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SHUTTLE FREE-FLYING TELEOPERATOR SYSTEM EXPERIMENT DEFINITION

FINAL REPORT

VOLUME III–PROGRAM DEVELOPMENT REQUIREMENTS

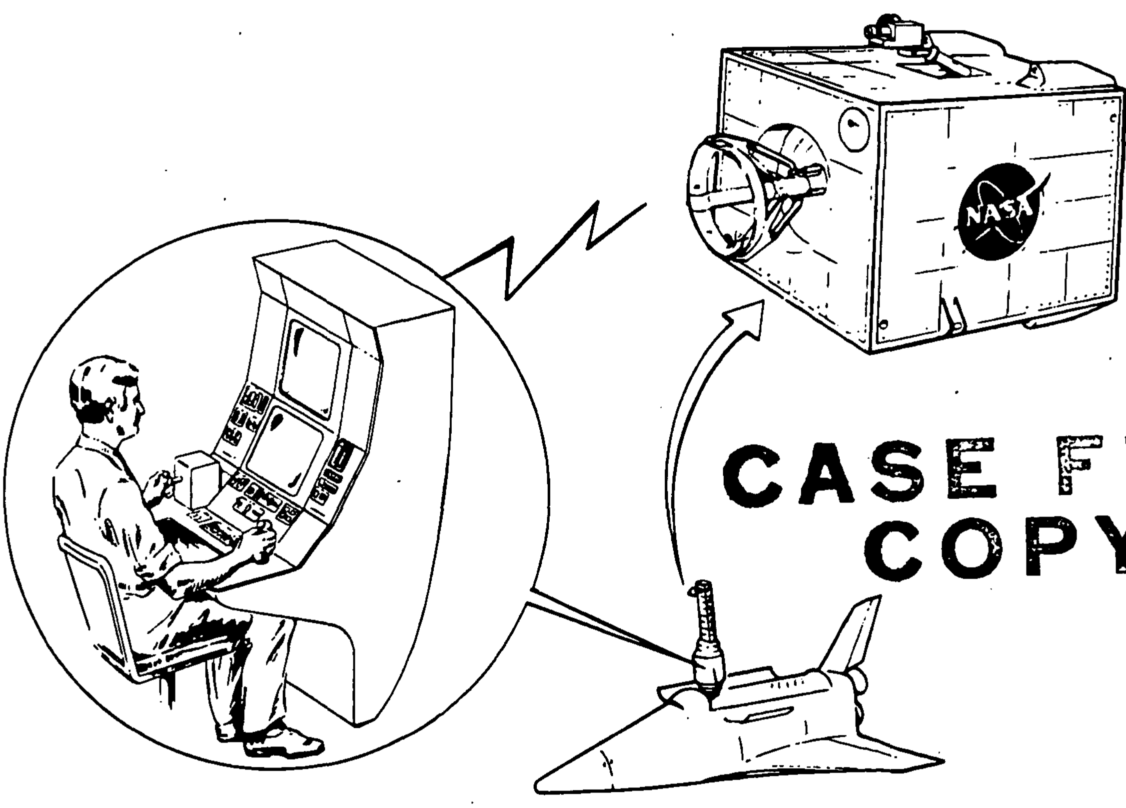
JUNE 1972

CONTRACT NAS8-27895

REPORT NO. D7425-953004

DPD 261 DR MA04

Prepared for NASA Marshall Space Flight Center
Huntsville, Alabama



Bell Aerospace Company DIVISION OF textron

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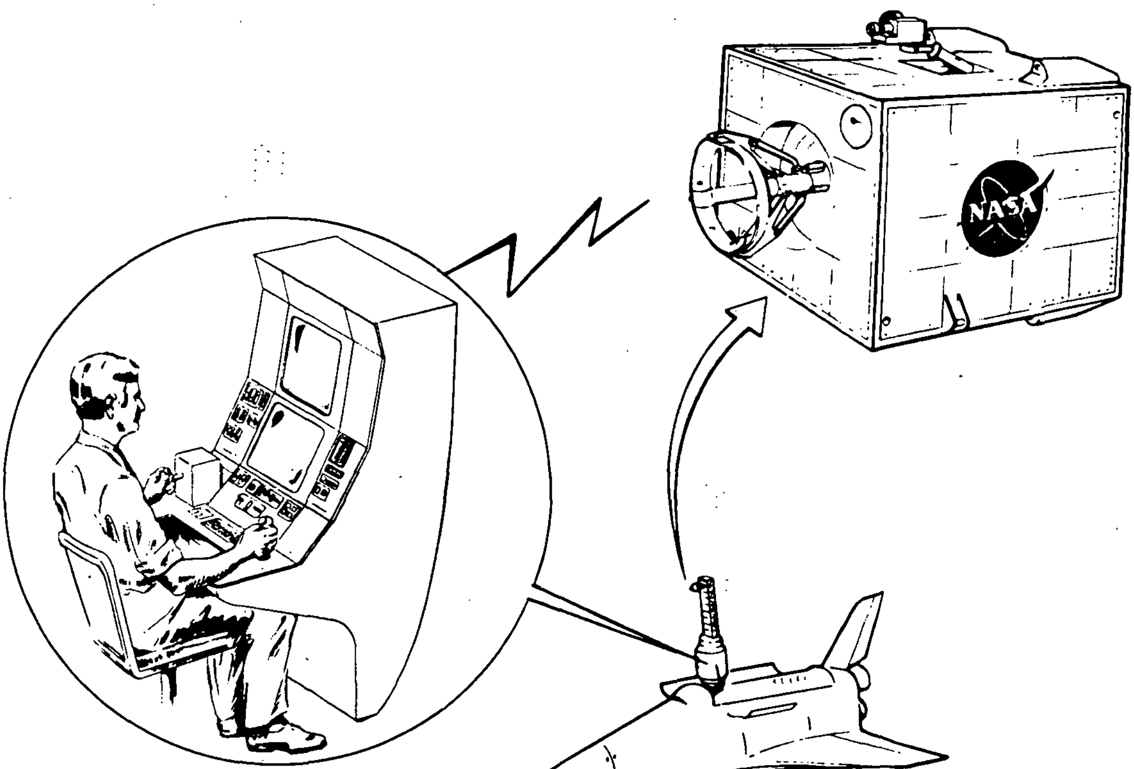

Reviewed and Approved by H. Fornoff

H. Fornoff

CHIEF ENGINEER
SPACE SYSTEMS

Bell Aerospace Company DIVISION OF textron

FOREWORD

This study was conducted by the Bell Aerospace Company, Buffalo, New York, for the NASA Marshall Space Flight Center, Huntsville, Alabama. It represents a six-month effort performed under contract NAS 8-27895. Mr. James H. Clingman was the NASA COR. George Onega was the Bell Study Manager. The following people contributed significantly to the study:

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The study final report is published in three volumes as follows:

Volume I:	Executive Summary
Volume II:	Technical Report
Volume III:	Program Development Requirements

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CONTENTS (CONT)

ILLUSTRATIONS

TABLES

I. INTRODUCTION AND SUMMARY

A. INTRODUCTION

This is Volume III of the final report on work accomplished on the Shuttle Free-Flying Teleoperator Experiment Definition Study conducted for the George C. Marshall Space Flight Center of NASA under contract NAS 8-27895. This volume contains the planning data for subsequent phases of an FFTO program and includes costs, schedules and supporting research and technology activities required to implement the free-flying teleoperator system and associated flight equipment. It has been prepared in accordance with the requirements of Task 6 of the contract Statement of Work.

The purpose of the data presented herein is to provide NASA with the information needed to continue development of the FFTO and integrate it into the Space Shuttle Program. The planning data describes three major program phases consisting of activities and events scheduled so as to effect integrated design, development, fabrication and operation of an FFTO system. Phase A, Concept Generation, represents a study effort directed toward generating and evaluating a number of feasible FFTO experiment system concepts. Phase B, Definition, will include preliminary design and supporting analysis of the FFTO, the shuttle based equipment and ground support equipment. Phase C/D, Design, Development and Operations will include detail design of the operational FFTO, its integration into the space shuttle, hardware fabrication and testing, delivery of flight hardware and support of flight operations.

Emphasis is placed on the planning for Phases A and B since these studies will be implemented early in the development cycle. Phase C/D planning is more general and subject to refinement during the definition phase. The overall program (see Figure I-1) is compatible with the space shuttle schedule* – that is, the experimental teleoperator system will be available by the end of 1977. This availability is substantiated by the schedules described in Parts II-B and III-B herein.

This volume is organized in accordance with NASA Data Requirement MA-O4 and contains the following:

Section II - Phase A Program Development Requirements

- Part A - Project Planning Requirements, Phase A
- Part B - Schedules, Phase A
- Part C - Supporting Research and Technology (see Section V)
- Part D - Cost Estimates, Phase A

Section III - Phase B Program Development Requirements

- Part A - Project Planning Requirements, Phase B
- Part B - Schedules, Phase B
- Part C - Supporting Research and Technology (see Section V)
- Part D - Cost Estimates, Phase B

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*From "Recommended Payloads for Early Shuttle Missions," by Payload Planning Advanced Missions Program, October 7, 1971.

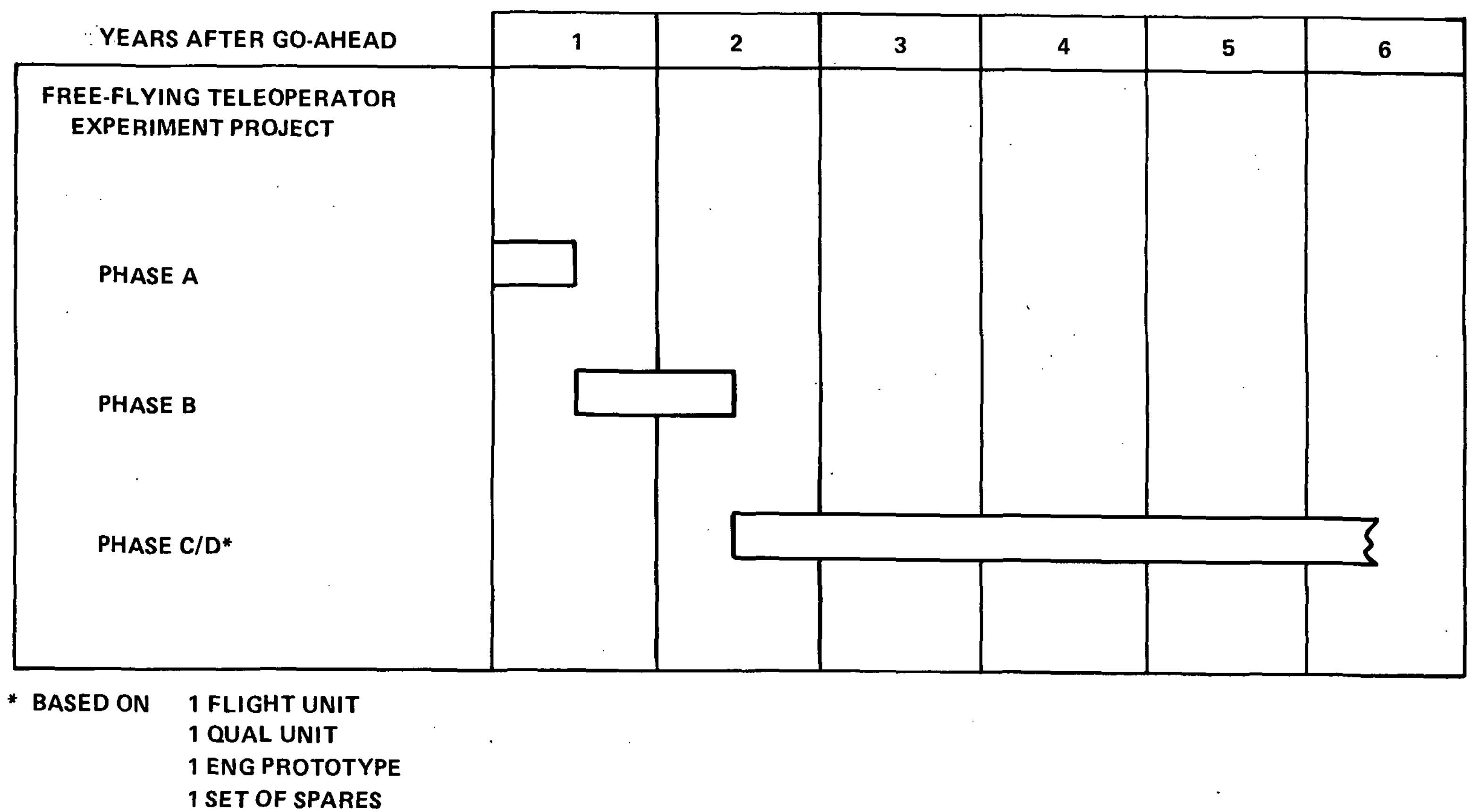

Figure I-1. Teleoperator Project Schedule

Section IV - Phase C/D Program Development Requirements

Part A - Project Planning Requirements, Phase C/D
Part B - Schedules, Phase C/D
Part C - Supporting Research and Technology (see Section IV)
Part D - Cost Estimates, Phase C/D

Section V - Supporting Research and Technology

Section VI - Technical Characteristics Data

B. SCHEDULE SUMMARY

Phase A is a six-month study consisting of:

1. System Engineering and Development Design
2. Preparation of Phases B, C/D Development Plans

Phase B is planned as a 12-month program consisting of:

1. System Engineering and Preliminary Design
2. Development of System Test Requirements
3. Preparation of Specifications
4. Preparation of Phase C/D Development Plan
5. Design and Fabrication of Mockups
6. Preparation of Contractual Documents

Phase C/D is tentatively planned as a program which, until delivery of the first flight system, will encompass 39 months. It will consist of:

1. Design
2. Development
3. Qualification
4. Fabrication of Flight Systems
5. Training
6. Operational Support

The overall schedules for the accomplishment of these phases are illustrated in Figures I-2, I-3 and I-4. The result of Phase A will be the identification of suitable system concepts. The output of Phase B will be:

1. a preliminary design of all elements of the teleoperator experimental system,
2. a set of system and subsystem specifications,
3. a plan for the subsequent phase of the program,
4. a soft mockup of the system.

To integrate the system into the shuttle in 1977, Phase B must begin in mid-1973 and be followed immediately by Phase C/D. Furthermore, the key technology programs required must be initiated soon so that the results of such programs are available during the Phases B and C/D efforts.

