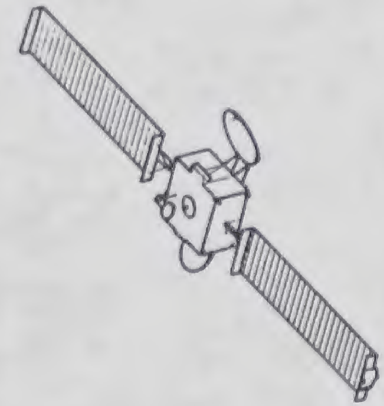
TRW

Pan American Satellite-2



Prepared for
Alpha Lyracom
Pan American Satellite
One Pickwick Plaza
Greenwich, CT 06830

September, 1990

TRW Space & Technology Group
Engineering & Test Division
One Space Park
Redondo Beach, CA 90278

6x 10w 36MHz
9x 20w 72MHz
240w

Contents

Proposal Outline

Volume I – Contracts

1. Terms and Conditions
2. Statement of Work
3. Satellite Specification
4. Master Schedule

Volume II – Cost

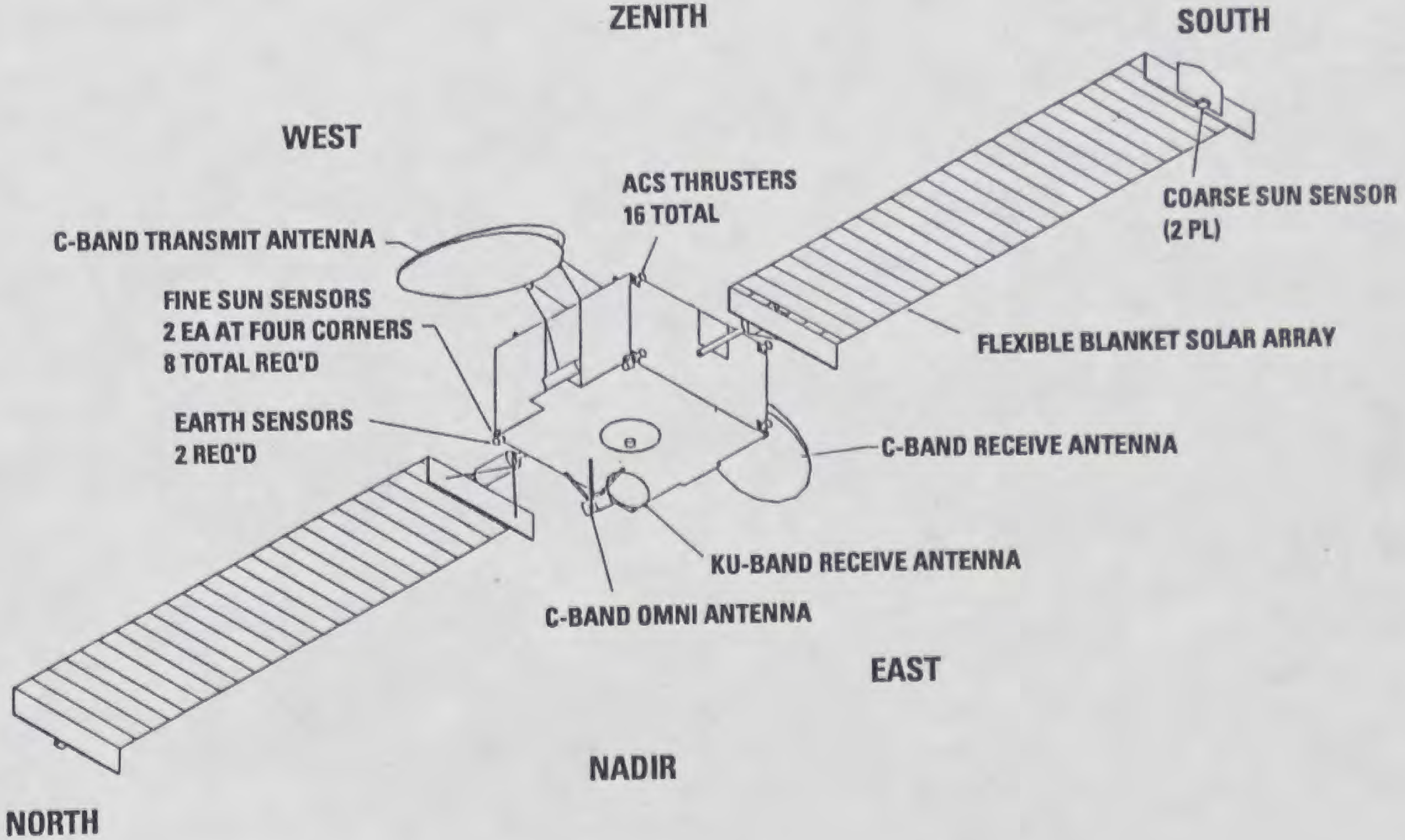
1. Baseline Price
2. Options Pricing Schedule
3. Payment Plan

Volume III – Technical/Management

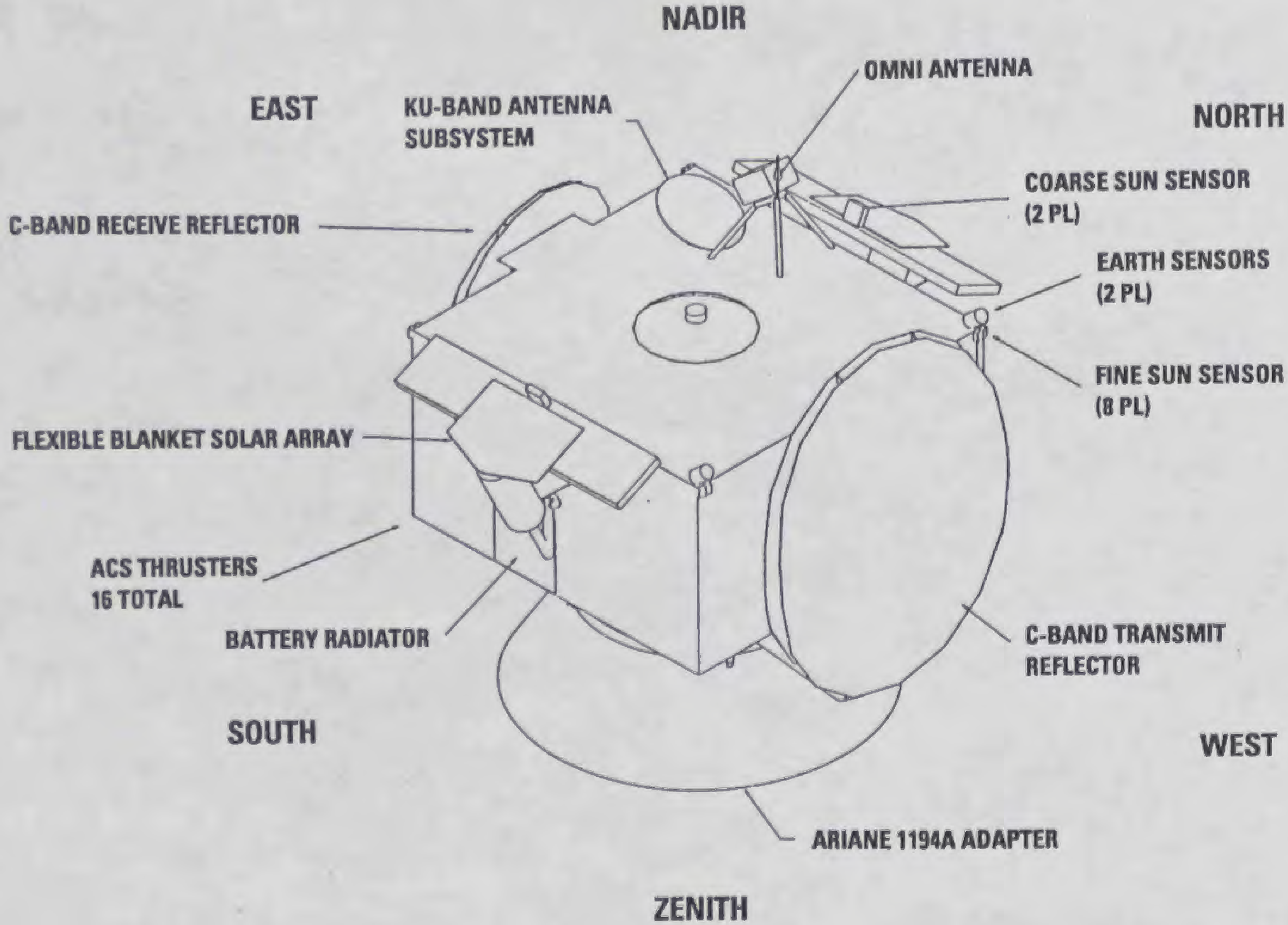
1. Mission and System
2. Communications Payload
3. Spacecraft
4. Integration, Verification, and Test
5. Launch Vehicle and Mission Analysis
6. Reliability and Life
7. Program Management

Technical Summary

Deployed Configuration



PAS–2 Stowed Arrangement

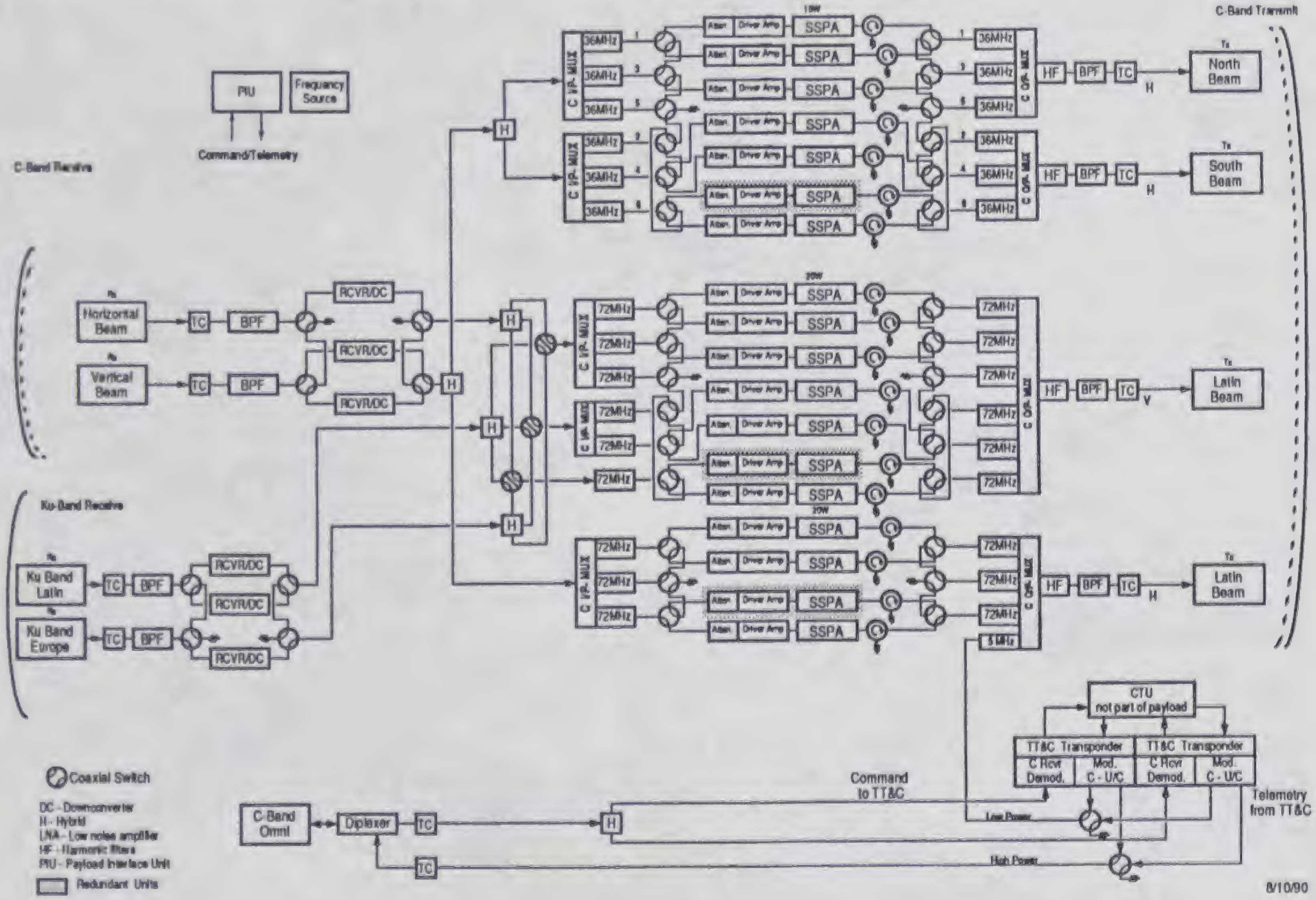


PAS–2 Weight Summary

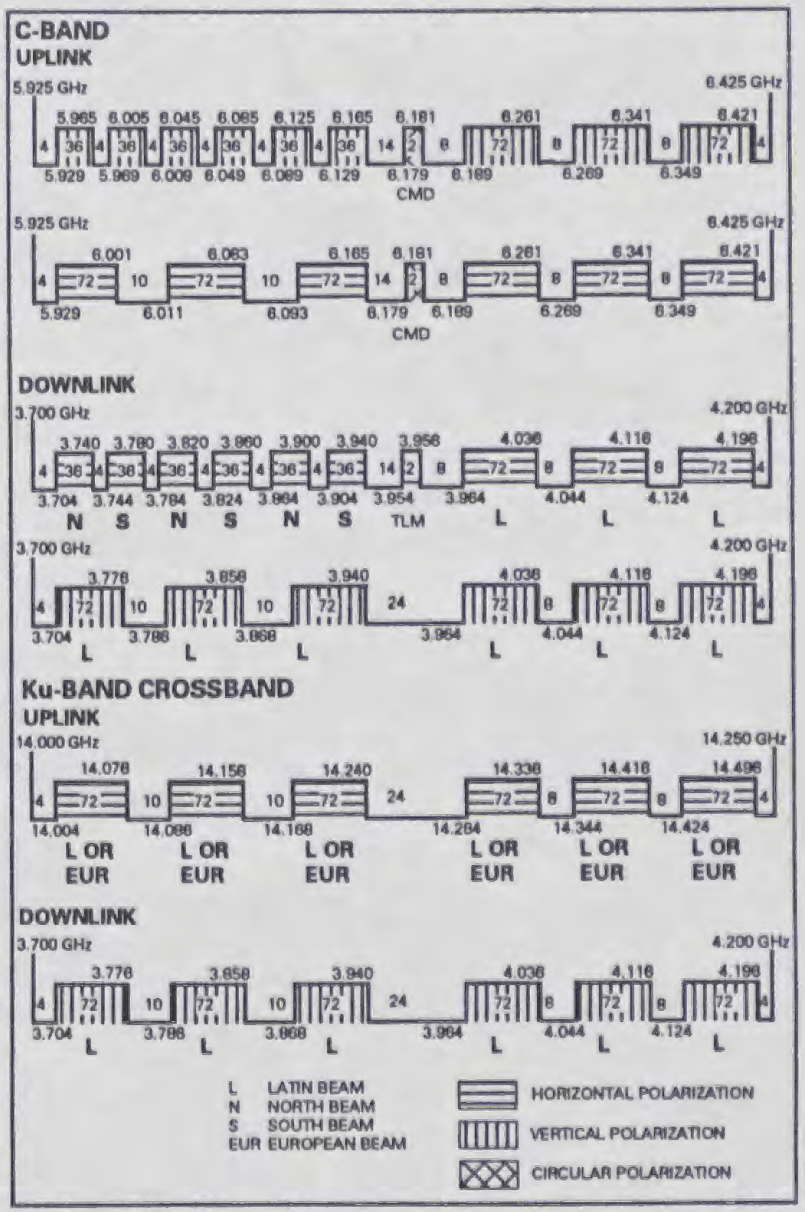
Payload	Weight (lb)
C–Band	184.1
Ku–Band	16.7
TT&CS	41.6
Subtotal	242.5
Spacecraft	
ACS	96.0
EPDS	211.7
Propulsion	149.3
Structures and Mechanisms	191.7
Thermal	21.1
Balance Weight	9.1
Contingency	129.0*
Satellite Dry Weight	**1050.4**
Total Propellants	1032.8
Total Fuel	509.8
Total Oxidizer	520
Pressurant	3.0
Satellite Weight at Launch	**2083.2 lb**

*14% of Total Dry Weight

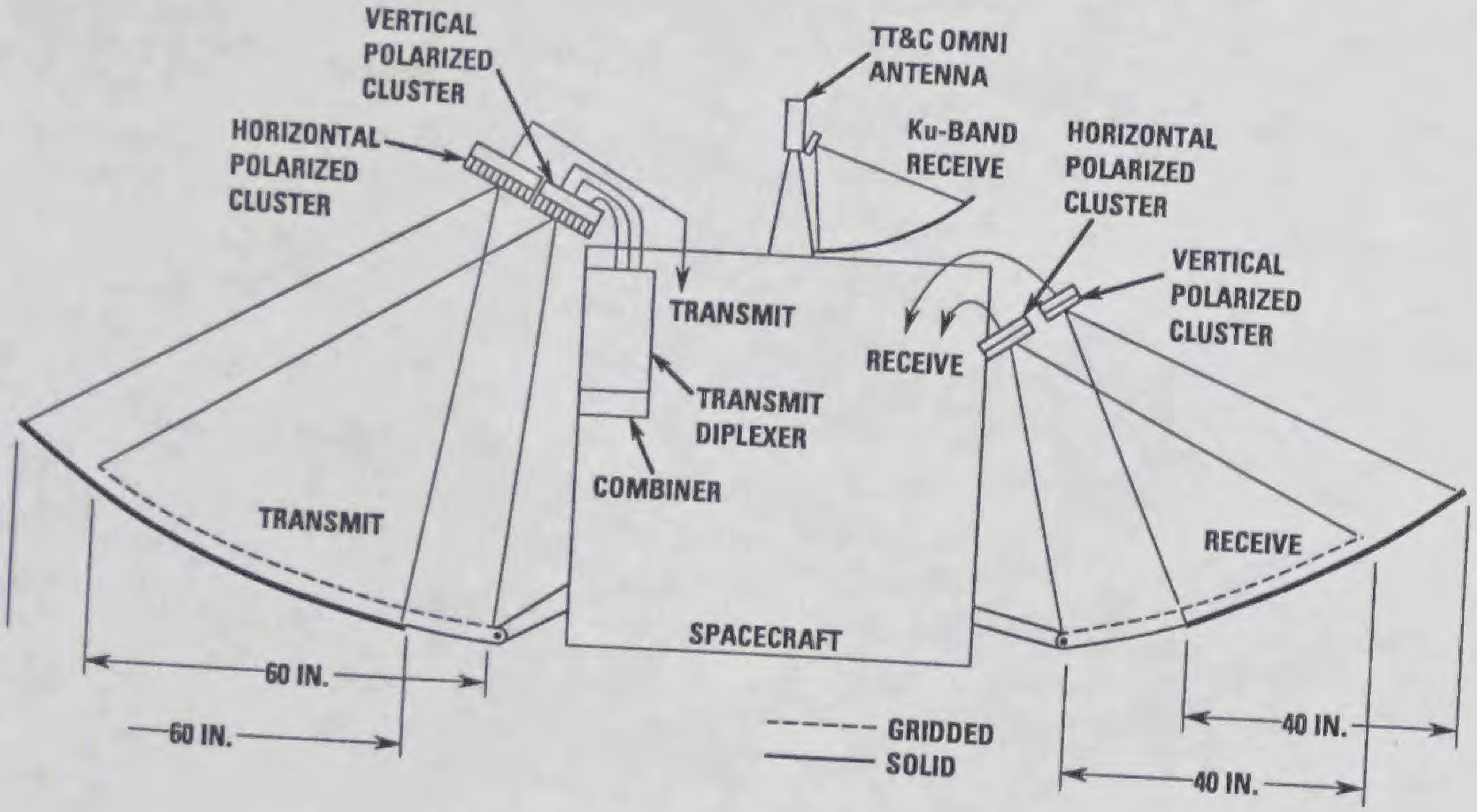
Payload Block Diagram



Frequency Plan



Antenna Configuration

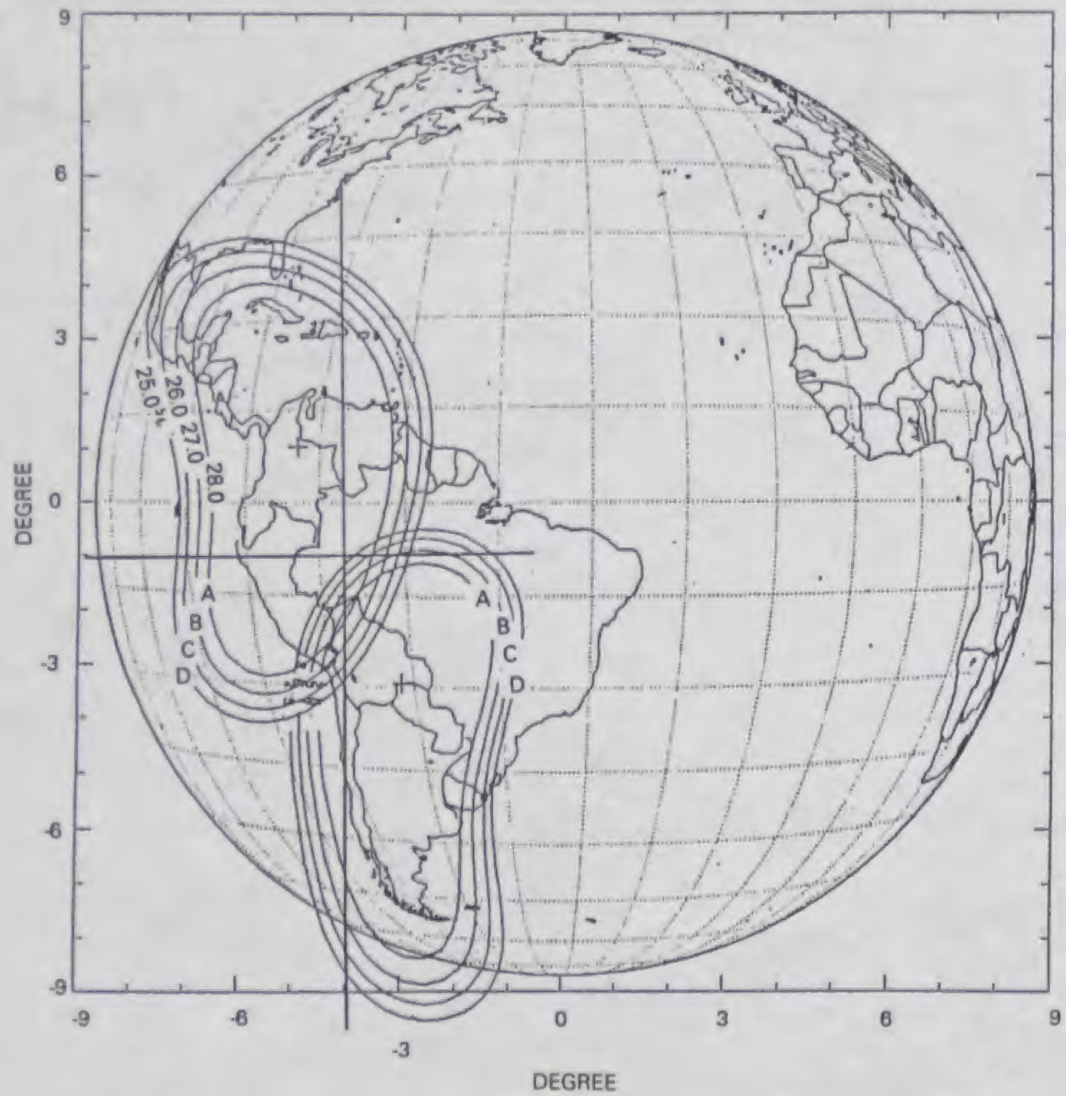


Payload Capabilities Summary

	UPLINK BEAM	NORTH BEAM	SOUTH BEAM	LATIN BEAM	Ku-BAND BEAM	
	UPLINK	DOWNLINK	DOWNLINK	DOWNLINK	UPLINK	UPLINK
FREQUENCY (MHz)	5925 6425	3700 4200	3700 4200	3700 4200	14000 14500	14000 14500
NUMBER OF CHANNELS	6+9	3	3	9	0 TO 6	6 TO 0
CHANNEL BANDWIDTH	36 MHz + 72 MHz	36 MHz	36 MHz	72 MHz	72 MHz	72 MHz
POLARIZATION	VERTICAL/ HORIZONTAL	HORIZONTAL	HORIZONTAL	HORIZONTAL/VERTICAL	HORIZONTAL	HORIZONTAL
ANTENNA COVERAGE	ALL OF LATIN AMERICA, U.S. EAST COAST (COMBINED LATIN AND SPOT BEAM)	VENEZUELA, COLOMBIA, CENTRAL AMERICA, CARIBBEAN, PERU, ECUADOR	CHILE, ARGENTINA, PARAGUAY, URUGUAY, BOLIVIA	ALL OF LATIN AMERICA, U.S. EAST COAST	LATIN AMERICA, U.S. EAST COAST	SPAIN, ITALY, SOUTHERN EUROPE, UNITED KINGDOM
CROSS-STRAPPING	–	–	–	UP TO 6 CHANNELS FROM Ku-BAND	UP TO 6 CHANNELS TO C-BAND	
RECEIVER REDUNDANCY	3:2	–	–	–	3:2	
SSPA POWER & REDUNDANCY	–	7:6 10 WATTS		7:6 + 4:3 20 WATTS	–	
G/T-EIRP (BEAM CENTER)	0.9 dB/°K	38.5 dBW	38.6 dBW	39.5 dBW	–1.0 dB/°K	6.3 dB/°K
DESIGN LIFE	12 YEARS					

