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Phase I Definition of the Laser Atmospheric Wind Sounder (LAWS)

Contract NAS8–37590

DR–19 Final Study Report

Volume III
Project Cost Estimates

APRIL 1990

ockheed
siles & Space Company, Inc.
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Prepared for:
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Final Study Report (Phase I) for Laser Atmospheric Wind Sounder (LAWS)

Volume III Project Cost Estimates

Submitted in Partial Fulfillment of

Contract NAS8-37590

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Prepared for:

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FOREWORD

This document presents the final results of the 12-month Phase I effort for the Laser Atmospheric Wind Sounder (LAWS). This work was performed for the Marshall Space Flight Center (MSFC) by Lockheed Missiles & Space Company, Inc., Huntsville, Alabama, under Contract NAS8-37590. The study was conducted under the direction of R.G. Beranek, NASA Program Manager, PS02. The period of performance was 24 March 1989 to 23 March 1990.

The complete Phase I Final Reports consist of the following three volumes:

Volume I - Executive Summary

Volume II - Final Report

Volume III - Program Cost Estimates.

Subcontractors contributing to this effort are Avco Research Laboratory, Inc.; GEC Avionics Ltd.: and Itek Optical Systems.

This volume is submitted to fulfill the requirements of DR-6, "Program Cost Estimates Document," and DR-19, "Final Study Report (Phase I)." Preliminary project cost estimates were presented at scheduled reviews as they were developed. Final study results of the Phase I cost estimating process is presented in this volume, which is Volume III of the Final Study Report (Phase I).

The Laser Atmospheric Wind Sounder (LAWS) cost modeling activities were initiated in Phase I to establish the ground rules and cost model that would apply to both Phase I and Phase II cost analyses. The primary emphasis in Phase I has been development of a cost model for a LAWS instrument for the Japanese Polar Orbiting Platform (JPOP). However, the Space Station application has also been addressed in this model; elements have been included, where necessary, to account for Space Station unique items. The cost model presented in the following sections defines the framework for all LAWS cost modeling. The model is consistent with currently available detail, and can be extended to account for greater detail as the project definition progresses.

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LIST OF ILLUSTRATIONS

LIST OF ACRONYMS AND ABBREVIATIONS

ASE	Airborne Support Equipment
CER	Cost Estimating Relationship
FRR	Flight Readiness Review
GFE	Government Furnished Equipment
GSE	Ground Support Equipment
JPOP	Japanese Polar Orbiting Platform
LAWS	Laser Atmospheric Wind Sounder
LRR	Launch Readiness Review
PRR	Program Requirements Review
SS	Space Station
WBS	Work Breakdown Structure

SECTION 1. COST ESTIMATING APPROACH, METHODOLOGY AND RATIONALE

This section discusses the estimating methodology used in the LAWS Phase I studies, identifies the Work Breakdown Structure (WBS) elements to which costs will be allocated, and identifies the Cost Estimating Relationships (CERs) and other cost factors used to determine the LAWS Phase C/D estimated costs.

1.1 COST ESTIMATING METHODOLOGY

Estimation of project cost is an evolutionary process which is illustrated in Figure 1. In the early project definition stages (e.g., the LAWS Phase I), there are uncertainties in the estimated cost because neither the hardware nor the programmatics (e.g., documentation deliverables, tasks, etc.) are completely defined. An integral part of the the cost estimating process is, therefore, to reduce the uncertainties as the system definition matures. As illustrated in Figure 1, cost modeling and analysis progress from the use of parametric and "similar to" studies in the early stages of a program to a detailed "bottom-up" analysis as the project definition nears maturity.

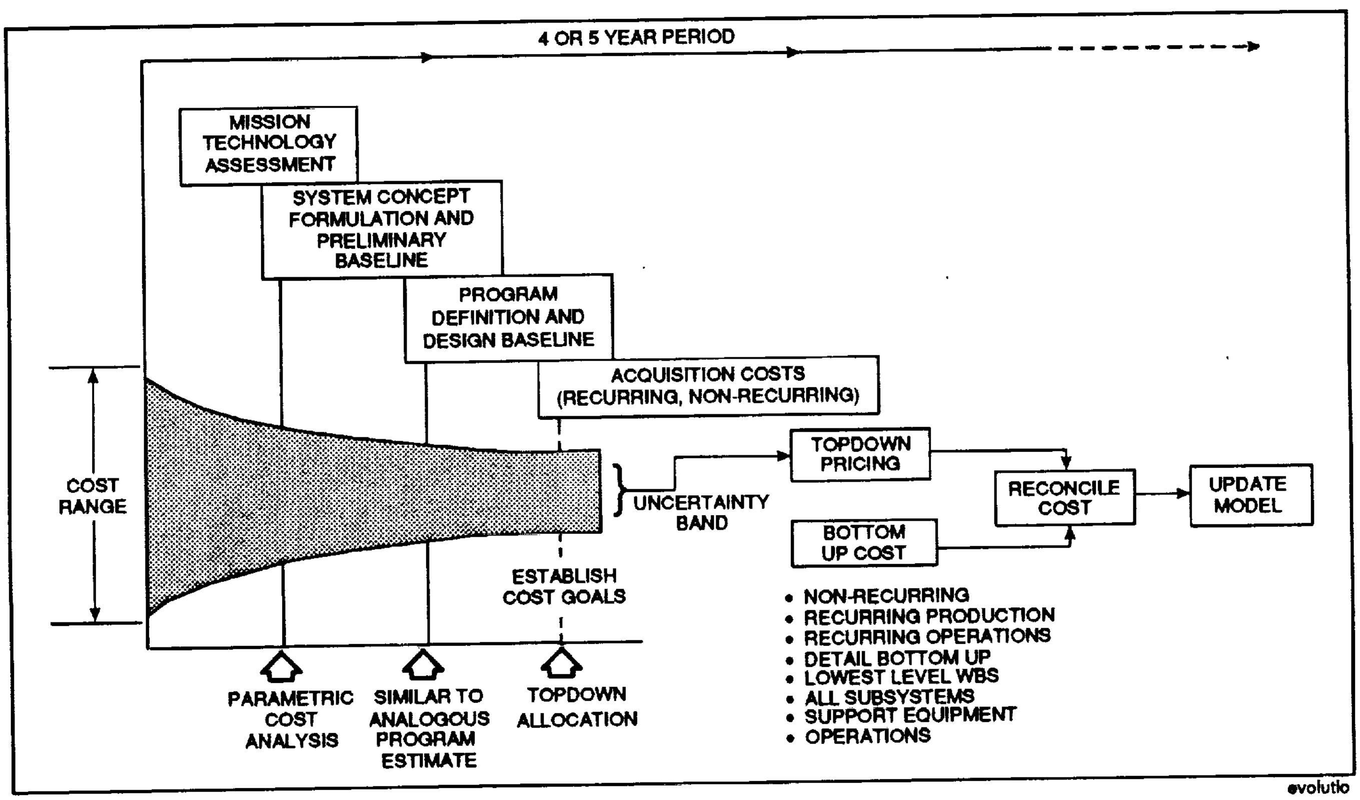

Figure 1. Evolution of Cost with Independent Costing Methods and Reconciliation of Results

Parametric pricing is a methodology used when little precise definition is known about the project elements (i.e., hardware, software, tasks, etc.). The methodology is based on the concept of being able to estimate the cost of a new item by correlating its known characteristics to existing items with similar characteristics. This methodology is employed in the LAWS Phase I studies. The parametric pricing tool used was the RCA-PRICE family of cost models. The correlating parameters in this model include generic class of the item under consideration, physical descriptions and specifications, and reliability factors. These are discussed in more detail below. During Phase II, the cost estimating methodology will be extended to include "similar to" analyses whereby actual costs of hardware/software designed, developed, and used in previous programs will be used to refine and further calibrate the Phase I cost model. Bottom-up costing is the process of determining the costs of lowest level WBS elements and then "rolling" these individual costs up to determine the total project costs. This process of bottom-up cost estimating will be initiated in the latter part of Phase II. However, the bulk of the the bottom-up estimating process will be left to the in-depth analysis required for the Phase C/D proposal.