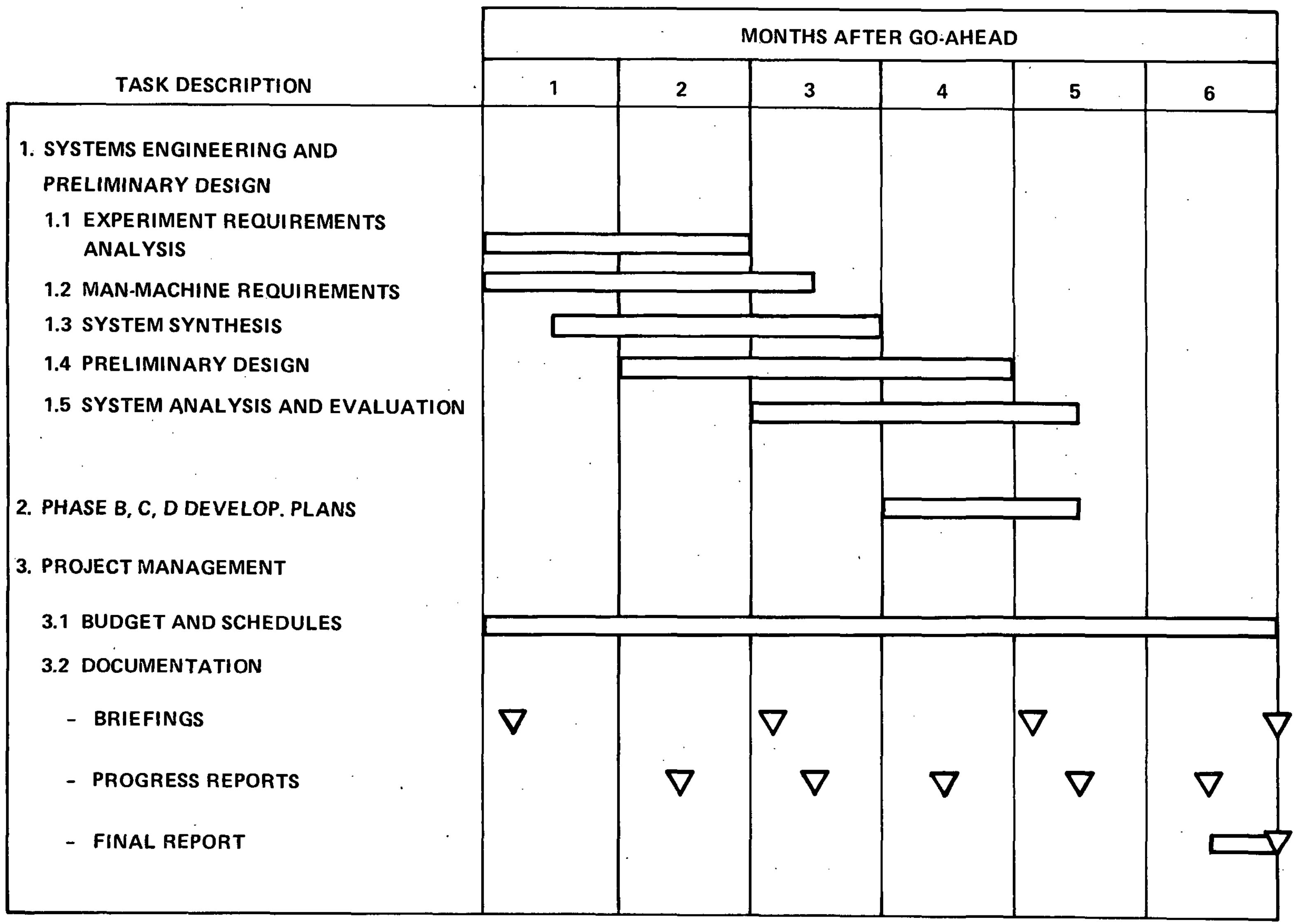

Figure I-2. Phase A Study Schedule

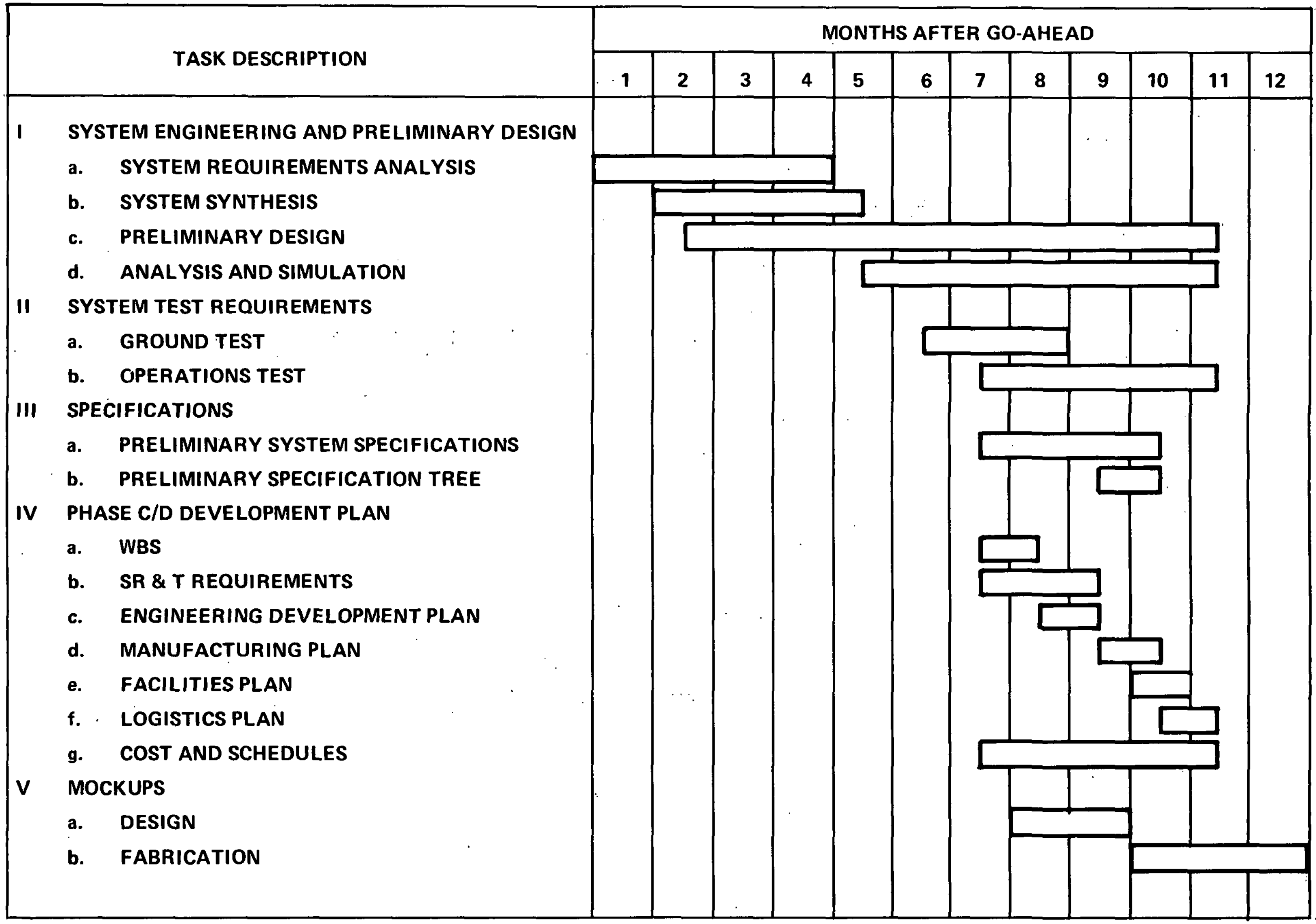

Figure I-3. Summary Schedule - Phase B

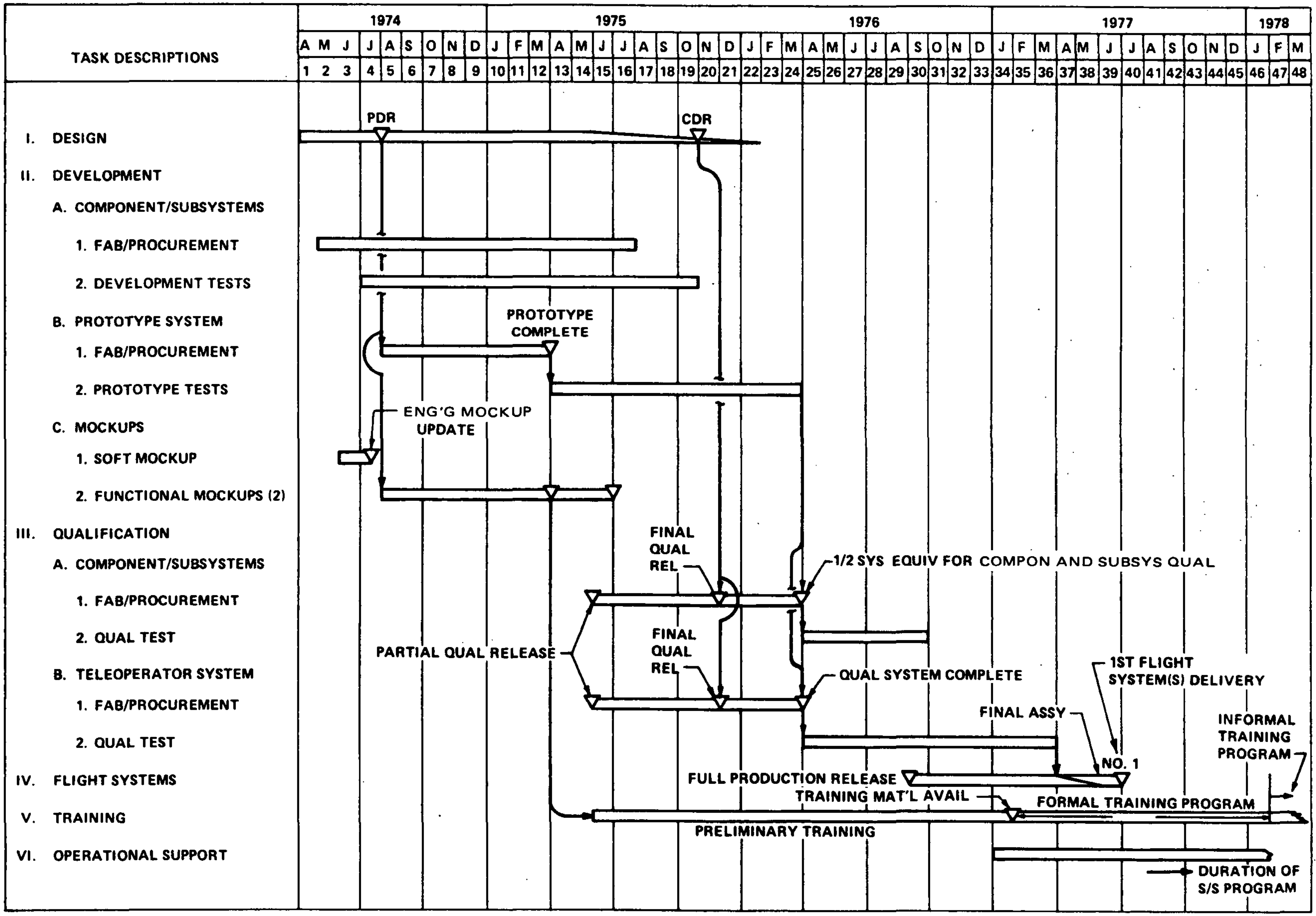

Figure I-4. Summary Schedule - Phase C/D

C. COST SUMMARY

Phase A, Phase B and Phase C/D costs are summarized in Tables I-1, I-2 and I-3.

Since emphasis in the planning effort has been placed on Phases A and B, the cost indicated for these phases is reasonably accurate. The manner in which they were derived and the supporting data are contained in Sections II-D and III-D respectively.

The cost for Phase C/D is an ROM cost intended only as an initial planning figure. This phase is only roughly defined; the depth of planning is insufficient at this early stage of the program to permit an accurate estimate. The manner in which the planning costs were derived is described in Section IV-D.

TABLE I-1.
COST DATA FORM A-1
NON-RECURRING (DDT&E) SUMMARY

STUDY TITLE Shuttle FFTO Experiment Definition Study, Phase A

CONTRACT NO. NAS 8-27895

DATE ________

PAGE 1 OF 1

IDENTIFICATION NUMBER	WBS IDENTIFICATION	WBS LEVEL	EXPECT. COST	CONFID. RATING	T_d	T_s	SPREAD FUNCT.
01-001-01	Program Mgmt., Administration, and Documentation		$ 33,000				
01-001-02	System Engrg & Prelim Design		$ 82,000				
01-001-03	Phase C/D Develop. Plans		$ 10,000				
Total Program			$ 125,000				

TABLE I-2. PHASE B COST SUMMARY

COST DATA FORM A-1

SUMMARY

STUDY TITLE Shuttle FFTO Experiment Definition Study, Phase B

CONTRACT NO. NAS8-27895

DATE

PAGE 1 OF 1

IDENTIFICATION NUMBER	WBS IDENTIFICATION	WBS LEVEL	EXPECT. COST	CONFID. RATING	T_d	T_s	SPREAD FUNCT.
01-001-01	Program Mgmt, Administration and Documentation		$ 117,262				
01-001-02	System Engineering and Preliminary Design		384,570				
01-001-03	System Test Requirements		15,015				
01-001-04	Specifications		7,016				
01-001-05	Phase C/D Develop. Plans		86,052				
01-001-06	Mock-Up		32,915				
TOTAL PROGRAM			$ 642,830				

TABLE I-3. PHASE C/D COST SUMMARY

COST DATA FORM - A1

SUMMARY

STUDY TITLE Shuttle FFTO Experiment Definition Study - Phase C/D

CONTRACT NO. NAS8-27895

DATE

PAGE 1 OF 1

IDENTIFICATION NUMBER	WBS IDENTIFICATION	WBS LEVEL	EXPECT. COST	CONFID. RATING	T_d	T_s	SPREAD FUNCT.
01-001-01	Project Management and Documentation		4,697,000				
01-001-02	System Engineering of Preliminary Design		6,593,000				
01-001-04	Teleoperator Spacecraft		3,093,000				
01-001-04	Shuttle Based Equipment		1,819,000				
01-001-05	Test Articles & Eval.		11,338,000				
01-001-06	Ground Support Equipment		653,000				
01-001-07	Mission Operations		1,275,000				
	Total Program		29,468,000				

II. PHASE A – PROGRAM DEVELOPMENT REQUIREMENTS

PART A - PROJECT PLANNING REQUIREMENTS

A. ENGINEERING

Engineering effort during Phase A will be directed toward the identification of concepts which have the highest potential of achieving, by further refinement, the specific objectives established for the FFTO System Experiment. Emphasis will be placed on the development of experiment requirements, and the preliminary analysis of previous baseline concepts as they apply to the following general engineering tasks of Phase A:

1. Experiment requirements analysis
2. Man-machine requirements
3. System synthesis
4. Preliminary design
5. Systems analysis and evaluation.

Experiment requirements analysis will be limited to a thorough review and updating of the early Shuttle FFTO experiment to establish new or additional requirements, based on the most recent NASA inputs. The output of this effort will be a listing of the functional requirements and design requirements of the FFTO.

A parallel effort will be conducted for the purpose of defining man-machine requirements. This effort will involve an interchange of information between the experiment procedures and operations and the preliminary design of the system. Those portions of the experiment which are heavily dependent on man's performance, will be analyzed to extract the critical variables and to establish procedural and/or design requirements which will be used during the preliminary design and design evaluation tasks.

Systems synthesis and preliminary design includes all those efforts required to establish preliminary teleoporatory system concepts. Based on the early Phase A development of a plan to establish the need for an experimental FFTO program, the flight experiment model will be modified to reflect new inputs from the mission analysis review. FFTO baseline concepts defined during prephase A studies, will be examined to assess the adequacy of the preliminary design in view of a revised flight experiment model, with emphasis on man/machine problems and interfaces.

Further refinements of specific areas such as the overall control station definition, will be generated and evaluated. The preliminary weight estimate of the FFTO will be modified, as the result of a materials analysis of the preliminary structural design.

Preliminary subsystem requirements concerning propulsion thrust levels, manipulator-grappler functions, thermal control, and range/range rate sensor performance will be analyzed to assure compatibility with revisions of the baseline concept.

Interface requirements pertaining to alternate Shuttle accommodation modes, such as no sorite can or pallet, as compared to a cargo handling boom for launch or recovery, will be defined, as well as the preliminary preflight procedures related to FFTO checkout, and operator/Shuttle crew interfaces.

Supporting research and technology development requirements will be evaluated for critical items which need immediate attention.

In coordination with NASA, test and maintenance philosophies and requirements will be developed. Guidelines utilized for similar space payloads will be developed. Guidelines utilized for similar space payloads will be investigated for possible application.

In terms of the end result of Phase A, all of the aforementioned engineering effort will be pointed toward the identification of system concepts that are suitable, feasible and acceptable.

An effort will be directed toward the establishment of preliminary design assurance criteria specifically related to the reliability, maintainability, and system safety aspects of a recommended system. For example, the system safety aspect will be analyzed on a failure mode and effects basis, by listing possible failure modes and identifying the consequences; critical single point failure modes will also be identified and possible hardware or procedural fixes, as well as monitoring requirements, will be generated.

B. PHASE B, C/D Development Plans

The preparation of development plans for Phases B and C/D will include delineation of an engineering definition and detail design effort for all system elements; the generation of preliminary, procurement and manufacturing plans, testing plans and quality and reliability assurance plans; facilities requirements; and project management plans.

C. PROJECT MANAGEMENT AND SCHEDULES

The project organization initiated in Pre-Phase A studies will be retained for management of the Phase A preliminary analysis effort. Expansion to incorporate additional disciplines will occur as requirements develop. Project controls will be applied to assure that activities grouped by work breakdown and structure, Figure II-1 are monitored for cost and schedule, Figure II-2.

The program schedule for Phase A is further expanded in Part B.

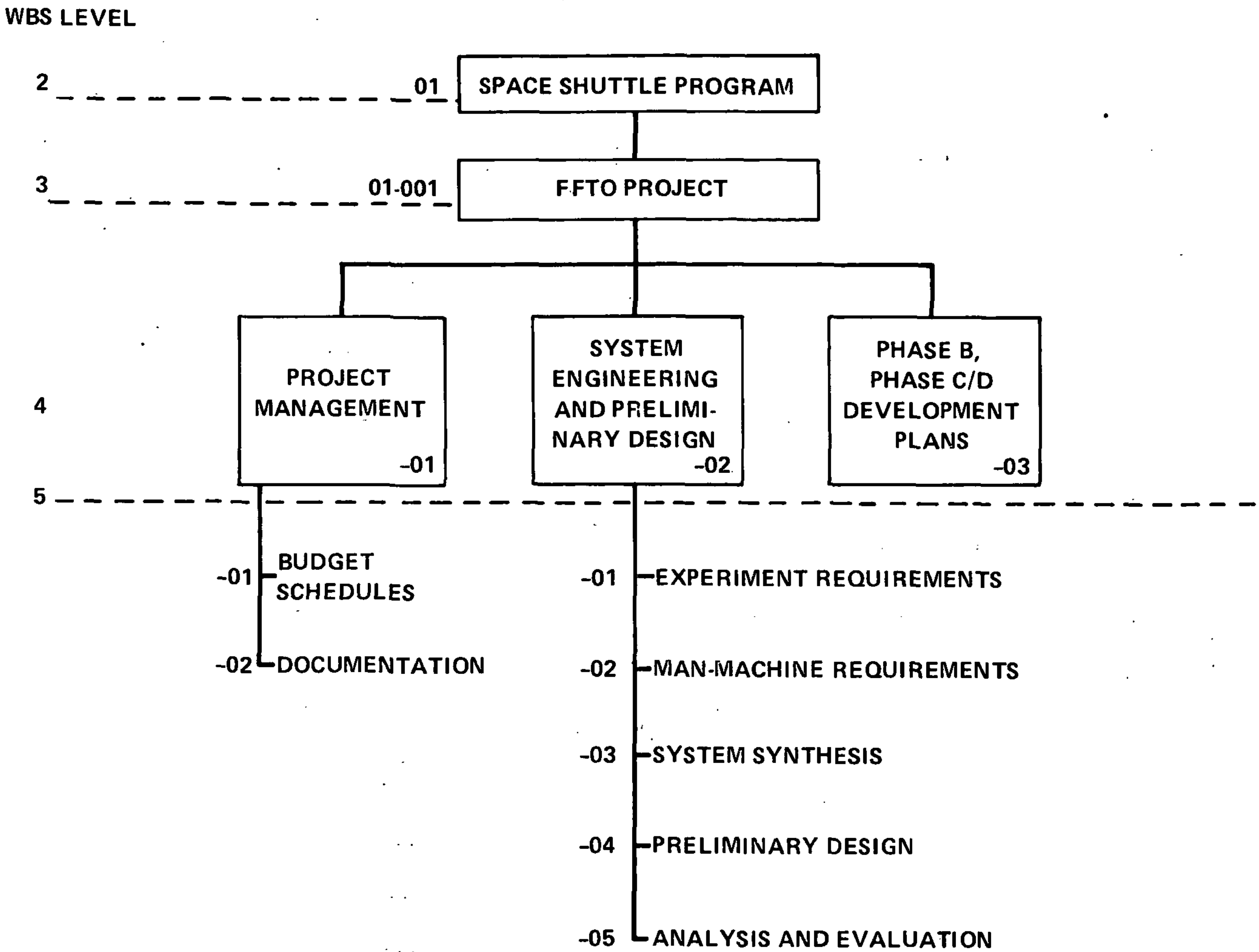

Figure II-1. Summary of Work Breakdown Structure – Phase A

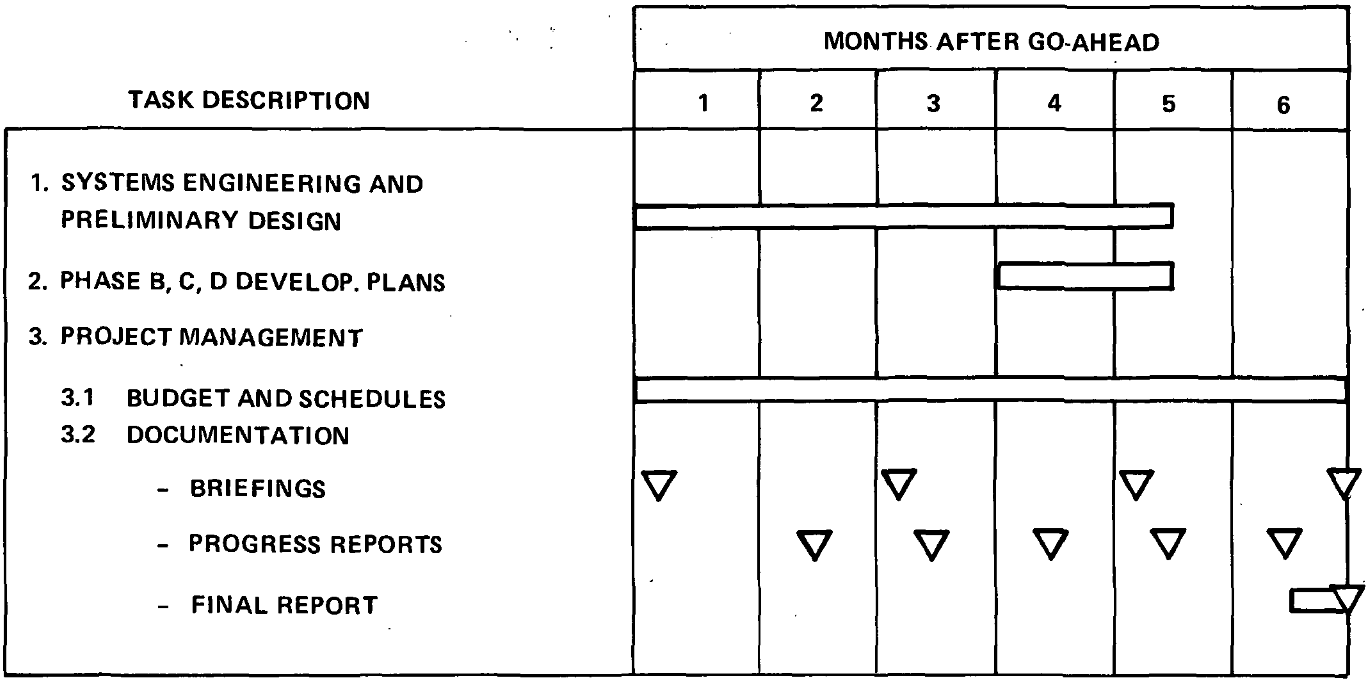

Figure II-2. Summary Schedule, Phase A

PART B - SCHEDULE MILESTONES AND NETWORK

The program schedule for Phase A is shown in Figure II-3.