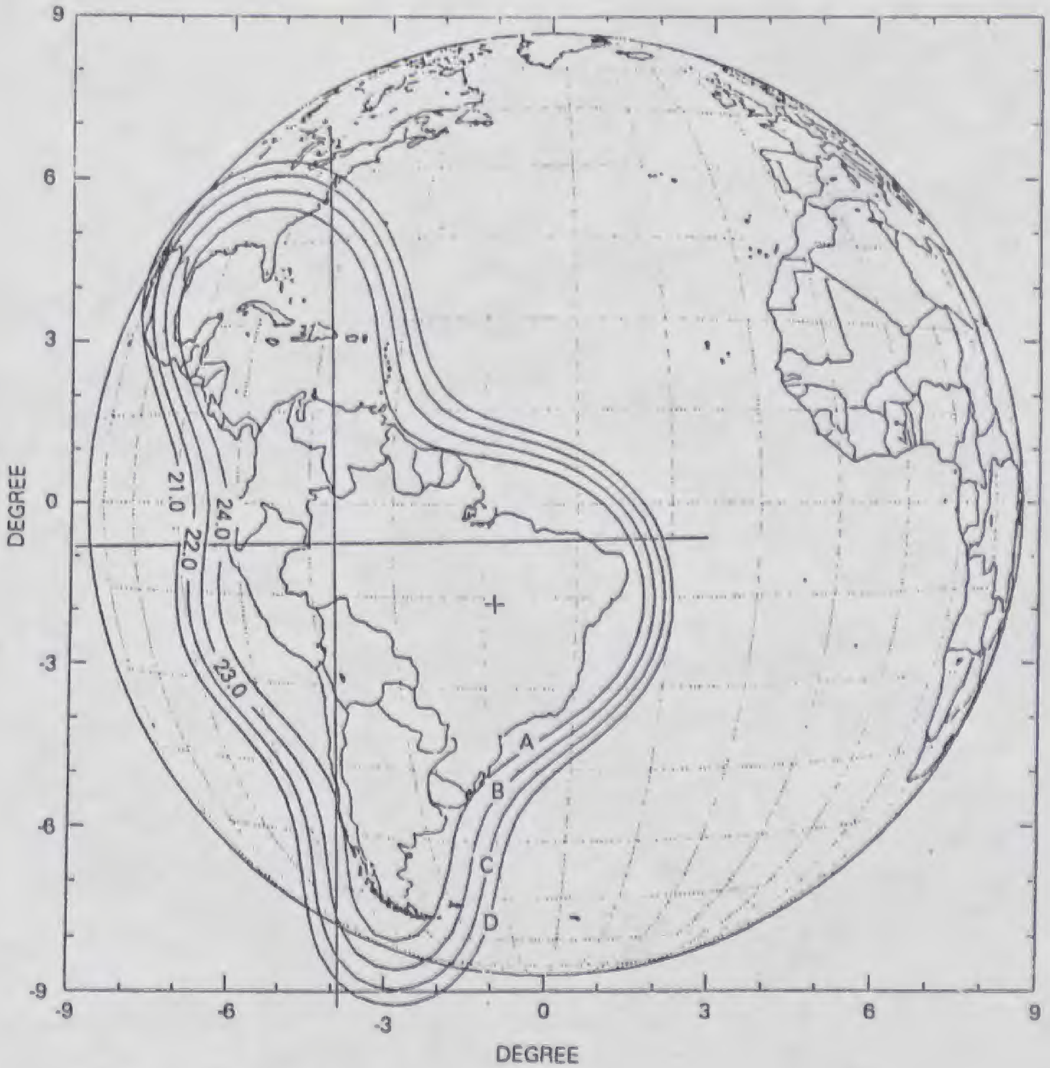
17351-158b

C–Band Spot Beam EIRP Contour Plot



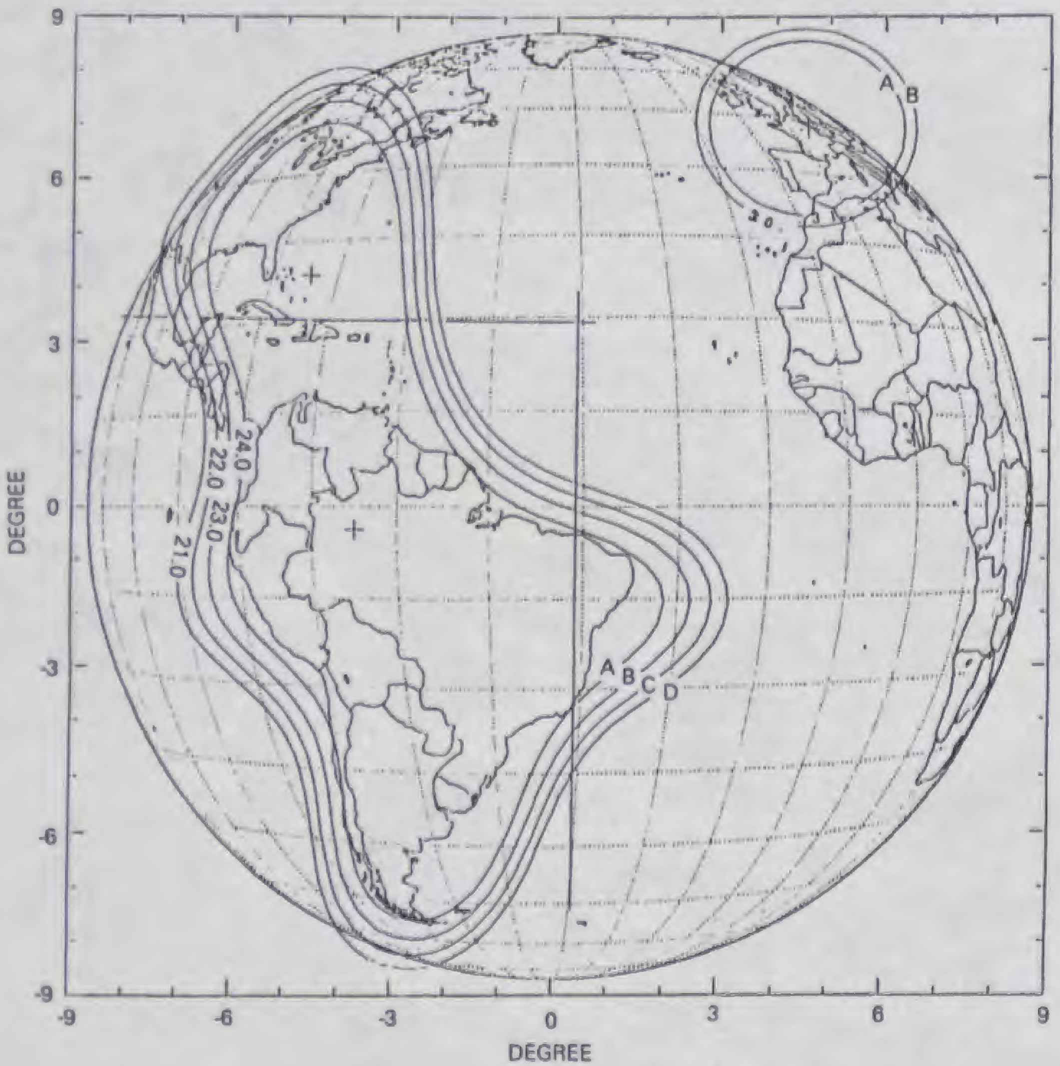
	EIRP (dBW)	
	NORTH	SOUTH
BEAM CENTER	38.5	38.6
CONTOUR		
A	35.0	35.1
B	34.0	34.1
C	33.0	33.1
D	32.0	32.1

C–Band EIRP and G/T Contour Plot



	G/T dB/$^\circ$K	EIRP (dBW)
BEAM CENTER	0.9	39.5
CONTOUR		
A	-4.2	34.4
B	-5.2	33.4
C	-6.2	32.4
D	-7.2	31.4

Ku–Band G/T Contour Plot



	G/T dB/ °K	
	LATIN	EUROPE
BEAM CENTER	-1.0	6.3
CONTOUR		
A	-4.5	2.9
B	-5.5	1.9
C	-6.5	
D	-7.5	

PAS–2 User Services per Transponder C–Band

Services	Type	Rate	Ground Antennas (m)		Ground Transmitter Power (Watts)	Downlink Carriers	Net System Margin* (dB)	
			Transmit	Receive				
1. C–Band Digital Phone	Digital	2.04 Mbs	3.0	3.0	10	7†	Venezuela (North)	0.3
							Peru (North)	0.6
							Chile (South)	0.8
							Argentina (Latin)††	1.4
2. C–Band Corporate Data	Digital	64 Kbs	1.8	1.8	10	100	Venezuela (North)	0.5
							Peru (North)	0.7
							Chile (South)	0.8
							Argentina (Latin)	1.6
3. C–Band Corporate Video Conference	Digital	5 Mbs	1.8	1.8	50	1	Venezuela (North)	0.2
							Peru (North)	0.5
							Chile (South)	0.7
							Argentina (Latin)	1.0
4. C–Band Broadcast TV	FM	27 MHz	10	10	12	1	Venezuela (North)	2.2
							Peru (North)	2.7
							Chile (South)	2.8
							Argentina (Latin)	3.2
5. C–Band Compressed Video	Digital	3 Mbps	10	3	10	10	Venezuela (North)	0.2
							Peru (North)	0.5
							Chile (South)	0.6
							Argentina (Latin)	1.6
						15	Argentina (Latin)**	0.2

*Net end–to–end system margin in one transponder after subtracting rain loss for 99.9% link availability.
†Each carrier holds 64 full duplex telephone circuits (32 kpbs) for a total of 448 duplex circuits.
††North and south spot beams use 36–MHz transponders; Latin beam uses 72–MHz transponders.
**Link margin when 72–MHz transponder loaded with extra 3–Mbps carriers at 4.8–MHz intervals.

Programmatics

TRW Organization

TRW Inc.
J.F. Gorman
President
and CEO

SPACE & DEFENSE SECTOR
E.D. Dunford
Executive Vice President
and General Manager

ELECTRONIC SYSTEMS GROUP
T.W. Hannemann
Vice President
and General Manager

- Spaceborne Electronics
- Communications
- Microelectronics
- Manufacturing

SPACE & TECHNOLOGY GROUP
D.S. Goldin
Vice President
and General Manager

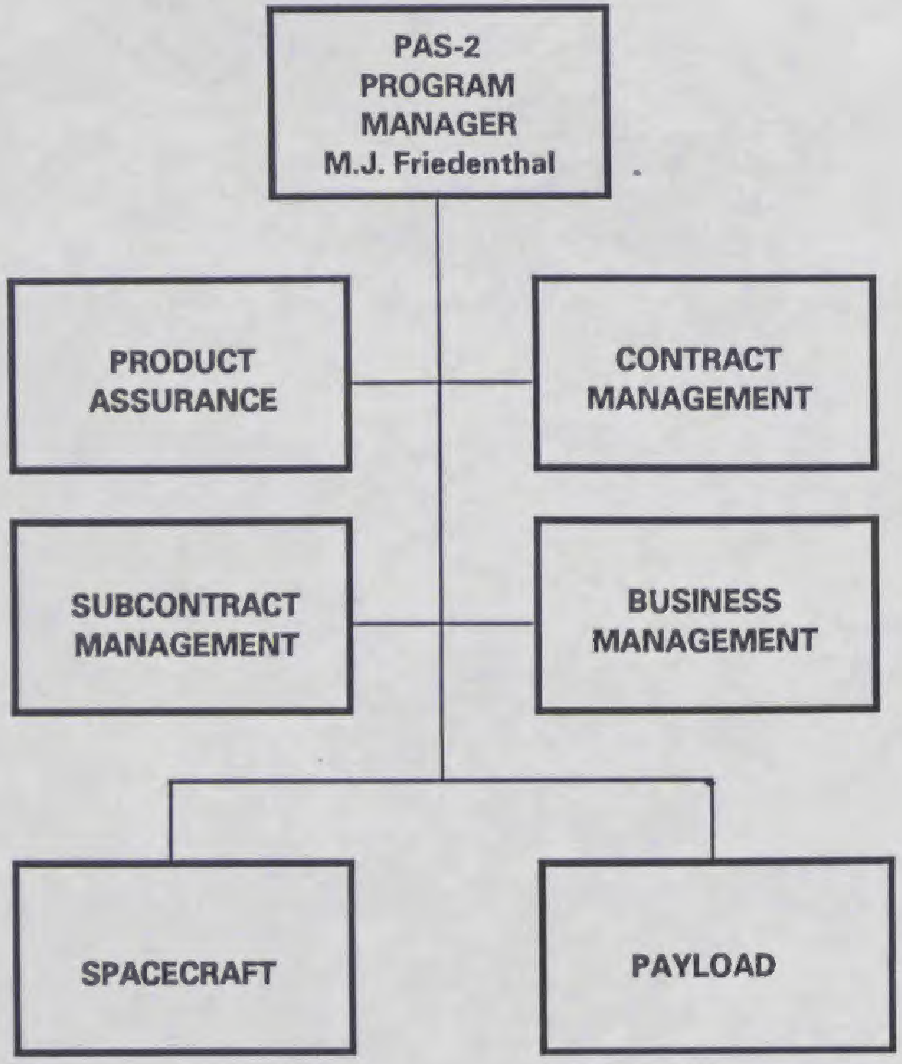
P.W. Mayhew
Vice President
and Deputy General
Manager for Programs

- Spacecraft
- Payloads
- Instruments
- Propulsion
- Control Systems
- Structures
- Launch Support

SYSTEMS INTEGRATION GROUP
J.P. Stenbit
Vice President
and General Manager

- Software
- Information Processing
- Command and Control
- Missions Management

TRW's PAS–2 Organization



PAS–2 Statement of Work Summary

Basic Program

TRW will provide the following:

- One complete communications satellite, in accordance with a defined specification
- A set of deliverable documentation
- Analytical integration with Arianespace

Options

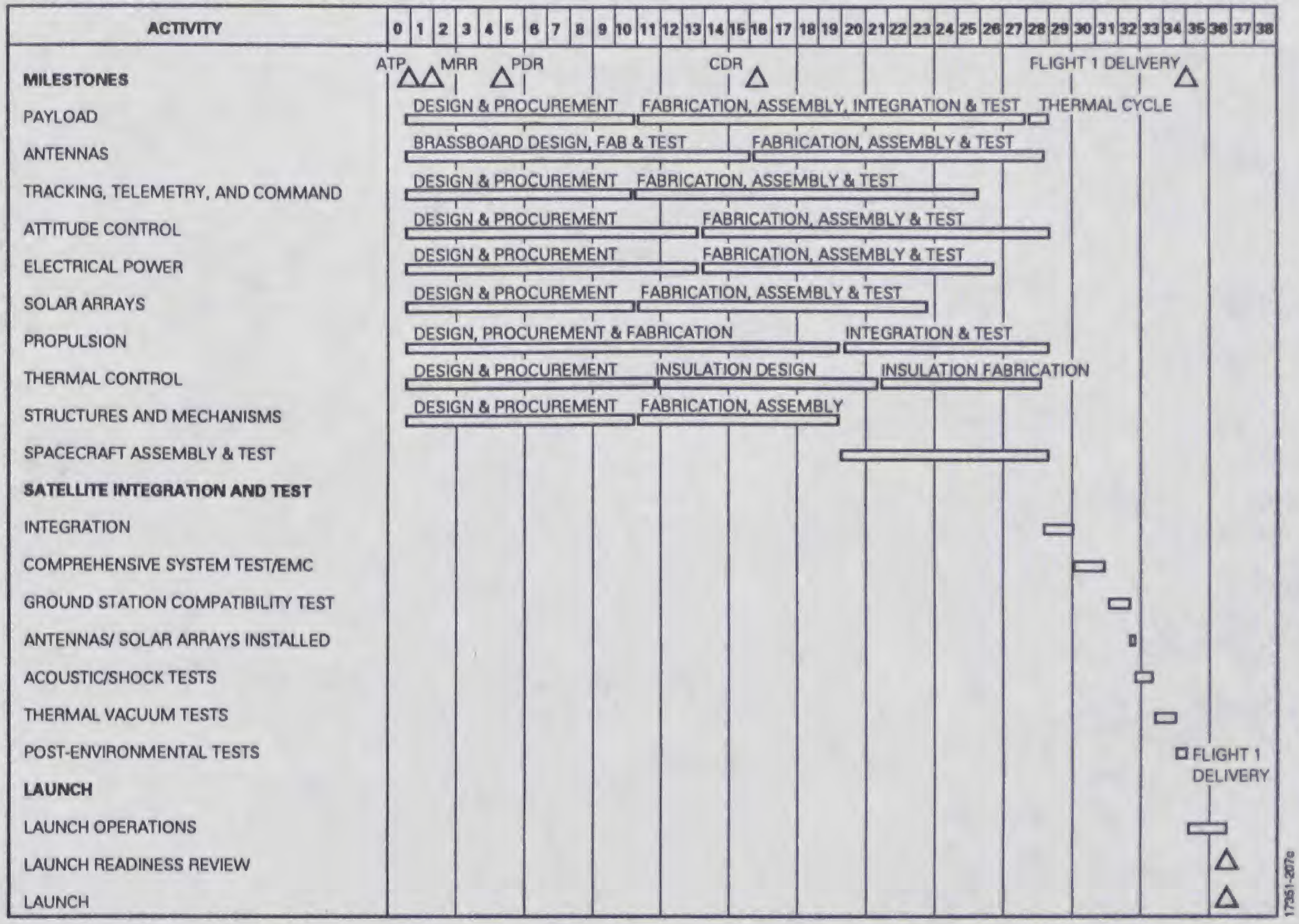
In addition, the following options are offered:

- Launch services, including
  - Contracting for the launch vehicle and supporting services
  - Delivery of the tested satellite and test equipment to Kourou, French Guiana, and launch support in Kourou

PAS–2 Statement of Work Summary (Continued)

- Orbital support
  - Specialized TT&C equipment
  - Orbital operations documentation
  - Orbital operations training
  - Orbital operations training simulator
  - Post–launch support during initial operations period
  - Mission operations support
  - TT&C facility assistance
- Command security

PAS–2 Master Program Schedule



$24 \times 15 = 360$

$$\begin{array}{r} 1200 \\ 240 \\ \hline 1440 \end{array}$$

$24 \times 50 = 1200$

$24 \times 15 = 360$

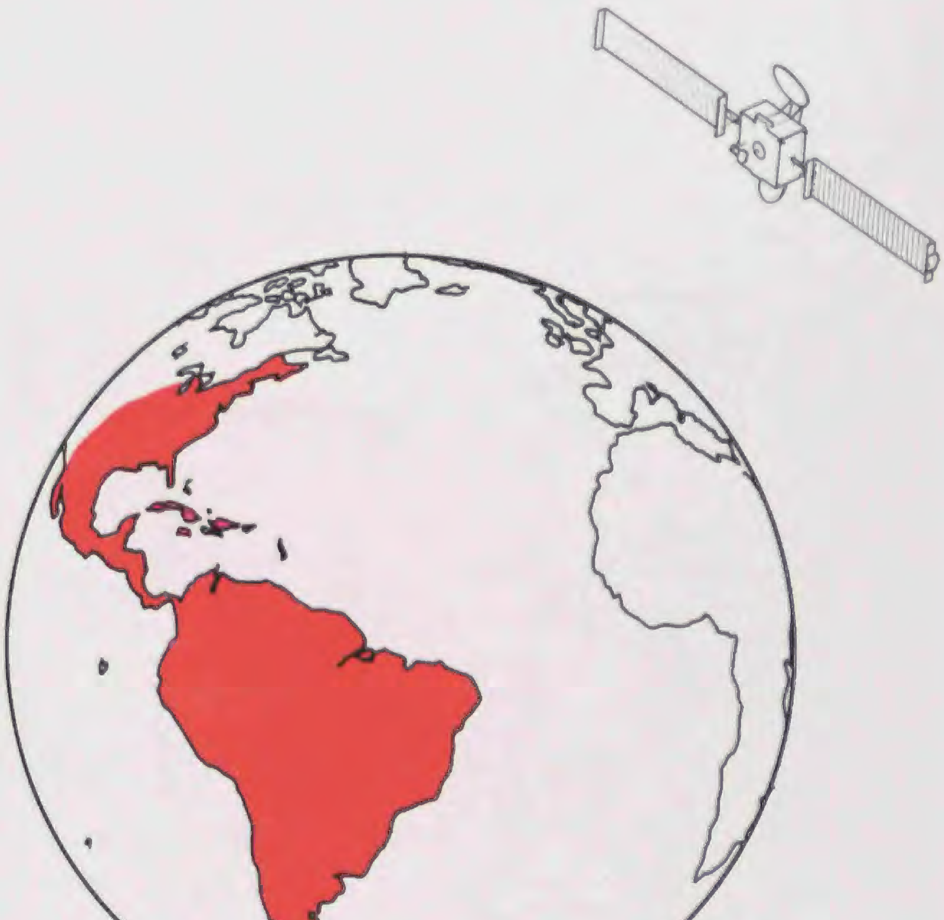
$1560 \div 240 = 6.5$

TRW

Proposal for

Pan American Satellite-2

Volume I – Contracts



Prepared for
Alpha Lyracom
Pan American Satellite
One Pickwick Plaza
Greenwich, CT 06830

In Response to
Letter of June 22, 1990

September, 1990

Prepared by
TRW Space & Technology Group
Engineering & Test Division
One Space Park
Redondo Beach, CA 90278

TRW Space & Technology Group
One Space Park
Redondo Beach, CA 90278
213.812.4321

57406.P331-ALC.90.021
August 31, 1990

Alpha Lyracom
Pan American Satellite
One Pickwick Plaza
Greenwich, CT 06830

Attention: Mr. Frederick A. Landman
President, Pan American Satellite

Subject: TRW Proposal Number 57406.000
Pan American Satellite-2 Program

Reference: (a) Pan American Satellite Technical Memorandum from Philip Rubin to Jacque Johnson/TRW; Subject: Design Parameters of PAS 2 Satellite, dated May 3, 1990.

