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R-74-032

CONTRACT DEFINITION
FINAL REPORT
FOR
GLOBAL POSITIONING SYSTEM
CONTROL/USER SEGMENTS

COPY 9

VOLUME I
INTRODUCTION AND SUMMARY

CS/UE DEFINITION CONTRACT
F04701-73-C-0298 [illegible] AD 921522

Prepared for

Space and Missiles Systems Organization
Los Angeles, California 90045

DATA ITEM A001

PRELIMINARY DRAFT

FEBRUARY 28, 1974

GENERAL DYNAMICS
Electronics Division
P.O. Box 81127, San Diego, California 92138 · 714 279-7301

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CONTENTS

1. INTRODUCTION

This preliminary draft of the Contract Definition Final Report is prepared in accordance with CDRL Data Item A001 and SAMSO data item description document (U) S-680. For convenience in reading, Part I of this report is divided into four separate volumes. In addition to the four volumes, Appendix A is provided, consisting of two books, which contain all of the Design Requirements Bulletins (DRB's) created under Supplemental Agreement 1 to the Contract. & This [illegible]

- Volume 1, Introduction and Summary, contains summaries of the baseline system functional design; summaries of other technical data items which comprise Part II of this report by reference; abstracts of planning data items which comprise Part III of this report by reference, but which are deliverable concurrent with the final draft of this report; summaries of preliminary acquisition planning efforts to date for both Control and User Segments; and discussion of technical and other problem areas.

- Volume 2, System Error Performance is devoted to the analysis and discussion of projected system performance and contains error analysis and error budgets which support that predicted performance.

- Volume 3, User Segment Description, Performance, Error Budgets, and RF Link Budgets is devoted entirely to treatment of User Segment performance analysis.

- Volume 4, Cost Effectiveness Criteria contains analysis and discussion of design to cost criteria developed to date in the definition contract.

2. SYSTEM FUNCTIONAL DESIGN SUMMARY

The implementation of the Global Positioning System (GPS) includes the four major segments of Control, Space Vehicle, User and Navigation Technology. The functions of each segment for the GPS Phase I are separately defined and implemented. Figure 2-1 shows an overview of the GPS and the interfaces between segments.

2.1 GENERAL DESCRIPTIONS

2.1.1 CONTROL SEGMENT (CS)

The Control Segment monitors the signals from all satellites, gathers and processes this data, uploads the GPS navigation data to each satellite and controls all data flow.

2.1.2 SPACE VEHICLE SEGMENT (SVS)

The Space Vehicle accepts and stores the data transmitted from the CS, re-formats the data, and transmits this data back to earth in accordance with established schedules. Further descriptions of the SVS are outside the scope of this CS/UD document.

2.1.3 USER SEGMENT (US)

The User Segment consists of passive GPS receiving stations that may be autonomous navigation or position location sets or may be integrated with other equipments for the accomplishment of more sophisticated missions.

2.1.4 NAVIGATION TECHNOLOGY SEGMENT

The Navigation Technology Segment is composed of the Navigation Technology Satellites, the Naval Research Laboratory-Telemetry, Tracking and Command, and a Pseudo Random Noise Navigation Assembly (provided by the SV segment). Included in this segment is the evaluation of behavior of space-based clocks and propagation characteristics.

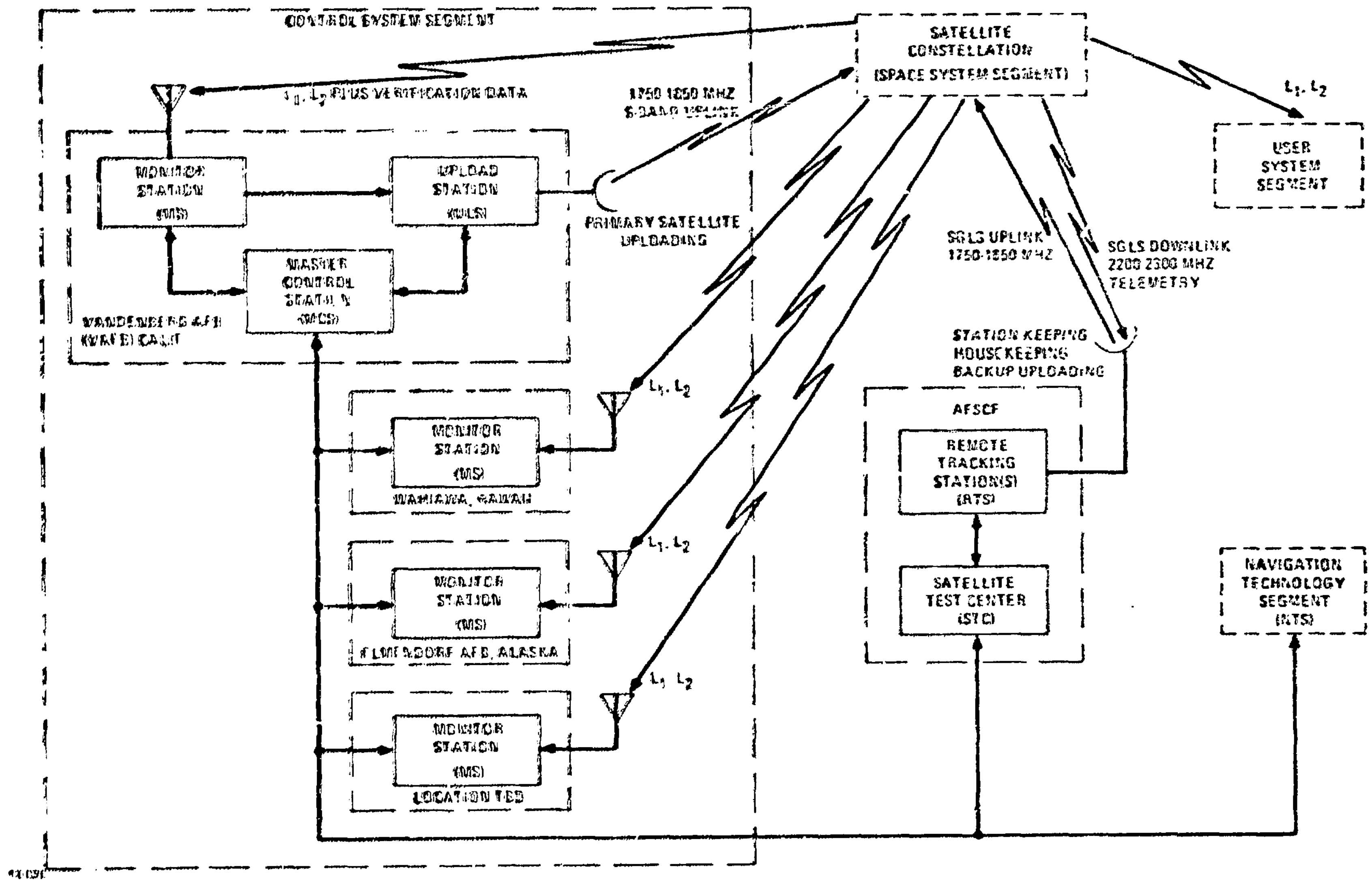

Figure 2-1. Global Positioning System (GPS), Overview Interface

2.2 CONTROL SEGMENT IMPLEMENTATION

The CS is comprised of three separate stations as described below. Each station is implemented to be autonomous and transportable so that the stations may be easily relocated. Facilities for housing all stations will be GFE.

2.2.1 MONITOR STATIONS (MS)

The MS performs the function of collecting satellite data and tracking information. This data is transferred to the Master Control Station (MCS) for the determination of GPS space vehicle orbital parameters and the refinements of other navigation data. The functional block diagram of the MS functions is shown in Figure 2-2. The MS is designed to operate unmanned with overall system control provided by the MCS.

2.2.1.1 MS ANTENNA ASSEMBLY — The antenna assembly is a fixed antenna that receives both L_1 and L_2 space vehicle signals from any point in space above 5° elevation. The antenna assembly will have 0 dB gain.

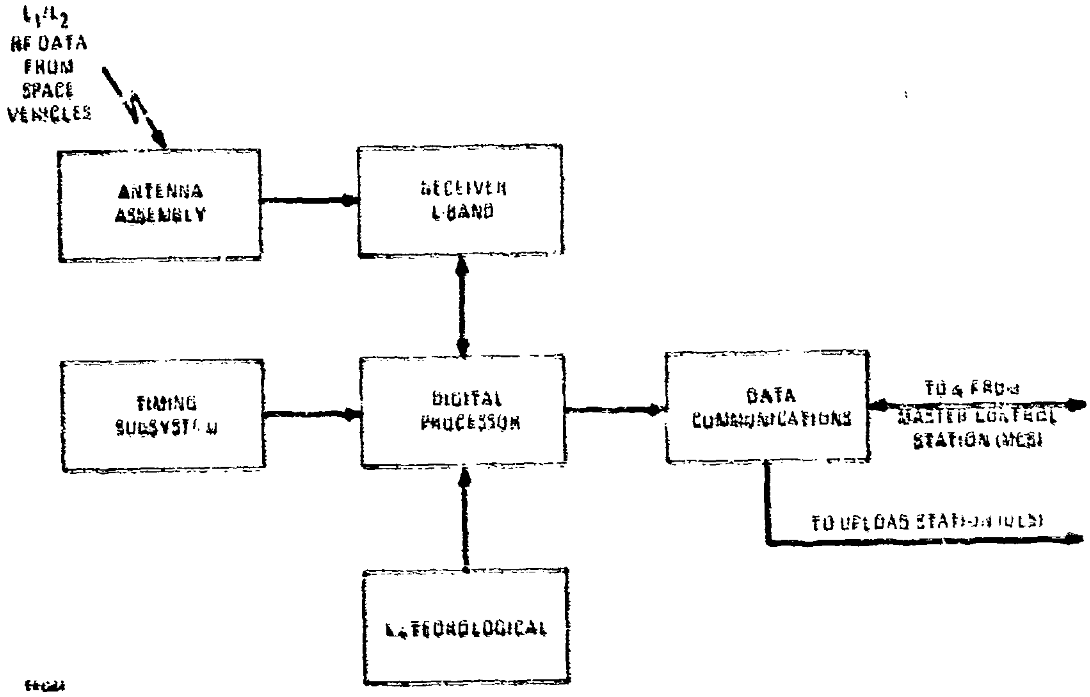

Figure 2-2. Monitor Station, Functional Block Diagram

2.2.1.2 MS L-BAND RECEIVER — The L-band receiver will be a multichannel receiver similar to the equivalent user segment equipment. The receiver acquires the space vehicles in accordance with control commands provided from the MS digital processor. The receiver and processor will be capable of making a position fix for its location and transferring data to the MCS. The receiver shall operate with both L_1 and L_2 signals under control of the MS processor.

2.2.1.3 MS TIMING SUBSYSTEM — The timing subsystem consists of an atomic reference frequency unit, frequency synthesizers and an IRIG timing code generator. The timing subsystem provides the references for ranging measurements, data clocking and time of day.

2.2.1.4 MS DIGITAL PROCESSOR — The digital processor subsystem consists of a teletype, a cassette recorder and a minicomputer utilizing both user equipment software and MS unique software. The digital processor controls the receivers and data communications and processes the received data prior to transmission to the MCS.

2.2.1.5 MS METEOROLOGICAL UNITS — Each MS will have meteorological instruments to monitor the external temperature, barometric pressure and relative humidity. The data from these instruments will be transferred to the MCS to permit correction of space vehicle data due to tropospheric effects.

2.2.1.6 MS DATA COMMUNICATIONS — The data communications subsystem consists only of a modem for dial-up transfer between the MS and MCS over commercial telecommunications lines and a standard telephone installation for voice communications, as required.

2.2.2 MASTER CONTROL STATION (MCS)

The MCS serves as a centralized facility to provide the integrated computational and data transfer capability to support the GPS communication and navigation data requirements. The MCS functional block diagram is shown in Figure 2-3. The facility is

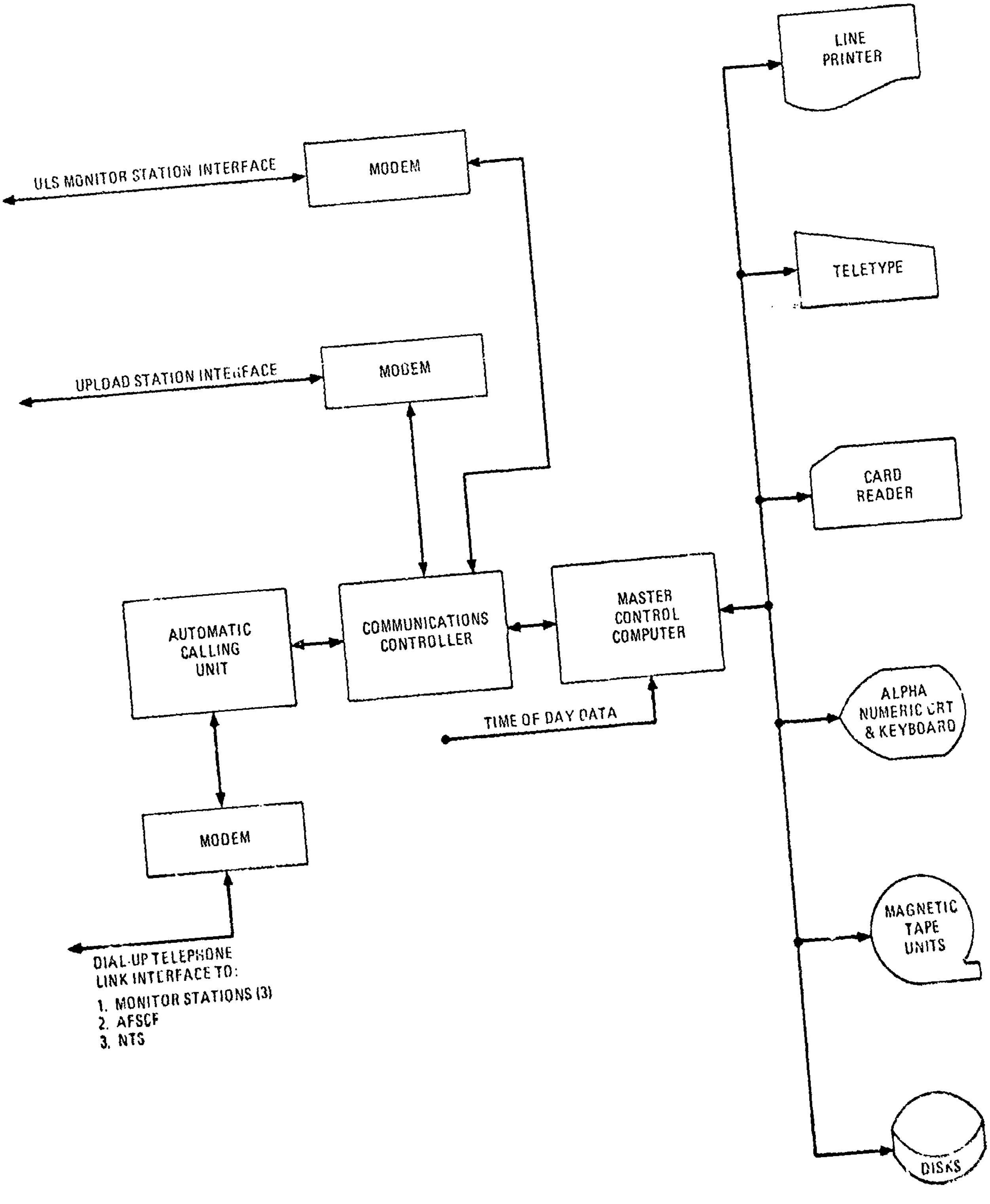

Figure 2-3. Master Control Station, Functional Block Diagram, Specifications Baseline

basically a computer with the peripheral equipment required to support the programming, computation, and data communications roles:

- Orbit determination and ephemeris generation
- Time synchronization offsets
- Navigation data formatting for uploading to the space vehicles
- Store and retrieve historical data
- Provide controls and displays for operation of MCS and the total CS
- Provide hard copy of data, as required
- Support MCS and MS program development

2.2.3 UPLOAD STATION (ULS)

The ULS provides an accurate link for transferring the GPS navigation data from the MCS to the space vehicles. The station is designed to be transportable from one location to another after appropriate disassembly and packaging. The ULS will transmit on the Space Ground Link Subsystem (SGLS) frequency or frequencies assigned to the space vehicles to permit the use of the SGLS Satellite Control Facility transmitters as back-up to the GPS ULS. The baseline ULS is a transmit-only station (Figure 2-4), and will be co-located with a GPS MS. Two receiving function options are also described below.

2.2.3.1 ULS DIGITAL PROCESSOR — The digital processor controls the ULS antenna pointing and throughput of navigation data for loading each space vehicle.

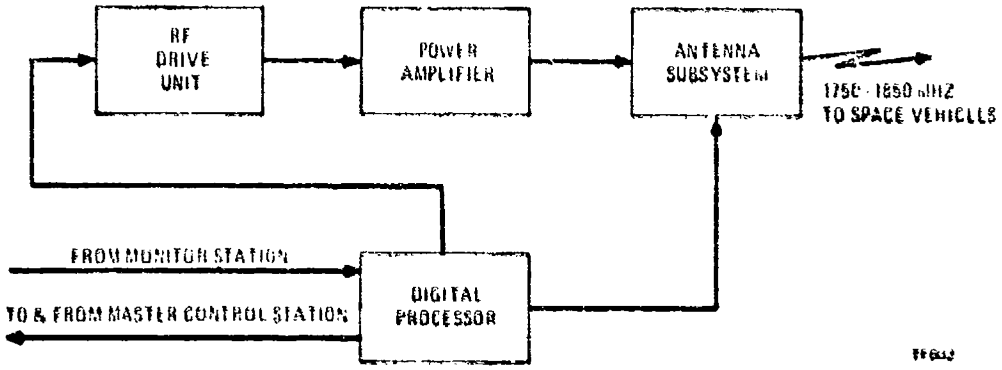

Figure 2-4. Upload Station, Functional Block Diagram

Verification of a satisfactory upload to each space vehicle will be received from the co-located MS.