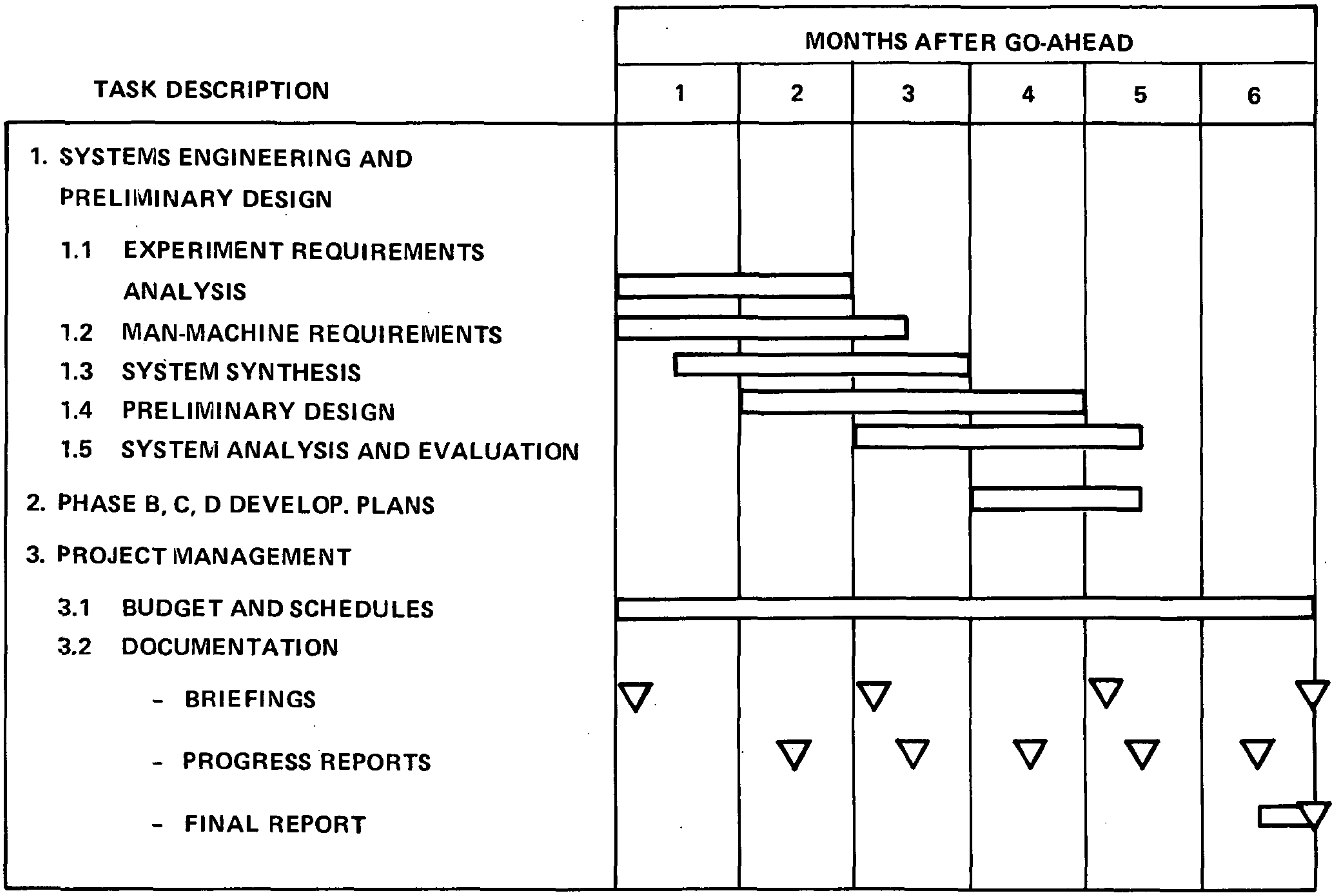

Figure II-3. Summary Schedule, Phase A

PART C - SUPPORTING RESEARCH AND TECHNOLOGY

(See Section V.)

PART D. COST ESTIMATES

A. SECTION 1 COST RATIONALE

1. Estimating Philosophy

Estimating of the program activities was done by the groups which will perform the tasks under the contract. This was accomplished by means of a Work Breakdown Structure (WBS), the elements of which are assigned to those groups which have responsibility for that particular element.

The program tasks necessary to fulfill the requirements of each WBS element were delineated. These tasks were analyzed and further divided into subtasks and activities to provide optimum visibility for estimating purposes. This avoids the possibility of duplications and omissions and optimizes the available resources and facilities.

The respective groups estimated their labor, furnished bills of material, travel by number of trips and destination, and other direct costs. These were reviewed by appropriate management and corrected as necessary to provide the minimum overall cost consistent with the performance and schedule constraints.

2. Methods of Estimating

The order of precedence for estimating is:

(1) Task-by-task,
(2) Apportioned effort, and
(3) Level of effort.

The order of precedence for rationale is:

(1) Standards, and
(2) Comparison (experience).

The preponderance of estimating was done on a task-by-task basis, some as apportioned effort, and level-of-effort held to a minimum. Standards are most effective for repetitive type operations and have limited application in the engineering creative disciplines, except for drafting and documentation, which are in turn based on an estimate of the number and size of drawings and page count.

B. SECTION 2 SUMMARY COST

See Section I.C for a summary of the cost of Phase A of the FFTO program.

C. SECTION 3 COST ESTIMATE BY WORK BREAKDOWN STRUCTURE (WBS)

Since Phase A represents a concept generation and evaluation phase the cost estimates are only in the nonrecurring category. DRDMF-03A Form Al is used to indicate the cost by WBS (See Figure II-4). The Phase A Work Breakdown Structure is shown in Figure II-7.

COST DATA FORM A-1

NON-RECURRING (DDT&E)

STUDY TITLE Shuttle FFTO Experiment Definition Study, Phase A

CONTRACT NO. NAS 8-27895

DATE ______

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IDENTIFICATION NUMBER	WBS IDENTIFICATION	WBS LEVEL	EXPECT. COST	CONFID. RATING	T_d	T_s	SPREAD FUNCT.
01-001-01	Program Management, Administration, and Documentation		$ 33,000				
01-001-02	System Engrg & Prelim Design		$ 82,000				
01-001-03	Phase C/D Develop. Plans		$ 10,000				
Total Program			*$ 125,000*				

Figure II-4. Cost Data

D. SECTION 4 TECHNICAL CHARACTERISTICS DATA

(See Section V.)

E. SECTION 5 TOTAL PHASE A FUNDING SCHEDULES

The funding schedule for Phase A is shown in DRD MF-03A Data Form C Figure II-5.

F. SECTION 6 DETAILED COST INFORMATION

As a result of Pre-Phase A studies elements of cost related to the Phase A effort can be identified. It is expected that further planning efforts will further crystallize the Phase A elements of cost especially in the area of concept evaluation effecting systems synthesis and preliminary design. DRD MF-03A Data Form D Figure II-6 presents the Phase A elements of cost. The elements are in accordance with the Phase A Work Breakdown Structure Figure II-7 repeated here for convenience.

FUNDING SCHEDULE DATA FORM - C

STUDY TITLE Shuttle FFTO - Experiment Definition Study - Phase A

CONTRACT NO. NAS8-27895

NON-RECURRING (DDT&E) x

RECURRING (PRODUCTION) ____

RECURRING (OPERATIONS) ____

DATE ____

PAGE 1 OF 1

PROJECT WBS ITEMS	FY	FY	FY	FY	FY	FY	1973 FY
Program Management, Administration & Documentation							$33,000
Systems Engineering and Preliminary Design							$82,000
Phase B, C/D Development Plans							$10,000
Total Program							$125,000

Figure II-5. Funding Schedule - Phase A

COST ESTIMATE DATA FORM -D

STUDY TITLE Shuttle FFTO Experiment Definition Study - Phase A

CONTRACT NO. NAS 8-27895

WBS IDENT. NO. 01-001-01

WBS IDENTIFICATION Program Management Admin. & Documentation

NON-RECURRING (DDT&E) x

RECURRING (PRODUCTION) ______

RECURRING (OPERATIONS) ______

DATE ______

PAGE 1 **OF** 3

ELEMENTS OF COST	SUBDIVISIONS OF WORK: Docum.	Prog. Mgmt. & Admin						TOTAL
Labor	20,600	6,900						27,500
Material								-
Computer		-						-
Travel		2,900						2,900
Total Cost	20,600	9,800						30,400
Fee	1,750	850						2,600
Total Price	22,350	10,650						33,000

Figure II-6. Cost Data

COST ESTIMATE DATA FORM -D

STUDY TITLE Shuttle FFTO Experiment Definition Study - Phase A

CONTRACT NO. NAS 8 - 27895

WBS IDENT. NO. 01-001-02

WBS IDENTIFICATION System Eng. & Prelim. Design

NON-RECURRING (DDT&E) x

RECURRING (PRODUCTION) ______

RECURRING (OPERATIONS) ______

DATE ______

PAGE 2 **OF** 3

ELEMENTS OF COST	SUBDIVISIONS OF WORK 01 Exp. Reg. Analysis	02 Man Mach. Reg.	03 System Synthesis	04 Prel. Des.	05 Syst. Anal. & Eval.			TOTAL
Labor	10,000	14,000	13,000	20,600	11,000			68,600
Material								-
Computer					1,000			1.000
Travel			1,000	3.000	2,000			6,000
Total Cost	10,000	14,000	14,000	23,600	14,000			75,600
Fee	800	1,200	1,200	2,000	1,200			6.400
Total Price	10,800	15,200	15,200	25,600	15,200			82,000

Figure II-6. (Cont)

COST ESTIMATE DATA FORM - D

STUDY TITLE Shuttle FFTO Experiment Definition Study - Phase A

CONTRACT NO. NAS 8-27895

NON-RECURRING (DDT&E) x

RECURRING (PRODUCTION) ______

RECURRING (OPERATIONS) ______

WBS IDENT. NO. 01-001-03

WBS IDENTIFICATION Phase B, C/D Develop. Plans

DATE ______

PAGE 3 **OF** 3

ELEMENTS OF COST	SUBDIVISIONS OF WORK							TOTAL
Labor								9,100
Material								-
Computer								100
Travel								-
Total Cost								9,200
Fee								800
Total Price								10,000

Figure II-6. (Cont)

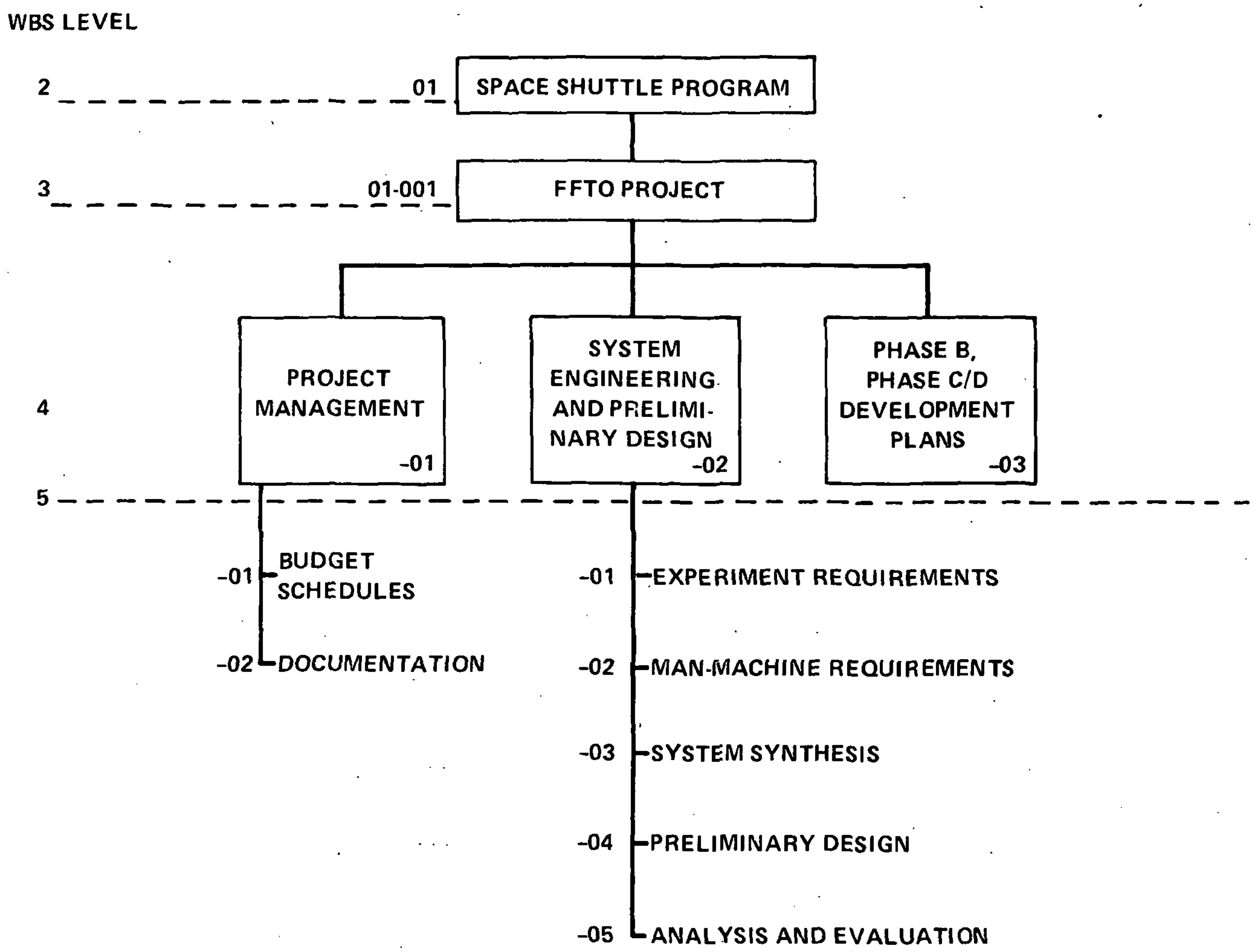

Figure II-7. Summary of Work Breakdown Structure - Phase A

III. PHASE B – PROGRAM DEVELOPMENT REQUIREMENTS

PART A. PROJECT PLANNING REQUIREMENTS, PHASE B

A. ENGINEERING AND MANUFACTURING

1. Engineering

Phase B engineering will encompass:

(1) System engineering and preliminary design,
(2) Development of system test requirements,
(3) Preparation of preliminary specifications,
(4) Preparation of the engineering portions of the Phase C/D development plan,
(5) Design of engineering mockups,
(6) Preparation of requisite documentation,
(7) Technical management of engineering effort.

System engineering and preliminary design consists of all effort required to define the overall teleoperator system. This task will be initiated with a system requirements analysis in which the teleoperator mission will be analyzed in detail and design requirements established. Emphasis will be placed on defining system interfaces and the requirements imposed on system elements, as for example in mating the free flight teleoperator with ground support equipment,with the Shuttle and related Shuttle payloads. Mission phases to be examined are:

(1) Pre-launch,
(2) In-flight, before deployment and
(3) Free flight.

The specifics of the experiments will be defined in detail.

Information developed during the mission analysis will be translated into system design requirements through further analysis directed toward establishing final functional and performance requirements. Subsystem requirements, as for example, propulsion thrust levels, total impulse and thruster locations, manipulator-grappler torque, spin rates and grasping force, guidance and control rates and accelerations, communications range and information rates, video camera maneuverability and resolution, thermal profiles, structure loads, etc. will be established.

The system concept developed during the phases preceding Phase B studies will be reexamined in view of the more detailed data derived per the above paragraphs and a more defined system synthesized.

Preliminary design of the FFTO spacecraft, the display and control station, the orbiter support equipment and the ground support equipment will be accomplished. Guidance, navigation and control techniques for the spacecraft will be slected and piloted simulation used to verify system functional compatibility. Particular emphasis on system integration will assure that all interfaces are properly designed and coordinated.

Propulsion system requirements from the design requirements analysis will be used to select components and prepare procurement documents where necessary. Proposals for subsystem components will be evaluated.

The Phase B preliminary design effort covering the electronic subsystems will be initiated with a review and planning activity. As with the other subsystems the requirements analysis tasks will establish the system requirements including contractual,specifications, mission, vehicle interface, environmental and preliminary performance requirements.

The Shuttle interface and systems requirements will be established in so far as is possible and these will be coordinated through NASA. These requirements cover mechanical, electrical, human factors, mission, data, radio, optical, environmental, timing, test, checkout, safety, and software/documentation. As these requirements are established and approved, they will be documented in an interface specification.

The work previously accomplished in Phase A will be reviewed for NASA approval, adequacy in the context of the latest requirements and applicability to the defined mission and interface requirements. The Phase A work will serve as a basis for the Phase B preliminary design effort.

The FFTO electronic systems will be defined, and analyzed, system by system down to the individual box or major component level. The following 12 guidelines, considerations and requirements will be used in this analysis:

(1) NASA requirements, contractual, specification, letter, directive or agreement

(2) Shuttle interface requirements

(3) Mission requirements

(4) FFTO vehicle systems requirements, installation, internal interfaces, limitations, etc.

(5) Existing, space qualified equipment where possible

(6) Equipment used on other NASA programs where possible

(7) State of the art; existing equipment to minimize development costs and risks

(8) Performance to meet required mission objectives

(9) Reliability and life adequate to assure high level of mission success and safety

(10) Minimum weight, size and electric power to keep the FFTO vehicle parameters within reasonable bounds while performing the required mission

(11) Costs and delivery to meet budget and schedule

(12) Best engineering practice, judgment and professional standards

In selecting particular systems and equipment, attention will be given to all of the preceding guidelines and requirements. Also, the electronics industry will be surveyed to assure that the highest quality and latest state-of-the-art equipments are used. Contacts will be made with vendors, data will be gathered and analyzed and selections will be made only after careful review. Competitive bidding procedures will be used on all major items. Procurement specifications will be written for all major items.

The seven electronic systems which are now identified as tentatively required in the FFTO include:

(1) Flight control including rate gyros, control moment gyros, amplifiers, logic and thruster control circuits.

(2) Communications which include command, back up emergency commands, telemetry and television video transmission links. These subsystems can be broken down into transmitters, receivers, antennas, coders, decoders, multiplexers, demultiplexers, analog to digital and digital to analog converters, sample and hold logic and amplifiers.

(3) A TV video system which is dual redundant and includes cameras, lenses, controls, variable geometry mounts, signal amplifiers, communication link, display monitors and video tape recorders.

(4) Manipulator/grappler electrical control.

(5) Electrical power source, batteries, plus distribution, switching battery banks to critical and noncritical load buses, protective circuit breakers and interconnection wiring.

(6) Range and range rate sensor, tentatively based on radar technology.

(7) Control and display console on the Shuttle which provides the necessary FFTO human factor interfaces and Shuttle interfaces including test, checkout and data recording.

Each of the electrical and electronic systems will be laid out in sufficient detail to permit a preliminary design layout of the entire FFTO. This includes the following eight items:

(1) Box sizes, weights, approximate c.g. location, connector size and location, cooling requirements and method, size and location.

(2) Mounting method,shock mounts, cooling mount, electrical conductivity mount, pressurization requirements, etc.

(3) Equipment electrical power requirements, voltage limits, frequency (if AC) limits, power, duty cycle, power factor and phasing (if AC).

(4) Operating controls, accessibility, moving parts and clearances for installation and removal, servicing, maintenance, test and checkout.

(5) Antennas, antenna patterns, clear field of view angles, antenna covers (radomes), gain, matching impedance, frequency band, etc.

(6) Test points, built-in test equipment (if any), test procedures, external test equipment, methods of test equipment connection or usage including test cables, connectors or test fixtures.

(7) Interconnecting cables and wire bundles in terms of cable routing, length, number of wires in bundles, weight, coaxial cables, where required, connectors and any special cable installation requirements such as shielding, coil or reel for extendable or flexible installations.

(8) Vendor drawings in the case of standard, selected hardware showing part numbers, nomenclature, etc.

System analysis and simulation will evaluate guidance, navigation and control performance, assist in defining and evaluating displays, and evaluate motions and loads associated with docking dynamics. System reliability will be determined through failure effects analyses using piloted simulation. Experiment operations will be analyzed and the man-machine interfaces and displays evaluated by means of piloted simulation. A propulsion system analysis will provide information on pressure schedules, performance maps, plume and contamination effects, duty cycles, and other design data as required.

The second major engineering effort, development of system test requirements, will provide the program for development, qualification and operational testing.

Specifications will be prepared to define the overall teleoperator system and will include preliminary specifications for procurement and acceptance of all major components as well as a model specification for each major system element.

Preparation of a Phase C/D development plan will include delineation of an engineering definition and detail design effort for all system elements. In particular, supporting research and technology requirements will be specifically defined and incorporated into an engineering development plan. Cost and schedules for Phase C/D will be influenced by the timelines of the engineering development plan.

An engineering mockup will be designed in Phase B which will be used in firming up the FFTO configuration. This mockup will be an engineering tool – that is, it will be a soft mockup, subject to change as indicated through evolution of the optimum FFTO design.

Other engineering activities required in completing the Phase B program will consist primarily of inputs to the contractual requirements imposed in the areas of documentation, and program management activities.

2. Manufacturing

Manufacturing activities during Phase B will be limited to support of the preliminary design effort and planning for Phase C/D. Specifically, mockups of the free-flying teleoperator system and of the orbiter control and display station will be fabricated in accordance with engineering drawings and the program schedule.

The manufacturing plan for Phase C/D will be as complete as possible. It will be based on the Work Breakdown Structure, which will be hardware oriented, and will interface with the Engineering Development Plan, and the Facilities Plan. It will be sufficiently accurate to provide the basis for the manufacturing cost estimate for Phase C/D.

