LMSC-HSV TR F320789-I

Phase II
Design Definition of the

Laser Atmospheric Wind Sounder (LAWS)

Contract NAS8-37590

DR-20
Vol. I: EXECUTIVE SUMMARY

June 1992

Prepared for

GEORGE C. MARSHALL SPACE FLIGHT CENTER
MARSHALL SPACE FLIGHT CENTER, AL 35812

Lockheed
Missiles & Space Company
4800 Bradford Blvd., Huntsville, AL 35807

DR-20

PHASE II

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CONTRACT NAS8-37590

Prepared for
National Aeronautics and Space Administration
George C. Marshall Space Flight Center (MSFC)
Marshall Space Flight Center, Alabama 35812

Approved by W. E. Jones
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LAWS Program Manager

Date 6/30/92

Submitted by

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FOREWORD

This report presents the final results of the 21-month Phase II Design Definition and 18-month laser breadboard efforts 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, and R.M. Baggett, LAWS Instrument Project Office, JA92. The period of performance was 24 August 1990 to 30 June 1992. Subcontractors contributing to this effort are Textron Defense Systems - Everett, and Itek Optical Systems.

The complete Phase II Final Report consists of the following three volumes:

Volume I	Executive Summary
Volume II	Final Report
Volume III	Program Costs.

This volume, Executive Summary, reviews all activities completed during the LAWS Phase II effort and summarizes results, methodologies, trade studies, recommended approaches, and design analyses.

CONTENTS

ILLUSTRATIONS

ILLUSTRATIONS (cont)

TABLES

ACRONYMS AND ABBREVIATIONS

A/D	analog-to-digital
ADP	acceptance data package
AGC	automated gain control
ARTS	automated requirements traceability system
ASE	airborne support equipment
BDU	bus data unit
BW	bandwidth
CART	condition of assembly at release and transfer
CCAM	collision/contamination avoidance maneuver
CCSDS	Consultative Committee for Space Data Systems
C&DH	command and data handling
CEI	contract end item
CG	center of gravity
CIL	critical items list
CPCI	computer program configuration item
CPDP	computer program development plan
CTE	coefficient of thermal expansion
CVCM	collected volatile condensable materials
DPA	destructive physical analysis
DVT	design verification test
EEE	electrical, electronic, and electromagnetic
EI	equipment item
EMC	electromagnetic compatibility
EO	electro-optical
EOS	Earth Observation System
EPS	electrical power subsystem
ESC/ESD	electrostatic compatibility/electrostatic discharge
EU	engineering unit
FFT	fast fourier transformer
FMEA	failure mode effects analysis
FOSR	flexible optical solar reflector
GFE	Government furnished equipment
GIDEP	Government-Industry Data Exchange Program
GIIS	General Instrument Interface Specification

ACRONYMS AND ABBREVIATIONS (cont.)

GSE	Ground Support Equipment
HOSC	Huntsville Operations Support Center
H&S	health and status
HST	Hubble Space Telescope
IARM	input annular reference mirror
IAS	integrated alignment sensor
ICD	Interface Control Document
IMU	inertial measurement unit
LAEPL	LAWS Approved EEE Parts List
LAWS	Laser Atmospheric Wind Sounder
LC&DH	LAWS Command and Data Handling
LO	local oscillator
LOS	line-of-sight
MA	multiple access
MAPTIS	Material Processing Information System
MCS	Manufacturing Control System
MLI	multi-layer insulation
MUA	Material Usage Agreement
NSPAR	Nonstandard Part Approval Request
OARM	output annular reference mirror
OR	obscuration ratio
PA	product assurance
PCP	platform command processor
PDS	power distribution system
PDT	product development team
PFN	pulse forming network
PIND	particle impact noise detection
PLF	payload fairing
PMP	program management plan
POCC	Payload Operations Control Center
PRACA	parts problem reporting and corrective action
PRF	pulse repitition frequency
PRL	program requirements list
PSATS	parallel spacecraft automated test system

ACRONYMS AND ABBREVIATIONS (cont.)

PZT	pezio-electric transducer
RCS	reaction control system
rms	root mean square
R&RR	range and range rate
SA	single access
SBA	scan bearing assembly
SLM	single longitudinal mode
SMS	structures and mechanical subsystem
SN	space network
SNR	signal-to-noise ratio
SQU	Structural Qualification Unit
STDN/DSN	Spaceflight Tracking and Data Network/Deep Space Network
ST&LO	system test and launch operations
STV	structural test vehicle
TAP	transportation adapter plate
TCS	Thermal Control System
TDRSS	Tracking and Data Relay Satellite System
TML	total mass loss
TWG	test working group
ULE	ultra-low expansion
VCRM	verification cross reference matrix
WFE	wavefront error
WSMC	Western Space and Missile Center

Section 1

INTRODUCTION

The objective of the Laser Atmospheric Wind Sounder (LAWS) Instrument Phase II Preliminary Design Definition and laser breadboard tasks is to further define in sufficient detail the selected configuration from the Phase I Concept Definition study to allow initiation of follow-on full-scale development.

This task has been successfully completed, with the restriction that the specific spacecraft on which the LAWS Instrument is to fly is yet to be confirmed.

Our configuration satisfies all science requirements and General Instrument Interface Specification (GIIS) requirements, can be accommodated on the MSFC LAWS spacecraft concept, and is compatible with potential French CNES configurations (Figures 1 and 2). LAWS will operate in the gravity gradient mode in a 525 km, sun synchronous 97.497 deg inclination orbit with the axis of rotation of the conically rotating telescope pointing to nadir. The telescope rotates at 6 rpm in a 45 deg off axis, full 360 deg scan to measure wind velocities from the Earth's surface to 20 km, with six shots within a 100 x 100 km grid pattern on Earth during each scan (see Figure 3). Adequate volume envelopes are available for both LAWS and the spacecraft in the Atlas IIAS (Figure 4) and Titan launch vehicles. With reduction of the telescope primary mirror diameter from 1.67 to 1.6 m, LAWS can be launched in a Delta vehicle (Figure 5).

The Lockheed LAWS program organization is shown in Figure 6. Lockheed-Huntsville is the prime contractor with overall program management and technical responsibility. Major contributors to the program are Textron Defense Systems for the Laser subsystem and breadboard activities and Itek Optical Systems for the Telescope subsystem. Significant inputs and contributions were also made by our consultants, particularly Dr. Carl Buczek, Laser Systems & Research Corp., and Dr. Chuck DiMarzio, Northeastern University.

The Phase II Preliminary Design Definition was a 21-month follow-on to the initial Phase I 12-month study for Concept Definition. Phase I period of performance was from March 1989 to March 1990 and was documented in Ref. 1. Phase II was initiated on 24 August 1990, with completion scheduled for 30 June 1992 (see Figure 7).

The laser breadboard was added to the basic contract to develop requirements, design, fabricate, assemble, and test the laser design to ensure orbital performance requirements can be met. The 18-month breadboard task was initiated in January 1991, with completion on 30 June 1992 to coincide with the end of the Phase II study. This concurrent effort provided maximum cross flow of data between the two tasks for maximum impact on the baseline instrument design and flight fidelity of the breadboard configuration and tests. First laser beam was accomplished on 21 April 1992, less than 16 months from ATP. Both performance tests and life tests were performed.

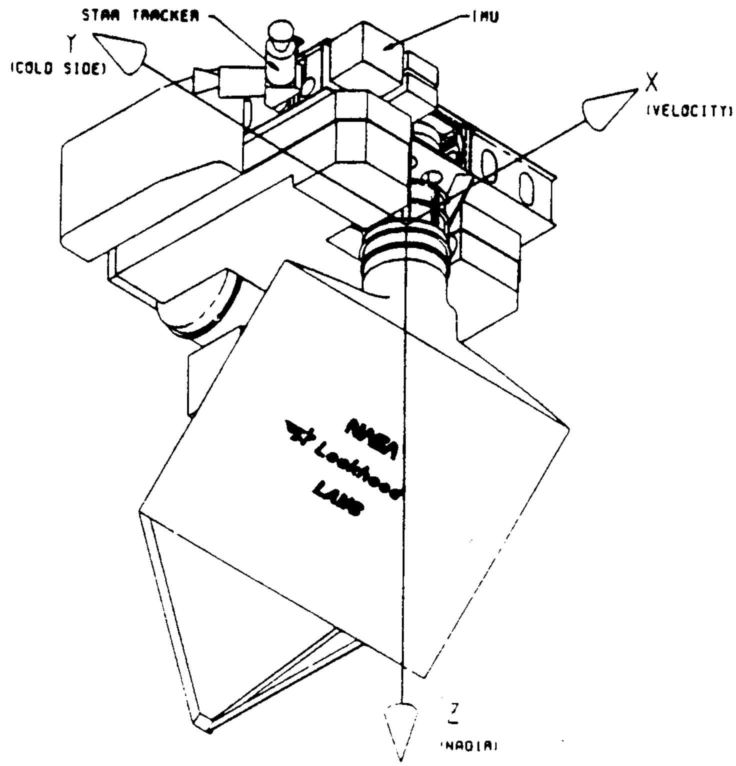

Figure 1. LAWS Baseline Design Flight Configuration

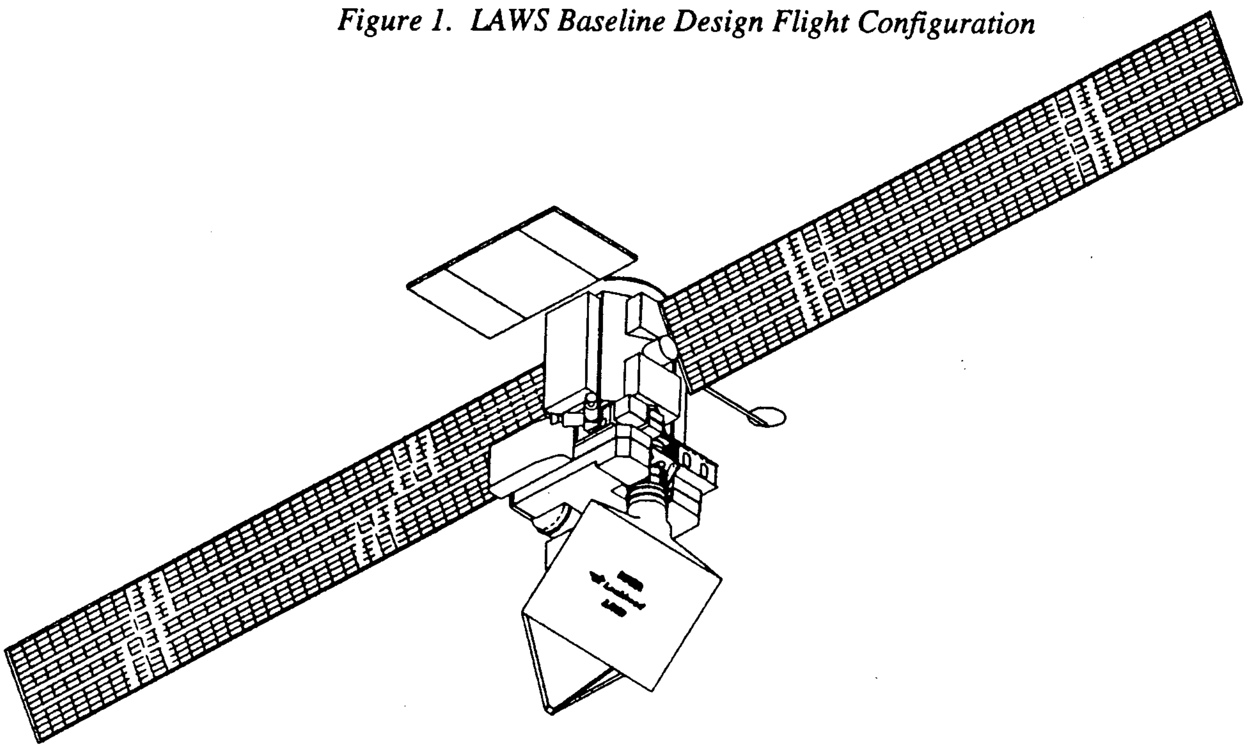

Figure 2. LAWS Package on Bus Assembly

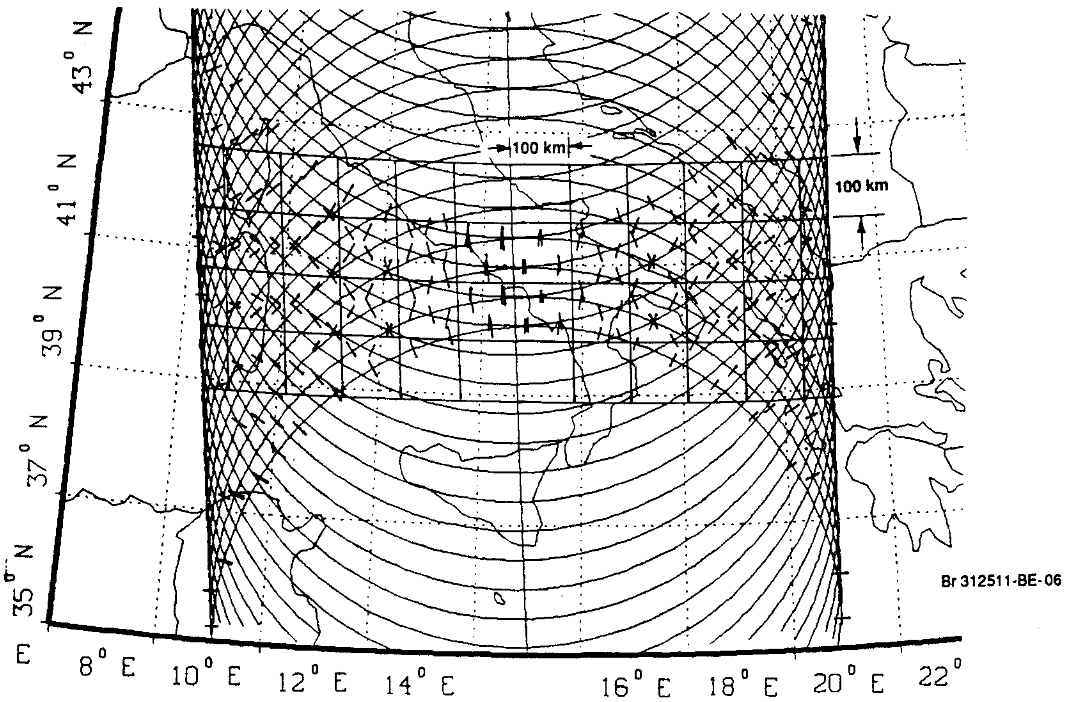

Figure 3. LAWS Shot Distribution

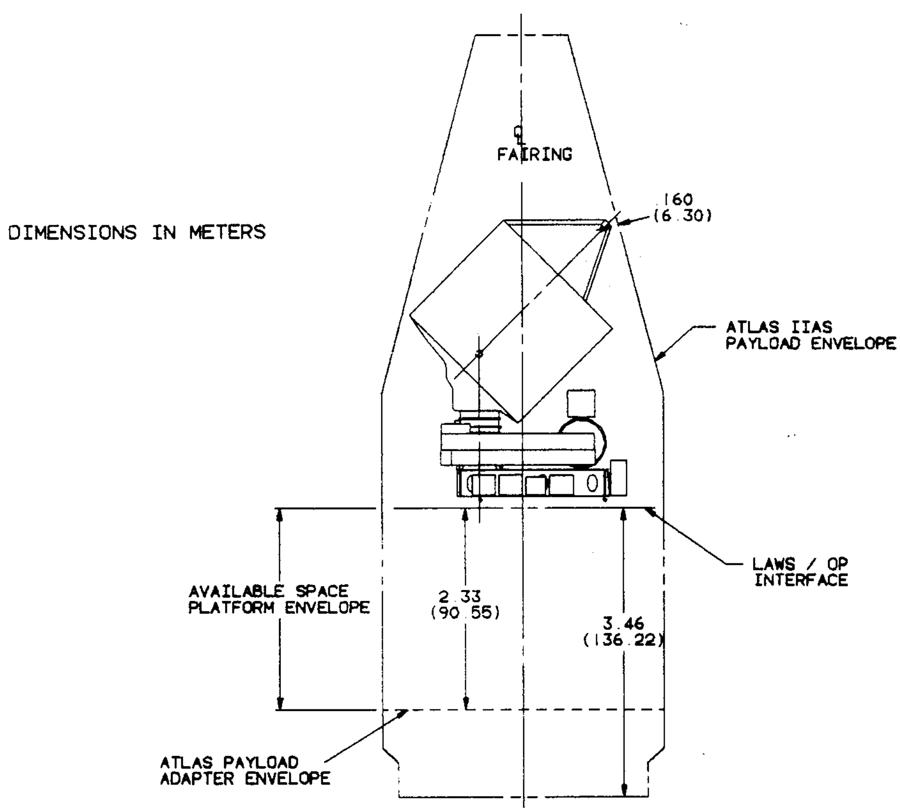

Figure 4. LAWS/POP in Atlas IIAS Large Fairing

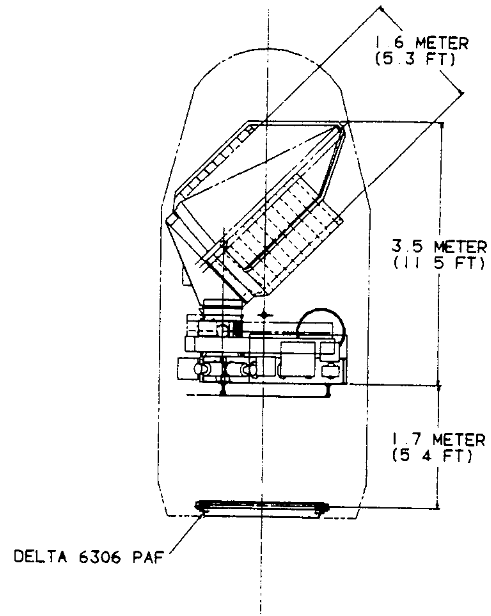

Figure 5. LAWS in Delta Large Fairing

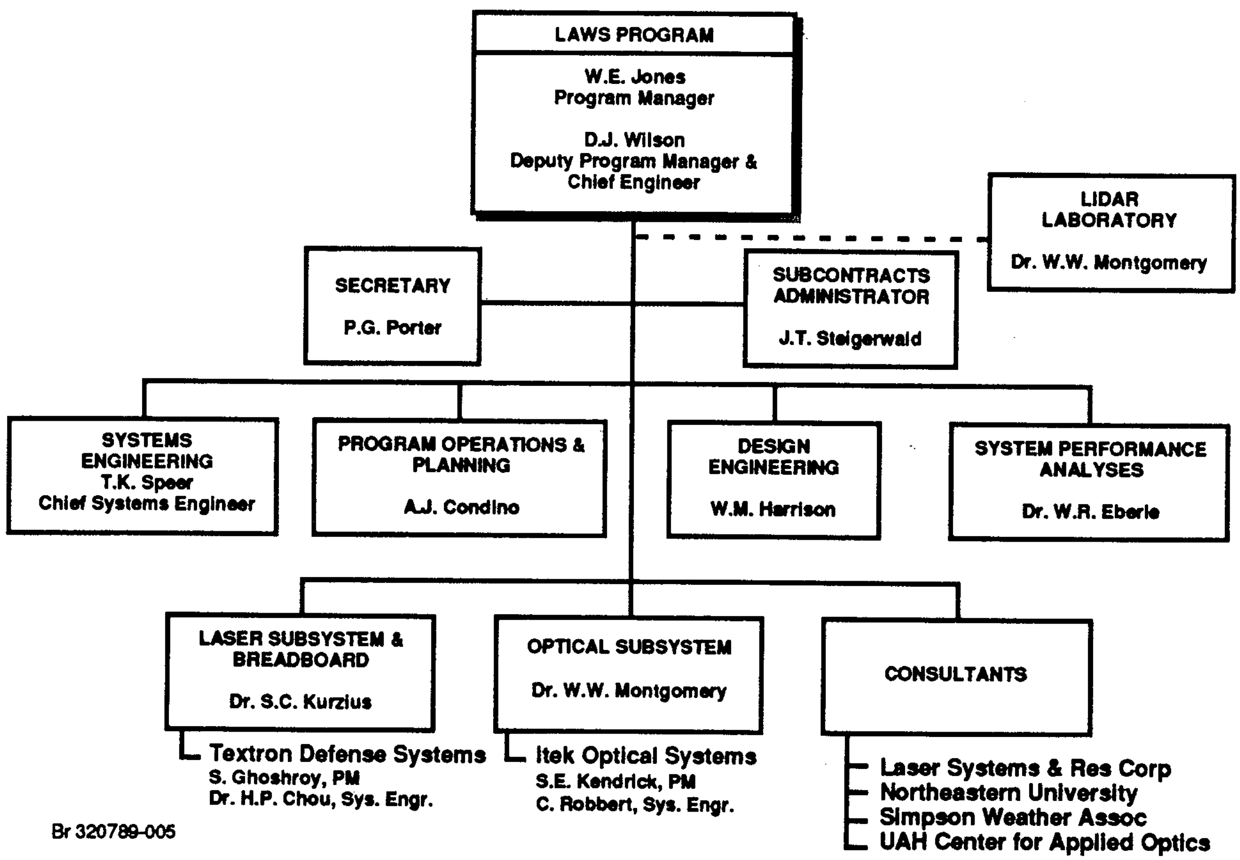

Figure 6. LAWS Program Organization

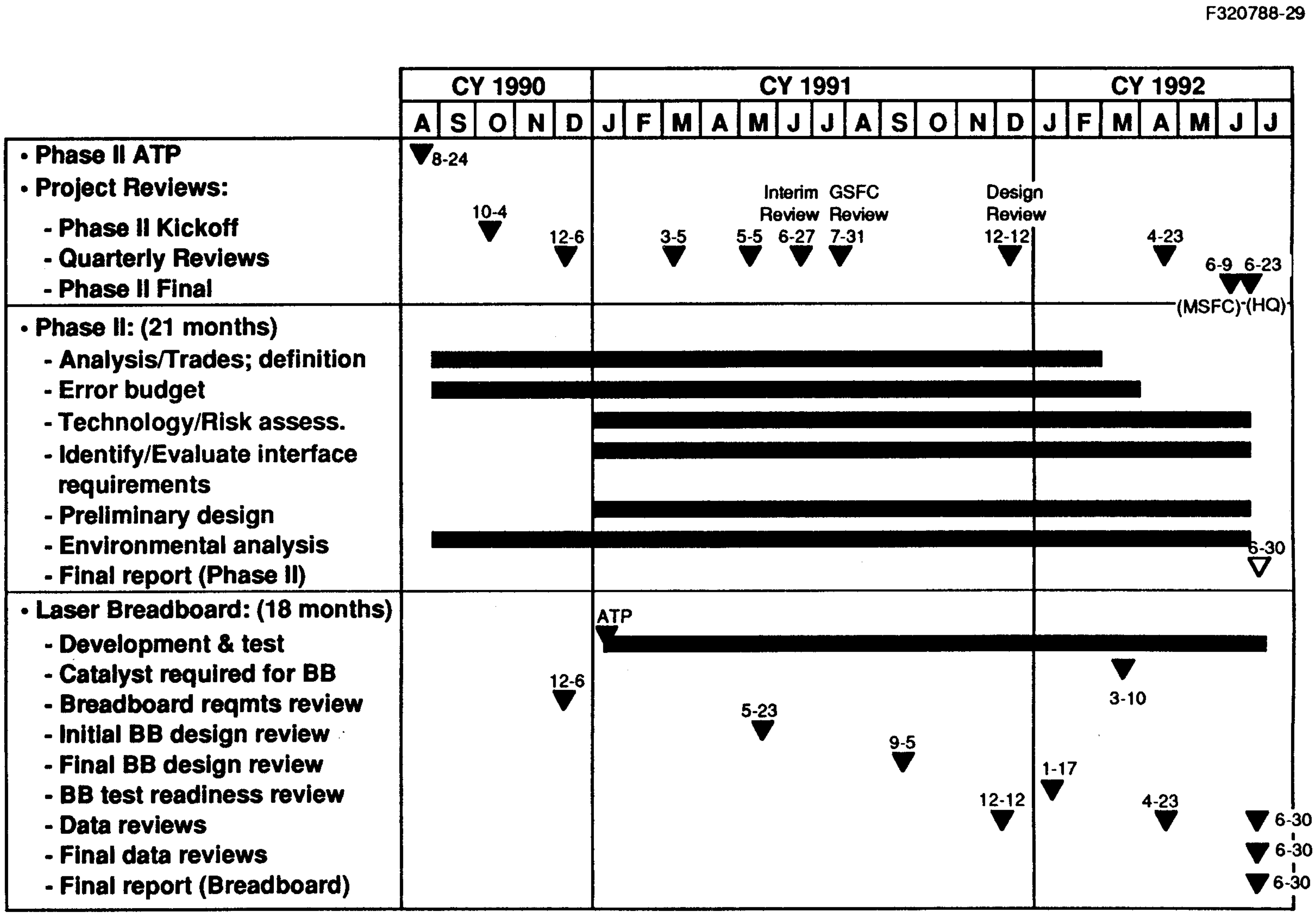

Figure 7. LAWS Phase II Schedule

The results of the Phase II design and breadboard tests are that LAWS full-scale development, verification, and successful mission operation are state-of-the-art technology. The LAWS system engineering studies and breadboard demonstration show that our design is able to accomplish the Science Team's requirements for global wind pattern measurements for the planned 5-year mission.

Section 2

TRADE STUDIES AND BASELINE DESIGN

Utilizing the selected LAWS configuration from the Phase I studies, system engineering trades were performed to further develop and optimize our baseline configuration. The science requirements, spacecraft resource budgets and interface requirements, launch vehicle loads and volume envelopes, and the atmospheric phenomena and variables were all incorporated with the subsystem's physical variables to ensure that the baseline design would meet all requirements (see Figure 8). Sensitivity analyses were also performed to optimize the performance requirements with respect to reliability and costs.