(b) PanAmSat Prospectus dated May 1990.

(c) Pan American Satellite Technical Memorandum from Philip Rubin to Jacque Johnson / TRW; Subject: TRW Proposal to PanAmSat, dated May 23, 1990.

(d) Response to PanAmSat Letter of 23 May 1990.

(e) PanAmSat Data Package, dated 20 June 1990.

(f) Alpha Lyracom Pan American Satellite letter from Philip Rubin to Daniel S. Goldin / TRW requesting a firm proposal, dated 22 June 1990.

Dear Mr. Landman:

In response to Alpha Lyracom Pan American Satellite's reference (f) letter, TRW is pleased to submit this proposal for Pan American Satellite-2.

Our proposal consists of three volumes:

Volume I - Contracts
Volume II - Cost
Volume III - Technical/Management Proposal

Some comparisons with the design described in our Prospectus (Reference 2) are noteworthy. Our transponder and antenna configurations retain full frequency reuse operation at lower weight and power to accommodate a 12 year satellite design life. We have improved C-Band antenna patterns through more elaborate feed designs. Receive link performance has also been improved. We have provided for simultaneous Ku-Band uplinks from southern Europe and Latin America. We have validated our solid state power amplifier efficiency through engineering model testing. Our satellite design (including margin for growth) is within the weight limit for the special launch price offered by Arianespace for Ariane 4 Spelda Dedicated Satellites.

This offer is forward priced while the estimates in the Prospectus were in constant 1990 dollars. Our offer consists of a spacecraft price and separately priced options to be exercised on or before the option dates. This approach allows flexibility for tailoring program funding.

This offer is valid until November 1, 1990, subject to further negotiations.

We appreciate the opportunity that you have afforded TRW and look forward to working with you in the future.

Please direct any inquiries of a contractual or administrative nature to the undersigned at (213) 813-3587 or Building 161, Mail Station 2319. Technical inquiries should be addressed to Mr. M. J. Friedental at (213) 813-2522 or Building 161, Mail Station 2351.

Please consider this letter and its attachment confidential and proprietary information subject to our Confidential Disclosure Agreement.

A. L. Crosner
Manager Communication Satellite Contracts
TRW Space & Technology Group

TRW

Proposal for

Pan American Satellite-2

Volume I – Contracts

Prepared for
Alpha Lyracom
Pan American Satellite
One Pickwick Plaza
Greenwich, CT 06830

In Response to
Letter of June 22, 1990

September, 1990

Prepared by
TRW Space & Technology Group
Engineering & Test Division
One Space Park
Redondo Beach, CA 90278

SATELLITE PURCHASE CONTRACT

BETWEEN

SPACE & TECHNOLOGY GROUP
OF TRW INC.

AND

ALPHA LYRACOM PAN AMERICAN SATELLITE

SEPTEMBER, 1990

SATELLITE PURCHASE CONTRACT

BETWEEN

SPACE & TECHNOLOGY GROUP
OF TRW INC.

AND

ALPHA LYRACOM PAN AMERICAN SATELLITE

_______________, 1990

CONTENTS

TABLE OF CONTENTS

EXHIBITS

A	STATEMENT OF WORK
B	SATELLITE PERFORMANCE SPECIFICATIONS
C	MASTER SCHEDULE
D	PRICES
E	PAYMENT PLAN

SATELLITE PURCHASE CONTRACT

This contract is entered into this ____ day of __________, 1990, between the Space & Technology Group of TRW Inc. (hereinafter referred to as "TRW"), an Ohio corporation with offices at One Space Park, Redondo Beach, California, and Alpha Lyracom Pan American Satellite (hereinafter referred to as "PAS"), a ______ corporation with offices at One Pickwick Plaza, Greenwich, Connecticut.

ARTICLE I
DEFINITIONS AND PRIORITY

1.1 Definitions

The following words and phrases shall have the meanings set forth below:

"Authorized Representative" means the individual holding the title __________ of PAS or Manager, Communications Satellite Contracts of TRW, as the case may be, for this Contract or his/her designees under a written delegation of authority communicated in writing to the other party.

"Contract" means this contract between TRW and PAS, including the following exhibits, attached hereto and made a part hereof:

- A Statement of Work
- B Satellite Performance Specifications
- C Master Schedule
- D Prices
- E Payment Plan

[Exhibits D and E are incorporated by reference to the cost volume of the TRW Proposal]

"Deliverable Data" means any Technical Data and Information (as defined below) identified in Exhibit A as being deliverable by TRW under this Contract.

"Force Majeure" means any act of God, war, act or failure to act of any government in its sovereign capacity, fire, flood, earthquake, strike, epidemic, quarantine, embargo, nuclear incident or any other act beyond the reasonable control and without the fault of TRW and its Subcontractors, including but not limited to the failure of PAS, and/or its contractors, subcontractors or vendors to perform in a timely manner their responsibilities under this Contract or any other contract for any PAS Purpose related to this Contract.

"Intentional Ignition" means intentional ignition of any first stage engine of the Launch Vehicle (as defined below).

"Launch Vehicle" means a launch vehicle designated by PAS with respect to the Satellite (as defined below) pursuant to Exhibit A.

"Orbital Life" means the satellite design life set forth in Exhibit B.

"PAS Purpose" means any purpose connected with the design, development, construction, establishment, operation, and maintenance of equipment and components for use with the PAS Space Segment.

"PAS Space Segment" means the telecommunications satellite, and the tracking, telemetry, command, control, monitoring, and related facilities and equipment owned or leased by PAS and required to support the operation of such satellite.

"Satellite" means all of the flight equipment necessary to meet the requirements in Exhibit B, including integration and compatibility with the Launch Vehicle.

"Subcontract" means any subcontract including purchase orders and all similar forms of agreement at any tier under this Contract.

"Subcontractor" means a contractor under any Subcontract and includes suppliers.

"Technical Data and Information" means all data and information including but not limited to technical writings, sound recordings, computer software, pictorial reproductions, drawings, and other graphic representations and works of similar nature, and any other data necessary for the use and operation of the Satellite, whether or not copyrighted, to the extent that such data and information are of the type customarily retained in the normal course of business. The term does not include TRW's or Subcontractor's financial reports, cost analyses, and other data and information incidental to contract administration.

"Work" means all of the equipment to be delivered and the services and activities required to be performed by TRW pursuant to this Contract.

1.2 Priority

In case of any inconsistencies between the text of this Contract and any of the Exhibits, the text of this Contract shall prevail. In the case of any inconsistencies among the Exhibits to this Contract, this Contract shall be interpreted in the same order of priority as the order of its Exhibits.

ARTICLE 2
SCOPE OF WORK

TRW shall provide the necessary personnel, material, equipment, services and facilities to perform the Work specified under the provisions of this Contract.

ARTICLE 3
TRW DELIVERABLES

3.1 Equipment

The equipment to be delivered by TRW and the delivery locations are specified in Exhibit A. The mode of delivery shall be by common carrier selected by TRW.

3.2 Documentation

The documentation to be delivered by TRW is specified in Exhibit A. All such documentation is to be delivered to PAS by electronic transmission, air mail, or surface mail, as directed in writing by PAS.

ARTICLE 4
PERFORMANCE SCHEDULE

All Work shall be performed in accordance with the master schedule set forth in Exhibit C. Deliverables shall be delivered in accordance with the delivery times specified in Exhibit C.

ARTICLE 5
PRICES

The prices for all Work are specified in Exhibit D and shall be paid in accordance with Article 6. These prices include all taxes and other charges associated with the performance of the Work, but are net of transportation, transport insurance and of sales, use and excise taxes, duties and taxes imposed by foreign governments. All such taxes and duties, if any, shall be paid by PAS and, if the transport option set forth in section 21.9 is not exercised, transportation and transport insurance shall be paid by PAS.

ARTICLE 6
PAYMENT TERMS

6.1 Progress Payments

The prices referred to in Article 5 shall be paid by PAS in accordance with Exhibit E and with the terms of this article. Within thirty (30) days of the date of this Contract, PAS at its sole expense shall establish and thereafter until termination or expiration of this Contract shall maintain with a commercial banking or other financial institution acceptable to TRW in its sole discretion an irrevocable letter of credit in favor of TRW in the principal amount of the contract price set forth in Exhibit E, as it may be adjusted from time to time pursuant to Articles 19 or 21. The terms of such letter of credit shall be acceptable to TRW in its sole discretion and shall provide for payments to TRW in United States dollars within two (2) days following presentation of a sight draft and an invoice, a copy of which shall have been forwarded to PAS.

6.2 Other Payments by Either Party

With respect to any other amount payable under this Contract, the party entitled to payment shall make written demand therefor, or shall submit an invoice if so requested by the payor, after such entitlement becomes established, and the payor shall make payment within ten (10) days after receipt of the written demand or invoice.

6.3 Manner of Payment

All payments hereunder shall be made by depositing, by bank wire transfer, the required amount (in immediately available funds) in an account designated by the payee for such purpose in the payee's written demand or invoice.

6.4 Late Payment

Late payments by PAS shall be subject to interest at the prime or reference rate as in effect from time to time at National City Bank, at its corporate headquarters, or if National City Bank ceases to exist, the prime or reference rate quoted by a commercial bank of national reputation, chosen by TRW in its sole discretion, calculated from the day following the due date until the date of actual payment.

ARTICLE 7
ACCESS TO WORK IN PROGRESS

7.1 Access

Subject to the receipt of any and all required government approvals, if any, and to TRW's and its Subcontractor's rights in Technical Data and Information, the PAS Authorized Representative shall have the right, at all reasonable times and intervals during the performance of this Contract, and upon reasonable notice to TRW, to monitor the Work in progress at the plants of TRW and, to the extent TRW has such right, its Subcontractors.

7.2 PAS Notification of Non-Conformance

If, during the performance of this Contract, the PAS Authorized Representative reasonably determines that any of the Work does not conform to the requirements of this Contract, the PAS

Authorized Representative shall promptly notify the TRW Authorized Representative, and confirm such notification in writing within two (2) business days, of the particulars in which the Work does not meet the requirements of the Contract, and TRW shall within a reasonable period of time remedy the defects. The decision as to how to make the corrections shall be in TRW's sole discretion.

ARTICLE 8
FINAL ACCEPTANCE

Upon delivery to PAS of any deliverables under this Contract, the PAS Authorized Representative shall promptly conduct a final inspection of such deliverables, or at PAS's option witness such inspection by TRW, and shall either accept them in writing or promptly notify TRW in writing of the particulars in which they are unacceptable. If no objection shall have been received by the TRW Authorized Representative within two (2) days of delivery of such deliverables, such deliverables shall be deemed to have been accepted by PAS. Upon remedy of such particulars to the reasonable satisfaction of the PAS Authorized Representative, such deliverables shall be accepted by PAS in writing. Corrections required to render the deliverables in conformance with this Contract shall be made by TRW at its own cost. The decision as to how to make the corrections shall be in TRW's sole discretion.

ARTICLE 9
TITLE AND RISK OF LOSS

9.1 Title

With respect to all deliverable equipment identified in Exhibit A, TRW warrants to PAS that it shall deliver good title, free and clear from any claim, lien, pledge, mortgage, security interest, or other encumbrances including, but not by way of limitation, those arising out of the performance of the Work.

9.2 Risk of Loss

Unless otherwise provided in this Contract, title and risk of loss of or damage to all deliverable equipment, other than specialized tracking, telemetry, command and ground equipment, shall pass to PAS at the Port of Entry, Kourou, French Guiana, except that in the event the Satellite transport option set forth in section 21.9 is not exercised, title and risk of loss to all deliverable equipment shall pass to PAS at Redondo Beach, California. Title and risk of loss of or damage to all deliverable documents and to tracking, telemetry and command and ground equipment shall pass to PAS at time of delivery by TRW to PAS.

ARTICLE 10
WARRANTY

10.1 Warranty

Notwithstanding any prior inspection or acceptance by PAS, TRW warrants that all equipment delivered in accordance with Section 3.1 shall be free from any defects in materials or workmanship, and that all services shall be performed in a skillful and workmanlike manner consistent with generally accepted custom and practice in the industry. All equipment and Deliverable Data shall conform in all material respects to the specifications of this Contract. The warranty for all equipment, other than specialized tracking, telemetry, command and ground equipment, shall commence at the time of final acceptance pursuant to Article 8 hereof and shall run until Intentional Ignition, or for a period of one (1) year, whichever occurs first. This warranty for specialized tracking, telemetry, command and ground equipment and Deliverable Data shall commence at the time of final acceptance pursuant to Article 8 hereof and shall run for a period of one (1) year.

10.2 Remedies

Subject to the limitations set forth in this Article 10, promptly after receipt of written notice from the PAS Authorized Representative that any equipment is defective or non-conforming, TRW shall either repair or replace any defective or nonconforming equipment or part thereof. The decision whether and how to repair or replace any equipment or part thereof shall be in TRW's sole discretion. With respect to any defects in Deliverable Data, TRW's sole obligation shall be to correct the Deliverable Data at no cost to PAS, and PAS shall have no other remedy against TRW.

10.3 Exclusion

THE WARRANTY IN THIS ARTICLE IS IN LIEU OF ALL OTHER WARRANTIES, EXPRESS OR IMPLIED, AT LAW OR IN EQUITY, INCLUDING BUT NOT LIMITED TO WARRANTIES OF MERCHANTABILITY OR FITNESS FOR A PARTICULAR PURPOSE. TRW'S WARRANTY OBLIGATIONS AND PAS'S REMEDIES ARE SOLELY AND EXCLUSIVELY AS STATED IN THIS ARTICLE 10.

10.4 Limitation of Liability

TRW shall have no liability or responsibility in contract or in tort with respect to the Satellite upon termination of the warranty set forth in Section 10.1 above. Notwithstanding any other provision in this Contract, in no event shall TRW be liable for any special or consequential damages, including but not limited to damages for loss of revenue, profits, including third-party profits, or contracts, however caused or arising.

ARTICLE 11
CORRECTIONS IN UNLAUNCHED SATELLITE

If, at any time prior to Intentional Ignition, TRW, as a result of data with respect to any other satellites, becomes aware that defects exist in the Satellite that TRW reasonably determines would materially and adversely affect the operation of the Satellite, TRW shall take prompt appropriate corrective measures at its own expense to eliminate any such defects from the Satellite. The decision as to how to make the corrections shall be in TRW's sole discretion. If such corrections will affect TRW's ability to comply with the delivery schedule referred to in Article 4, PAS and TRW shall agree upon reasonable adjustments to that schedule, provided that such adjustment shall be without penalty to TRW.

ARTICLE 12
RIGHTS IN DELIVERABLE DATA

12.1 Use of Deliverable Data by PAS and Others

TRW hereby grants to PAS an irrevocable, non-exclusive and world wide right to use, and to authorize any third party to use, Deliverable Data for PAS Purposes without payment of additional compensation to TRW. The data rights granted under this Contract shall not survive the termination of this Contract by TRW for the default of PAS and, in such event, all such rights previously granted shall revert to TRW and PAS shall have no rights whatsoever with respect to any and all such Deliverable Data.

12.2 Copyrights in Deliverable Data

If any Deliverable Data furnished pursuant to this Article 12 is copyrighted, and to the extent that TRW now has or hereafter acquires the authority to authorize copying, TRW hereby grants to PAS the royalty-free right to copy such copyrighted material for the purpose of this article, provided that PAS shall apply the appropriate copyright notice to all copies made. If any Deliverable Data furnished pursuant to this Article 12 is copyrighted and TRW is not entitled to authorize copying, notice to that effect shall be given to PAS at the time the material is furnished.

12.3 Other Authorizations

Notwithstanding any other provisions of this Article 12, use of any Deliverable Data shall be free, unconditional, and unlimited to the extent, and from the time, that any such data lawfully comes into the public domain. No other right or license of any nature whatsoever is granted or extended directly or by implication, estoppel or otherwise under this Contract and nothing herein shall imply the granting of a license under any patent.

12.4 Markings

All Deliverable Data furnished pursuant to this Article 12 shall be marked as follows:

> "This document contains Deliverable Data furnished pursuant to a Contract between PAS and TRW dated __________, 1990. Such data may be used only in the manner specified in that Contract, unless the data lawfully comes into the public domain or lawfully becomes available to the user on other terms."

PAS shall be entitled to ignore and remove any other marking[, other than those affixed pursuant to the terms of the Non-Disclosure Agreement between the parties dated _______, 1990,] but only after notice and a reasonable opportunity to modify or defend the marking have been given to TRW.

ARTICLE 13
INDEMNIFICATION

13.1 Indemnification by TRW

TRW shall indemnify and hold PAS, its officers, agents, servants, employees, subsidiaries, successors and assigns, or any of them, harmless from any and all loss, damage, liability or expense, resulting from damage to all tangible property and injuries, including death, to all persons (natural or juridical), arising from any occurrence caused by a negligent act or omission or willful misconduct of TRW, its Subcontractors or agents, or any of them, in the performance of the Work, except that TRW shall have no obligation to provide indemnification from liabilities caused by the Satellite after Intentional Ignition, and TRW shall at its sole expense defend any claims, actions, suits and proceedings, whether in law or equity, brought against PAS, its officers, agents, servants, employees, subsidiaries, successors and assigns, or any of them, on account thereof, and shall pay all expenses, including reasonable attorneys' fees, and satisfy all judgments as may be incurred by or rendered against them, or any of them, in connection therewith, provided TRW is given prompt notice of any such claim, action, suit or proceeding and provided TRW is given, at TRW's written request and sole expense, such assistance and information as may be reasonably provided by PAS.

13.2 Indemnification by PAS

PAS shall indemnify and hold TRW, its Subcontractors, and their officers, agents, servants, employees, subsidiaries, successors and assigns, or any of them, harmless from any and all loss, damage, liability or expense, resulting from damage to all tangible property and injuries, including death, to all persons (natural or juridical), arising from any occurrence caused by a negligent act or omission or willful misconduct of PAS, its subcontractors or agents, or any of them, in conjunction with this Contract and PAS shall at its sole expense defend any claims, actions, suits and proceedings, whether in law or equity, brought against TRW, its Subcontractors, and their officers, agents, servants, employees, subsidiaries, successors and assigns, or any of them, on account thereof, and shall pay all expenses, including reasonable attorneys' fees, and satisfy all judgments as may be incurred by or rendered against them, or any of them, in connection therewith, provided PAS is given prompt notice of any such claim, action, suit or proceeding and provided PAS is given, at PAS's written request and sole expense, such assistance and information as may be reasonably provided by TRW.

13.3 Launch Site

With respect to loss of or damage to property, or personal injury or death, arising out of activities at the launch site, the parties agree to enter into any standard and customary inter-party waiver of liability that is required by the launch provider in connection with launch site operations and launch services. In addition to any agreements required in connection with launch site operations and launch services, and notwithstanding anything to the contrary in Section 13.1 and 13.2 above, the parties hereby waive any claims against each other arising out of activities at the launch site, except that risk of loss of or damage to the Satellite shall continue to be governed by Article 9 hereof. To the extent it is not already provided pursuant to agreements with the appropriate launch agency, PAS shall purchase at its cost one or more third party liability insurance policies against the liabilities described in this Section 13.3 naming TRW as an additional named insured on such policy or policies. The liability limits on such insurance shall be no less than One Hundred Million Dollars ($100,000,000).

ARTICLE 14
FORCE MAJEURE

Any party whose ability to perform is affected by a Force Majeure event shall take all reasonable steps to mitigate the impact of such event. If the effect of a Force Majeure event is temporary, the party so affected shall not be responsible for any delay caused by it, and the relevant schedule or time period shall be extended accordingly, if notice is given to the other party within twenty (20) days after the party affected becomes aware, or should reasonably have become aware, that the event has occurred. At the time of the initial notice of the occurrence of the event, or as soon thereafter as possible, the party affected shall inform the other party of the extent of the delay expected as a result of the event and of the actions, if any, proposed to be taken to mitigate the effects of such delay. In the case of Force Majeure events permanently preventing TRW from complying with the schedule, PAS may declare this Contract to be discharged. In such event, Article 17 shall be applied to determine the impact on TRW and the disposition of the Work affected by the discharge, and TRW shall be entitled to the amounts to which it would have been entitled under Article 17.

ARTICLE 15
DELIVERY PAYMENTS

15.1 Delivery Premium

PAS and TRW desire to give TRW an incentive for delivery of the Satellite as soon as possible. Accordingly, in the event that the Satellite is delivered on or before the thirtieth (30th) day prior to the delivery date set forth in Exhibit C (as it may be adjusted pursuant to Articles 11, 14 or 19 hereof), PAS shall pay to TRW an early delivery premium in the principal amount of One Million Dollars ($1,000,000).

15.2 Delays

If the Satellite is not delivered on or before the delivery deadline specified in Article 4, TRW agrees to be subject to liquidated damages for late delivery as provided below. Subject to Articles 11, 14 and 19 hereof, if the Satellite delivery deadlines specified in Article 4 are not met, TRW shall pay to PAS One Million Dollars ($1,000,000) for the first day of delay and Ten Thousand Dollars ($10,000) for each day of delay thereafter; provided, however, in no event shall the total damages payable by TRW hereunder for the Satellite exceed a maximum amount of Two Million Dollars ($2,000,000). In the event that the Satellite delivery deadlines specified in Article 4 are not met and the Satellite launch has been delayed for reasons other than such late delivery of Satellite by TRW, then TRW shall not be responsible for liquidated damaged under this Article 15 until the revised launch schedule date has passed.

15.3 Determination of Payments

For the purpose of this Article 15, delivery of the Satellite shall be deemed to have occurred at the time that it has arrived at the delivery point specified in Exhibit A. Such delivery shall be subject to PAS's rights under Article 8. In the event that PAS subsequently rejects the Satellite pursuant to Article 8, delivery shall not be deemed to have occurred until the defects that led to such rejection have been remedied as provided in Article 8; provided, however, that liquidated damages shall not apply during the period between delivery and discovery of such defects. In the event that the Satellite delivery deadlines specified in Article 4 are not met due to the failure of PAS and/or its contractors, subcontractors or vendors to perform in a timely manner their responsibilities under this Contract or any other contract for any PAS Purpose related to this Contract, there shall be an equitable adjustment to the price and/or the delivery schedule to reflect the delay caused by PAS in completing the Work.

15.4 Election of Remedies

If TRW does not meet the delivery dates for the Satellite specified in this Contract and PAS does not exercise its right to terminate this Contract for cause in accordance with Article 18, the price reduction provided for in this Article 15 shall be the sole compensation to which PAS shall be entitled for delays in delivery of Satellite. However, if at any time PAS exercises its right to terminate this Contract for TRW's default pursuant to Article 18, PAS's rights and remedies shall be governed solely by the provision of that Article and this Article 15 shall not apply.