B. TESTING

Testing activities during this phase will be directed toward the preparation of test requirements and plans for Phase C/D. It is important that these documents be prepared in conjunction with other plans so as to assure schedule compatibility as well as an integrated program in which test levels are consistent with component, subsystem and system performance requirements. Optimum test objectives must be established to provide the basis for all tests and allow a comprehensive test program at minimum cost.

Test requirements are generally separated into ground test and operations tests. Plans to be prepared must address these two test categories but must also recognize the sequential nature of testing and the requirements already established by NASA, including generalized guidelines and those governing the Shuttle and its related systems.

In the latter consideration, it must be further recognized that the teleoperator is unique in that its performance and reliability are not vital to Shuttle operation. It may be more accurately considered experiment hardware or even payload. And so, attention must be given in developing test objectives and plans to assuring realistic requirements, avoiding over testing such as could be imposed if, for example, the FFTO were to be man-rated. It is suggested that NASA investigate test requirements for equipment in this category and establish an appropriate test philosophy.

Ground testing will include development testing, carried out to prove the feasibility of design concepts and provide data for selection of the best design, and qualification testing to assure that the selected hardware will function as required in all anticipated environments. It will also include system testing and ground operational tests to assure functional compatibility of all system elements and pre-flight checkout at the launch site. These various tests will be planned and coordinated appropriately in Phase B and will be further detailed in Phase C/D.

Operations testing includes these functional tests and checks carried out in orbit before deployment of the FFTO and upon its retrieval. The test plan for this test phase will establish tentative requirements for equipment, procedures, and on-board data readouts.

C. QUALITY AND RELIABILITY ASSURANCE

Required activities in this area include four specific tasks:

(1) Inspection of mockups,
(2) Preparation of a Quality and Reliability Assurance Plan for Phase C/D,
(3) Preparation of Quality Assurance specifications, and
(4) Preparation of Reliability Assurance specifications.

The soft mockups of the free-flying teleoperator and of the control and display station must be visually inspected for compliance with the requirements specified by engineering via design drawings. The mockups will be primarily engineering tools and will be subject to change during the preliminary design activities. However, it is required that they be accepted in their initial configuration to complete contract accountability.

The Quality and Reliability Assurance Plan which must be prepared in Phase B will delineate the requirements for acceptance testing of all hardware before delivery and establish the approach to reliability testing, data collection and reporting. Test equipment and availability requirements will be established.

Quality surveillance requirements will be analyzed and the responsibilities to be imposed on subcontractors or suppliers will be considered. In this area in particular, the quality assurance program requirements of NASA will be incorporated in accordance with contractual documents, NPC200-2 for example, including the requirements for review by cognizant NASA representatives if so specified.

The quality assurance department will be charged with the responsibility of maintaining the plan, providing reporting documentation and change control as required. Preparation of the quality assurance plan will, therefore, be the prime responsibility of this department.

The third activity, noted earlier, involves the preparation of Part 4.0 of pertinent specifications which details the specific requirements for design verification tests, acceptance tests, and qualification tests. These requirements must be based on, and consistent with, the Test Plans for the FFTO program.

Design verification tests are advanced development tests conducted to ascertain correctness of design for the intended mission and when successfully completed permit a design freeze. Acceptance tests will be performed during production of a part, component, subsystem or system. The acceptance test specification will recognize the requirements of the test plans insofar as it delineates testing levels during system buildup. Qualification tests, as previously noted, verify that all parts, systems and integrated systems are unconditionally suitable for their intended use.

The fourth major activity is that of preparing the reliability assurance specification for use in Phase C/D. It is essential that the preparation of this document be closely coordinated with system design. A reliability prediction analysis will provide data which, through feedback into the design effort, and iteration if necessary, will greatly facilitate design optimization and provide the requisite reliability at minimum cost. Reliability goals must be established and translated into Mean Time Between Failure (MTBF) requirements. The specification must spell out the requirements for reliability compliance and the related reliability demonstration requirements.

D. FACILITIES

The following are the facility requirements for the conduct of Phase B.

1. Visual Simulation Laboratory

The visual simulation laboratory presently available at Bell Aerospace Company has the facilities and equipment to meet the requirements listed.

a. General

- Provide simulation of visual scenes as they appear to astronauts controlling the FFTO in orbit and free space.
- Provide the capability to reproduce all important operating cues such as stereo effect, rotating star field, wide angle views, and earth horizon.
- Provide for flexibility of models and multiplicity of missions and mission modes.

b. Specific

- See Figure III-1 for block diagram of the visual simulation laboratory.
- Generate and project the scene that the operator will have when maneuvering through various mission phases.
- Generate and project stereoptically a distant target, stars or earth.
- Simulate and project the image of a vehicle – that is, parent craft, target vehicle, or some special object to be examined or retrieved.
- Generate and project stereoptically the image of another vehicle including distinguishing marks and shadow effects.
- Simultaneously display all scenes and vehicles.

2. Space Simulation Laboratory - Air Bearing Platform

The requirements for the space simulation laboratory can be met with the equipment and facilities presently available at Bell for performance evaluation of a teleoperator. These facilities are shown in Figure III-2. They include:

- BAC Remote Maneuvering Unit and Operator's Console (RMU)
- BAC Air Bearing Platform (ABP)
- BAC Precision Floor (PF)

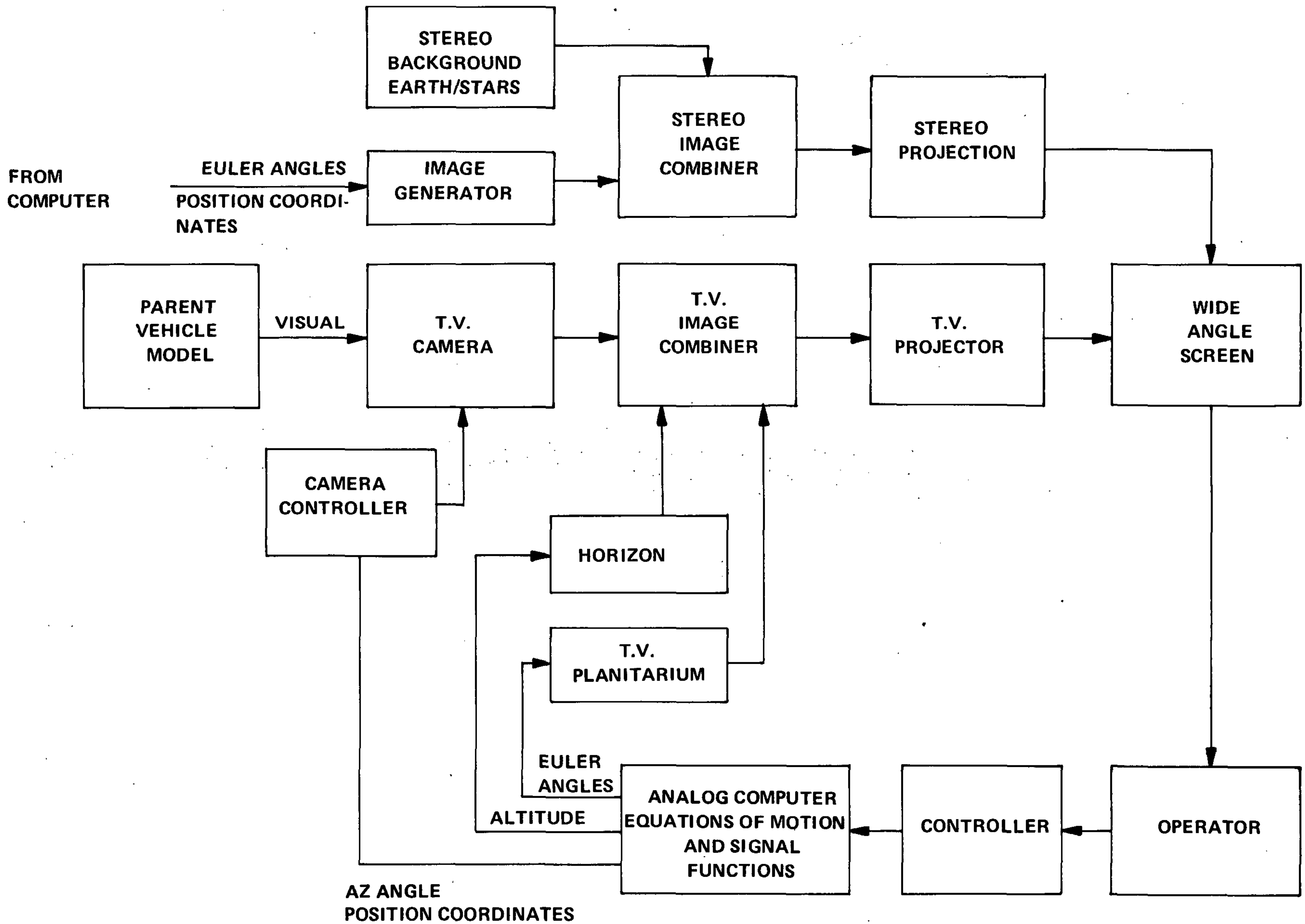

Figure III-1. Block Diagram of Visual Simulation Laboratory

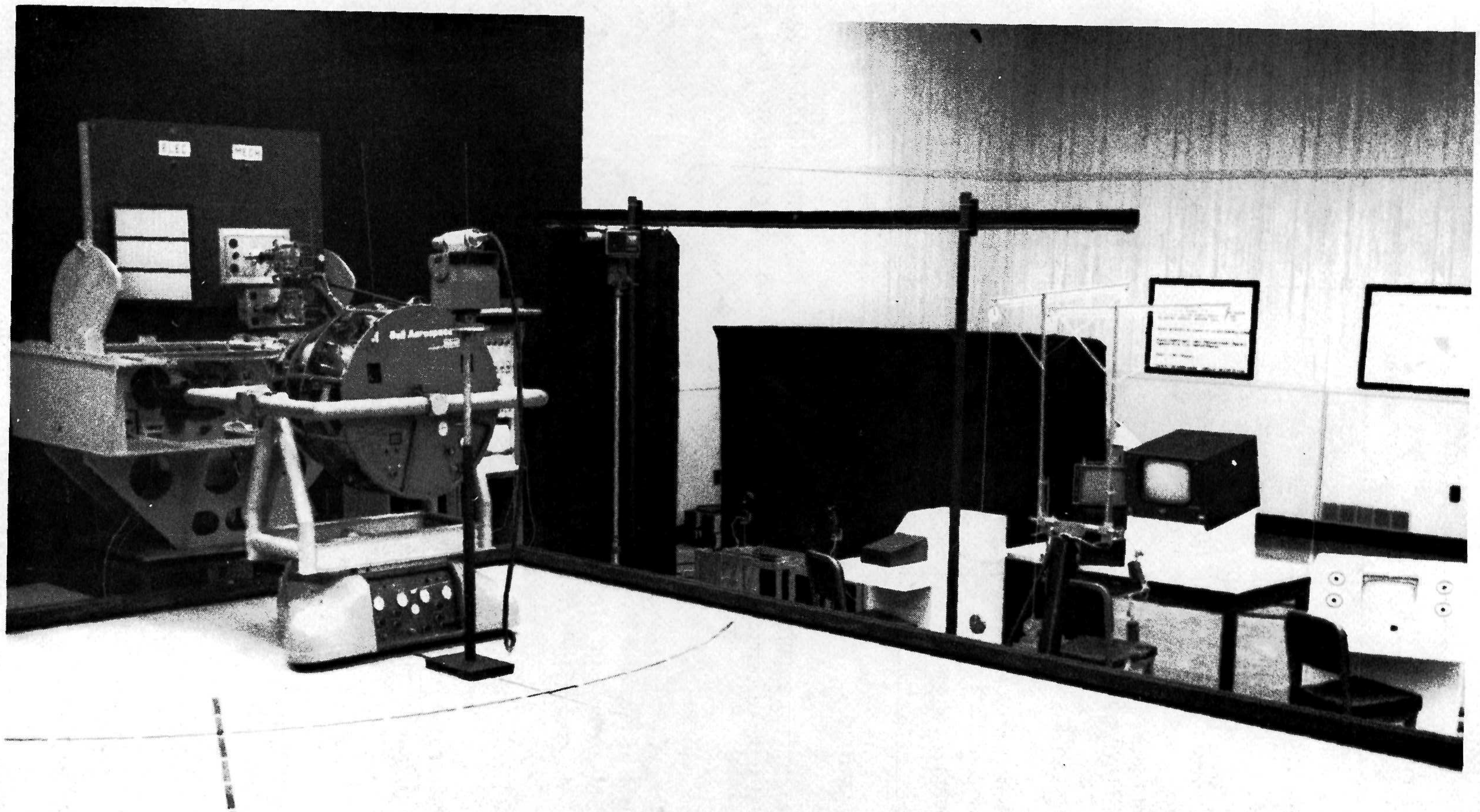

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Figure III-2. Bell's 5 DOF Teleoperator Subsatellite Facility

Specifications for these devices are presented in Table III-1.

TABLE III-1
SPECIFICATION FOR THE BELL SUBSATELLITE FACILITY

Remote Maneuvering Unit	Air Bearing Platform	Precision Floor
500 lb 5/8 scale Flight Equipment	3 Air Bearing Pads	2 in. Aluminum Plates on Jacks
Automatic Target Acquisition and Stationkeeping	1000 lb. Capacity	20 ft x 24 ft Overall
3 Stabilization Control Options -Mass Expulsion	60 to 80 minute Air Supply	Lapped Polyurethane Surface
-Control Moment Gyros with Electrical Torquing -Rate Gyros	Less than 0.04 oz. Friction	Level to 0.002 in
±40 deg. Roll and ±40 deg. Pitch		
30 Channel Up-link Control and 10 Channel Down-Link Data		
Remote 4:1 Zoom Lens Video System		

3. Computer Facilities

The requirements for engineering computation facilities can be met with facilities and equipment presently available at Bell Aerospace Company's Electric Data Processing Center. They include:

a. Digital Facilities

(1) IBM system 360 Model 65 computer
(2) IBM system 360 Model 50 computer
(3) IBM system 7090 computer

b. Analog Facilities

(1) Electronic Associates Pace 231 R and Console
(2) Applied Dynamic A01-4 analog/hybrid computers

c. Hybrid Facilities

This system links the analog computers through D/A and A/D equipment to the IBM 7090 or 360/65. The link is a direct data connection transmitting 14-bit data words.

d. Graphic Facilities

(1) Calcomp Model 663/770 digital plotting system..

4. Facility Requirements

The facility requirements for Phase B include development of the facility plan for Phase C/D.

E. PROJECT MANAGEMENT

The management of the Phase B preliminary analysis and definition phase will be governed by the Work Breakdown Structure of Figure III-3. The related schedule is shown in Figure III-4. This schedule is further expanded in Part B.

The project organization initiated in Pre-Phase A will be expanded to incorporate the additional disciplines required for the Phase B effort. This will include support in the areas of preliminary design, simulation, mockup fabrication and Phase C/D planning. Project controls will be required to assure that activities are monitored for cost and schedule.

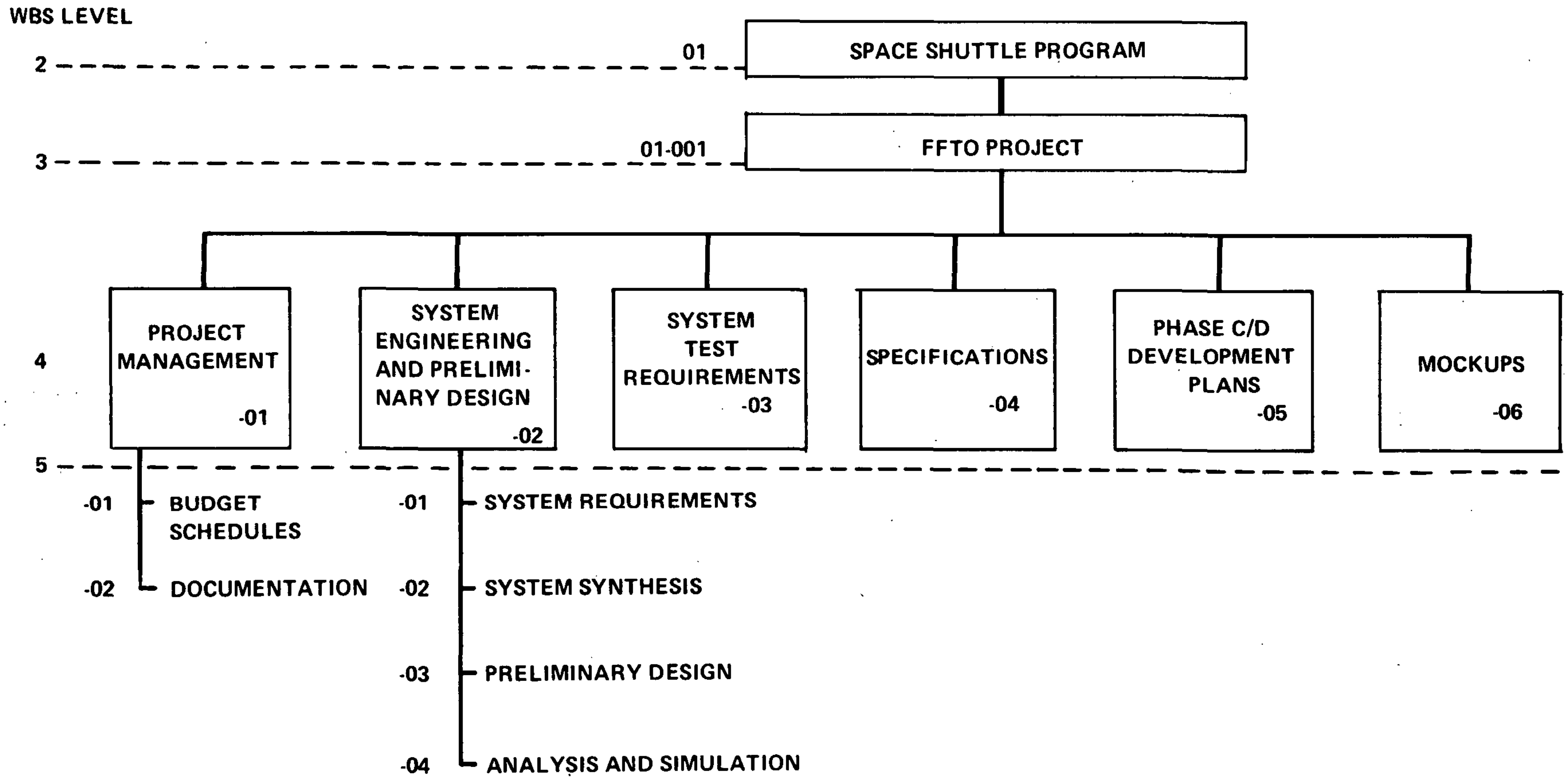

Figure III-3. Summary of Work Breakdown Structure – Phase B

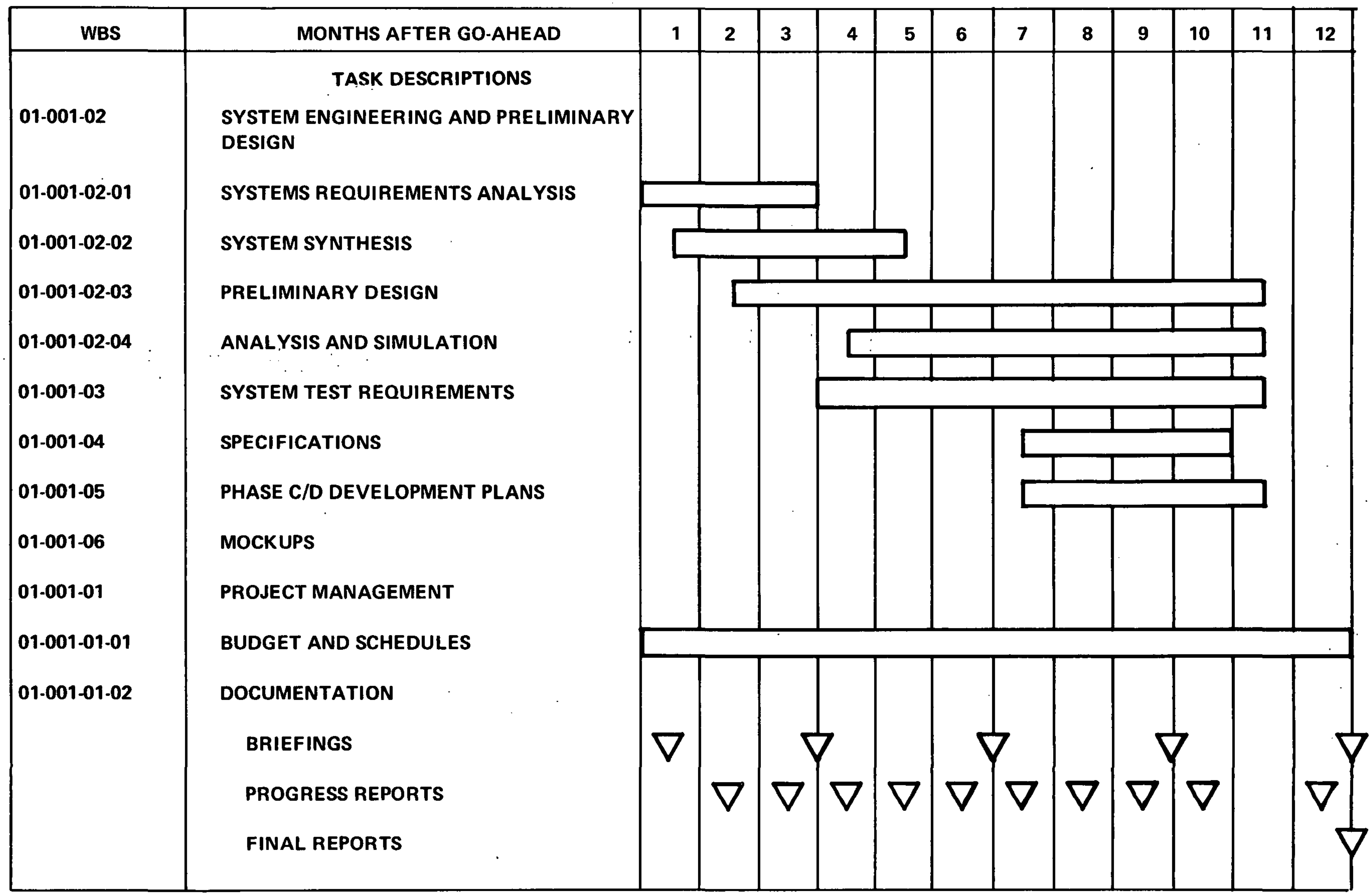

Figure III-4. Phase B – Program Schedule

PART B – SCHEDULES, MILESTONES AND NETWORKS

The program schedule for Phase B is presented in Figure III-5.