The cost estimating process described above implies an iteration process in that the cost model is continually being refined as the project definition matures. This process, shown in Figure 2, is an integrated estimating methodology because it starts with requirements from which the system is synthesized and proceeds to an analysis conducted to determine sensitivities and cost drivers. As shown in Figure 2 and previously noted, both parametric and bottom-up pricing models are used. The time each is used depends on the maturity of the system definition. However, the key to this process is that at each iteration the uncertainties decrease rapidly because as the system synthesis matures, differences in the cost model (i.e., parametric and "similar-to") can be reconciled. Cost risks can also be identified and folded into the system synthesis process.

Assumptions and Ground Rules. For the LAWS cost estimating studies, two assumptions have been made. First, the Japanese Polar Orbiting Platform (JPOP) Instrument is the baseline design. Second, the Space Station instrument will be adapted from the JPOP design, with Space Station specific requirements incorporated into the design.

The LAWS cost estimating studies adopted the following ground rules.

1. All costs are estimated in calendar year 1989 dollars.
2. Costs are allocated by WBS elements identified in DR-5, "Draft WBS and WBS Dictionary"

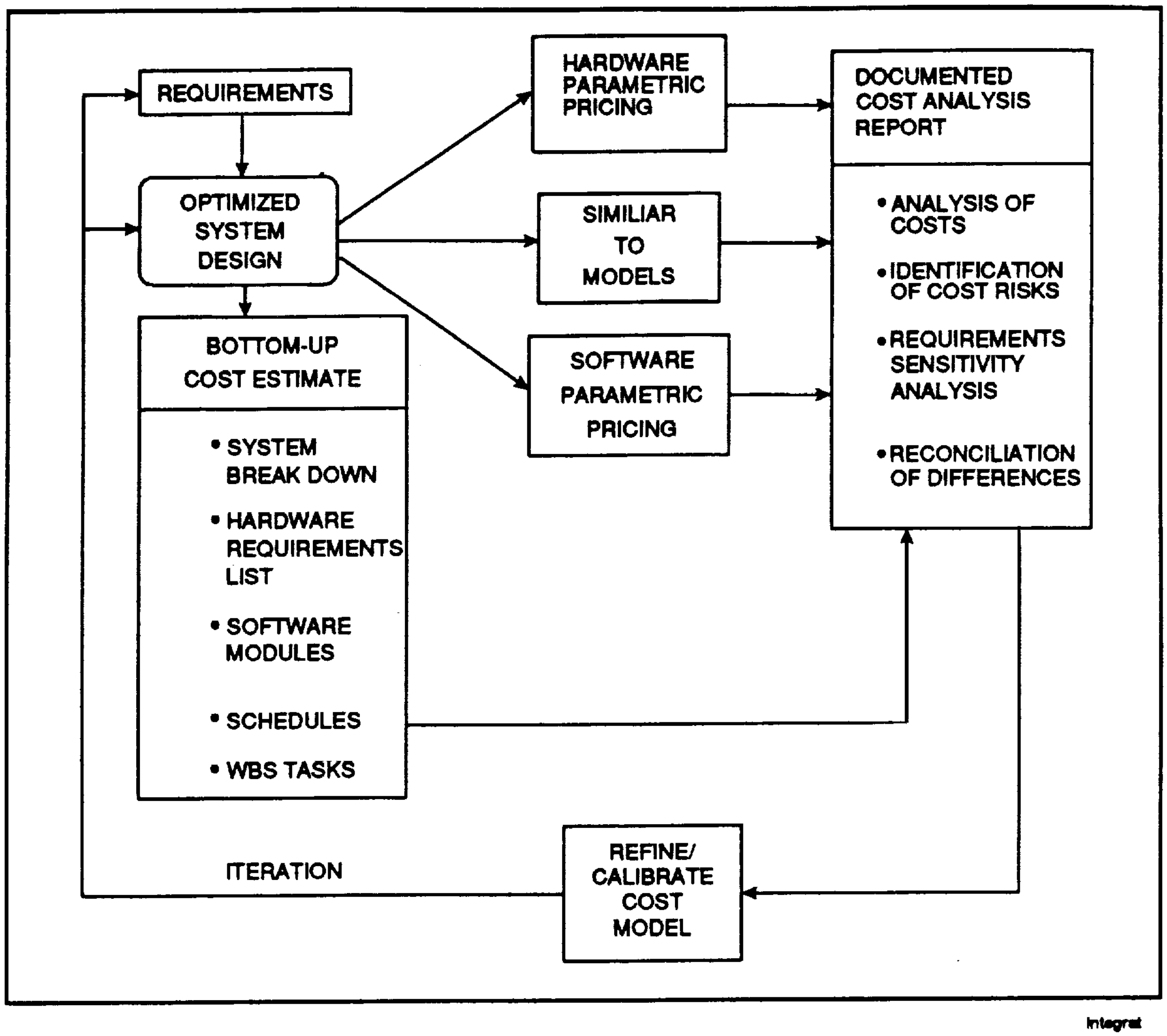

Figure 2. The Integrated Cost Estimating Methodology

3. The LAWS instrument development for the JPOP and Space Station platforms are accomplished in a sequential manner.
4. There will be no orbital servicing of the JPOP.
5. Estimated costs will be audited against historical data at appropriate stages in the LAWS project definition.
6. Schedule and budget will be added where technical risk is incurred and development is needed.
7. All project burdens (i.e., fees etc.) are assumed to be 15 percent of the total project costs.

These assumptions and ground rules apply for both Phase I and Phase II analyses. The RCA-PRICE model is based on a large historical data base for generically similar items. In Phase II "similar to" analyses will begin to compare estimated cost of hardware elements against existing and previous programs. This comparison will assist in calibrating the LAWS cost model parameters and thus reduce uncertainties in the model. Ground rule 6 is a risk reduction measure. For Phase I, risk reduction has been addressed in general by employing a conservative estimating approach. During Phase II, risk analyses are planned to address specific areas identified in Phase I and Phase II studies.

1.2 LAWS PROJECT WBS ELEMENTS

A draft WBS and WBS dictionary for the LAWS Phase C/D project is presented in DR-5, "Draft WBS and WBS Dictionary." The elements of that WBS are presented in Figure 3. The WBS dictionary defines the tasks to be accomplished and thus indicates the allocation of project costs. Tasks associated with these elements are defined to produce the following deliverables:

- One assembled and verified LAWS Instrument flight article
- Data
- Spares
- Systems support equipment
- Software end items.

The WBS presented in Figure 3 is end item oriented for the hardware and software to be produced, services to be performed (e.g., project management, systems engineering, etc.) in producing the end items and data to be submitted to NASA-MSFC during the Phase C/D contract activities. It was prepared to Level II, except for software development and orbital servicing task descriptions. The Software Development WBS Element (2.3.2) has been extended to Level IV to clearly delineate separate end items for the software. These are flight, ground, mission, and simulation software end items. The orbital servicing tasks encompassed in WBS element 2.8 comply with the requirement of the LAWS Statement of Work, dated 15 March 1988 for servicing and maintenance of the LAWS instrument on both the JPOP and the Space Station. Orbital servicing tasks have been extended to Level IV to delineate the various elements required to develop the mission servicing equipment and verify the orbital procedures and/or the equipment developed for servicing the LAWS instrument.