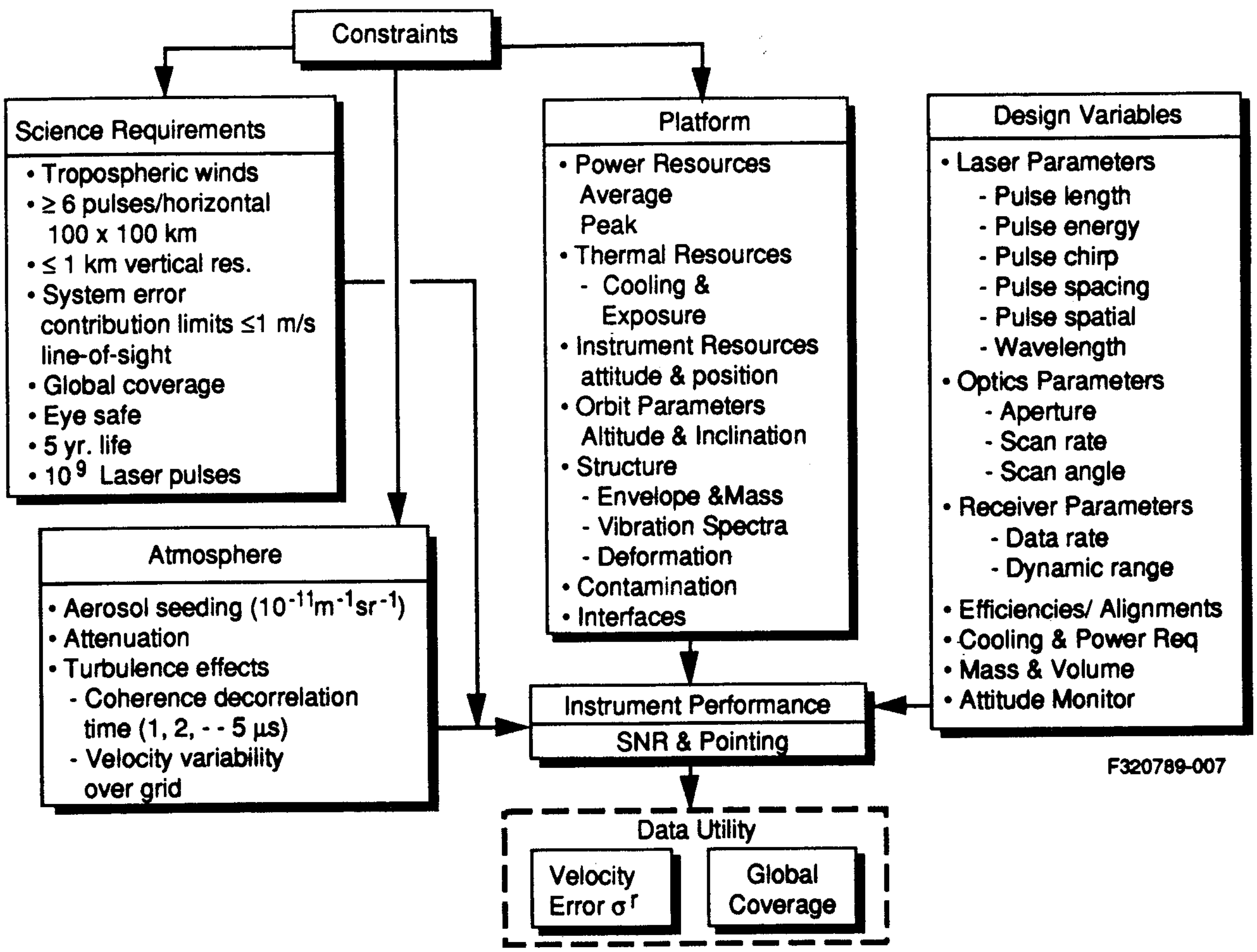

Figure 8. System Level Trades

During Phase I, the requirements were developed for the LAWS system to enable it to accurately measure the wind vectors on a global scale for five years. These requirements were then allocated to either the entire LAWS system or to a specific element or subsystem (see Figure 9). These requirements include both "given" (from the SOW) and "derived" (lower level requirements established to implement a higher level requirement, usually based on system trade studies). They were integrated into a LAWS system diagram (Figure 10), which led to definition of the six specific subsystems (Figure 11) needed to accomplish the mission objectives. (The Thermal Control subsystem is part of the Structures and Mechanical subsystem but is discussed separately in later sections of this document.)

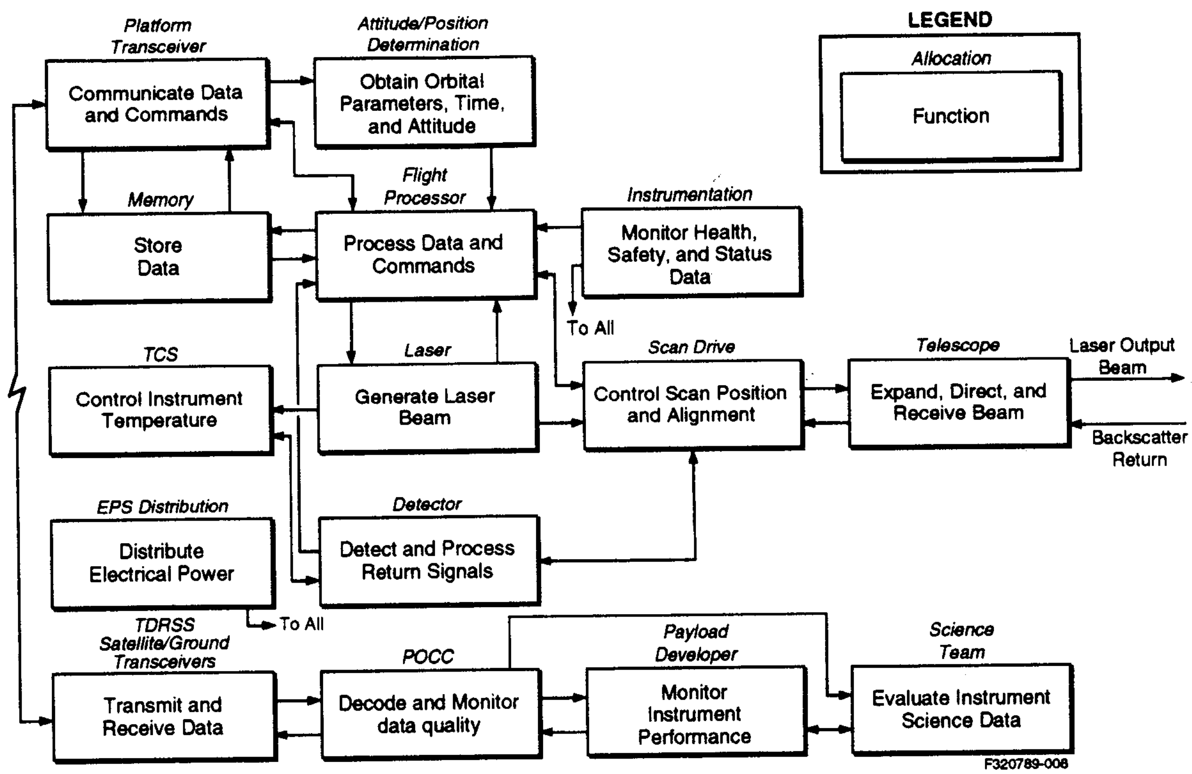

Figure 9. LAWS System Functional Flow Diagram

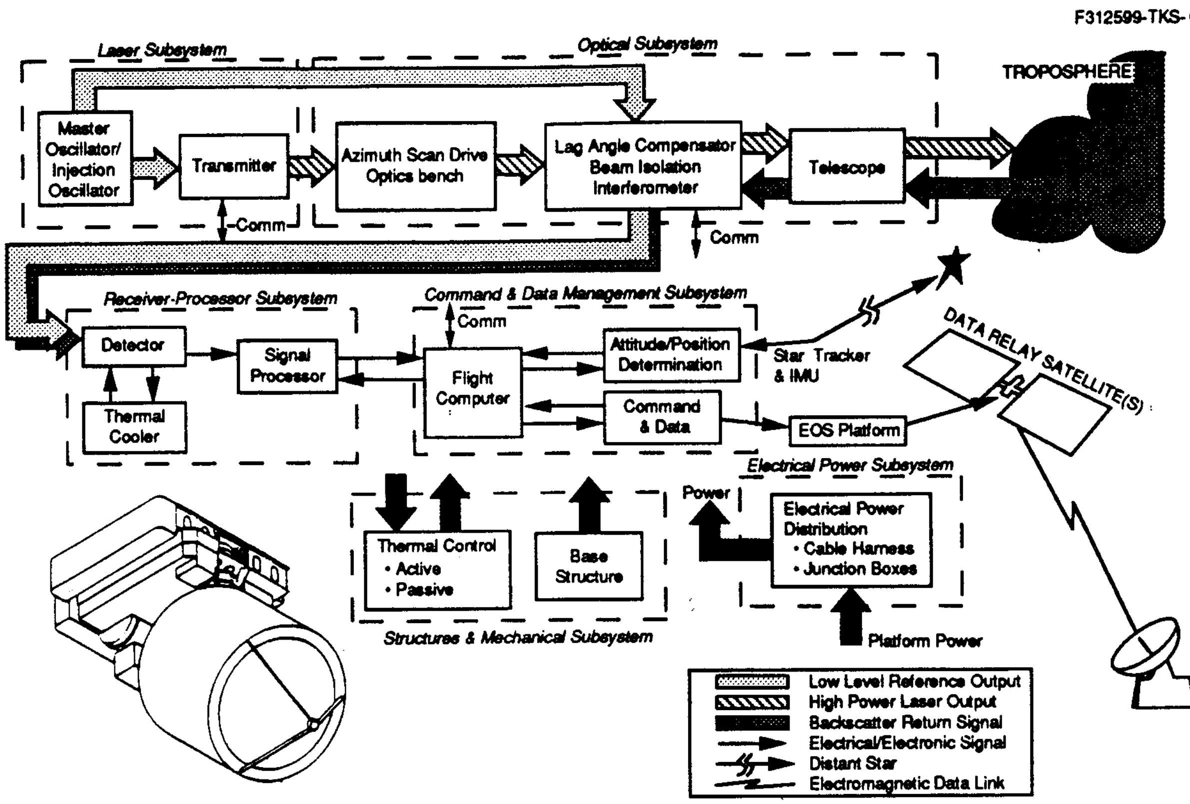

Figure 10. LAWS System Diagram

OPTICAL SUBSYSTEM Telescope Assembly Momentum Compensator Azimuth Scanning System Interferometer Assembly Lag Angle Compensator	**LASER SUBSYSTEM** Transmitter Laser Local Oscillator Seed Laser Laser Subsystem Interface
RECEIVER-PROCESSOR SUBSYSTEM Photo Detector Array Active Cooling Assembly Analog-Digital Converter Down Converter Preamplifier/Bias Electronics Interfaces	**COMMAND & DATA MANAGEMENT SUBSYSTEM** Flight Computer Software Module Attitude and Position Determination Transceiver Interface Modules Subsystem Interfaces
STRUCTURES & MECHANICAL SUBSYSTEM Base Structure Optical Bench Attach Mechanisms Satellite Bus Accommodations Component Support Structures Thermal Control System • Active • Passive	**ELECTRICAL POWER SUBSYSTEM** Power Distribution Unit Platform Electrical Power Interface LAWS Electrical Power Interfaces EMI Control

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Figure 11. LAWS Subsystem Assemblies

The signal flow through the Laser, Optics, and Receiver subsystems, plus the volume constraints of the candidate Atlas IIAS and Delta launch vehicles, led to the baseline LAWS flight configuration layout shown in Figure 12. The velocity vector is along the X-axis, with the telescope bearing on the leading side of the Instrument platform, the laser on the trailing side, and the telescope rotating about nadir. Dual Star Trackers are shown on the cold side of the Instrument in close proximity to the inertial measurement unit (IMU). This configuration meets all packaging requirements for the Atlas IIAS launch vehicle and can be accommodated by the Titan vehicle and, with minor changes, the Delta vehicle. It is designed with clear access for assembly, installation, checkout, and maintenance of all components before launch. Components are located either around the perimeter of the Instrument base or on the optical platform. The laser tank and telescope bearing are mounted to the Instrument base, with critical optical components mounted to the optics bench, which is isolated from the base. The base is, in turn, kinematically mounted to the spacecraft. The optical bench provides a thermally and structurally stable platform for mounting and alignment of critical optical elements. The telescope motor-bearing assembly and laser pressure vessel are mounted directly to the base structure through cut-outs in the optical bench. Baseline dimensions are shown in Figure 13 for the Atlas IIAS configuration. Figure 14 shows the basic changes required for a Delta launch vehicle accommodation. The LAWS Instrument with telescope can be fitted into a Delta (large) fairing (Figure 5) by reducing the telescope aperture from 1.67 to 1.60 m diameter. This size reduction results in a signal-to-noise loss of approximately 0.5 dB.

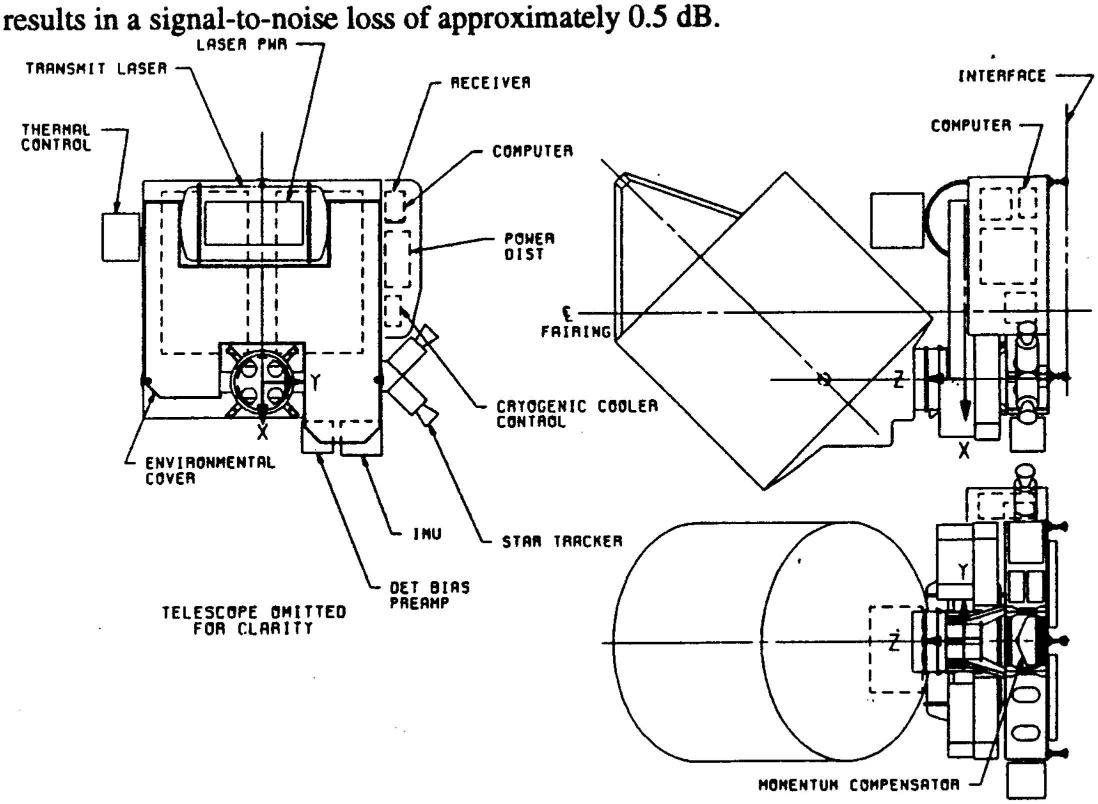

Figure 12. LAWS Baseline Configuration

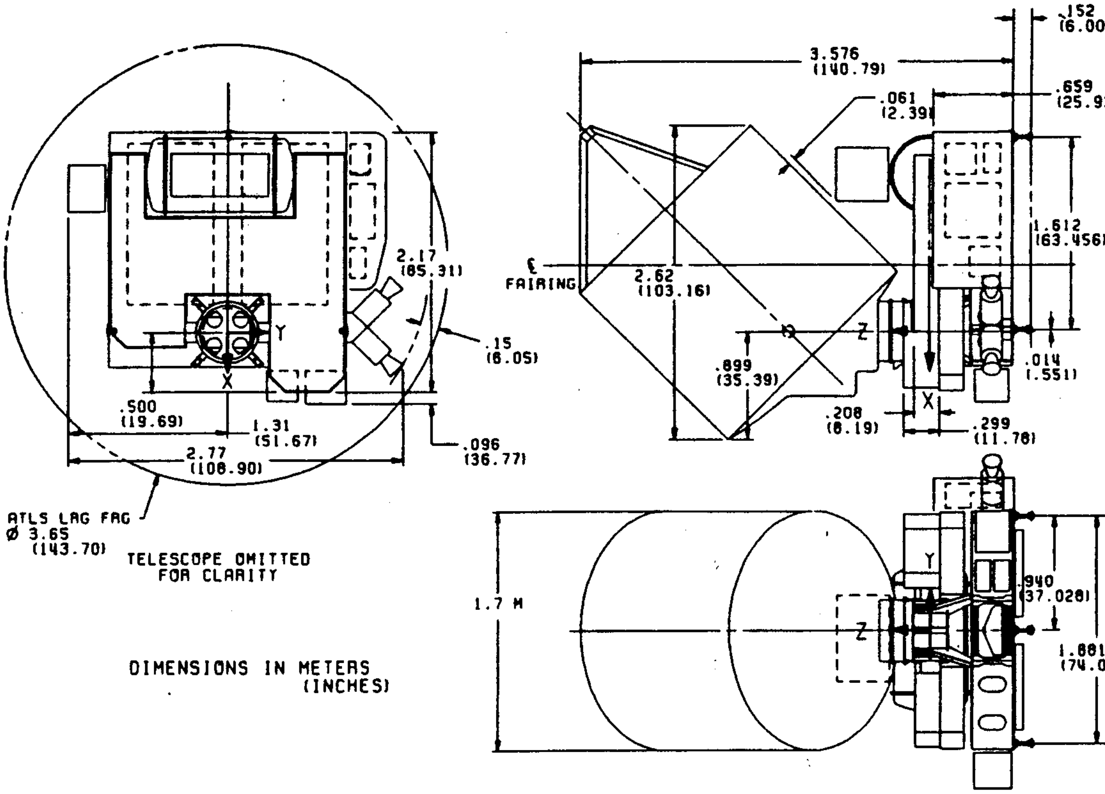

Figure 13. LAWS Baseline Dimensions

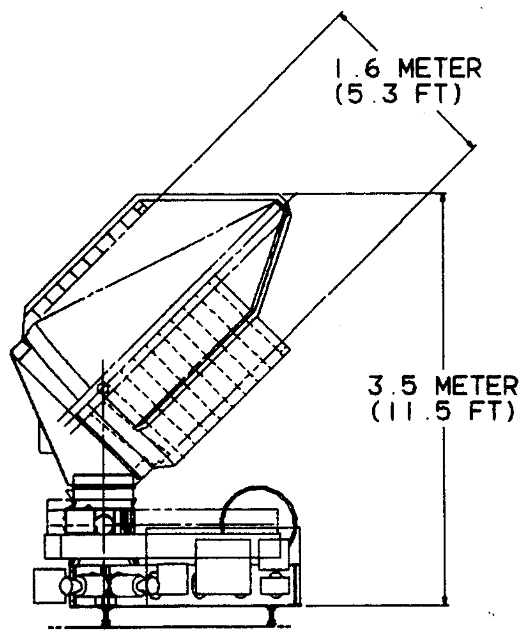

Figure 14. LAWS Configured for Delta Large Fairing

Due to the present uncertainty of the specific spacecraft and launch vehicle to be used for the LAWS mission, Titan launch design load factors were used for all structural analyses for conservation (see Table 1). As further shown in Table 1, our LAWS baseline can be accommodated by Atlas IIAS, Delta, and Titan vehicles, with minor changes.

Table 1. Potential Launch Vehicles

LAUNCH VEHICLE	FAIRING DIAMETER (m)	DESIGN LOAD FACTORS (g)	LAWS CONFIGURATION
Atlas IIAS	4.19 large	6.0 axial 2.0 axial	Baseline
Delta	3.0 large	6.3 axial 3.0 axial	Reduces telescope diameter & base mount height
Titan	5.08	6.5 axial 3.5 axial	Baseline

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A schematic of the LAWS signal flow through the Laser, Optics, and Receiver subsystems is shown in Figure 15. Tip-tilt mirrors are depicted for low bandwidth adjustment of the local oscillator beam; higher bandwidth adjustment is required for the dynamic lag angle compensation. Telescope internal alignment is maintained by an out-of-band alignment assembly. Focus/defocus capability at the receiver provides increased field-of-view for initial acquisition. Figure 15 shows optical paths as dashed, and electrical paths as solid lines. The twos (2's) are components which have been tentatively selected for redundancy to maintain higher reliability for mission operations. Actual component layout is shown in Figure 16.

A condensed baseline mass properties table is depicted in Table 2. The weight values are based on design, analyses, or vendor data for selected hardware elements. The weight budget of 800 kg is met, but little contingency is presently available. Major emphasis will be placed on weight reduction when the specific LAWS spacecraft is selected. The CG is located close to the longitudinal (X) centerline. The telescope rotating mass has been minimized to 161.5 kg. The telescope mass CG is located on the axis of rotation for minimum inertia effects. The momentum compensator is included to compensate for telescope rotational momentum.

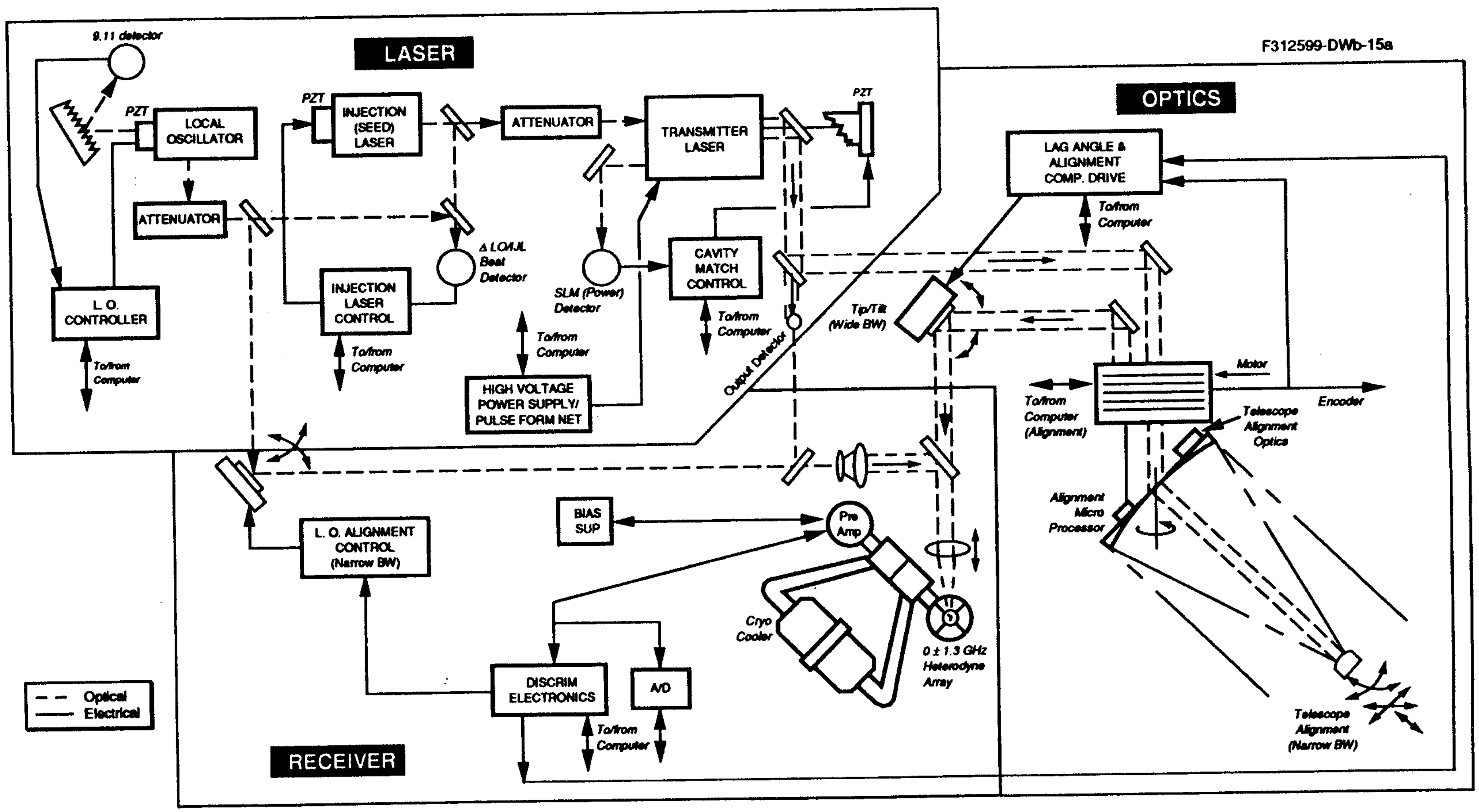

Figure 15. LAWS Signal Flow

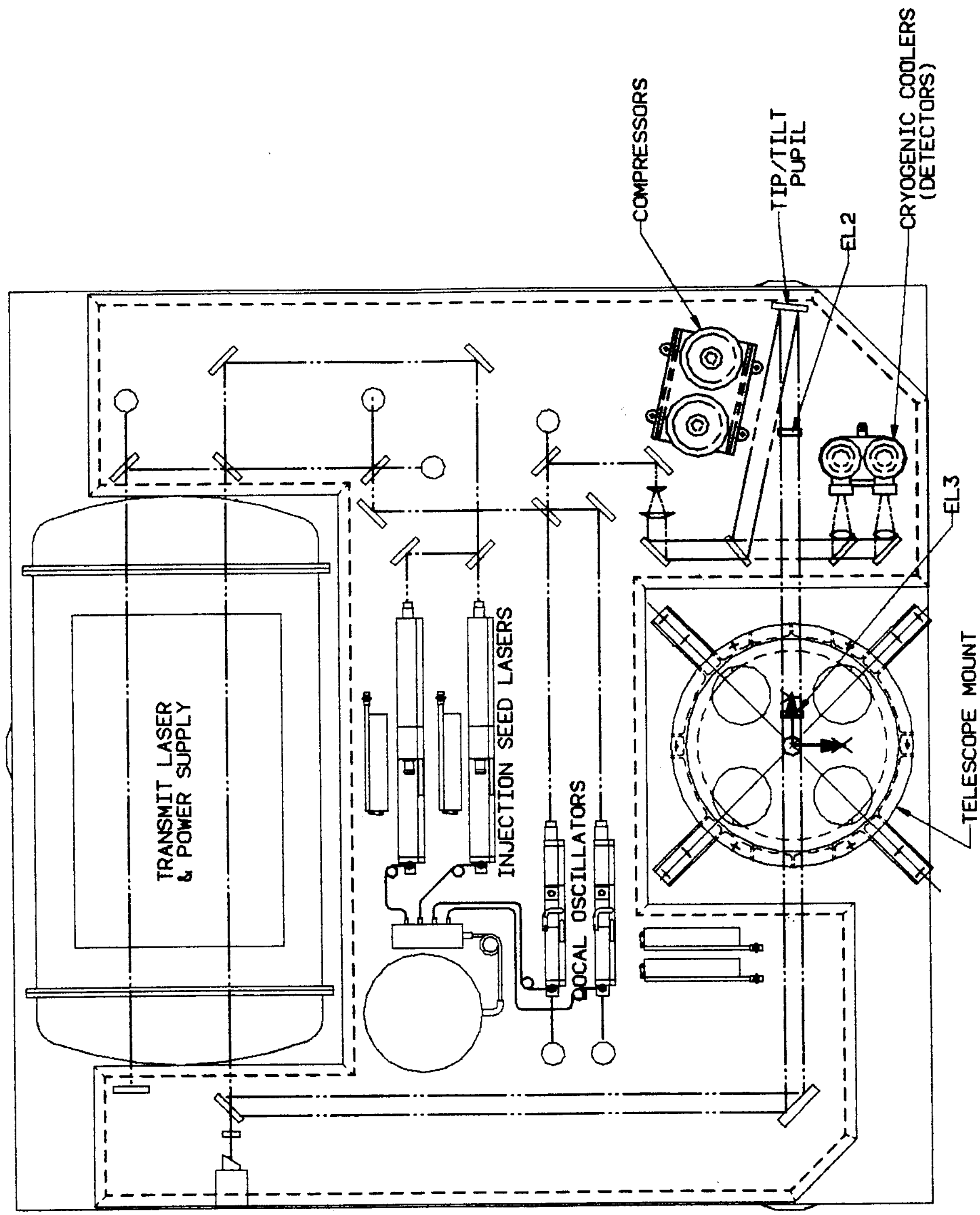

Figure 16. LAWS Optical Bench Layout

Table 2. LAWS Baseline Mass Properties

System	Contents	System Weight (kg)	C.G. Location (m) X	Y	Z
Structure	Base, Bench, Environmental Cover, Mounts	127.5	-0.57	0.03	-0.34
Power	Distrubutor, Cable	13.6	-0.88	0.77	-0.32
Thermal	Pump Package 15.5 * ,Heaters, Cable EOS Cold Plates 21.**, Lines, Misc.	92.95	-0.82	-0.02	-0.38
Telescope	Mirrors, Reaction & Metering Structures, TCS, Motor/Bearing, Misc.	204.6	0.0	0.0	0.92
Laser	Laser & Power Supp., Oscillators & Power Supp., Seed Lasers & Power Supp., Misc.	212.6	-1.20	-0.05	0.21
Data	Computer, Cables	20.4	-0.79	0.29	-0.28
Receiver/ Detector	Electronics, Cryo Cooler, Controller Compressors, Displacers, Bias, Preamp, Misc.	52.0	-0.26	0.62	-0.24
Momentum Comp.	Momentum Compensator, Heat Exchanger	12.9	0.0	0./0	-0.62
Pointing	IMU, Star Trackers	41.0	-0.17	0.97	-0.50
Total		***777.5 kg***	***-0.55 m***	***0.08 m***	***0.16 m***

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* *Could be replaced by platform pump if LAWS goes on dedicated platform.*
** *Could be replaced with 5 kg heat exchanger if LAWS goes on dedicated platform.*

Section 3

LAWS FULL SCALE DEVELOPMENT AND VERIFICATION

The guideline development schedule for the LAWS Phase C/D Full Scale Design, Development, Test & Evaluation (DDT&E), was specified by MSFC for this Phase II study contract. ATP was 1 January 1994, with launch scheduled for March 2001. The LAWS flight unit was to be shipped for spacecraft integration on 1 January 1999, and the integral LAWS/spacecraft configuration shipped for launch vehicle integration on 1 January 2001 (see Figure 17).