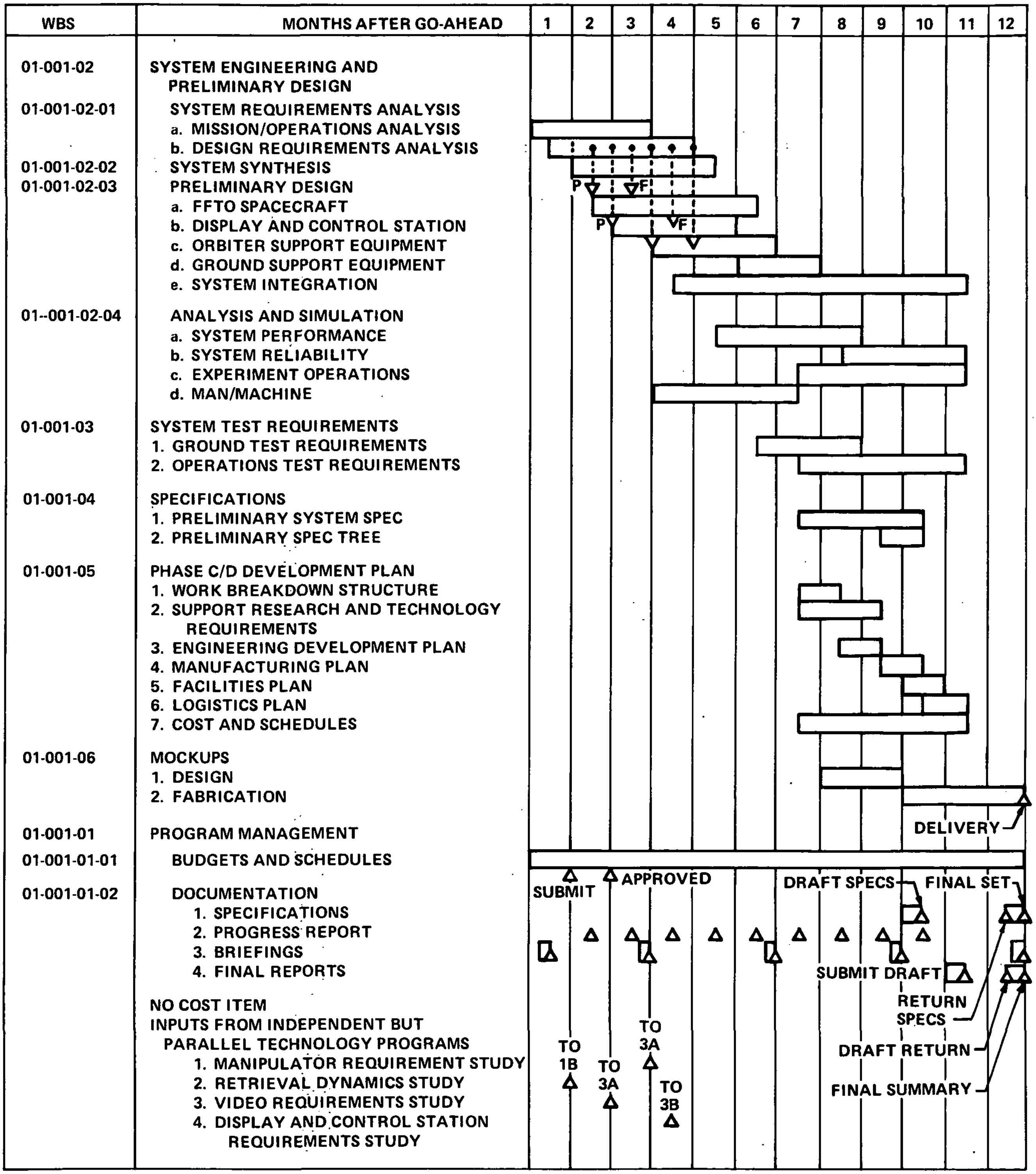

Figure III-5. Phase B Program Schedule

PART C - SUPPORTING RESEARCH AND TECHNOLOGY

(See Section IV).

PART D. COST ESTIMATES

A. SECTION 1 COST RATIONALE

1. Estimating Philosophy

Estimating of the program activities was done by the groups which will perform the tasks under the contract. This was accomplished by means of the Work Breakdown Structure (WBS), the elements of which are assigned to those groups which will have responsibility for that particular element.

The program tasks necessary to fulfill the requirements of each WBS element were delineated. These tasks were analyzed and further divided into subtasks and activities to provide optimum visibility for estimating purposes. This avoids the possibility of duplications and omissions and optimizes the available resources and facilities.

The respective groups estimated their labor, furnished bills of material, travel by number of trips and destination, and other direct costs. These were reviewed by appropriate management and corrected as necessary to provide the minimum overall cost consistent with the performance and schedule constraints.

2. Methods of Estimating

The order of precedence for estimating is:

(1) Task-by-task,
(2) Apportioned effort, and
(3) Level of effort.

The order of precedence for rationale is:

(1) Standards, and
(2) Comparison (experience).

The preponderance of estimating was done on a task-by-task basis, some was done as apportioned effort, and level-of-effort estimating held to a minimum. Standards are most effective for repetitive type operations and have limited application in the engineering creative disciplines, except for drafting and documentation which are in turn based on an estimate of the number and size of drawings and page count.

B. SECTION 2 SUMMARY COST

See Section I.C for a summary of the cost of Phase B of the FFTO program.

C. SECTION 3 COST ESTIMATE BY WORK BREAKDOWN STRUCTURE (WBS)

Since Phase B represents a preliminary analysis and definition phase the cost estimates are only in the nonrecurring category. DRDMF-03A Form A1 is used to indicate the cost by WBS (See Figure III-6). The Phase B Work Breakdown Structure is shown in Figure III-3.

COST DATA FORM - A1

NON-RECURRING (DDT&E)

STUDY TITLE Shuttle FFTO Experiment Definition Study - Phase B

CONTRACT NO. NAS8-27895

DATE

PAGE 1 OF 1

IDENTIFICATION NUMBER	WBS IDENTIFICATION	WBS LEVEL	EXPECT. COST	CONFID. RATING	T_d	T_s	SPREAD FUNCT.
01-001-01	Program Management, Admin., and Documentation	4	$117,262				
01-001-02	System Engineering and Program Design	4	$384,570				
01-001-03	System Test Requirements	4	15,015				
01-001-04	Specifications	4	7,016				
01-001-05	Phase C/D Development Plans	4	86,052				
01-001-06	Mock-up	4	32,915				
Total Program			$642,830				

Figure III-6. Phase B Cost Estimate

D. SECTION 4 TECHNICAL CHARACTERISTICS DATA

(See Section V).

E. SECTION 5 TOTAL PHASE B FUNDING SCHEDULES

The funding schedule for Phase B is shown in DRD MF-03A Data Form C Figure III-7.

F. SECTION 6 DETAILED COST INFORMATION

As a result of Pre-Phase A studies elements of cost related to the Phase B effort can be identified. It is expected that further planning efforts will further crystalize the Phase B elements of cost especially in the area of preliminary design. DRD MF-03A Data Form D Figure III-8 presents the Phase B elements of cost. The elements are in accordance with the Phase B Work Breakdown Structure Figure III-6.

FUNDING SCHEDULE DATA FORM – C

STUDY TITLE Shuttle FFTO Experiment Definition Study - Phase B

CONTRACT NO. NAS8-27895

NON-RECURRING (DDT&E) x

RECURRING (PRODUCTION)

RECURRING (OPERATIONS)

DATE

PAGE 1 OF 1

PROJECT WBS ITEMS	1973 FY	1974 FY	FY	FY	FY	FY	Total FY
Program Management, Administration, and Documentation	$58,631	$58,631					$117,262
System Engineering and Preliminary Design	200,000	184,570					384,570
System Test Requirements	3,000	12,015					15,015
Specifications	-	7,016					7,016
Phase C/D Development Plans	-	86,052					86,052
Mock-Up	-	32,915					32,915
Total Program	$261,631	$381,199					$642,830

Figure III-7. Funding Schedule - Phase B

COST ESTIMATE DATA FORM – D

STUDY TITLE Shuttle FFTO Experiment Definition Study - Phase B

CONTRACT NO. NAS8-27895

NON-RECURRING (DDT&E) x

RECURRING (PRODUCTION)

RECURRING (OPERATIONS)

WBS IDENT. NO. 01-001-01

WBS IDENTIFICATION Program Management, Admin., and Documentation

DATE

PAGE 1 OF 6

ELEMENTS OF COST	SUBDIVISIONS OF WORK							TOTAL
	Documen.	Program Mgmt. & Doc.						
Labor	$71,737	$33,377						$105,114
Material								
Computer								
Travel		2,962						2,962
Total Cost	$71,737	$36,339						$108,076
Fee @ 8.5%	6,098	3,088						9,186
Total Price	$77,835	$39,427						$117,262

Figure III-8. Phase B Elements of Cost

COST ESTIMATE DATA FORM - D

STUDY TITLE Shuttle FFTO Experiment Definition Study - Phase B

CONTRACT NO. NAS8-27895

NON-RECURRING (DDT&E) x

RECURRING (PRODUCTION)

RECURRING (OPERATIONS)

WBS IDENT. NO. 01-001-02

WBS IDENTIFICATION System Engr. & Prelininary Design

DATE

PAGE 2 OF 6

ELEMENTS OF COST	SUBDIVISIONS OF WORK 01	02	03	04				TOTAL
	System Req. Anal.	System Synthesis	Prelim. Design	Simul. Anal.				
Labor	$36,281	$4,976	$227,019	$78,782				$347,058
Material	-	-	-	-				-
Computer	-	-	-	1,388				1,388
Travel	-	1,006	3,032	1,958				5,996
Total Cost	36,281	5,982	230,051	82,128				354,442
Fee @ 8.5%	3,084	509	19,554	6,981				30,128
Total Price	$39,365	$6,491	$249,605	$89,109				$384,570

Figure III-8. (contd)

COST ESTIMATE DATA FORM - D

STUDY TITLE Shuttle FFTO Experiment Definition Study - Phase B
CONTRACT NO. NAS8-27895

WBS IDENT. NO. 01-001-03
WBS IDENTIFICATION Sys. Test Requirements

NON-RECURRING (DDT&E) x
RECURRING (PRODUCTION) ____
RECURRING (OPERATIONS) ____

DATE ____
PAGE 3 OF 6

ELEMENTS OF COST	SUBDIVISIONS OF WORK							TOTAL
Labor								$13,839
Material								-
Computer								-
Travel								-
Total Cost								$13,839
Fee @ 8.5%								1,176
Total Price								$15,015

Figure III-8. (contd)

COST ESTIMATE DATA FORM - D

STUDY TITLE Shuttle FFTO Experiment Definition Study - Phase B

CONTRACT NO. NAS8-27895

WBS IDENT. NO. 01-001-04

WBS IDENTIFICATION Specifications

NON-RECURRING (DDT&E) x

RECURRING (PRODUCTION)

RECURRING (OPERATIONS)

DATE

PAGE 4 OF 6

ELEMENTS OF COST	SUBDIVISIONS OF WORK							TOTAL
Labor								$6,272
Material								-
Computer								-
Travel								194
Total Cost								$6,466
Fee @ 8.5%								550
Total Price								$7,016

Figure III-8. (contd)

COST ESTIMATE DATA FORM - D

STUDY TITLE Shuttle FFTO Experiment Definition Study - Phase B

CONTRACT NO. NAS8-27895

NON-RECURRING (DDT&E) x

RECURRING (PRODUCTION)

RECURRING (OPERATIONS)

WBS IDENT. NO. 01-001-05

WBS IDENTIFICATION Phase C/D Development Plan

DATE

PAGE 5 OF 6

ELEMENTS OF COST	SUBDIVISIONS OF WORK							TOTAL
Labor								$79,241
Material								-
Computer								70
Travel								-
Total Cost								$79,311
Fee @ 8.5%								6,741
Total Price								$86,052

Figure III-8. (contd)

COST ESTIMATE DATA FORM - D

STUDY TITLE Shuttle FFTO Experiment Definition Study - Phase B
CONTRACT NO. NAS8-27895

NON-RECURRING (DDT&E) x
RECURRING (PRODUCTION)
RECURRING (OPERATIONS)

WBS IDENT. NO. 01-001-06
WBS IDENTIFICATION Mock-Up

DATE
PAGE 6 OF 6

ELEMENTS OF COST	SUBDIVISIONS OF WORK							TOTAL
Labor								$7,257
Material								22,073
Computer								-
Travel								1,006
Total Cost								30,336
Fee @ 8.5%								2,579
Total Price								$32,915

Figure III-8. (contd)

IV. PHASE C/D PROGRAM DEVELOPMENT REQUIREMENTS

PART A. PROJECT PLANNING REQUIREMENTS, PHASE C/D

A. ENGINEERING AND MANUFACTURING

1. Engineering

Engineering plans for Phase C/D encompass three major efforts:

(1) design of the FFTO spacecraft system,
(2) integration of the FFTO system into the space shuttle, and
(3) engineering support of the operational program.

These plans will be developed during Phase B and implemented in Phase C/D in accordance with the schedule shown in Part B of this section.

The design effort will define in detail the system defined in preliminary fashion in Phase B and provide production drawings for procurement and fabrication of all parts, components, subassemblies and assemblies of all hardware in the program including development hardware, mockups, prototypes and deliverable systems. Major system elements to be designed include the FFTO spacecraft, the shuttle based display and control station, the orbiter based equipment and the ground support equipment.

The integration task will be primarily directed toward assuring that the interfaces between the shuttle based elements of the teleoperator system and the space shuttle itself are properly defined and detailed. These interfaces will be both physical and functional and will be controlled by means of the system specification. The preliminary specification established in Phase B will be expanded and submitted to NASA for coordination and approval. In particular, the design of the FFTO control and display station and the launch-retrieval station will be governed to a considerable degree by the integration requirements.

During the operational portion of the FFTO program in which the spacecraft will be used in various experiments, engineering support will be provided to assure that all functional aspects of the FFTO system are satisfactory and to assist in collecting and reducing experiment results.

2. Manufacturing

Manufacturing activities during Phase C/D will encompass procurement and/or fabrication of all program hardware. The manufacturing plan prepared in Phase B will include the major manufacturing requirements in terms of quantities and delivery times. Based on these requirements the requisite manufacturing tasks will also be defined to establish the details for implementation of the manufacturing plan and the resources required.

Tentatively, there will be five principal manufacturing activities:

(1) Fabricate/procure in accordance with the delivery schedule requirement, design verification test hardware for the free-flying teleoperator system, the orbiter display and control station, and the orbiter launch/docking station.

(2) Fabricate/procure in accordance with the delivery schedule requirements, one prototype of the free-flying teleoperator system, the orbiter display and control station, the orbiter launch/docking station, and the ground support equipment.

(3) Fabricate/procure in accordance with the delivery schedule requirement, one set of qualification test hardware for the free-flying teleoperator system, the orbiter display and control station, and the orbiter launch/docking station.

(4) Fabricate/procure in accordance with the delivery schedule requirements, one set of flight hardware of the free-flying teleoperator system, the orbiter display and control station, and the orbiter launch/docking station; and fabricate/procure one set of ground support equipment.

Refurbish in accordance with the delivery schedule requirements, the qualification test hardware for the free-flying teleoperator system, the orbiter display and control station, and the orbiter launch/docking station. This refurbished hardware constitutes the second set of flight hardware.

(5) Fabricate/procure in accordance with the delivery schedule requirements, one spare set of the free-flying teleoperator system, the orbiter display and control station, and the orbiter launch/docking station.

These activities will be supported by fabrication of such nondeliverable equipment as required including special tooling, special test equipment, material and parts protection equipment.

Manufacturing engineering will provide the support required to assure producability, tool design, design of special support equipment and the most practical use of applicable manufacturing processes.

Even though the quantities involved in the program as planned are relatively small, production control will assure the orderly and timely delivery of the contract items. Such assurance will be provided through in-process controls such as programming and scheduling and the monitoring of in-work activities.

Remanufacturing or refurbishment in support of flight operations, if required, will dictate the need for special transport and handling equipment.

B. TESTING

During Phase C/D the test plan prepared during Phase B will be implemented. The test schedules will be detailed and integrated into the overall program development schedule. The test objectives will be predicted on compatibility with the requirements of the shuttle program together with the ramifications introduced because of the fact that the shuttle itself must be man-rated whereas the FFTO spacecraft may more reasonably considered to be payload. It is also recognized that much of the equipment in the FFTO system is already space qualified and such experience will allow substantial reduction of development and qualification testing.

Development testing will be conducted to verify design concepts. Such testing will be conducted, in accordance with the master schedule and the requirements of the test plan. Development tests will provide engineering evaluation of the performance of components, subsystems, the free-flying teleoperator, the display and control station and support equipment.

A functional mockup will be used early in the test program to assure that the design concept provides the anticipated output functions.

Qualification testing, or technical evaluation, will be conducted at the component level on those items not previously qualified for the space shuttle, on the FFTO, and on the shuttle based systems. Such testing will verify the functional performance of the hardware in the specified operational environment and demonstrate compliance with appropriate specifications.

The qualification criteria developed in Phase B will provide the basis for the qualification test program. One complete set of flight hardware will be provided for the tests. Test levels will not exceed design specifications, and the hardware, after successful completion of qualification testing, can be refurbished for flight use.

Operational evaluation of the complete system will be conducted by the user with support and assistance by the contractor using the flight hardware. This part of the overall test plan will include ground operational tests and checkout before integration into the space shuttle and a final systems test to verify operational readiness. Operational evaluation will ultimately be conducted in the shuttle flight and experiment program.

The test plan also includes those tests needed to assure that the hardware as produced will meet applicable specifications. So, all flight and support hardware will be subjected to acceptance testing in accordance with the approved test specifications, prior to final delivery to the customer. All components delivered to the prime contractor by suppliers will also be required to pass an acceptance test by either the supplier, under cognizance of a representative of the prime, or after receipt by the prime. Additional acceptance testing will be done at subsystem and system levels as required.