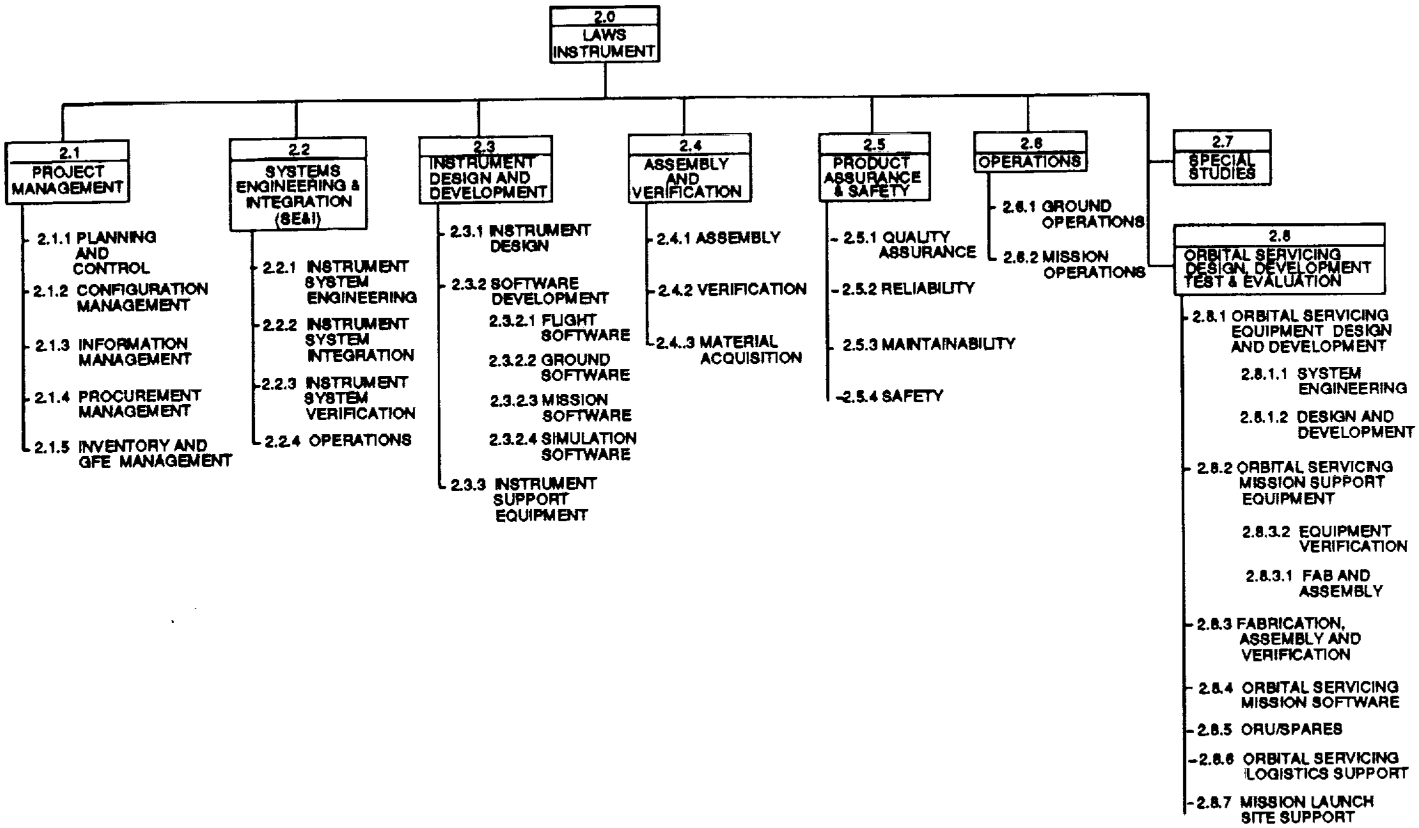

Figure 3. LAWS Project Work Breakdown Structure

The LAWS instrument development effort is divided into eight Level II elements. Collectively these eight elements cover the effort to

- Provide project and technical management
- Derive and maintain system technical and interface requirements and configurations
- Study, analyze, design, and support all flight and ground hardware and software fabrication and testing
- Fabricate, assemble, and verify all flight and ground hardware
- Support all operational aspects of the LAWS flight instrument.

It is important to note the The RCA–Price cost model allocates costs to systems, data, design, and drafting for hardware items. The manufacturing costs include the material, labor to fabricate, and quality control for the item.

For the purposes of the Phase I analyses, it has been assumed that all subsystems are procured. Therefore, the costs allocated to WBS Elements 2.1, 2.2, 2.3, 2.5., and 2.6 are the prime contractor's costs associated with the LAWS Phase C/D systems engineering, development, product assurance, and operations. All hardware acquisition costs are allocated to WBS Element 2.4. Therefore, this element includes the costs for system integration and verification as well as the hardware. Obviously a prime contractor will not procure all subsystems from outside sources in assembled and integrated configurations. Therefore, as the project progresses and the respective hardware components are defined in detail, the cost elements for the subsystems will be segregated and allocated to appropriate WBS elements. Labor costs will be allocated to the appropriate WBS elements, and hardware (flight, GSE, etc.) will be allocated to WBS Element 2.4.

The Level II WBS elements are summarized below to indicate the type of tasks to be accomplished in the LAWS Phase C/D project activities.

WBS Element 2.1, Project Management. This element includes business management (i.e., project planning, performance measurement, and reporting and controls), configuration management, information management, procurement and management of Goverment Furnished Equipment (GFE) items.

WBS Element 2.2, Systems Engineering and Integration. This element includes the performance of all activities necessary to ensure compliance with contractual requirements through the establishment of detailed technical requirements and the use of system specifications to ensure LAWS performance and maintainability. Integration is accomplished through system and interface requirements analysis and definition, system performance and functional analysis and allocations, configuration definition, performance audits, technical performance measurement, system verification, and system operations requirements and planning analysis.

WBS Element 2.3, Instrument Design and Development. This element includes all design and development efforts for the LAWS instrument and required system support equipment. The engineering effort includes optical engineering, laser support, structures and mass properties, electromagnetic compatibility, thermodynamics, environmental compatibility, and electronics engineering. Software development includes all efforts to design, develop, code, integrate, verify/validate, and document the development and maintenance of the software. This element also includes the design and support of all LAWS instrument support equipment to include ground and orbital servicing equipment.

WBS Element 2.4, Instrument Assembly and Verification. This element covers the costs of all efforts to (1) provide manufacturing support to design engineering, (2) plan and control manufacturing operations, (3) fabricate, process, assemble, and check out flight and ground support equipment, (4) construct mockups and test articles, and (5) plan and define test procedures, and perform developmental and environmental verification tests on the flight hardware. The costs of procuring all hardware elements are allocated to this element. This element does not include any costs associated with definition of requirements. It does include all effort to accomplish software integration with the hardware.

WBS Element 2.5, Product Assurance and Safety. This element covers all efforts to establish, implement, and maintain a product assurance and safety program. Product assurance covers quality assurance, reliability, and maintainability. Safety addresses the efforts to establish, implement, and maintain a LAWS safety program which meets project requirements and which complies with the safety program for the transportation system, host platform, and EVA design compatibility for orbital servicing.

WBS Element 2.6, Operations. This element is divided into ground operations and mission operations. Ground operations include planning for and supporting preflight integration into the launch vehicle, logistics, and packaging and shipping. Mission operations cover planning for the mission facilities, training of mission operations personnel, supporting missions operations, and supporting orbital verification.

WBS Element 2.8, Orbital Servicing Space Support Equipment Design and Development. This element includes the system engineering and engineering design efforts to design and develop LAWS orbital space support equipment for servicing the LAWS instrument on the Space Station or the JPOP. It includes ground support of servicing, mockups, and systems development software.

Figure 4 presents the Phase C/D schedule for development of the LAWS instrument orbiting platform. This schedule corresponds to the WBS elements defined above and to the logic chart presented in Volume II of this final report.