ARTICLE 16
SATELLITE PERFORMANCE INCENTIVES

If PAS uses the Satellite for commercial purposes beyond the Orbital Life set forth in Exhibit B, PAS shall pay to TRW a monthly performance incentive for each month beyond the Orbital Life that the Satellite is so used of Five Thousand Dollars ($5,000) times the number of channels on the Satellite that are active. Use of the Satellite for revenue producing purposes, including but not limited to sale or lease of capacity on the Satellite to third parties, and use of the Satellite for backup to other satellites, shall be deemed utilization for commercial purposes. After terminating use of the Satellite, if PAS subsequently decides to use the Satellite, TRW shall again be entitled to its performance incentive under this Article 16.

ARTICLE 17
TERMINATION FOR CONVENIENCE

17.1 Termination

PAS may, prior to TRW's completion of all Work, by written notice issued by PAS's Authorized Representative, terminate this Contract in whole or in part, for its convenience, whereupon TRW shall cease work in accordance with the terms of such notice.

17.2 Termination Charges

TRW shall promptly submit to PAS a detailed written statement of TRW's total direct and indirect costs incurred in the performance of Work and total direct and indirect cost resulting from such termination as determined in accordance with TRW's Standard Practice Instructions and accounting practices and, if requested by PAS, verified to PAS by TRW's independent auditors at PAS's expense (hereinafter referred to as the "Total Verified Termination Cost"). The termination charges to be paid to TRW by PAS shall be the lesser of one hundred twenty-five percent (125%) of the Total Verified Termination Cost or the total Contract price, less (i) amounts previously paid by PAS pursuant to this Contract, and (ii) amounts representing termination charges attributable to equipment which TRW or any of its subcontractors elects to retain. The termination charges shall be paid by PAS within thirty (30) days after receipt of TRW's invoice therefor or, in the case PAS has requested verification of costs by TRW's independent auditors, within ten (10) days following the receipt of such verification of costs, whichever is later. In the event of a termination pursuant to this Article 17, all inventory generated under this Contract except that identified pursuant to this Section 17.2 as being retained by either TRW or a Subcontractor shall become the property of PAS.

ARTICLE 18
TERMINATION FOR DEFAULT

18.1 Termination by PAS

PAS may, by written notice issued by PAS's Authorized Representative, terminate this Contract, in whole or in part, if TRW fails (i) to deliver the Satellite within one hundred sixty (160) days after the due date for delivery set forth in Exhibit C; (ii) to comply in any material respect with any of the provisions of this Contract; or (iii) to make progress so as to ensure completion of this Contract in accordance with its terms and, in each case, fails to take reasonable measures to cure such failure within sixty (60) days from the date of Contractor's receipt of written notice thereof from PAS's Authorized Representative, setting forth in detail PAS's basis for termination of the Contract. If PAS terminates TRW's right to proceed, TRW shall pay any reasonable increased costs to PAS occasioned by such delay in completing the Work subject to the limitations stated in Article 20.

18.2 Termination Without Cause

If, after termination under the provisions of Section 18.1, it is determined for any reason that TRW was terminated without cause, or that the delay causing such termination was excusable, the rights and obligations of the parties shall be the same as if termination had been effected pursuant to Article 17, excluding, however, the limitations in termination charges stated in Section 17.2.

18.3 Limitation

The rights and remedies of PAS provided in this Article 18 are in lieu of any other rights and remedies provided at law, in equity, or under this Contract.

18.4 Termination by TRW

TRW may, by written notice to PAS's Authorized Representative, terminate this Contract if PAS fails (i) to pay TRW any amounts when due and payable hereunder and fails to cure such failure within fifteen (15) days; or (ii) to perform any other material obligations required to be performed by it under any provision of this Contract and fails to take reasonable measures to cure such failure within thirty (30) days from the date of PAS's receipt of written notice thereof from TRW's Authorized Representative. In the event of termination of this Contract by TRW for PAS's default as provided for hereinabove, TRW shall be entitled to all rights and remedies provided by law or in equity or under this Contract.

ARTICLE 19
CHANGES

19.1 Changes Requested by TRW

(a) Any changes requested by TRW during the performance of this Contract, within the general scope of this Contract, which would add or delete Work, affect the design of the Satellite, change the method of shipment or packing, or place or time of delivery, or would affect any other requirement of this Contract, shall be submitted in writing to PAS sixty (60) days prior to the proposed date of the change. If such TRW requested change causes an increase or decrease in the total price of this Contract, TRW shall submit to PAS at the time the requested change is submitted, or at a later date agreed to by PAS, the details of such increase or decrease.

(b) PAS shall notify TRW in writing within thirty (30) days after receipt of the requested change and price adjustment, if any, whether or not it agrees with and accepts such change. If PAS agrees with and accepts TRW requested change, TRW shall proceed with the performance of the Contract as changed and an amendment to the Contract reflecting such change, and price adjustment, if any, shall be issued. TRW shall, within a reasonable time thereafter, provide updated information which reflects the final agreed price of the change. In the event the parties are unable to reach agreement on a TRW requested change, or price adjustment, if any, or both, TRW shall proceed with the performance of the Contract, as unchanged.

19.2 Changes Requested by PAS

Any changes requested by PAS during the performance of this Contract, within the general scope of this Contract, which would add or delete Work, affect the design of the Satellite, change the method of shipment or packing, or place or time of delivery, or would affect any other requirement of this Contract, shall be submitted in writing to TRW. TRW shall respond to an PAS requested change in writing within thirty (30) days after receipt of such request. If such PAS requested change causes an increase or decrease in the total price of this Contract, TRW shall submit to PAS at the time the response to the requested change is submitted, the details of such increase or decrease. PAS shall notify TRW in writing, within thirty (30) days after receipt of TRW's response, whether or not it agrees with and accepts TRW's response. If PAS agrees with and accepts TRW's response, TRW shall proceed with the performance of the Contract as changed and an amendment to the Contract reflecting such change, and price adjustment, if any, shall be issued. TRW shall, within a reasonable time thereafter, provide updated information which reflects the final agreed price of the change. If the change results in an increase to the total Contract price, PAS shall increase the principal amount of the letter of credit provided pursuant to section 6.1 to include the amount of such price increase. In the event the parties are unable to reach agreement on an PAS requested change, or price adjustment, if any, or both, TRW shall proceed with the performance of the Contract as unchanged.

ARTICLE 20
LIMITATION OF LIABILITY

In the event that TRW shall default in the performance of its obligations under this Contract, the total liability of TRW on any claim, whether in contract, tort (including sole or concurrent negligence) or otherwise, arising out of, connected with, or resulting from the Work to be performed by TRW hereunder shall not exceed Two Million Dollars ($2,000,000). In no event shall TRW be liable for any special or consequential damages, including, but not limited to, damages for loss of revenue, profits, including third-party profits, or contracts, however caused or arising.

ARTICLE 21
OPTIONS

21.1 Specialized Tracking, Telemetry and Command Equipment

If PAS elects by written notice to TRW no later than twelve (12) months after the date of this Contract, TRW shall provide to PAS specialized tracking, telemetry and command ("TT&C") equipment as provided in paragraph 4.1 of Exhibit A. The price for such TT&C equipment shall be as specified in Exhibit D.

21.2 Orbital Operations Support Documentation

If PAS elects by written notice to TRW no later than eighteen (18) months after the date of this Contract, TRW shall provide to

PAS orbital operations support documentation as provided in paragraph 4.2 of Exhibit A. The price for such documentation shall be as specified in Exhibit D.

21.3 Orbital Operations Training

If PAS elects by written notice to TRW no later than eighteen (18) months after the date of this Contract, TRW shall provide to PAS orbital operations training as provided in paragraph 4.3 of Exhibit A. The price for such operations training shall be as specified in Exhibit D.

21.4 Post Launch Support

If PAS elects by written notice to TRW no later than twenty (20) months after the date of this Contract, TRW shall provide to PAS post launch support services, including transfer orbit operations support, post launch services and in-orbit acceptance testing and operational support, as provided in paragraph 4.4 of Exhibit A. The price for such post launch services training shall be as specified in Exhibit D.

21.5 Mission Operations Support

If PAS elects by written notice to TRW no later than sixty (60) days after the date of launch of the Satellite, TRW shall provide to PAS mission operations support services as provided in paragraph 4.5 of Exhibit A. The price for such services shall be as specified in Exhibit D.

21.6 Operations Training Simulator

If PAS elects by written notice to TRW no later than twelve (12) months after the date of this Contract, TRW shall provide to PAS an operations training simulator as provided in paragraph 4.6 of Exhibit A. The price for such simulator shall be as specified in Exhibit D.

21.7 TT&C Facility Assistance

TRW shall provide PAS with assistance in establishing a TT&C facility as provided in paragraph 4.7 of Exhibit A. The price for such coverage shall be as specified in Exhibit D. [PAS to select at time of contract award.]

21.8 Command Security

TRW shall provide command security capability as provided in paragraph 5.0 of Exhibit A. The price for such capability shall be as specified in Exhibit D. [PAS to select at time of contract award.]

21.9 Launch Support Services

If PAS elects by written notice to TRW no later than ten (10) months prior to the Satellite delivery date projected on Exhibit C, TRW shall provide logistics support for and transport, including transport insurance, of the Satellite to the Port of Entry, Kourou, French Guiana, and Satellite test equipment, launch base support and launch operations rehearsals as provided in paragraph 6.1 of Exhibit A. The price for such launch support services shall be as specified in Exhibit D.

21.10 Launch Vehicle

TRW shall use its best efforts to arrange for launch of the Satellite by Ariane 44L and to provide related launch support services as provided in paragraph 6.2 of Exhibit A. The prices for such launch vehicle activities shall be as specified in Exhibit D. [PAS to select at time of contract award.]

ARTICLE 22
SATELLITE NOT LAUNCHED WITHIN SIX MONTHS

If a Satellite is not launched within six (6) months after final acceptance under Section 8.1 and is subsequently ordered to be launched, the Satellite shall be returned, at PAS's sole expense, to TRW's facility in Redondo Beach, California for inspection and refurbishment. The cost of such inspection and refurbishment, plus a reasonable profit to TRW, shall be paid by PAS, unless the delay in launch is caused solely by TRW's gross negligence. All charges to return the Satellite to the launch site shall be borne by PAS.

ARTICLE 23
MISCELLANEOUS

23.1 Headings

The headings and titles to the articles, sections and paragraphs of this Contract are intended for convenience only and shall not be deemed a part hereof or affect the construction or interpretation of any provision hereof.

23.2 Law and Venue

All questions concerning the validity and operation of this Contract shall be governed by and construed in accordance with the laws of the State of California applicable to contracts entered into and wholly to be performed in the State of California. PAS and TRW agree that any action which, in whole or in part, in any way arises under this Contract shall be brought in the United States District Court for the Central District of California and each hereby submit to the exclusive jurisdiction and venue of such court for purposes of any such action and agree that any notice, document or complaint in any such action may be served on it by delivery to the addresses identified in Section 23.7 below.

23.3 Assignment

This Contract may not be assigned, in whole or in part, by either party without the prior written consent of the other party, which shall not be unreasonably withheld, except that, without securing such prior consent, either party shall have the right to assign the Contract to any company controlling, controlled by or under common control with such party or to any successor of such party by way of merger or consolidation or the acquisition of all or substantially all of the assets of such party relating to the subject matter of this Contract, provided that such successor shall expressly assume all of the obligations of the assignor under this Contract.

23.4 Duty Drawback

If requested by TRW, PAS shall take all reasonable efforts to assist in obtaining authorization for duty-free import of non-U.S. goods to be installed on the Satellite. Such assistance shall include but not be limited to providing such documents, executed by PAS if required, relating to the export of the Satellite from the United States as may be required to enable TRW to pursue duty free import of or duty drawback on the Satellite or its components. Such documents may include properly completed and signed U.S. Customs forms and copies of applicable launch reports, airway bills and bill of lading, as well as written authorization to TRW to make entry and receive and retain duty drawback on the Satellite and identifying the Satellite and the date of export from the United States.

23.5 Export Laws

This Contract is subject to all United States laws and regulations relating to exports and to all administrative acts of the United States Government pursuant to such laws and regulations.

23.6 Public Release of Information

Each party shall obtain the prior written approval of the other concerning the content and timing of news releases, articles, brochures, advertisements, prepared speeches, and other information releases proposed to be made by such party concerning this Contract or the Work performed or to be performed hereunder. Such other party shall be given a reasonable time to review the proposed text prior to the date scheduled for its release.

23.7 Notices

All notices, reports, invoices and other correspondence to be provided pursuant to this Contract shall be in writing and shall be effective upon delivery if delivered in person or by facsimile or sent by registered airmail as follows:

If to TRW: TRW Inc.
Space & Defense Sector
Space & Technology Group
One Space Park
Redondo Beach, California 90278
Attention: Manager, Communications Satellite Contracts
Space & Technology Group

If to PAS: Alpha Lyracom Pan American Satellite
One Pickwick Plaza
Greenwich, Connecticut 06830
Attention: ____________________

or to such other address and to the attention of such person as may be designated in writing to a party's Authorized Representative by the other party's Authorized Representative from time to time.

23.8 Time Limits

Unless otherwise indicated, any time limits to which this Contract binds TRW or PAS shall be counted in calendar days from the day following that of the event marking the start of the time limit, and shall end on the last day of the period specified. When the last day of a time limit is a Saturday or Sunday, or a legal holiday in the country in which the particular contractual performance is required, such time limit shall be extended to the first working day following.

23.9 Confidentiality

Except as a party's Authorized Representative may otherwise consent in writing, neither party shall disclose at any time to any third party Technical Data and Information which was disclosed to such party by the other party in connection with this Contract. The foregoing obligation shall not be applicable to Technical Data and Information which such party can establish was already in or comes into such party's lawful possession independent of disclosures in connection with this Contract.

23.10 Entire Agreement

This Contract constitutes the entire agreement between the parties with respect to the subject matter hereof, and supersedes all prior or contemporaneous correspondence, representations, proposals, negotiations, understandings, or agreements of the parties, whether oral or written. The parties also hereby acknowledge that there are no collateral contracts between them with respect to the subject matter hereof.

23.11 Severability

Any provision hereof prohibited by or unlawful or unenforceable under any applicable law of any jurisdiction shall as to such jurisdiction be ineffective without affecting any other provision of this Contract. To the full extent, however, that the provisions of such applicable law may be waived, they are waived, to the end that this Contract be deemed to be a valid and binding agreement enforceable in accordance with its terms.

23.12 Subcontracts

TRW may subcontract all or any part of its obligations hereunder without the consent of PAS.

23.13 Waiver

No waiver of any right or remedy in respect of any occurrence or event on one occasion by either party hereto shall be deemed a waiver of such right or remedy in respect of such an occurrence or event on any other occasion by such party.

23.14 Counterparts

This Contract may be signed in one or more counterparts which together shall constitute one and the same instrument.

IN WITNESS WHEREOF, the parties hereto have executed this Contract.

TRW INC.
an Ohio Corporation

By: ______________________________
Signature

____
Typed Name

____
Title

ALPHA LYRACOM PAN AMERICAN SATELLITE
a _______ Corporation

By: ______________________________
Signature

____
Typed Name

____
Title

EXHIBIT A

Statement of Work

CONTENTS

PAN AMERICAN SATELLITE–2
STATEMENT OF WORK

1. SCOPE

This Statement of Work defines the tasks and deliverables required as part of the Pan American Satellite–2 (PAS–2) program. The PAS–2 program shall include the following elements:

1) One complete communications satellite designed in accordance with a satellite specification provided by TRW as part of its proposal and agreed to by both parties, and analytical integration and coordination with Arianespace.
2) Option for orbital support including:
   - Specialized TT&C equipment
   - Documentation in the form of handbooks for the command and control of the satellite, satellite performance, etc.
   - Orbital operations training for the staff of the ground control station
   - Post–launch support during initial operation period (60 days)
   - Time and materials support to mission operations for the lifetime of the satellite after the initial operating period
   - Operations training simulator
   - Assistance to establish a TT&C facility at a location chosen by Alpha Lyracom Pan American Satellite (PAS).
3) Option for the capability for the satellite to accept encrypted commands.
4) Option for launch services including:
   - Contracting for the launch vehicle and launch base support services
   - Launch support in Kourou for the launch, including launch base requirements planning.
   - Shipment (including insurance) of the tested satellite to the launch site at Kourou, French Guiana, together with test gear required for prelaunch checkout and launch support in Kourou for activities prior to, during, and after the launch.

2. DELIVERABLE DOCUMENTATION

Deliverable data and documentation provided by TRW shall be as defined in the Data Requirements List (Figure 1).

DATA ITEM	SCHEDULE	COPIES	APPROVAL
01) Monthly Progress and Status Reports	10 working days after end of calendar month	3	R
02) Management Plan	With proposal	3	R
03) Program Schedule	With proposal, update as required	3	R
04) Spacecraft Test Plan	PDR	5	R
05) Launch Site Test Plan	CDR	3	R
06) Orbital Test Plan	CDR	5	A1
07) Satellite Specification	With proposal	3	A1
08) Launch Site Safety Plan	Initial at First Safety Review, updates at subsequent reviews	5	A2
09) Product Assurance Plan (including PM&P and Reliability)	ATP plus 60 days	3	R
10) Application To Use Ariane	Launch minus 29 months	5	A2
11) Ground Control Station Interface Control Document	CDR	5	A1
12) Manual for Specialized TT&C Equipment*	Launch minus 6 months	3	R
13) Orbital Operations Handbook (including Command and Telemetry Handbook and Orbital Operations Procedures)*	Launch minus 6 months	10	R
14) Orbital Operations Training Materials*	Launch minus 6 months	20	R
15) Spacecraft Parameters Data Base*	Launch minus 3 months	3	R
16) Spacecraft Acceptance Test Data Package	Launch minus 2 months	1	R

NOTES:
All data items to be prepared in TRW format
Data Item approval code:
A1: Alpha Lyracom Pan American Satellite Approval
A2: Arianespace Approval
R: Review by Alpha Lyracom Pan American Satellite

*Denotes documents included in Options

Figure 1. Data Requirements List

3. SATELLITE AND LAUNCH VEHICLE INTEGRATION

3.1 SATELLITE

TRW shall furnish a satellite in accordance with the satellite specification. This satellite shall be manufactured under the terms of the contract between the parties and be available at TRW for shipment to the launch site at Kourou, French Guiana, as required by Arianespace prior to a specified launch date for an Ariane rocket.

3.2 ANALYTICAL INTEGRATION WITH ARIANESPACE

TRW shall be responsible for coordination with Arianespace and for the provision to Arianespace of necessary data for, and all engineering resulting from, the coupled loads and coupled thermal analyses.

4. OPTION FOR ORBITAL SUPPORT

4.1 SPECIALIZED TT&C EQUIPMENT

TRW shall furnish the TT&C equipment necessary to operate the satellite to the buyer. This includes two command encoders and two telemetry demodulating systems. If the Command Security Option in Section 5 has been exercised, command encryption features will be added to the specialized TT&C equipment. No antennas or RF equipment is included. This equipment shall be delivered to a satellite ground control station provided by PAS and installed by the operator of that station with the assistance of TRW. Documentation shall be in accordance with Item 12 of the Data Requirements List.

4.2 ORBITAL OPERATIONS SUPPORT DOCUMENTATION

Documentation shall be in accordance with Items 13 through 15 of the Data Requirements List.

4.3 ORBITAL OPERATIONS TRAINING

TRW shall furnish orbital operations training, including the necessary training materials, to the staff of the satellite ground control station provided by PAS. This training shall commence between launch minus 4 months and the launch of PAS-2 and shall be completed by launch.

4.4 POST-LAUNCH SUPPORT DURING INITIAL OPERATION PERIOD (60 DAYS)

Transfer Orbit Operations Support. TRW shall make arrangements for tracking, telemetry, and command facilities to support transfer orbit operations. TRW shall make arrangements for the communications network that will connect these facilities to the satellite ground control station provided by PAS. During the transfer orbit operations, TRW will have sufficient staff to handle all satellite and orbital-related material. This staff shall be a satellite ground control station provided by PAS.

Post-Launch Activities. TRW shall provide personnel, operational procedures, operational commanding plans, and documentation necessary to support acquisition of satellite telemetry and orbit data, performance of necessary calculations and analysis, and generation of the necessary commands to take the satellite from geosynchronous transfer orbit (GTO) to the specified orbit. Once in the GTO, TRW shall provide the procedures and operational commanding plans and shall support performance of all maneuvers required to make the satellite operational (e.g., solar panel deployment, antenna deployment); control the satellite during drift operations; stop satellite at its required orbital location; and perform all other necessary tests on the satellite. This support shall be furnished at a satellite ground control station provided by PAS.

In-Orbit Acceptance Tests. TRW shall perform, in association with PAS representatives, in-orbit checkout of all satellite bus systems (nonpayload) during drift to final orbit location.

Once on station, TRW shall perform, in association with PAS representatives, in-orbit checkout of all communications systems. All testing shall be in accordance with test procedures prepared and submitted by TRW and approved by PAS. The final communications performance checkout shall take place at the PAS teleport in Homestead, Florida. Any specialized equipment required for such tests will be provided by TRW. All in-orbit acceptance tests shall be completed within a 60-day period from the time of injection into the geostationary drift orbit. PAS will make available an earth station large enough to permit full communications with the satellite.

In-Orbit Operational Support. TRW shall be available to assist in solving any anomalies which occur with the satellite during the 60-day in-orbit acceptance test period.

4.5 MISSION OPERATIONS SUPPORT

Following the 60-day in-orbit acceptance test period, TRW shall be available to assist PAS in solving any anomalies which occur with the satellite. Such services shall be provided to PAS on a time and materials basis.

4.6 OPERATIONS TRAINING SIMULATOR

TRW shall provide a microcomputer-based simulator for training of operator personnel at the satellite ground station provided by PAS.

4.7 TT&C FACILITY ASSISTANCE

TRW shall provide assistance to PAS in establishing a TT&C facility to operate PAS-2 from a ground station at a location chosen by PAS. This assistance shall provide for definition of computational requirements, development or acquisition of software, procurement of computing equipment, command generators, telemetry receivers, and operator consoles.

5. OPTION FOR COMMAND SECURITY

Subject to receipt of approval from the National Security Agency, TRW shall provide the capability for the satellite to accept encrypted commands.

6. OPTION FOR LAUNCH SERVICES

6.1 LAUNCH SUPPORT

Logistics and Shipping. TRW shall provide for the necessary logistics support and shipment (including insurance) to the port of entry for the launch site at Kourou, French Guiana, of the satellite, together with the test gear required for prelaunch checkout.

Satellite Test Equipment. TRW shall provide at the launch site all test equipment necessary to fully assemble and test the satellite prior to launch.

Launch Base Support. TRW shall provide a launch support team to Kourou, French Guiana, to accomplish the tasks required prior to, during, and after the launch.

Launch Operations Rehearsals. TRW will have appropriate personnel at all rehearsals for launch operations held prior to launch at various times and places as designated by Arianespace.

6.2 LAUNCH VEHICLE SUBCONTRACT

TRW shall use its best efforts to contract with Arianespace for the Ariane 44L and associated launch support services. TRW shall be responsible for coordinating all activities involved with the launch directly with Arianespace and for keeping PAS informed of all such activities.

EXHIBIT B

Satellite Performance Specifications

CONTENTS

CONTENTS (Continued)

PAN AMERICAN SATELLITE–2
SATELLITE PERFORMANCE SPECIFICATION

1. SCOPE

This specification sets forth the requirements for the Pan American Satellite–2 (PAS–2) launch, deployment, operation design, development, construction, and verification.