Integrated systems testing will be accomplished using the prototype hardware to demonstrate subsystem compatibility, integration of the system into the experiments for which it is intended and integration of the man-machine interface.

C. QUALITY AND RELIABILITY ASSURANCE

Quality and reliability assurance are closely related to the test plan in that acceptance testing is the ultimate measure of quality and test results will be used to measure reliability.

During the procurement and fabrication tasks, quality assurance personnel will monitor subcontractor acceptance testing and provide surveillance of material quality, traceability, and specification compliance. Inspection procedures at the prime contractor facility will be implemented at various stages of fabrication of all hardware. All such procedures will be prepared early in Phase C/D as directed by the applicable quality requirements of the contract.

Reliability goals established in Phase B will be the basis for measuring system MTBF, estimating system reliability and design of reliability demonstrations. A formal reliability plan will be detailed and implemented.

D. FACILITIES

The facility plan developed in Phase B will establish the requirements for those facilities to be acquired and used in Phase C/D. Four major categories can be considered:

- engineering
- manufacturing

- testing, and
- quality assurance.

Engineering facilities will consist principally of those prepared and used in accomplishing Phase B. Key facilities among these are the computer facilities needed during system analysis, the visual simulation facility used in system design and the air bearing platform facility used in development test. These are described in Section II, Phase B Program Development Requirements. Additional engineering facilities as may be needed during development testing will be defined during Phase B

Manufacturing facilities needed will include tooling, machining, heat treat, welding, cleaning, plating and assembly. Besides the basic industry equipment, a clean room is needed in the assembly area. All propulsion systems and components of the FFTO are designed as clean room level assemblies together with specified electrical and electronic systems. Sufficient plant space for and acceptance inspection and checkout will also be required.

Test facilities to be used in Phase C/D include, besides general laboratory facilities, environmental test facilities and rocket test facilities. Environment test facility capabilities must be compatible with the test requirements and governing specifications including vibration, temperature, heat rate, pressure/vacuum, pressure change rate and acceleration. Rocket test facilities must be suitable for individual thrust chamber test and complete propulsion/attitude control systems tests. Supporting facility requirements such as instrumentation and data acquisition and processing systems must be adequate for the data rates and quantities involved as determined by the test procedures.

Quality assurance facilities to be used in inspection and acceptance of the prototype and flight hardware are those which permit all measurements to be obtained as necessary to meet the requirements of applicable specifications and governing documents as well as supporting facilities including, for example, a standards and calibration laboratory.

E. PROJECT MANAGEMENT

Management of the overall FFTO project during Phase C/D will be governed by the project schedule described in Section III Part B and the Work Breakdown Structure, Figure IV-1. The project organization initiated in Phase B will be expanded to incorporate the additional management functions required during the detail design, fabrication and delivery activities. Project controls will be needed to assure that all activities are monitored for cost and schedule and to further assure that all project interfaces are exercised as necessary to obtain task and system compatibility. An integrated cost and schedule control plan, established at the beginning of Phase C/D will make program status visible at all times. A documentation plan, developed in general accordance with NPC-500-6, will be implemented. A configuration management plan will control hardware production.

The Work Breakdown Structure categorizes the various program elements and provides the basic reference for program cost estimates. The terms used are defined in the Work Breakdown Structure Dictionary in Section III Part D.6.

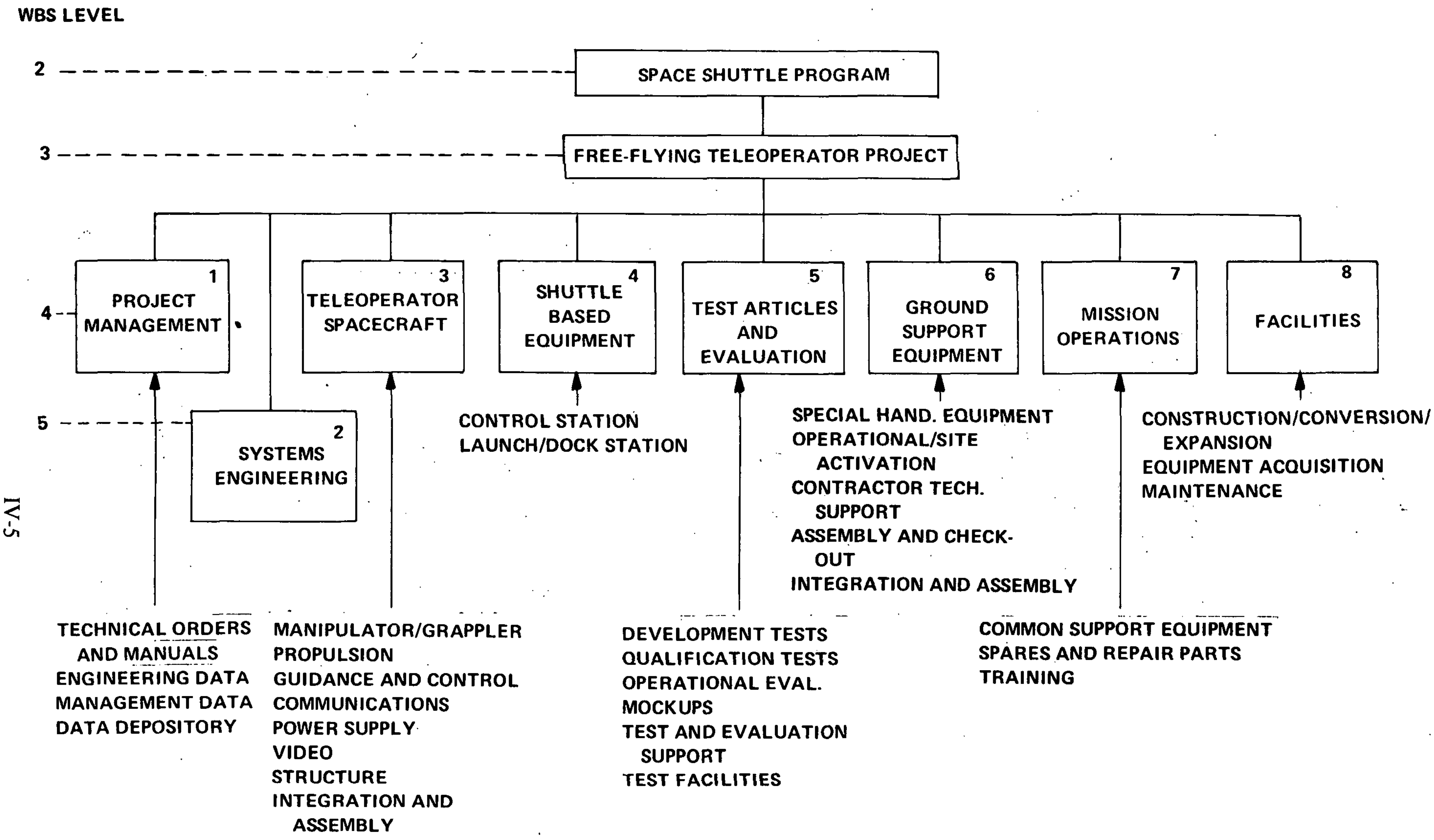

Figure IV-1. Summary of Work Breakdown Structure – Phase C/D

PART B - SCHEDULE, MILESTONES AND NETWORKS

The program milestone schedule and Program PERT network are presented here as Figures IV-2 and IV-3.

A. INTRODUCTION

The plan shown on these two figures shows delivery of two* Flight FFTO Systems occurring in midcalendar year 1977. The four major program elements which pace these deliveries are:

- Component and Subsystem Development/Verification tests
- Engineering Prototype system tests
- Qualification System tests
- Flight FFTO Systems Fabrication, Acceptance test and delivery

The relationships between these key program elements have been optimized within the constraints of the currently available information.

1. Design and Interface

The FFTO system design tasks are closely interrelated with design of the experiment packages, spacecraft and total shuttle system; for this reason we have included several interface tasks and milestones in this plan. The most important are the two format design reviews, PDR (Preliminary Design Review) and CDR (Critical Design Review). PDR is shown on the plan as scheduled to occur at the end of the 4th month, before the start of fabrication of the prototype FFTO. CDR is scheduled to occur at the end of the 19th month, following completion of about half of the prototype system test program and before the final release of Qualification Hardware design.

As more detailed planning information becomes available it may be advantageous to include incremental CDR's for various systems or components that require more design coordination than currently planned.

2. Mockups

The plan includes three mockups which aid and support all facets of the FFTO design and interface tasks.

The first of these is the soft mockup initially fabricated for the Phase B program. This mockup will be updated to reflect the current configuration at the time of PDR.

The second and third mockups are functional mockups. The former will be delivered to NASA for the CVT, (Concept Verification Testing). The latter mockup will be used by BAC as an Engineering work aid and early training program training aid.

3. Test Program

The test program consists of component and subsystem development/verification tests, prototype system tests, and component, subsystem and system qualification tests. These test phases are time-phased to reflect a buildup of design confidence at component and subsystem level before comparable testing at system level.

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*Second flight FFTO is obtained by refurbishing the Qualification Test Unit.

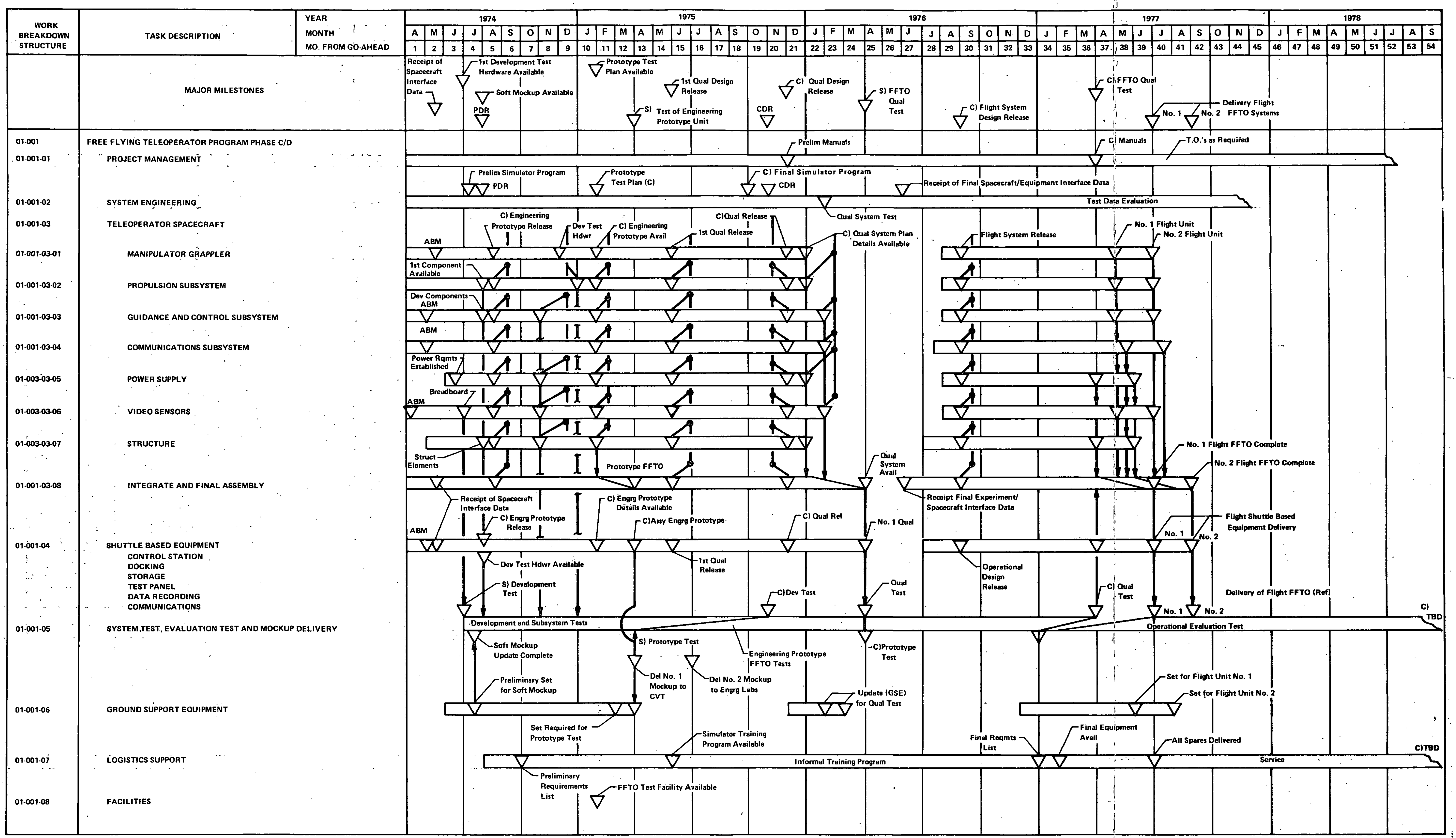
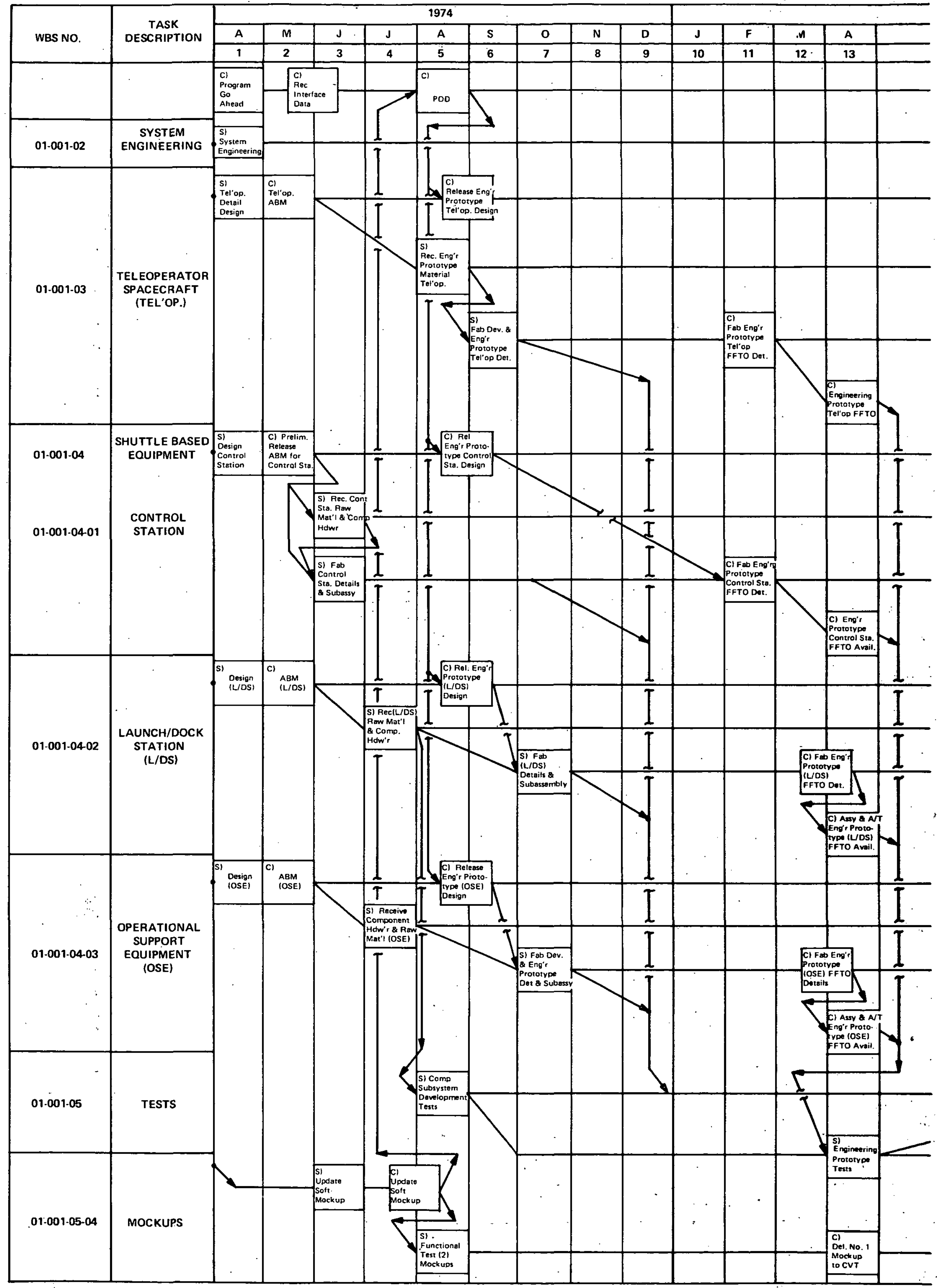


Figure IV-2. Teleoperator Phase C/D Program Milestone Schedule



WBS NO.
TASK DESCRIPTION
1974
A M J J A S O N D J F M A
1 2 3 4 5 6 7 8 9 10 11 12 13
C) Program Go Ahead
C) Rec Interface Data
C) PDD
01-001-02
SYSTEM ENGINEERING
S) System Engineering
01-001-03
TELEOPERATOR SPACECRAFT (TEL'OP.)
S) Tel'op. Detail Design
C) Tel'op. ABM
C) Release Eng'r Prototype Tel'op. Design
S) Rec. Eng'r Prototype Material Tel'op.
S) Fab Dev. & Eng'r Prototype Tel'op Det.
C) Fab Eng'r Prototype Tel'op FFTO Det.
C) Engineering Prototype Tel'op FFTO
01-001-04
SHUTTLE BASED EQUIPMENT
S) Design Control Station
C) Prelim. Release ABM for Control Sta.
C) Rel Eng'r Prototype Control Sta. Design
01-001-04-01
CONTROL STATION
S) Rec. Cont Sta. Raw Mat'l & Comp Hdwr
S) Fab Control Sta. Details & Subassy
C) Fab Eng'r Prototype Control Sta. FFTO Det.
C) Eng'r Prototype Control Sta. FFTO Avail.
01-001-04-02
LAUNCH/DOCK STATION (L/DS)
S) Design (L/DS)
C) ABM (L/DS)
C) Rel. Eng'r Prototype (L/DS) Design
S) Rec(L/DS) Raw Mat'l & Comp. Hdw'r
S) Fab (L/DS) Details & Subassembly
C) Fab Eng'r Prototype (L/DS) FFTO Det.
C) Assy & A/T Eng'r Prototype (L/DS) FFTO Avail.
01-001-04-03
OPERATIONAL SUPPORT EQUIPMENT (OSE)
S) Design (OSE)
C) ABM (OSE)
C) Release Eng'r Prototype (OSE) Design
S) Receive Component Hdw'r & Raw Mat'l (OSE)
S) Fab Dev. & Eng'r Prototype Det & Subassy
C) Fab Eng'r Prototype (OSE) FFTO Details
C) Assy & A/T Eng'r Prototype (OSE) FFTO Avail.
01-001-05
TESTS
S) Comp Subsystem Development Tests
S) Engineering Prototype Tests
01-001-05-04
MOCKUPS
S) Update Soft Mockup
C) Update Soft Mockup
S) Functional Test (2) Mockups
C) Det. No. 1 Mockup to CVT

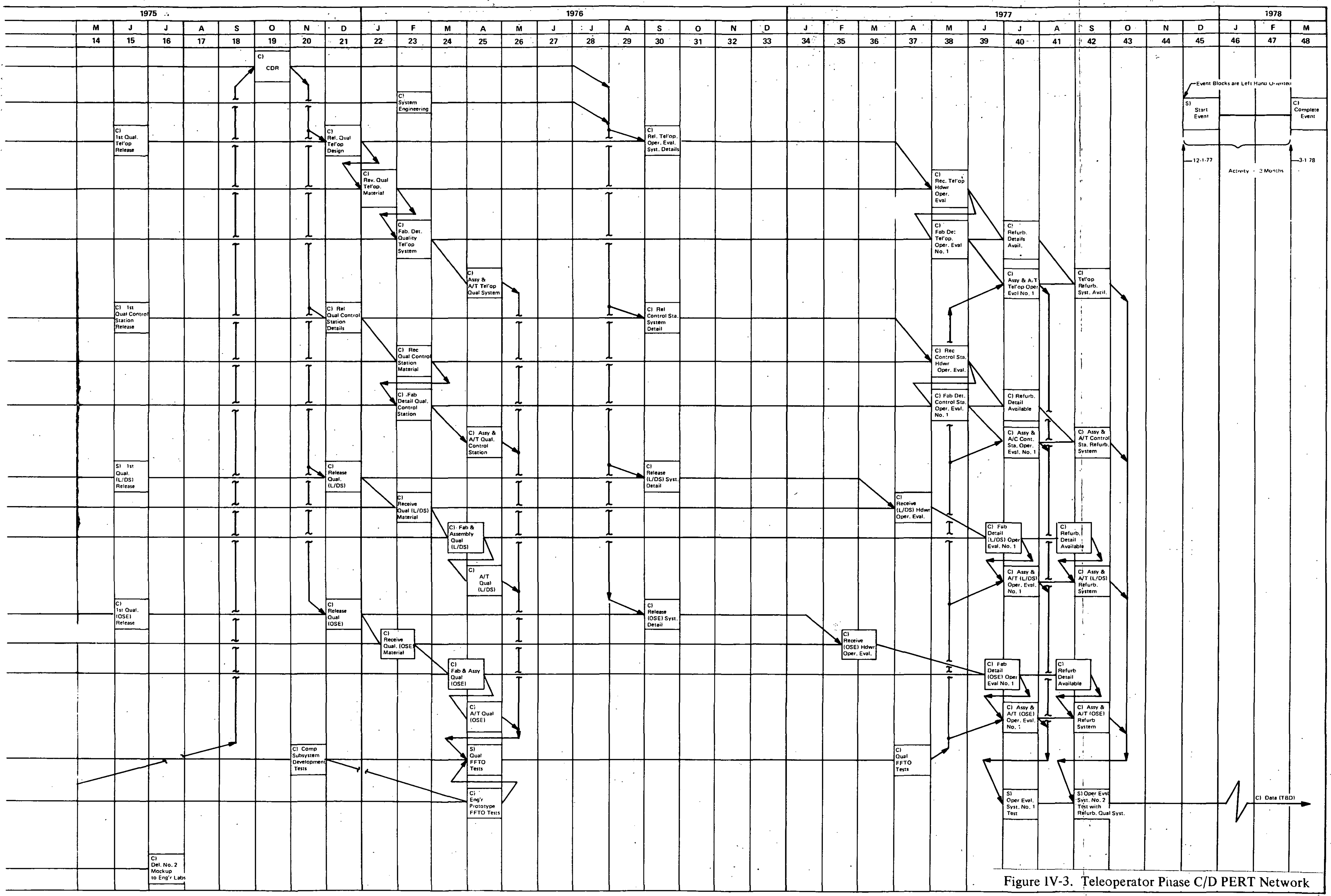


Figure IV-3. Teleoperator Phase C/D PERT Network

4. Training Program

The training program will be planned to accommodate spacecraft, experiments and FFTO operators and maintenance crew members, as all will necessarily be affected by the FFTO operations. Facsimile hardware and simulator training programs will be used in the early phases of the training program. These will be replaced by actual flight type hardware as the final details of the FFTO flight hardware configuration becomes available.