The LAWS development process includes three units to minimize risk during the 5-year DDT&E program. An engineering unit, a qualification unit, and a flight unit are used for a success oriented, minimum risk approach. The engineering unit is maintained throughout the 5-year orbital mission life for sustaining engineering and trend analysis activities. Initially the engineering unit is constructed of non-flight components to allow an early start on system integration, checkout, and performance testing (see Figure 18).

The qualification unit consists of flight configuration hardware to be tested to flight centrification levels. Subsystem and components are required to pass acceptance level tests before being subjected to full-up qualification level tests. Upon successful completion of component and subsystem qualification testing as shown in Figure 19, the LAWS Instrument, composed entirely of qualified units, will be subjected to vehicle qualification testing, as shown in Figure 20.

Functional testing, as defined in MIL-STD-1540, will be performed immediately before and after conducting all environmental testing. Functional testing is divided into two sections: mechanical and electrical. Operation of the transmitter laser, elector-optical devices, software, and data processing functions will apply to testing these sections. During mechanical testing, all mechanical operational modes are fully operated and alignment tests are conducted. During electrical tests, all primary and redundant circuits, commands, and operational modes will be activated and sequenced as they will be performed in space.

Thermal vacuum tests will be conducted as a part of the vehicle qualification tests (Figure 20) and flight unit acceptance tests (Figure 21) as required by MIL-STD-1540. During the first and the last temperature cycles, a full functional test will be conducted at both the specified high and low temperature extremes. Functional and operational parameters will be instrumented and monitored during all test cycles.

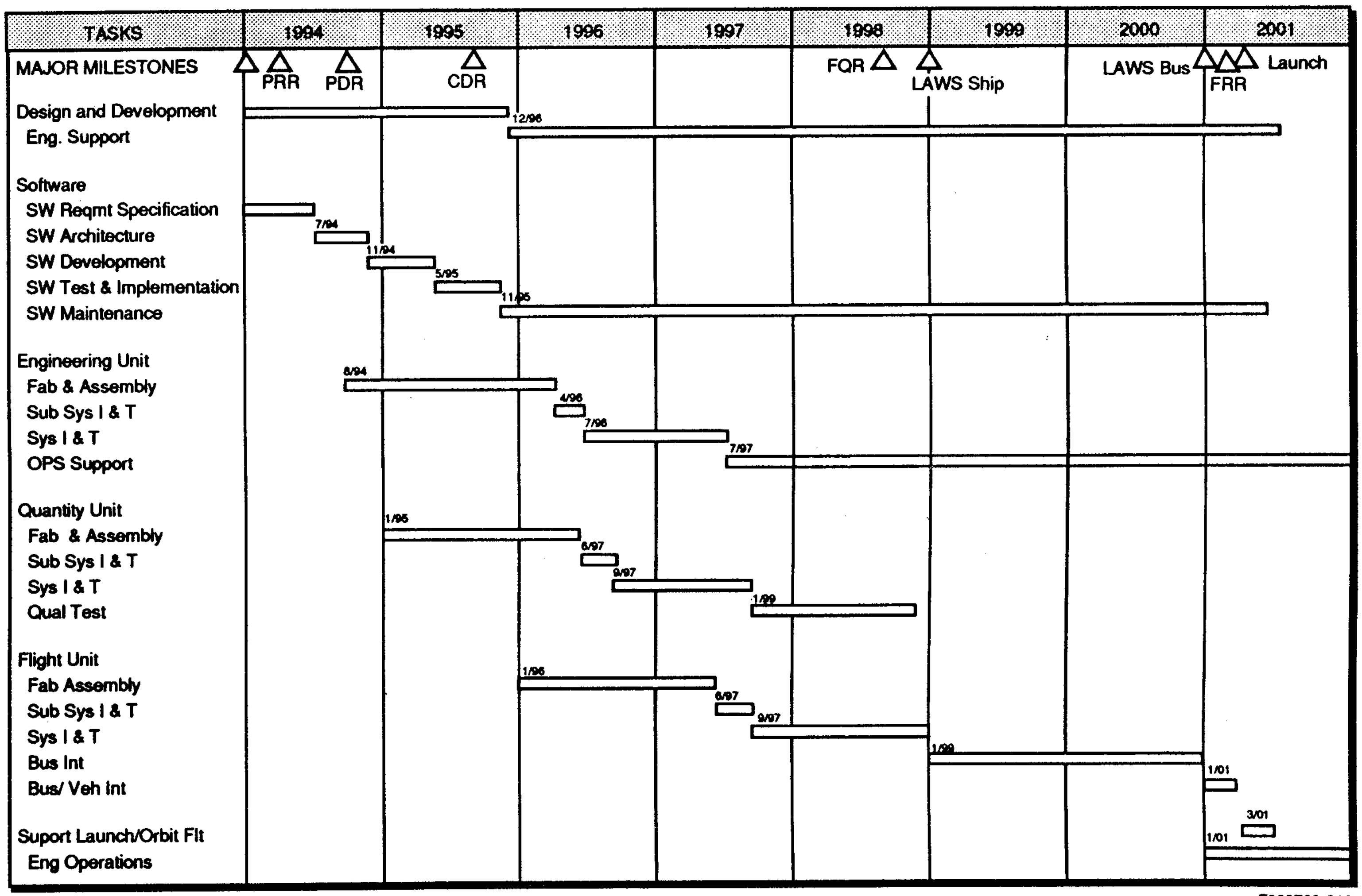

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Figure 17. LAWS Development Schedule

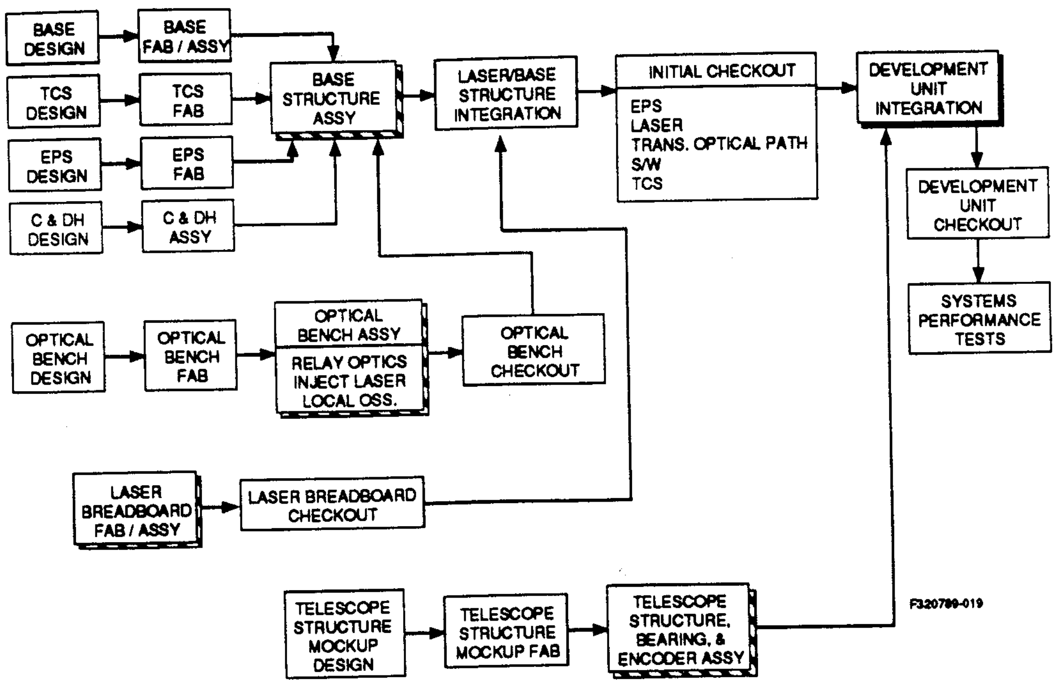


Figure 18. Development/Engineering Unit

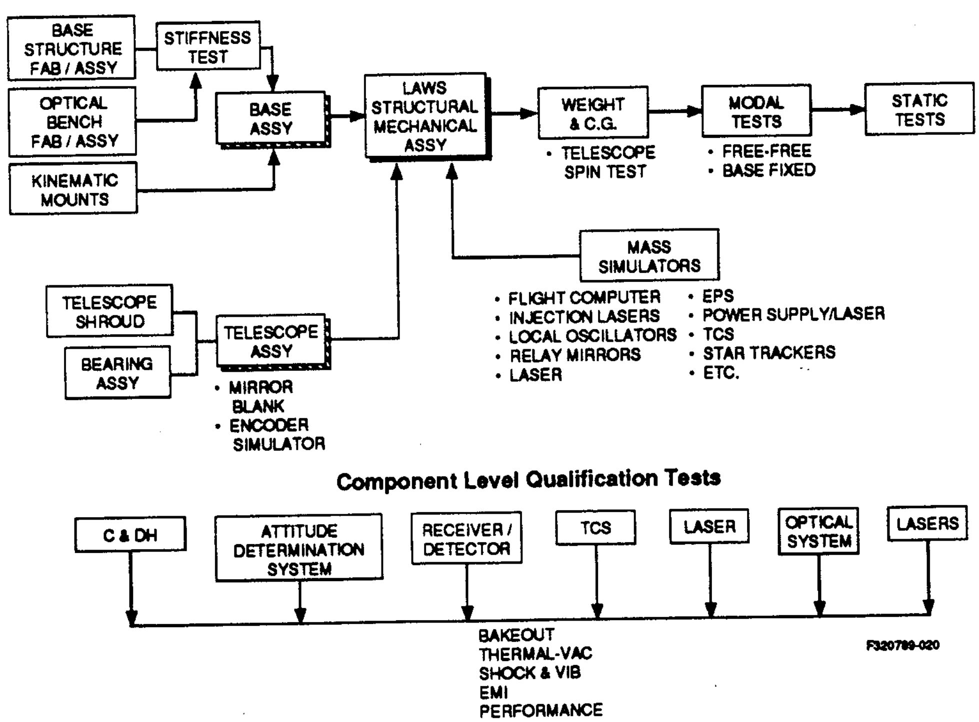


Figure 19. Subsystem and Component Qualification Test

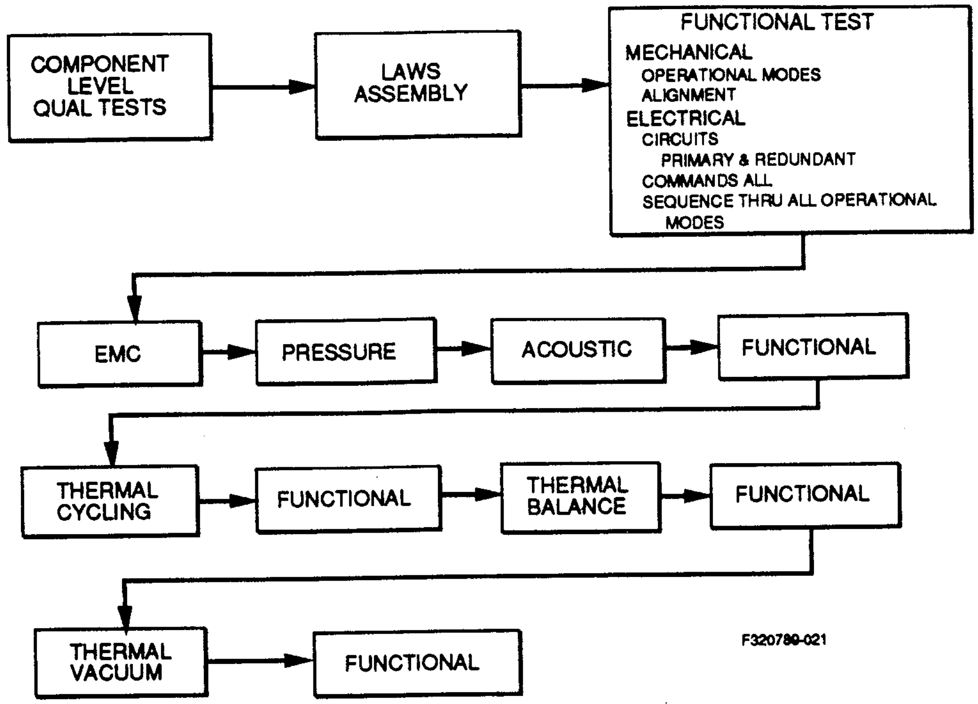


Figure 20. Vehicle Qualification Tests

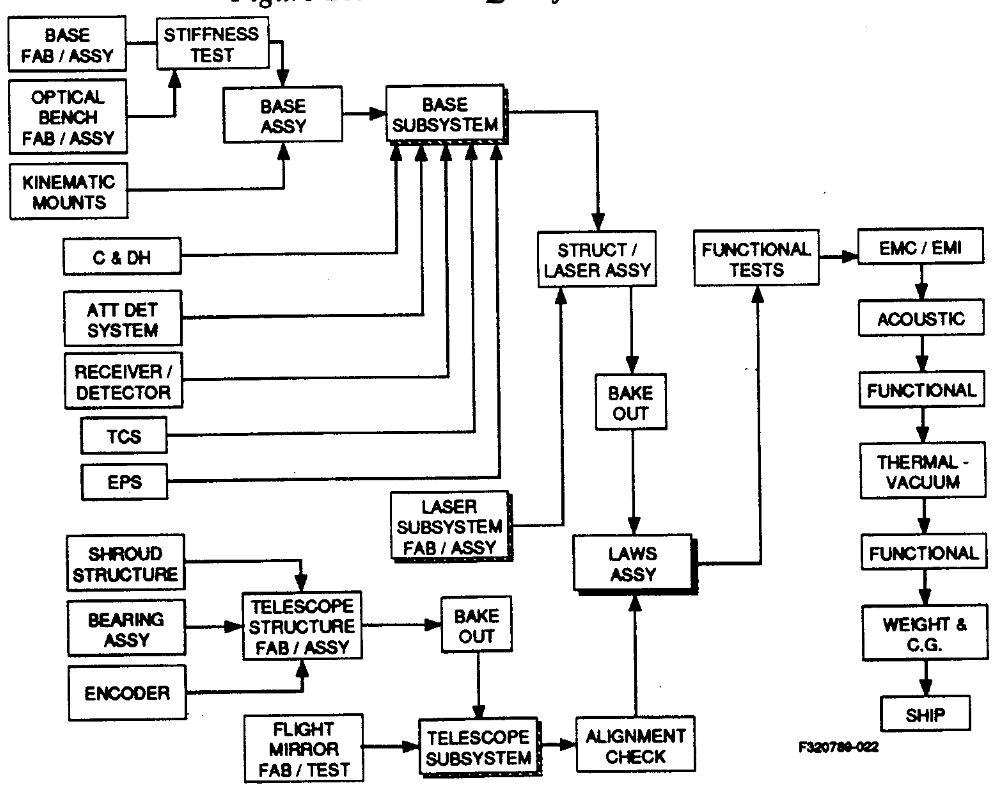


Figure 21. Flight Unit Assembly and Test

The preliminary assembly/test flow plan is illustrated by Figure 22. Following installation and tests of Laser and Telescope subsystems and return of the units to LMSC, the qualification unit and the flight unit will be further tested. The flight unit will be shipped for spacecraft integration and then to the launch site. The TDS and Itek facilities are located within 30 miles of each other in the Boston area, which provides for maximum interface and minimum cost during laser and optical subsystem integration and tests.

The following sections provide a brief summary for each of the LAWS subsystems.

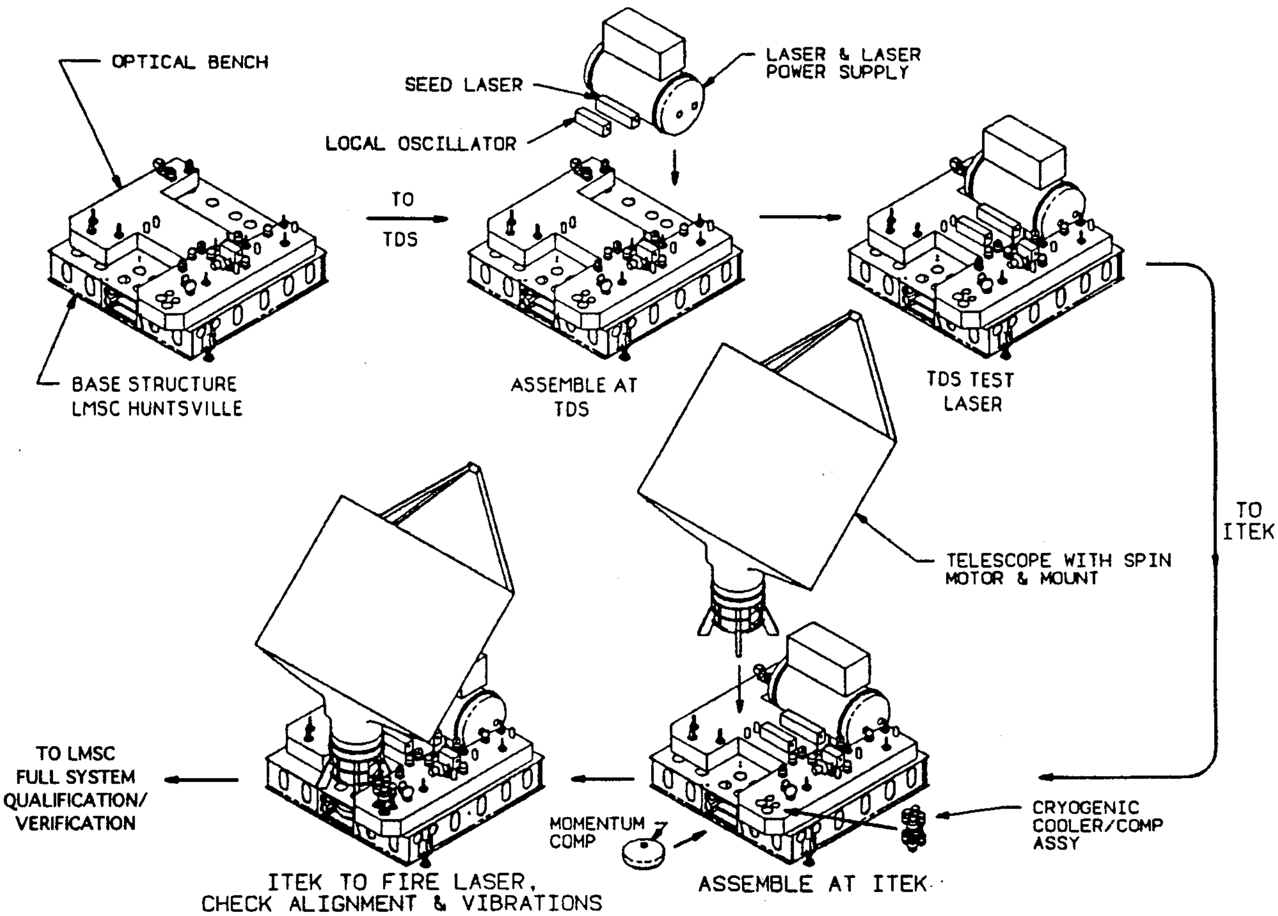
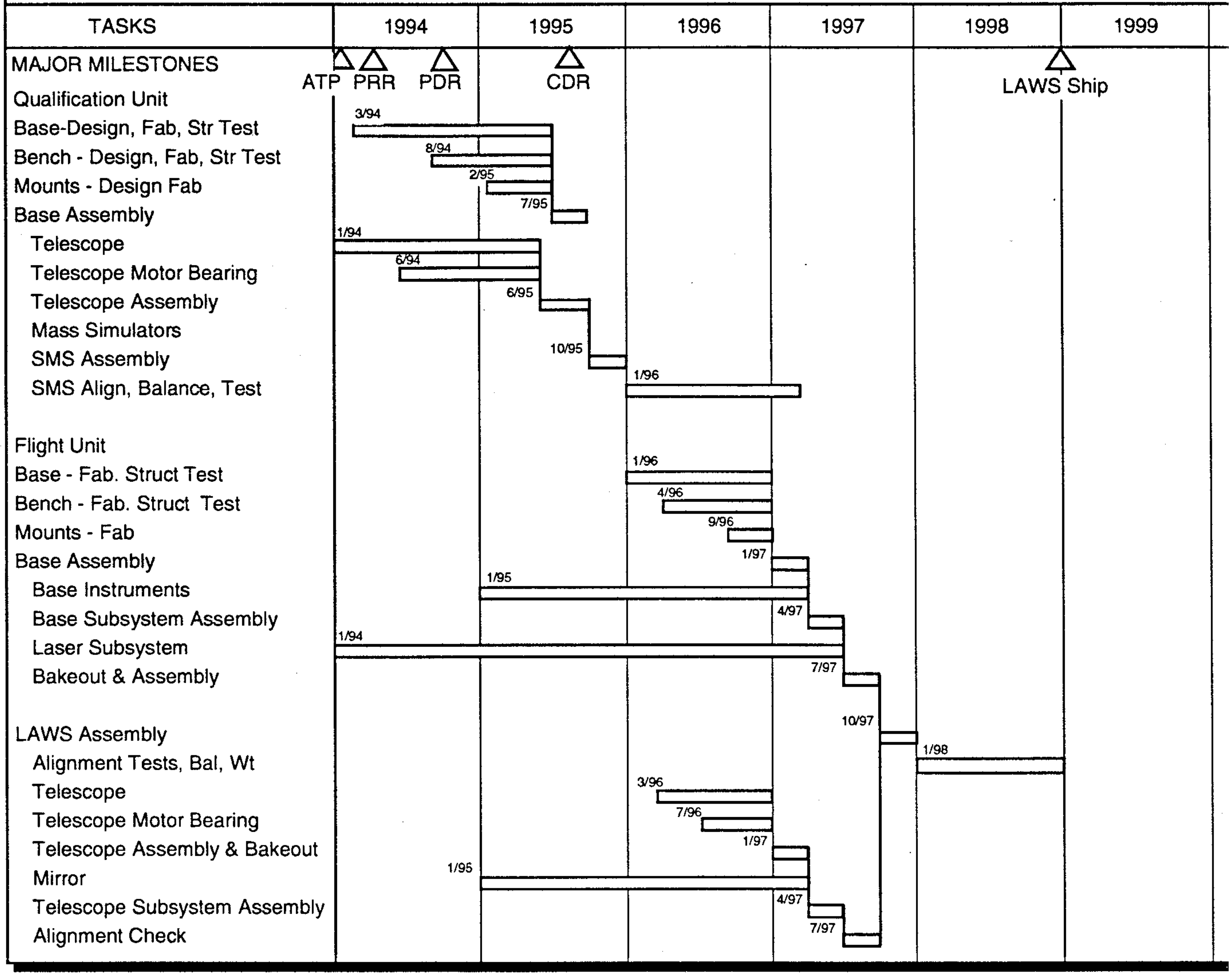


Figure 22. LAWS Assembly and Test Flow

3.1 STRUCTURES AND MECHANICAL SUBSYSTEM

Figure 23 describes key analyses, trades, and verification plans for the LAWS Structures and Mechanical subsystem (SMS). (The Thermal Control subsystem, which is part of the Structures and Mechanical subsystem, is discussed in a separate section.) The major structural elements of the SMS are the base platform, the telescope mounting pedestal, the optical bench, and the telescope structure. The SMS mechanism is composed of the telescope motor/bearings with V-band caging device for offloading the bearings during ascent.

A STRUCTURES & MECHANICAL DDT&E PLAN OVERVIEW



B SMS REQUIREMENTS/VERIFICATION

KEY REQUIREMENT	IMPLEMENTATION
Launch Vehicle Interface • Shroud Envelope • Interface Loads	Designed to meet envelope for max ascent loads
Contamination	Contamination shield material selection
Strength/Dynamic Characteristics	Designed for positive margins with adequate factors of safety & inert structural frequency/stiffness requirement
Operational Life	Motor bearing design
Redundancy Management	Redundant motor bearings
Allignment/Stability	
• Telescope Rotation	Telescope dynamically balanced
• Laser Pulse	Structure stiffness/shock mounts
• Thermal Deflections	Thermal covers/control
• On Orbit Dynamics	Structural stiffness design
• IG/OG Distortion	Structural stiffness design

ATTITUDE DETER

FOLDOUT FRAME /

2000	2001
LAWS Bus △	△ Launch

C DESIGN ANALYSES & TRADE STUDIES

ITEM	ANALYSES
Optical Bench*	To determine weight/stiffness/strength optimum for Honeycomb or multiple truss core
Base Structure*	To determine weight/stiffness/strength optimum for GE member size and layup
Telescope Pedestal	To determineweight/stiffness/strength optimum for material trade and design
Laser Mounts*	To determine laser pulse effects on telescope pointing
SMS*	To determine sensitivity of telescope imbalance on telescope attitude & optics alignment
SMS	To determine the effect of gravitational field alignment at on orbit conditions
SMS	To determine changing structural design effects on dynamic modes & natural frequencies (thereby, attitude control)
SMS	To determine space platform effects on attitude control
SMS	To determine thermal distortion effects on attitude control and optics alignment

*Ongoing analyses begun in Phase B.