1.3 LAWS COST MODEL, REPRESENTATIVE CERs, AND COST FACTORS

This section addresses the development of the LAWS cost model and its application to the cost estimating process by discussing the following topics:

- Cost model elements
- LAWS cost model

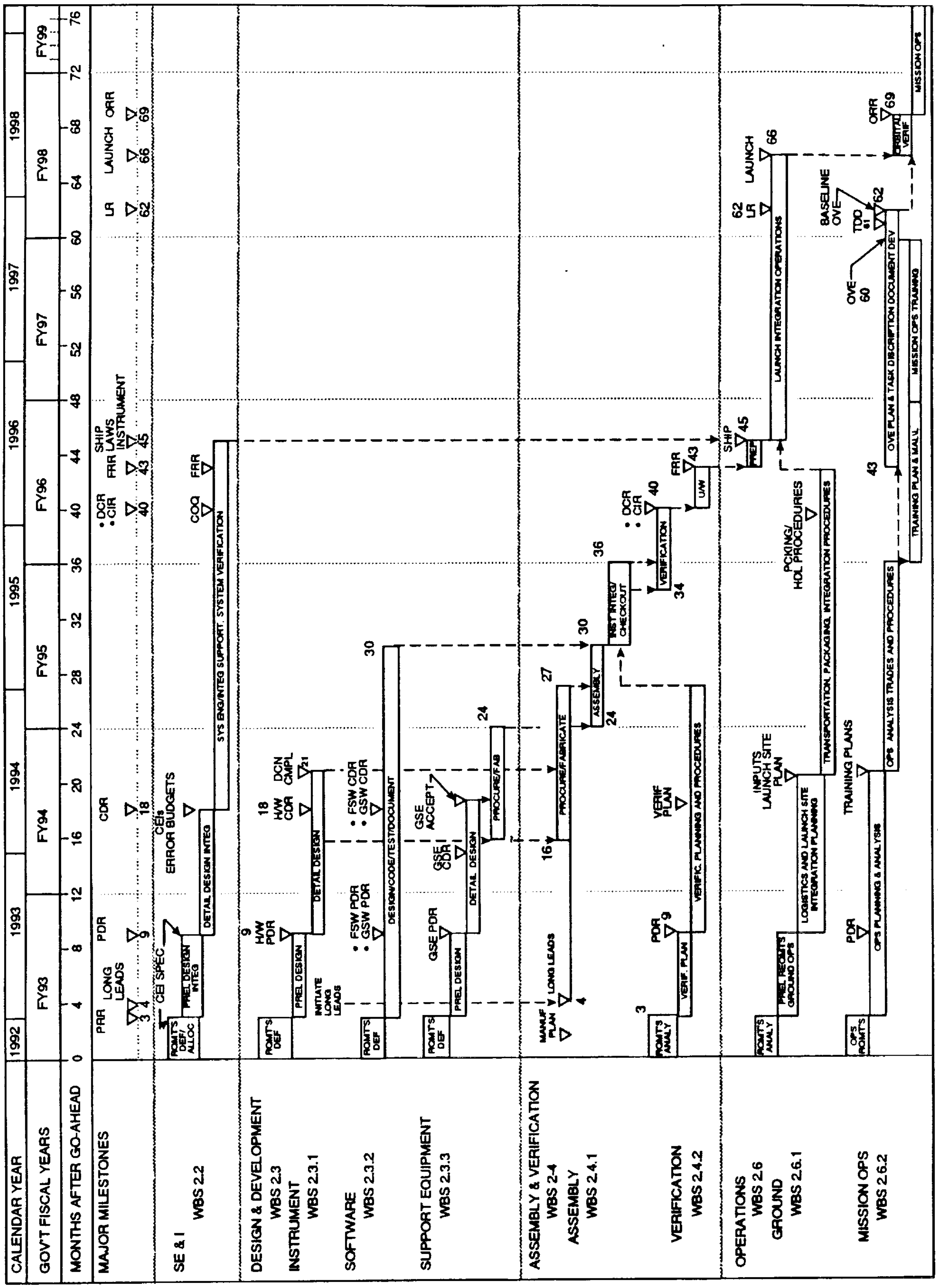

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Figure 4. Preliminary LAWS Master Schedule for JPOP Phase C/D

- CERs and cost factors
- Component cost modeling.

The discussion of cost model elements identifies the categories used to develop the cost estimates. These categories cover the entire project costs. The LAWS cost model details the physical model used to develop the individual costs. The CER and cost factor discussion explains what is included in the CERs and cost factors and how they were computed. The component cost modeling topic describes the application of the cost model to the component level.

Cost Model Elements. The primary cost elements for both the JPOP and the Space Station applications are

- Design and development
- Launch vehicle integration and support
- Flight operations and support.

These elements are illustrated in Figure 5 and apply to development of both the JPOP and the Space Station. Design and development includes all costs required to design, fabricate, verify, and plan for the flight hardware and system support equipment, and the cost to provide all software. The LAWS instrument flight hardware consists of the following six subsystems:

1. Laser
2. Optical
3. Command, Communication, and Control
4. Receiver/Processor
5. Electrical Power Distribution
6. Mechanical Support Structure.

Each subsystem is further divided into the assemblies and components identified in Figure 5. There is also a subelement labeled "other" in each subsystem which accounts for additional items that may later be added to that subsystem as the design synthesis matures. The basis for the subelement "other" is a distribution of the system weight contingency. For the current analysis, a cost has been assigned to each item labeled "other." The method for cost allocation to the category "other" is described below.

The associated labor for system design, integration, verification, and operations support of the hardware is identified as Item 9 in Figure 5, System Design, Integration and

I. DESIGN AND DEVELOPMENT

1. LASER SUBSYSTEM, WBS 2.4.3.1.1
   - TRANSMITTER
   - OTHER
2. OPTICAL SUBSYSTEM, WBS 2.4.3.1.2
   - TELESCOPE
   - BEAM SCANNER
   - INTERFEROMETER
   - LOCAL OSCILLATOR ASSEMBLY
   - LOCAL OPTICAL BENCH
   - OTHER
3. CMD, COMM, CTRL, WBS 2.4.3.1.3
   - FLIGHT COMPUTER
   - OTHER
4. RECEIVER/PROCESSOR SUBSYSTEM, WBS 2.4.3.1.4
   - IR DETECTOR ASSEMBLY
   - CRYOGENIC ASSEMBLY
   - RECEIVER ELECTRONICS
   - OTHER
5. ELECTRICAL POWER SUBSTATION, WBS 2.4.3.1.5
   - POWER DIST NETWORK
   - POWER COND ELECTRONICS
   - OTHER
6. MECHANICAL SUPPORT SUBSYSTEM, WBS 2.4.3.1.6
   - INSTRUMENT OPTICAL BENCH
   - THERMAL CONTROL SYSTEM
   - OTHER
7. SPARES, WBS 2.4.3.4
8. SYSTEM SUPPORT EQUIPMENT, WBS 2.4.3.2
   a. GROUND SUPPORT EQUIPMENT
      - MECHANICAL
      - ELECTRICAL

   b. AIRBORNE SUPPORT EQUIPMENT
9. SYSTEM DESIGN, INTEGRATION & TEST, WBS 2.1 - 2.8
   a. SYSTEM ENGINEERING
   b. INSTRUMENT ENGINEERING
   c. ASSEMBLY AND VERIFICATION
   d. PRODUCT ASSURANCE AND SAFETY
   e. OPERATIONS/LOGISTICS
   f. PROJECT MANAGEMENT
   g. SOFTWARE DEVELOPMENT FLIGHT, SIMULATION, GROUND

II. LAUNCH INTEGRATION, WBS 2.6.1.3

III. PROTOTYPE MISSION OPERATIONS, WBS 2.6.2.3

COSTELEM

Figure 5. LAWS Instrument Cost Elements

Test. As indicated, software development includes flight, simulation, and system support. The flight software resides in the flight article and is used for command, communication, and control purposes. Simulation software is any software module used for training, design/evaluation, or support of mission operations. Activities included in the respective labor elements of Item 9 (i.e., a through g) are identified below:

a. System Engineering - System engineering, integration and verification
b. Instrument Engineering - Design, analysis, drawing preparation, test support
c. Assembly and Verification - Procurement, fabrication, assembly and checkout, test planning and conduct
d. Product Assurance and Safety - Quality engineering, reliability engineering, maintainability engineering, and safety engineering
e. Operations/Logistics - Ground and mission operations
f. Project Management - Project planning and implementation, financial reporting, configuration management, and documentation.
g. Software Development - Flight, simulation, and ground test.

Ground operations, as identified in Item 9.e, include all activities associated with planning for the logistics and shipping of the flight article and ground support equipment (GSE), and planning for launch integration. Mission operations address the cost of the prime contractor's mission planning and support activities. The above items are further addressed in Section 1.2 of this volume and in DR-5, "Draft WBS and WBS Dictionary."

Spares will support development and flight operations. Spare utilization in development includes replacement due to breakage (e.g., in the unlikely event a telescope mirror is broken) and failed components.