5. Flight System Delivery

The first flight FFTO system is planned to be delivered at the end of the 39th month and the 2nd FFTO system at the end of the 41st month. The go-ahead for flight system fabrication is planned to occur at the end of the 29th month with the fabrication go-ahead being constrained by successful completion of the Initial Qualification test series, and FFTO Final Assembly Fabrication being constrained by successful completion of all qualification tests. The 2nd FFTO system is obtained by refurbishing the Qualification Test System.

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PART D – COST ESTIMATES

A. SECTION 1 COST RATIONALE

For purposes of this ROM estimate, it was necessary to use broad parameters so that the rough magnitude of the program could be ascertained. We used similar type programs for which we had an estimating base, supplemented with quotes from potential vendors. These cost elements were then updated for current rates and overheads.

A hardware oriented WBS was used as described in the Work Breakdown Structure dictionary given later under subsection F., Section 6 of this overall Part D; Section III.

B. SECTION 2 SUMMARY COST

See Section I C.

C. SECTION 3 COST ESTIMATE BY WORK BREAKDOWN STRUCTURE

Table IV-1 represents the preliminary planning estimates for the FFTO Phase C/D schedule shown in Figure IV-2, Part B. Costs are shown for level 4 of the WBS – except in the case of the Teleoperator Space Hardware. Here, preliminary estimates include the level 5 subsystems.

D. SECTION 4 TECHNICAL CHARACTERISTICS DATA

See Section V.

E. SECTION 5 TOTAL PHASE C/D FUNDING SCHEDULES

The funding schedule for Phase C/D is shown in the following figures. (Reference: DRD MF-030 data form C)

Figure IV-4	Nonrecurring DDT and E
Figure IV-5	Recurring

F. SECTION 6 WBS DICTIONARY AND DETAILED COST

The following is a preliminary Work Breakdown Structure Dictionary. Refer to Figure IV-1, WBS Since Phase C/D – Program Planning – requires further investigation, detailed elements of cost are not given. This information will be available as the result of Phase B planning efforts. A preliminary planning estimate of the Recurring and Nonrecurring costs are shown in Figures IV-6 and IV-7.

WBS DICTIONARY

01. Space Shuttle Program. The space shuttle program is defined as a reusable space transportation system which employs a manned vehicle for transporting a variety of payloads, both manned and unmanned, from the surface of the earth to low-earth orbit and return.

TABLE IV-1
PHASE C/D FFTO PROGRAM COSTS

WBS Identification Number						
01-001-01	**01-001-02**	**01-001-03**	**01-001-04**	**01-001-05**	**01-001-06**	**01-001-07**
Subject Management and Documentation	**Systems Engineering**	**Teleoperator Space Hardware**	**Shuttle Based Hardware**	**System Test**	**G.S.E.**	**Mission Operation**
$4 697,000	$6,593,000	$3,093,000	$1,819,000	$11,338,00	$653,000	$1,275,000
Doc. P.M.		Manipulator 546,000 Propulsion 810,000 Guidance 490,000 Communication 225,000 Power Supply 135,000 Video 554,000 Structure 250,000 Integr. Assy. 83,000	Control Sta. Launch Dock Oper. Suppt Integr. Assy.	Develop. Test Qual. Test Oper. Eval. Mockups Test Eval. Spt. Test Facilities	Spec, Hand. Eq. Op/site Act. Assy Checkout Integration	Spares Tech. Support

Total Program	$29,468,800

FUNDING SCHEDULE DATA FORM

STUDY TITLE Shuttle FFTO Experiment Definition Study - Phase C/D

CONTRACT NO. NAS8-27895

NON-RECURRING (DDT&E) x

RECURRING (PRODUCTION) ____

RECURRING (OPERATIONS) ____

DATE ____

PAGE 1 OF 1

PROJECT WBS ITEMS	74 FY	75 FY	76 FY	77 FY	78 FY	79 FY	Total FY
Project Mgmt. and Documentation	497,000	1,200,000	1,500,000	1,200,000	300,000		4,697,000
Systems Engineering	1,000,000	3,600,000	1,500,000	493,000			6,593,000
Test Articles and Eval.	900,000	4,000,000	4,000,000	2,000,000	438,000		11,338,000
Ground Support Equipment		100,000	453,000	100,000			653,000
Total Non-Recurring	2,397,000	8,900,000	7,453,000	3,793,000	738,000		23,281,000

Figure IV-4. Funding Schedule Phase C/D

FUNDING SCHEDULE DATA FORM

STUDY TITLE Shuttle FFTO Experiment Definition Study - Phase C/D

CONTRACT NO. NAS8-27895

NON-RECURRING (DDT&E) ____
RECURRING (PRODUCTION) x
RECURRING (OPERATIONS) ____

DATE ____
PAGE 1 OF 1

PROJECT WBS ITEMS	74 FY	75 FY	76 FY	77 FY	78 FY	79 FY	Total FY
Teleoperator Spacecraft			1,500,000	1,500,000	93,000		3,093,000
Shuttle Based Equipment			900,000	900,000	19,000		1,819,000
Mission Operation		150,000	250,000	155,000	360,000	360,000	1,275,000
Total Recurring		150,000	2,650,000	2,555,000	472,000	360,000	6,187,000

Figure IV-5. Funding Schedule Phase C/D

COST DATA FORM - A2

RECURRING (PRODUCTION)

STUDY TITLE Shuttle FFTO Experiment Definition Study - Phase C/D

CONTRACT NO. NAS8-27895

DATE: ______

PAGE 1 **OF** 1

Identification Number	WBS Identification	WBS Level	No. of Units	1st Unit Cost T_1	Expected Cost	Ref. Unit	Ref. Unit Cost	Confid. Rating	T_d	T_s	Spread Funct	Learn Index
01-001-03	Teleoperator Spacecraft				3,093,000							
01-001-04	Shuttle Based Equip.				1,819,000							
01-001-07	Mission Oper.				1,275,000							
	Total Recurring				6,187,000							

Figure IV-6. Preliminary Planning Estimate Phase C/D

COST DATA FORM – A1
NON-RECURRING (DDT&E)

STUDY TITLE Shuttle FFTO Experiment Definition Study - Phase C/D

CONTRACT NO. NAS8-27895

DATE ____

PAGE 1 OF 1

IDENTIFICATION NUMBER	WBS IDENTIFICATION	WBS LEVEL	EXPECT. COST	CONFID. RATING	T_d	T_s	SPREAD FUNCT.
01-001-01	Project Mgmt. and Documentation		4,697,000				
01-001-02	System Engineering		6,593,000				
01-001-05	Test Articles & Eval.		11,338,000				
01-001-06	Ground Support Equipment		653,000				
	Total Non-Recurring		23,281,000				

Figure IV-7. Preliminary Plan Estimate Phase C/D

01-001. Free Flying Teleoperator Project. The free-flying teleoperator is defined as those systems which employ unmanned, selfpropelled vehicles to extend the capabilities of man's eyes, arms, hands, legs and brain from a control station on the Shuttle to the space environment around the Shuttle.

01-001-01. Project Management. The project management element refers to the technical and business management of particular systems/projects including the planning, directing, and controlling the definition, development, and production of a system/project; and assuring that planning is accomplished by organizations responsible for the complementary functions of logistics and maintenance support, personnel training, operational testing, activation, or deployment of a system. System/project management effort which can be specifically associated with the hardware elements is excluded.

Supporting project management activities refer to the technical and administrative planning, organizing, directing, coordinating, controlling, and approval actions designed to accomplish overall project objectives which are not associated with specific hardware elements. Examples of these activities are configuration management, cost/schedule management, data management, contract management, transportation and packaging program, vendor liaison, value engineering, and quality assurance.

The documentation refers to all deliverable data required. The data requirements will be selected from the departmental or agency authorized data list. This element includes only such effort that can be reduced or will not be incurred if the data item is eliminated. If the data are "government-peculiar," include the effort for acquiring, writing, assembling, reproduction, etc. If the data are not "government-peculiar," include the effort for reproduction, packaging, and shipping. This element also includes the effort for repreparing into government format with reproduction and shipment if data are identical to that used by the contractor, but in a different format.

01-001-01-01 Technical Orders and Manuals. The technical orders and manuals elements refers to those handbooks, technical manuals, technical orders, technical data sheets, etc. required by NASA.

01-001-01-02 Engineering Data. The engineering data element refers to those engineering drawings, associated lists, specifications, and other documentation required by the government. This element includes all plans, procedures, reports, and documentation pertaining to systems, subsystems, component engineering, and testing.

01-001-01-03 Management Data. The management data element refers to those data items necessary for configuration management, cost, schedule, contractural data management, programs management, etc., required by the government.

01-001-01-04 Data Depository. The data depository element refers to a facility designated to act as custodian in establishing and maintaining a master engineering specification and drawing depository service for government-approved documents that are the property of the U.S. Government. As custodian for the government, the contractor is authorized by approved change orders to maintain these master documents at the latest approved division level. When documentation is called for on a given item of data retained in the depository, the charges (if charged direct) will be to the appropriate data element. This element represents a distinct entity of its own and includes all effort of drafting, clerical, filing, etc., needed to provide the service outlined above. All similar effort for the contractor's internal specification/drawing control system, in support of his engineering/production activities, is excluded.

01-001-02 Systems Engineering. The systems engineering refers to the systems engineering effort of including systems engineering, design engineering, support engineering and specialty fields (that is, reliability, maintainability, system effectiveness, safety, human factors, etc.). This element also includes the system engineering effort to:

- Transform a stated requirement or need into an appropriate functional description and systems delineation through the use of an iterative process of definition, synthesis, design, test, and evaluation.

- Integrate related technical functions and interfaces to optimize the total system definition and design, and

- Integrate special technical effort such as reliability, maintainability, safety, human factors, etc., into the engineering effort.

System engineering effort includes; for example, system definitization, overall system design, design integrity analysis, system optimization, cost/effectiveness analysis, weight and balance analysis, and intrasystem and intersystem compatibility analysis. It also includes reliability, maintainability, safety and survivability program requirements, human engineering and manpower factors program, preparation of equipment and component performance specifications, security requirements, logistics support integration, and design of test and demonstration plans.

01-001-03 Teleoperator Spacecraft. The teleoperator spacecraft element refers to the complex of equipment, software, services,tooling and facilities required to develop, produce and test the capability of employing a teleoperator for performing a variety of space tasks in an operational environment.

01-001-03-01 Manipulator/Grappler. The manipulator/grappler refers to the means for performing the manual space operations. This element includes; for example, the end effectors, arms, controllers and the structural entity associated with operator hand and arm motions and forces.

01-001-03-02 Propulsion. The propulsion element refers to the means for generating propelling forces on the teleoperator. This element includes; for example, the structure, propellant and fuel, distribution and control of propellant and thrusters fuel, starting means, safety devices, and internal environmental control when grouped as a functional entity.

01-001-03-03 Guidance and Control Equipment. The guidance and control equipment element refers to the means for generating or receiving guidance intelligence, conditioning the intelligence to produce signals, and generating appropriate control forces. Controllers may interface with the propulsion system to produce and control movable reaction forces, or may independently produce reaction forces for control. If design is such that electronics are packaged into a single rack or housing as an assembly, this rack or housing will be considered part of the guidance and control system, but the circuit boards will be considered as parts of the appropriate subsystems. This element includes; for example, the guidance intelligence system, computer, sensing elements, autopilot, etc.

01-001-03-04 Communications. The communications element refers to the means for distribution of intelligence within the teleoperator system. This element includes inter-communications subsystems of the Shuttle for message flow and ties between sensoı, data processing, and launch and guidance control subsystems. Communications may interface with existing fixed-communications facilities or communications subsystems of the Shuttle which are associated systems to the teleoperator system. (Subsystems involved in safety and destruct or test and training are not included, unless they are required operational items. Otherwise they are included under test and evaluation support under systems test and evaluation.)

01-001-03-05 Power Supply. The power supply element refers to that equipment required to supplement or provide service to other level 5 elements within the teleoperator. This element includes; for example, power supply, power distribution, environmental control, shock alleviation, safety and protective subsystems, destruct system, etc. It also includes equipment of a single purpose and function which is necessary for accomplishing the assigned mission.

01-001-03-06 Video Sensors. The video sensors element refers to those sensors required to support teleoperator systems by maintaining surveillance and providing the data required for targeting, launch, midcourse guidance, manipulation and docking. They may include tracking of the teleoperator system space vehicles as required for guidance and control or range safety. (Subsystems involved in safety and destruct or test and training are not included, unless they are required operational items. Otherwise they are included under test and evaluation support under systems test and evaluation.) This element may include; for example, sensors of any spectrum whether optical, infrared, radar, etc.

01-001-03-07 Structure. The structure element refers to the means and hardware for assembling and integrating the subsystems into a teleoperator spacecraft. This element includes the structure for supporting the subsystems and for resisting the docking and manipulator loads.

01-001-03-08 Integration and Assembly. The integration and assembly element refers to all effort outlined below as well as that portion of the vehicle furnished by the integrating contractor to provide interface/mating surfaces necessary to permit the integration and assembly of the other level 5 elements into a Shuttle. This element includes; for example, external appendages for stable and controllable flight, interstage sections, structure, framework, skirts, umbilical receptacles and cables, umbilical raceways, covers, fail safe system, and other miscellaneous items which are homogeneous to the integration effort.

In those instances where an integration and assembly element is used, it will include all effort of technical and functional activities associated with the design, development, and production of mating surfaces, structures, equipments, parts, and materials required to assemble the other level 5 product elements into a level 4 prime mission product as a whole and not directly part of any other individual level 5 element. Integration and assembly includes all effort associated with the development of engineering layouts, determination of overall design characteristics, and determination of requirements of design review; the setup, conduct, and review of testing assembled components or subsystems before installation; the detail production design; inspection activities related to receiving, factory, and vendor liaison; design maintenance effort, quality planning and control, tooling (planning, design and fabrication), and administrative engineering. Integration and assembly also include all effort involved in the joining or mating and final assembly of level 5 product elements to form a complete prime mission product that is performed at the manufacturing facility and the conduct of acceptance testing. All system/project management (system engineering management/system engineering and supporting project management activities) and system test and evaluation (development tests, etc.) which are associated with the overall system are excluded. When an integration and assembly element is used at lower levels of the extended contractor WBS, it will be summarized into the next higher level hardware WBS element and should never be summarized into the level 5 integration and assembly element set forth in this standard.

01-001-04 Shuttle-based Equipment. The Shuttle-based equipment refers to the means for enabling the operator on the Shuttle to launch and dock the teleoperator and to control it during flight and in the performance of space operations.

01-001-04-01 Control Station. The control station refers to the Shuttle volume which houses the operator and equipment used for remotely controlling the teleoperator. For example, this element includes: communication, computer/processor, controls, displays associated electronics, and operator and equipment support structures.

01-001-04-02 Launch/Dock Station. The launch/dock station element refers to the subsystems installed aboard the Shuttle required to store, make ready, and dock or launch the teleoperator vehicle. This element includes those equipments required to acquire and condition the necessary intelligence to select targets, reach launch or dock decisions, command the launch or dock and provide guidance and control where such capability is not self contained aboard the teleoperator. This element includes design, development, and production of complete units (prototype and operational configured units which satisfy the requirements of their applicable specification(s), regardless of their end use).

01-001-04-03 Operational Support. The operational support element refers to the means for refurbishing the teleoperator. This element includes for example, the docking adaptors, battery recharger, and emergency equipments.

01-001-05 Systems Test and Evaluation. The systems test and evaluation element refers to the use of prototype, production, or specially fabricated hardware to obtain or validate engineering data on the performance of the teleoperator system. This element includes the detailed planning, conduct, support, data reduction and reports from such operations, and all hardware items which are consumed, or planned to be consumed, in the conduct of such operations. It also includes all effort associated with the design and production of models, specimens, fixtures, and instrumentation in support of the test program. Test articles which are complete units (that is, functionally configured as required by the mission equipment) are excluded. Development, component acceptance, etc., testing which can be specifically associated with the hardware element, unless these tests are of special contractual or engineering significance (for example, associate contractor), are also excluded.

01-001-05-01 Development Tests. The development tests element refers to the test planning and use of prototype equipment to acquire engineering data and confirm engineering hypotheses. This element includes integration, flight, and ground tests. It also includes such models and tests as hydrostatic, fatigue, etc.

01-001-05-02 Qualification Tests. The qualification test element refers to the evaluation of the performance characteristics of production (or near production) configured hardware, culminating in government acceptance of contractual performance requirements. It includes such tests as flight tests, spin demonstrations, stability tests, range and accuracy demonstrations, etc., and support thereto.

01-001-05-03 Operational Evaluation. The operational evaluation element refers to evaluation of production hardware by the ultimate using command to demonstrate system performance and the use of the system under operational conditions.

01-001-05-04 Mockups. The mockups element refers to the design engineering and production of system or subsystem mockups which have special contractual or engineering significance, or which are not required solely for the conduct of one of the above elements of testing.

01-001-05-05 Test and Evaluation Support. The test and evaluation support element refers to all support elements necessary to operate and maintain systems and subsystems during testing and evaluation which are not consumed during a particular category of testing. For example, this element includes: instrumentation, repairable spares, test and support equipment, contractor technical support, tracking vessels, etc., not allocable to preceding test and evaluation elements. Operator and maintenance personnel, consumables, special fixtures, special instrumentation, etc., which are used and/or consumed in a single element of testing, and which should, therefore, be included under that element, are excluded here.