D PLANNED TRADE STUDIES

TRADE ITEM	BASELINE DESIGN
Telescope Support Pedestal	Titanium vs. Graphite Epoxy
Optical Bench Core	Honeycomb vs. Multiple Truss
Base Thickness	Thick, Thin, Medium (completed)

VERIFICATION
Test & Analysis
Test & Analysis
Test & Analysis
Test & Analysis
Test
Test
Test & Analysis
Test & Analysis
Test & Analysis
Test & Analysis

E SMS VERIFICATION SUMMARY

	Functional	Static	Modal	Random Vib.	Thermal Vac	Acoustic UCB	Pyroshock
SMA Qualification Structure w/Mechanism	X	X	Q	Q	Q	Q	Q
SMS Flight Structure	X	X	A	A	A	A	A

X = Same Levels Qual/Flight
Q = Qualification Test Levels*
A = Acceptance Test Levels*
* = Levels Per Mil-Std-1540B

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ATION SUBSYSTEM

Figure 23. Overview/Summary of the Structures and Mechanical Subsystem (1 of 2)

F DYNAMIC TEST PLAN/FEATURES

- Free-Free Modal Test
- Measure dynamic stiffness of spacecraft interface via impedance test
- Combine results of these two tests to produce fixed base mode shapes and natural frequencies
  - Test article suspended by air bearings
  - All suspension system modes below 2 Hz
  - Pure random excitation
  - -50 + acceleration measurements
  - Modal curve fitting techniques extract mode shapes, natural frequencies, and modal dam

G RISK SUMMARY

RISK ITEM	RISK LEVEL	RISK REDUCTION APPROACH
Structural Assembly Failures	Low	– Large strength margins
		– Early identification and control of fracture critical items
Motor/Bearing Failure	Low	– Redundant motor wiring
		– Similarity with other flight proven units
SMS Attitude Control Failure	Low/Med	– Dynamic analyses with respect to space platform perturbanc
		– High rev dynamic balance of telescope
		– Deflection analyses supported by tests
Optics Alignment Failure	Low/Med	– Thermal deflection analyses and testing
		– Dynamic analyses with respect to space platform perturbanc

H REQUIRED SUBSYSTEM EQUIPMENT

COMPONENT	SOURCE	HERITAGE	FLT	QUAL	MOCKU
Base	LMSC	New	1	1	
Bench	LMSC	New	1	1	
Telescope Mount	Vendor	New	1	1	
Motor Bearing	Vendor	Modified Flight Proven	1	1	
Telescope	Vendor	New	1	1	
Mirror	Vendor	New	1	0	1
Test Hardware:					
Mass Simulators	LMSC	New		1 ea	
Test Fixture	LMSC	New		1	

FOLDOUT FRAME /

ıg

ENG
1
1
1
1
1
1

I PLANNED SMS ANALYSES

ANALYSIS TYPE	ALL SMS EQUIPMENT	ALL SMS STRUCTURES	SMS MECHANISMS
Strength	X		
Dynamics		X	
Thermal	X		
Mass Properties	X		
Producibility	X		
Life Cycle Cost	X		
FMEA	X		
Reliability	X		
Venting	X		
Stress Controls			X
Performance			X
Math Model Verification		X	

312594-MT-FO-2 of 2

J PHASE B STRESS/DYNAMICS MODEL

Equipment packages are reproduced as point masses (not plotted).

454 Grids
1034 Elements

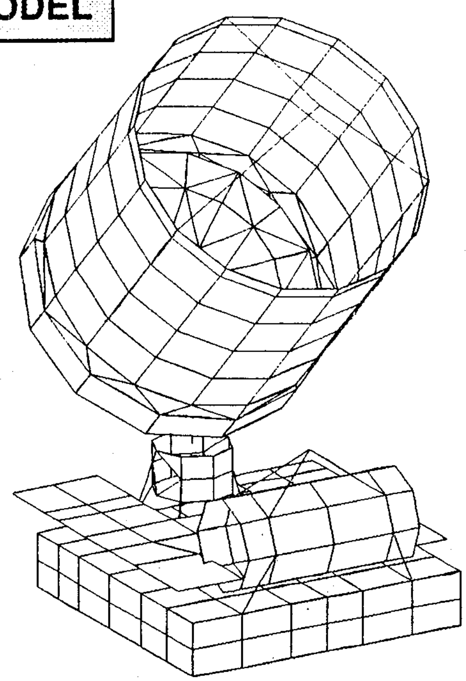


Figure 23. Overview/Summary of the Structures and Mechanical Subsystem (2 of 2)

The base structure design is composed of structural edge beams with internal cross beams covered by top and bottom face sheets. All components are constructed from graphic epoxy for light weight, high strength, and low thermal coefficient of expansion. Three kinematic mounts provide the structural interface between the LAWS Instrument and the spacecraft. All components are sized for the launch loads with the prescribed safety factors.

The base structure is the mounting platform for the laser, telescope, and the majority of the other subsystem components. The subsystem components are mounted around the perimeter on the edge beams. The location is based on thermal requirements to take maximum advantage of passive heating or cooling.

The optical bench is attached to the base structure by three kinematic mounts. The optical bench is a honeycomb structure with face sheets, and is made of graphic epoxy material for minimum distortions and light weight. The seed laser, local oscillator, detectors, and all relay optical system elements are mounted on the bench.

3.2 COMMAND AND DATA MANAGEMENT SUBSYSTEM

The Command and Data Management (C&DM) subsystem is composed of a flight computer, Star Trackers (2), inertial measurement unit (IMU), and command and data transceiver interface modules. The flight computer, applying associated software, provides autonomous direction to the LAWS Instrument, controlling when the laser is to be fired to achieve measurements for selected wind components. The flight computer also receives and executes commands from the spacecraft via the bus data unit (BDU) and exercises stored math models to compute the time associated with the telescope pointing angles for the laser pulses. The Star Trackers and IMU are located on the LAWS Instrument baseplate. Outputs from these sensors to the LAWS Instrument are managed by the attitude and position determination elements of this subsystem. The command and data transceiver assembles and transfers data from the LAWS Instrument to the spacecraft for transmission via data relay satellites.

All communications with the LAWS Instrument, to and from the spacecraft, and with the NASA control centers are directed through the LAWS C&DM subsystem via the BDU. The few interfaces not controlled by this subsystem are related to the LAWS spacecraft electrical, thermal, and mechanical interfaces. These interfaces, however, are monitored and reported by the health and status instrumentation sensors.

The flight computer controls laser shot management firing commands, computes orbital platform position location, collects telescope line-of-sight azimuth angle values for each laser shot, provides short time storage of wind data for transmission to the spacecraft data management system and formatting of data into Consultative Committee for Space Data Systems (CCSDS) format, and performs other command and data management functions.

Figures 24 and 25 describe the key analyses, trades, and verification plans for the LAWS Command and Data Management subsystem and the Attitude Determination subsystem, respectively.

3.3 ELECTRICAL POWER SUBSYSTEM

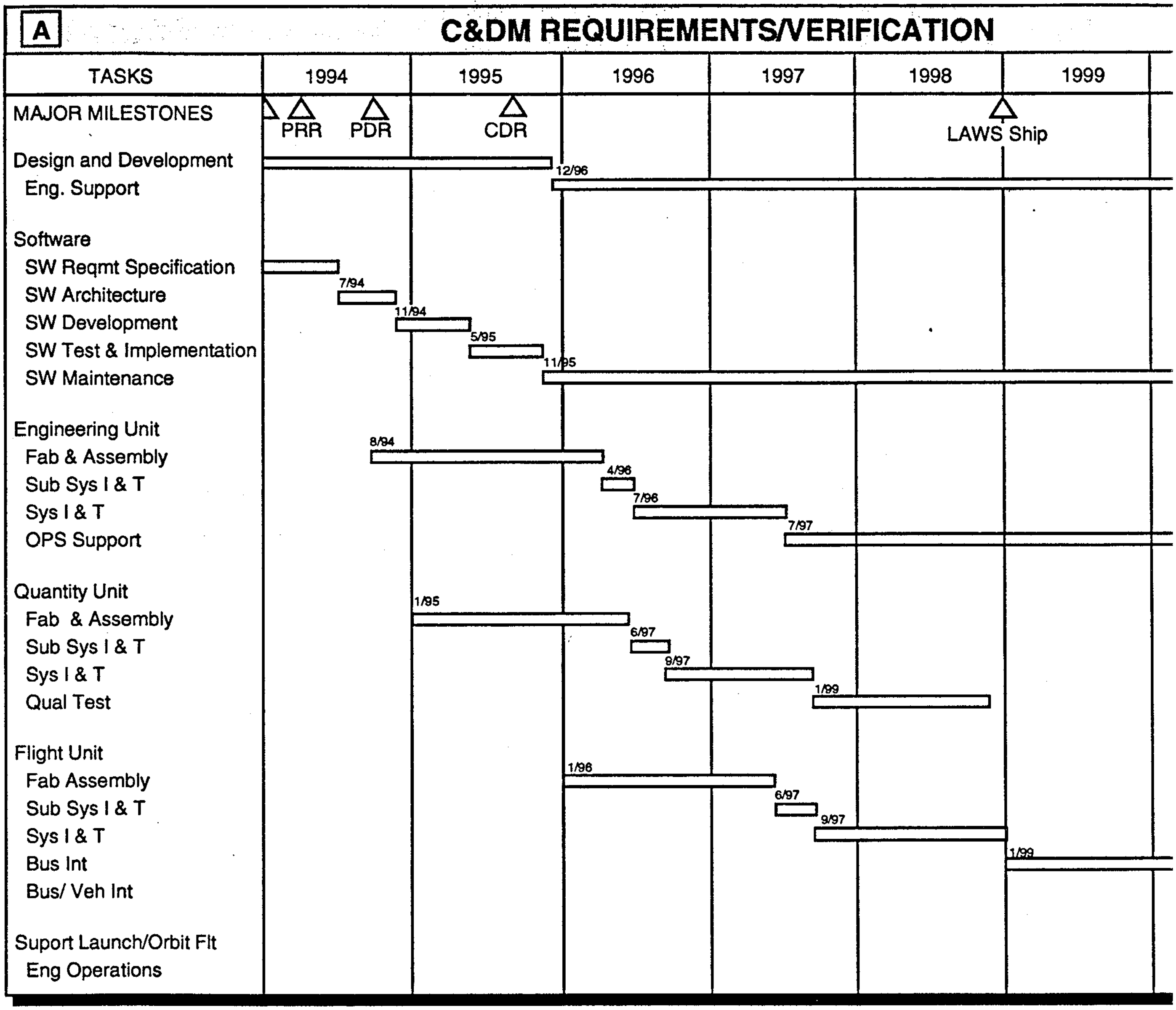
The block diagram of the LAWS power Electrical Power Subsystem is shown in Figure 26. The spacecraft's two 120 Vdc (GIIS-specified) power buses are labeled Platform +120 Vdc bus 1 and Platform +120 Vdc bus 2. The PDS will derive two redundant 28 Vdc power buses from the spacecraft's two 120 Vdc power buses. Each of the two buses will be capable of supplying all power required by the LAWS Instrument. Since both buses will be active simultaneously, each bus will supply half of the LAWS power load. For clarity, the redundancy of individual components in the PDS is not shown. The PDS will supply 120 Vdc to the transmit laser and 28 Vdc to the other LAWS subsystems. Only power distribution to the transmit laser, computer, and receiver is shown in Figure 26. Power distribution to other LAWS subsystems is similar.

As shown in Figure 26, circuit breaker 1 and circuit breaker 2 will protect the spacecraft 120 Vdc power bus from faults in the LAWS system. Circuit breakers 3 and 4 will protect the PDS dc/dc converters from faults occurring in the individual LAWS subsystems. These circuit breakers will be remotely resettable. If a circuit breaker trips, it can be reclosed by commands from the flight computer or spacecraft. The LAWS flight computer will monitor the health and status of the PDS and issue commands to the PDS.

Figure 27 describes the phase C/D schedule, requirements, components, and verification summary for the PDS.

3.4 THERMAL CONTROL SUBSYSTEM

On-orbit thermal control for the LAWS Instrument is achieved by a hybrid form of thermal control subsystem (TCS). An active fluid loop is used to transport the heat from high powered components such as the main laser, oscillator, seed laser, and azimuth drive. The heat is transferred through interfacing coldplates to be rejected to space via EOS central thermal bus radiators. Heat is also rejected passively by radiation from external surfaces of all components with an adequate field-of-view to space. Components are placed on the LAWS platform such that, in combination with conventional passive thermal techniques, they are controlled effectively within their allowable temperature limits by proper orientation during orbit (see Figure 28). Passive thermal control is achieved by use of multilayer insulation (MLI), thermal coatings and tapes, thermal covers, and thermal isolation materials. The passive TCS is based on HST TCS design with a wide application of low α/ε atomic oxygen resistant Ag FOSR (a flexible optical solar reflector composed of Teflon with vapor deposited silver) designed for a 15 year lifetime. The TCS for the telescope and mirrors, although primarily passive, will need to be augmented with heaters.

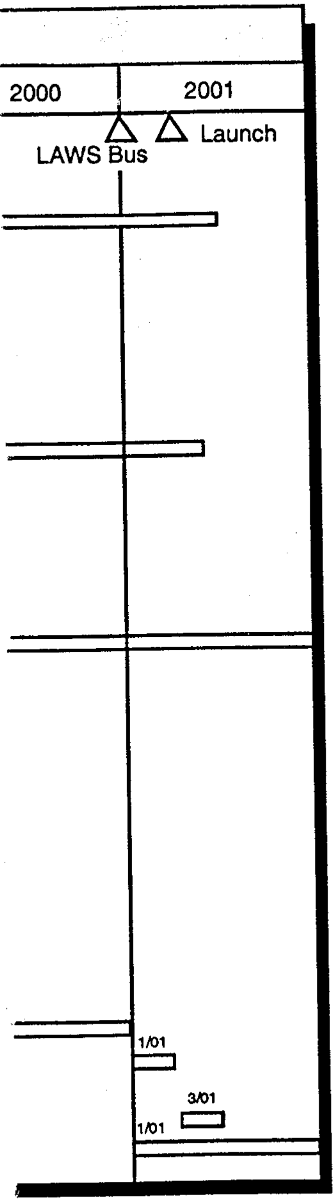


B REQUIRED COMMAND AND DATA MANAGEMENT SYSTEM EQUIPMEN

Component	Source	Maturity/heritage	Bread-boards*	Development Units	Fl U
Flight processor	NASA	Modified NASA/ESs		2	
Observatory bus interface unit			0	2	
Oscillator	Lockheed	Modified HSI	0	0	
So Atlantic anomaly detector		Modified/HEAO-2	0	1	

*Number of cards to be bread boarded

FOLDOUT FRAME /



Spares
1
1
0

C REQUIREMENTS IMPLEMENTATION/ VERIFICATION

Requirement	Implementation	Verification
Merge ENG and SCI data	FP, BDU	T, S
Selectable fixed and programmable telemetry formats	FP	T
Command decoding with error detection	FP	T
Digital processing with 100% margin	FP	A, I
Timing accurate to 10^{-9} in 24 hr, time coding to within 100 μsec of UTC	FP, BDU Oscillator	A, S
High energy protect	MCU, OBS BDU, SAAD	T, A

*A = Analysis/simulation, I = inspection, S = Similarity, T = test

D PLANNED TRADE STUDIES

Structured vs. object oriented tech.
ADA vs C language

E RISK SUMMARY

Risk Item	Risk Level	Risk Reduction Approach
Command processing	Low	Utilize existing designs as applicable. Engineering Specialist (ES) to monitor process flow.
TLM format and rates	Low	Utilize existing formats as available, provide hardwired contingency format. ES to monitor process flow.
Computer processes	Medium	New S/W design – ES to evaluate HW/SW design.
Subsystem integration	Low	Identified hardware/ software test facility. Critical path monitored by ES. Assure QA surveillance of parts used.
Safe mode control	Medium	Minor modification to existing design. ES to monitor standard process flow.

F VERIFICATION SUMMARY

Development tests

- FP development test
  - Purpose: establish functional FP operation
  - Equip required: development unit, MCU development cards, test equipment
- Integrated avionics test
  - Purpose: establish functional CDMS operation of the MCU with BIUs via the serial bus
  - Equip required: tested MCU dev unit, a tested OBS BIU development unit, a tested SI BIU development unit, a non-flight-item oscillator, a vehicle systems simulator, and the MCU test equipment
  - Environment: ambient
- SAAD development test
  - Purpose: establish functional SAAD operation
  - Equip required: SAAD dev unit and standard digital test equipment
  - Environment: ambient

Qualification/acceptance tests

- On units shown above
  - Purpose: individual equipment qualification
  - Equipment required: per unit as shown above
  - Environment: ambient, thermal vacuum, thermal cycle, vibration, and EMI

G SCIENCE INSTRUMENT ACCOMMODATION PLAN

South Atlantic anomaly detector provides warning to instruments based on software selectable thresholds.

Safe mode power control commands backup primary science instrument power switching system.

H DESIGN MARGINS AND GROWTH

Processor sized to ensure 100% margin in worst case: average processor margin is 240%

Memory sized to ensure 100% margin in worst case; average margin provided is 260%

Serial bus provide 320% margin at 1 MHz

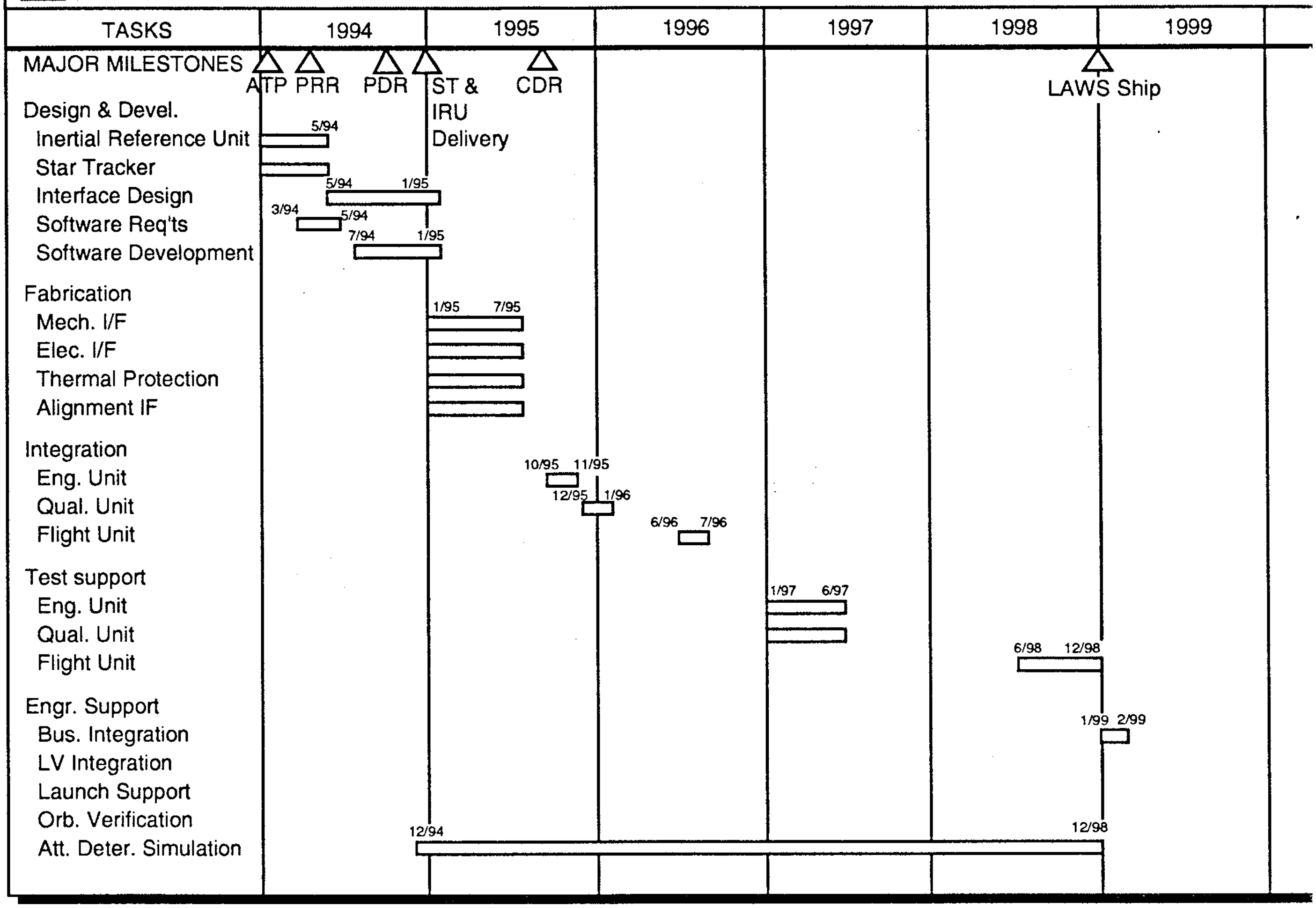
Bus design allows for additional BIUs

BIU design allows command and telemetry to be added in discrete increments by adding appropriate cards

Modular design allows the incorporation of new technologies

Figure 24. Overview/Summary of the Command and Data Management Subsystem

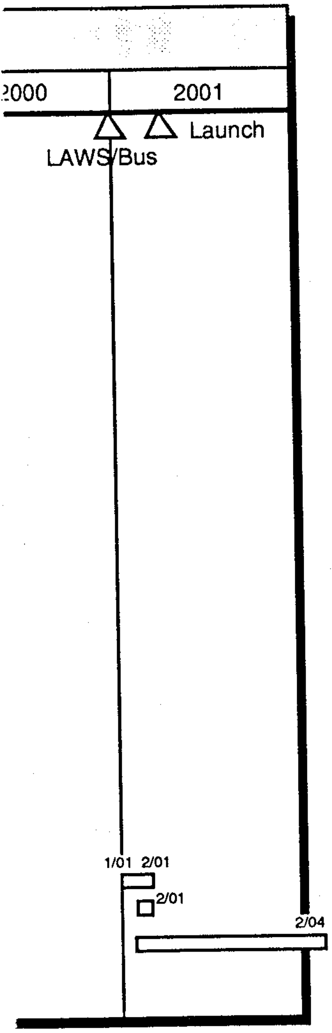
A ATTITUDE DETERMINATION PLAN OVERVIEW



B REQUIRED SUBSYSTEM EQUIPMENT

COMPONENT*	SOURCE	QUANTITY/UNIT	ENG. UNIT	QUAL. UNIT
Inertial Reference Unit	AD1	1	1	1
Star Tracker	AD2	2	2	2
Mechanical Interface	LMSC	3	3	3
Cables	LMSC	6	6	6

* "S" Parts
**Engineering Unit Components Used for Spares



FIT UNIT**
1
2
3
6

312594-RJ-FO

C REQUIREMENT IMPLEMENTATION/VERIFICATION

KEY REQUIREMENT	IMPLEMENTATION	VERIFICATION
Operational Life	5 yr on Orbit	Comparison and Test
Performance	• Attitude Knowledge: 100 µrad/Axis, One Sigma • Receive Transmit Align: 3 µrad/Axis, One Sigma • Pointing Accuracy: 8 mrad/Axis, One Sigma	Analysis and Simulation
Interfaces and Software Functions	• IRU Attitude Update • Star Tracker Update • Lag Compensation • Receive-Transmit Alignment Loop	Simulation and Test

D PLANNED TRADE STUDIES

TRADE ITEM	BASELINE DESIGN
No. of Star Updates Per Orbit vs. IRU Performance	10 Updates/Orbit, Scale Factor Error < 75 PPM, Gyro Drift Rate Uncertainty < 0.01 deg/hr
On Orbit Recalibration Procedures for Attitude Determination	Use Hard Target Return to Recalibrate LOS of Outgoing Laser Beam
Methodology of Compensating for Space Platform Jitter; Active vs. Passive	Passive; Use Isolators Between Base Assembly and Optical Bench as Required *(Need Goddard to Supply Jitter PSD of Space Platform)*

E RISK SUMMARY

RISK ITEM	RISK LEVEL	RISK REDUCTION APPROACH
IRU Failure	Low	Space Qualified and Demonstrated Unit with Built-in Double Redundancy for Each Attitude Axis
Star Tracker Failure	Low	Space Qualified and Demonstrated Unit
Misalignment Due to Zero g and Launch	Moderate	Develop Methodology to Recalibrate Using Hard Target Returns