2.2.3.2 ULS RF DRIVE UNIT — The drive unit accepts the digital navigation data, formats it into the SGLS tone format, and modulates these tones onto the RF drive to the power amplifier.

2.2.3.3 ULS POWER AMPLIFIER — The power amplifier is a broadband, variable output power amplifier. The amplifier is capable of operating on any of the 20 SGLS frequency assignments. The output power is variable to 10 kilowatts to insure adequate uplink power to achieve a data error rate of not less than 1 part in 10^7. The power amplifier is totally self-contained with its own power regulators and liquid cooling system.

2.2.3.4 ULS ANTENNA SUBSYSTEM — The antenna subsystem consists of a 14-ft parabolic reflector, SGLS feed, control servo-systems, radome and environmental control systems. The 14-ft reflector is adequate to achieve the 10^{-7} bit error rate with the power amplifier operating at 4 kilowatts output power. The 14-ft reflector is also compatible with the optional requirements for SGLS downlink reception for GPS upload verification and for precision GPS space vehicle signal analysis.

2.2.3.5 ULS GROWTH OPTIONS — Two optional capabilities are planned for as a part of the basic upload station:

- SGLS S-band reception for verification of the GPS navigation upload
- GPS L-band reception for precision analysis of the magnitude and quality of the signals being transmitted by the satellite

2.3 USER SEGMENT IMPLEMENTATION

The User Segment consists of three different configurations of passive L-band receiving and processing sets capable of providing accurate position or navigation data. The different configurations evolve from the different military operations scenarios and priorities of requirements. Three configurations are shown in Figure 2-5 and, as noted, each satisfies one or more of the classes (military scenarios) defined. Each

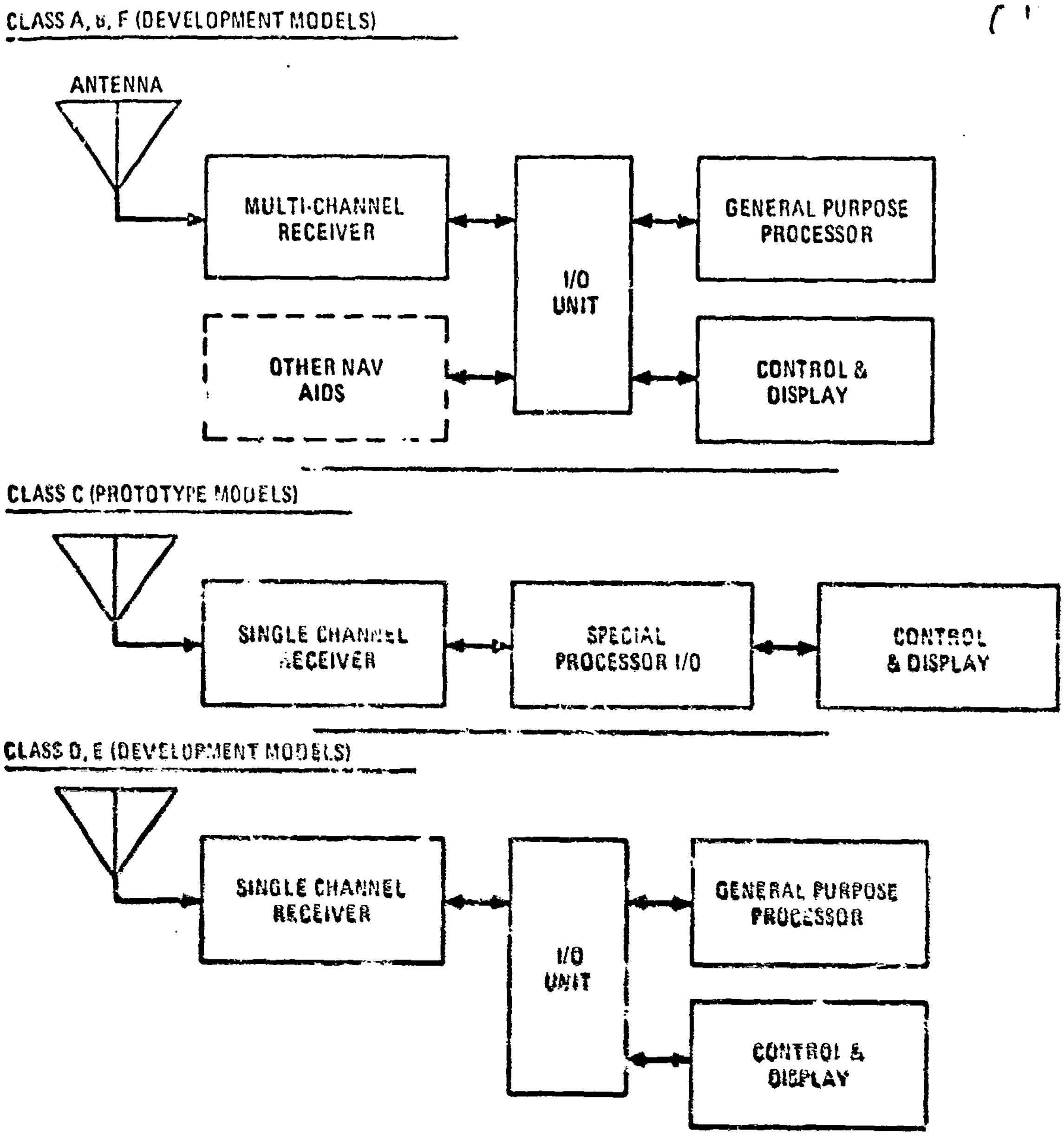

Figure 2-5. GPS Phase I – User Equipment Block Diagrams

user equipment (UE) set consists of an antenna, receiver, processor, and display. Other equipment may also be used depending on the application, i.e., Inertial Measurement Units (IMU), Air Mass Dead Reckoning Units (AMDRU), altimeters, displays, interface units, etc.

2.3.1 CONTINUOUS TRACKING USER EQUIPMENT

The continuous tracking UE is the most complex configuration. This configuration continuously and simultaneously tracks four space vehicles on either frequency L_1 or L_2 and uses both the clear/acquisition (C/A) and protected (P) codes. Simultaneous tracking of four space vehicles provides the shortest time to first fix and the greatest immunity to jamming, particularly when aided by other navigation sensors such as the IMU and AMDRU.

2.3.2 SEQUENTIAL TRACKING USER EQUIPMENT

The sequential UE provides the same data as the continuous UE except that the time to first fix is obviously longer. This unit is basically a single channel receiver and, therefore, is sequenced from tracking one space vehicle on L_1 or L_2 frequencies to tracking another space vehicle on L_1 or L_2 frequencies.

2.3.3 SEQUENTIAL TRACKING USER EQUIPMENT – CLEAR/ACQUISITION ONLY

The sequential C/A-only user equipment is similar in construction to the sequential UE defined in Paragraph 2.3.2 and is referred to as the Class C UE. This configuration operates on only frequency L_1 and the C/A code. The time to first fix, accuracy and anti-jamming immunity are secondary to low cost for this configuration.

2.3.4 GENERAL DEVELOPMENT MODEL USER EQUIPMENT

A general development model (GDM) UE capable of demonstrating any of the other configurations will be developed prior to initiating the designs for the other three configurations. The GDMs will be design and development tools to be used by the UE developer and in early field tests to prove basic implementation techniques and compatibility with other GPS segments hardware. One GDM will remain in-plant as a design improvement test bed.

3. SUMMARIES OF PART II TECHNICAL DATA ITEMS

Part II of the Contract Definition report contains other CDRL items delivered concurrently with this report but under separate cover; brief summaries are presented for each of these items. These are:

- A002 System Design Trade Study Report
- A003 System Segment Specifications
- A004 Computer Program Development Specification
- A005 Configuration Item development Specification
- A008 Test Facilities Requirement Document
- A00C System Integration Plan

3.1 SYSTEM DESIGN TRADE STUDY REPORT

The System Design Trade Study Report is submitted as CDRL Data Item A002. The purpose of the report is to document the decision rationale used to resolve the design approaches. The trade studies presented are the major decision efforts required during this definition phase. The design of the Global Positioning System (GPS) for Phase I required the evaluation of alternatives for a variety of design problems. The trade studies contained in A002 are:

Number	Title
1.	Satellite Memory Loading
2.	Satellite Orbits
3.	Monitor Station Sites
4.	Control Segment Computers
5.	User Segment Computer
6.	User Cost/Performance
7.	User Ionospheric Model
8.	User Ephemeris Model
9.	Ephemeris Determination

3.1.1 SATELLITE MEMORY LOADING

The Satellite Memory Loading trade study investigates the alternatives for uploading and storing in satellite memory that portion of the user navigation data frame generated by the Master Control Station. The alternatives considered dealt with the implementations and error contributions of the upload station design, upload message format, satellite receiver and decoder configuration, data verification method, and downlink communication channel to the ground.

The recommended satellite loading method is S-band uplink/L-band downlink with onboard verification of upload messages and the AFSCF is its backup. The S-band upload frequency is one of the standard SGLS frequencies with a three-tone FSK data modulation. The L-band downlink is the TLM words of the user navigation data frame; they will contain the addresses of erroneous blocks.

3.1.2 SATELLITE ORBITS

The Satellite Orbits trade study investigates the selection of the satellite Constellation and orbits for the Phase I. The important parameters are resulting GDOP's and visibility over the expected test areas. Results of this study indicate that the 2/2/0 Aerospace Final Constellation provides the best compromise between the requirements of GDOP, test area co-visibility, and pre-visibility. The characteristics of the orbital parameters of this constellation are:

Satellite Number	Longitude of the Ascending Node (deg)	Argument of Perigee (deg)	Orbit Inclination (deg)	Orbital Period (min)
1	240	330	63.0	718.0342
2	240	5	63.0	718.0342
3	120	0	63.0	718.0342
4	120	70	63.0	718.0342

The performance of this satellite constellation in terms of Holloman, Yuma, and Vandenberg test site coverage and GDOP and the period of time all satellites are visible prior to the Holloman visibility are:

PERFORMANCE

Test Area	Coverage Time	GDOP Range
Holloman	2 Hours 32 Minutes	4.2 to 7.2
Yuma	2 Hours 11 Minutes	4.2 to 9.1
Vandenberg	2 Hours 4 Minutes	4.2 to 10.8

PRE-VISIBILITY TIME

Location	Pre-visibility Time (all four satellites)
Vandenberg, Ca.	20 Minutes
Wahiawa, Hawaii	1 Hour 20 Minutes
Elmendorf, Alaska	1 Hour 45 Minutes

The selection of configuration and orbit parameters for the initial four satellites is documented in the Satellite Orbit trade study. Because only four satellites were considered and their orbits were optimized for specific test areas, the results are only applicable to GPS Phase I.

3.1.3 MONITOR STATION SITE SELECTION

This trade study investigates the possible locations of Upload Station (ULS), Monitor Stations (MS), and Master Control Station (MCS) for collecting processing and uploading pseudo range data of the satellites. The satellite visibility and viewing times of these sites must be compatible with the satellite navigation system updates prior to testing over southwestern CONUS. The recommended control segment configuration based upon the satellite viewing time and tracking geometry analysis is:

FUNCTION	LOCATION/TYPE
Monitor Sites	1. Wahiawa, Hawaii 2. Vandenberg AFB, California 3. Elmendorf, AFB, Alaska 4. TBD
Master Site	Vandenberg AFB, California
Upload Station	Vandenberg AFB, California Command Data — AFSCF
Telemetry	AFSCF
Off-line Computations	NWL
Data Communications	Commercial Dial-up

3.1.4 CONTROL SEGMENT COMPUTERS

The Control Segment Computers trade study investigates the computational equipment required by the Master Control Station and Monitor Stations for Phase I. This effort is to perform a preliminary evaluation and sizing of computer equipment that will satisfy the mandatory requirements of the stations. The computers must be capable of supporting a constellation of 12 satellites. At this juncture, a final selection of computers is impossible without a formal submission of vendor proposals that guarantee their hardware, software, and service capabilities. Therefore, all types of computers that satisfy the mandatory requirements of the Master Control Station and Monitor Stations are identified. These candidate computers and their manufacturers are:

MANUFACTURER	MCS CANDIDATE	MS CANDIDATE
Data General Corporation	840	Nova 2
Digital Equipment Corporation	11/45	11/40
Hewlett-Packard Co.	3000	2100
Modular Computer System	IV	II
Varian Associates	V73	V73 or 620

This listing is limited to manufacturers that are capable of supplying both the Master Control Station and Monitor Station Computers. If possible, candidate computers should be selected from the same family thereby, simplifying support and maintenance requirements. The question not resolved is whether or not it is feasible to employ the User Segment computer for the Monitor Station. Analysis is continuing to resolve this question. Computers that appear feasible to satisfy both User Segment and Monitor Station requirements are: the Data General, ROLM Rugged Nova 1602R; Digital Equipment, 22/20/R; Hewlett-Packard 2100; and Varian Associates R620. The HP 2100 is not ruggedized but undergoes more stringent testing and has been successfully used in more airborne, and maritime applications than any other standard version of minicomputer.

3.1.5 USER SEGMENT COMPUTERS

The purpose of the Control Segment Computer trade study is to identify those computers that will satisfy the mandatory computational requirements of the Master Control Station and Monitor Station. In terms of future phase requirements, it is desired to make the computer selection assuming that the configuration be adequate at least until the latter stages of GPS Phase II or possibly the beginning of GPS Phase III.

From the analysis, it was determined that a very small number of candidates can satisfy the mandatory requirements of higher-order language capability, floating point double precision hardware, and proven reliability. At this time the preliminary evaluation indicates that the ROLM rugged Nova-1602R is the superior selection. However, there are other computers that merit serious consideration: General Electric CP24A; Univac MPC-16; Honeywell 516; and Rockwell D216.

This analysis is continuing in terms of desirable features such as ability to interface with auxiliary sensors and the ability to perform the computational and control functions of a monitor station. This analysis will continue through the evaluation of formal proposals from capable vendors.

3.1.6 USER COST/PERFORMANCE

The purpose of this trade study is to identify specific design techniques that have significant impact upon the cost and performance of User Segment equipment. The primary emphasis on the user equipment design is to develop a minimum cost set of user systems that will provide adequate operational capability for a specified military mission. The following table summarizes candidate design techniques, range of cost deltas, and performance range.

Cost/Performance Summary

Candidate	Cost Delta Range	Performance Range
Oscillator Stability for Direct Acquisition	$53 - $190	10 - 100 times longer operation
Standard Oscillator Frequencies	$200/unit	Logistics and maintenance only
Error Correcting Codes	$300/unit	2-3dB Lower Threshold
IMU Calibration and Modeling	$100/unit	2dB AJ increase
IMU Dynamic Aiding	$300/unit	Lower Acquisition & reacquisition time - values TBD
Dual Ionospheric Frequency Measurement	$680/unit	Residual error less than 10 ft.
Plated wire memory hardening	TBD	Nuclear threat protection
Kepler Alert Program	$60/unit	Improved best GDOP selection aids direct acquisition by factor of six.
Analog vs. Digital Circuits	Implementations known cost - TBD	TBD
Hardware vs. Software Implementations	Software Cost increase $200/unit - hardware cost savings- TBD	Software has 0.5 to 1 dB sensitivity loss

In all cases, the cost/performance evaluations are not finalized. It is expected that these and other design techniques will be continually quantified throughout the Phase I testing program as the performance of GPS is verified.

3.1.7 USER IONOSPHERIC MODEL

The purpose of the User Ionospheric Model trade study is to develop analytic models that will provide to the user (from the Master Control Station via the satellite) accurate knowledge of the ionospheric delay. These models must be compatible with the low rate channel available with the L_1/L_2 navigation channel and require a minimum computational burden upon the user equipment. It is desirable that these models be suitable for all Phases of the GPS program. Changes within the constraints of the communication capacity of the system are possible during the test portion of Phase I with little impact upon user software.

The recommended ionospheric model for determination of atmospheric delay by the user is a series representation of the line-of-sight signal delay. This method is referred to as the Satellite Transmit Delay model. It provides a polar coordinate model of the signal propagation delay in terms of range, azimuth, and coelevation angle from a known subsatellite point. This approach saves considerable user computation complexity because the signal delay is obtained directly from the model without an intermediate step of computing the total electron content of the atmosphere along the ray path of the signal.

We are also investigating two static models:

1) A simple tabulation of total electron content in magnetic latitude and longitude vs local time of day

2) A simple tabulation of total electron content vs only local time of day

The determination of the best static model and evaluation of residual statistics is continuing.

3.1.8 USER EPHEMERIS MODEL

The User Ephemeris Model trade study investigates possible mathematical models of satellite position that will permit the users to determine the satellite location via the L-band user navigation data. The models must not overburden the user navigation data frame and provide an error of less than 1 foot with respect to the predicted satellite orbit. The recommended ephemeris model for determination of the satellite position by the user is the Keplerian orbit computation. A set of 13 parameters is required to solve for the satellite position in an inertial frame of reference using the classical two body configuration for Newtonian mechanics. Of the 13 parameters, 9 are fixed, 3 are variable, and the last is time or mean anomaly.

3.1.9 EPHEMERIS DETERMINATION

The Ephemeris Determination trade study provides the computational approach that yields the detail of the interface between the Master Control Station software and the Monitor Station pseudo-range measurements. The resulting computational approach should be adequate for all Phases of the GPS program.

Results of this trade study are still incomplete at the time of this submittal. They will be added at a later date.

3.2 SYSTEM SEGMENT SPECIFICATION

3.2.1 USER SEGMENT SPECIFICATION

The User Segment Specification, Performance and Design Requirements for the User Segment, Global Positioning System, SS-US-101, describes the functional relationship between the Satellite Vehicle segment and of the intra-functional elements which constitute the User Segment. The User Segment specification was developed and submitted under CDRL Item A002. The specification tree for the User Segment is shown in Figure 3-1. This specification tree describes the Configuration Item and Computer Program Development Specifications that constitute the User Segment and which separately describe each class of user within the segment. The Configuration Item and Computer Program Specifications are defined per the requirements of MIL-STD-490, with the Computer Program Development Specifications also adhering to the direction given by MIL-STD-483.