2. APPLICABLE DOCUMENTS

The following documents of the indicated issue form a part of this specification to the extent specified herein. In the event of conflict between the documents referenced herein and the detailed content of this specification, the requirements provided herein shall govern.

CD–016	Electromagnetic Interference and Susceptibility Requirements Document
CD–017	EMC Control Plan
CD–034	PAS–2 Verification Plan
CD–035	Product Assurance Implementation Plan
CD–036	System Environmental Specification
CD–0093	Parts Requirements
CD–0095	Quality Assurance Requirements
RC–CSG–Ed.3(0)	CSG Safety Requirements
TBD	Arianespace Interface Control Document
TBD	PAS–2/Ground Control Station Interface Control Document

3. REQUIREMENTS

3.1 DEFINITION

3.1.1 General Description

The PAS–2 satellite provides communications services in the C– and Ku–bands to commercial users. Launched to a transfer orbit as a companion payload on Ariane 4 launch vehicle, PAS–2 achieves its final orbital position in the equatorial plane at geostationary altitude, 43° west longitude, with the use of its own (integral) propulsion system.

The three–axis stabilized PAS–2 consists of the communications payload and the spacecraft. The spacecraft provides power and pointing capability to the payload, as well as the resources and capabilities required to maintain the satellite operational for 12 years.

PAS–2 is controlled by the ground station; the spacecraft provides for communications with the ground in the C–band. The spacecraft receives and executes ground commands and transmits satellite status data.

The PAS-2 design consists of a basic structure, panel-mounted payload and spacecraft equipment, a propulsion module and deployable solar array panels, and communications antennas. The PAS-2 architecture is annotated in Figure 1.

3.1.2 Operational Concept

PAS-2 shall be launched as a companion payload on an Ariane 4 from Kourou, French Guiana. During ascent to a geosynchronous transfer orbit (GTO), the spacecraft shall have the capability to provide power to satellite equipment, as may be required.

After separation from Ariane, PAS-2 shall perform all operations necessary to achieve its final orbital position under ground control. GTO operations shall include satellite stabilization, establishment of the command and telemetry communications link, deployment of the solar array, and powered flight maneuvers utilizing the onboard liquid apogee engine (LAE).

PAS-2 shall achieve its orbital position in the equatorial plane at geostationary altitude, 43° west longitude. On-station operations shall include deployment of the payload antenna(s), satellite testing, and initiation of service. Periodic orbit maintenance maneuvers shall be performed, as required, during the entire PAS-2 service life with no interruption of communications services to the commercial users.

At the end of its service life, PAS-2 shall provide the propulsive capability for an end-of-life (EOL) disposal maneuver.

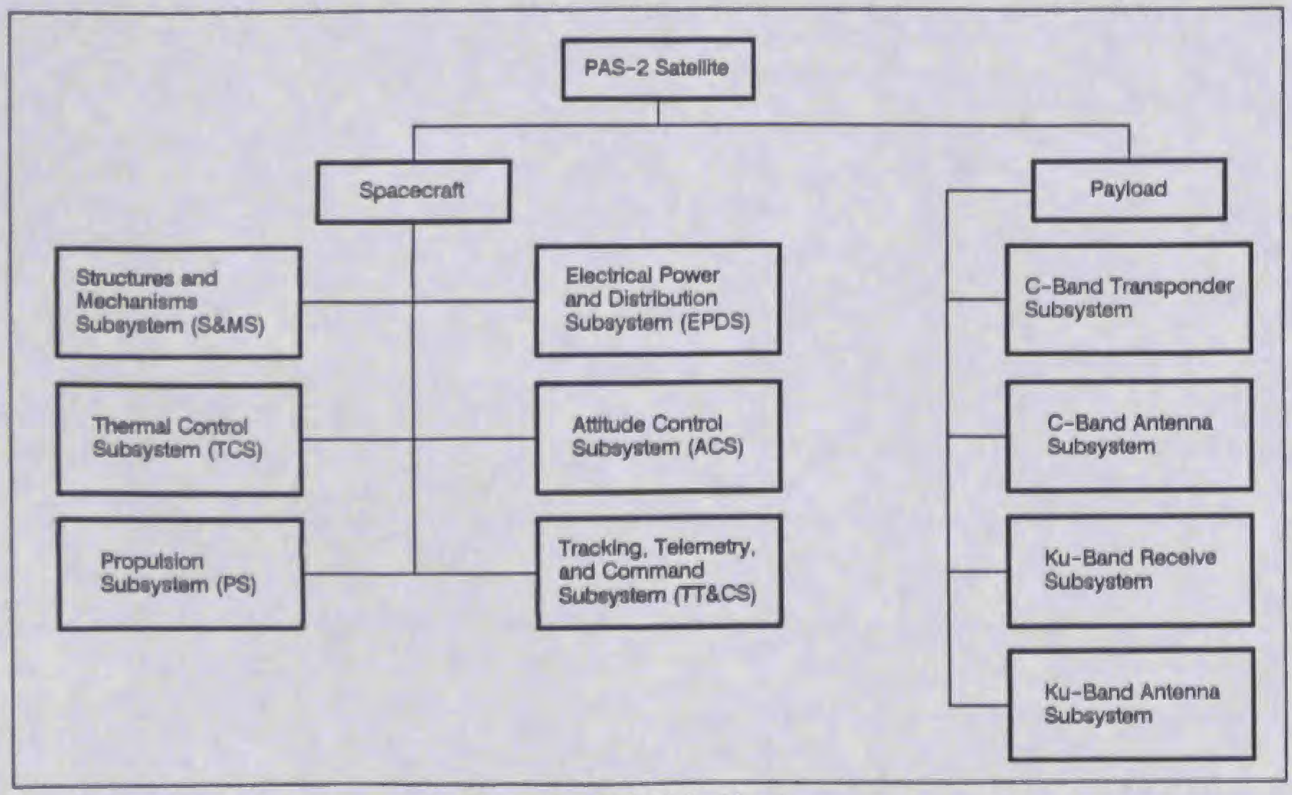


Figure 1. PAS-2 Architecture

3.1.2.1 Satellite Control

GTO and on-station satellite operation shall be under the control of the ground station(s); capability for autonomous operation shall be provided only in accordance with paragraphs 3.1.3.1 and 3.1.3.7.

PAS-2 shall allow the ground station to override

(a) Any on-going on-board operation

(b) The execution of any onboard stored command or sequence of commands.

3.1.2.1.1 Stationkeeping

The satellite shall facilitate north/south and east/west stationkeeping maneuvers to an accuracy of ± 0.1 degree under ground control.

3.1.2.2 Operational Constraints

Solar array deployment and LAE firings shall occur only when PAS-2 is in view of the ground station(s).

3.1.2.3 Eclipse Operation

PAS-2 shall provide the capability for full eclipse operation.

3.1.3 Satellite Operational Modes

In support of the operational concept of paragraph 3.1.2, the satellite shall be capable of operating in the following mutually exclusive modes:

(a) Prelaunch

(b) Launch

(c) Transfer

(d) On-orbit test

(e) Service

(f) Safe hold

(g) End-of-life disposal.

3.1.3.1 Mode-to-Mode Transitions

The satellite shall be capable of transitioning between modes by:

(a) Hardline command prior to launch

(b) Ground command during GTO and on-station operations

(c) Autonomously from launch to transfer mode based on separation from the launch vehicle

(d) Autonomously into safehold.

The satellite shall provide the capability for autonomous transition from the transfer or service modes to the safe hold mode under the following conditions:

(a) Loss of attitude reference

(b) Loss of time-critical command and telemetry.

The satellite shall be capable of inhibiting such autonomous transitions if so commanded by the ground station.

3.1.3.2 Prelaunch Mode

In the prelaunch mode, the satellite shall provide the capability required to support prelaunch checkout. In this mode, satellite equipment shall be active and thrusters inhibited. Prelaunch mode functions shall include:

(a) Support spacecraft subsystem and payload initialization, checkout and shutdown
(b) Implement automatic checkout procedures stored in and executed by the onboard computer (OBC), as well as real-time commands from the electrical ground support equipment
(c) Provide for commanded switchover from external to internal power, or from internal to external power
(d) Accept commands and transmit telemetry via hardline communications.

3.1.3.3 Launch Mode

The launch mode is defined in the period between lift-off (t = O) and separation from the launch vehicle. In this mode, the satellite shall have the capability to provide power to selected equipment.

3.1.3.4 Transfer Mode

In this mode, the satellite shall be capable of supporting transfer orbit operations. The transfer mode functions shall include:

(a) Accept launch vehicle separation signal and initialize onboard clock
(b) Execute spacecraft subsystem initialization procedures stored in the OBC
(c) Stabilize satellite and maintain attitude
(d) Execute real-time ground commands and transmit satellite status data to the ground station
(e) Support appendage deployment (under ground control)
(f) Support LAE firings (under ground control)
(g) Provide the capability for transitioning to the safe hold mode in accordance with paragraph 3.1.3.1
(h) Support final low-thrust maneuvers to achieve orbital position.

3.1.3.5 On-Orbit Test Mode

In this mode, the satellite shall provide the capability to support on-station testing of the spacecraft and payload subsystems. Test mode functions shall include:

(a) Support payload initialization
(b) Maintain attitude and solar array sun pointing
(c) Provide power to onboard users
(d) Execute stored and commanded test procedures
(e) Transmit test data to the ground station.

On-orbit testing shall apply to primary satellite equipment; redundant equipment which is normally off need not be tested.

3.1.3.6 Service Mode

This is the primary mode of satellite on-station operation, whereby communications services are provided to commercial users.

Service mode functions shall include:

(a) Provide communications services to the required quality

(b) Maintain antenna and solar array pointing

(c) Support stationkeeping maneuvers under ground control

(d) Execute stored and real-time commands

(e) Transmit satellite status data to the ground station

(f) Provide the capability for transitioning to the safe hold mode in accordance with paragraph 3.1.3.1.

3.1.3.7 Safe Hold Mode

In the safe hold mode, the satellite shall be placed autonomously in a configuration of minimum power utilization in accordance with a stored sequence of commands. Payload equipment shall be turned off and sun-pointing attitude shall be maintained. The satellite shall exit from this mode only upon ground command.

3.1.3.8 End-of-Life Disposal Mode

In this mode, all spacecraft subsystems shall be active, and payload equipment shall be off. The spacecraft shall provide the communications and propulsive capabilities required to support end-of-life disposal of the satellite.

3.1.4 Coordinate System

The coordinate system fixed to the satellite shall be defined as follows:

(a) The origin shall be the center of the satellite-launch vehicle separation plane.

(b) The +X-axis shall be in the direction of the C-band receive antenna.

(c) The +Z-axis shall be perpendicular to the separation plane, toward the Ku-band antenna.

(d) The +Y-axis completes the right-handed system.

Rotations about the X,Y,Z axes define roll, pitch, and yaw, respectively.

3.2 CHARACTERISTICS

3.2.1 Performance Characteristics

3.2.1.1 Satellite Design Life

The satellite shall be designed for 12-year on-orbit service.

3.2.1.2 Electromagnetic Compatibility

The satellite shall comply with the electromagnetic compatibility requirements of CD–016 and CD–017.

3.2.1.3 Communications Services

The PAS–2 shall relay signals from Latin America, Eastern United States, and Western Europe to regions of South America, Central America, and Eastern United States. The payload shall transmit to ground terminals at C–band and shall receive signals from ground terminals at both C–band an Ku–band.

3.2.1.3.1 Service Area Coverage

Transmit/receive services shall comply with the beam assignments and area coverage requirements of Table 1.

3.2.1.3.2 Transponder Assignments

3.2.1.3.2.1 C–Band

Full frequency reuse at C–band by means of 15 active transponders shall be provided. Transponder assignments/characteristics and redundancy shall comply with Table 2.

Table 1. Beam Assignments and Service Area Coverage

SERVICE	BEAM	FREQUENCY RANGE (GHz)	SERVICE AREA
Transmit (C–band)	North (spot)	3.7 – 4.2	Ecuador, Peru, Venezuela, Colombia, Central America, Caribbean
	South (spot)	3.7 – 4.2	Bolivia, Uruguay, Paraguay, Chile, Argentina
	Latin	3.7 – 4.2	Latin America (Continental Land Mass), U.S. East Coast
Receive (C–band)	Latin and spot	5.925 – 6.425	Same as for Latin transmit beam
Receive (Ku–band)	European	14.0 – 14.5	Western Europe (Spain, Italy, Southern Europe, United Kingdom)
	Latin	14.0 – 14.5	Same as for Latin transmit beam

Table 2. Transponder Assignments

BEAM	NUMBER OF TRANSPONDERS		BANDWIDTH (MHz)	RF OUTPUT POWER (WATTS)
	ACTIVE	REDUNDANT		
North	3	1	36	10 (each)
South	3		36	10 (each)
Latin	6	1		20 (each)
	3	1	72	

3.2.1.3.2.2 Ku-Band

The Ku-band receivers shall provide for simultaneous receiving of signals from Western Europe, Latin America, and the U.S. East Coast. The Ku-band signals shall be switchable into the C-band downlink Latin beam (Table 1).

3.2.1.3.3 Receive Performance

The gain to noise temperature (G/T) performance shall be:

(a) C-band	Latin beam:	-6.0 dB/°K
(b) Ku-band	European beam:	0.9 dB/°K
	Latin beam:	-6.5 dB/°K

3.2.1.3.4 Transmit Performance

PAS-2 shall provide the following minimum EIRP levels over the service areas of Table 1:

North beam:	33.0 dBW
South beam:	33.1 dBW
Latin beam:	32.4 dBW

3.2.1.3.5 Polarization Isolation

Polarization isolation greater than, or equal to, 30 dB shall be provided.

3.2.1.4 Command and Telemetry Link Performance

Command and telemetry shall utilize C-band to provide for PAS-2 ranging, control, and monitoring.

3.2.1.4.1 Command Link Frequency and Data Rate

The link frequency and data bit rate shall be 6.18 GHz and 1 kbps, respectively.

3.2.1.4.2 False Commands

The probability of false command acceptance shall be less than, or equal to, 10^{-9} without command authentication.

3.2.1.4.3 Telemetry Link Frequency and Data Rate

The link frequency and data bit rate shall be 3.955 GHz and 1 kbps, respectively.

3.2.1.4.4 Transmit EIRP

The telemetry EIRP level shall be at least -5 dBW, corresponding to an antenna coverage area of ±100 degrees during transfer mode operation.

3.2.1.4.5 Tracking

Capability shall be provided for the reception and turnaround of a ground-generated tracking signal with a delay variation less than, or equal to, 50 ns.

3.2.2 Physical Characteristics

3.2.2.1 Weight Limit

The satellite launch weight, excluding the PAS-2/Ariane adapter, shall not exceed 2,083 pounds (945 kg).

3.2.2.2 Volume

In the stowed configuration, the satellite shall conform to the mini–SPELDA dynamic envelope constraints as defined in Arianespace Interface Control Document TBD.

3.2.3 Reliability

The satellite shall be one–fault tolerant to credible failures. To the extent practicable, satellite design shall be such that a failure in one component shall not propagate to other subsystems and components.

3.2.3.1 Reliability Assessment

Reliability assessments in support of satellite subsystem implementation trades shall result in a predicted satellite mean service mode duration of at least 9.0 years.

3.2.3.2 Fault Management

In the event of onboard failure, failure detection, isolation, and corrective action shall be a ground station function. Autonomous (onboard) fault management shall be implemented to the extent specified in paragraph 3.1.3.1.

3.2.3.3 Redundancy

Redundancy shall be utilized in the design of PAS–2 to ensure compliance with reliability requirements. Transponder redundancy shall comply with paragraph 3.2.1.3.2.1; antenna release and deployment mechanisms shall incorporate redundant devices. Capability for test verification of electronic component redundancy shall be provided.

3.2.4 Maintainability

3.2.4.1 Test Points

Where practicable, the design shall incorporate test and telemetry points to allow verification of performance and shall accommodate easy installation and replacement of major assemblies during factory assembly and at the launch site.

3.2.4.2 Access

Access shall be provided to those test plugs, harness break–in points, external umbilical connections, safe and arm devices, pressurant and propellant fill and drain valves, and other devices required for maintenance, alignment, and servicing. Alignment references for critically aligned components shall be visible directly or through windows.

3.2.5 Safety

The satellite shall be fully compliant with Arianespace launch site safety requirements of RS–CSG–Ed.3(0). PAS–2 safety shall be assessed during scheduled safety reviews and on the basis of documentation according to the requirements of Arianespace.

3.2.6 Transportability

The satellite and its components shall be designed for both ground and air transportability using available carriers.

The satellite and its components shall be capable of being transported and handled in both the vertical and horizontal attitude. Attach points for transportation and handling shall be provided. Cleanliness shall be maintained during transportation using appropriate protective containers or covers. The modes of transportation or other provisions shall be chosen to assure that transportation and handling do not impose thermal, vibration, acoustic, or shock environmental conditions to excess of those specified in CD-036.

3.2.7 Environments

The satellite shall meet the requirements of this specification during and/or following exposure to the environmental conditions specified in CD-036.

3.3 DESIGN AND CONSTRUCTION

Parts, materials, and processes shall be selected and controlled in accordance with contractor-established and documented procedures to satisfy the specified requirements. The selection and control procedures shall emphasize quality and reliability to meet the mission requirements and to minimize total life cycle cost. The parts, materials, and processes selected shall be of sufficient proven quality to allow the equipment to meet the performance, reliability, and strength requirements of this specification, including all environmental degradation effects.

3.3.1 Identification and Marking

Satellite equipment shall comply with the identification requirements provided in CD-035.

3.3.2 Parts Derating

Parts shall be derated in accordance with CD-0093.

3.4 PERSONNEL AND TRAINING

Training and training materials shall be provided for the PAS-2 customer personnel to perform planned satellite normal and contingency operations.

3.5 SATELLITE EXTERNAL INTERFACE REQUIREMENTS

The satellite to Ariane 4 structural interface shall comply with the Arianespace Interface Control Document (ICD) TBD.

The satellite to ground station communications interface shall comply with the protocol and format requirements of the PAS-2/Ground Control Station Interface Control Document TBD.

4. QUALITY ASSURANCE PROVISIONS

4.1 QUALITY ASSURANCE

The quality assurance controls for fabrication, inspection, and testing of the integrated satellite and its equipment shall be in accordance with the requirements of CD-0095.

4.2 VERIFICATION

Verification of PAS-2 performance, at all levels of assembly and phases of the program, shall be in accordance with CD-034.

4.2.1 Verification Methods

The PAS-2 verification program shall rely primarily on test to substantiate performance in accordance with the requirements of this and lower-level specifications. Analysis and/or simulation shall be used in lieu of testing only when testing in the 1-g environment is either not feasible or too costly and when there is sufficient confidence in approved analytical verification methods.

4.2.1.1 Verification by Test

Verification by test shall require measurement of performance parameters relative to functional, electrical, mechanical, and environmental requirements imposed on the article under test.

In general, the PAS-2 test program shall adopt the "protoflight concept" at both the component (box) level and the integrated satellite level. Accordingly, test levels and durations shall be so adjusted as to both qualify the equipment under test and preserve its flight worthiness.

4.2.1.1.1 Structure Qualification Test

In order to reduce the structure design safety factors and, therefore, satellite weight, a prototype of the primary structure (central cylinder) shall undergo qualification testing to verify structural integrity to static and dynamic loading. The primary structure shall be tested to 1.25 times limit loads.

4.2.1.1.2 Performance and Functional Tests

Performance testing shall consist of an individual or a series of tests at conditions appropriate to the article under test which addresses the stated performance requirements of the pertinent specifications.

Functional testing shall consist of a suitably abbreviated series of performance tests.

4.2.1.1.3 Environmental Tests

Environmental testing shall consist of an individual or a series of tests under flight environmental conditions, such as thermal, acoustic, and vacuum.

4.2.1.1.4 Satellite Tests

The integrated satellite shall undergo performance/functional and environmental testing to ensure compliance with the requirements of this specification (which are verifiable by test).

A "tape transfer" end-to-end test shall also be performed to verify satellite/ground station interface compatibility prior to shipment of the satellite to the launch site.

4.2.1.1.5 On-Orbit Tests

Prior to initiation of service, the satellite shall undergo performance testing under ground station control. The on-orbit test shall validate performance previously verified by testing during satellite integration and test, as well as verify (to the extent possible) requirements which could not be verified by test in the 1–g environment.

4.2.1.2 Verification by Analysis

This method of satellite requirements verification shall employ one or a combination of the following types of analyses, as appropriate:

(a) Quantitative analyses based on closed form, digital computer, or analog circuit representation of the satellite (e.g., satellite thermal and dynamic models)

(b) Qualitative analysis relative to specific attributes (such as maintainability, failure modes and effects analysis, safety, accessibility) which permeate the design as a qualitative measure of performance.

4.2.1.3 Verification by Simulation

Simulations, as a means of performance verification, shall be primarily applicable to PAS–2 flight operations (e.g., orbit maintenance) with the use of computer modeling.

4.2.1.4 Verification by Inspection

This verification method shall apply physical measurement, examination, or comparison of the satellite with the pertinent design drawing(s) and/or schematic(s).

4.2.1.5 Verification by Validation of Records

Validation of records shall consist of examination/assessment of manufacturing records at end–item acceptance to verify manufacturing processes and construction features of satellite hardware.

When applied to software, this verification method shall consist of examination of appropriate software code and documentation.

4.2.2 Verification Management

Management of the satellite verification process (including failure/retest management during satellite testing) shall be in accordance with the procedures/controls defined in CD–034.

4.2.3 Relationship to Management Reviews

Development testing (if any) shall be reviewed at the Preliminary Design Review (PDR) and the Critical Design Review (CDR).

Satisfactory completion of all satellite testing and related verification activities shall be a prerequisite of the Flight Readiness Review (FRR).

4.2.4 Verification Traceability

The verification of each requirement of this specification shall be traceable to ensure that satellite performance has been fully verified. A correlation matrix between the requirements of this specification and of CD–034 shall be constructed to support traceability. Verification documentation (test reports, verification analyses, and simulations) shall be "keyed" to this matrix.