Figure 25. Overview/Summary of the Attitude Determination Subsystem

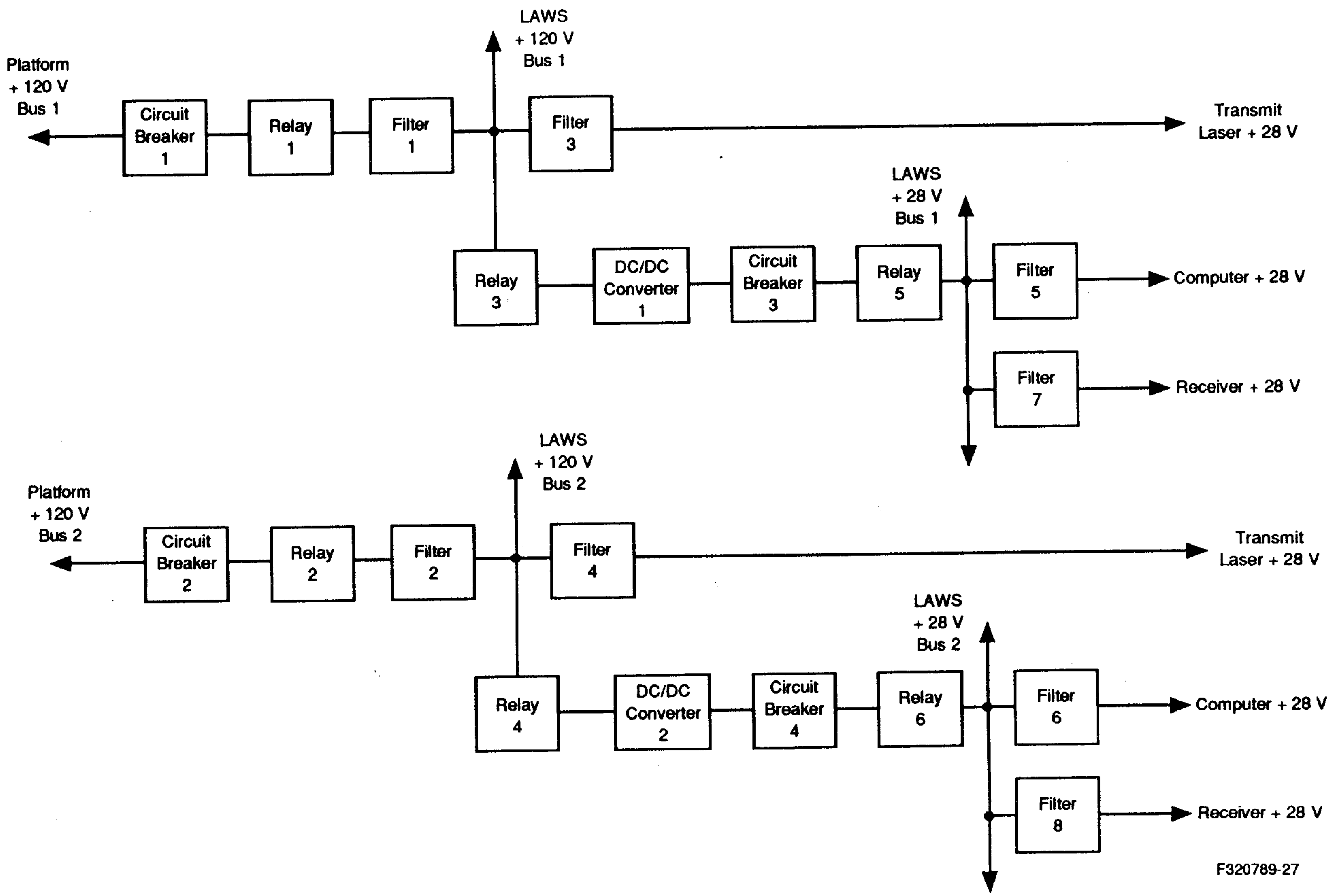
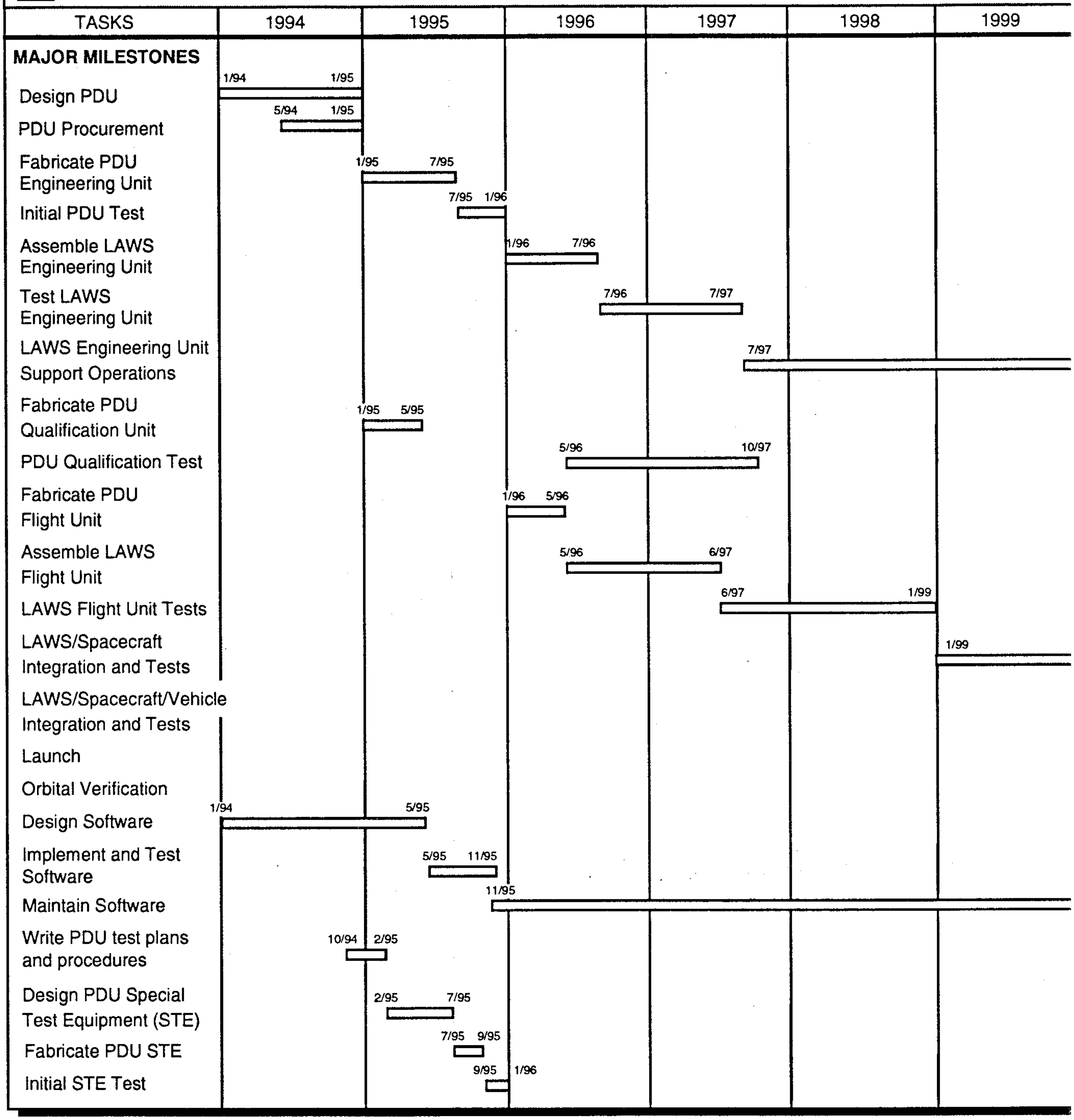


Figure 26. LAWS PDS Block Diagram

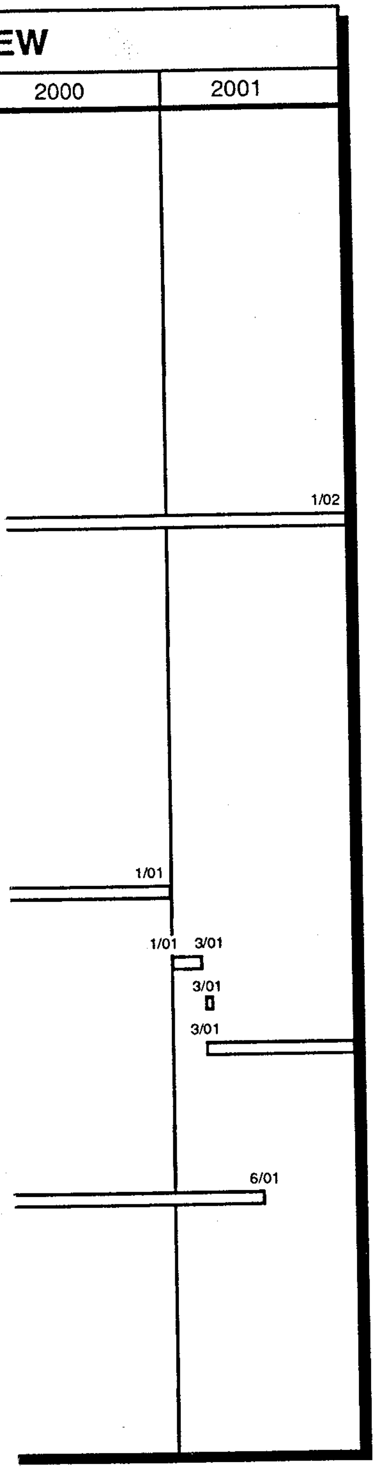
A ELECTRICAL POWER DISTRIBUTION SUBSYSTEM OVER



B REQUIRED SUBSYSTEM EQUIPMENT

COMPONENT	SOURCE	MATURITY/HERITAGE	MOCKUPS	ENGINEERING UNIT
Power Distribution Unit	LMSC	Modified/HST	1	1
Cables	LMSC	Modified/HST	28	28

FOLDOUT FRAME /



QUAL. UNIT	FLIGHT UNIT
1	1
28	28

F320789-02

C REQUIREMENT IMPLEMENTATION/VERIFICATION

KEY REQUIREMENT	IMPLEMENTATION	VERIFICATION
28 V ± TBD Vdc	dc/dc Converter output voltage = TBD Vdc	A/T
TBD W of power	dc/dc Converter output voltage = TBD W	A/T
Energy storage	Batteries	A/T
Circuit protection	Remotely resettable circuit breakers	A/T
Redundancy	Multiple parallel components in power path; two redundant isolated power busses	A/T

D PLANNED TRADE STUDIES

Distributed vs. centralized power distribution units

E RISK SUMMARY

RISK ITEM	RISK LEVEL	RISK REDUCTION APPROACH
PDU Failure	Low	Space qualified parts, redundancy, system testing

F VERIFICATION SUMMARY

Acceptance, development, and verification testing per MIL-STD-1540

G SI ACCOMMODATION

Standard power control and distribution interface

H DESIGN MARGIN AND GROWTH

Multiple power buses rated for 20% growth in loads

Figure 27. Overview/Summary of the Electrical Power Subsystem

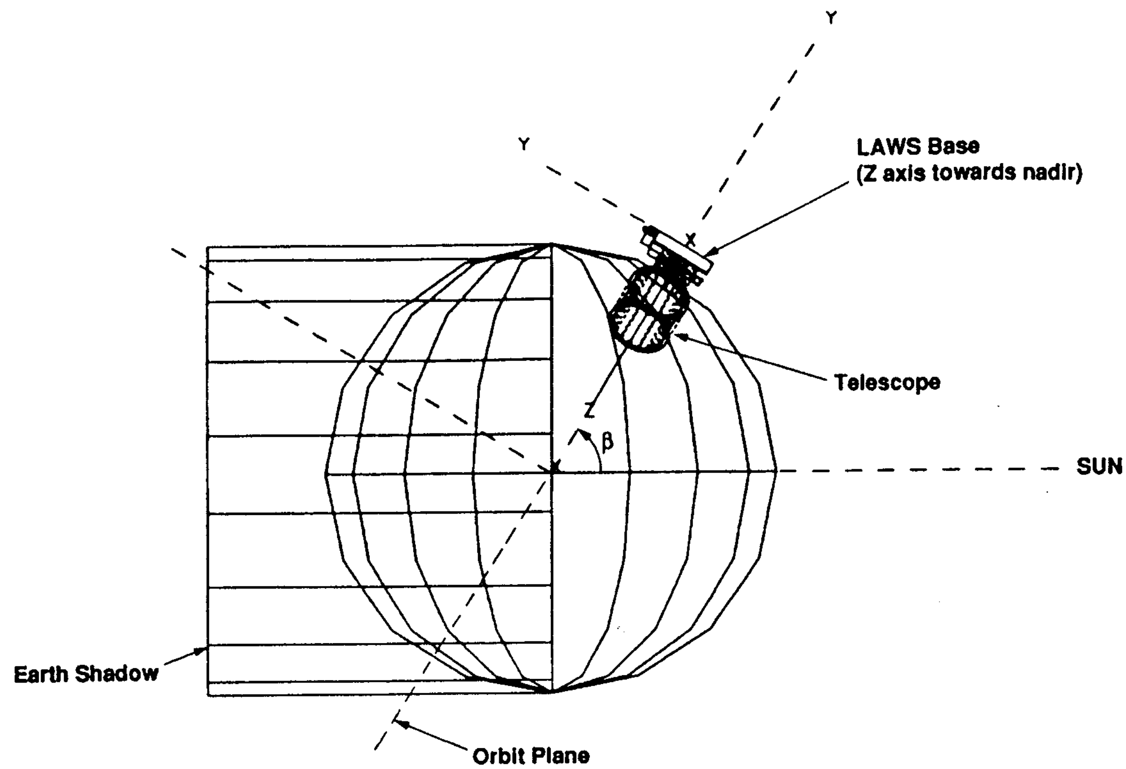


Figure 28. LAWS Instrument in Earth Orbit

Figure 29 shows the passive thermal coatings for the telescope and LAWS base components. Figure 30 presents the Phase C/D summary for the development of the thermal control system.

3.5 OPTICAL SUBSYSTEM

The LAWS Optical subsystem has two major functions. It first acts as a transmitter in the role of a beam expander, taking the 4 cm output of the 9.11 μm laser and forming a 1.67 m diameter beam which is scanned via a bearing assembly across the Earth's atmosphere. Secondly, it performs the function of a receiver, acquiring the Doppler shifted scattered energy from the troposphere. The Optical subsystem interferes with the LAWS laser via the transmitter relay optics and with the LAWS receiver at the tip/tilt mirror, which performs dynamic lag angle compensation.

The Optical subsystem functional flow diagram is shown in Figure 31. The selected baseline design for the telescope is a two-mirror afocal configuration operating with a split field. With a F/1.5 primary mirror, the telescope fits within the current packaging envelope. The transmit optic axis is oriented off-axis by 0.2 deg in objects space in order to remove the course lag angle resulting from the telescope scanning in azimuth and the round trip time for each transmitted laser pulse. Compensator optics are required in the transmit path to balance focus error from telescope field curvature. The receive channel is oriented on-axis. Pupil relay optics are required to limit the size of the radiation through the scan bearing over the entire ±0.3 mrad object space field-of-view. The pupil relay also creates a real pupil at which a single tip/tilt mirror can correct for second order dynamic lag angle compensation.

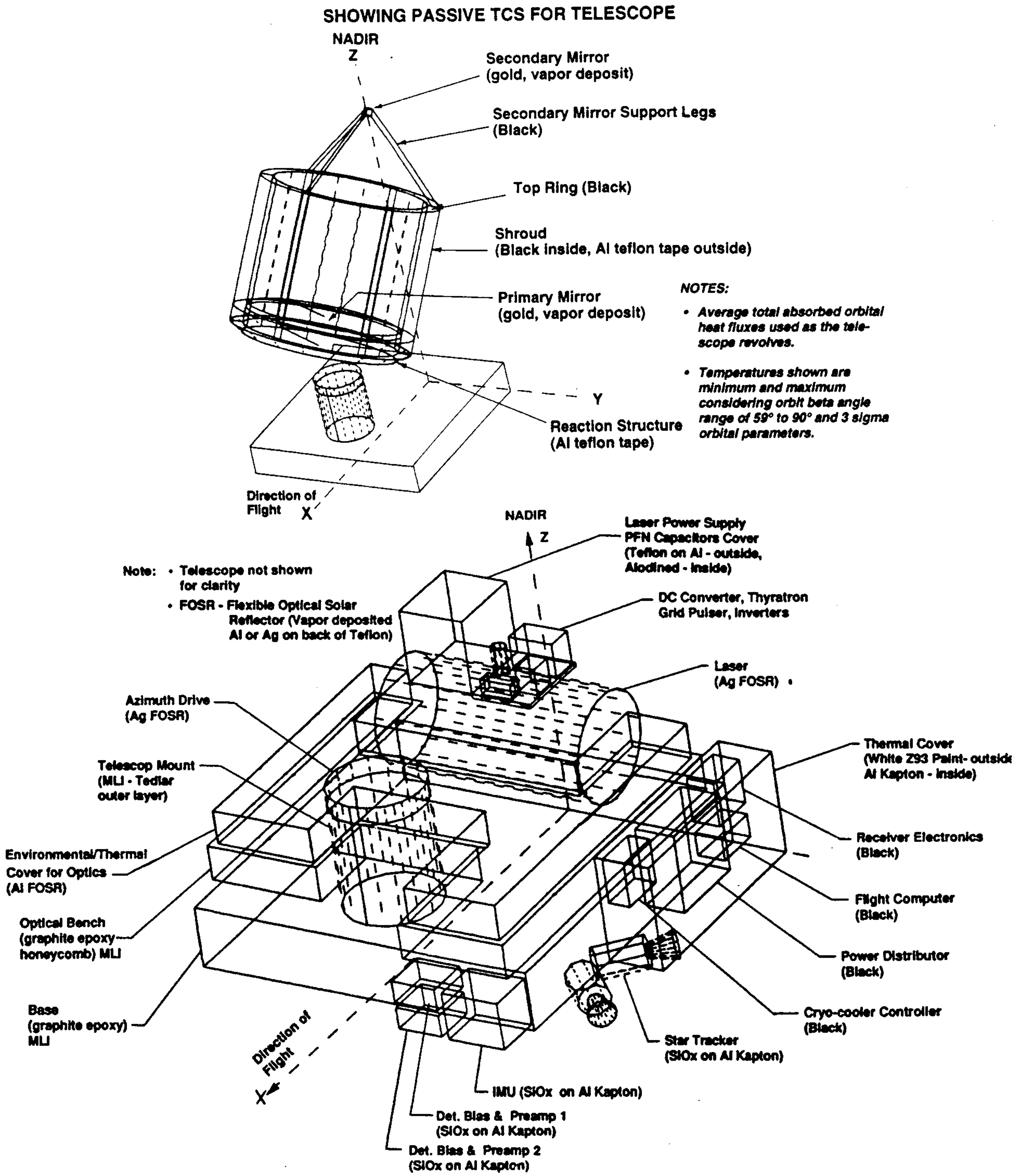
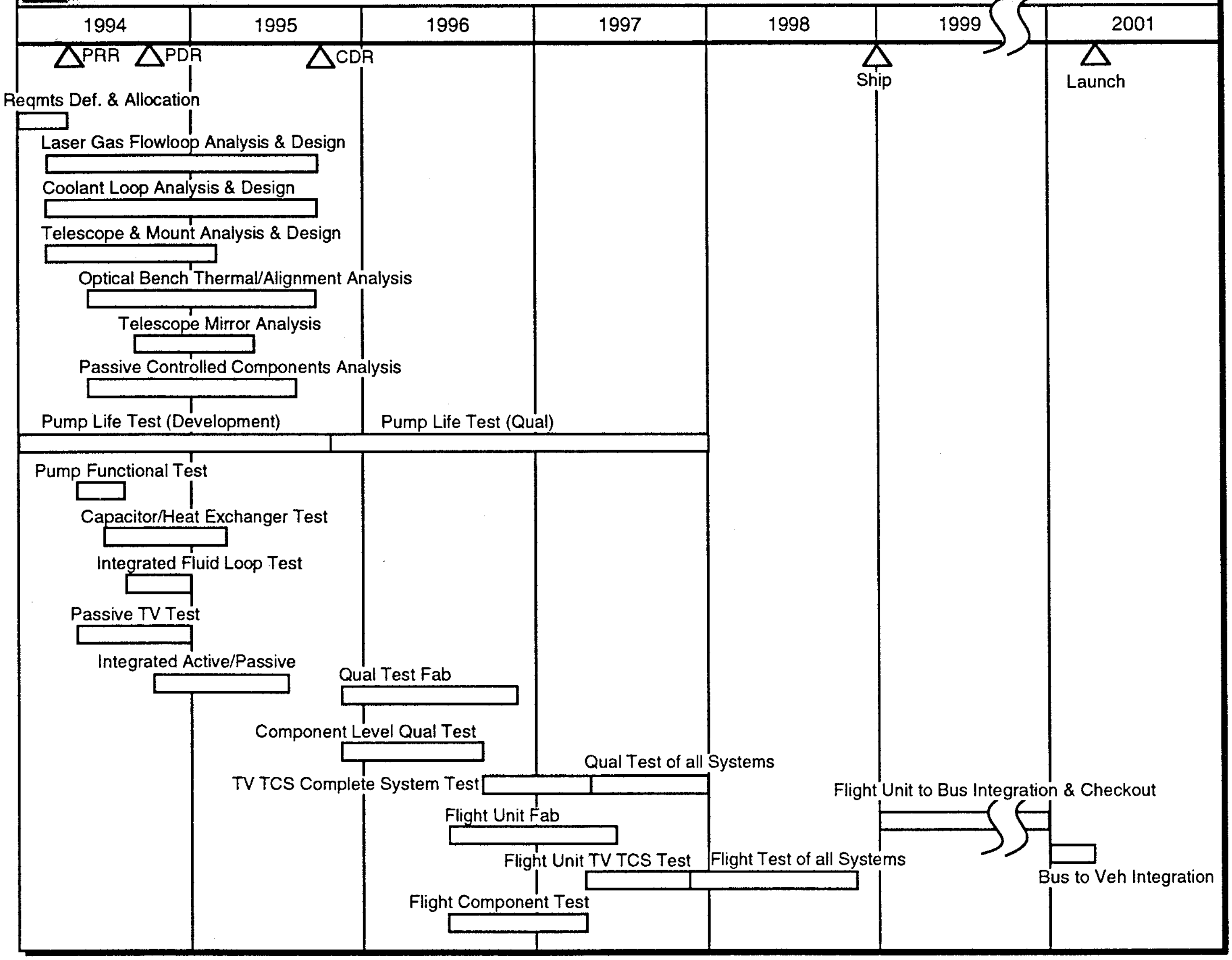


Figure 29. Thermal Radiation Model Plot of LAWS Instrument Showing Passive TCS Surface Coatings

A THERMAL CONTROL SUBSYSTEM DEVELOPMENT, TEST AND EVALUATION PLAN OVERVIEW



B REQUIRED THERMAL CONTROL SUBSYSTEM EQUIPMENT

COMPONENT	SOURCE	MATURITY/HERITAGE	LIFE TESTING	ENGINEERING MODEL	QUAL UNIT	FLIGHT UNIT	SPARES
Pump Package	Supplier 1	Space Qual/Space Lab	1	1	1	1	1
Pumps	Supplier 1	Space Qual/Space Lab	3				1
Cold Plates	TBD	Same as EOS		2	2	2	
Diverter Valves/Controllers	Supplier 1	Space Qual/Shuttle	1	1	1	1	1
Heat Exchangers	TBD	Modified/Breadboard		2	2	2	2
Ag FOSR	Supplier 2	Off the Shelf/HST		TBD	TBD	TBD	
MLI	Supplier 2	Off the Shelf/HST		TBD	TBD	TBD	
Heaters, Kapton	Supplier 3	Off the Shelf/HST		TBD	TBD	TBD	

FOLDOUT FRAME

C TCS REQUIREMENT IMPLEMENTATION/ VERIFICATION

KEY REQUIREMENTS	IMPLEMENTATION	VERIFICATION
1. Maintain laser gas temp at all PRF	Convective heat exchanger within active cooling loop	Analysis, test
2. Five year life on active cooling system	Redundant pumps	Life test
3. Maintain temp limits of components for all mission phases	Active cooling and passive Ag FOSR outer surfaces, MLI	Analysis, TVT
4. Control of thermally sensitive optical bench, telescope & mirror/ supports	Controlled by FOSR, heaters, ULE optics, gold coatings	Analysis, TVT
5. Minimize contamination of optics	Optical bench thermal cover as contamination collector and spatial separation of fluid lines from optics	Analysis, TVT
6. Design for 5 year atomic oxygen environment	Teflon Ag FOSR, $\Delta\alpha = 0.012$ per year based on flight data	Analysis, LDEF data
7. Decouple optics from orbit environment	Thermal covers, Ag FOSR outer surfaces, low α/ε external, thermal isolators	Analysis, TVT
8. No single point failure	Redundant pumps, valves heater systems	Analysis
9. Maintain hardware and components above survival temperatures	Safe mode developed with heaters/thermostats to maintain component above lower survival limits	Analysis
). Maintain struct temp gradients and changes to meet pointing requirem"ts	Thermal cover, Ag FOSR and heater system	Analysis, TVT

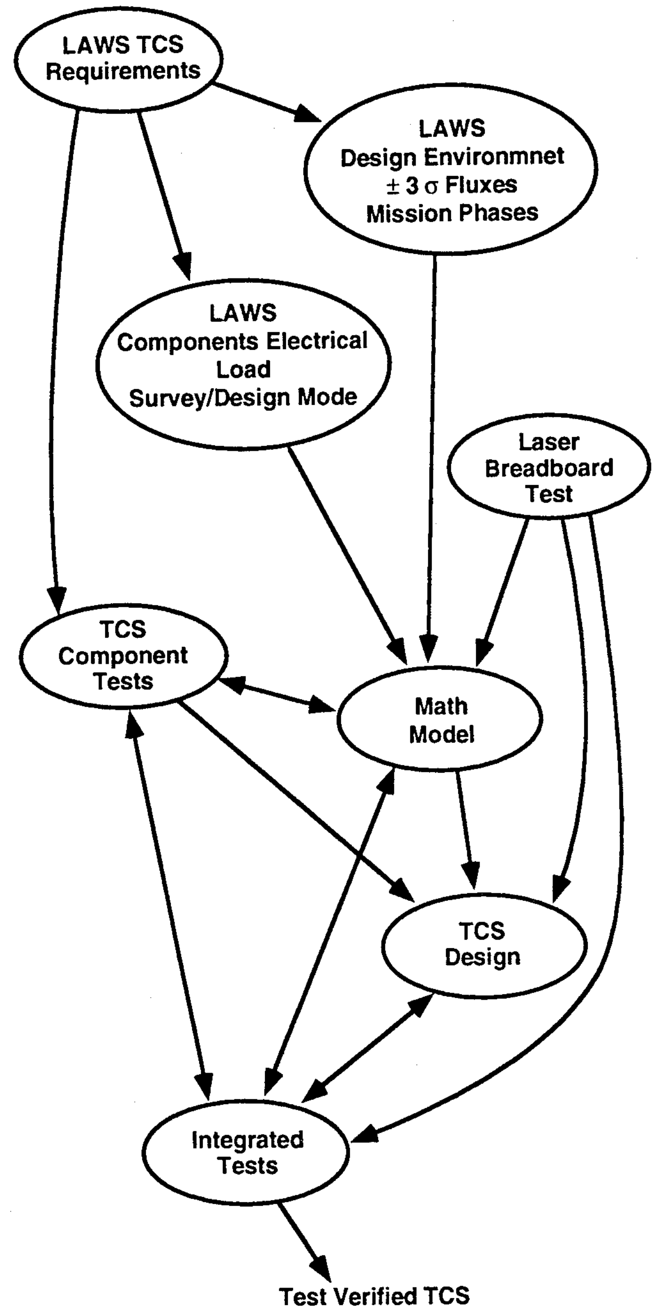
D TCS TRADE STUDIES AND ANALYSIS

1. Position of passively controlled avionics components on the base.
2. Compact convective heat exchanger versus back-to-back cold plates for EOS/LAWS active thermal control interface.
3. Pumped loop versus heat pipe active TCS.
4. Redundant loops versus single loop with redundant pumps for active TCS.
5. Existing space qualified pump packages versus new development long life pumps.
6. Passive versus active cooling of main laser power supply.

