estimating methodology, evaluating new estimating techniques, or for analyzing cost trade-offs for alternate designs or alternate schedules.

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APPROVAL

COST ESTIMATING METHODOLOGY AND TECHNIQUES FOR PREPARING INDUSTRIAL-ENGINEERING TYPE MANHOUR AND MATERIAL-BASED COST ESTIMATES

By Rodney D. Stewart

The information in this report has been reviewed for security classification. Review of any information concerning Department of Defense or Atomic Energy Comission programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determine to be unclassified.

This document has also been reviewed and approved for technical accuracy.

T. P. Shell

H. E. THOMASON
Director, Systems Analysis and Integration Laboratory