EXHIBIT C

Master Schedule

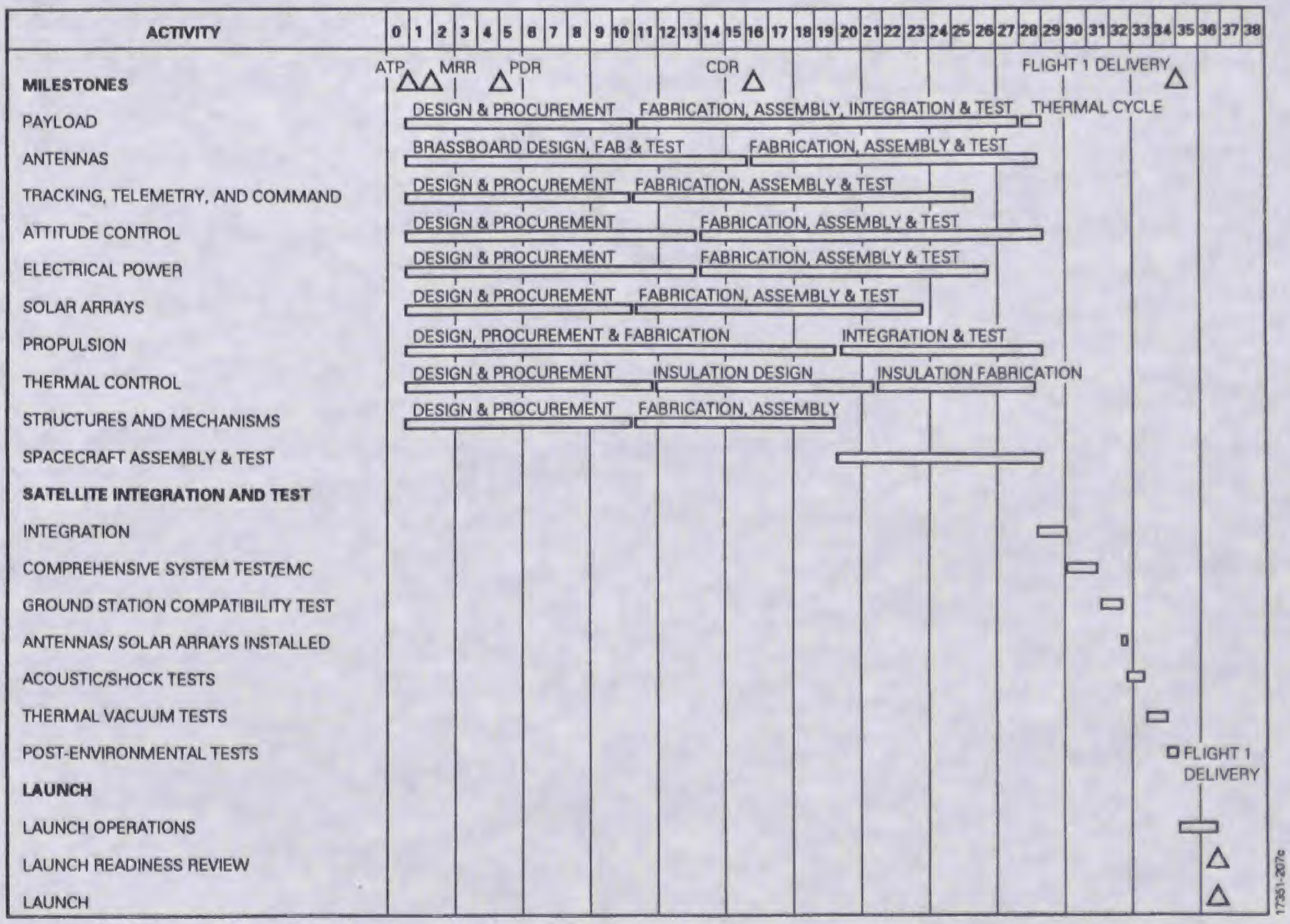

ACTIVITY
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38
MILESTONES
ATP
MRR
PDR
CDR
FLIGHT 1 DELIVERY
PAYLOAD
DESIGN & PROCUREMENT
FABRICATION, ASSEMBLY, INTEGRATION & TEST
THERMAL CYCLE
ANTENNAS
BRASSBOARD DESIGN, FAB & TEST
FABRICATION, ASSEMBLY & TEST
TRACKING, TELEMETRY, AND COMMAND
DESIGN & PROCUREMENT
FABRICATION, ASSEMBLY & TEST
ATTITUDE CONTROL
DESIGN & PROCUREMENT
FABRICATION, ASSEMBLY & TEST
ELECTRICAL POWER
DESIGN & PROCUREMENT
FABRICATION, ASSEMBLY & TEST
SOLAR ARRAYS
DESIGN & PROCUREMENT
FABRICATION, ASSEMBLY & TEST
PROPULSION
DESIGN, PROCUREMENT & FABRICATION
INTEGRATION & TEST
THERMAL CONTROL
DESIGN & PROCUREMENT
INSULATION DESIGN
INSULATION FABRICATION
STRUCTURES AND MECHANISMS
DESIGN & PROCUREMENT
FABRICATION, ASSEMBLY
SPACECRAFT ASSEMBLY & TEST
SATELLITE INTEGRATION AND TEST
INTEGRATION
COMPREHENSIVE SYSTEM TEST/EMC
GROUND STATION COMPATIBILITY TEST
ANTENNAS/ SOLAR ARRAYS INSTALLED
ACOUSTIC/SHOCK TESTS
THERMAL VACUUM TESTS
POST-ENVIRONMENTAL TESTS
FLIGHT 1 DELIVERY
LAUNCH
LAUNCH OPERATIONS
LAUNCH READINESS REVIEW
LAUNCH
17361-207c

EXHIBIT D

Prices
(In Volume II - Cost)

EXHIBIT E

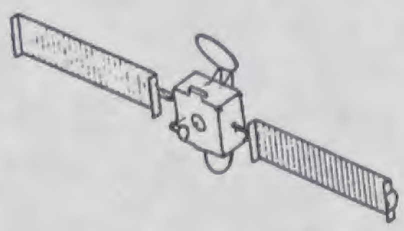
Payment Plan
(In Volume II - Cost)

Proposal for

Pan American Satellite-2

TRW

Volume II – Cost



Prepared for
Alpha Lyracom
Pan American Satellite
One Pickwick Plaza
Greenwich, CT 06830

In Response to
Letter of June 22, 1990

September, 1990

Prepared by
TRW Space & Technology Group
Engineering & Test Division
One Space Park
Redondo Beach, CA 90278

CONTENTS

Cost Volume

1.0 Introduction

This cost volume contains pricing information in support of the TRW proposal to furnish a communication satellite and associated documentation and services. The volume is structured as follows:

Baseline Price

Options Pricing Schedule

Payment Plan

The TRW offer provides low total cost to Alpha Lyracom Pan American Satellite. To demonstrate the TRW commitment to the commercial communications satellite business, our firm fixed price for the baseline program and the launch vehicle subcontract option represents TRW's cost without fee or profit. TRW has also built in flexibility by offering technical options to allow tailoring of program funding.

The payment plan and option pricing are provided as a basis for contractual discussion. They will be finalized after agreement is reached on the basic program and the selected options.

2.0 Baseline Price

SOW 3.0 Satellite and Launch Vehicle Integration: $66,700,000

3.0 Options Pricing Schedule

SOW 4.1 Specialized TT&C Equipment: $549,000

SOW 4.2 Orbital Operations Documentation: $468,000

SOW 4.3 Orbital Operations Training: $221,000

SOW 4.4 Post Launch Support During Initial Operating Period: $981,000

SOW 4.5 Mission Operations Support: $150.00 per hour plus expenses

SOW 4.6 Operations Training Simulator: $237,000

SOW 4.7 TT&C Facility Assistance: $349,000

SOW 5.0 Command Security: $473,000

SOW 6.1 Launch Support: $1,231,000

SOW 6.2 Launch Vehicle Subcontract: $26,100,000 (based on exhange rates as of August 1990)

4.0 Payment Plan

SOW 3.0 Baseline Program Payment Plan

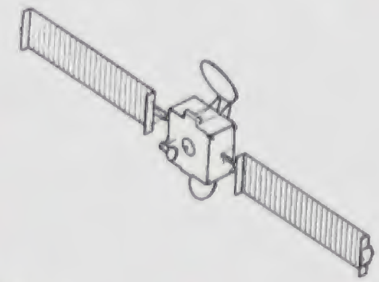
Year	Month	Amount	Cumulative Amount
1990	Nov	288,196	$288,196
	Dec	812,815	1,101,011
1991	Jan	1,264,245	2,365,256
	Feb	1,648,248	4,013,504
	Mar	1,970,331	5,983,835
	Apr	2,235,755	8,219,590
	May	2,449,523	10,669,113
	Jun	3,116,393	13,785,506
	Jul	3,240,870	17,026,376
	Aug	3,327,205	20,353,581
	Sep	3,379,403	23,732,984
	Oct	3,401,211	27,134,195
	Nov	3,396,133	30,530,328
	Dec	3,367,414	33,897,742
1992	Jan	3,318,053	37,215,795
	Feb	3,250,797	40,466,592
	Mar	3,168,140	43,634,732
	Apr	3,072,324	46,707,056
	May	2,765,346	49,472,402
	Jun	2,348,944	51,821,346
	Jul	2,224,608	54,045,954
	Aug	1,593,580	55,639,534
	Sep	1,456,846	57,096,380
	Oct	1,315,142	58,411,522
	Nov	1,168,956	59,580,478
	Dec	1,018,520	60,598,998
1993	Jan	762,625	61,361,623
	Feb	762,625	62,124,248
	Mar	762,625	62,886,874
	Apr	762,625	63,649,499
	May	762,625	64,412,124
	Jun	762,625	65,174,749
	Jul	762,626	65,937,375
	Aug	762,625	66,700,000

TRW

Proposal for

Pan American Satellite-2

Volume III – Technical/Management Proposal



Prepared for
Alpha Lyracom
Pan American Satellite
One Pickwick Plaza
Greenwich, CT 06830

In Response to
Letter of June 22, 1990

September, 1990

Prepared by
TRW Space & Technology Group
Engineering & Test Division
One Space Park
Redondo Beach, CA 90278

Proposal for

Pan American Satellite-2

TRW

Volume III – Technical/Management Proposal

Prepared for
Alpha Lyracom
Pan American Satellite
One Pickwick Plaza
Greenwich, CT 06830

In Response to
Letter of June 22, 1990

September, 1990

Prepared by
TRW Space & Technology Group
Engineering & Test Division
One Space Park
Redondo Beach, CA 90278

CONTENTS

CONTENTS (Continued)

1. MISSION AND SYSTEM

The Pan American Satellite–2 (PAS–2) provides communication services to commercial users in the C– and Ku–bands. Launched to a geosynchronous transfer orbit (GTO), the satellite achieves its final orbital position in the equatorial plane at geostationary altitude, 43° west longitude, with the use of its own (integral) propulsion system. This volume describes our satellite and our management plan.

The PAS–2 satellite is comprised of the payload plus the spacecraft. Figure 1–1 gives satellite architecture and principal subsystem functions.

1.1 MISSION ANALYSIS/REQUIREMENTS SUMMARY

The communications payload relays signals from Latin America, the Eastern United States, and Western Europe to regions of South America, Central America, and the Eastern United States. The payload transmits to ground terminals at C–band and receives signals from ground terminals at both C–band and Ku–band. Figure 1.1–1 summarizes transmit and receive services.

Fifteen active transponders in the payload ensure full frequency reuse at C–band. Figure 1.1–2 summarizes transponder assignments, characteristics, and redundancy. The Ku–band receivers accept simultaneous signals from both Western Europe, Latin America and the U.S. East Coast. A variety of combinations is available for the transponders on each beam. For example, three uplink Latin beam C–band transponders can be used simultaneously with two European and one Ku–band Latin beam transponder. Possible transponder combinations are shown in Figure 2.1–2 of Section 2.

Figure 1.1–3 lists the payload performance requirements at edge of coverage (EOC). Our design provides a 2–dB performance margin above these EOC requirements. Figure 1.1–4 summarizes satellite requirements. These requirements form the basis for appropriate requirements allocations to the satellite subsystems. Section 3 discusses subsystem capabilities versus requirements.

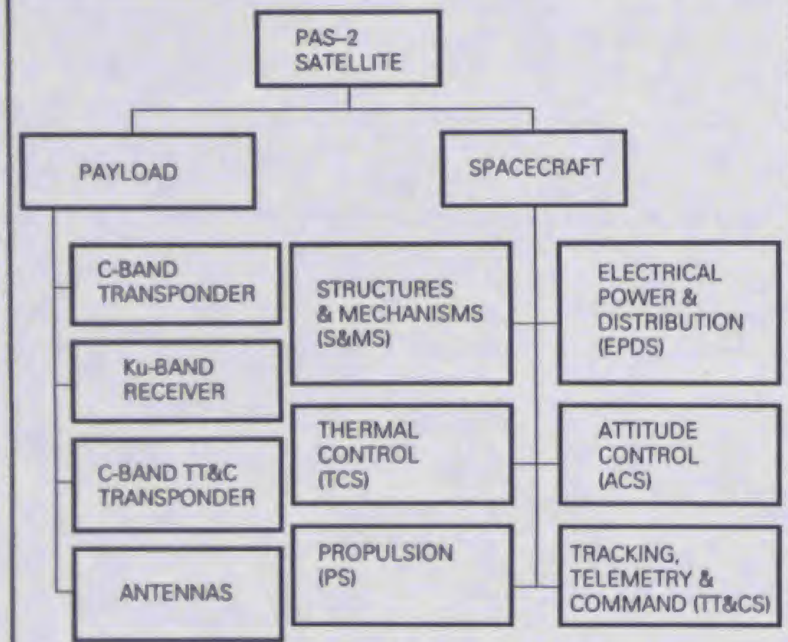
The TRW design is fully compliant with performance requirements to support the PAS–2 twelve–year design life.

1.2 SYSTEM SUMMARY

PAS–2 is a geosynchronous communications satellite for transmitting telephone, data, and television signals. Figures 1.2–1 through 1.2–4 show the satellite and its principal features. Three major factors drive the system design:

- Payload equipment that meets the desired performance parameters
- Robust spacecraft subsystems that support the payload equipment
- Selection of the Ariane 4 as the launch vehicle.

PAS–2 will be a secondary payload on the Ariane, a launch vehicle designed to accommodate multiple payloads. To provide the desired communications services at an economical



SUBSYSTEM	FUNCTION
S&MS	• PROVIDE FOR MOUNTING/HOUSING OF SATELLITE EQUIPMENT • PROVIDE FOR INTERFACING WITH ARIANE 4
TC	• ENSURE EQUIPMENT TEMPERATURES ARE WITHIN ACCEPTABLE LIMITS
PS	• PROVIDE CAPABILITY FOR ORBIT INSERTION AND MAINTENANCE
EPDS	• GENERATE, STORE, DISTRIBUTE ELECTRICAL POWER TO SATELLITE USERS
ACS	• ACHIEVE/MAINTAIN SATELLITE ATTITUDE AND PAYLOAD ANTENNA POINTING
TT&CS	• RECEIVE/EXECUTE GROUND COMMANDS • COLLECT, FORMAT, TRANSMIT SATELLITE STATUS DATA TO GROUND STATION(S)

Figure 1-1. PAS-2 Architecture

cost, we have based the PAS-2 system design on demonstrated technologies.

Configuration

Figure 1.2-1 is an isometric view of the deployed satellite in geosynchronous equatorial orbit (GEO). A complement of C-band and Ku-band communications payload antennas dominate the configuration. Section 2 of this volume gives details of their beam patterns. Each is boresighted to optimize coverage patterns across Europe and the Americas.

SERVICE	BEAM	FREQUENCY RANGE (GHz)	SERVICE AREA
TRANSMIT	NORTH (SPOT)	3.7-4.2	ECUADOR, PERU, VENEZUELA, COLOMBIA, CENTRAL AMERICA, CARIBBEAN
(C-BAND)	SOUTH (SPOT)	3.7-4.2	BOLIVIA, URUGUAY, PARAGUAY, CHILE, ARGENTINA
	LATIN	3.7-4.2	LATIN AMERICA, US EAST COAST
RECEIVE (C-BAND)	SPOT/LATIN COMBINED	5.925-6.425	SAME AS FOR LATIN TRANSMIT BEAM
RECEIVE	EUROPEAN	14.0-14.5	WESTERN EUROPE
(KU-BAND)	LATIN	14.0-14.5	SAME AS FOR LATIN TRANSMIT BEAM

Figure 1.1-1. Beam Assignments and Service Area Coverage

There are six spacecraft subsystems. The tracking, telemetry and command subsystem (TT&CS) processes commands and status data throughout the satellite and is used for ground control. The attitude control subsystem (ACS) provides transfer orbit orientation and maintains required antenna pointing during normal mission operation.

BEAM	NUMBER OF TRANSPONDERS		BANDWIDTH (MHz)	RF OUTPUT POWER (WATTS)
	ACTIVE	REDUNDANT		
NORTH	3	1	36	10 (EACH)
SOUTH	3		36	10 (EACH)
LATIN	6	1	72	20 (EACH)
	3	1		

17351-115d

Figure 1.1-2. C-Band Transponder Assignment

BEAM	RECEIVE G/T (dB/°K)	TRANSMIT EIRP (dBW)
C-BAND	-6.2	33.0 (NORTH SPOT) 33.1 (SOUTH SPOT) 32.4 (LATIN)
Ku-BAND		
EUROPEAN	0.9	N/A
LATIN	-6.5	N/A

17351116d

Figure 1.1-3. Payload Performance Requirements

Two solar array wings generate up to 1207 watts of power and a 65-Ah battery stores power for full eclipse communications service in the electrical power and distribution subsystem (EPDS). The propulsion subsystem (PS) has two components: a liquid apogee motor to attain the final GEO from the transfer orbit into which the launch vehicle places the satellite, and a set of 16 thrusters to provide impulse for attitude control during transfer orbit burns, orbit adjustment and maintenance, and momentum wheel unloading. The thermal control subsystem (TCS) and structure and mechanisms (S&MS) subsystems ensure all components of the PAS-2 remain within defined operational limits after the stresses of launch. They also maintain required pointing and alignments.

Figure 1.2-2, a nadir view of PAS-2, gives the overall dimensions of the satellite (approximately 18 by 53 feet) and shows the main C-band reflectors (each dual gridded), the solar array, and the nadir-mounted C-band and Ku-band antennas.

Figures 1.2-3 and 1.2-4 show the stowed satellite. The dimensions of the Mini-SPELDA, the shroud for Ariane's secondary payloads in this weight class, govern its arrangement.

For ease of integration, the satellite features a central cylinder and horizontal platform assembly that includes the Ariane interface. The primary structural element of the satellite, the platform assembly, supports the majority of the propulsion subsystem components. Its north and south facing panels accommodate the payload and spacecraft subsystem

REQUIREMENT	PARAMETER VALUE
SERVICE LIFE	12 YEARS
LAUNCH WEIGHT	2083 lb
MINIMUM FIRST MODE FREQUENCY (STOWED CONFIGURATION)	LATERAL: 10 Hz AXIAL: 31 Hz
DESIGN FACTORS OF SAFETY	YIELD: 1.375 ULTIMATE: 1.563 FITTING FACTOR FOR JOINTS: 1.15
ORBIT INSERTION	
• MINIMUM THRUST	97 lbf
• MINIMUM TOTAL IMPULSE	2.54×10^{5} lbf-sec
• TRANSFER ORBIT ATTITUDE ERROR DURING FIRING	± 0.3 DEG
ORBIT MAINTENANCE	
• ATTITUDE DETERMINATION ERROR (1-SIGMA)	ROLL: ± 0.1 DEG PITCH: ± 0.1 DEG YAW: ± 0.15 DEG
• POSITION KNOWLEDGE ERROR,1-SIGMA (GROUND STATION FUNCTION)	RANGE: ± 40 METERS LONGITUDE: ± 0.01 DEG LATITUDE: ± 0.01 DEG
• STATIONKEEPING ERROR, 1-SIGMA (GROUND STATION FUNCTION)	NORTH/SOUTH: ± 0.1 DEG EAST/WEST: ± 0.1 DEG

REQUIREMENT	PARAMETER VALUE
• MINIMUM THRUST	EAST/WEST STATIONKEEPING: 0.1 lbf NORTH/SOUTH STATIONKEEPING: 2.5 lbf
• MINIMUM TOTAL IMPULSE	EAST/WEST STATIONKEEPING: 2,043 lbf-sec NORTH/SOUTH STATIONKEEPING: 52,400 lbf-sec
• MINIMUM IMPULSE BIT	0.020 +0/–0.008 lbf-sec
ON-STATION POINTING ERROR, 1-SIGMA	ROLL: ± 0.2 DEG PITCH: ± 0.2 DEG YAW: ± 0.6 DEG
COMMAND LINK	
• FREQUENCY	6.180 GHz
• DATA BIT RATE	1 kbps
• PROBABILITY OF FALSE COMMAND ACCEPTANCE	$\leq 10^{-9}$
TELEMETRY LINK	
• FREQUENCY	3.955 GHz
• DATA BIT RATE	1 kbps
• EIRP, GTO	-6.7 dBw
• EIRP, ON-STATION	8 dBw
ELECTRICAL POWER	
• SOLAR ARRAY OUTPUT	≥ 1156 W (EQUINOX)
• STORED ENERGY	≥ 1497 Whr

17351 117d

Figure 1.1-4. Satellite Requirements Summary

components. Secondary elements support the nadir–mounted and omni antennas, attitude control sensors, and east and west closeout panels.