E TCS RISK REDUCTION SUMMARY

RISK	LEVEL	RISK REDUCTION APPROACH
Five year pump life	High	Life testing & redundant pumps
Five year valve life	Med	Cyclic testing
Five year life of other TCS compon.	Low	Stable materials
Contamination due to outgassing	Low	Material selection, bakeout & design
Contamination due to coolant leaks	Low	Use of brazed joints and leak containment devices
Contamination due to biological growth in coolant	Low	Sterilization system

F VERIFICATION SUMMARY



G DESIGN MARGINS AND GROWTH

1. Using hot and cold design cases with 3σ fluxes
2. Range of equipment duty cycles and MLI/thermal coating performance
3. Heaters sized 1.5X required at minimum bus voltage
4. Controlling to levels well within requirements
5. 2.0 x pump life
6. Redundant pump controller and power circuits
7. Redundant heaters & heater thermostats

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Figure 30. Overview/Summary of the LAWS Thermal Control System

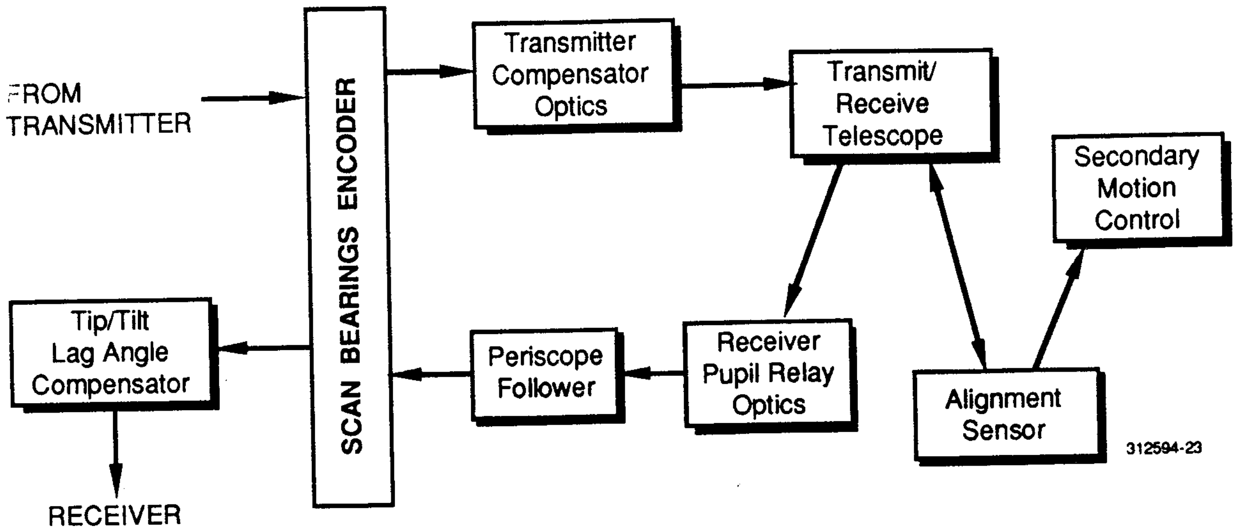


Figure 31. Optical Subsystem Functional Flow Diagram

The periscope follower is a two-mirror assembly which rotates synchronously with the telescope to fold the receive radiation back on axis. Telescope alignment is monitored by additional active sensors and maintained by actuators controlling the location and orientation of the secondary mirror. Other design features include a lightweight system with a 90 percent lightweight ULE primary mirror, silicon carbide fold optics, and graphite epoxy structures. The low residual waveform error is due to a low sensitivity design, the alignment maintenance system, and the use of ULE with its virtually zero CTE and variation of CTE.

The Optical subsystem development schedule is shown in Figure 32 (block A). The major long lead time items are the ULE blanks for the 1.67 m primary mirror. The first primary will require approximately 9 months to fabricate.

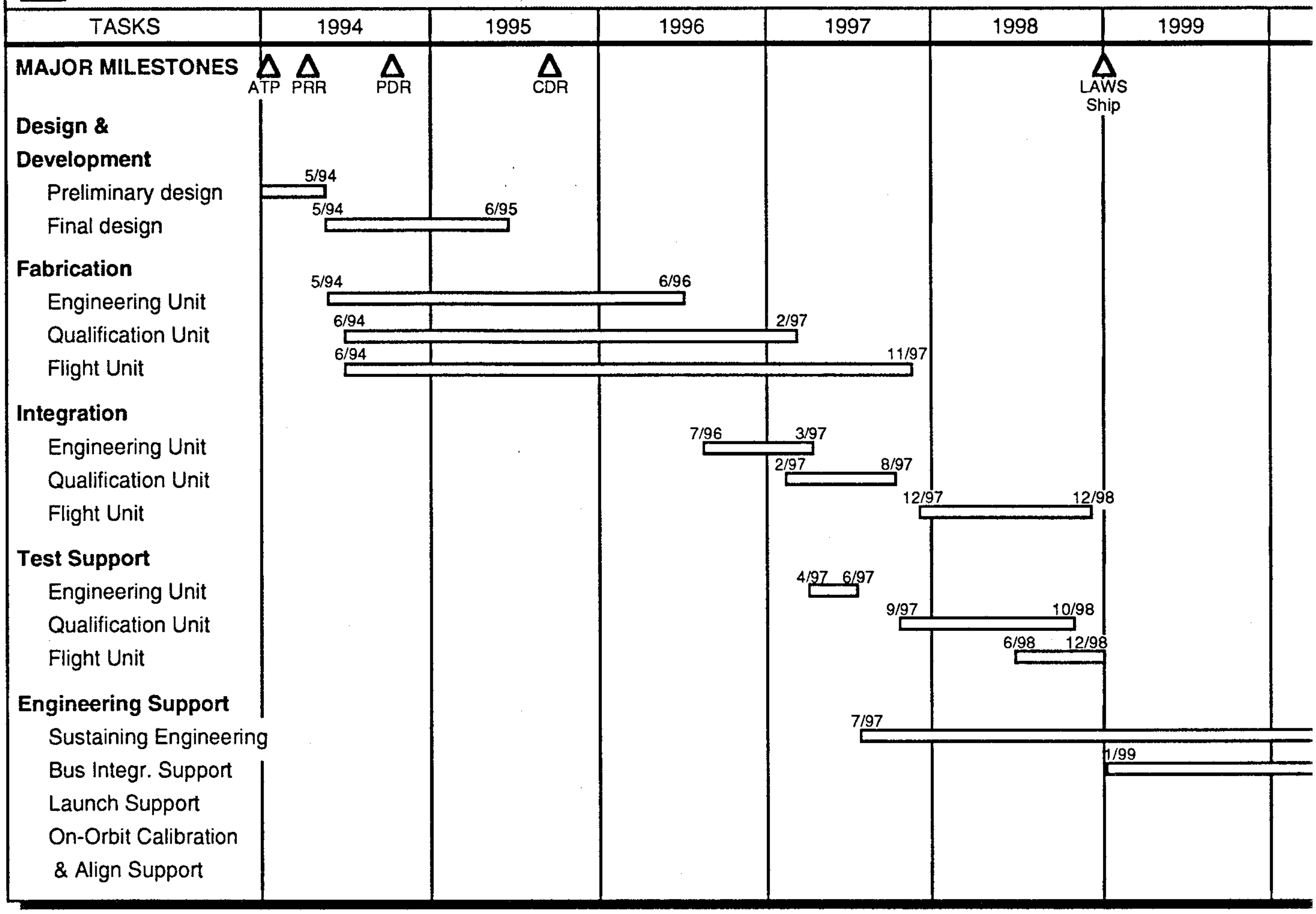
Subassemblies for various units are listed in Figure 32 (block B). Key requirements, implementations, and verification approaches are also shown in Figure 32 (block C).

3.6 RECEIVER/PROCESSOR SUBSYSTEM

The Receiver/Processor subsystem baseline is summarized as follows:

- Redundant HgCdTe photovoltaic detector arrays with 52 percent effective quantum efficiency at 100 MHz and 43 percent at 1300 MHz (47.5 percent average)
- Mixing efficiency of 0.33 for uniformly illuminated annular aperture with ratio of inner to outer diameter of 0.44

A OPTICAL SUBSYSTEM OVERVIEW

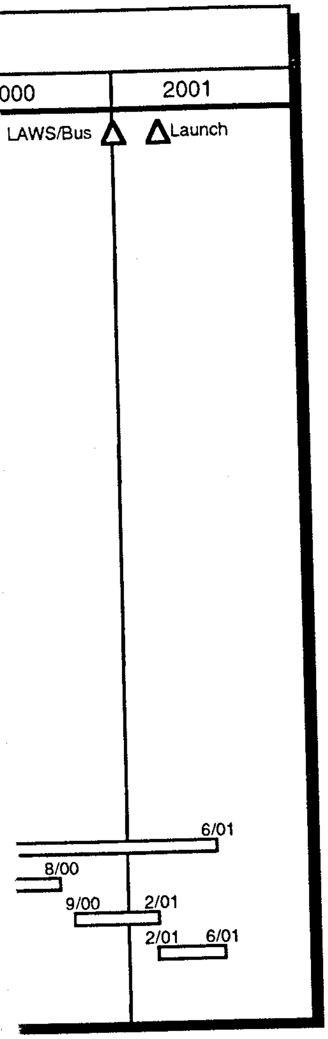


B REQUIRED SUBSYSTEM EQUIPMENT

COMPONENT*	SOURCE	QUANTITY/UNIT	ENGINEERING. UNIT	QUA
Primary Mirror Assembly	Litton-Itek Optical Systems	1	1	
Secondary Mirror Assembly	Itek	1	1	
Metering Structure	Itek	1	1	
Reaction Structure	Itek	1	1	
Transmit Relay Optics Set	Itek	1	1	
Receive Relay Optics Set	Itek	1	1	
Fold Optics Set	Itek	1	1	
Thermal Control System	Itek	1	1	
Azimuth Scanning System	Itek	1	1	
Tip/Tilt Mirror	Itek	1	1	
Telescope Alignment System	Itek	1	1	
Mechanical, Thermal, Electrical, and Optical Interfaces	LMSC	5	5	

* "S" Parts
**Engineering unit components used for spares

FOLDOUT FRAME

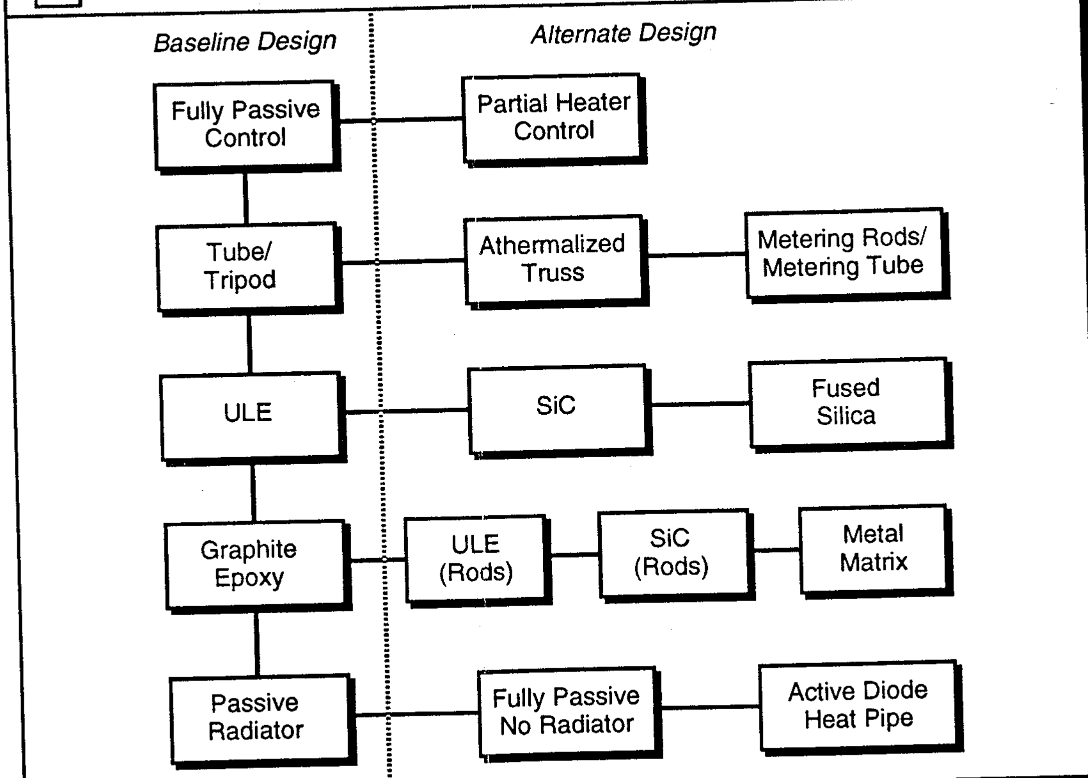


UNIT	FLIGHT UNIT**
	1
	1
	1
	1
	1
	1
	1
	1
	1
	1
	1
	5

C REQUIREMENT IMPLEMENTATION/VERIFICATION

KEY REQUIREMENT	IMPLEMENTATION	VERIFICATION
Operational Life	5 years on orbit	Comparison and test
Maximize Heterodyne Efficiency	• Wavefront error ≤ 0.07 waves RMS • Flat field over receive FOV • Obscuration < 3% • Round trip pointing stability ≤ 1.5 µrad • Magnification: 42X	Analysis, simulation, and test
Lag Angle Compensation	• Format: 2 points separated in field by 0.185° • Dynamic tip/tilt mirror	Analysis and simulation

D PLANNED TRADE STUDIES



E RISK SUMMARY

RISK ITEM	RISK LEVEL	RISK REDUCTION APPROACH
Motor/Bearing/Encoder	Low	Space qualified and demonstrated unit
Optical Coating Fatigue	Low	Risk reduction testing with LAWS laser breadboard
Telescope Alignment System	Low	Risk reduction testing with alignment system breadboard

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Figure 32. Overview/Summary of Optical Subsystem

FOLDOUT FRAME

- Signal aligned on central element of array with exterior elements for alignment monitoring
- Local oscillator beam tailored for central (signal) element for shot noise limited operation with phase front matched to signal beam; spill over to alignment elements
- Redundant Split Stirling Cycle cryogenic coolers to optimize detector operating temperature
- Redundant Split Stirling cycle cryogenic coolers to optimize preamp operating temperature
- Bias supply and preamplifiers space-qualified versions of standard units
- Automatic gain control for wide dynamic range between aerosol and ground returns
- 10 bit 75 million samples per s analog-to-digital (A/D) converter for adequate wind signal frequency response and dynamic range.

The LAWS Receiver/Processor subsystem consists of a wide bandwidth photo detector array, active cooling for the photo detector, bias circuitry, preamplifiers, and on-board signal processing electronics. For each of these components, several options were considered before the selection of the baseline Receiver/Processor subsystem components.

Figure 33 is the Receiver/Processor subsystem block diagram. The local oscillator optical source (upper left hand corner of Figure 33) from the master oscillator is expanded to match the 4 cm diameter of the beam received from the telescope before being focused on the photo detector. The Doppler signal is received from the telescope and optical train, superimposed on the local oscillator, and directed toward and focused on the photo detector array. Cooling is provided for the detectors. Outputs from the detectors are amplified and frequency shifted to the frequency/amplitude range of the A/D converter. The "zero" Doppler (relative to the ground) is set for the center of the 0 to 30 MHz baseband to minimize A/D frequency span requirements. The levels of each channel from the detector array are measured to monitor the received optical signal spot location upon the detector array for optimal alignment. The output of the A/D is buffered and telemetered to the platform data interface. The Receiver/Processor development schedule is shown in Figure 34.

3.7 LASER SUBSYSTEM

The CO_2 Transmitter Laser subsystem is shown in the block diagram in Figure 35. The following components make up the Laser subsystem:

- Optical resonator
- Electrical discharge
- Pulse power supply
- Pressure vessel structure
- Gas flow loop

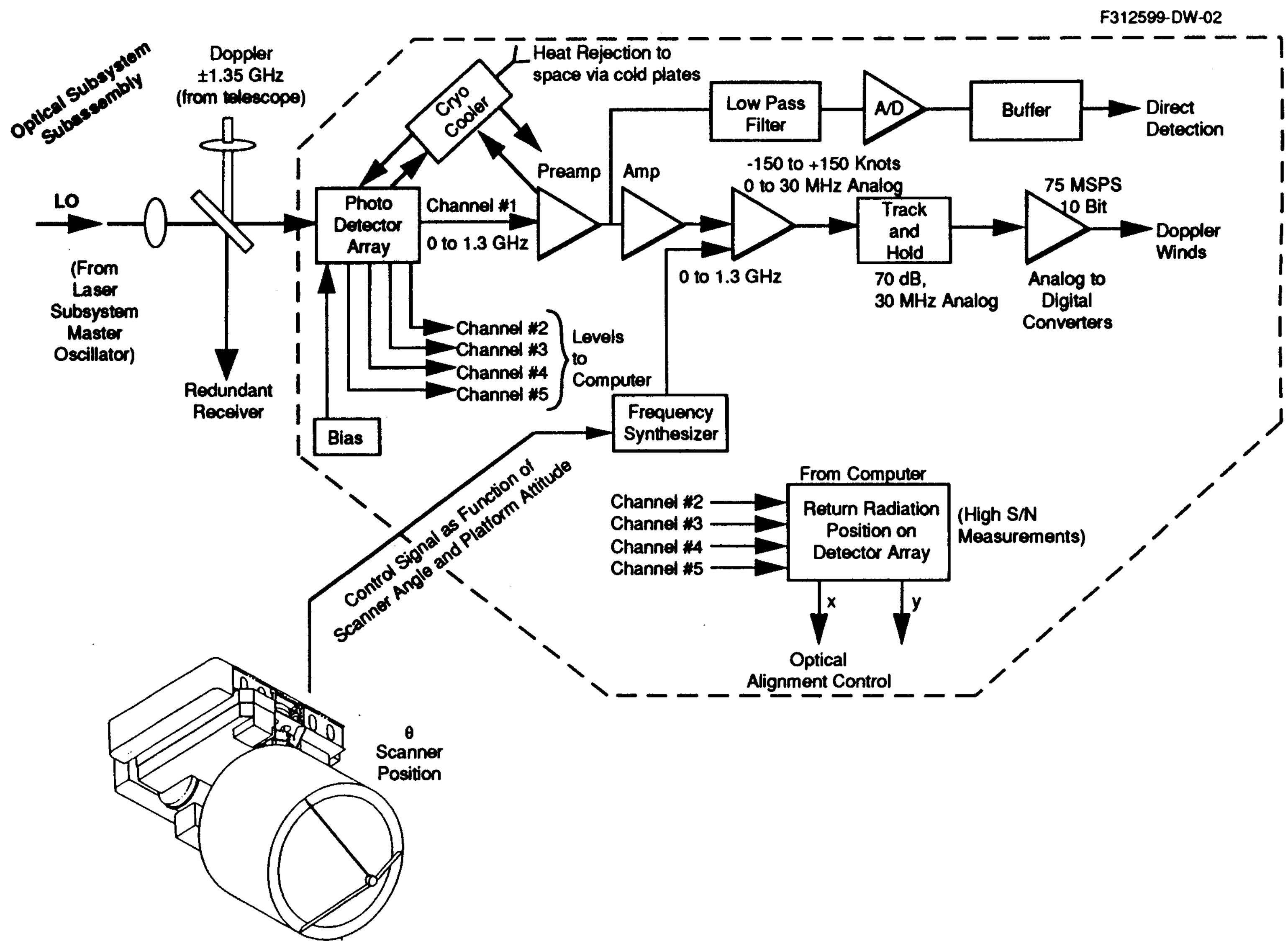
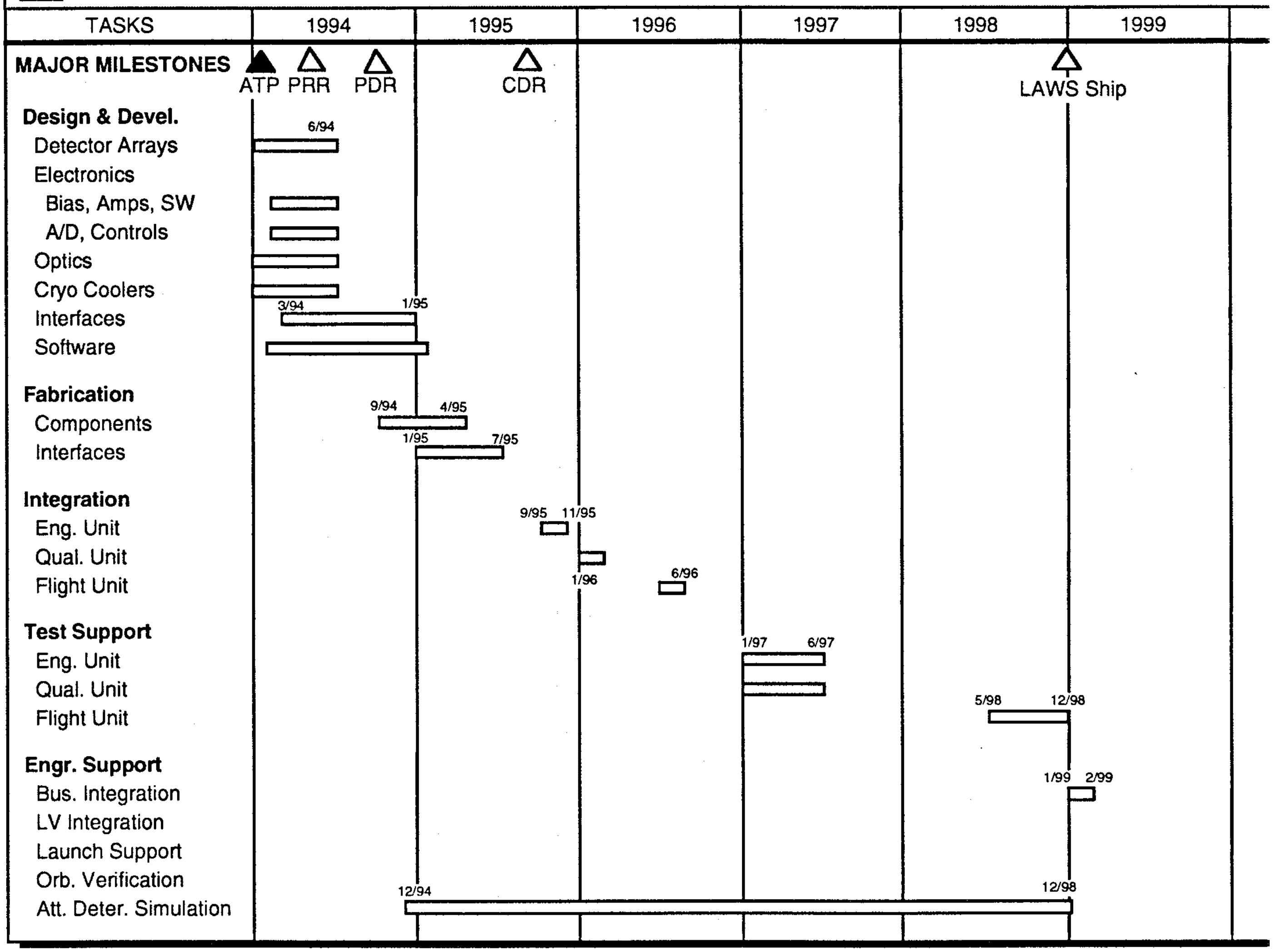


Figure 33. LAWS Receiver/Processor Subsystem Block Diagram

A

RECEIVER / PROCESSOR PLAN OVERVIEW



B

REQUIRED SUBSYSTEM EQUIPMENT

COMPONENT*	SOURCE	QUANTITY/UNIT	ENG. UNIT	QUAL. UNIT
Detector Array	RP 1	2	2	2
Support Optics	RP 2	1 set	1 set	1 set
Support Electronics				
Bias ckt, Amps	RP3	1 set	1 set	1 set
A/D Conv., Controls	RP4	2 sets	2 sets	2 sets
Cryo Cooler Assembly	LMSC	4	4	4
Cables	LMSC	2 sets	2	2

** "S" parts*
*** Engineering unit components used for spares*

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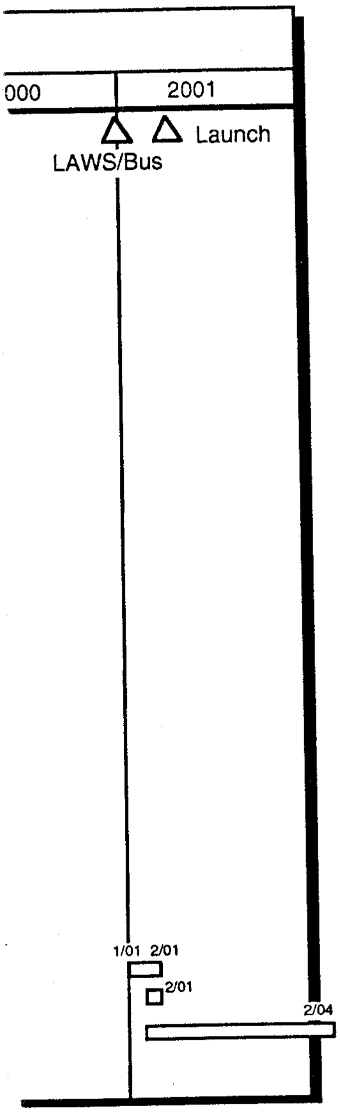

FLIGHT UNIT**
2
1 set
1 set
2 sets
4
2

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C REQUIREMENT IMPLEMENTATION/VERIFICATION

KEY REQUIREMENT	IMPLEMENTATION	VERIFICATION
Operational Life	• 5 yr on orbit • No single point fail	Comparison and test Analysis and test
Performance	• A/C quantum effect • Closed loop tracking • Acceptable aging • Temperature control • Data handling/control	Measurement Analysis, measurement and simulation Measurement, analysis, comparison Measurement and analysis Simulation
Interfaces and Software Functions	• Ground return alignment • Automated gain control • Data digitization & storage • System performance monitor	Simulation and test

D PLANNED TRADE STUDIES

TRADE ITEM	BASELINE DESIGN
Cooled vs. uncooled Amps	Cooled where noise figure is improved
Number of pre-amps for signal detector	Baseline is four switched pre-amps
Redundant vs. nonredundant	Redundant detectors and coolers
Adjustable focus vs. fixed miniscus lens	Adjustable focus
Dual tip-tilt vs. single for L.O. adjustment	Dual
Number of array elements	Four alignment plus central

E RISK SUMMARY

RISK ITEM	RISK LEVEL	RISK REDUCTION APPROACH
Detector Failure	Moderate	1. Produce several batches of detectors and perform accelerated aging tests. 2. Design with redundant detectors.
Loss of S/N from misalignment	Moderate/Low	1. Design for graceful S/N loss from misalignment. 2. Design for low BW on orbit alignment correction.
Cooler failure	Low	1. Lockheed developing/qualifying under EOS-A contracts.

F PERFORMANCE ENHANCEMENT TOOLS

ITEM	POTENTIAL ENHANCEMENT
Detector A/C quantum efficiency	Perform 18 to 30 month development/test effort; anticipate 30 to 60 % performance improvement.