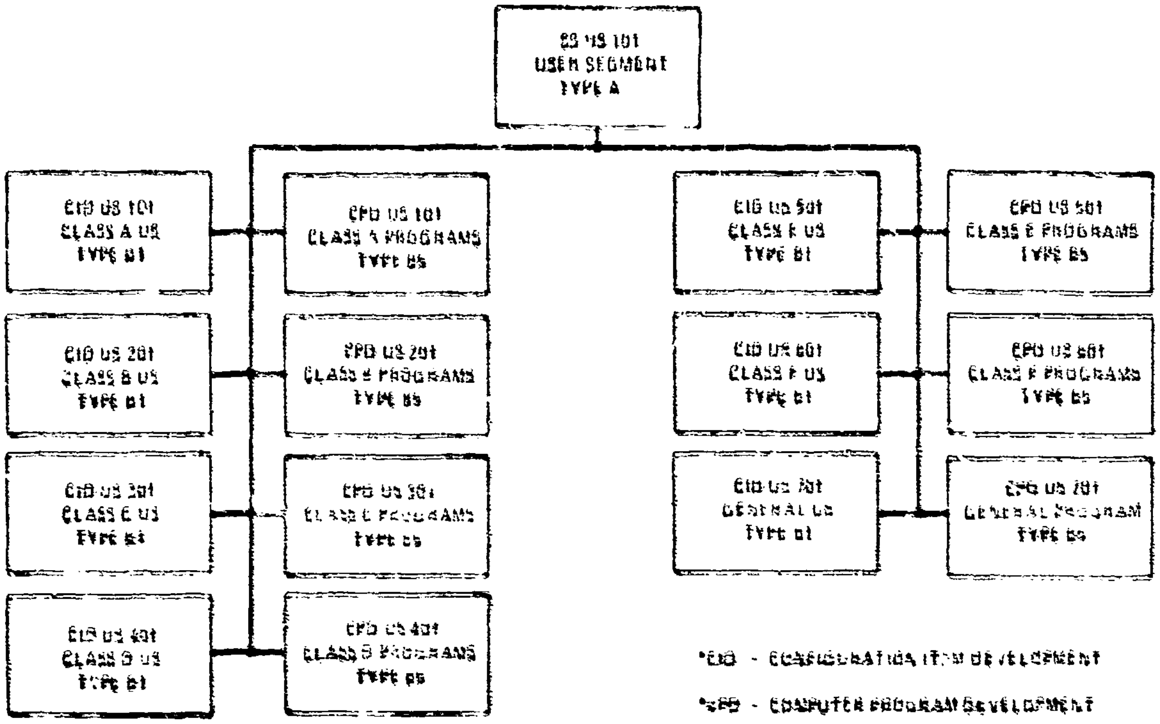

Figure 3-1. GPS Specification Tree

3.2.1.1 SATELLITE VEHICLE INTERFACE — Interfaces between the User Segment and the Satellite Vehicle are defined in terms of the navigation signal transmitted by the satellite for the purpose of position, velocity, and time determination. The SS-US-101 specification defines the navigation signal in terms of the signal format, data content, and information rate. Generally, the navigation signal follows the content described in the GPS System Specification, SS-GPS-101A, dated 29 Jan 1974, with variations which are unique to the selected implementation being defined in SS-US-101. The material in the user segment navigation signal is derived from study results obtained in the Signal Selection study task discussed in Volume III of this report.

Navigation signal density available to the user segment is defined in terms of the minimum signal power available to a user segment isotropic antenna within line of sight of the satellite at an elevation angle of five degrees. This concept allows the user segment to be defined independent of the RF link and satellite power variations. In reality, the user segment must function in a variety of situations which will violate the specified received signal power and hence the user segment performance will deviate accordingly. Variations and potential shortcomings in the RF link and satellite power budget are considered in the RF Link Analysis study task presented in Volume III.

3.2.1.2 USER SEGMENT FUNCTIONS — A generic functional flow diagram showing the various elements which constitute the user segment is shown in Figure 3-2. The various classes of user segment equipments may employ only portions of the functions shown. As an indication, the Class A, B, and F equipments may employ the total group of elements with the Auxiliary Sensors being an inertial measurement system. In contrast, the Class D and E user equipments will not employ the Auxiliary Sensors. The Class C user equipment will not employ the Auxiliary Sensors, and also will not require the use of a Transec Device for secure decryption.

These implementations are unique to each class and are described in the individual class Configuration Item (CI) specifications.

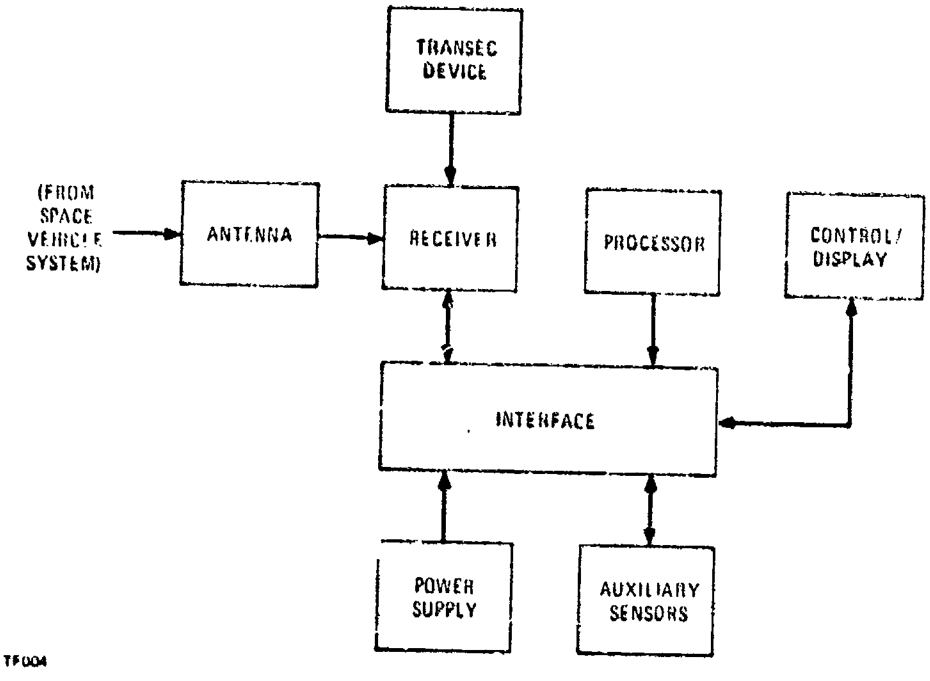

Figure 3-2. User Segment, Functional Flow Diagram

3.2.1.3 PERFORMANCE — The navigation capability defined for the user segment is a function of the available orientation of the satellite vehicle with respect to the user segment. This geometrical orientation dependency is denoted as the geometrical dilution of precision (GDOP) and the number of satellites, time, and method of navigational solution establishes the numerical accuracy of navigation which may be achieved by the user segment. Performance constraint for the user segment has been obtained by defining the user equivalent ranting error (UERE) toward an individual satellite. Performance allocation for the user segment is based upon the budgeting of the user segment contribution to the UERE and accordingly, to the user equivalent range-rate error (UERRE). The error contributions to the UERE and UERRE have been categorized into five distinct budgets:

1) User Receiver Error — Consists of all errors contributed due to noise, tracking and resolution errors within the receiver function. These error

contributions are dependent upon the specific CI dynamic and environmental operating conditions.

2) Residual Tropospheric Error — Encompasses all errors contributed to the user segment due to utilization of an imperfect algorithm to compensate for the actual tropospheric delay and refraction vagaries.

3) Residual Ionospheric Error — Contributions injected due to errors in dual frequency measurements or due to limitations in the model being employed by the user segment.

4) User Processor Error — Consists of all errors contributed due to resolution, timing delay, or scaling error introduced by the processor function.

5) Unassigned Error — The allocation which allows for error sources which are transitory or varying error contributions such as multipath, and others.

3.2.2 CONTROL SEGMENT SPECIFICATION

The Control Segment Specification establishes the performance, design, test and functional requirements for Phase I of the GPS program. Emphasis was placed on being consistent with the performance requirements of the System Specification for the Global Positioning System, Phase I, SS-GPS-101A, dated 29 January 1974.

The specification for this segment has been prepared in accordance with contract requirements for Type A Specifications per MIL-STD-490 (DI-E-3117). It consists of 7 configuration items:

No.	Quantity	Configuration Item
1.	4	Monitor Stations
2.	1	Upload Station
3.	1	Master Control Station
4.	1	Control Segment Computer Control Program
5.	1	Monitor Station Computer Program
6.	1	Master Control Station Computer Program
7.	1	Upload Station Computer Program

Performance characteristics of the segment necessary to realize the GPS system accuracy goals are assigned quantitative physical values. In subsequent subsections, the performance of the major subdivisions of the Control Segment are allocated their performance requirements. Design and construction of electronics are required to comply with MIL-E-4158.

Functional area characteristics of the segment and the major subdivisions, configuration items 1, 2 and 3, delineate the features and qualities of the segment. These features include tracking, propagation delay modeling, and system calibration for the segment. For the Master Control Station functional features such as communications and computer operations are required. For the Monitor Stations features such as antenna characteristics, reference frequency generation, and computer software, are required. Similar features of the Upload Station are required.

Qualification and verification test requirements for the segment are called for in accordance with the system requirements.

FORTRAN computer programming standards and navigation signal structure are incorporated in two separate appendices.

3.3 USER SEGMENT CONFIGURATION ITEM SPECIFICATIONS

The User Segment Configuration Item Specifications (7) were submitted to the JPO on 30 January 1974 in accordance with CDRL Item A005.

The User Segment Configuration Item (CI) Specifications provide the technical performance requirements and functional descriptions of the 6 classes of User Segment equipment. The user class definitions and the appropriate CI specifications are:

CLASS A	Tactical and strategic aircraft who experience medium dynamics in the presence of severe jamming	User Element Strategic bombing Strategic reconnaissance Tactical interdiction Aerial photomapping
SERVICES	USA, USN, USAF, USMC	
SPECIFICATION	CID-US-101	
CLASS B	Tactical and strategic aircraft who experience high dynamics in the presence of medium to low jamming	User Element Air defense-interception Air superiority Tactical reconnaissance Close air support
SERVICES	USA, USN, USAF, USMC	
SPECIFICATION	CID-US-201	
CLASS C	Low Cost Avionics Set Aircraft who experience medium to low dynamics in natural EMI environments only	User Element Airlift Search and rescue Refueling and rendezvous Aerial delivery
SERVICES	USA, USN, USAF, USMC, Commercial	
SPECIFICATION	CID-US-301	

CLASS D	Land wheeled and tracked vehicles, and marine vehicles who experience low dynamics in the presence of severe jamming	User Element Personnel carriers, jeeps Tanks Amphibious vehicles Artillery, missile launchers Riverines
SERVICES	USA, USMC, USN	
SPECIFICATION	CID-US-401	
CLASS E	Manned Backpack. Ground troops who operate in the presence of severe jamming	User Element Manned backpack (could be a backup for land vehicles and helicopters if necessary)
SERVICES	USA, USMC	
SPECIFICATION	CID-US-501	
CLASS F	Surface vessels and submarines who experience low dynamics in the presence of severe jamming	User Element A/C carrier (ship navigation and A/C landing system) Destroyer, Cruisers Submarines (Polaris, etc.)
SERVICES	USN	
SPECIFICATION	CID-US-601	

An additional specification CID-US-701 was also developed defining the requirements for a General Developmental Model which provides the functional capability and performance level of each of the user classes of equipment by utilization of hardware module replacement and software mode modification. This General Development Model is intended for laboratory design validation testing and for limited operational flight verification testing during the Phase I program.

Each CI specification presents the detail requirements imposed on the antenna, receiver, processor, interface, power supply, and control/display elements which constitute the user class equipment. In addition, the unique mechanical and packaging features which are needed to specify each class are also detailed.

Performance requirements generated for the various classes were determined to fall into three main categories and the CI specifications reflect this orientation. In general, the class A, B, and F user classes have identical requirements for performance in terms of C and P signal acquisition times, jamming signal margin, time to first fix and UERE. The only significant variation between the A, B, and F users was in the area of operational mechanical packaging requirements where the F class user (a submarine) would demand a unique enclosure and shock environment which could be met by utilizing a separate rack mounting unit. Basic Phase I UERE for the A, B, and F class is apportioned to be 10 to 20 feet depending upon ionospheric levels and multipath variations.

Class D and E environments and operational requirements were also deemed to be similar and the CI specifications reflect this condition. The limited power source capability and display variations for the D and E user differentiate these systems from the above A, B, and F. System accuracy limits are identical and if direct P-signal acquisition does become an operational requirement, these classes will require an oscillator stability and quality in excess of the airborne user. Operation of the Class C user with only the clear (C/A) signal establishes a separate performance level from each of the other classes. The Class C development is also being pursued along a different design level appropriate to the more sophisticated prototype level of testing and design control. The UERE performance level for the Class C will be 60 to 70 feet.

3.4 CONTROL SEGMENT CI SPECIFICATIONS

The Control Segment consists of 3 primary Configuration Items (CI) which are defined by:

1) Master Control Station (MCS); CI Specification D9000620B
2) Monitor Station (MS); CI Specification D9000612B
3) Upload Station (ULS); CI Specification D9000619B

These CI's are prepared in accordance with the contract requirements for Type B1 Prime Item Development Specifications per MIL-STD-490 (DI-E-3102A).

The CI Specifications establish the performance, design, development, and test requirements for each Control Segment station. Only Part I of each CI is prepared under the current contract.

The CI specifications describe the overall performance requirements with particular emphasis on the interface requirements between stations and between the stations and other GPS segments. The CI specifications are compatible with the Control Segment Specification D9000602B and reference the segment specification as appropriate for brevity and clarity of requirements. Duplication of requirements is avoided unless required for clarification.

The CI specifications describe the requirements in quantitative physical terms with tolerances which can be verified by subsequent analysis, test or inspection.

Each CI specification includes a description of the characteristics required from each major component within the station. The major components reflect the minimum implementation of the requirements of the GPS as determined by General Dynamics.

3.5 USER SEGMENT COMPUTER PROGRAM CONFIGURATION ITEM SPECIFICATIONS

The User Segment Computer Program Development specifications (7) were submitted to the JPO on 30 January 1974 in accordance with CDRL Item A004.

The User Segment Computer Program Specifications establish the Part I requirements for performance, design, test, and qualification of the computer programs which are identified with each class of user equipment as discussed in Paragraph 3.3. The appropriate CPCI specifications for each class have been identified:

Class A	CPD-US-101
Class B	CPD-US-201
Class C	CPD-US-301
Class D	CPD-US-401
Class E	CPD-US-501
Class F	CPD-US-601
General Development Model	CPD-US-701

Consideration of operational requirement similarities has led to basically only two separate and truly distinct specification contents and these encompass the A, B, F, and General (G) class and another which encompasses the C, D, and E classes. The basic distinction between the two software developments is the inclusion of a Kalman filter subroutine for estimation in the A, B, F, and G and the replacement of the Kalman in the C, D, and E with a much less complex navigation algorithm.

Capabilities provided by the CPCI to the user segment consist of the processing of range and range rate data from the user equipment receiver, determination of satellite ephemerides, and internal monitoring of equipment status. The results of the data processing produce a determination of position, altitude and time. For airborne users, data on ground track, ground speed, or optional steering signals is also provided. Additional processing provides control for signal search and acquisition, signal tracking and input/output control. The CPCI specifications define each of the specific functions required of the software processing programs and the detailed interface between functions of the program and interfaces external to the program. Software architecture used for the program defines a main or executive program that monitors the status of peripheral units and determines the required processing mode and applicable subroutines that will be employed to perform specific computational or data processing tasks. Specific subroutines are defined for each software function to provide maximum control and flexibility to the executive program. Floating point and double precision arithmetic are stipulated to insure computational integrity. Operational hierarchy and mode selection flow logic are indicated in the CPCI. Timing and sequencing of data into and between modules is defined in the CPCI especially in the area of the Kalman filter execution. Interfacing to auxiliary sensors and to ancillary functions such as Steering/Landing or Mission and Traffic Control is also defined.

3.6 CONTROL SEGMENT CPCI SPECIFICATIONS

The Control Segment CPCI's cover the computer programs allocated to the various computing elements of the Control Segment, and the interfaces between those elements. The relationship between the specification is shown in Figure 3-3.

3.6.1 CONTROL SEGMENT CPCI

The Control Segment CPCI describes the overall software requirements for the Monitor Stations, the Master Control Station, and the Upload Station. This CPCI also specifies the communication between the stations, required data rates, and message types. The following specific functions are covered in this specification. Also included in the specification are special programming restraints which apply to all other Control Segment CPCI's.

1) Monitor Station Function
2) Communications, Command, and Control functions
3) Master Control Station Program function
4) Upload Station Program function

3.6.2 MONITOR STATION COMPUTER PROGRAM CPCI

The Monitor Station CPCI details the functional software requirements for the Monitor Station. The emphasis is on the functions required for the Monitor Station which are

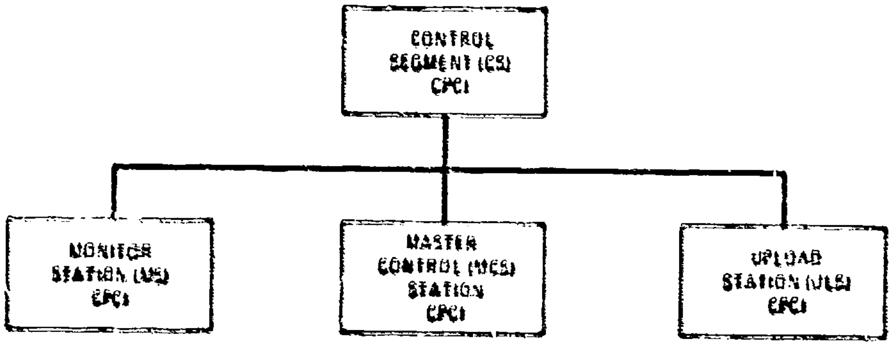

Figure 3-3. Control Segment CPCI's

above and beyond those which would normally be performed in a user computer. These added functions are:

1) Communications handler
2) Station scheduling routine
3) Antenna control
4) Pseudo range data edit and curve fit

The user equipment functions are also included so that a complete set of Monitor Station program requirements is available within the context of the specification.