System Schematic

Figure 1.2–5 shows the principal features of the PAS–2 C–band and Ku–band communications payload and the supporting subsystems that constitute the spacecraft, the key electrical interfaces, and functional implementation of the major RF, data, control, and power line interfaces. Of note are the interfaces of the Ku–band receivers with the C–band rebroadcast transmitters, the C–band TT&C transponders with the TT&CS, and the control, data, and valve ordnance

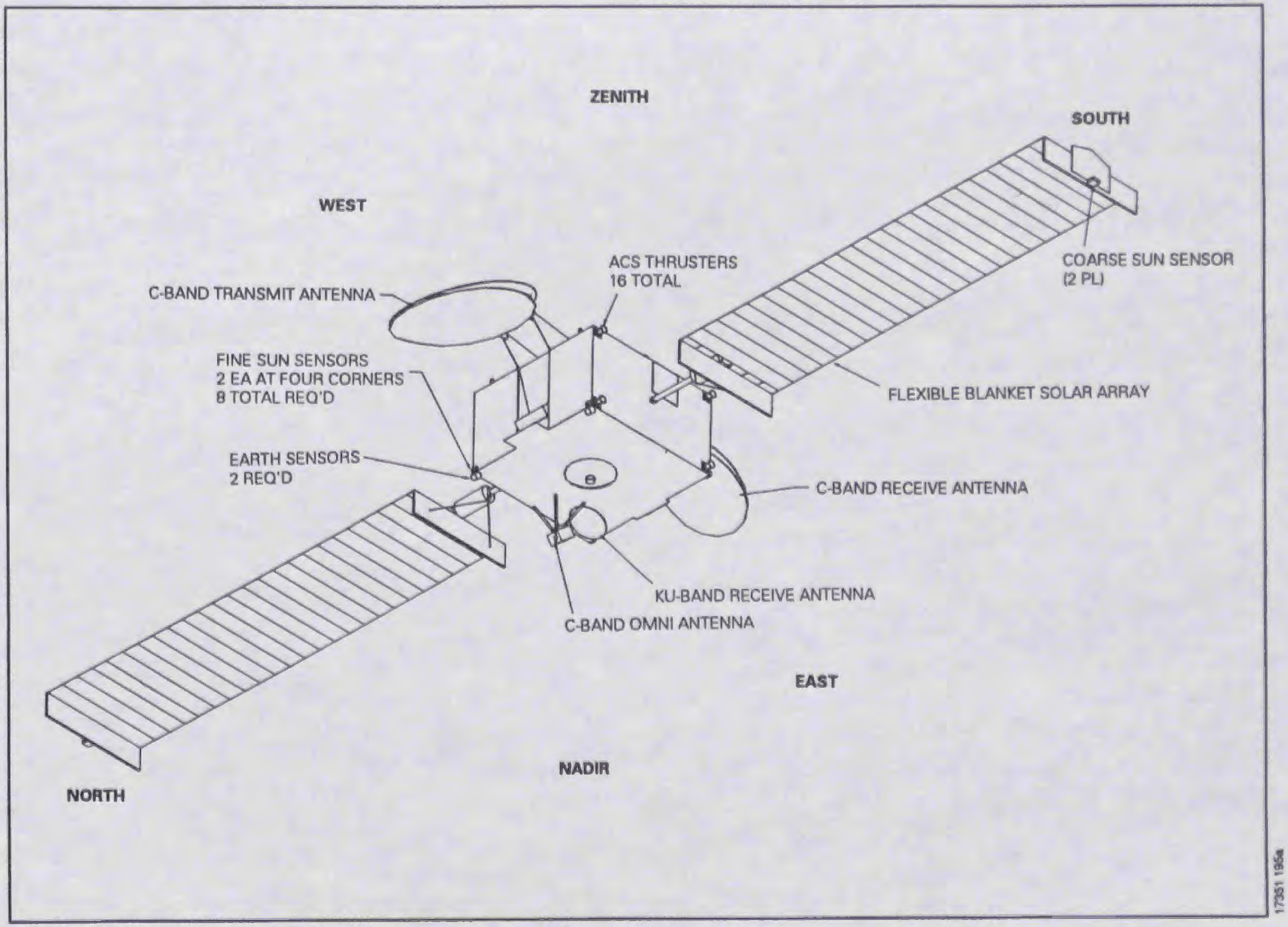


Figure 1.2-1. Isometric View of Deployed PAS-2

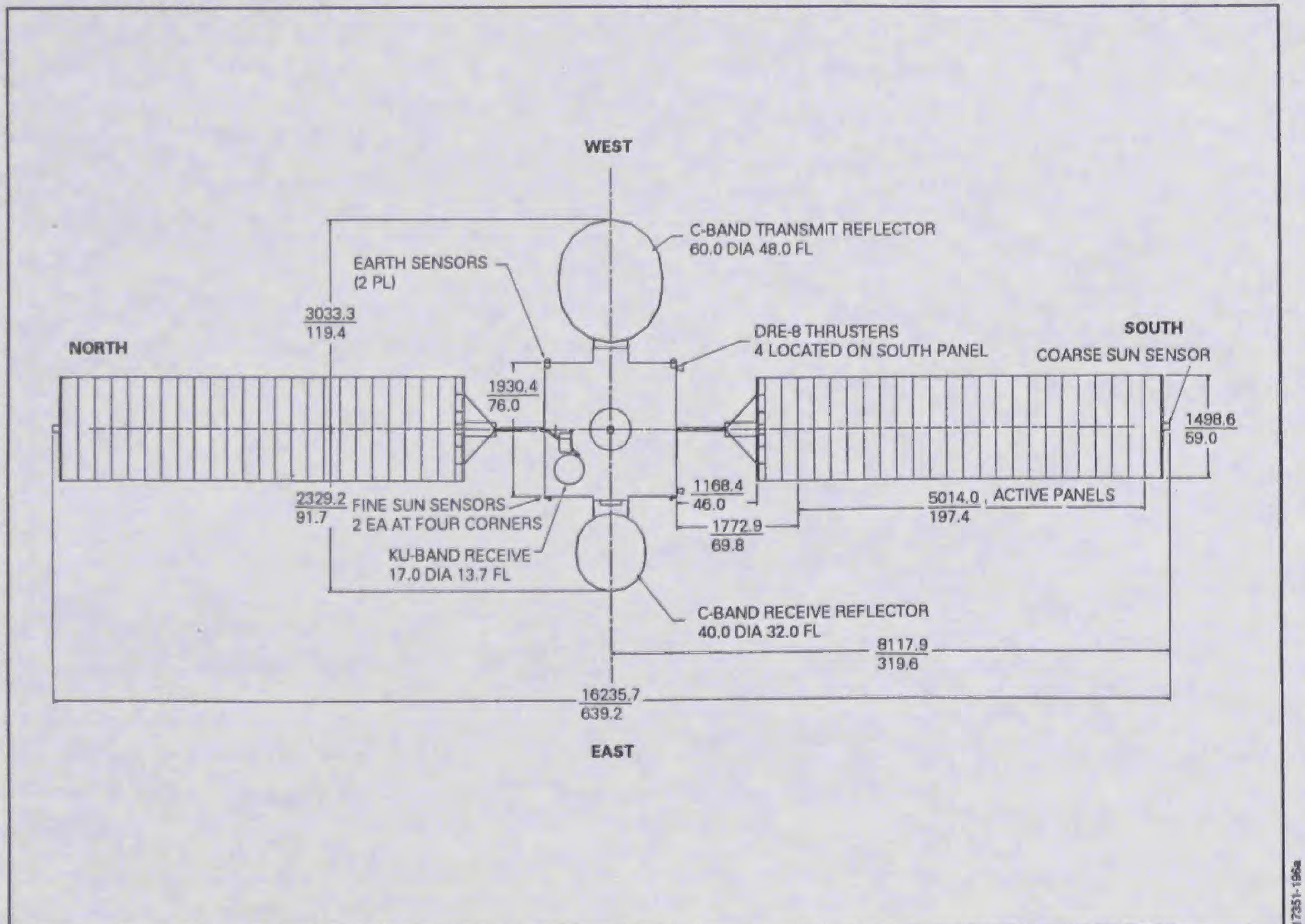


Figure 1.2-2. Nadir View

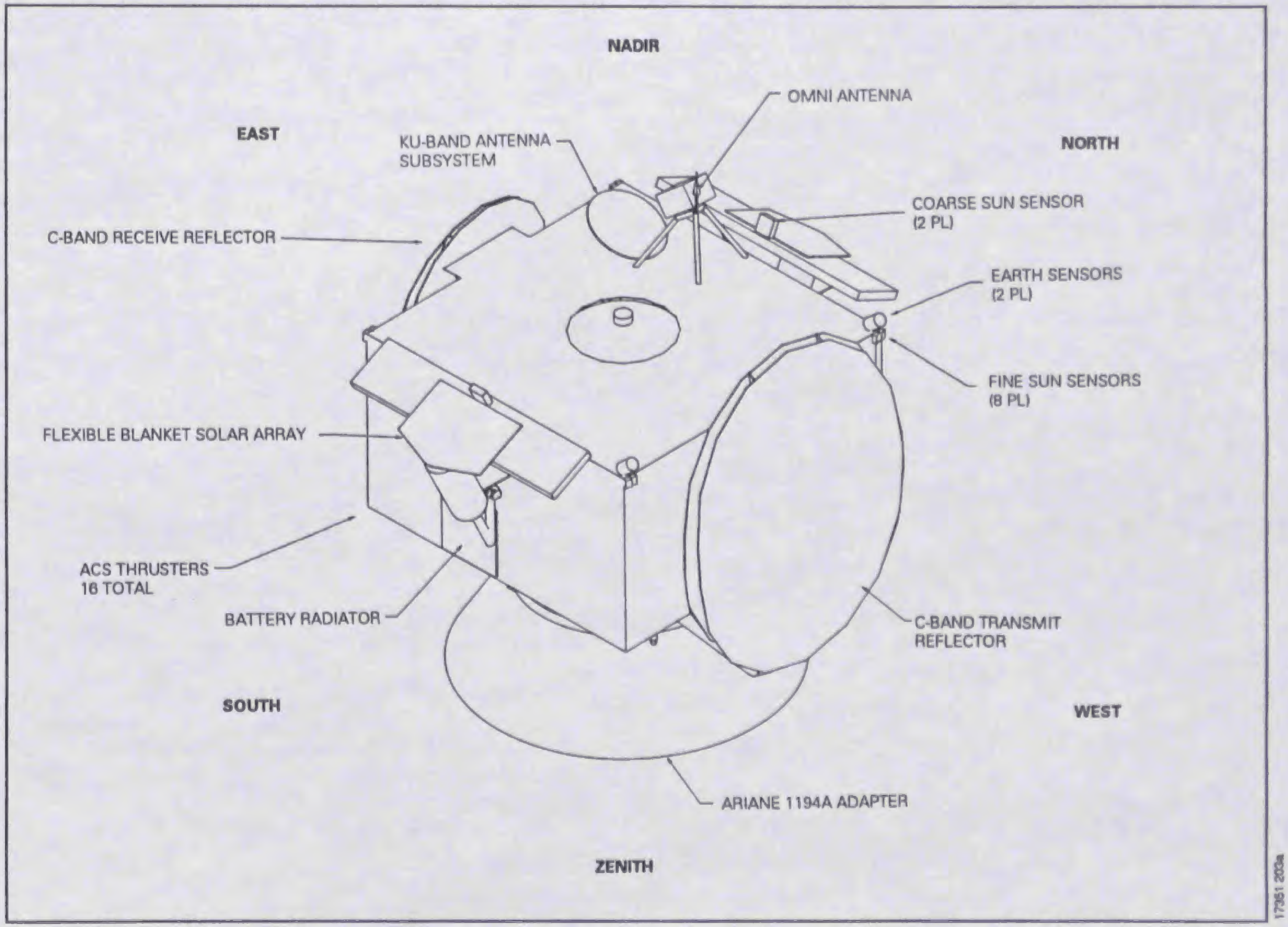


Figure 1.2-3. PAS-2 Stowed Configuration

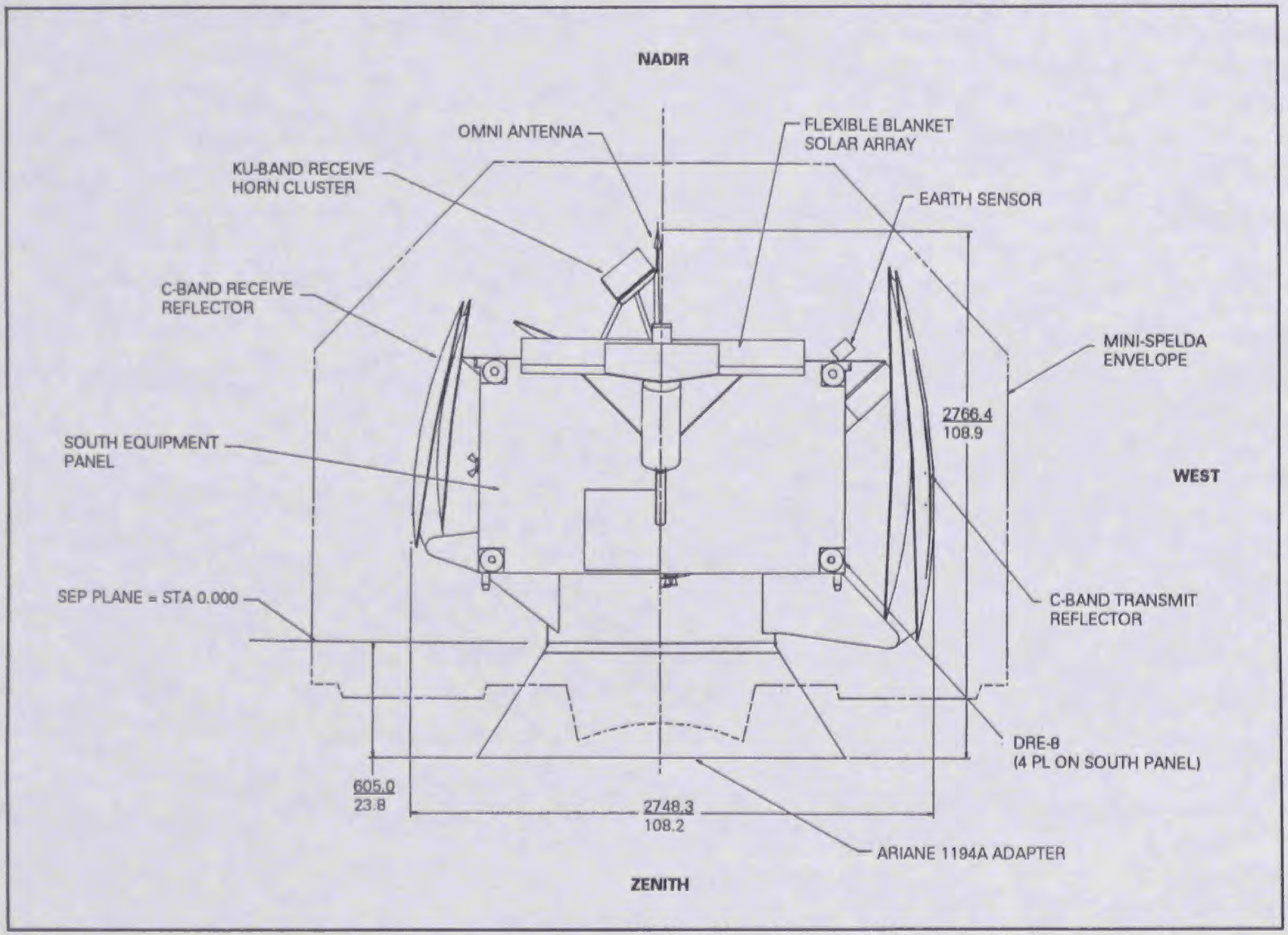


Figure 1.2-4. PAS-2 Stowed in the Mini-SPELDA

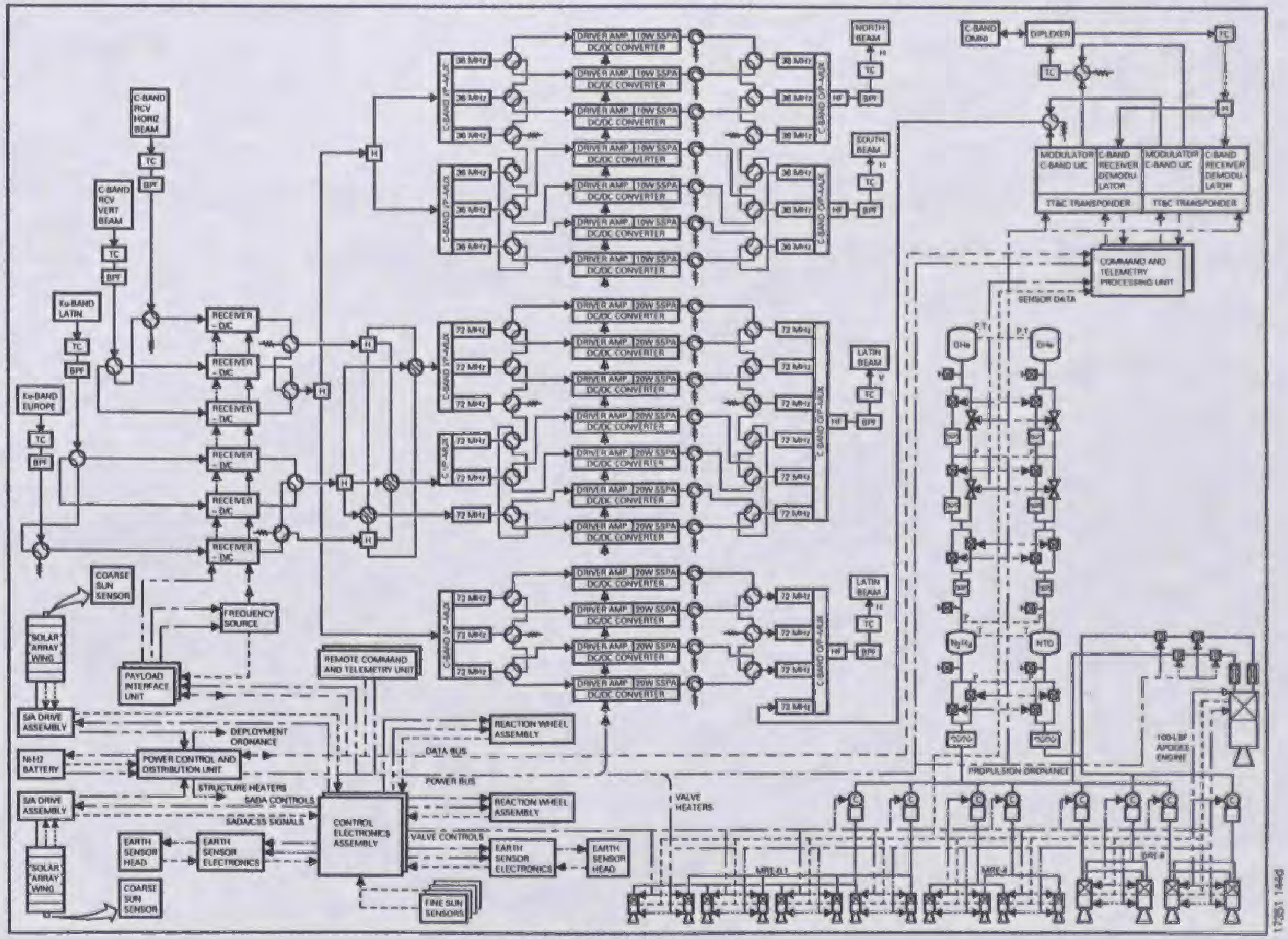


Figure 1.2-5. PAS-2 Electrical System Schematic

interfaces of the propulsion subsystem with the ACS and EPDS.

Physical redundancy of the major functions and hardware and redundant data buses and electrical power distribution at internal payload and subsystem interfaces provide single-fault tolerance. For clarity, this illustration shows only a portion of the internal subsystem and payload interfaces.

Primary Power Allocations

The primary power allocations of Figure 1.2-6 reflect the target power levels assigned to the PAS-2 payload and

	SUMMER SOLSTICE		FALL EQUINOX (SUN)		EQUINOX (ECLIPSE)	
	DC POWER EOL	THERMAL DISSIPATION	DC POWER EOL	THERMAL DISSIPATION	DC POWER EOL	THERMAL DISSIPATION
PAYLOAD						
C-BAND ITEMS	634.0	443.4	634.0	443.4	634.0	443.4
TT&C RF	22.5	17.5	22.5	17.5	22.5	17.5
Ku-BAND ITEMS	3.0	2.5	3.0	2.5	3.0	2.5
	659.5	463.4	659.5	463.4	659.5	463.4
SUBSYSTEMS						
ACS	33.0	33.0	33.0	33.0	33.0	33.0
EPDS	23.0	23.0	23.0	23.0	23.0	23.0
PROPULSION	46.0	46.0	46.0	46.0	46.0	46.0
C&T	37.1	37.1	37.1	37.1	37.1	37.1
THERMAL CONTROL	40.0	40.0	40.0	40.0	75.0	75.0
	179.1	179.1	179.1	179.1	214.1	214.1
SUBTOTAL (PAYLOAD AND SUBSYSTEMS)	838.6	642.5	838.6	642.5	873.6	677.5
65 Ah BATTERY CHARGE (C/20)	24.0	24.0	111.0	14.0	N/A	179.3
DC HARNESS (1 v R/T)	24.6	24.6	24.6	24.6	39.7	39.7
ARRAY REGULATOR ELECTRONICS (3%)	26.6	26.6	29.2	29.2	0.0	0.0
TOTAL ALLOCATIONS	913.8	717.7	1003.4	710.3	913.3	896.5
EOL ARRAY CAPABILITY	1118.0		1207.0			
EOL SYSTEM MARGIN	204.2		203.6 (20.3%)			

17351-143b

Figure 1.2-6. Primary Power Allocations (Watts)

subsystems under full payload operating conditions. Thermal dissipation corresponds to expected per–orbit average levels. Eclipse power and dissipation levels reflect battery–driven operation of the EPDS and resultant differences in internal battery heat generation and increased harness losses due to constant power operation.

The communications payloads under full power operation are assigned approximately 74% of total satellite power allocations. As indicated in Figure 1.2–6, the design provides a 20% power margin between the total current satellite power allocations and the end–of–life (EOL) solar array output power capability.

The PAS–2 satellite power allocations are predicated on control of system growth during the detail design process. The objective is to limit growth in power demand to less than 8.5% from program start to critical design review (CDR), leaving a 1.5% post–CDR growth allowance for manufacturing tolerances and for estimating uncertainties. Beyond this, an additional 5% power margin is allowed to establish minimum required end–of–life (EOL) solar array output. EOL solar array output has been sized to sustain simultaneous full power operation of the communications payload and a full recharge of the spacecraft battery. Current assessments indicate that a positive margin (~50 watts) exists between the system power allocations and estimated system power requirements, confirming the initial power allocation process in terms of setting achievable payload and subsystem power consumption targets.

Weight Summary

Figure 1.2–7 is a summary of satellite weight by major element. The launch weight of 2083 pounds includes a contingency of 129 pounds to account for design maturity, an adequate value to meet the design weight based on a detailed assessment of each subsystem and the maturity of components. To arrive at this contingency, we used factors for different levels of design maturity based on many past spacecraft programs at TRW.

	WEIGHT (lb)
PAYLOAD	
C-BAND	184.1
Ku-BAND	16.7
TT&CS	41.6
SUBTOTAL	242.5
SPACECRAFT	
ACS	96.0
EPDS	211.7
PROPULSION	149.3
STRUCTURES & MECHANISMS	191.7
THERMAL	21.1
BALANCE WEIGHT	9.1
CONTINGENCY	129.0*
SATELLITE DRY WEIGHT	1050.4
TOTAL PROPELLANTS	1032.8
TOTAL FUEL	509.8
TOTAL OXIDIZER	520.0
PRESSURANT	3.0
SATELLITE WEIGHT AT LAUNCH	2083.2 lb

*14% OF TOTAL DRY WEIGHT

17351 206a

Figure 1.2-7. PAS-2 Weight Summary

Satellite balance meets center-of-gravity-to-thrust axis constraints during launch and through GTO operations. Careful placement of payload and spacecraft components achieves coarse balance and adding balance weights as required assures fine balance. Deployables and propellant tanks are placed to minimize the displacement of the center of gravity with respect to the center of pressure during orbital operation. This reduces the amount of fuel needed for attitude control.

Specific impulse of the dual-mode propulsion subsystem determines required propellant weights. Bipropellant is used for injection into orbit and north-south stationkeeping, and monopropellant for attitude control (wheel unloading) and east-west stationkeeping. Figure 1.2-7 shows the specific impulse and delta-velocity increments for each operation of the satellite. Propellant accounts for approximately 50% of the total satellite weight.

Equipment List and Hardware Heritage

Figure 1.2-8 delineates design maturity, supplier, and heritage of the equipment for the major satellite elements. With the exception of the satellite structure and electrical harnesses, which are mission dependent, PAS-2 payload and spacecraft subsystem components are all based on existing designs or are modifications of existing designs.