01-001-05-06 Test Facilities. The test facilities element refers to those special test facilities or sites required for performance of the various developmental tests necessary to prove the design and reliability of the system or subsystem. For example, this element includes: test chambers, white rooms, shakers, etc. The brick-and-mortar-type facilities allocable to industrial facilities are excluded here.

01-001-06 Ground-support Equipment. The ground support equipment refers to the special handling, test and checkout and consumable servicing provisions which enable the teleoperator to be maintained and serviced while it is being integrated and assembled to the Shuttle.

01-001-06-01 Special Handling Equipment. The special handling equipment element refers to the equipment, including tools, required to maintain and care for the system or portions of the system while not directly engaged in the performance of its mission, and which have application peculiar to a given materiel item. For example, this element includes: vehicles, equipment, and tools used to fuel, service, transport and hoist, repair, overhaul, assemble, disassemble, test, inspect, or otherwise maintain the mission equipment. It also includes all effort associated with the design, development, and production of peculiar support equipment.

01-001-06-02 Operational/Site Activation. The operational/site activation element refers to the real estate, construction, conversion, utilities, and equipment to provide all facilities required to house, service, and launch prime mission equipment at the organizational and intermediate level. This element includes conversion of site, vehicle, and system assembly, checkout, and installation into site facility or Shuttle to achieve operational status. It also includes contractor support in relation to operational/site activation.

01-001-06-03 Contractor Technical Support. The contractor support element refers to all materials and services provided by the contractor related to activation. For example, this element includes: standby services, final turnover, etc.

01-001-06-04 System Assembly, Installation and Checkout On Site. The system assembly, installation, and checkout on site element refers to all materials and services involved in the assembly of mission equipment at the site. This element, for example, includes: installation of mission and support equipment in the Shuttle, operations, or support facilities; and complete system checkout or shakedown to ensure achievement of operational status.

01-001-07 Mission Operations. The mission operations element refers to the means for enabling the teleoperator system to operate throughout its useful life. This element includes the common support equipment for maintenance, spares and repair parts, and training.

01-001-07-01 Common Support Equipment. The common support equipment element refers to the equipment, including tools, required to maintain and care for the system or portions of the system while not directly engaged in the performance of its mission, and which are presently in the NASA inventory for support of other systems. This element includes all effort required to assure the availability of this equipment for support of the particular materiel item. It also includes the acquisition of additional quantities of these equipments if caused by the introduction of the materiel item into operational service.

01-001-07-02 Spares and Repair Parts. The spares and repair parts element refers to the spare components or assemblies used for replacement purposes in major end items of equipment.

01-001-07-03 Training. The training element refers to the training services, devices, accessories, aids, equipment, and parts used to facilitate instruction through which personnel will acquire sufficient skills and aptitudes to operate and maintain the system with maximum efficiency. This element includes all effort associated with the design, development, and production of training equipment as well as the execution of training services.

01-001-07-03-01 Equipment. The equipment element refers to those distinctive end items of training equipment, assigned by either a contractor or NASA, to meet specific training objectives. For example, this element includes: operational trainers (that is, simulators), maintenance trainers (that is, MTU's) and other items such as cutaways, mockups, and models.

01-001-07-03-02 Services. The services element refers to services, devices, accessories, and aids necessary to accomplish the objectives of training. This element, for example, includes: training plans, training aids, training course materials, contractor-conducted training including inplant and service training, etc.

01-001-07-03-03 Training Facilities. The facilities element refers to that special construction necessary to accomplish the objectives of training. (Primarily, the brick-and-mortar-type facility constructed solely for the training mission.) The equipment used for the purpose of acquainting the trainee with the system or establishing trainee proficiency is excluded.

01-001-08 Facilities. The facilities element refers to the construction, conversion, or expansion of facilities for production, inventory, and contractor depot maintenance required by one or more suppliers for the specific system. This element includes, for example: equipment acquisition, or modernization, where applicable, and maintenance of the above facilities or equipment.

01-001-08-01 Construction/Conversion/Expansion. The construction/conversion/expansion element refers to the real estate, and preparation of system peculiar facilities for production, inventory, depot maintenance, and other related activities.

01-001-08-02 Equipment Acquisition or Modernization. The equipment acquisition or modernization element refers to production equipment acquisition, modernization, or transferral of equipment for the particular system. (Pertains primarily to government owned and leased equipment under facilities contract.)

01-001-08-03 Maintenance (Industrial Facilities). The maintenance (industrial facilities) element refers to the maintenance, preservation, and repair of industrial facilities and equipment.

V. SUPPORTING RESEARCH AND TECHNOLOGY

The objective of this section is to report on the supporting research and technology (SRT) requirements necessary for the development of a free-flying teleoperator system experiment. SRT requirements were established by comparing hardware and technology required by the FFTO with those expected to be available in the 1973-1974 time frame. The results are presented in Table V-1. In all cases, a preliminary SRT output is needed for the continuing Phase B effort. To be effective in steering the Phase B effort, this preliminary SRT output is needed at the half-way point of the Phase B effort. Final SRT data are needed early in the Phase C/D effort (within the first year).

A. MANIPULATOR/GRAPPLER

From the mission analysis, a variety of manipulative devices are needed ranging from grappler/docking mechanisms which establish and maintain a rigid contact with a worksite or payload, to manipulator mechanisms which perform useful work or manipulative tasks at a worksite. The device requirements may be further grouped according to whether or not a prepared site is needed. Until the functional requirements of manipulators and grapplers are established, the technology development can't efficiently proceed, even though the component technology capability is available, i.e. motors, gears, etc. A standardized modular spacecraft, which is one of the approaches being considered, would enhance the determination of the manipulator/grappler requirements since the payload characteristics to be serviced would be known.

Additional design and development of a manipulator controller must also be considered, although many earth-based control techniques have been devised. The extent of the technology deficiency can not be determined until the functional requirements of the manipulator have been established.

B. VIDEO

One of the critical sensory links for the teleoperator is the video subsystem, since it must be capable of operating continuously with high reliability under a variety of conditions. The teleoperator video system differs slightly from previous systems which were generally designed to operate in a known and fairly constant environment. A status review of the development in this area indicates that the majority of the elements comprising the video subsystem have either been space-qualified, or are scheduled to be flown within a short time. Even the persistent problem of operating over the wide illumination spectrum of space has been alleviated by the various control techniques.

The technology building blocks are available. It remains then, to evaluate the techniques and establish the requirements for specific teleoperator applications. Like the manipulator subsystem, it is the area of specific requirements definition that needs to be pursued. The development of specific requirements, possibly by means of tradeoff studies or further elaboration of existing programs, should be directed towards the following component or system performance areas:

Illumination
Color versus black and white
Resolution
Camera control
Stereo versus 2D multicamera systems

TABLE V-1
SUPPORT RESEARCH AND TECHNOLOGY SUMMARY

Title	Status	Justification	Technical Plan
Guidance and Control			
Range/Range Rate Sensor	Technology is available, but hardware choice is small.	Range and range rate are needed from 10-20 ft out to 1000 ft. To be practical for FFTO use, a small unit (10 lb) is needed. No such sensor exists.	1. Develop an R-$\dot{R}$ sensor to meet performance requirements. 2. Demonstrate performance on an earth-based antenna range. 3. Package and test qualify the unit for FFTO use.
Elec. and Cost	No SRT Needed.		
Stability	No SRT Needed.		
Communications	No SRT Needed.		
Power Supply	No SRT Needed.		
Video Systems	Only one 7-in. monitor is being developed for use in space.	Although a thorough analysis has not been conducted, preliminary indications are that a monitor larger than the 7-in. size will be most suitable for FFTO navigating, inspection and docking. A 16-in. monitor size has been selected.	1. Study monitor size requirements for FFTO use. 2. Develop a large monitor if study output indicates one is needed. 3. Qualify the unit for use in the Shuttle experiment module environment.
Control Station			
Communications	No SRT Needed.		
Video Requirements	Limited data have been gathered on video requirements for near-earth operations considering: 1. Environment 2. Lighting 3. Space Tasks/Missions 4. Human Factors and Man/Machine Functions 5. Grappler/Manipulator Video Requirements 6. Payload/Target Characteristics	A portion of the experiment is conducted while the FFTO is in the earth's shadow (night time). Video requirements to give navigating etc. inputs are not known. Worksite video requirements are needed to establish video system arrangement for manipulation tasks.	Study objectives would identify: 1. Light levels required. 2. Guidance procedures and sensors compatible with night operation. 3. Artificial lighting requirements. 4. Contrast and video picture quality required. Idenfity fields of view, number of cameras required, motion requirements and system characteristics, light sensitivity, zoom requirements, etc.
Manipulator/ Grappler	1. No grapplers have been required for space. 2. Grapplers not available for specific space tasks. 3. Small, lightweight grapplers not available.	Only functional requirements are known. These must be translated into design requirements and various designs generated.	1. Analyze payloads to determine dynamics to be expected for specific payloads. Important considerations are mass and inertia properties and the probable failure modes. 2. Study grappling procedures and the ability to assess dynamics by using a visual computer simulation. 3. Design grappler and conduct hardware simulation to check design. 4. Human factors and man-machine task analysis considering:

TABLE V-1 (CONT)

Title	Status	Justification	Technical Plan
Manipulator/ Grappler (cont)			a. Variable dynamics of FFTO vehicle and payload. b. Space environment. c. Typical payloads. d. Video system parameters. e. Grappler/manipulator dynamics. f. Lighting/contrast/frame rate motion/video resolution.
Structure	No SRT Needed.		
Propulsion	No SRT Needed.		
Launch/Dock Station	No SRT Needed.		
Ground Support Equipment	No SRT Needed.		

C. GUIDANCE, NAVIGATION AND CONTROL

The Range/Range Rate Sensor (RRRS) must be carried on the FFTO. Size and weight are primary considerations when the specific hardware item is selected, assuming other performance specifications have been satisfied. Although several RRR sensors, in the form of radar systems, are available as space qualified hardware, a smaller unit is not available off the shelf, which satisfies the following performance or configuration parameters:

Range, max	-	10,000 feet with MEM target or 1,000 feet with BRM target
Range, min	-	5 - 10 feet
Range rate, max	-	±20 feet/sec
Operational Mode	-	Noncooperative
Weight	-	$\leqslant$ 10 pounds
Power, max	-	15 watts

These parameters are suggested as guidelines defining the development effort required. To illustrate the development increment which must be reduced before firm hardware procurement of an RRRS, a low power space radar for rendezvous with passive targets is under development by RCA, as a modification to the Lunar Module rendezvous radar. This possible-candidate unit satisfies several of the aforementioned parameters such as maximum range and range rate. But, the expected weight of the combined electronics and antenna assembly is 77 pounds, and it needs an input power of 160 watts. More development would be needed to achieve the stated objectives in the time span allotted to teleoperator design and development, if it is chosen.

D. DISPLAYS AND CONTROLS

A less urgent item (in terms of hardware complexity), but nonetheless important, is the need for a large screen TV display monitor as specified for the teleoperator control console. Human factors analyses indicate that emphasis should be placed on getting large screen displays to enhance the man/machine interface. As a development goal, a screen size of 16 inches across the diagonal is considered to be an adequate starting point. There are several monitor displays satisfying this goal, but none are space qualified. Please note that these are goals and not requirements. Much smaller displays, could be used in the teleoperator application such as a seven inch monitor under development by the Conrac Company for the Skylab program. Video system requirements must be more clearly defined before the effects of monitor display sizes in this application can be determined.

E. STATE-OF-THE-ART SUMMARY AND PROJECTION

Besides the directly related supporting research and technology performed as part of the FFTO program, it will be possible to realize benefits to the FFTO program from on-going research and technology and state-of-the-art advances within the various technological community sectors such as industrial organizations, government (ASA, military and other agencies) laboratories, non-profit organizations, universities and foreign research and development groups.

Projections of technology advances are based on extrapolated results of the last ten years leading up to the present level and on a best estimate of the probable continuing trends. In some cases, completely new approaches may be possible to satisfy a given functional requirement. For example, a flat-screen solid-state matrix of light emitters may replace a cathode ray tube (CRT) type display. In such cases, ancilliary benefits may be realized such as enhanced reliability, simplified mounting and installation, reduced size, weight or electric power, improved safety, etc.

Note that none of the state-of-the-art advances are absolutely essential to the operation of the FFTO. In every case, there are existing equipments or technology available today which would allow the FFTO to be built and operated within a minimum program implementation time period. However, each suggested state-of-the-art enhancement would benefit the FFTO in regard to improved performance, reduced size and weight, etc.

Typical examples of projected state-of-the-art advances in the electrical and electronic subsystems of the FFTO are shown in Table V-2.

TABLE V-2
STATE OF THE ART SUMMARY AND PROJECTIONS

Technology/Equipment	Present State Of Art Or Limitations	Projected Technology Approx. 1978
Television Displays Size	7 Inch NASA Qualified for Space 16 Inch Military Airborne Ruggedized Cathode Ray Tube (CRT) Displays	Flat Screen, Non-CRT, any Size Electro-luminescent or Solid State Light Emitter Matrix
Small Camera Light Level (Camera Under 7.0 lbs)	1/2 Inch Vidicon 50 Foot Lamberts Tube Type Camera	Using Image Intensifiers Less Than 0.1 Foot Lambert Probably Still Lower Light Level Using New Solid State Sensor Devices
Small Camera Size	6 lb 1/2 Inch Vidicon Tube Type Camera	1.0 lb Solid State Matrix Camera Sensor Unit
Range Only Sensor (Also Range Rate)	Existing Rendezvous Radars and Lasers, All Over 20 lbs, All Use Moving Parts, Gimbals, Etc.	7.0 lb Solid State Radar 10,000 Ft Range, 10 Sq Meter Passive Target, No Moving Parts
Electric Power Sources	40 Watt Hours/Lb Silver-Zinc Battery Cells	Over 100 Watt Hours/Lb Zinc-Air Cells or Hydrazine Fuel Cells
Video Data Recording Ruggedized Light Weight Longer Recording Time	73 lb, Wide Bandwidth 2 Inch Wide Tape, 15 Inches/Second Transverse Video Recorder Alternate Film Recording Without Playback Evaluation In Space Capability	Light Weight Video Recorder Longitudinal Recording Narrow Tape, Greater Bit Packing Density. Alternate Film Recording and Rapid Processing Techniques
Artificial Illumination Capability	Small, Light Weight Incandescent Halogen Lamp 1200 Lumens/Watt	Small Mercury Arc 4700 Lumens/Watt
Three Dimensional "Depth" Display	Split Image or Dual Cameras With Polarized Viewing Devices	Alternate Laser Illuminators for Holographic Display in Three Dimensions

VI. TECHNICAL CHARACTERISTICS DATA

Table VI-1 provides (in accordance with NASA DRD MF03A Data Form B) a preliminary listing of the technical, physical and mission characteristics of the FFTO system. See Section III Part D.6 for a Phase C/D Work Breakdown Structure (WBS) list and WBS dictionary.

The characteristics identified describe the sizing, performance, complexity and reliability of the item both qualitatively and quantitatively. The quantity or value of the characteristic has been determined from preliminary design considerations and will be updated as the design becomes finalized.

TABLE VI-1
TECHNICAL CHARACTERISTICS DATA FORM B (1 of 3)

WBS Identification No.	WBS Identification	Quantity or Value	Units of Measure	Characteristics	Notes
01-001-03	Teleoperator Spacecraft	32 x 36.8 x 48.5	in.	Size	
		433	lb	Weight	
		<0.03	in.	Visual (Minimum identifiable dimen)	At a distance of ten feet
		40	deg/sec	Maximum spin rates	
		0.1	deg/sec	Minimum attitude rates	
		0.2	ft/sec	Minimum velocity	
		0.5 or.1%	feet	Range accuracy	
		240°	min	Activity duration	
		TBD	lb-sec	Docking loads (impulse)	
01-001-03-01	Manipulator/ Grappler	1	-	Degrees of freedom (angular travels)	Spin-design
		TBD	lb	Force level	
		150	in-lb	Torque level	
		TBD	in.	Positioning Accuracy	
		3	fingers	Configuration (hook, fingers, tool, etc)	
		<1	min	Operating time	
		80	watts	Power	
		1	-	Number of arms	
		25	lb	Weight	
		2000	cu. in.	Volume	
01-001-03-02	Propulsion	15,000	lb-sec	Total impulse	
		16	-	Configuration (No. of thrusters)	
		205	sec	Specific impulse	Hydrazine (duty cycle average)
		0.15	lb-sec	Impulse increment	
		6000	-	Number of restarts	Each thruster
		3000	sec	Operating life	Each thruster
		3-12	months	Storage time	Reusable three cycles no refurb.
		145.8	lb	Weight	
		6000	cu. in.	Volume	Two tanks 32 x 10 in dia.
01-001-03-02	Propulsion	1800	deg. F	Combustion gas temperature	(Can be lowered with water if necessary for environment)
01-001-03-03	Guidance and Control	0.5 or 1%	ft	Position accuracy	
		0.2	deg	Angular accuracy	With TV zoom
		0.2	ft/sec	Minimum linear velocity	
		0.1	deg/sec	Minimum angular rate	
		40	ft/sec	Maximum linear velocity	
		40	deg/sec	Maximum angular rate	
		30	deg	Acquisition window	Radar beamwidth
		10,000	ft	Maximum range	
		10	ft	minimum range	
		±1.8	ft-lb-sec	CMG total angular momentum	
		117	watts	Power	217 watts during 20 min. warmup for CMG
		69.9	lb	Weight	
		1500	cu. in.	Volume	gyro triad 3 x 3¼ x 4¼ CMG 8.6 x 5 in. dia electronics 5 x 5 x 8.5 ant. 8 in. dia 2 in. deep

TABLE VI-1 (2 of 3)

WBS Identification No.	WBS Identification	Quantity or Value	Units of Measure	Characteristics	Notes
01-001-03-04	Communications	3840	bits/sec	Data rate (telemetry)	Backup link has 640 bits/sec
		360	deg sphere	Acquisition window	
		5	MHz	Bandwidth (TV)	
		38.5	lb	Weight	
		61	watts	Power	
		1200	cu. in.	Volume	
01-001-03-05	Power Supply	610	watts-hr	Total energy	
		11.2	kilowatts hr	Minimum discharge time	
		6	months	Wet Storage time	Charge >85%
		-40 to +165	°F	Operating temp.	
		80	Recharge cycles	Operating life	
		740	cu. in	Volume	2 bat 11.4 in. x 9.1 in. dia.
		27	lb	Weight	
01-001-03-06	Video	32.6	lb	Weight	Includes weight of tracker drives
		200	watts	Power	Includes 100 watt lamp
		50	ft-lamb.	Sensitivity, min	Filters used to image sun
		450	TV Lines	Resolution	Limiting with 85% at 320 TV lines
		47	deg	Horizontal angle of view	8 to 1 zoom with automatic iris ±180° in azimuth (one camera)
		600	cu. in.	Volume (3 TV cameras and lamp)	
01-001-03-07	Structure	32 x 36.8 x 48.5	in.	Size	
		75	lb	Weight	
		TBD	lb-sec	Docking loads (impulse)	
		150	in-lb	Manipulator torques	
		3	g's	Flight load factors	
		TBD	cycles/sec	vibration	
01-001-04	Shuttle-based Equipment	7	days	Life support (time)	
		4	hr	Operator duty cycle	
		1	—	No. of operators	
		140	cu. ft	Volume	
		500	lb	Weight	Does not include operator
		0.77	kilowatts	Power	
01-001-04-01	Control Station	~100	cu. ft.	Volume	
		475	lb	Weight	Includes 288 lb of recorder equipment
		470	watts	Power (average)	Includes 210 watts of recording power
		3840	bits/sec	Data rates	
		16	in.	TV monitor size	Diagonal
		2	—	Number of TV monitors	
		2	—	Number of recorders	
		2.5	hr	Storage (video operating time)	

TABLE VI-1. (3 of 3)

WBS Identification No.	WBS Identification	Quantity or Value	Units of Measure	Characteristics	Notes
01-001-04-02	Launch/Dock Station	~40	cu. ft	Volume	
		TBD	lb	Docking loads	
		TBD	g	Flight loads	
		6 x 6	ft	Acquisition window	
01-001-04-03	Operational Support	11	Pins	Umbilical connections	
		16	hr	Recharge time	Nominal
		300	cu. in.	Volume	
		8	lb	Weight	
		300	watts	Power (average)	Includes 50 watts recharger