3.6.3 MASTER CONTROL STATION COMPUTER PROGRAM CPCI

The Master Control Station (MCS) is the major data processing element within the GPS system and its functions are defined within this specification. The MCS software functions are:

1) Executive Routine
2) MS Data Initialization
3) ULS Data Initialization
4) Meteorological Data Processing
5) Tracking Data Processing
6) Satellite Ephemeris Determination and Clock Update
7) Ephemeris Polynomial Generation
8) Satellite Data Load Preparation
9) MS/ULS Transmission Handler
10) MS/ULS Reception Handler
11) Pre-pass Routine
12) Special Requirements
    a) SCF telemetry data interface
    b) Ionospheric Data Collection
    c) Reference trajectory generation

3.6.4 UPLOAD STATION COMPUTER PROGRAM CPCI

The Upload Station Computer Program has the basic task of controlling the data to be uploaded to the satellite. The program is capable of either complete or partial data loads. The uploading functions specified are:

1) Interrupt processing
2) Telecommunication processing
3) Data file verification
4) Target selection
5) Antenna vectoring
6) Upload verification
7) Upload file management.

3.7 TEST FACILITIES REQUIREMENTS DOCUMENT

The Test Facilities Requirements Document, Data Item A008 defines the test facilities required for the performance of the GPS Phase I validation program including test sites, test vehicles, and special test equipment. Success of the Phase I validation program will be based upon meeting the system static and dynamic navigation accuracy specified in the Segment Specification.

3.7.1 TEST FACILITIES REQUIREMENTS & SCHEDULES

Specific test facilities required and time period needed are listed in Table 3-1.

Table 3-1. Required Test Facilities and Time Period

REQUIREMENT	TEST RANGE	SEA TEST RANGE	SURVEYED SITES	TEST AIRCRAFT	EQUIPMENT SHELTERS	NAVAL SHIPS
Test Facility Requested	White Sands Missile Range Alternate - USA Yuma Proving Gnd	San Clemente Island Sea Range	Sites Used in DOD Geoceiver Test Program, DMA Report 001, July 72	C141 C130E F4D B1	Two trucks or vans for carrying user Equipment	Carrier Other small ship (TBD)
Specific Need	Precision Space Positioning of Gnd & Airborne vehicles	Precision Space Positioning of Naval Ships	Determine System Static Navigation Accuracy	Test Platform For User Equip.	Test Platform for User Equip.	Test platform for User Equip.
Schedule				C141 C141 C130E C130E F4D F4D B1		
Pretest Preparation	1-76	7-77	None	1-76 9-77	2-77	7-77
Initiation of Tests	2-76	8-77	8-77	2-76 10-77	3-77	8-77
Completion of Tests	3-78	9-77	11-77	6-77 1-78	5-78	9-77
Special Equipment and Instrumentation	Laser Tracking Sys. (Para. 3.7.2) Radar Tracking Inverted Satellite Simulation	Laser or Cinetheodolite tracking System	None	Inertial Navigation System Type (TBD) CIGTF Pallets AFWTF Pod (similar to that used for Class?)	None	None
Housekeeping Requirements	Work, office, & storage space Communications Shop Support	None	None	None	None	None

3.7.2 SPECIAL EQUIPMENT AND INSTRUMENTATION

It is expected that GPS will provide test vehicle horizontal position information on the range to a position accuracy of about 20 feet 1σ. To determine the success of the Phase I validation program and to permit separation of system errors, the primary space positioning system used on the test range should have a demonstrated 1σ position accuracy of less than 2 feet.

These Satellite Simulators will be required:

- A navigation system simulator from the satellite contractor will be required for tests at Magnavox by December 1975 then at Vandenberg for the System Operations Test for the period July-August 1976.
- A telemetry, tracking, and command (TT&C) simulator from the satellite contractor will be required at Vandenberg for the Systems Operations Test during the period July-August 1976.

3.7.3 DATA ACQUISITION, REDUCTION, HANDLING, AND ANALYSIS

A Best Estimate of Trajectory (BET) must be available to the contractor no later than one working day after a flight on the test range; it should be provided on magnetic tape. The required BET accuracies are: 5 ft 1σ (mandatory) and 2 ft 1σ (Desired). Although not mandatory, a real time comparison of GPS performance with a range tracking system of approximately the same accuracy would facilitate test operations.

The real time GPS solution would be telemetered to a central processing center for real time comparison with an independent system and display of the residuals. Flight decisions and in-flight adjustments could then be facilitated — the success or failure of each flight or phase of a flight would be known instantly.

3.8 R&M ASSESSMENTS

The Reliability and Maintainability Allocations, Assessments, and Analysis Report for Global Positioning System User Equipment, CDRL Item Number A006, General Dynamics Report Number R-74-027, dated 30 January 1974, was submitted to the JPO on 30 January 1974.

The User Equipment (UE) R&M assessments contained in the submitted report were based on the UE designs (parts lists, etc.) as configured at this point in time in satisfaction of the UE definitions provided by the JPO. The UE receivers are the only new development required. The Class C UE was chosen as the detail model for the R&M assessment because the method for implementing the six (6) classes of UE receivers provides significant commonality of functions and parts, and the Class C UE will be the first UE to go into production.

The Class C functional elements (modules) were then expanded to develop a complement of elements for each of the other classes. Classes C, D, and E were also expanded to incorporate the necessary additional functions required to provide a faster time-to-first-fix.

From these listings, the particular parts lists were inputted to our computer program for a reliability assessment (prediction) based on 3 different part quality levels. The part quality levels assessed were commercial grade, standard military, and high/established reliability military. The results of this prediction are shown in Table 3-2. The class identification with subscript 2 is the receiver configuration with improved time-to-first-fix.

A Class C maintainability model and analysis was prepared based on the reliability prediction and the estimated maintenance tasks to repair and check-out a failed Class C UE. This analysis provided a predicted Mean Time to Repair (MTTR) of 9.6 minutes.

Table 3-2. User Equipment Receiver MTBF Predictions (Hrs)

User Class	Total Parts	Parts Concept Hi Rel	Mil	Com
$A/B/F_1$	9117	704	200	136
C_1	2058	2871	901	618
C_2	3360	2019	628	430
D_1	2170	2569	772	527
D_2	3622	1712	494	335
E_1	2171	2504	766	524
E_2	3623	1683	492	334

The UE R&M assessment will be updated as the receiver designs are made firm. The reliability predictions for the various classes will also be used to evaluate and optimize the maintainability concept through iterations of our Life Cycle Cost Models (LCCM).

3.9 SYSTEM INTEGRATION PLAN

The system Integration Plan, Data Item ADDC, defines the responsibilities and procedures for timely and effective system integration and interface control. The Joint Program Office (JPO) is designated as responsible for the overall management of the system integration. The Control Segment/User Segment (CS/US) contractor is designated to act as an extension of the JPO in the implementation of the integration. The plan is intended for use by the JPO and the CS/US Contractor to plan, implement, direct and control the integration. The plan identifies tasks, responsibilities, schedules and interface control procedures for the Segment contractors and DOD agencies.

While the System Integration Plan is the basic overall integration plan coordinated between the JPO and CS/US Contractor, a Joint Operating Plan (JOP) is the basic operating plan between all Segment contractors/agencies. A sample JOP is included in the Appendix to the System Integration Plan. The JOP specifies within the limits of each contract that:

1) The task areas of responsibility to be undertaken jointly by each and every party in fulfillment of their contracts. It includes only those tasks of mutual concern and requiring joint cooperative effort.

2) Procedures to be used for the timely interchange of data, information and/or equipment.

The System Integration Plan identifies other required integration documentation:

Interface Control Plan establishes the format, content, approval and control of detailed Interface Control Documents.

Interface Control Documents describe by text, lists and/or drawings the detailed hardware, software and procedural interfaces between elements of two or more segments of the GPS.

System integration schedules establish requirements for all segment contractors/ agencies to provide their hardware, software and services.

While all segment contractors/agencies contribute to integration/interface, the documentation, distribution and change control is accomplished by the Control Segment/User Segment contractor, with JPO approval.

The integration/interface task is coordinated through formal and working group meetings of the Interface Control Working Group (ICWG) comprised of the JPO and all Segment contractors/agencies; these meetings consist of:

- o Integration Management
- o Integration Engineering
- o Special Problem Resolution

All integration documentation is approved by the JPO, CS/UE Contractor and other Segment contractors/agencies. These documents are subject to formal change control and are not unilaterally modified except by JPO direction.

The System Integration Plan may be revised from time to time during the DT&E phase so that it reflects the current overall system integration plans.

4. ABSTRACTS OF PART III PLANNING DATA ITEMS

Part III of the Contract Final Definition report contains, in addition to the proposal for the Acquisition phase, separate deliverable plans covered under separate CDRL's:

A007	System Engineering Management Plan
A00A	Program Milestones
A00D	System Test Plan
A00E	Reliability/Maintainability Program Plan

This section addresses abstracts of these plans which will be delivered concurrently with the proposal on June 17.

4.1 SYSTEM ENGINEERING MANAGEMENT PLAN

The System Engineering Management Plan (SEMP) will be delivered as CDRL Data Item A007 on June 17, 1974. The SEMP will consist of System Engineering Process (SEP) and System Engineering Management (SEM) elements. The major characteristic items within each of these elements are analysis, allocation, synthesis, and definition. The SEMP establishes methods of obtaining technical achievement, program visibility, and traceability on a timely basis during conduct of the program.

During the Contract Definition Phase, applications of the process have led to the development of data and information necessary for system requirement and equipment definition and Acquisition Phase SEM.

The SEMP for the acquisition phase will provide for the update and expansion of the system requirements and equipment definition. The SEM is implemented to provide a smooth system development and production operation.

The SEP essentially consists of a number of iterative loops which start with performance requirements and end in system definition. These loops consist of the interconnection of a number of functions:

1. Mission and Requirements Analysis
2. Functional Analysis
3. Requirements Allocation
4. Trade Studies
5. Design Optimization/Effectiveness Analysis
6. Synthesis
7. Technical Interface Comptibility
8. Logistics Support Analysis
9. Producibility Analysis
10. Generation of Specifications

The SEM functions are iterative processes which reflect the management system of defining, assessing, controlling, and recycling. The SEP and SEM are "mechanically" connected through the Work Breakdown Structure (WBS) and the following SEM functions:

1. Technical Program Assurance
2. Technical Performance Measurement
3. Design Reviews
4. Program Reviews
5. Configuration Control
6. Interface Control

The SEM functions are part of the overall Technical Program Planning and Control. Other elements involved in technical program planning and control are:

1) Program Risk Analysis
2) Assignment of Responsibility and Authority
3) Engineering Program Integration

Throughout the SEMP an effort is made to achieve an integrated/balanced system configuration. In order that this may be achieved, engineering specialty disciplines are considered and are active in the SEMP operations. These include:

1) Reliability
2) Maintainability
3) Safety
4) Human performance
5) Producibility
6) Transportability

In addition, Quality Assurance, Value Engineering, Subcontract Management, and Data Management are included in the SEMP functions as necessary.

4.1.1 OBJECTIVES OF PLAN

The System Engineering approach to be used by General Dynamics has these fundamental objectives:

- Produce for SAMSO a User and Control segment system design and development plan for the most effective system obtainable within the required time frame and allocated cost
- Integrate all aspects of procurement
- Plan and produce a clear and concise communication channel for describing system design solutions between the Joint Program Office (JPO), General Dynamics' GPS Project Office, and the subcontractors

- Provide SAMSO and General Dynamics internal management with the necessary visibility on all significant design decisions and the logic behind the decisions, and provide traceability to the driving functions
- Ensure that clearly defined and discrete work packages and assignments are identified. Provide a method for concise and rapid auditing of the tasks

4.1.2 FUNDAMENTAL APPROACH

The Acquisition Phase System Engineering Management Plan (SEMP) is based on 1) Criteria and requirements resulting from Contract Definition Phase (the updated Systems and Segment Specifications); 2) Requirements of MIL-STD-499; and 3) General Dynamics experience on past and existing systems. Figure 4-1 shows the progression from initial technical requirements to the design, development, and verification of the complete system.

Figure 4-2 shows the elements of the SEMP. Each of the SEM elements in the lower portion represent functions that actually involve all elements of the SEP. A basic

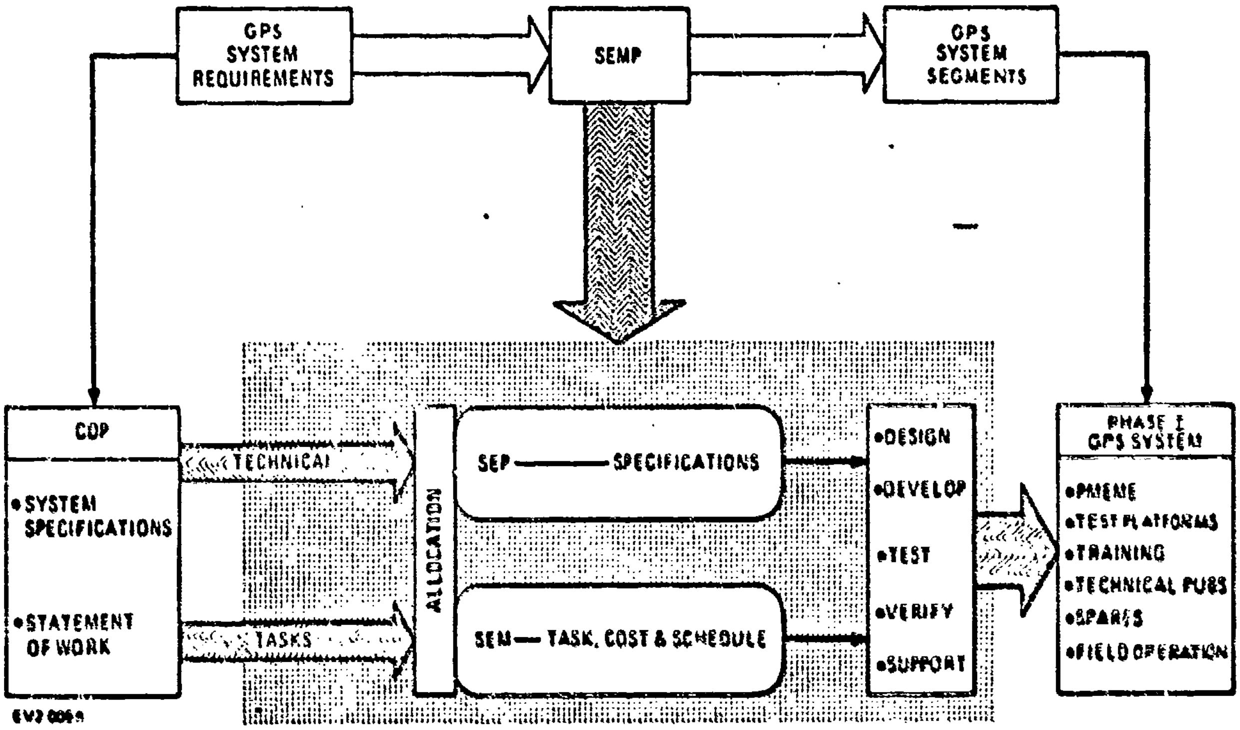

Figure 4-1. Basic Approach to System Engineering Management Plan

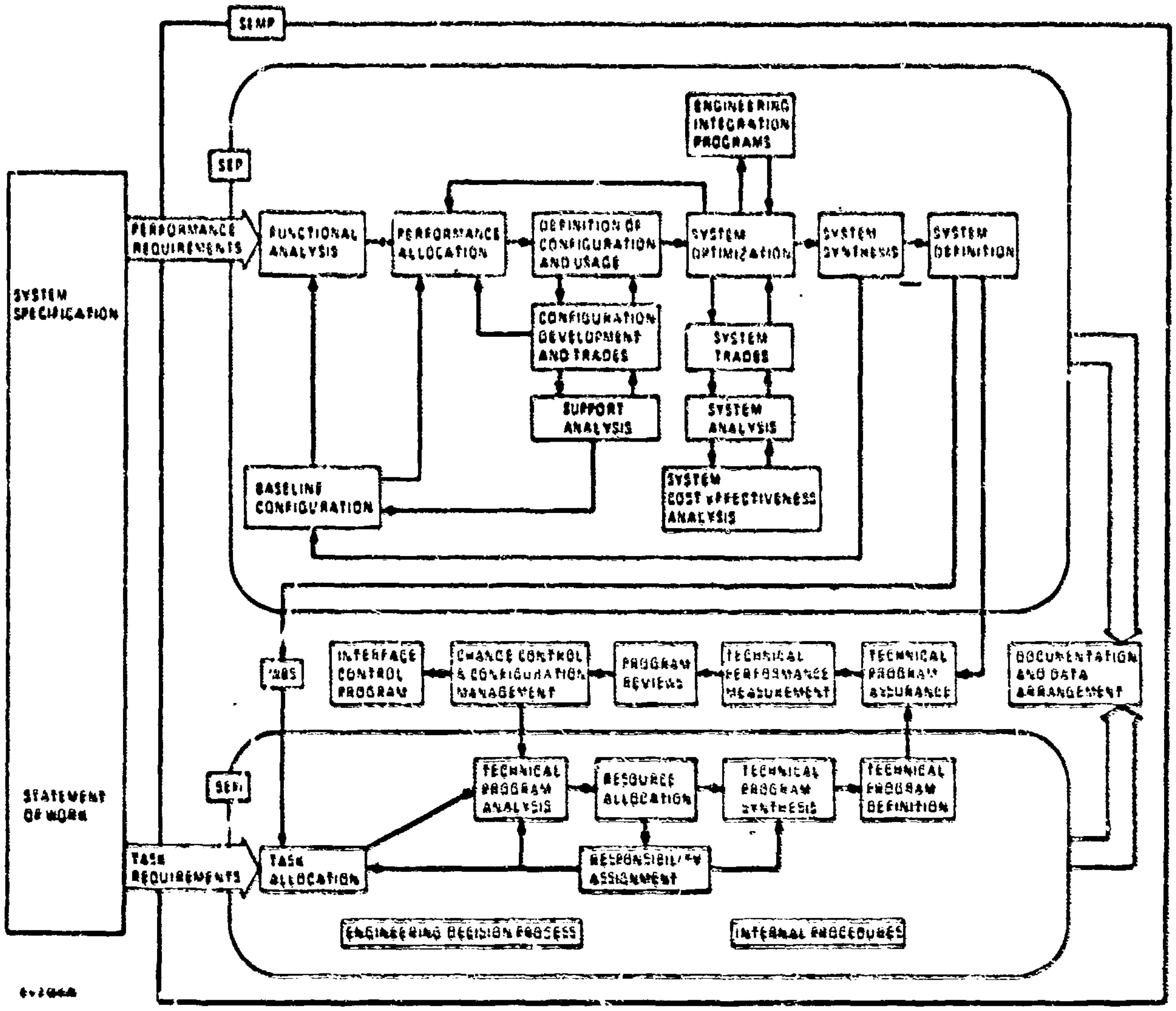

Figure 4-2. System Engineering Management Plan

iterative flow exists among the SEM functions which reflects the management system of defining, assessing, controlling, and recycling. In addition, a number of elements designated as SEM functions exist that interconnect the technical and management functions to achieve an integrated program. These elements are shown between the SEP and SEM blocks on Figure 4-2. They consist of Technical Program Assurance, Technical Performance Measurement, Design Reviews and Program Reviews, Configuration Control and the Interface Control Program. These functions are being planned and defined during Contract Definition Phase, and will be incorporated as major elements of the Acquisition Phase SEM. There are three additional functions inherently involved in all of the SEMP elements: the engineering decision process, internal procedures, and Documentation and Data Management.