Figure 34. Overview/Summary of the Receiver/Processor Subsystem

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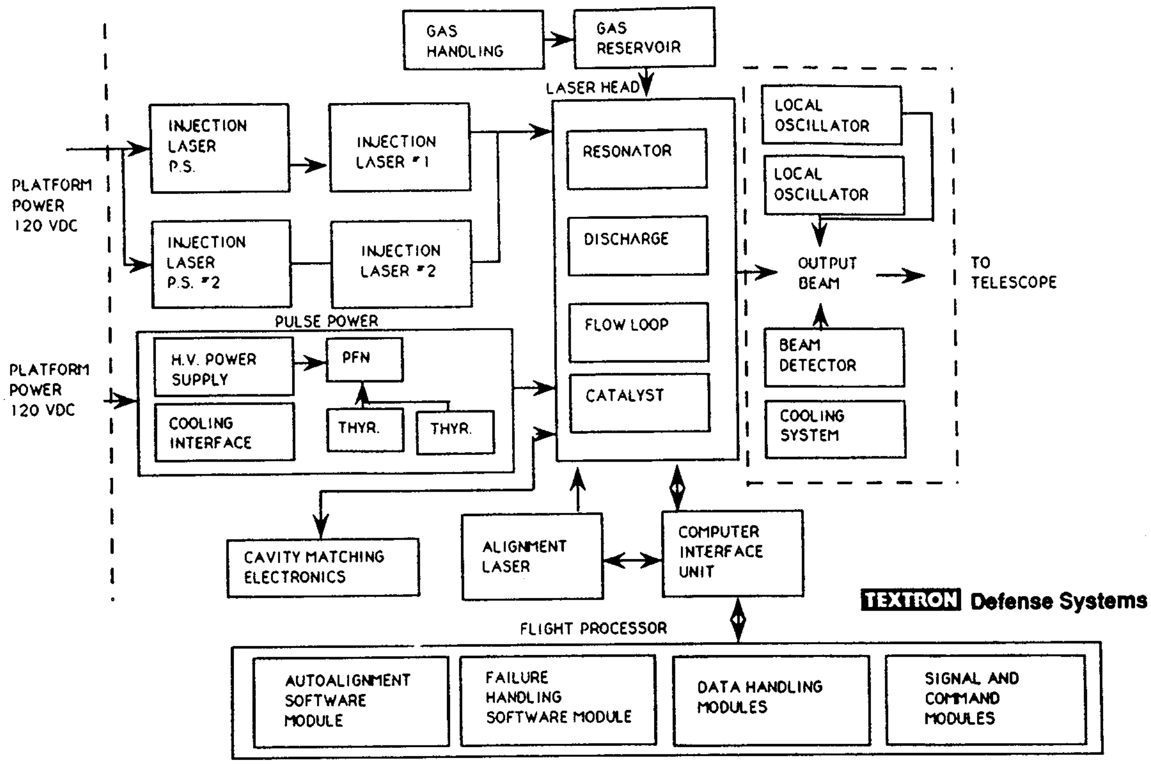


Figure 35. Laser System Block Diagram

- Controls and instrumentation
- Injection laser
- Local oscillator.

The physical layout of the Transmitter Laser subsystem is shown in Figure 36. Its general configuration is fundamentally that proposed in Phase I. Modifications of note are removal of the resonator optics from the pressure vessel, the addition of a contraction to the flow loop, and relocation of the catalyst beds upstream of the heat exchangers. The functional interaction between the Transmitter Laser subsystems is outlined in Figure 35.

The transmitter laser and its power supply are mounted to the LAWS base structure, while the other components are mounted to the optical bench. This design feature, plus load isolators used to mount the laser, provide sufficient vibration isolation to the Optical subsystem from the laser acoustic impulses. Redundant injection lasers and local oscillators are a feature of our design for high reliability.

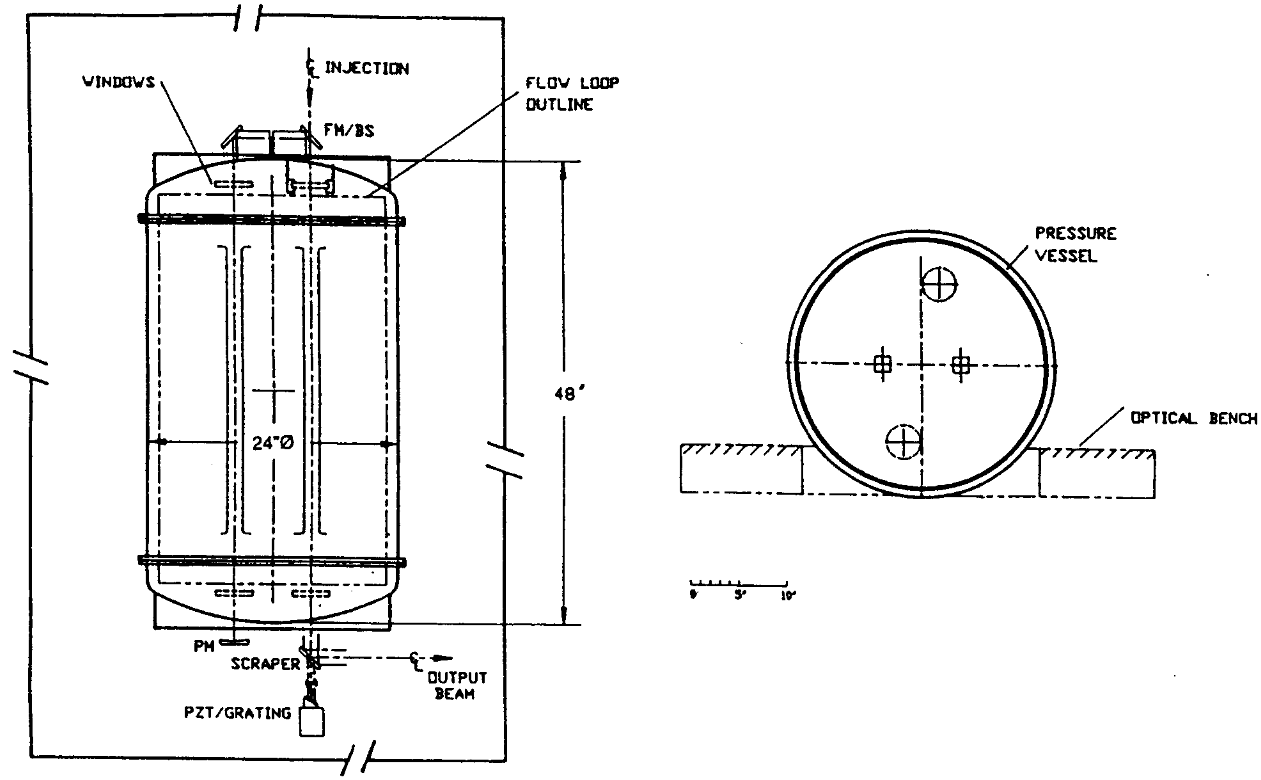


Figure 36. Laser Transmitter

Optical Resonator. The optical resonator configuration, shown in Figure 37, closely resembles that of the breadboard design. Although some design parameters were modified to accommodate the interface of the transmitter with LAWS optical bench, care was taken to ensure that performance parameters such as mode discrimination and sensitivity to misalignment were not adversely affected. The key resonator parameters are listed below.

• Type	unstable
• Equiv. fresnel no.	1.56
• Magnification	2.25
• Cavity length	3.0 m
• Gain length	1.5 m
• Beam size	4 x 4 cm.

The resonator is of the unstable type, with a conventional concave primary mirror and a lens/grating combination acting as the feedback mirror. A folded cavity configuration was chosen for compactness, with both folding mirrors partially reflecting.

The seed laser light is injected through one of the folds with the single longitudinal mode (SLM) detector monitoring the light transmitted through the same fold. The intensity of light transmitted through the opposite fold is measured by a cavity matching detector. Information from the "finesse" curve thus obtained will be used by the cavity matching electronics to adjust the piezo-electric transducer (PZT) drive on which the feedback assembly is mounted.

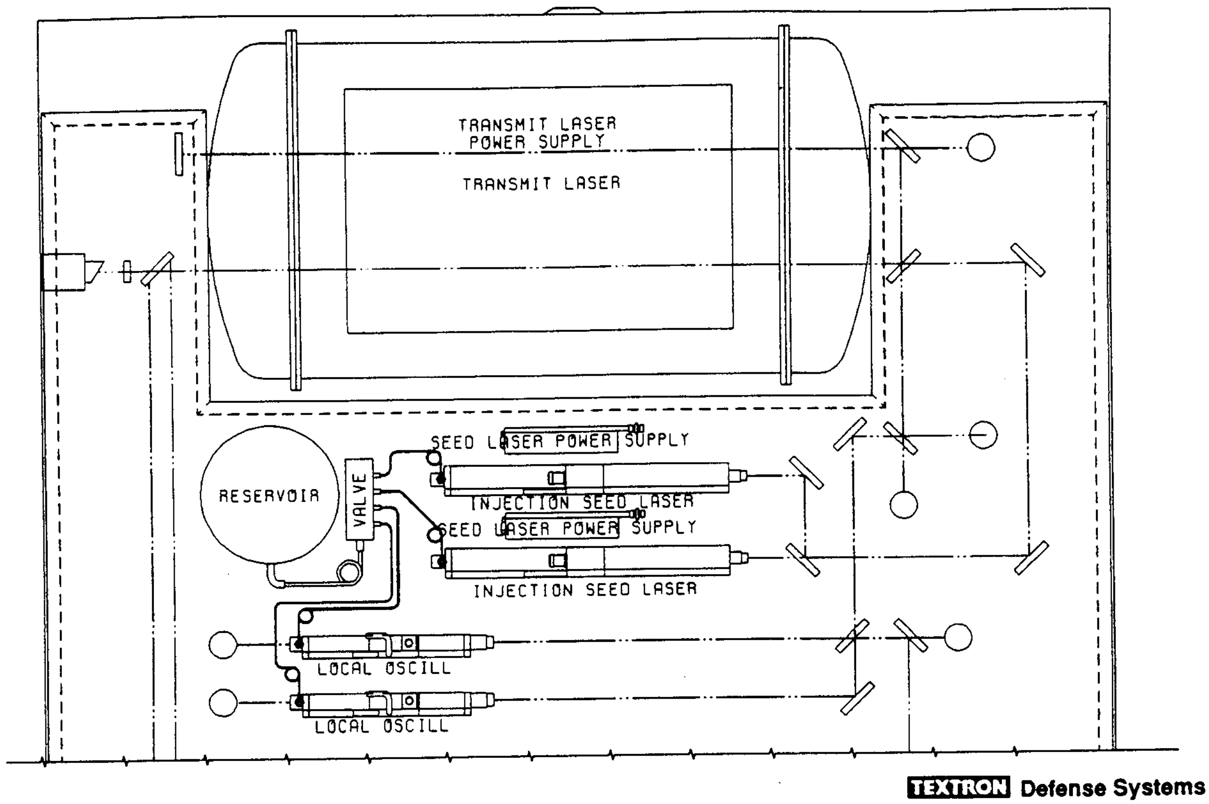


Figure 37. Resonator Optics Layout

Laser output energy is extracted by a scraper mirror located near the feedback assembly and measured by the pyrodetector located between the scraper and the telescope. The primary and scraper mirrors will either be made of copper or dielectrically coated silicon substrates, while the folding mirrors and pressure vessel windows will be made of ZnSe to allow alignment in the visible regime.

Flow/Discharge Subsystem. These assemblies have been defined as one subsystem because of their high level of mechanical integration and functional interdependency. As Figures 38 and 39 indicate, the layout closely matches that of the breadboard. Differences arise primarily in the choice of materials and addition of redundant components wherever failure mode analysis and breadboard lifetime tests indicate a need.

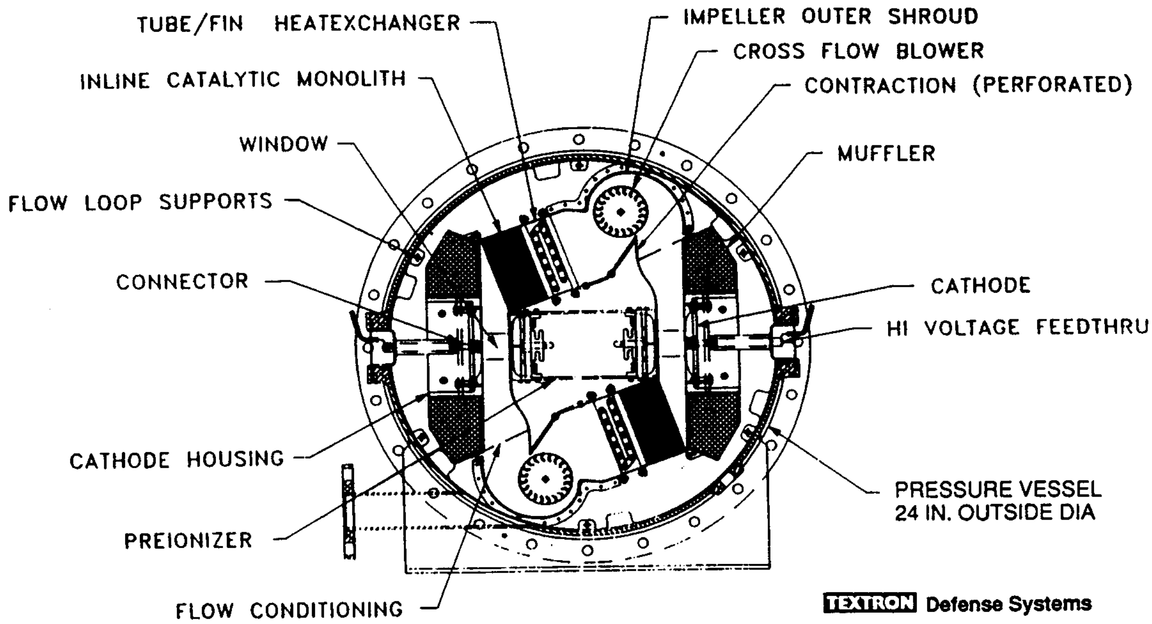


Figure 38. LAWS Discharge/Flow Loop, End View

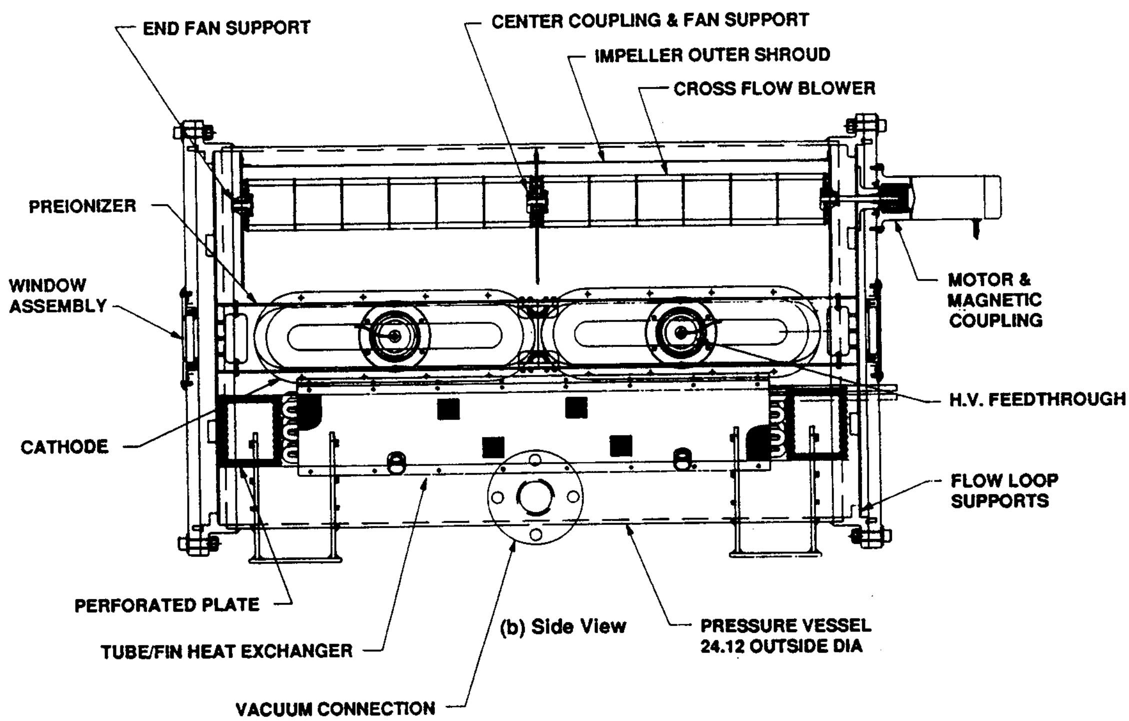


Figure 39. Two-Electrode Configuration, Side View

A UV preionized self-sustained discharge scheme was chosen with four electrode pair modules (two per side) providing redundancy and eliminating alignment and current distribution problems associated with long electrodes. A modified Ernst profile was selected for the cathode based on extensive electrostatics code calculations substantiated by the DVT results. A flat anode profile was chosen for flow compatibility and compactness. Preionization is achieved through holes in the anode utilizing a dielectric/corona bar assembly. The preionizer housing dielectric material can be machined and is impermeable. The relevant operating parameters of the discharge are listed below.

• Gas mixture	3:1:1 He:CO_2:N_2
• Gas pressure	0.625 atm
• Discharge dimensions	4.2 x 4 x 150 cm
• Pulse length	3.2 - 4.0 μs
• Specific energy loading	86 J/L
• Discharge voltage	21-23 kV

Flow Loop. The flow loop is designed to accommodate the discharge assembly described in the previous section. It provides fresh gas to the discharge and moves the used hot gas at the appropriate speed to prevent arcing. This gas is subsequently reconditioned by the catalyst bed, where recombination of CO and O into CO_2 dissociated during the discharge occurs. Subsequently, the thermal energy resulting from the inefficiencies inherent in the laser kinetics processes is removed by a fan and tube heat exchanger. The sidewall mufflers, located in both sides of the cathode, attenuate the acoustic waves generated by the discharge in order to maintain the homogeneity of the lasing medium in the cavity below the levels dictated by beam quality and cavity matching requirements.

Key features of the flow loop design are the dual tangential fans chosen for both compactness and modularity, the contractions upstream of each discharge which assist in restoring flow uniformity, and the skewed positioning of the catalyst bed and heat exchanger which provides compactness and causes a gradual equilibration and cooling of the hot gas. This last feature minimizes density perturbations to the laser medium which could otherwise affect the medium homogeneity in the cavity. The relevant flow parameters are listed below.

• Mass flow rate	23 g/s
• Flow velocity in cavity	1.26 m/s
• Fan speed	1700 rpm
• Cavity flush factor	3.0 at 10 Hz
• Available catalyst volume	12.6 L
• Porosity of muffler wall	3 percent - no packing resistance Backup Design: 30 percent - 1 cgs rayls/cm

Pulse Power. The pulse power system in a discharge pumped CO_2 laser is formed by three primary components: a high voltage dc-dc converter, a pulse forming network (PFN), and a thyratron. The function of the high voltage power supply is to step up the 120 Vdc prime power input to the 40 kV charge voltage required by the PFN. The PFN in turn is charged by this power supply and, upon switching by the thyratron, generates a pulse with the desired length as well as voltage and current characteristics. The pulse energy is subsequently discharged into the gas by the discharge assembly described in the previous section. A functional diagram of these processes is shown in Figure 40.

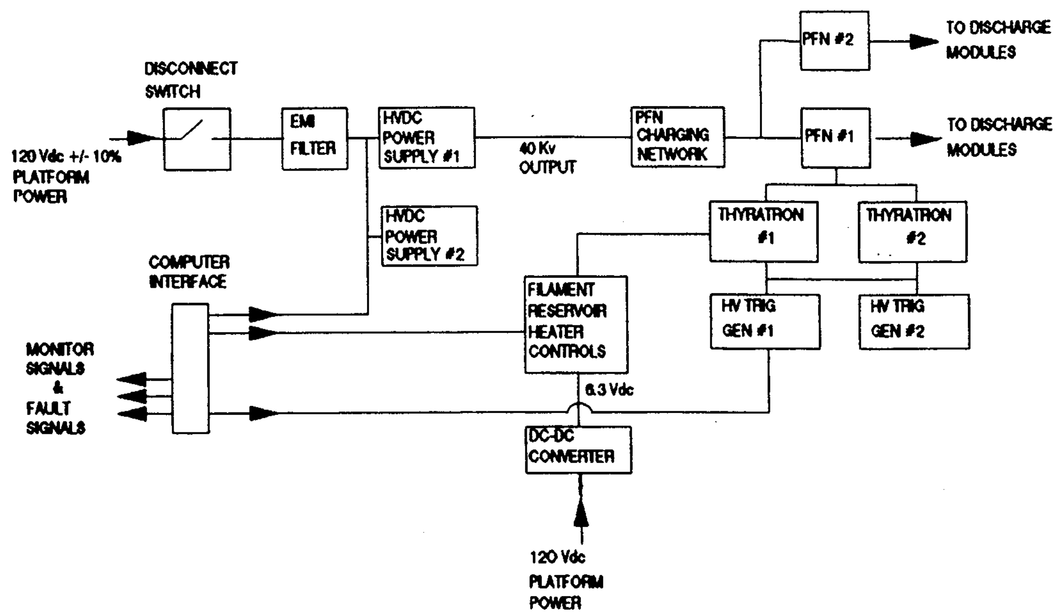


Figure 40. Energy Discharge Processes

The configuration of the PFN, shown in Figure 41, will be an E-type, thyratron switched scheme similar to that utilized in the breadboard. Primary differences will arise in the choice of lighter weight, space qualified components, particularly capacitors, and the use of redundant critical components such as the thyratron, capacitors, and diodes. Also, because operating the PFN in a pressurized environment would result in a considerable weight penalty, vacuum operation is anticipated. This will require mounting components on a coldplate and active cooling of the thyratron. The operating parameters of the pulse power subsystem are listed below.

- Total energy stored in PFN — 264 J
- PFN charge voltage — 40 kV max
- PFN current — <2.5 kA
- Total capacitance — 400 nF
- Pulse length — 4.5 μs max
- PRF — 10-15 Hz

The development schedule for the Laser subsystem is shown in Figure 42.

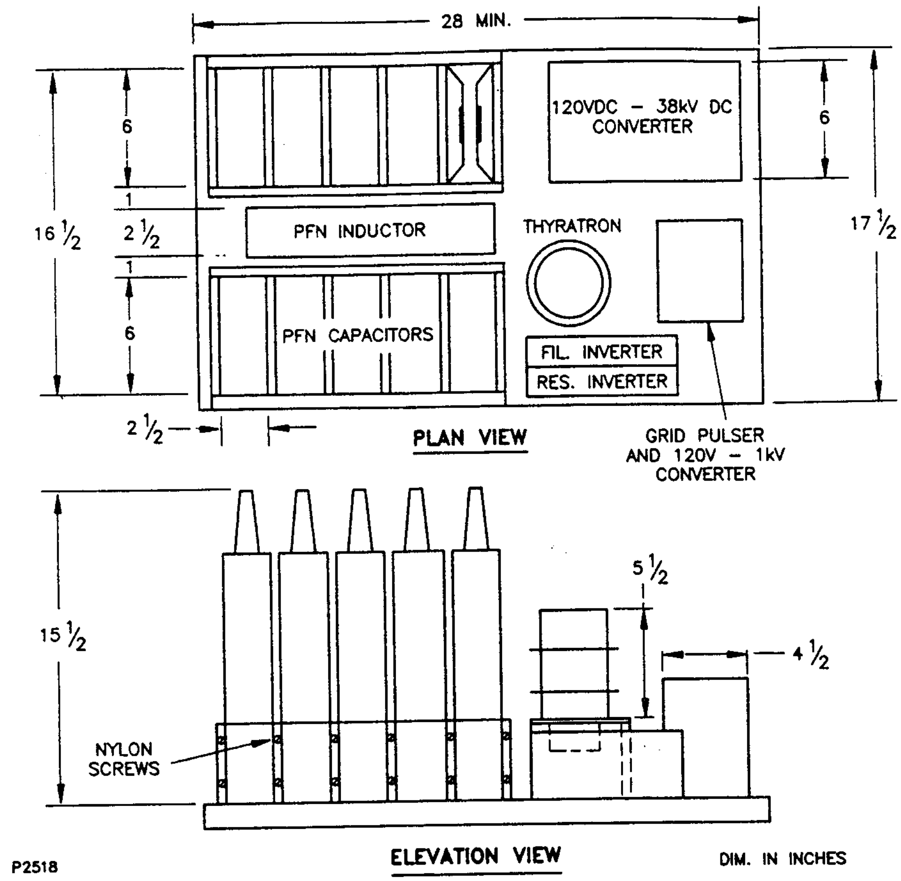
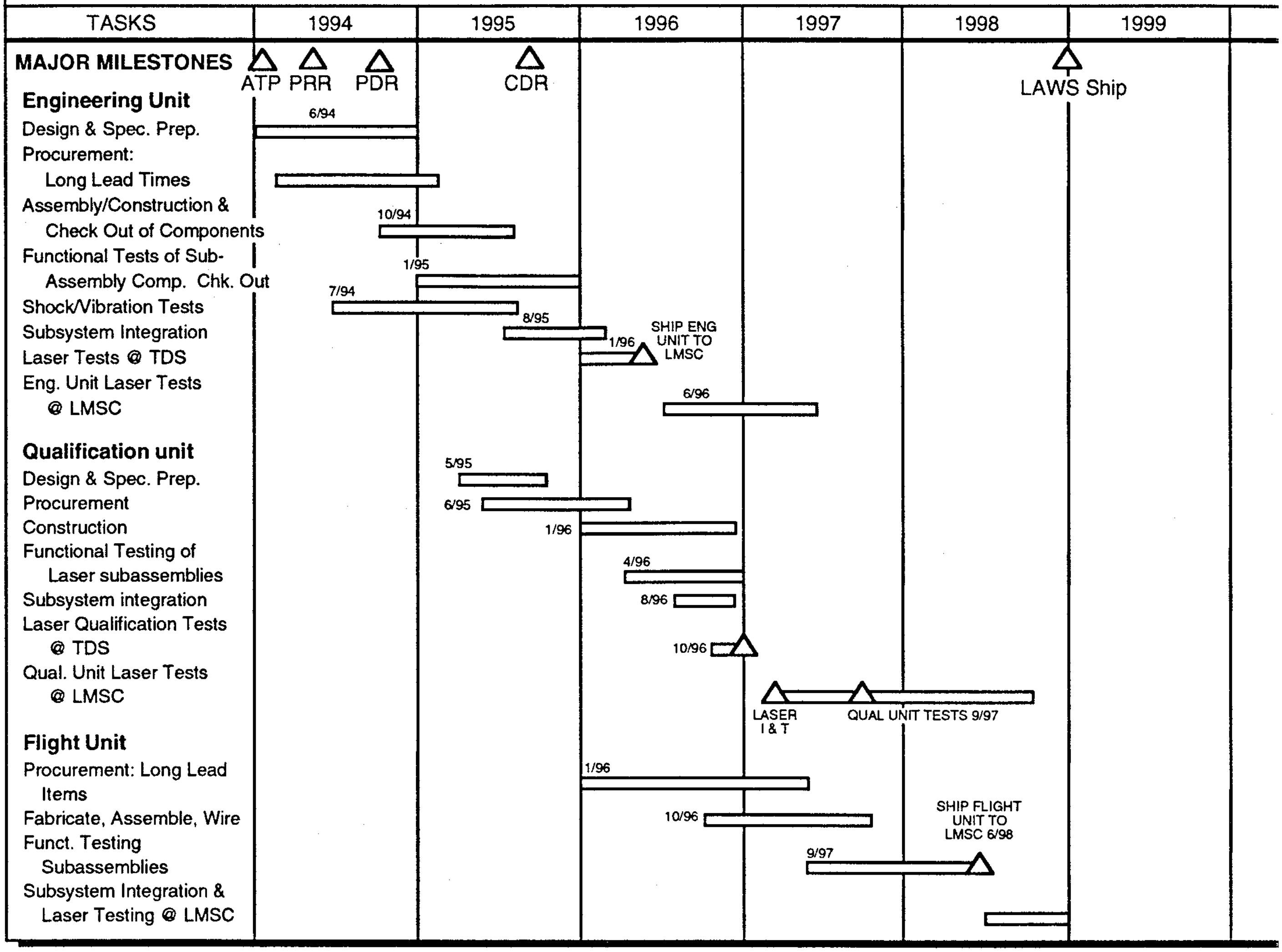