As indicated in Figure 5, the cost element system support equipment is divided into GSE and airborne support equipment (ASE). Ground support equipment is further divided into mechanical and electrical categories. Mechanical support equipment includes items such as jigs, fixtures, dollies, mockups, optical alignment benches, and shipping containers. This list is not inclusive, but indicates the principal items that constitute mechanical support equipment. Electrical support equipment includes anything used to check out the flight hardware article. This equipment can range from specialized black boxes to general purpose computers. The Phase I analysis assumed there would be no airborne support equipment for the JPOP. This element has been included primarily to account for the airborne support equipment required for Space Station applications.

Category II is the cost of the prime contractor's activities to support flight article processing through the launch site and integration into the launch vehicle. Category III is the cost of the prime contractor's activities required to support orbital verification and evaluation of instrument performance.

The elements described above are used to identify the project costs and allocate costs to the respective WBS elements. The cost models for these elements are described below. These elements are not to be confused with the WBS elements described in Section 1.2. The WBS elements are used to allocate and collect costs during the contract implementation.

LAWS Cost Model. The LAWS Phase I cost model utilized the RCA-PRICE family of cost models, other vendor cost models as appropriate, and CERs derived by Lockheed. An Itek estimating relationship was used for the telescope, and a Lockheed-generated CER was used for the detector assembly identified in the Receiver/Processor Subsystem (Item 4 of Category I in Figure 5). The RCA-PRICE cost model was used for estimating the design, development and fabrication of the remaining components that constitute the six subsystems listed under Category I of Figure 5. The WBS elements to which the respective costs are allocated is also indicated. Program wrap CERs were developed by Lockheed to estimate costs not included in the Itek or RCA-PRICE models.

The RCA-Price input categories are:

1. Generic class of equipment
2. Physical descriptors
3. Specification and reliability factors
4. Quantities
5. Performance schedules
6. Year of the technology.

The physical descriptors include weight, characteristics of a given item in terms of the percentage distribution of its mechanical and electrical weight, manufacturing complexities (electrical and mechanical), amount of new design required to produce the item, and a parameter entitled "Platform." Secondary factors affecting the cost are assumed to be volume of the item, integration complexities, design repeat, and engineering complexity. The amount of new design for each item is an indication of the number of new drawings required for manufacturing the item. The parameter platform describes the specification level to which the item is designed and manufactured, the operating environment to which it is designed to comply with, and the reliability requirements associated with that environment.

Both the RCA-PRICE and Itek cost models estimate the cost to design, fabricate, and check out a given item. The individual cost elements for each item are drafting, design, systems analyses, project management, data, and production. The item production includes the cost of fabrication and materials for the items. For the production estimate, the RCA-PRICE global defaults were used for the production cost estimator. This default assumes the manufacturing to be 50 percent and the material to be 50 percent of the production costs. Quality control cost for the individual item is also included in both models. The cost of quality control for system integration is included in the product assurance and safety element discussed in the next paragraph.

CERs and Cost Factors. Design at the system level, project management at the system level, system integration, and test for operation were accounted for by the program wrap CERs mentioned above. These CERs were used to compute the following cost elements:

1. System engineering
2. Instrument engineering
3. Assembly and verification
4. Product assurance and safety
5. Operations/logistics
6. Project management
7. Spares
8. GSE.

Travel is included in each CER. The assembly and verification CER includes utilization of privately owned test facilities. It does not include the construction of any LAWS unique facilities. Current analysis does not indicate a requirement for LAWS unique facilities. The operations/logistics CER includes shipping.

LAWS program wrap CERs were computed as a function of the total subsystem costs. Launch integration and mission operations support are estimated values at this stage of the analysis. Spares were estimated as a function of the total subsystem.

RCA-PRICE default values were used for all "GLOBALS" in the model. The year of economics was input as 1989. The year of technology was assumed to be 1992. For purposes of the current analysis, the RCA-PRICE model computed the development schedule.

Component Cost Model. The LAWS input values for the subsystem weights are presented in Figure 6. Mechanical and electrical percent distributions are presented in Figure 7. The weights identified in Figure 6 are the current allocations for the respective subsystems. Since the LAWS subsystem synthesis at this stage of the project definition is an iterative process with respect to the hardware definitions, the RCA-PRICE model was used as described below.

For each subsystem identified in Figure 7, RCA-PRICE cost data was generated for a representative schedule of weights about the nominal weight allocation for each. CERs as a function of weight were then generated for each subsystem or components within the respective subsystems. The elements labeled "other" in Figure 3 were assumed to be representative of that subsystem. The cost for each subsystem element label "other" was then computed by first determining from the RCA-PRICE results the cost per pound to manufacture that class of hardware. A "wrap" factor considered representative of the programatics was then applied to the cost per pound multiplied by

WBS	ITEM DESCRIPTION	WEIGHT (kg)
2.4.3.1.1	LASER SUBSYSTEM	
	TRANSMITTER	171.00
	OTHER	14.27
		185.27
2.4.3.1.2	OPTICAL SUBSYSTEM	
	TELESCOPE ASSEMBLY	107.00
	BEAM SCANNER ASSEMBLY	67.00
	INTERFEROMETER/BENCH	41.00
	LOCAL OSCILLATOR ASSEMBLY	2.30
	STAR TRACKER	20.00
	OTHER	14.27
		251.57
2.4.3.1.3	COMMAND, COMMUNICATION CONTROL SUBSYSTEM	
	FLIGHT COMPUTER	18.10
	OTHER	14.27
		32.37
2.4.3.1.4	RECEIVER/PROCESSOR SUBSYSTEM	
	DETECTOR ASSEMBLY	.45
	COOLING ASSEMBLY	8.40
	RECEIVER ELECTRONICS	6.80
	OTHER	28.53
		44.18
2.4.3.1.5	ELECTRICAL POWER SUBSYSTEM	
	WIRING HARNESS	18.10
	POWER CONDITIONING ELECTRONICS	4.56
	OTHER	28.53
		51.13
2.4.3.1.6	MECHANICAL SUPPORT SUBSYSTEM	
	INSTRUMENT OPTICAL BENCH	102.00
	THERMAL CONTROL SYSTEM	90.70
	OTHER	42.80
		235.50
	TOTAL ALLOCATED WEIGHT	800

Figure 6. LAWS Instrument Weight Allocations

SUBSYSTEM	WT. DISTRIBUTION		MFG COMPLEXITY		NEW DESIGN		PLATFORM
	ELECT	MECH	ELECT	MECH	ELECT	MECH	
LASER	5%	95%	9.8	9.5	25%	100%	2.0
OPTICAL							2.0
BEAM SCANNER	0	100%	9.31	7.4	100%	100%	
INTERFEROMETER	0	100%	—	7.5	0	100%	
OSCILLATOR	20%	80%	5.3	9.4	0	0	
CMD,COMM,CTRL	10%	90%	9.94	6.5	50%	25%	2.0
RECEIVER/PROCESSOR							2.0
ELECTRONICS	20%	80%	9.0	5.3	25%	25%	
COOLER	14%	86%	5.3	6.75	0	0	
EPS	5%	95%	7.53	5.3	75%	100%	2.0
SUPPORT STRUCTURE	0%	100%	—	7.0	0%	100%	2.0

pricein

Figure 7. Parametric Pricing Input Data for RCA-Price Cost Model

the weight allocated to the element to determine the estimated cost. The "wrap" factor accounts for the same elements as the RCA-PRICE model (i.e., data, design, systems, etc.).

For the LAWS JPOP application, the manufacturing complexities and the platform parameters were assumed to be representative of unmanned space applications. Values used were, in general, those recommended by the RCA-PRICE input manual. A platform parameter input value of 2.0 was used for all components (see Figure 7). The electrical manufacturing complexity of 9.94 used for the command, communication and control subsystem is considered mid-range and the electrical density factor is 0.689.

The electrical manufacturing complexity of 9.0 used for the receiver/processor electronics is also considered mid-range. The mechanical complexity for the electrical power subsystem is representative of hermetically sealed connectors and cabling.

The category "new design" is a measure of the number of new drawings required to produce an item. For the LAWS applications, it was assumed that virtually all new drawings will be required for the laser, optical, electrical power, and mechanical support subsystems. The command, communications, and control and the receiver/process subsystems will consist of processing equipment, detectors, receivers, cooling devices, etc. It was assumed that components for these subsystems will be procured largely as "off-the-shelf" assemblies with minimal modifications and/or new drawings required for production.