Methodology has been established for all of the SEM and SEP elements and documented in preliminary issues of the SEMP. In the final SEMP to be submitted on June 17, this methodology will be coupled with the specific Phase I Statement of Work agreements established for the RFP and the resulting WBS to provide the final SEMP for the acquisition phase.

4.2 PROGRAM MILESTONES

The program milestones document will be submitted as Data Item A00A in accordance with DI-A-3009 on June 17, 1974. It will contain a PERT-type schedule layout of the entire control and user segment acquisition plans tied to the Work Breakdown Structure being generated by the Air Force for the CS/UE RFP. This schedule will be prepared in sufficient detail so that with an initial 30-day update after an acquisition phase contract award, it can serve as the program operating schedule compatible with periodic PERT/time network analysis and reporting per DI-A-5025 during the acquisition phase.

General Dynamics has prepared a master Gannt-type planning schedule containing major milestones, which will be used as a baseline until such time as any conflicting schedule requirements are identified in the RFP; see Figure 4-8.

The master schedule assumes that a CS/UE contract award will be made in October 1974 and that the NTS-2 launch will be accomplished in October 1976 — a key driving date to all of the Control Segment activities and to the supporting User Equipment activities.

Also assumed are the most optimistic NDS satellite launch dates based upon the constraints of the Space Segment RFP (F04701-74-R-0006) issued by SAMSO on January 31, 1974. These launch dates are:

NDS-1	March 1977
NDS-2	May 1977
NDS-3	July 1977

With these optimistic launch dates, the DSARC II date could not be much earlier than the end of the first quarter of 1978 if the Phase I test objectives were to be adequately fulfilled. Accordingly, An April 1978 date has been assumed as the end of the Phase I effort. In all probability, satellite launch dates will be even three months later than those assumed, driving the necessary DSARC II decision even further downstream, or further compromising the Phase I test objectives. This condition is discussed further in paragraph 8.2 (Other Problems).

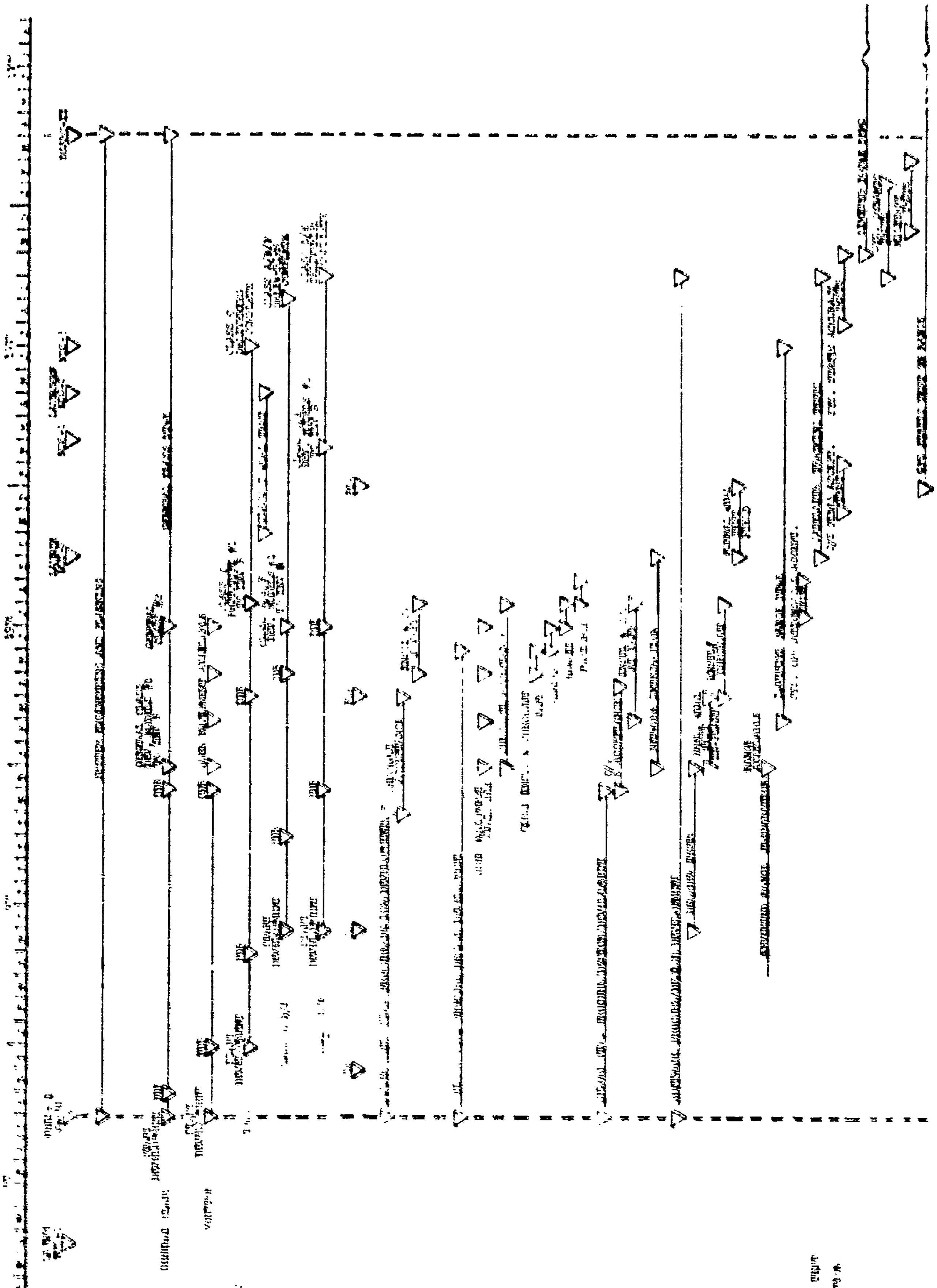

Figure 4-3. GPS Phase I Schedule

Summarizing the key assumed milestones:

CS/UE Contract Award	October 1974
NTS-2 Launch	October 1976
NDS-1 Launch	March 1977
NDS-2 Launch	May 1977
NDS-3 Launch	July 1977
DSARC II/Phase I Completion	April 1978

Based upon these dates, the following additional key milestones have been established:

Inverted test range availability	January 1976
First General Class UE set to inverted test range	January 1976
In-plant completion of Control Segment elements	April 1976
Field integration completion of CS elements	August 1976
Control Segment acceptance	January 1977
User Segment ABF development model to inv. test range	July 1976
UE Class C prototype to inverted test range	August 1976
UE Class D/E develop. model to inv. test range	February 1977
Start system static accuracy tests	August 1977
Start system dynamic tests	October 1977
Start limited IOT&E	November 1977
Start Military tests	December 1977

4.3 SYSTEM TEST PLAN

The System Test Plan will be submitted as Data Item A00D on June 17. This section provides an abstract of the contents of the System Test Plan.

The purpose of this test plan summary is to provide an overall outline of the test program for the Global Positioning System (GPS) Control Segment (CS) and User Segment (US). The plan includes a general description of the types of equipment to be used in implementing the CS/US and objectives and scope of the tests required to assure that the CS/US is adequate to support the GPS, Phases I and II.

4.3.1 CONTROL SEGMENT TESTING

The Control Segment (CS) consists of 3 separate station configurations:

Station	Location
Master Control Station (1)	VAFB
Monitor Stations (4)	VAFB
	Hawaii
	Alaska
	TBD
Upload Station (1)	VAFB

The CS stations will be implemented with off-the-shelf available designs with a few exceptions. The CS tests will therefore primarily address equipment interface compatibility and the development and proofing of software programs.

Functional testing of the CS will include:

1) Component testing in accordance with the contractor's approved Quality Control Program.

2) Off-the-shelf assembly (purchased) tested in accord with the requirements of the contractor's Purchase Order (PO). Vendor test data will be required.

3) Laboratory testing of new or modified designs, software, subassemblies, and subsystems to proof design and system implementation concepts.

4) In-plant testing to confirm interface compatibility between assemblies, subsystems and software.

5) Checkout and acceptance testing to insure that all hardware and software satisfies the GPS requirements as specified in the JPO approved acceptance test procedures prior to delivery to field test sites.

6) Qualification testing shall be limited to new designs and modified off-the-shelf designs to assure satisfactory performance in the environments specified and after transport per approved packing and shipping requirements.

7) Segment testing shall be those tests on-site to demonstrate acceptable integration and performance. These tests will be conducted with approved test programs, simulators, etc., and the satellites.

4.3.2 USER SEGMENT TESTING

The User Segment consists of classes of user equipment (UE) plus a general development model to be used as a design tool. The classes of UE can be implemented by three basic configurations and in the model types as shown in Figure 4-4.

The test and evaluation during the evaluation of the UE designs will be performed as follows:

1) Component Tests will be performed in accordance with the Contractor's approved Quality Control Program.

2) Engineering Bench Tests will be performed to provide corroborative data on circuit design by circuit analysis, simulation and breadboard tests.

3) Breadboard Verification Tests will be performed to insure signal flow and circuit performance in accordance with design requirements.

4) Software Validation Tests will be performed to verify software logic flow and efficiency within the digital data processing unit, including algorithm logic validation, hardware/software emulation, and I/O interface verification.

5) Laboratory Integration Tests utilizing both static and dynamic signal simulations to demonstrate the performance of the initial development configuration.

6) Integration tests will be performed on the general development model to provide the following design confidence data:

   a) Signal level sensitivity
   b) Signal dynamic range performance
   c) Measurement accuracy, errors and biases
   d) Data processing accuracy and efficiency
   e) Acquisition and reacquisition capability

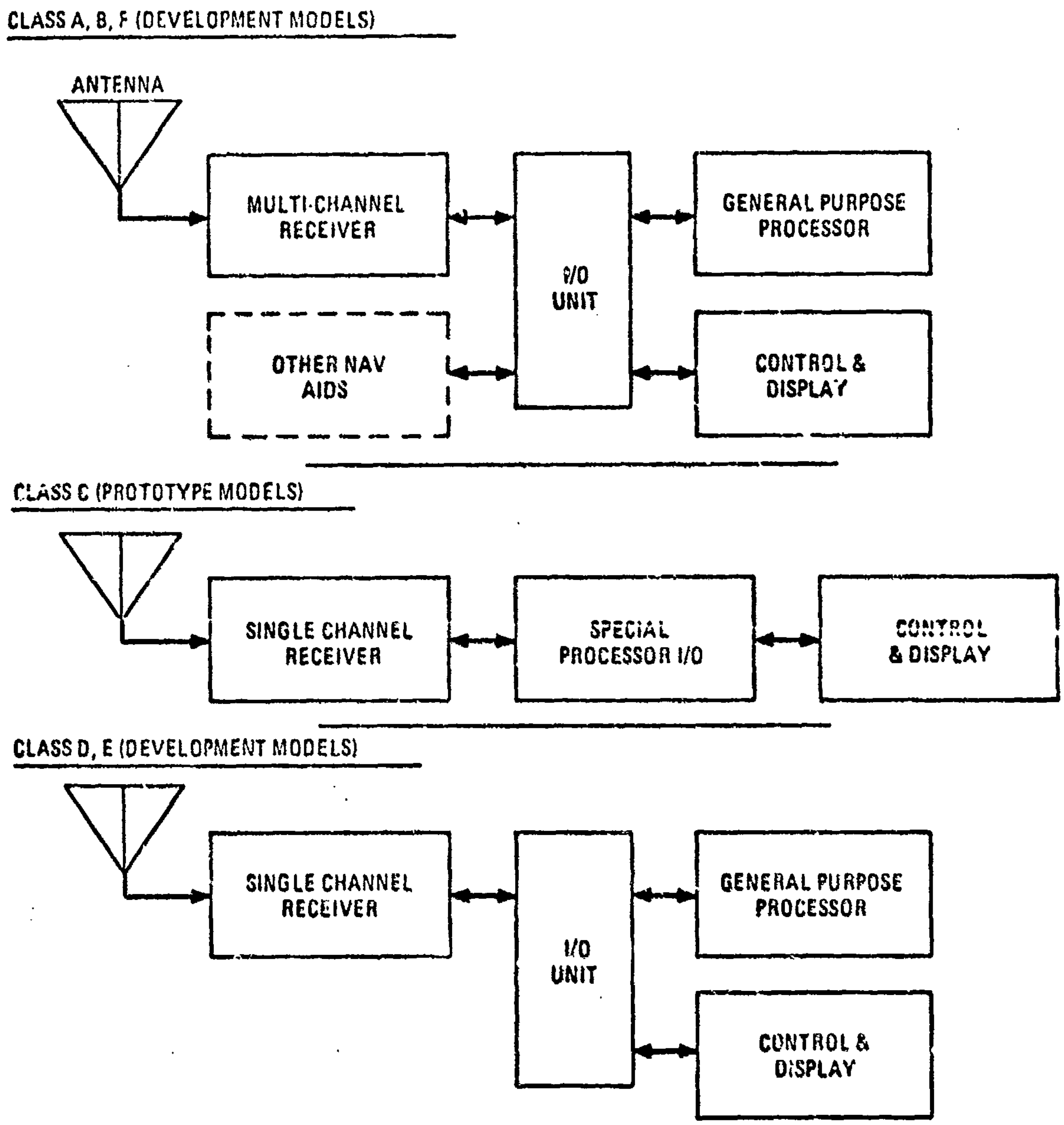

Figure 4-4. GPS Phase I – User Equipment Block Diagrams

f) Measurement resolution in range, velocity

g) Waveform modulation, code sequence and

h) Data word format verification

i) RF, IF and oscillator frequency check

j) Track loop performance with dynamic acceleration and jerk

4.3.3 CS/US SYSTEM TESTS

The series of systems tests required to demonstrate the program objectives are summarized in the following paragraphs.

4.3.3.1 INVERTED RANGE TESTING — The Inverted Range Tests are designed to provide an early end-to-end checkout of the User equipment and test range operation and interfaces prior to satellite launch.

The inverted range consists of four ground-based transmitters radiating the GPS signal structure, and spaced so as to simulate the GPS satellite geometry. User equipment is installed in the same test vehicles that will later be used for the system dynamic accuracy tests. This test will check system operation, data acquisition and data reduction systems, thus providing a complete "dress rehearsal" prior to launch for the system dynamic accuracy tests.

4.3.3.2 SYSTEM INTERFACE TESTS — The System Interface Test is primarily a test of the various control segment communication interfaces. Communications between the Master Control Station, the Monitor Stations, the Upload Station, the Satellite Test Center and the appropriate control center for the Navigation Technology Segment will be exercised. The tests will be performed after on-site installation and checkout of each of the control segment stations.

The tests will be structured to exercise the data and voice communication links in each mode of link operation. Particular attention will be paid to ensure that the necessary communications plans and procedures are available and evaluated.

4.3.3.3 SYSTEM OPERATION TEST — The System Operation Test will check out all segments of the GPS prior to satellite launch. The successful completion of this test will constitute the preliminary acceptance of the control segment and will be complete prior to the first satellite launch. The test will ensure compatibility between all segment elements in a complete "all up" dress rehearsal of system operation. Portions of this test will also be performed as necessary to support the pre-launch operations of the satellite segment.

The test will involve the Master Control Station, the Monitor Station at Vandenberg AFB, the Upload Station and the AFSCF including the RTS at Vandenberg, and the Satellite Test Center, the communication links, a generalized model of the User Equipment, and the Satellite TT&C and Navigation Simulators.

The test will include the normal operation of the Monitor Station obtaining pseudo-range and data from the Satellite Simulator, performing the processing functions, and transmitting the resulting data upon request to the Master Control Station. The Master Control Station will utilize this information together with simulated data from the other Monitor Stations to determine an ephemeris. The Master Control Station will prepare an upload message and transmit it to the Upload Station, which will then load the memory in the Satellite Navigation Subsystem Simulator.

The back-up mode utilizing the AFSCF RTS to load the satellite simulator will be exercised. The User Equipment utilizing signals from the satellite simulator will "track" the simulator, demodulate the data and perform a "navigation" solution.

The portions of this test that will be performed to support satellite launches have yet to be determined.

4.3.3.4 SATELLITE TRACKING TESTS — The Satellite Tracking Test is performed to evaluate the ability of the Control Segment hardware and software to determine the satellite ephemeris. This test (utilizing satellite NTS-2) will be the final acceptance test of the Control Segment; it will be repeated after succeeding satellites are launched.