Figure 41. Preliminary Layout of Pulsed Power Section

A LASER TRANSMITTER PLAN OVERVIEW



B REQUIRED SUBSYSTEM EQUIPMENT

COMPONENT*	SOURCE	QUANTITY/UNIT	ENG. UNIT	QUAL. UNIT	FLIGHT UNIT**
Pulsed Power Laser	TDS	1	1	1	1
Discharge Cavities	TDS	2	2	2	2
Flow Loop/Fans/Catalyst	TDS/VOP	1/2/2	1/2/2	1/2/2	1/2/2
Pressure Vessel	TDS	1	1	1	1
Pulse Forming Network	TDS	1	1	1	1
Thyratrons	TDS	2	2	2	2
Pulsed Power Supply	ALE	1	1	1	1
Optical Resonator/Bench	TDS/LMSC	1/1	1/1	1/1	1/1
CW Injection Laser	MPB	2	2	2	2
Single Mode PZT Controller	BURLEIGH	1	1	1	1
CW Local Oscillator Laser	MPB	2	2	2	2
Controls and Instrumentation	TDS	1	1	1	1
Alignment Laser and Mechanism	ITEK	1	1	1	1
Laser Thermal Control System	TDS	1	1	1	1

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* *"S" parts*
** *Engineering unit components used for spares*

E

Fan Failur
Individual
Catalyst C
Thyratron
PFN Capa
Feedback
Mirror Dar
Window D

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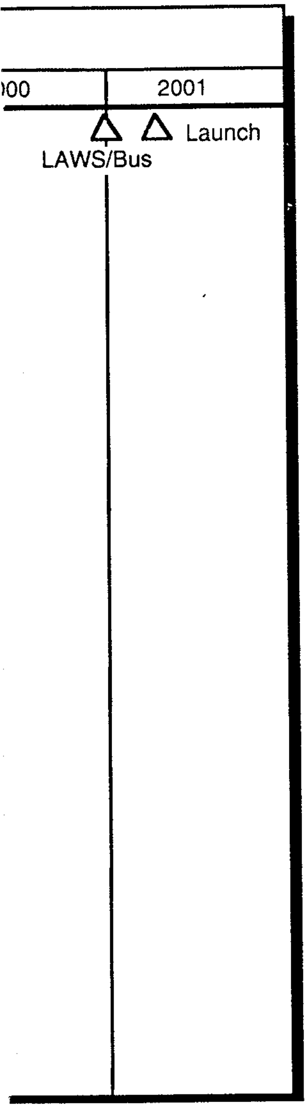

C REQUIREMENT IMPLEMENTATION/VERIFICATION

KEY REQUIREMENT	IMPLEMENTATION	VERIFICATION
Operational Life and Reliability	• 5 yr on orbit • 10^9 Shots	Extended Life Tests • Components to > 10^9 • System to > 3×10^8 Design for; Robustness and Key Component Redundancy
Performance	• 9.11 µm ($C^{18}O^2$) • 20 J/Pulse • Single mode pulses • 3 µp FWHM pulse length • <200 kHz CHIRP • 4.67 Hz scan mode } xπ/2 • 10 Hz design mode } (max PRF)	Performance Validation Test • Breadboard • Eng Unit • Qual Unit • Flight Unit
Interfaces and Software Functions	• Flight Processor – Auto alignment SW – Failure handling SW – Data handling SW – Signal & Command SW • Telescope control system • Platform Power Control System • Platform Thermal Control System • Beam Detector System • Gas Handling System	Simulation and test

D PLANNED TRADE STUDIES

TRADE ITEM	BASELINE DESIGN
Discharge Parameters	
• Gas mixture composition	• He : $C^{18}O^2$: N_2 = 3:1:1
• Gas pressure	• 0.625 atm
• Electrodes/Preionizers materials	• Proprietary
• Cavity dimensions/Gain length	• 4.2 x 4 cm/150 cm
• Voltage/Energy Loading	• 35 kV/80 J/L
• Flush factor	• 3.0
Resonator Parameters	
• Magnification	• 2.25
• Scraper geometry	• Square (square vs. circular)
• Cavity reflectivity	• Uniform (uniform vs. graded)
Flow Loop Parameters	
• Catalyst configuration	• Dual in-line Beds, 400 cells/in^2

RISK SUMMARY

RISK ITEM	RISK LEVEL	RISK REDUCTION APPROACH
	Moderate	1. Dual fans provide redundancy; laser can operate on one fan.
charge Arc or Preionizer Failure	Moderate	1. Redundant preionizer and associated discharge modules. 2. Operation at lower discharge voltages to reduce probability of arcing and failure
amination	Probably Low (not yet established)	1. Catalyst reactivation heaters, flushing of pressure vessel laser gas refill, plus pre-launch clean room and bake out procedures.
lure	Moderate	1. Backup provides redundancy.
or Short Circuit	Moderate	1. Isolate faulty capacitor, switch in backup spare.
rror PZT Drive Failure	Low	1. Robust design is essential.
ge or Contamination	Risk not yet established	1. Robust design and cleanroom and bake out procedures to minimize effects.
age or Contamination	Risk not yet established	1. As above; also addition of lasing mixture, cope with a small crack.

Figure 42. Laser Transmitter Subsystem Summary

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Section 4

LASER BREADBOARD

An 18 month laser breadboard effort was initiated in January 1991 to demonstrate the performance parameters and shot life requirements of the LAWS system. The breadboard effort was to be performed concurrent with the Phase II design to provide high fidelity between the flight configuration and the breadboard and maximum feedback of test results for the design activities.

The goals of the breadboard program were to demonstrate

- Output parameters at 10.6 µm in normal CO_2 mixture
- Output parameters at 9.11 µm in isotopic CO_2 mixture
- Lifetime at 10.6 µm on the order of 10^8 shots.

A comparison of the transmitter laser flight design requirements and the breadboard design goals is given in Table 3. Figure 43 shows the breadboard system in block diagram as it exists in the Textron Defense System laboratory. To make full use of the available contract funds, all hardware components were developed and supplied on LMSC and TDS fixed asset funds. Contract dollars were used for DVT, breadboard setup and integration, system analysis, and testing and data analysis.

Table 3. LAWS Transmitted Requirements and Breadboard Design Goals Compared

	LAWS Transmitter	Breadboard
Energy Per Pulse	15 J	15 - 20 J
Pulse Width	≥ 2.5 µs	2.5 - 3 µs
PRF	10 Hz (avg); 16 Hz (peak)	10 Hz (life test @ 20 Hz)
Beam Quality	1.2	1.1
Wavelength	9.11 µm	10.6 and 9.11 µm
Beam Mode	Single transverse & longitudinal	Single transverse & longitudinal
Chirp	<100 kHz	<200 kHz
Lifetime	10^9 pulses	10^8 pulses (goal)
Weight	200 kg	Not applicable
Wall-plug Efficiency	> 5%	Demonstrate laser extraction efficiency and project wall-plug efficiency

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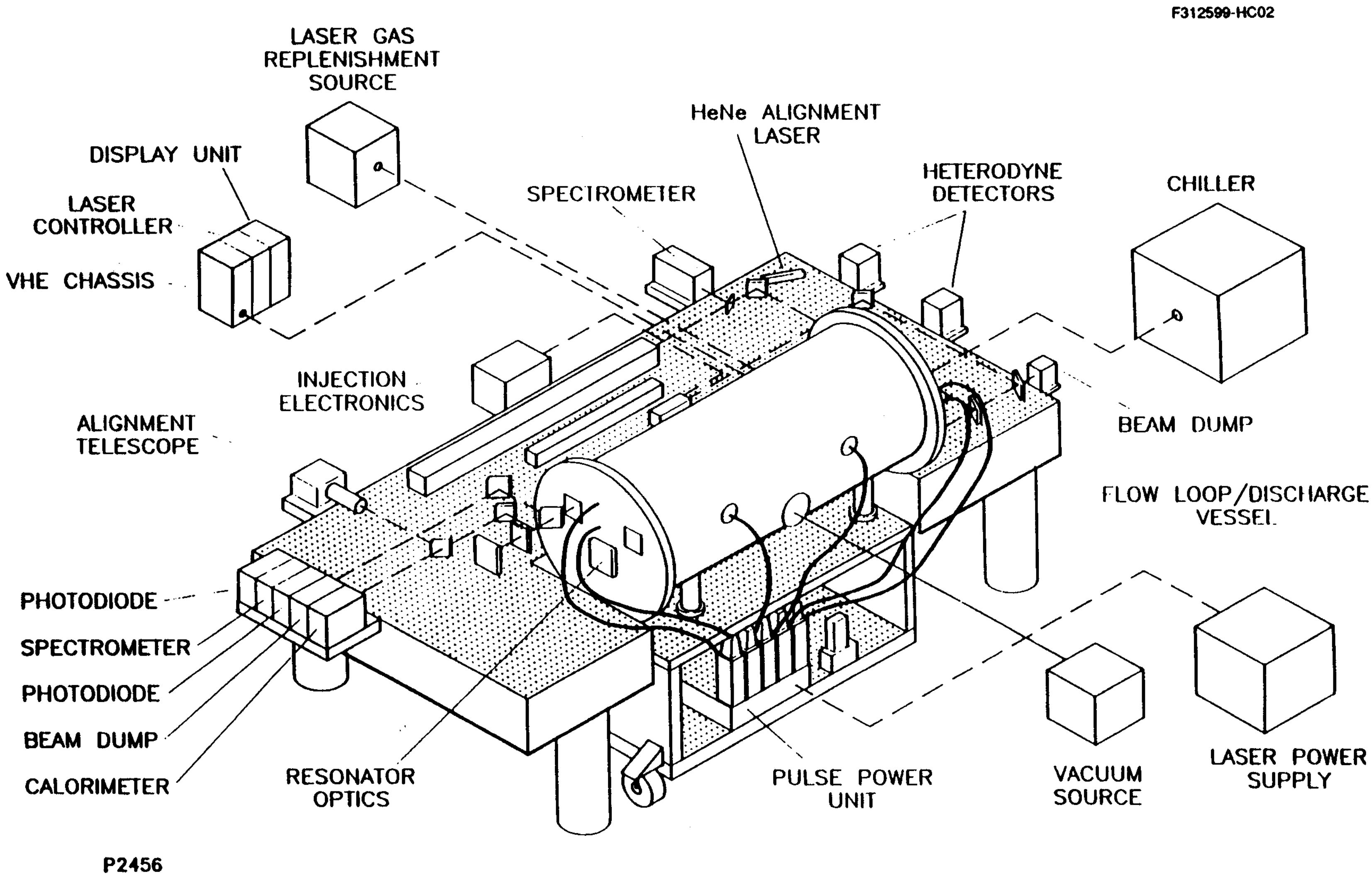
TEXTRON Defense Systems



TEXTRON Defense Systems

Figure 43. LAWS Breadboard System Block Diagram

First laser beam was accomplished on 21 April 1992, less than 16 months after program initiation. Other major milestones are listed below.

- Demonstrated single mode operation at 7 J and 10 Hz
- Demonstrated 20 Hz operation at 5 J
- Measured low chirp at 3 μs pulse length
- Measurements show very small beam jitter.

The laser breadboard in the *first of its kind to reach single mode output at this energy and pulse rate*.

Our breadboard has built-in flexibility without sacrificing traceability to the flight hardware. It has the demonstrated capability to operate at a variable repetition rate and energy levels, so test data can be obtained at the LAWS baseline design levels as well as the relevant downsized LAWS system. A new data base has been established for gain, rate constants, and intrinsic efficiency of laser operation in isotopic $^{12}C^{18}O_2$ gas mixtures over a wide range of operating temperatures. Low chirp, which is essential for lidar operations, has been demonstrated near the baseline LAWS design point. Lifetime in excess of 10^8 shots has been demonstrated for corona UV preionizers, which is an improvement of two orders of magnitude over previous life of corona preionizers.

In the LAWS laser breadboard program, we have built a piece of hardware that represents the cutting edge of CO_2 lidar technology. The close-cycle repetition operation of a CO_2 laser utilizing a self sustained corona UV preionizer and an in-line catalyst has been demonstrated for the first time. Also, single mode laser operation has been demonstrated at output energy and pulse length higher than any existing device.

We are confident that, with an extended breadboard test program over the next 18 months, laser lifetime can be adequately demonstrated to proceed with full scale development of flight hardware.

Section 5

DOWNSIZED LAWS

Recent discussions between NASA Headquarters and the LAWS Science Team have led to the consideration of a downsized LAWS configuration of a 5 to 7 J/pulse laser and 0.75 m diameter primary mirror telescope. While not satisfying the original Science Team requirement of measurements to backscatter coefficients to 10^{-11} m^{-1} SR^{-1}, this would still provide significant global wind measurement data in subvisible cirrus, cloud tops, in the boundary layer, and during significant volcanic events.

Trade studies were performed on the S/N loss to be experienced for various reduced laser energy levels and primary mirror diameters (Figure 44). For a 5 J/0.75 m LAWS system, a 13 dB loss over our baseline would be experienced.

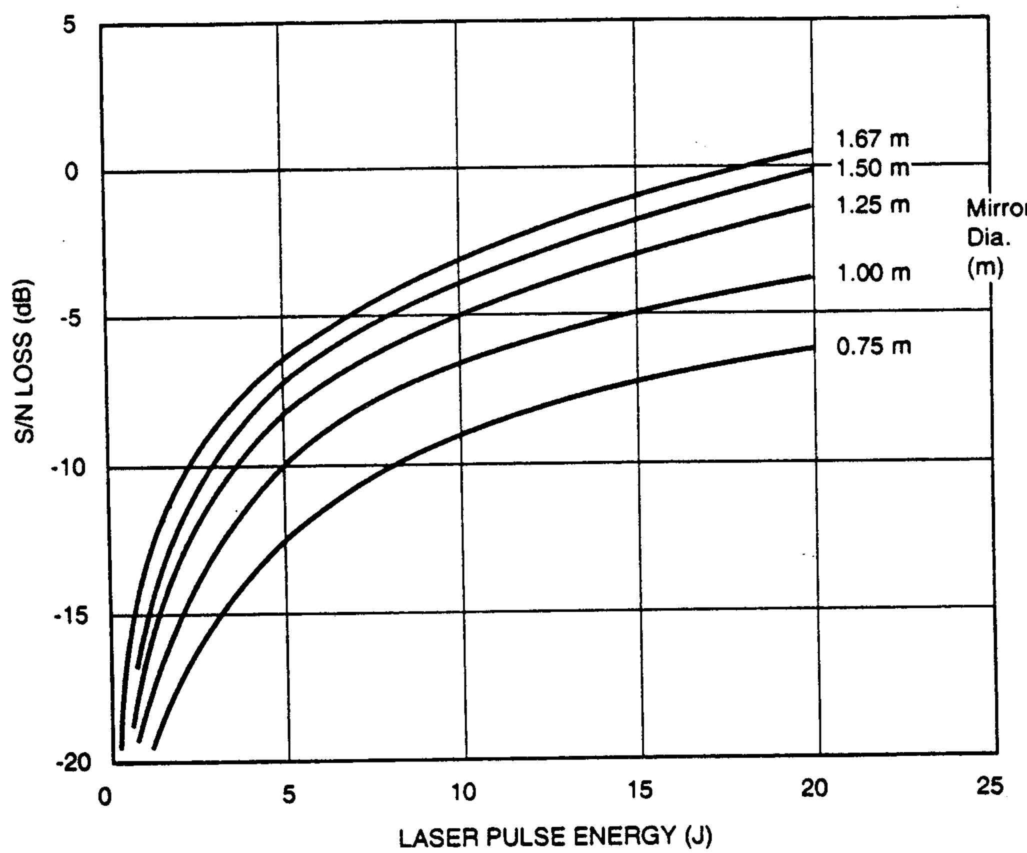


Figure 44. S/N Performance for 525 km Orbit

Our downsized configuration is shown in Figures 45 and 46. The volume envelope of the delta shroud allows adequate space for the LAWS Instrument, with a full length telescope shroud, and more than 3.2 m of length for the spacecraft.

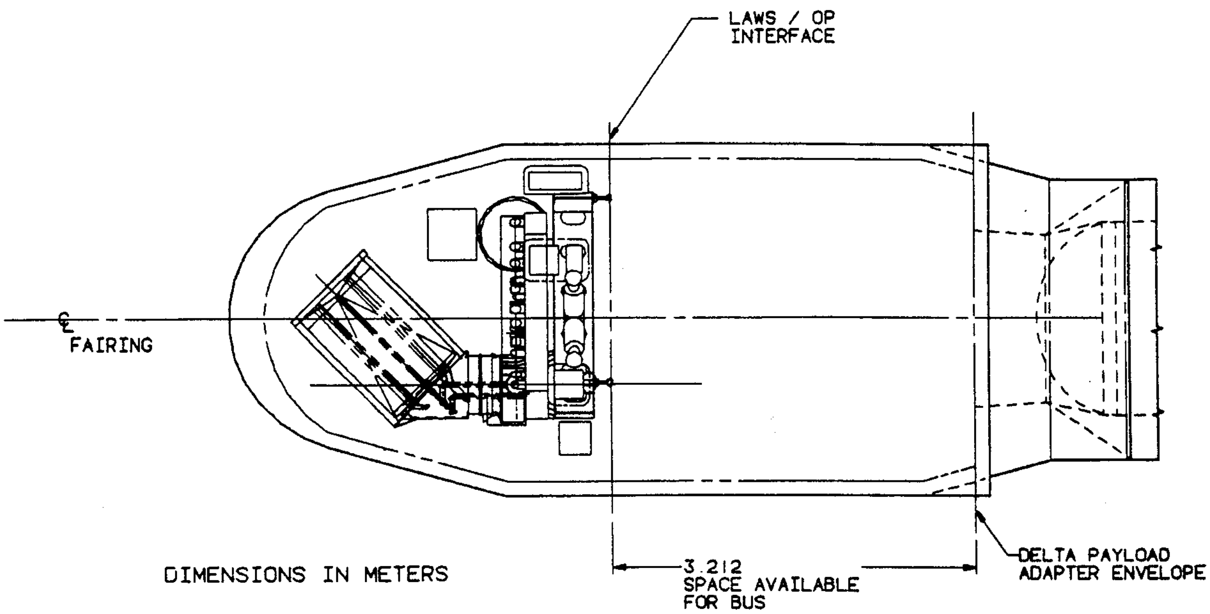


Figure 45. LAWS Telescope with 0.75 m Diameter Mirror in Delta Fairing

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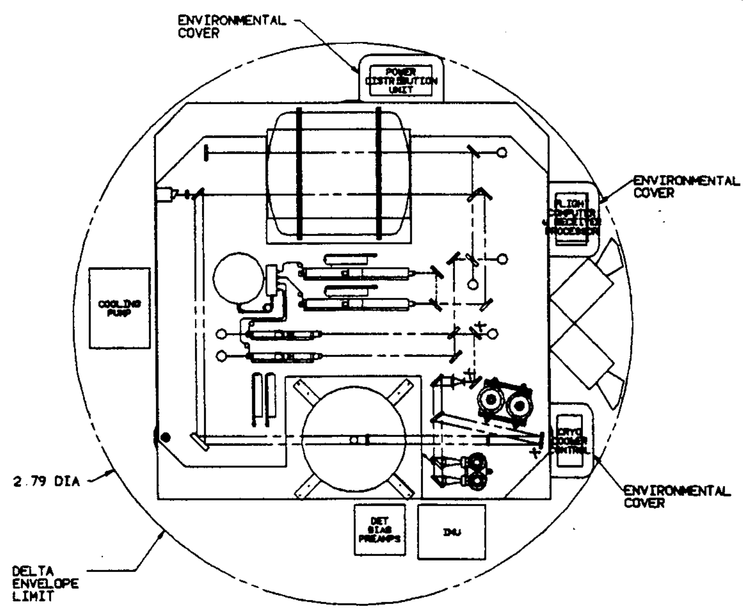


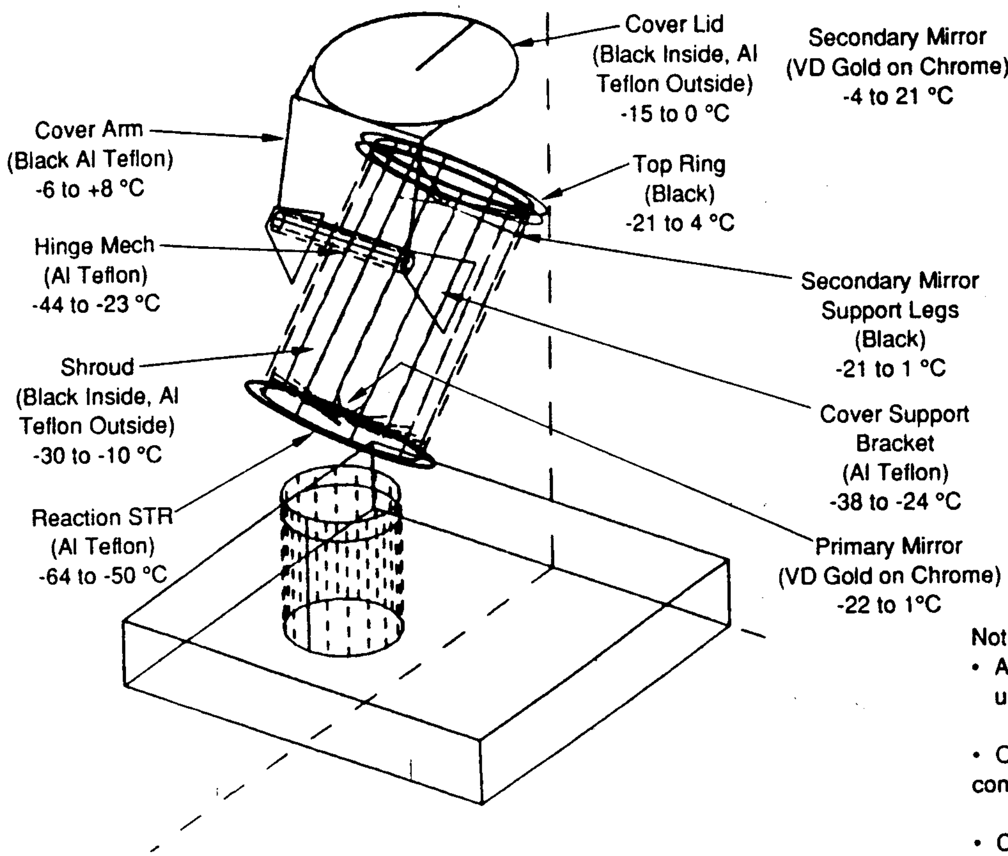
Figure 46. LAWS Instrument Fit-Check in Delta Fairing

Analyses have shown that the downsized configuration is well within the allocated power and weight budgets. Initial weight calculations show a total Instrument weight of 599 kg. A comparison of constant power requirements for the various subsystems is given in Table 4 for baseline and downsized configurations. A 106 W reduction is possible.

Table 4. LAWS Electrical Power Comparison

Component	Full Sized Electrical Power, W		Downsized Electrical Power, W	
	4.61 Hz Ref PRF	10 Hz Avg Power, W	4.61 Hz Ref PRF	10 Hz Avg Power, W
Constant Power/Thermal Load				
Laser				
Laser Fans	40	40	20	20
Thyratron Filament/Reservior	135	135	135	135
Local Oscillator	30	30	30	30
Seed Laser	100	100	70	70
Receiver	80	80	80	80
Optics				
Azimuth Drive	30	30	10	10
Moment Compensator	15	15	15	15
Telescope Thermal Control	40	40	20	20
Electrical Power Distribution	10	10	4	4
Thermal Control	66	66	66	66
Flight Computer	15	15	15	15
Attitude and Position References	48	48	48	48
Total Constant Load	609	609	503	503
Variable Load	1,537	3,333	513	1111
Total (fixed and variable)	2,146	3,943	1,016	1,614

Orbital thermal analyses show that the temperature ranges between hot and cold cases are well within the allowable temperature with the passive thermal control materials and coatings design shown (Figure 47). The corresponding cost impact of the downsized configuration is given in Section 6 of this report.



Notes:

- Average total absorbed heat fluxes used for the revolving telescope
- Orbit Beta angles of 59° and 90° considered
- Cold and hot orbit parameters considered

Figure 47. Preliminary Steady-State Temperatures on Downsized LAWS Telescope

Section 6

SUMMARY

The LAWS Phase I and Phase II studies have been completed on schedule and have led to significant advances in CO_2 laser development. The Phase II Design Definition study has shown that a large scanning mirror/high pulse energy laser LAWS Instrument is feasible and within the existing technology. The capability to monitor wind velocities with backscatter ratios of 10^{-11} m^{-1} SR^{-1} is feasible. The weight budget allocated for the baseline LAWS is adequate, and sufficient reserves exist with the potential downsized configuration.

With the possible decrease in available power from the baseline of 2.2 kW guideline, power and shot management is critical for the baseline configuration (15 to 20 J). This is particularly true during the 100 day occultation period each year.

With the downsized configuration (5 to 7 J), power management is still necessary during the occultation but is primarily limited to shot management over the polar regions.

The breadboard effort has produced significant laser advances for a tight 18 month schedule and the minimum budgets available from NASA, Lockheed, and TDS. Using the NASA funds and Lockheed and TDS fixed assets budgets, the breadboard was designed, fabricated, and brought on-line with first laser light within 16 months after ATP. First laser beam was obtained on 21 April 1992 at a 5 J power level. Tests since then have been conducted at sustained, repetitive pulse levels of over 7 J and 20 Hz. This is an increase of over two to three times greater than any system previously developed from this type laser. Increased power levels and additional life tests will be accomplished in the next LAWS phase.

The Lockheed LAWS design will operate in the gravity gradient mode on-orbit, and all possible Instrument vibration and jitter modes have been considered. Adequate pointing stability and control is state-of-the-art technology for the critical time periods, frequency rates, and control responses required by LAWS.

Lockheed recommends a 6-1/2 year phase C/D program for LAWS to provide adequate feedback from the engineering unit and the qualification unit to the final flight unit. Assuming a one year period for LAWS integration to the spacecraft, followed by a six-month period for launch vehicle integration, LAWS could be successfully developed and launched in eight years. Our baseline design or downsized design can be accommodated by either the Atlas IIAS or the Delta launch vehicles.

Lockheed's recommendation is that, based on the successful Phase II design study and breadboard program, a follow-on 18 month extended breadboard testing program and additional system engineering studies, primarily in interfacing with a to be defined platform, be initiated. This should be immediately followed by the Phase C/D program, leading to a LAWS launch in late 2001 or early 2002.