The laser costs were estimated in two different ways. Costs were estimated first by using the laser cost estimator incorporated in RCA-PRICE and second by modeling the respective major assemblies for each laser. To model the individual lasers, the cost models for each were developed in the following manner. The pre-ionized, pulsed sustained laser was treated as two major assemblies, a transmitter and a pulse forming network. The electron beam laser was treated as an integral unit. For each laser, a part/subassembly count was made and manufacturing complexities computed from the following input parameters:

1. Machining precision required
2. Machinability index
3. Maturity factor
4. Number of assemblies to be machined and integrated
5. Platform factor.

For Item 1 a value of .001 was used. A value of 50 was used for Item 2 which indicates considerable sheeting, plating, and tubing to work with. For Item 3 a value of 2.5 was used, which indicates considerable manual fabrication and some mechanized cutting and robotics. The anticipated part count for each assembly was used as the input for Item 4. A space level complexity factor was used for Item 5. The RCA-PRICE laser estimator gave a slightly higher cost estimate than either of the two individual models. This is the value accepted for the current analysis because both lasers are new designs, and the higher value was used for risk consideration measures.

The optical subsystem cost model was described by the subelements identified in Figure 5. A reasonableness test for the telescope cost estimated by the Itek CER was made by comparing it with the RCA-PRICE optical model. The interferometer and optical bench were modeled as an integral unit. The local oscillator assembly was assumed to be a secondary laser which was modeled by the laser cost model of the RCA-PRICE. This is a low-power laser that is considered to be an off-the-shelf assembly. Therefore no new drawings (i.e., no additional design) are required to fabricate the laser assembly. The interferometer was considered to be an all new design in the sense that a complete assembly drawing package must be prepared for the mirror arrangement and for integration of the mirror and mounts to the interferometer optical bench.

The receiver/process subsystem was modeled as a detector assembly, a cooler, and signal processing electronics. The detector cost estimator was developed using commercial cost data for a detector similar to that anticipated for the LAWS application and applying a wrap to account for modifications and hardening that will probably be required for the LAWS instrument. The cooler was parametrically modeled with the RCA–PRICE cost model using an off-the-shelf assembly that is adequate for the LAWS application. The receiver electronics is assumed to be essentially an array processor and was modeled accordingly.

The electrical power distribution subsystem encompasses the wiring harness and power conditioning equipment. These were modeled parametrically with the RCA–PRICE model using input values typical of cabling and hermetically sealed connectors.

A very preliminary analysis of the software effort was conducted using a COCOMO model which considers the number of functions required to be implemented by the software and the associated complexities. Indications are that approximately 20,000 lines of deliverable source instructions will be required for the flight hardware. It was assumed the flight software would be coded in the ADA high–order language. All complexities factors considered by the estimator were input as "AVERAGE" except for a parameter labeled "PROCESSING COMPLEXITIES," which was input as "SIGNIFICANT".

There was not sufficient information available in the Phase I analysis to realistically estimate the cost for GSE, mission, and simulation software. The estimating procedure for these software elements was to add a delta value to the order of magnitude analysis conducted for the flight hardware and show all software estimates as one value for the purposes of Phase I. It is assumed the GSE or simulation software will be developed under the same structured programming guidelines but will be documented and tested. Chart 6 in Section 2 alludes to separate software packages for JPOP and Space Station by indicating separate costs for each. The assumption was made that the software for both would be developed simultaneously as one integral software package or that, at a minimum, so called "software hooks" required for the Space Station application would be incorporated in the initial software development. A major risk in software development is modifying existing operational software, and avoiding this risk was the rationale of this assumption. The Space Station software will probably include additional functions required for deactivation, safing, and more complex communication to the platform and graceful failure mode operations.

SECTION 2. SUMMARY COST PRESENTATIONS

This section summarizes the the LAWS Phase I cost modeling and analysis activities in a series of charts presented in viewgraph format suitable for presentation. This presentation includes forward facing text for each chart. The material in Charts 1 through 14 indicates the project WBS, schedule, and LAWS cost elements. The presentation concludes with the parametric cost input data (Chart 5) and the Phase C/D cost estimates (Chart 6). Chart 6 presents the cost estimates for both the JPOP and the Space Station instruments. Subsystem costs were estimated at the component/assembly level and "rolled up" to the appropriate subsystem level. The same procedure was used for the system integration wraps used to generate the cost estimates for WBS Elements 2.1 through 2.7. This procedure is consistent with definitions currently available and the uncertainties that exists in the cost estimates.

The expected value for the JPOP instrument is $168.1M. With uncertainties considered, the cost estimate is expected to be between $155M and $181M, which is within the 15 to 20% estimating accuracy normally accepted for this type of estimate. The primary contributions to the uncertainties are weight, manufacturing complexities, and the "Platform" factor discussed previously. The uncertainties were estimated by considering an expected error in the above parameters and then computing the associated cost impact. These uncertainties represent a contingency to account for unknowns in the program and in hardware and software definitions. The uncertainty contributions were assumed to behave as a normal error distribution.

PROGRAM DEFINITION

AND

COST MODELING

LEADFRME

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LAWS PROGRAM DEFINITION PROCESS

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WHAT IS THE END PRODUCT?

DELIVERABLES

HARDWARE
- LAWS INSTRUMENT
- SPARES
- SSE

SOFTWARE

DOCUMENTATION

WHAT ARE THE WICKETS WE HAVE TO GO THROUGH?

MILESTONES

GOVERNING DOCUMENTS

- ACCOMMODATIONS
  - NSTS-07700, V14
  - JPOP - TBD
- LAUNCH INTEGRATION
  - ICD 2-19001
  - H-2 - TBD
- SAFETY
  - JA-418
  - MMI 1700.18
- NASA/MSFC 8010.5
- OTHER

WHAT FUNCTIONS WILL BE REQUIRED?

ORGANIZATION
- TESTING
- DESIGN
- ETC

WHAT TASKS WILL BE REQUIRED?

WBS

WHEN WILL IT BE DONE?