The Control Segment will track NTS-2 and produce an estimate of the satellite ephemeris. The NTS-2 will also be tracked by the Naval Research Laboratory ground network. A comparison of the ephemerides can be made, and together with an analysis of the system co-variances and measurement residuals should permit detailed evaluation of the systems accuracy. The test will be repeated with the later NDS satellites, however, as no tracking of these satellites by the Navy Network is planned, the test evaluation will be restricted to only Control Segment and AFSCF data.

4.3.3.5 SYSTEM STATIC ACCURACY TEST

The System Static Accuracy test is designed to permit an evaluation of user static accuracy, obtained over a large test area. The user equipment truck mounted in Standard Army Communication Shelters will also be used to evaluate the ability of mobile receivers to operate in a wide variety of ground environments.

The static position performance of the entire system will be evaluated by the System Static Accuracy test. The test will be performed by deploying two user equipments to selected locations in CONUS. The test locations and time spent at each location will be chosen to obtain data on signal level and absolute user position accuracy over the service area. The sites will be chosen to permit evaluation of the relative accuracy of the system over various distances. While being deployed, the effects upon user equipment of vehicle environment, ground multipath and vehicle antennas will be evaluated.

4.3.3.6 SYSTEM DYNAMIC ACCURACY TESTS — The Dynamic Accuracy Tests are designed to obtain information on the effects upon system accuracy of typical user equipment environments, such as high dynamics, propeller and rotor blade modulation and multipath.

User equipments installed in a variety of test vehicles such as turbojet and turboprop aircraft, helicopters, ships and ground vehicles will be operated on instrumented test ranges under conditions simulating typical dynamic operational environments. Test data acquisition and data reduction methods will be structured for rapid response to facilitate day-to-day test operations.

4.3.3.7 MILITARY DEMONSTRATIONS — A limited set of demonstrations will be conducted to establish military value of the GPS. The demonstrations to be accomplished will be limited to:

1) Coordinate bombing (one aircraft type, one type of bomb, and one set of release conditions)
2) Terminal navigation and landing approach capabilities (one aircraft type, no autopilot coupling, VFR conditions)
3) Airborne Refueling Operations (one aircraft simulating tanker orbiting rendezvous point, second aircraft guided to same point, but at 1000 feet lower altitude)
4) Army land operations (details TBD)
5) Special operational techniques for anti-jam margins and system vulnerability (details TBD)

4.3.3.8 IOT&E TESTING — A limited IOT&E test program will be performed to enable User command personnel to obtain field experience with the Class C prototype equipment.

A TBD number of class C User equipments will be installed into Military Airlift Command (MAC) Aircraft, Type TBD, and used to provide navigation and steering information to the crew. The degree of integration into the aircraft's cockpit instrumentation is (TBD). The aircraft will be flown on regular MAC missions, and when satellite visibility permits, the GPS will be utilized, and its performance and utility evaluated by the crew.

4.4 RELIABILITY AND MAINTAINABILITY (RM) PROGRAM PLAN

The Reliability and Maintainability (RM) Program Plan that will be implemented during Phase I will be submitted in full detail as Data Item A00E.

RM tasks will be implemented as stipulated in Annex 2 to Attachment 1 of the contract, titled Reliability and Maintainability, October 16, 1973. The following summary describes the General Dynamics approach to comply with these requirements.

4.4.1 PROGRAM OBJECTIVES

The objectives of the GPS RM Program during Phase I are to:

1) Achieve the specified level of GPS system conditional availability consistent with the budget constraints of the validation program. (Conditional availability means that the system is available when needed.)

2) Provide data that can be used to validate and/or establish realistic RM design requirements for operational GPS hardware and its logistics support systems.

Quantitative RM goods are specified as follows:

Phase I

The GPS Control Segment (i.e., the master station, monitor stations and upload station) shall have, over any 10 day period, an operational availability of not less than 70%, based on 10 hour per day operation, 7 days per week. The maximum down time at the 90th percentile shall not exceed 72 consecutive calendar hours.

Operational

1) The operational GPS Control Segment shall have an availability of 99%. The maximum down time at the 90th percentile shall not exceed 2 hours for the master station and 48 hours for a monitor station.

2) The User Segment shall have an availability of 99.5%, based on a mission time up to 30 hours and a 1200 hour MTBF requirement.

4.4.2 RM APPROACH

To achieve the availability goals specified, several alternate reliability and maintainability approaches will be assessed to permit the selection of one approach that minimizes the total validation phase costs while satisfying the availability goal. Control Segment equipment will consist largely of off-the-shelf hardware.

4.4.2.1 RELIABILITY — Historical reliability information for these equipments will be obtained where possible, otherwise, prediction analyses will be performed. Alternate approaches to improve the reliability of existing equipment includes:

1) Redundant equipment.

2) Procurement of alternate equipment that performs the same function and has a higher MTBF.

3) Engineering changes for reliability improvement.

For the limited equipments which are new design parts will be of military standard reliability levels. Conservative application by means of parts stress derating will be followed. Full scale design reliability efforts will be deferred to subsequent GPS program phases when operational requirements have stabilized.

4.4.2.2 MAINTAINABILITY — The Master Station complex will be manned continuously by contractor operating personnel during Phase I. Contractor maintenance personnel will be available, either on site or on call, as conditions warrant. A central maintenance facility at or near the Master Station complex will repair failed equipment, and maintain a spares inventory. As many of the repair actions as economically practical will be done at this facility.

The system will have self check capability sufficient to monitor functional operating status continuously. For major or serious degraded modes, automatic periodic monitoring shall be sufficient. Checks for minor degradation shall be initiated manually. The computer manufacturers standard diagnostics will be periodically performed on the computer subsystem.

When a functional failure or major degradation is detected, the system shall immediately indicate the finding to the operator through an alarm subsystem. When such a condition occurs, the system shall have the capability to automatically isolate the fault to a major functional equipment area.

Monitor Station maintenance will include:

1) Monitor Stations will operate unmanned, and will be maintained by a mobile maintenance team. Local maintenance capability may be used where feasible.

2) Monitor Station performance will be monitored by computer at the Master Station as a function of the Control Segment self-check mode of operation.

3) Fault isolation at the Monitor Station will include localization to the equipment using BITE capability and local testing facilities, and isolation to the replacement level within the equipment using BITE, common accessory test equipment, and logical troubleshooting procedures. The requirement for accessory test equipment will be minimized and will be limited to equipment types that are easily transported by the mobile maintenance team.

4) The maintenance team at the Monitor Station will, through the teletype units and other special equipments, be able to inject signals, load programs, exercise control, and print results. The control system will permit specialized control and printout features to be invoked for fault isolation.

5) A failed equipment will be restored to operation by replacement of faulty subassemblies using spares that are stored at the Monitor Station site. The requirement for using hand tools will be minimized.

6) Following repair, performance will be verified using local BITE and Control Segment self-check.

7) Failed items removed from a Monitor Station will be repaired at the central maintenance facility. Repaired items will be returned to the Monitor Station site to replenish the maintenance spare stock.

4.4.3 PROGRAM ELEMENTS

The RM Program is design oriented and interfaces with other GPS program elements. A brief description of the key elements is outlined below.

RM PROGRAM MANAGEMENT

1) Maintain plan and procedures
2) Establish supplier requirements and control
3) Report on progress to JPO and to management

RM ENGINEERING

1) Perform RM modeling and predictions in support of establishing requirements and trade studies
2) Update and refine the detailed maintenance concept, including test equipment, tools, spares, and manning
3) Provide a critical items list for the identification and control of critical items
4) Identify credible failure modes as a basis for design improvements and maintenance planning
5) Participate in the JPO Suspect Material Deficiency Program
6) Perform circuit stress analysis on new designs and on critical items where appropriate
7) Implement a parts control task (for new designs) including a parts control list and nonstandard parts approval
8) Conduct failure analysis and implement corrective action
9) Demonstrate compliance with RM goals by tracking and analyzing equipment operation
10) Accumulate RM data for planning subsequent GPS phases

5. CONTROL SEGMENT ACQUISITION PLAN SUMMARY

This section summarizes the preliminary control segment acquisition planning to date. Because this preliminary draft of the Contract Definition Final Report is coincident with the submittal of the preliminary Control Segment Specifications and precedes the Hardware Definition first-draft documents by 2 weeks, planning has not yet been carried to detail levels. The final proposal will contain detailed plans and schedules which are tied directly to the Work Breakdown Structure which results from the RFP, and to the specific hardware definition which evolves from the preliminary segment and CI Specifications submitted concurrently with this document. Summarized below is the present approach and results of preliminary planning efforts.

5.1 APPROACH

The approach for Phase I implementation of the Control Segment of the Global Positioning System is driven by a single major objective and many secondary objectives. The major objective is to maximize the amount of DT&E and IOT&E demonstration of user equipments in their respective operational environments in support of DSARC II.

The principle constraint on this primary objective is the timely availability of the space segment to support the all-up configuration testing of the GPS concept. Because of this, the control segment development must be planned and executed so that control segment elements are tested and ready when the satellite launches and operational readiness dates are achieved.

In addition to the primary objective, there are several secondary objectives which must be fulfilled. First, the structuring of the Phase I tasks must be compatible with the overall three phase plan. Figure 5-1 illustrates the three-phase GPS planning schedule forseen at this time. It is important that planning for the first phase

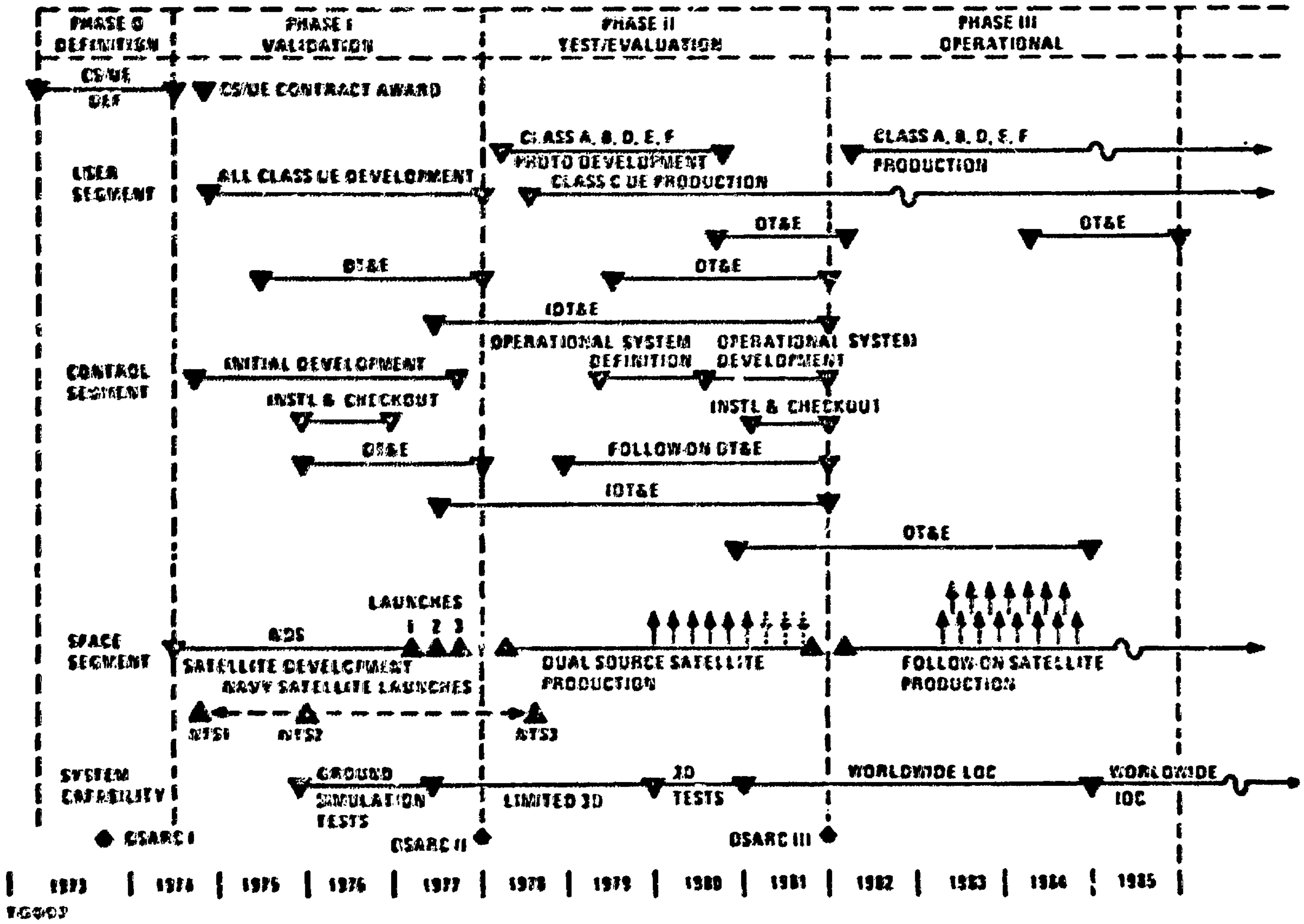

Figure 5-1. GPS Program Schedule

takes into account capability of growth into Phases II and III, and also provides an optimal tradeoff of legacy to these follow-on phases with the costs and risks associated with the acquisition of Phase I.

In this regard, the initial approach that has evolved in control segment development planning is to define the control segment elements so as to make maximum utilization of existing facilities and hardware, to minimize the risk of new hardware development as well as the cost of acquisition of new hardware and facilities preparation. Use of the existing satellite control facilities at Vandenberg Air Force Base is a prime element of the current approach. There is a major risk, however, of facilities utilization in relationship to the satellite upload function. This major risk will be mitigated by providing a dedicated upload terminal at Vandenberg Air Force Base.

The small added acquisition costs of the transmitter and antenna functions necessary to implement this concept far overshadows the risks involved in the loss of test time during the crucial period between satellite launches and DSAR[illegible] because of the very low probability of upload function availability of the satellite c[illegible] facility.

The Control Segment hardware will be developed to support the GPS program through Phase II, requiring a minimum of 7 years of design life. The concept of hardware development will be for use as an engineering development test bed as contrasted to an operational ground system. This approach assures minimum acquisition costs during Phase I as well as maximum flexibility to support Phase I and Phase II objectives. The approach does not provide a large hardware legacy to the operational Phase III, but because very little new hardware development has to be accomplished to support the Phase I/II requirements (and appreciable amounts of existing hardware and facilities can be utilized) this is not considered to be a major consideration. It is conceived, at this time, that the operational control segment hardware would be defined and specified early in Phase II, and designed, fabricated, and installed later in Phase II, so that checkout is complete to support the start of Phase III.

The principle legacy that the control segment can provide to the operational phase is in the software area. The software development is then the singularly most important aspect of the control segment development planning. It is mandatory that the initial software design take into account the ultimate compatibility with the full all-up operational requirements. While the hardware can be designed with limitations of handling the 9-12 satellites required in Phase II, the software must be designed for compatibility with the 24-27 satellite capability in Phase III. The design must anticipate possible evolution of computer technology into the 1980 time frame and at the same time, be compatible with implementation into current or existing computer configurations. FORTRAN will be used throughout to ensure flexibility for rapid modifications, if required.

5.2 ACQUISITION PHASE PLANNING

The Phase I schedule plan is shown in Figure 5-2. The user segment plan is discussed in Section 6. The System Test and Evaluation is discussed under test planning in Paragraph 4.3. This paragraph concentrates on summarizing the control segment planning to date, and the dependency on, and to, the user segment planning and system test and evaluation planning.

The key milestone which drives the control segment development schedule is the launch of NTS-2 in October, 1976, which will become the first live data source to based full operation tests. To allow contingency for procurement and development problems, the control segment elements will be scheduled to complete their pre-launch checkout and systems operations tests 2 months in advance of the NTS-2 launch date (August, 1976) so that there is little probability of the control segment readiness impacting the planned test and evaluation schedules once NTS-2 is launched. To structure contract incentives with the control segment contractor, it is recommended to set a preliminary conditional acceptance of control segment hardware and software based on a date which is coincident with the NTS-2 launch date, so that these incentives can be independent of the NTS-2 launch date over which the CS/UE contractor has no control. Final acceptance

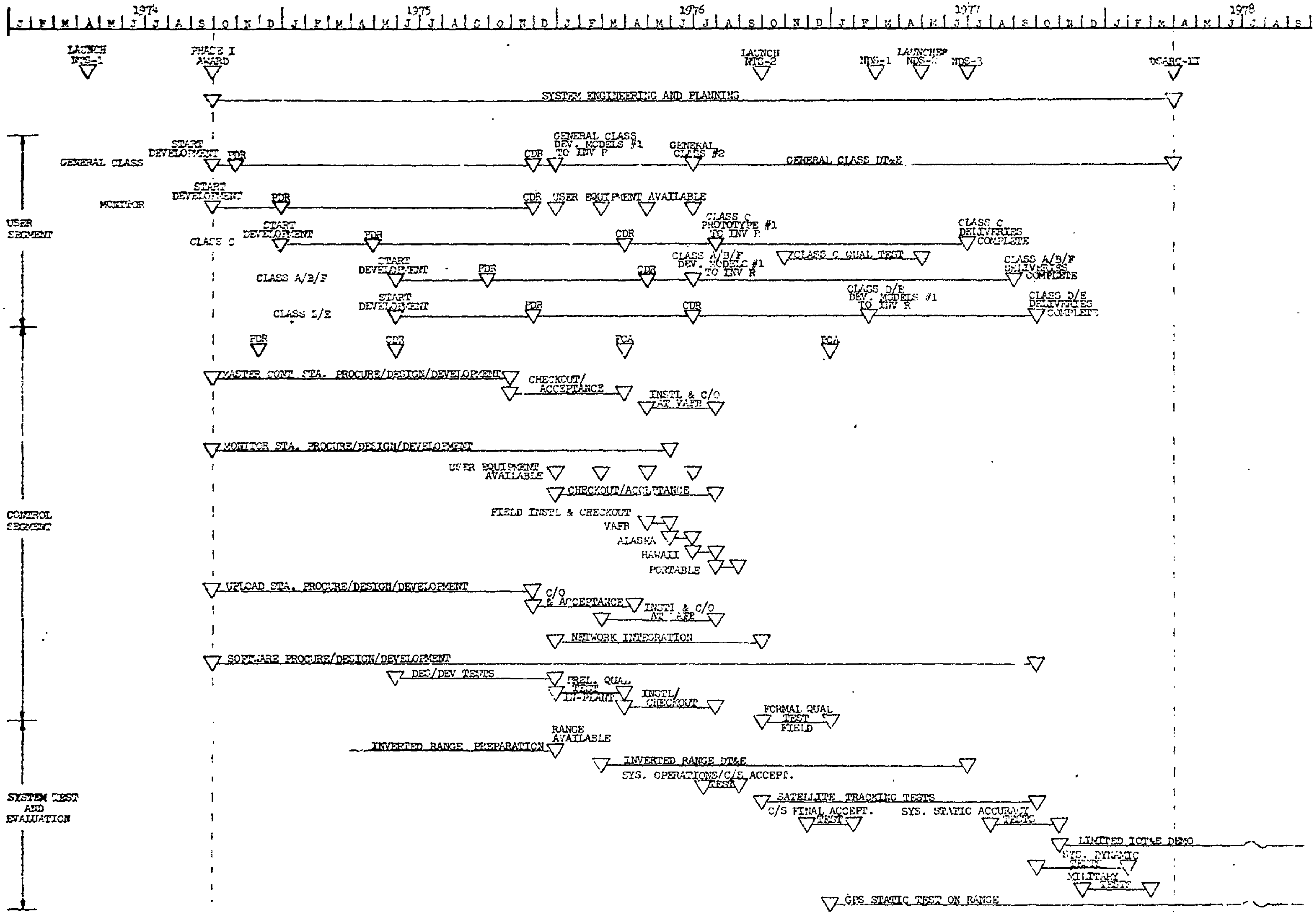

Figure 5-2. GPS Phase I Schedule

of the control segment can be established once a live date source is available and is scheduled for January 1977, two months in advance of the most optimistic NDS-1 launch date.