SCHEDULE
- TIER 1
- TIER 2
- TIER 3

CHART 1

PROGDEFN

LAWS
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LAWS LEVEL 2 WBS

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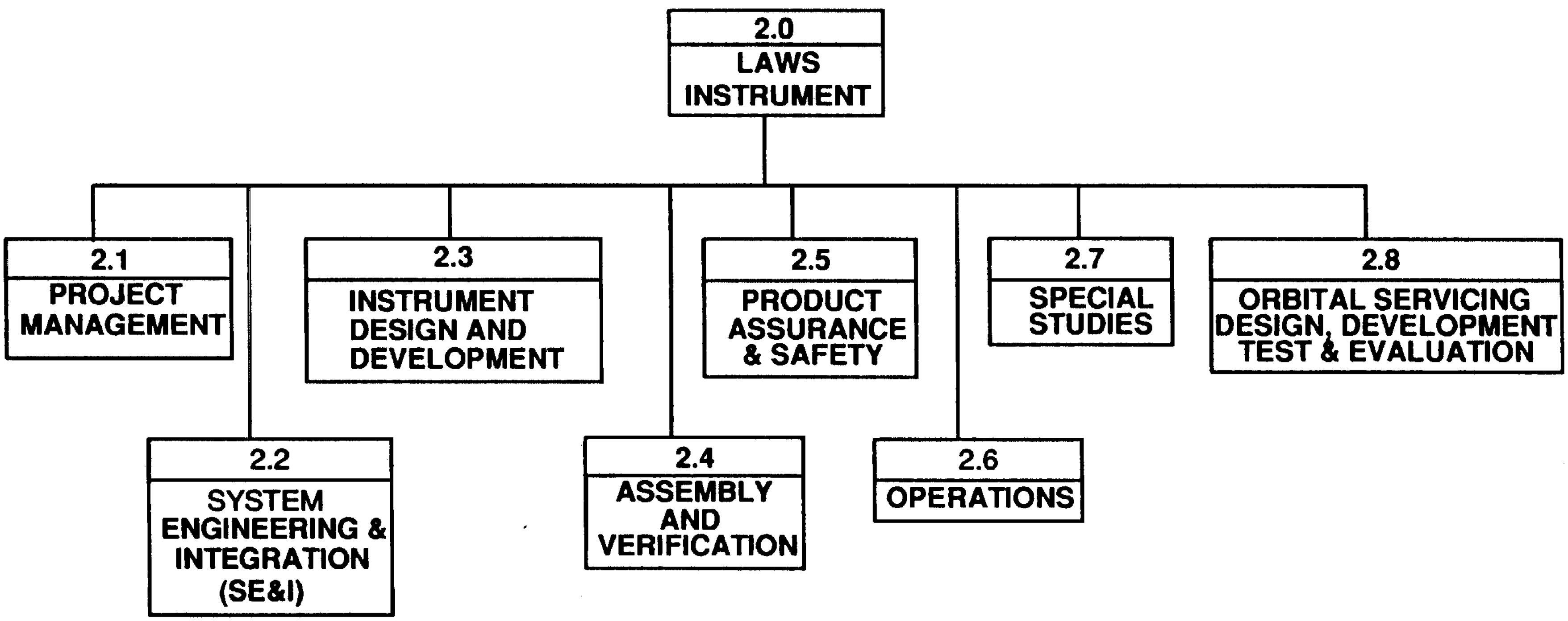
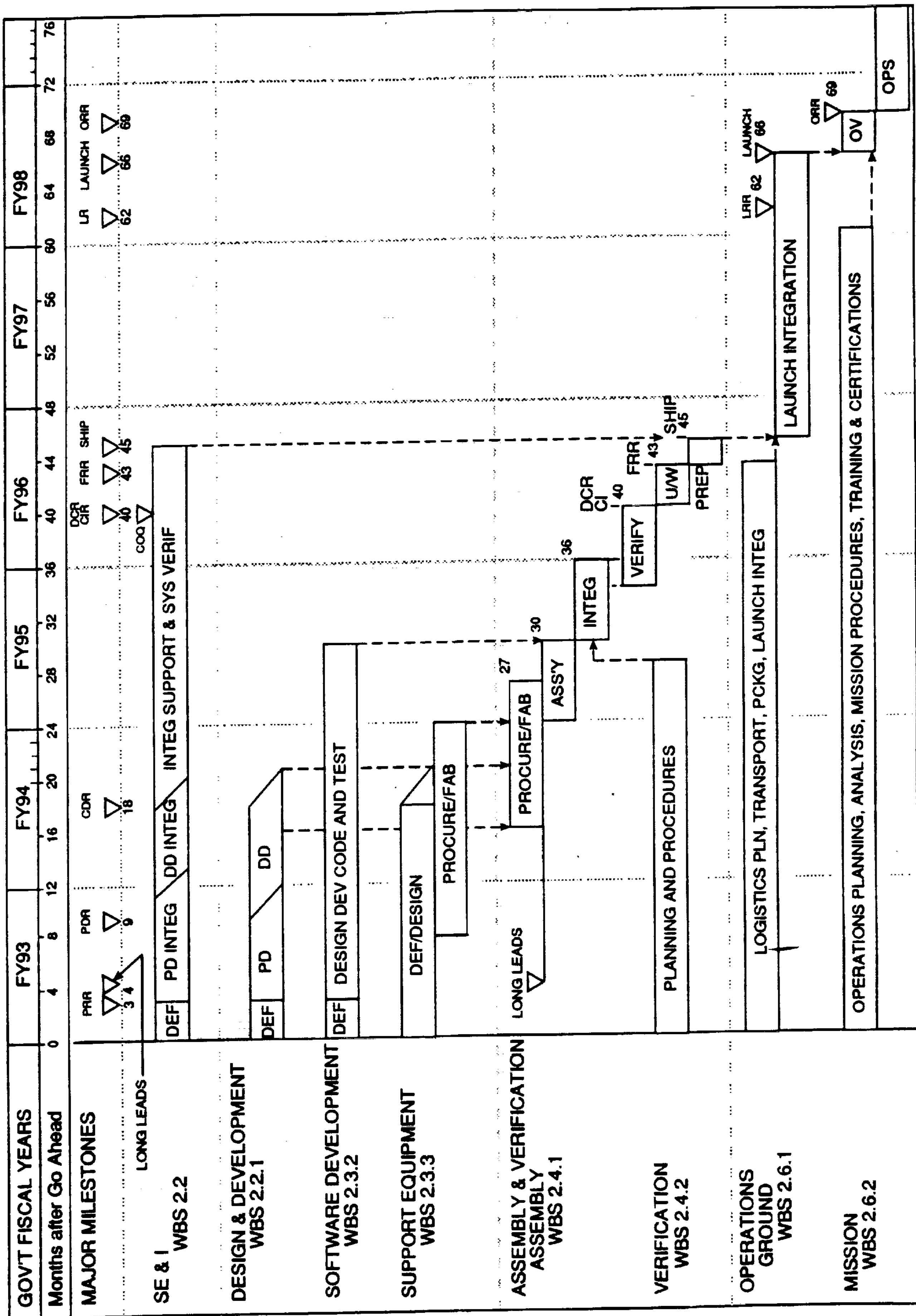


CHART 2

LAWSLV2

CHART 3

LAWS PHASE C/D SCHEDULE



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LAWS DEVELOPMENT COST ELEMENTS

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I. DESIGN AND DEVELOPMENT

- LASER SUBSYSTEM
  - TRANSMITTER
  - OTHER
- OPTICAL SUBSYSTEM
  - TELESCOPE
  - BEAM SCANNER
  - INTERFEROMETER
  - LOCAL OSCILLATOR ASSEMBLY
  - LOCAL OPTICAL BENCH
  - OTHER
- COMMAND, COMMUNICATION, CONTROL
  - FLIGHT COMPUTER
  - OTHER
- RECEIVER/PROCESSOR SUBSYSTEM
  - IR DETECTOR ASSEMBLY
  - CRYOGENIC ASSEMBLY
  - RECEIVER ELECTRONICS
  - OTHER
- ELECTRICAL POWER DISTRIBUTION
  - POWER DIST NETWORK
  - POWER COND ELECTRONICS
  - OTHER
- MECHANICAL SUPPORT STRUCTURE
  - INSTRUMENT OPTICAL BENCH
  - THERMAL CONTROL SYSTEM
  - OTHER
- SPARES
- GROUND SUPPORT EQUIPMENT
  - MECHANICAL
  - ELECTRICAL
- SYSTEM DESIGN, INTEGRATION & TEST
  - SYSTEM ENGINEERING
  - INSTRUMENT ENGINEERING
  - ASSEMBLY AND VERIFICATION
  - PRODUCT ASSURANCE AND SAFETY
  - OPERATIONS/LOGISTICS
  - PROJECT MANAGEMENT
  - SOFTWARE DEVELOPMENT
    FLIGHT, SIMULATION, GROUND

II. LAUNCH INTEGRATION

III. PROTOTYPE MISSION OPERATIONS

CHART 4

DEVCOSEL

LAWS
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PARAMETRIC PRICING INPUT-RCA PRICE MODEL NOMINAL VALUES

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SUBSYSTEM	WT. DISTRIBUTION		MFG COMPLEXITY		NEW DESIGN		PLATFORM
	ELECT	MECH	ELECT	MECH	ELECT	MECH	
LASER	5%	95%	9.8	9.5	25%	100%	2.0
OPTICAL [2]							
BEAM SCANNER	0	100%	9.31	7.4	100%	100% [3]	2.0
INTERFEROMETER	0	100%	-	7.5	0	100%	
OSCILLATOR	20%	80%	5.3	9.4	0	0	
CMD,COMM,CTRL	10%	90%	9.94 [4]	6.5	50%	25%	2.0
RECEIVER/PROCESSOR							
ELECTRONICS	20%	80%	9.0	5.3	25%	25%	2.0
COOLER	14%	86%	5.3	6.75	0	0	
EPS	5%	95%	7.53	5.3	75%	100%	2.0
SUPPORT STRUCTURE	0%	100%	—	7.0	0%	100%	2.0

NOTE: (1) APPLIES TO JPOP OR PROTOTYPE DEVELOPMENT.
(2) APPLIES TO INTERFEROMETER, BEAM SCANNER AND BENCH.
(3) CONSERVATIVE ESTIMATE.
(4) ELECTRICAL DENSITY = 0.689.