To support the August, 1976 readiness date for the control segment elements, it is necessary to commence field installation operations by February, 1976, particularly in the area of Upload Station Transmitter/Antenna integration.

The in-plant testing of hardware and software is scheduled to be completed in March and April of 1976, with the functional configuration audit (FCA) milestone.

It is planned to schedule a single critical design review for all control segment hardware elements, which will pick up the Master, Monitor and Upload Station elements. This milestone is scheduled for June, 1975, 8 months after CS/UE award. The preliminary design review is scheduled for December, 1974 — two months after contract award.

Because of the special criticality of the software design, it is planned that three separate PDR's and CDR's be scheduled to cover the Monitor, Master, and Upload Station computer programs. These PDR's and CDR's would nominally be in the same time period as the hardware PDR's and CDR's, but would be staggered somewhat in time to allow for separate preparation and coverage.

The Master Station hardware will require very little new development, but early procurement of the Master Station computer is required to support the software design and development testing. Initiation of procurement would be planned to be coincident with the successful completion of the preliminary design review, 2 months after contract award. This would allow approximately 6 months of span time for delivery to the CS contractor's plant to support the start of design and development tests of the software.

The checkout and acceptance of the Master Control Station would commence in November, 1975, allowing a full 5-months of acceptance testing in-plant before delivery to Vandenberg Air Force Base in April, 1976.

Monitor Station development is paced by the development of the user equipment which, under the preferred approach, would be the nucleus of the monitor station hardware implementation. To support the control segment availability dates, monitor station receivers and processors would have to be delivered to the Control Segment contractor's plant commencing with the first set on January, 1976, and continuing at a one per each two months until all four sets are delivered by July, 1976.

This concept imposes an additional constraint upon the user equipment development schedule. From the standpoint of Monitor Station requirements, the class ABF user set is most compatible, however, solely from the user equipment development standpoint. This development should not start until 8 months after contract award to get maximum benefit from initial DT&E testing of the generalized class. The Class ABF user equipment does not, therefore, support the needs for the Monitor Station hardware deliveries. On the other hand, the general development model is more on the order of a laboratory tool, and is not totally compatible with the requirements of the Monitor Station. The monitor station receiver design, if performed by the UE contractor, will then be a hybrid development somewhere between the general class and the class ABF, and will be a minor takeoff development, scheduled for an earlier start than the class ABF development, of the general development model.

An alternate approach is to develop Monitor Station receiver and processor independent of the user equipment by a separate contractor and designed to the specific operability and maintenance requirements of the Monitor Station. This approach is being evaluated during the definition phase by General Dynamics, and tradeoffs will be performed between the two approaches. The most cost effective solution will be proposed.

Regardless of the approach selected, the Monitor Station receiver and processor will be integrated by the CS contractor at the CS contractor's plant, and the entire Monitor Station will be tested and accepted there before delivery to the respective Monitor Station sites. The first completed station is scheduled for delivery to Vandenberg AFB in May, 1976. Installation and field checkout spans should take 1 month for each station, assuring that all site preparation is accomplished prior to delivery of the hardware.

It is not currently deemed cost effective to perform integrated tests of the Upload Station elements at the CS Contractor's plant. The transmitters and antennas will be accepted at a subcontractor's facility and then drop shipped to the Vandenberg facility for integration. The antenna and transmitter elements will be scheduled for in-plant test completion in February, 1976, to allow a 6 month test and integration period at Vandenberg AFB to support the August, 1976 control segment availability.

The software development is the critical path in the control segment development plan. The flow plan for the software development is shown in Figure 5-3.

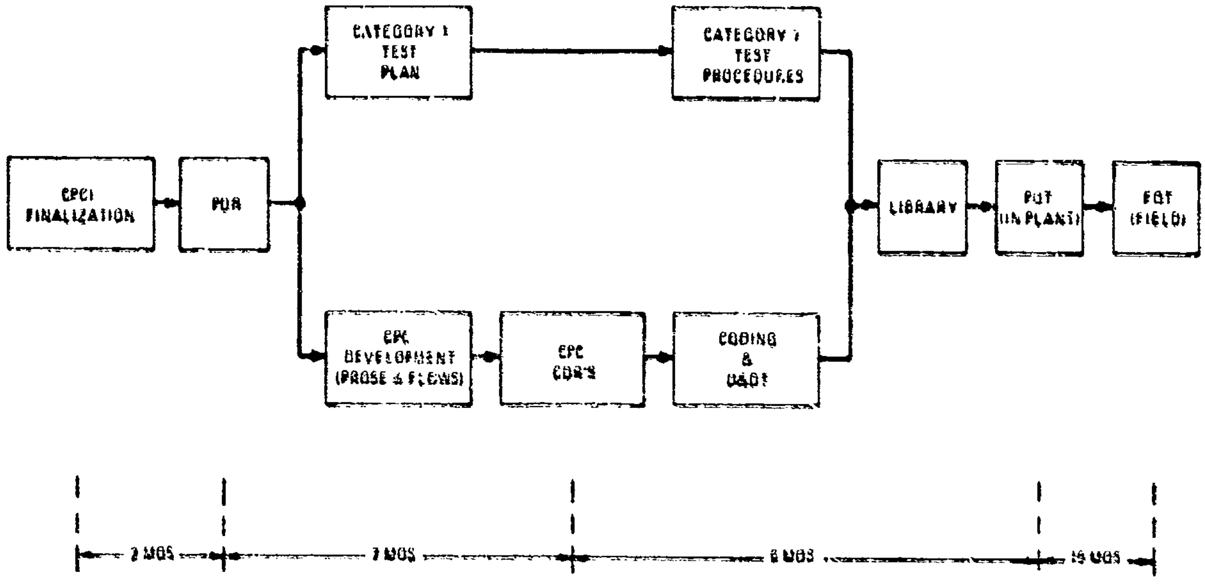

Figure 5-3. Software Development Steps

The initial task to be performed is revision of the Part I CPCI's to conform with the System segment specification as finally released by the JPO. When these specifications have been approved in the Preliminary Design Review, the actual process of software implementation can begin.

The software design process will be performed in a "top-down" manner with the highest level program designed first. Design shall then proceed to successively lower levels as determined by the control and calling structure of the program. As each segment of design is completed, it shall be documented in the form of a CPCI (Type C5) and approved by the JPO. Category I test plans, to be used during Preliminary and Formal Qualification Testing shall also be formulated in conjunction with each CPC.

After the approval of the CPC's, the actual program coding will begin. The coding, as did the design, will proceed in a top down manner with the use of closed logic structures. As each module of code is produced, it will be tested to verify its design concepts and its relationship to programs higher in the program structure. Also produced along with the coding shall be a technical description of the module, revised flow charts, and a record of the Design and Development Test Results. Paralleling the code development will be the production of Category I test procedures and initial operating procedures.

When a module of code has been produced and documented, it will be placed under the control of a software librarian. The librarian shall have the responsibility of verifying the adequacy and completeness of the supporting documentation, and shall be responsible for maintaining the history of the module from the time it comes under his control until Category B test is complete.

Preliminary Qualification Testing (PQT) will demonstrate that the integrated software system performs in an environment which approaches the operational mode. The primary purpose of the PQT is to reveal errors caused by scheduling or resource conflicts, interference between interrupts or other similar operational type circumstances. The results of this testing will be reflected back into the code, CPCI's and CPC's, as well as all supporting documentation.

Formal Qualification Testing (FQT) will be done in the operational environment and will simulate normal system operations to the maximum degree possible. FQT will demonstrate that each CPCI meets all requirements and that the software system is ready to support satellite operations.

6. USER SEGMENT ACQUISITION PLAN SUMMARY

6.1 DESIGN APPROACH

The User Segment will conform to the overall GPS Phase I design approach. The typical User Equipment to be developed may be described as consisting of an antenna, a receiver, a processor, and a display in addition to ancillary equipment such as a power supply and necessary interface equipment.

The first User Equipment (UE) to be developed will be the General Development Models (GDM) which will be used as a design total to proof concepts, interfaces, software, and designs. This version will be readily adaptable to simulate any of the 6 classes of UE. Two units are planned to permit continuity of development in-plant and at the same time to use one unit for initial compatibility tests of UE with other GPS hardware in the field. The GDM units will operate in either the sequential (one satellite at a time) or continuous (4 satellites simultaneously) receiving modes.

Concurrent with the development of the GDM's will be the development of the receivers to be used in the Control Segment Monitor Stations. The Monitor Station receivers will be multi-channel units utilizing the UE software modules to the maximum extent possible. Early development of these receivers is required to support the overall Control Segment development, field, and system tests.

The next development will be the Class C, sequential, clear signal UE design. This class of UE will be developed into military qualifiable prototype equipment. The Class C is characterized as follows:

CLASS C:	Low Cost Avionics Set	User Element
	Aircraft who experience medium to low dynamics in natural EMI environments only	Airlift Search and Rescue Refueling and rendezvous Aerial delivery
SERVICES:	USA, USN, USAF, USMC, Commercial	

Following initiation of Class C prototype development will be the start of the development of the Engineering Development Models (Advance Development Models per MIL-STD-280) for all other classes. As shown in the subsequent schedules, the units for Classes A, B, and F will be completed a few months prior to the class D and E units.

The rapidity of sequential demodulation is limited only by the time requirement for acquisition of the separate signals. The demodulated data are stored until all are available at which time the data processor performs the operations required to produce the necessary outputs. Accuracy is slightly degraded in this configuration but the receiver cost savings are estimated at this time to be 50%. This sequential User Equipment development is contemplated for the Class C, D and E User Equipments which are characterized by low dynamic environments which do not jeopardize the acquisition and reacquisition sequence required of the sequential receiver function. The low dynamic Class D and E users are characterized as follows:

CLASS D	Land wheeled and tracked vehicles, and marine vehicles who experience low dynamics in the presence of severe jamming.	User Element Personnel carriers, jeeps Tanks Amphibious vehicles Artiller, missile launchers Riverines
SERVICES	USA, USMC, USN	
CLASS E	Manned Backpack, Ground troops who operate in the presence of severe jamming.	User Element Manned Backpack (could be a backup for land vehicles and helicopters if necessary).
SERVICES	USA, USMC	

A corresponding development approach to the above employs a design which continuously demodulates signals from the four satellites. The continuous design employs additional processing channels but a significant portion of the processing function may be time-shared. The continuous design development is contemplated for the Class A, B, and F user classes. The allocation to the A and B classes is due to the increased dynamic environments. For the Class F user the need to rapidly establish a navigation fix leads to continuous data channel demodulation intervals. The user classes are characterized as follows:

CLASS A	Tactical and strategic aircraft who experience medium dynamics in the presence of severe jamming.	User Element Strategic bombing Strategic reconnaissance Tactical interdiction Aerial photomapping
SERVICES	USA, USN, USAF, USMC	
CLASS B	Tactical and strategic aircraft who experience high dynamics in the presence of medium to low jamming.	User Element Air defense-interception Air superiority Tactical reconnaissance Close air support
SERVICES	USA, USN, USAF, USMC	
CLASS F	Surface vessels and submarines who experience low dynamics in the presence of severe jamming.	User Element A/C carrier (ship navigation and A/C landing system) Destroyers, cruisers Submarines (Polaris, etc.)
SERVICES	USN	

These users are also characterized by the availability of auxiliary navigation sensors which allows for a major variation in the direction of increased sophistication. This version utilizes cooperation with the navigational systems which may exist on board the user vehicle and derives advantage both to the user and directly to the operation of the GPS User Equipment. In this variation the output positional data of the on-board sensors is combined with the output of the User Equipment to produce a combined output. The technique employed is that of Kalman filtering which has the virtue of producing combined output data by a proportional weighting of input data based on the measured qualities of the various navigational system parameters. The weighting is continuously refined during operation resulting in high quality navigation data.

Another advantage to the GPS User Equipment lies in the reduction of signal acquisition time. The reduction of signal acquisition time results from the continuous knowledge within the User Equipment of current position even in cases of non-use of the satellite signals. The knowledge of current position (and rates) together with a prediction of current positions of the satellites permits a reduction of the required signal acquisition time resulting from a marked reduction of the range of doppler offsets which must otherwise be searched for acquisition.

6.2 SCHEDULES

An abbreviated set of schedules is shown in Figures 6-1, 6-2, and 6-3 for the 5 development efforts required. These schedules are based on a contract award date of October 1, 1974, but in the event of other award dates elapsed times would be identical. The schedules assume that the GDM version and the version intended to serve as a monitor station receiver are the critical items for early development.