CHART 5

para

LAWS
NASA\MSFC

JPOP AND SPACE STATION DEVELOPMENT COST

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WBS ELEMENT	COST ELEMENT	JPOP INSTRUMENT		SPACE STATION		SPACE STATION & JPOP
		SUBTOTAL $M	TOTAL $M	SUBTOTAL $M	TOTAL $M	TOTAL $M
2.4.3.1.1	LASER SUBSYSTEM	36.5		19.6		
2.4.3.1.2	OPTICAL SUBSYSTEM	27.8		8.8		
2.4.3.1.3	CMD, COMM, CTRL	2.8		.9		
2.4.3.1.4	RECEIVER/PROCESSOR	3.8		2.7		
2.4.3.1.5	ELECT PWR DIST	3.7		1.0		
2.4.3.1.6	MECH STRUCTURE	10.8	85.4	2.3	35.3	120.7
2.4.3.4	SPARES	17.1		3.5		
2.4.3.2	GSE	6.8	23.9	0.7	4.2	28.1
see note	SYS DES, INT & TEST	27.9		5.9		
2.3.2	SOFTWARE	3.0	30.9	1.0	6.9	37.8
2.6.1.3	LAUNCH INTEGRATION	3.0		1.5		
2.6.2.3	OPERATION & SUPPORT	3.0	6.0	3.0	4.5	10.5
2.8	ORBITAL SERVICING			14.8	14.8	14.8
	FEE/BURDENS	21.9	21.9	9.8	9.8	31.7
2.0	TOTAL PROJECT	EXPECTED: 168.1 LOW: 154.9 HIGH: 181.4			75.5	243.6

NOTE: includes 2.1 - 2.7

PRCOSEST

CHART 6

SECTION 3. FUNDING PROFILES AND EXPENDITURES DATA

Figure 8 displays the funding curve and the expenditures for the activities associated with the LAWS instrument development for the JPOP. Funding profiles are based on 1989 dollars. The profiles represent the time phasing of the cost model results presented in Chart 6 of Section 2. The top profile of Figure 8 depicts the cumulative project cost. The bottom profile represents the project wrap activities and includes labor, travel, launch integration, and mission operations support activities and other direct costs. These are Items II and III from Figure 5. For Phase I analysis it has been assumed that common PDRs and CDRs will be held for the flight hardware and software and for the GSE hardware and software.

The middle profile is presented in bar chart format because it represents the commitment to procure the hardware items. Phase I analysis indicates that the laser and telescope are long lead items. The commitment for these is shown at month four. The second commitment of hardware acquisition funds is expected to occur shortly before

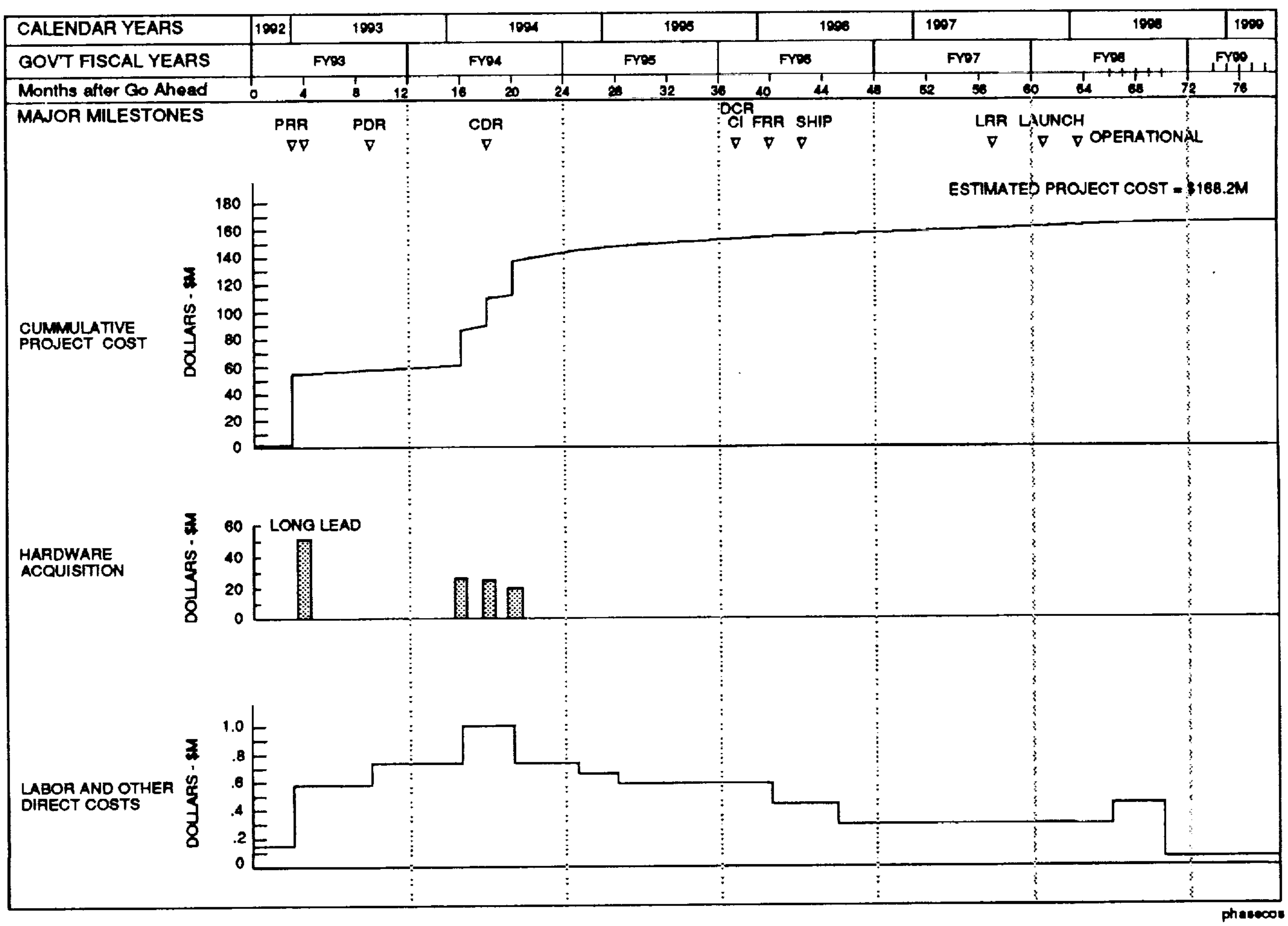

Figure 8. Projected Funding Profiles for LAWS Phase C/D to Develop the JPOP Configuration

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the flight hardware CDR as drawings and specifications are released for the procurement and fabrication process. The second and fourth commitments of hardware acquisition occur as the final drawings are released after CDR. It should be remembered from previous discussions that the assumption has been made for Phase I analysis purposes that all subsystems are procured from outside sources. In reality there are some prime contractor labor and other direct costs associated with the subsystem cost allocations. These will be redistributed to proper WBS cost elements and the funding profiles adjusted once the subsystem components are defined.

SECTION 4. CONCLUSIONS AND FUTURE WORK

A cost model has been developed to estimate the cost of delivering LAWS instruments for the JPOP and Space Station platforms. The fidelity of the model is consistent with the hardware and programatic definitions currently available. The basis for the LAWS cost model is the RCA–PRICE family of parametric models and CERs developed by Lockheed that are based on previous experience. Reasonable results have been produced with the model presented.

During Phase II, the fidelity of the LAWS cost model will be improved by refining the parametric pricing input data. Specifically analysis will be directed toward acquiring more knowledge for

- Manufacturing complexities associated with a LAWS type instrument
- Weight estimates
- Platform parameter
- The design maturity of the instrument components.

Software estimates will be extended to include GSE and simulation and mission related software. It is recommended that the software for both the JPOP and Space Station platforms be developed simultaneously.

The laser is a developmental item and considered to be the only instrument component to represent any significant risk to the project. The risk mitigation for this item is the implementation of a "breadboard" activity which addresses the risk items associated with the laser. The cost analysis of Phase II will address the laser risk by conducting sensitivity analyses which examine cost impact to the Phase C/D effort.