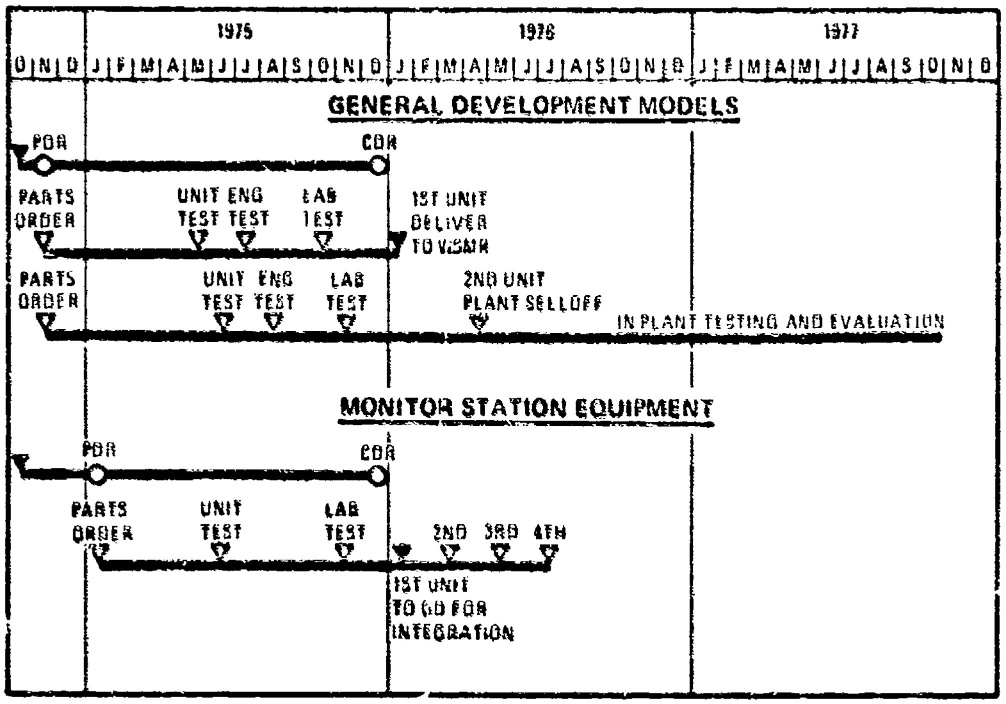

Figure 6-1. General Development Model and Monitor Station Schedule

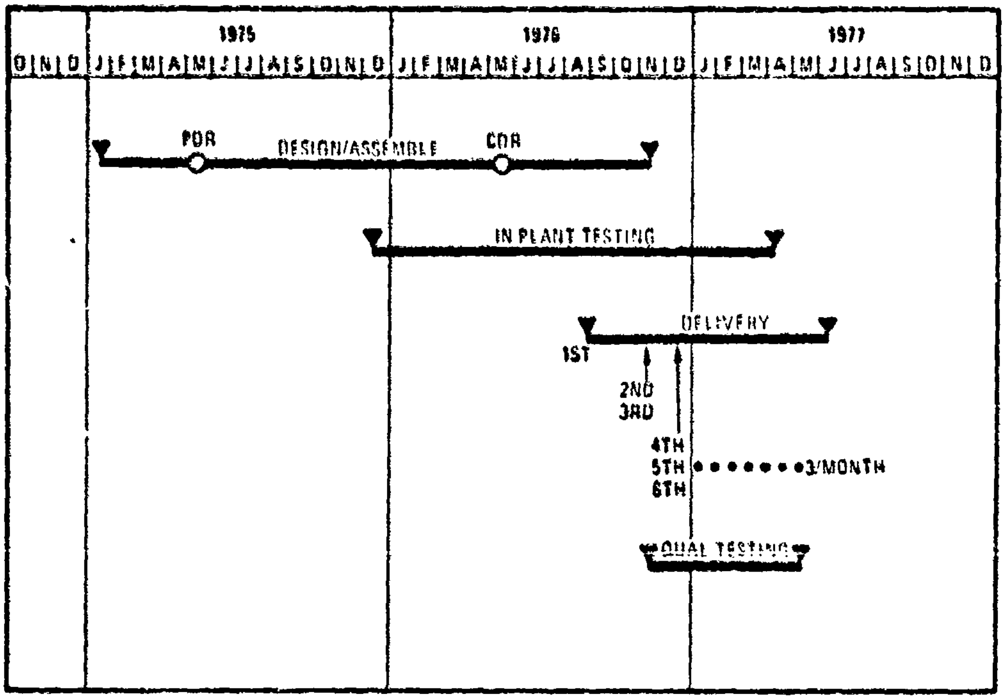

Figure 6-2. Class C, Development Schedule

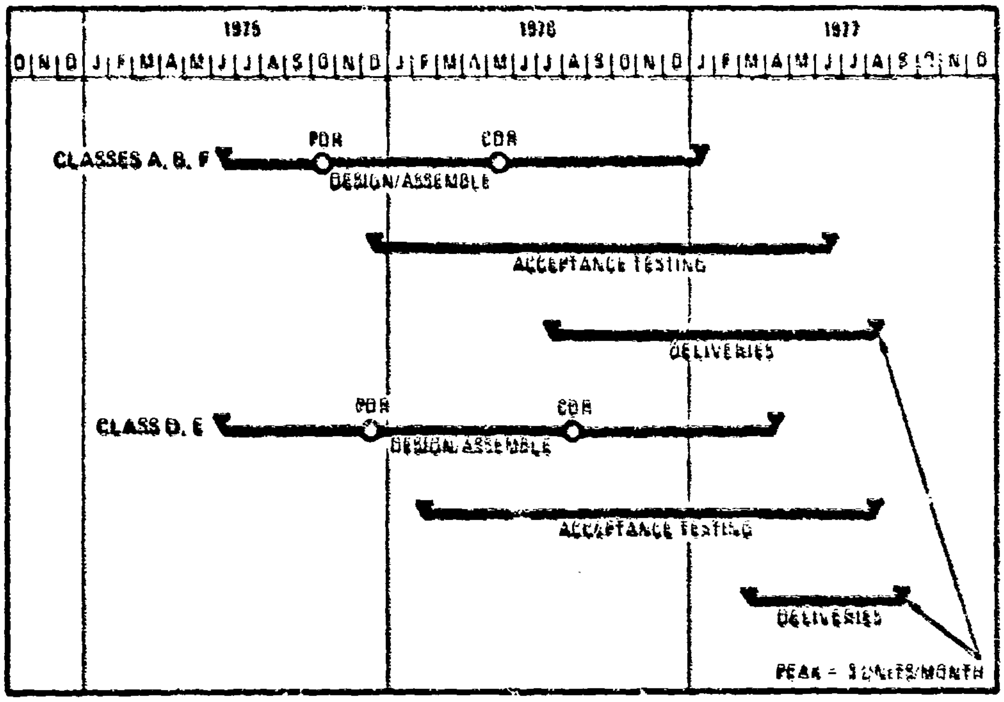

Figure 6-3. Classes A, B, F and D, E, Development Schedule

6.3 DEVELOPMENT

No unusual User Segment development problems are evident. The two major functional areas for development are the receiver and computer program software. The receiver implementations bear a close resemblance to those which we have repeatedly solved in other PRN systems and it appears that only small modifications of those techniques are required for solution of the problems.

Software development in terms of documentation and standardization is recognized as being a potential hazard especially in a dynamic development stage of the Phase I program where flexibility will be demanded. The natural tendency to get things done must be tempered to provide for a software concept which is easily altered and is maintainable through many generations of change and growth alteration. The need for software programming visibility is considered to be both a design and management undertaking.

6.4 PROCUREMENT

The majority of procurement will be of available parts. Subsystems to be procured are considered at this time to be the data processor and the power supply. The required lead times for the procurement of parts and subsystems must be recognized and this is further discussed in Section 8.

6.5 TEST APPROACH

The User Segment required testing is assumed to be only the in-plant testing that is required to prove conformance to the User Segment specifications and the CI specifications which are subsidiary to that specification. It is recognized that the UE contractor, during its field support of the UE during GPS system testing may contribute to that system testing but that is not a specific testing responsibility of the UE contractor.

Detail testing will be described in each of the CI and CP development specifications as they will be approved by the procuring agency. The tests will generally encompass the following:

o Performance	o Human Factors
o EMI	o Reliability
o Workmanship	o Maintainability
o Safety	o Environmental

6.5.1 DEVELOPMENT TEST PLANS

The general categories of testing of the User Equipment are:

1. In-plant Subsystem Testing
2. User Segment Integration Testing
3. Final Acceptance Testing
4. User Segment Flight Testing

The In-plant Subsystem Testing of UE sets, a UE Contractor responsibility, consists of:

1. Engineering Data Tests
2. Breadboard Verification Tests
3. Subsystem Readiness Tests
4. Laboratory Integration Tests

User Segment Integration Tests will be in-plant, laboratory tests.

The System Flight Test is the overall GPS testing and will be supported by all subcontractors but is General Dynamics prime responsibility.

6.5.1.1 IN-PLANT SUBSYSTEM TESTING – This testing is subdivided into:

1. Engineering Tests
2. Breadboard Verification Tests
3. Laboratory Integration Tests

Engineering Data Tests will provide corroborative data on design parameters such as circuit vibration sensitivity, new technology circuits and calibration level adjustment. These tests will be performed as a part of, and during, the design development phase and will generally be of an informal nature.

Breadboard Verification Tests are similar but will generally consist of testing of larger circuit assemblies than the preceding tests including assemblies up to the complete receiver. These tests will be accomplished prior to design commitment.

6.5.1.2 USER SEGMENT INTEGRATION TESTING — This testing will consist of laboratory testing of operational configurations in both static and dynamic signal simulations under limited environmental conditions. Integration with other navigation systems will be accomplished for certain classes of UE during these integration tests.

6.5.1.3 FINAL ACCEPTANCE TESTING — Final acceptance testing will include:

1. Mechanical and Electrical inspe
2. Prime Power Interface Verification
3. Verification of Interoperability of Receiver/Computer/Auxiliary IO
4. Environmental tests in accordance with approved test procedures

Parameters and functions tested during the acceptance testing are:

- Signal level sensitivity
- Signal dynamic range performance
- Measurement accuracy, errors and biases
- Acquisition and reacquisition capability
- Measurement resolution in range and velocity
- Wiring interfaces
- Waveform modulation, code sequence, and code rate
- Data word format verification
- RF, IF and oscillator frequency check
- Tracking loop performance with dynamic acceleration and jerk

- o Software and manual mode execution
- o Computer and tape check

Performance testing of the GDM equipment will consist of preliminary informal subsystem tests and formal testing demonstrating compliance with specification requirements. Informal subsystem testing will be initiated prior to CDR and gradually approach formal performance testing following CDR and in the case of each equipment class, the total performance testing period will encompass about 8 months, of which approximately 2 months are for unit testing, and 3 months for engineering and laboratory test. These various test phases are not exclusively devoted to functional performance testing but will also include elements of the more specialized tests.

EMI testing, workmanship validation, safety, human factors, reliability and maintainability validation will be performed shortly prior to delivery and environmental testing will be performed as required prior to delivery.

One testing problem common to all the user classes is the requirement for a relatively sophisticated simulator to produce controllable replicas of the signals normally transmitted by the satellites.

The same testing will be required for other equipment classes with some change in emphasis anticipated and caused by the different development cycles and usages of the other equipment classes.

The GDM equipment is designed exclusively to be used for GPS system testing and will never be a production system. Thus, while its reliability, operability, and maintainability must be high, it is also anticipated that redundancy and ultra-conservative design will be employed to enhance those qualities at the expense of such attributes as minimum weight and volume, power consumption, etc. It is likewise indicated that standardization of subsystems is not required, as for production systems, and thus extra ruggedness, greater component spacing, and other similar measures may be employed to enhance performance under all environmental conditions.

For testing purposes there are two other equipment categories of interest. One of these, Class C, is to undergo development leading directly to a production version and will require obvious changes of testing emphasis. The remaining classes of equipment are of a developmental nature, eventually to result in production models; it is currently anticipated that the testing sequence of those models will be generally similar, in this phase, to the testing procedures employed for the GDM.

The Monitor Station receiver will generally resemble the GDM equipment and its testing will be similar.

6.5.1.4 USER SEGMENT FLIGHT TESTING — The UE contractor will be responsible for integration and checkout of UE installed in test pallets, pads, etc. as required in-plant.

6.6 SUPPORT

Support will be provided as required following delivery; it is currently anticipated to include:

1. Installation and initial testing
2. Calibration
3. Support in interface conformance with antennas, displays and system test equipment
4. Training support
5. Support in miscellaneous other areas to be defined

7. TECHNICAL PROBLEMS AND PROPOSED SOLUTIONS

Several technical areas are identified as requiring special attention in Phase I. It is important to note, however, that these areas are NOT problems in the sense of high risk to achieving prime objectives of the system. The areas are identified and the approach to their resolution is outlined below.

7.1 SYSTEM ERROR COMPENSATION

PROBLEM

When Control Segment operations begin, it is likely that there will be unacceptable discrepancies between the predicted and measured satellite ephemerides. This is to be expected because of inherent limitations in predetermining every system error contributor and adequately controlling, modeling, and compensating for their effects. Calibration of system delays, delay variations, time transfer techniques, and ability to compensate for these effects with the ephemeris determination software is inherent in this problem. The time required to resolve such discrepancies can be substantial and can impact Control Segment hardware and software.

SOLUTION

The planned basic approach for minimizing this risk is to:

1. Improve the predictions to minimize the probability of discrepancies
2. Be well prepared to solve discrepancies when they do arise
3. Achieve comprehensive checkout of the Control Segment before launching satellites

To implement these solutions, a continuing analysis and simulation effort is planned. In addition, the Master Control Station computer and software will have expansion capability. The implications for the analytic effort is described in this subsection, Segment checkout is a planning and scheduling consideration and, Master Control Station implications are described in the following subsection.

The prime tool for improving the initial predictions is continuing refinement of the system simulation model developed for the Definition Phase. This iterative effort includes the identification and analysis of error contributions and modeling their effects; magnitudes, stabilities, correlations and calibration. Adequate characterization of the errors is essential to development of algorithms for compensating these effects in the ephemeris determination program at the Master Control Station. Simulations to define the systems sensitivity to changes in individual parameters is a very useful aid in resolving discrepancies between predicted and measured results.

A significant benefit of the continuing analysis is the availability of highly specialized system analysts, thoroughly knowledgeable in this specific system, for the resolution of discrepancies when they do occur. This nucleus of specialists also provide high assurance that:

1. System requirements are properly implemented in designs
2. Measured performance of hardware and software is consistent with the simulation models.

7.2 MASTER CONTROL STATION

PROBLEM

There are three potential problem areas associated with the Master Control Station computer; each interacts with the other two:

1. Processing Speed
2. Core and High-Speed Mass Storage Capacity
3. MCS Software Changes

SOLUTION

1. PROCESSING SPEED: The MCS computer must have the capability to perform the ephemeris determination and prediction in time to upload to the four GPS satellites in Phase I. The time line for the uploading process is:

Upload to Satellite	173 Seconds

Transmit Load to ULS	173 Seconds
Total per Satellite	346 Seconds

At the present time, the ephemeris determination and prediction cycled on the General Dynamics CDC Cyber 72 (a 1.2 microsecond cycle time machine) requires 24.2 seconds for a combined Kalman solution. Comparable estimated computational cycle times for some other computers are:

SEL 86	72 Seconds	600 nanoseconds cycle time
NOVA 840	96 Seconds	800 nanoseconds cycle time
DEC 11/45	98 Seconds	850 nanoseconds cycle time
MODCOMP IV/25	240 Seconds	640 nanoseconds cycle time

Allowing for the worst-case timing, the ephemeris prediction problem appears to be solvable at a more rapid rate than the satellites can be uploaded.

Higher speed cores than the ones used for this timing estimates are generally available, including dual CPU configurations, which offer speed increases should the need arise.

2. CORE SIZE REQUIREMENTS: Total storage requirements for the main line computational function (16-bit words) break down to:

System	24K
Program	20K
Data & Working Storage	120K
	164K words

The combined Kalman solution for four satellites is the largest single program which would have to be core resident and this function would require 40K of instructions and storage and the 24K of system for its simplest and most unsophisticated implementation. Hence, the minimum suggested core size is 64K. All of the machines cited in the previous example are field expandable to 131K of core and have significant capability to support large amounts of disk storage for overlaying purposes.

3. MCS SOFTWARE CHANGES: Initial operational experience undoubtedly will show areas which have been insufficiently modeled or otherwise neglected. The MCS software must be constructed in such a fashion that modules are easily replaceable within the system. A system simulation must also be maintained which permits experimentation with program changes prior to this incorporation into the MCS software library.

   Both processing time and capacity can be effectively increased by relaxing the time line for satellite uploading. An approximate 50% "gain" in processing capacity is realized by uploading at 600 second intervals instead of 346 second intervals.

7.3 REQUIREMENT FOR 80 dB ANTI-JAM MARGIN

Performance studies for the receiver designs considered to date (i.e., coherent delay lock, AFC aided noncoherent delay lock, and noncoherent tau dither) have yielded a design AJ margin of about 60 dB maximum. These approaches considered use of a 0.001 Hz code tracking bandwidth and velocity aiding of the order of 1-2 feet/second. Examination of the potential for increasing the accuracy of the inertial aiding signal indicates that calibration of IMU via extended Kalman filtering could be accomplished to accuracies of 0.1 ft/sec. but the demands on the system to meet these bounds would require:

1. Well modeled IMU error state
2. Lever arm calibration for remote IMU's
3. Angular rate data input for remote IMU's
4. Higher direction cosine updating in the processor
5. Expanded state vector in the Kalman filter

   Gyro drift rate
   Acceleration biases
   Acceleration scale factor and misalingment
   Gyro 'g' coefficient compensation

6. Dynamic azimuth alignment maneuvers

The eventual lower limit on aiding velocity information will also ultimately be bounded by errors due to unknwon gravity anomoly effects and satellite velocity and drag errors.

Incorporation of aiding data of the above quality does not significantly alter the potential A-J margin and the burden placed on even the most demanding user class by the above constraints does not seem justified. Our present thinking leads to the conclusion that 80 dB will not be achievable with present or contemplated design concepts. One solution to satisfy this requirement is to postulate a directive antenna which provides up to 20 dB of gain or jammer rejection and is capable of pointing toward each satellite as required.

7.4 USER EQUIPMENT INTERFACING UNKNOWNS

Utilization of aiding sensors in the contemplated Phase I time frame for the program can be approached from two distinct directions. The first concept is to employ existing GFE which is bailed to the program and the second is to give total control to the integrating contractor to procure the system or systems of his choice. In the latter method, the definition of the interface between systems can be established early in the program and maintained during the course of the development. The bailed method may tend to delay definition of the exact interfaces until a Government Furnished item is identified and eventually delivered. Definition of the desired method by the JPO would simplify the design alternatives which presently confront the study since each potential IMU/AMDRU and computer interface permutation represents an almost unbounded set of designs. It should also be noted that selection of an IMU platform without integrated navigation computer at the present time is limited to only three potential units whichare currently in military production, the ASN-90, the LP 36, and the CAINS LN15. A fourth platform-only candidate is the commercial LTN-58 which, however, does not incorporate a vertical channel.

8. OTHER PROBLEMS

8.1 PHASE I DURATION

The critical path through the entire GPS program network is the Satellite Development Schedule. Getting the three NDS satellites in an operational condition to support a sufficient amount of 3D testing and test analysis to insure a successful DSARC II is essential.

The space segment RFP (F04701-74-R-0006) issued on 31 January has fixed the date for latest completion of orbital test operations at 3 January 1978, leaving launch schedule dates at the discretion of the proposing contractors, but with a maximum of 90 days between transfer orbit attainment and operational achievement. To avoid a major negative incentive, most satellite contractors will in all probability propose launch dates which extend to October 1977, assuming the successful bidder will be under contract by June 1974 which, in itself, is an optimistic projection.

The net effect of this problem is to create the need for extending the DSARC II date well beyond the current April 1978 planning date -- probably to as late as the third quarter of 1978 if, in fact, sufficient test data is to be available for DSARC II. This, then, will affect the duration of the CS/UE contractor's period of performance and should be appropriately addressed in the planning for the CS/UE RFP to be issued by April 15.

8.2 USER EQUIPMENT DEVELOPMENT SCHEDULE

The anticipated schedule for Phase I is feasible and will be met as long as the technical problems discussed in Section 7 are addressed. However, it must be recognized that the current shortages facing the U. S. can impact the schedule. Specific areas of concern include: parts availability, GFE and Test Vehicles. Current lead times on specialized parts can approach 12 months while the more mundane parts can take 3 - 4 months. For the ADM/GDM type equipments, maximum use can be made of "off-the-shelf" components. The C-Class equipment will, however, require more in the way of special non-standard parts as we attempt to drive its cost, weight and size down to prototype packaging.

Maximum use should be made of the Defense Electronic Supply Center in Ohio to alleviate this problem. Additionally, the full purchasing power of G/M^3 can be brought to bear on component suppliers. As a large manufacturer of consumer electronics, we can influence component suppliers to meet schedules. The Government can help with respect to the DO rating it assigns to the GPS.

The use of GFE such as military computers and displays is a clear way to reduce program costs. Advantage can only be gained if such GFE is identified early enough in the program so that its timely application is assured. To date no available GFE has been located for the user equipment, however, it is expected that once a computer selection has been finalized, GFE computers will be identified. Similar remarks apply to the test vehicles. However, their selection and availability are under the Government's control. Late delivery will obviously impact the testing schedules.

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