PANAMSAT EQUIPMENT LIST

Item	N,M,A	Supplier	Heritage
C-Band Items			
Test Coupler-Input	M	Transco	DSP
Input Bandpass Fltr (6 GHz)	M	Transco	TDRSS
Input Coax Switch	A	Transco/ComDev	TDRSS/Intelsat VII/ERS-1/SC
Rec (6/4 GHz)	M	FEI Microwave	TDRSS/Milstar/DSP/ERS-1/LOC
PIU (DC/DC Conv + RCTU)	M	FEI N.Y.	DSP/TDRSS
Master Oscillator	M	FEI N.Y.	FltSatCom/DSP/Milstar
Input Mux(4 GHz)(3 Channel)	M	Transco/ComDev	TDRSS/DSP
C-Band SSPA's & Dr. Amp(4GHz 10W)	M	FEI Microwave	DSP MDM/TDRSS
C-Band SSPA's & Dr. Amp(4GHz 20W)	M	FEI Microwave	DSP MDM/TDRSS
Output Isolators	M	FEI N.Y.	DSP MDM/TDRSS
Coax Switch Matrix	M	Transco/ComDev	TDRSS/Intelsat VII/ERS-1/SC
Output Mux(4 GHz)(3 Channel)	M	Transco/ComDev	SCS-1/Anik-E/SatCom-K
Output Mux(4 GHz)(6 Channel)	M	Transco/ComDev	SCS-1/Anik-E/SatCom-K
Harmonic Filter (4 GHz)	M	Transco/ComDev	SCS-1/Anik-E/SatCom-K
Output Bandpass Filter (4 GHz)	M	Transco/ComDev	SCS-1/Anik-E/SatCom-K
Test Coupler-Output	M	Transco	DSP
W/G, Brkt, Coax Cable & Harn	N		
C-Band Rx Ant (Dish & Arms)	N	Spar	Anik-E
C-Band Tx Ant (Dish & Arms)	N	Spar	Anik-E
C-Band Rx Feeds & Brkts	N	Spar	Anik-E
C-Band Tx Feeds & Brkts	N	Spar	Anik-E
Depl, Holddown/Rel Mech	N		
TT&C RF Items			
Diplexer	A	Cubic	SatCom/Anike-E
Receiver	A	Cubic	Satcom
Transmitter	A	Cubic	Satcom
W/G, Brkts, Coax Cable & Harn	N		
TT&C Omni Ant	M	TRW	TDRSS/FltSatCom/DSP

Note: N = New; M = Modified; A = Actual

17351-179

Figure 1.2-8. Hardware Heritage (1 of 5)

PANAMSAT EQUIPMENT LIST

Item	N,M,A	Supplier	Heritage
TT&C Digital Items			
Comnd & Telem Unit (CTPU)	M	Gulton	T2C2 Technology
Remote Comnd & Telem Unit (RCTU)	M	Gulton	T2C2 Technology
Ku-Band Items			
Input Test Coupler	M	Transco/ComDev	DSP
Input Band Pass Filter(14-14.5 GHz)	M	Transco/ComDev	TDRSS
Waveguide Input Switches	A	Transco/ComDev	TDRSS
Receiver/Dn Conv (14.5-4 GHz)	A	FEI Microwave	Milstar/ESA/ERS-1 and -2
Coax Switches	A	ComDev	SatCom/Anik-E
Hybrids	N	FEI Microwave	Milstar
Ku-Band Ant (Dish & Back Struct)	N	TRW	Milstar
Ku-Band Feed Horns (14 GHz)	N	TRW	Milstar
W/G, Brkts, Coax Cable & Harn	N		
Attitude Control Subsystem			
Coarse Sun Sensor	A	TRW	TDRSS
Fine Sun Sensor	A	TRW	TDRSS
Conscan Earth Sensor	A	Barnes	COBE/Landsat
Control Electronics	M	TRW	TDRSS
Reaction Wheel Assy	A	Honeywell	FltSatCom
Solar Array Drive	A	TRW	TDRSS
Electrical Power & Distribution Subsystem			
Solar Array Wing	M	TRW	APSA
Array Reg Elect (ARE)	N	TRW	new
Battery (Cell redund, 65 AH)	M	Eagle Pitcher	Intelsat
Power Control & Distrib Unit	M	TRW	TDRSS
DC Harness	N	TRW	new

Note: N = New; M = Modified; A = Actual

17351-179

Figure 1.2-8. Hardware Heritage (2 of 5)

PANAMSAT EQUIPMENT LIST

Item	N,M,A	Supplier	Heritage
Propulsion Subsystem (Dual Mode)			
Helium Tanks, G/E Wrap	N	SCI	ERIS
Oxidizer Tank, G/E Wrap	N	TRW	IR&D
Fuel Tank, G/E Wrap, w/PMD	N	TRW	IR&D
Apogee Engine	M	TRW	S-5000
DRE-8 Thruster	N	TRW	IR&D
MRE-4 Thruster	A	TRW	DSP
MRE-0.1 Thruster	A	TRW	FSC
Hi Press Non-Latch Elec Valve	N	MOOG	OMV
Latching Iso-Valves	A	ECC	TDRSS
NC Pyro Valves (Large)	A	Pyronetics	MMBPS
NC Pyro Valves (Small)	A	Pyronetics	MMBPS
NO Pyro Valves	A	Pyronetics	MMBPS
Gas Filter	A	Wintec	MMBPS
Liquid Filter	A	Wintec	TDRSS
Press Transducers	A	Statham	FSC
Fill & Drain Valves	A	Pyronetics	TDRSS
Test Ports	A	Lee	KEW
Thermistors	A	FENWAL	TDRSS
Disposal Prop Stowage	N	TRW	I-VII
Heat Shield	N	TRW	S-5000
Trim Orifices	A	TRW	MMBPS
Thermostats	A	Elmwood	GRO/DSP
Thruster Valve Htrs	A	Tayco	DSP/FSC
Tank Heaters	N	Tayco	GRO
Line Heaters	N	Tayco	DSP
Integ Hdwre, Lines, Ftngs	N	TRW	new

Note: N = New; M = Modified; A = Actual

17351-179

Figure 1.2-8. Hardware Heritage (3 of 5)

PANAMSAT EQUIPMENT LIST

Item	N,M,A	Supplier	Heritage
Thermal Control Subsystem			
Multilayer Insul (MLI) & Paint	N	TRW	TDRSS/FltSatCom/DSP/GRO
Optical Solar Reflectors (OSR)	N	TRW	TDRSS/FltSatCom/DSP/GRO
Heaters, Tstats & Thermistors	N	TRW	TDRSS/FltSatCom/DSP/GRO
Structure & Mechanisms Subsystem		COI/Hercules	new
Primary			
Central Tube	N		
Separation Plane I/F Ring	N		
Horiz Platform	N		
East Panel	N		
Hinge Part (East)	N		
Side Panels (East)	N		
Shear Panels (East)	N		
Feed Box (East)	N		
Attach Members (East)	N		
West Panel	N		
Hinge Part (West)	N		
Side Panels (West)	N		
Shear Panels (West)	N		
Feed Box (West)	N		
Attach Members (West)	N		
N/S Panels	N		
Shear Panels	N		
Supt Arms (C-Band Ant)	N		
Hinges (C-Band Ant)	N		
Deployment Sys (C-Band Ant)	N	TRW	TDRSS/FltSatCom/DSP/GRO
Integ Hdwre (C-Band Ant)	N		
Attachments, Struct	N		

Note: N = New; M = Modified; A = Actual

17351-179

Figure 1.2-8. Hardware Heritage (4 of 5)

PANAMSAT EQUIPMENT LIST

Item	N,M,A	Supplier	Heritage
Secondary			
Brkts for RWA, SADA, Sens & Misc			
Brkt, SADA	N		
Brkt, RWA	N		
Brkt, Earth Sensor	N		
Brkt, Fine Sun Sens	N		
Brkt, Thruster	N		
Brkt, Engine	N		
Brkt, Coax Supt	N		
Brkt, Waveguides	N		
Integration Hardware	N		
Tiedown & Rel Mech, S/A & Ant's (incl ord & squibs)	N	TRW	TDRSS/FltSatCom/DSP/GRO

Adapter/Sep, S/C to LV (Ariane supplied)
Note: Not in weight budget.

Note: N = New; M = Modified; A = Actual

17351-179

Figure 1.2-8. Hardware Heritage (5 of 5)

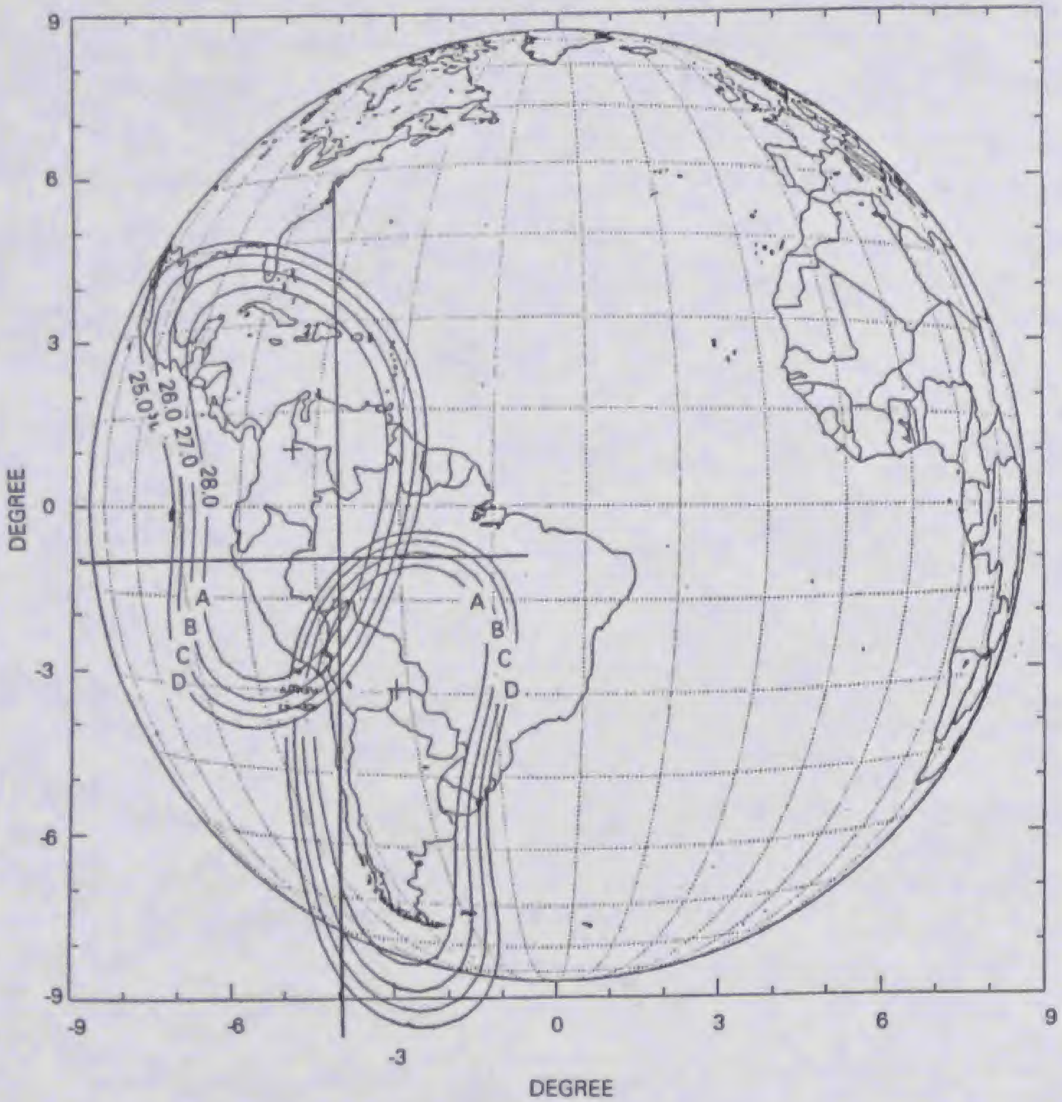
2. COMMUNICATIONS PAYLOAD

The PAS-2 payload provides both C-band and Ku-band uplink and C-band downlink communications. Three C-band beams cover two spot areas over South and Central America and a regional area over Latin America and the U.S. East Coast. The Ku-band uplink consists of two beams: a spot beam covers southern Europe and the United Kingdom; a regional beam covers Latin America and the U.S. East Coast. Each downlink spot beam provides three 36-MHz 10-watt channels. The Latin beam consists of nine 72-MHz, 20-watt channels with uplink either from C-band or Ku-band beams, or from both Ku-band and C-band beams simultaneously. Figure 2-1 summarizes key performance characteristics and predicted EIRP and G/T at beam center for each beam. Figures 2-2 to 2-4 are EIRP and G/T contour plots of four

	UPLINK BEAM	NORTH BEAM	SOUTH BEAM	LATIN BEAM	Ku-BAND BEAM	
	UPLINK	DOWNLINK	DOWNLINK	DOWNLINK	UPLINK	UPLINK
FREQUENCY (MHz)	5925 6425	3700 4200	3700 4200	3700 4200	14000 14500	14000 14500
NUMBER OF CHANNELS	6+9	3	3	9	0 TO 6	6 TO 0
CHANNEL BANDWIDTH	36 MHz + 72 MHz	36 MHz	36 MHz	72 MHz	72 MHz	72 MHz
POLARIZATION	VERTICAL/ HORIZONTAL	HORIZONTAL	HORIZONTAL	HORIZONTAL/VERTICAL	HORIZONTAL	HORIZONTAL
ANTENNA COVERAGE	ALL OF LATIN AMERICA, U.S. EAST COAST (COMBINED LATIN AND SPOT BEAM)	VENEZUELA, COLOMBIA, CENTRAL AMERICA, CARIBBEAN, PERU, ECUADOR	CHILE, ARGENTINA, PARAGUAY, URUGUAY, BOLIVIA	ALL OF LATIN AMERICA, U.S. EAST COAST	LATIN AMERICA, U.S. EAST COAST	SPAIN, ITALY, SOUTHERN EUROPE, UNITED KINGDOM
CROSS-STRAPPING	–	–	–	UP TO 6 CHANNELS FROM Ku-BAND	UP TO 6 CHANNELS TO C-BAND	
RECEIVER REDUNDANCY	3:2	–	–	–	3:2	
SSPA POWER & REDUNDANCY	–	7:6 10 WATTS		7:6 + 4:3 20 WATTS	–	
G/T-EIRP (BEAM CENTER)	0.9 dB/°K	38.5 dBW	38.6 dBW	39.5 dBW	–1.0 dB/°K	6.3 dB/°K
DESIGN LIFE	12 YEARS					

17351-158

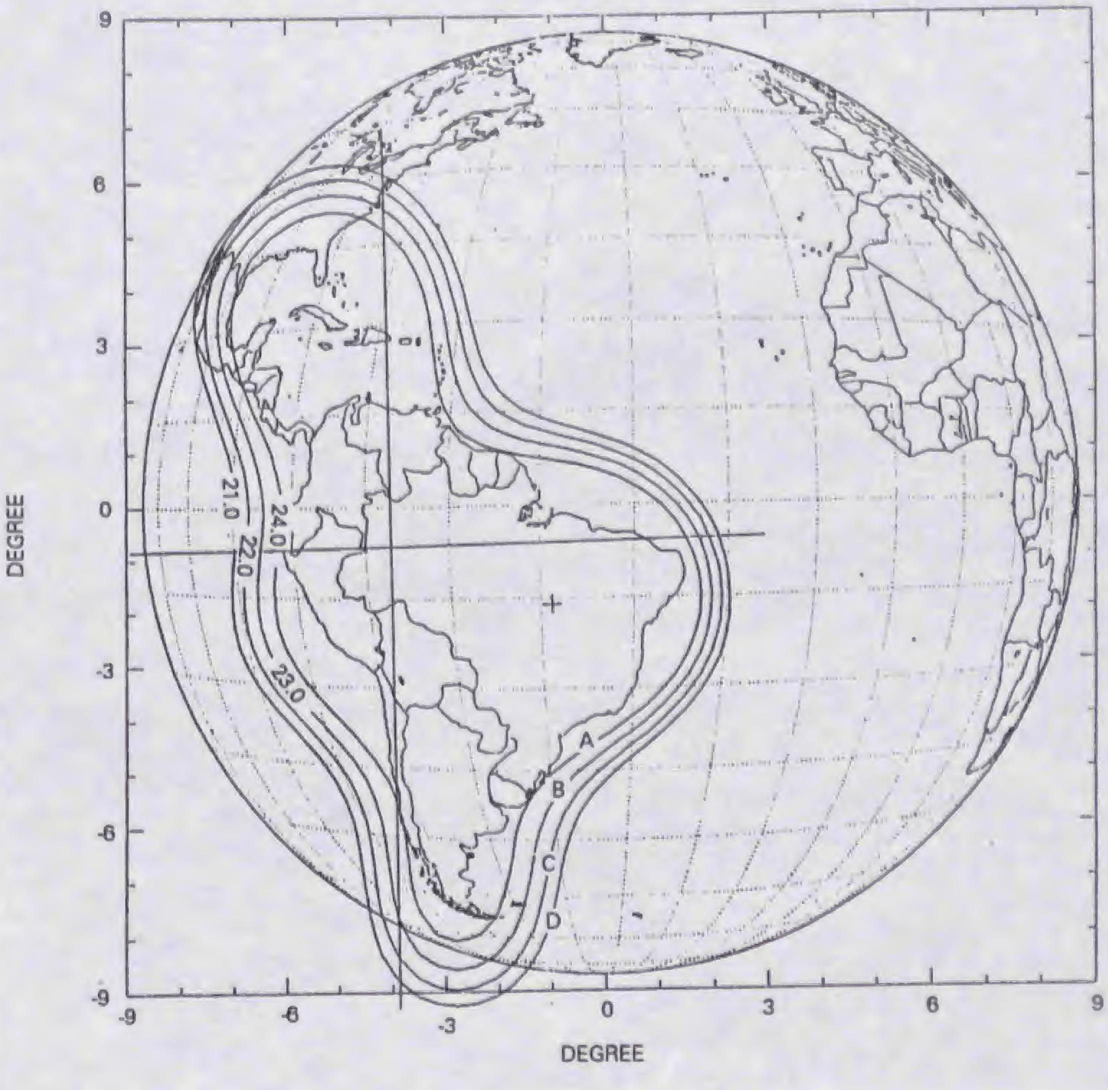
Figure 2-1. Predicted Payload Capabilities Summary



	EIRP (dBW)	
	NORTH	SOUTH
BEAM CENTER	38.5	38.6
CONTOUR		
A	35.0	35.1
B	34.0	34.1
C	33.0	33.1
D	32.0	32.1

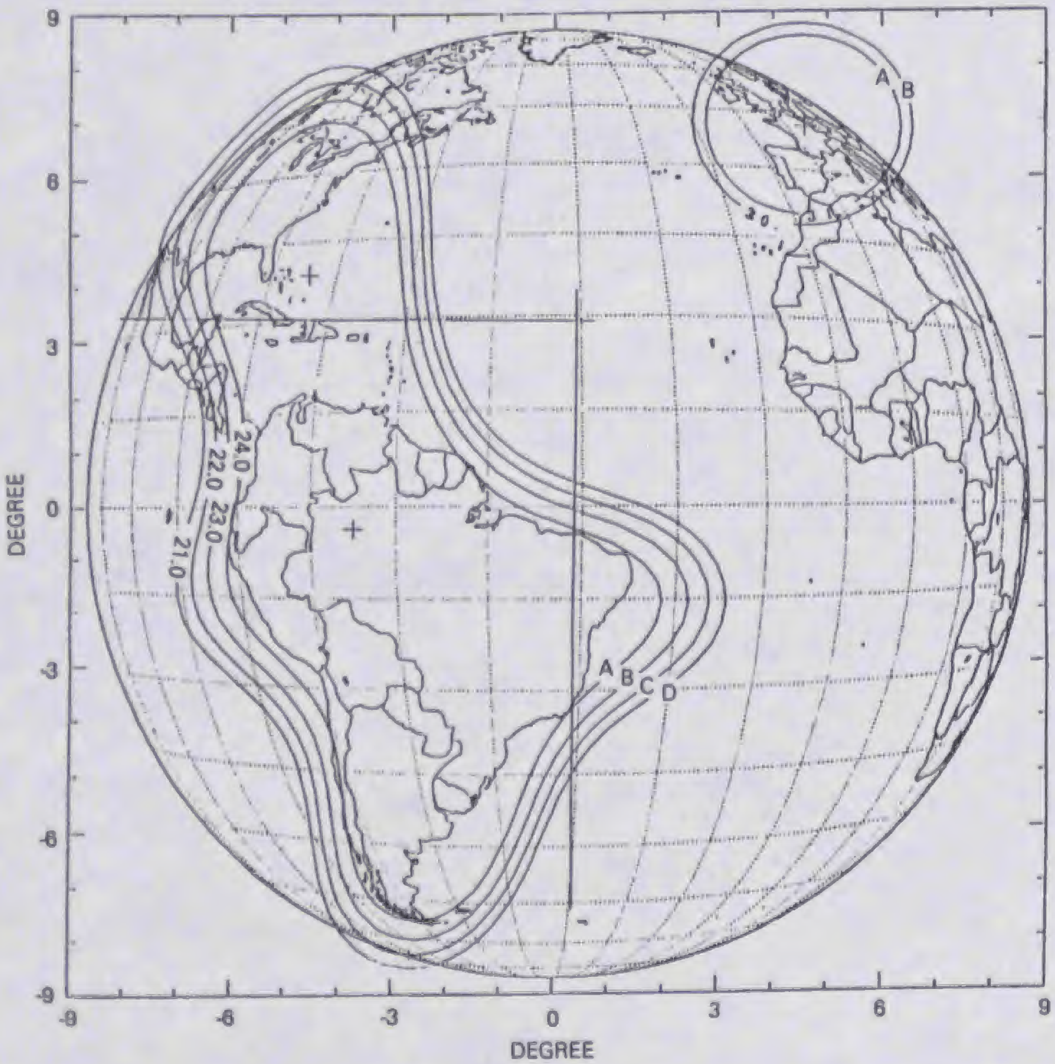
17351-164b

Figure 2-2. C-Band Spot Beam EIRP Contour Plot



	G/T dB/°K	EIRP (dBW)
BEAM CENTER	0.9	39.5
CONTOUR		
A	-4.2	34.4
B	-5.2	33.4
C	-6.2	32.4
D	-7.2	31.4

Figure 2-3. C-Band EIRP and G/T Contour Plot



	G/T dB/ °K	
	LATIN	EUROPE
BEAM CENTER	-1.0	6.3
CONTOUR		
A	-4.5	2.9
B	-5.5	1.9
C	-6.5	
D	-7.5	

17351 161b

Figure 2-4. Ku-Band G/T Contour Plot

coverage areas. Sections 2.3 and 2.4 discuss in detail the EIRP and G/T budget and antenna directivity plots.

2.1 PAYLOAD DESIGN

The PAS-2 payload consists of six active 36-MHz C-band transponders for spot beams and nine active 72-MHz Ku/C band to C-band transponders for the Latin beam. A telemetry, tracking, and command subsystem (TT&CS) provides spacecraft control and monitoring. The payload completely satisfies performance objectives. It uses existing designs and flight-proven hardware to minimize cost and risk (Figure 2.1-1). Our payload design features:

- Separate C-band receive and transmit reflectors to minimize passive intermodulation products (PIM) and to facilitate feed network design for frequency reuse
- Antennas optimized for high-polarization isolation, low sidelobe level, and maximum gain for spot and Latin coverage.
- Channel interleave and polarization isolation to reduce interference from frequency reuse and beam overlapping
- High-efficiency, low-risk, verified solid-state power amplifiers (SSPAs) to provide high power at low dc power use
- Complete flexibility to select up to six uplink channels from C-band and/or Ku-band beams for downlink transmission on the Latin beam
- Dual command receiver via the omni antenna for reliable command reception
- Option of telemetry transmission via high-gain Latin beam antenna.

A 40-inch, dual-gridded deployable C-band reflector receives the orthogonally polarized uplink signals from combined Latin and spot coverage areas. Each of the two beam outputs is bandpass-filtered and fed to a receiver or downconverter. The receiver redundancy is 3 for 2, one for each of the combined orthogonally polarized beams. The vertically polarized beam output is split between two groups of input multiplexers (IMUXs): one group for the six 36-MHz channels from spot coverage and the other for the three 72-MHz channels from Latin coverage. The spot beam output is again split for even and odd channels. The horizontally polarized beam output, together with two Ku-band outputs, feeds through a switching matrix. The result is six channels for common channeling filtering (Figure 2.1-1). This design allows complete uplink channel switching (Figure 2.1-2) with minimum hardware. Six 36-MHz receiving channels serve the spot coverage area and nine 72-MHz receiving channels serve the Latin coverage area.

The driver amplifier/SSPAs are redundantly switched for simplicity. However, each driver amplifier can be individually commanded for gain control. Six active SSPAs are lumped together with a redundancy of 7 for 6 in one group; three active SSPAs are lumped together with a redundancy of 4 for 3 in another group. Each 36-MHz channel SSPA outputs 10 watts and each 72-MHz channel SSPA, 20 watts.

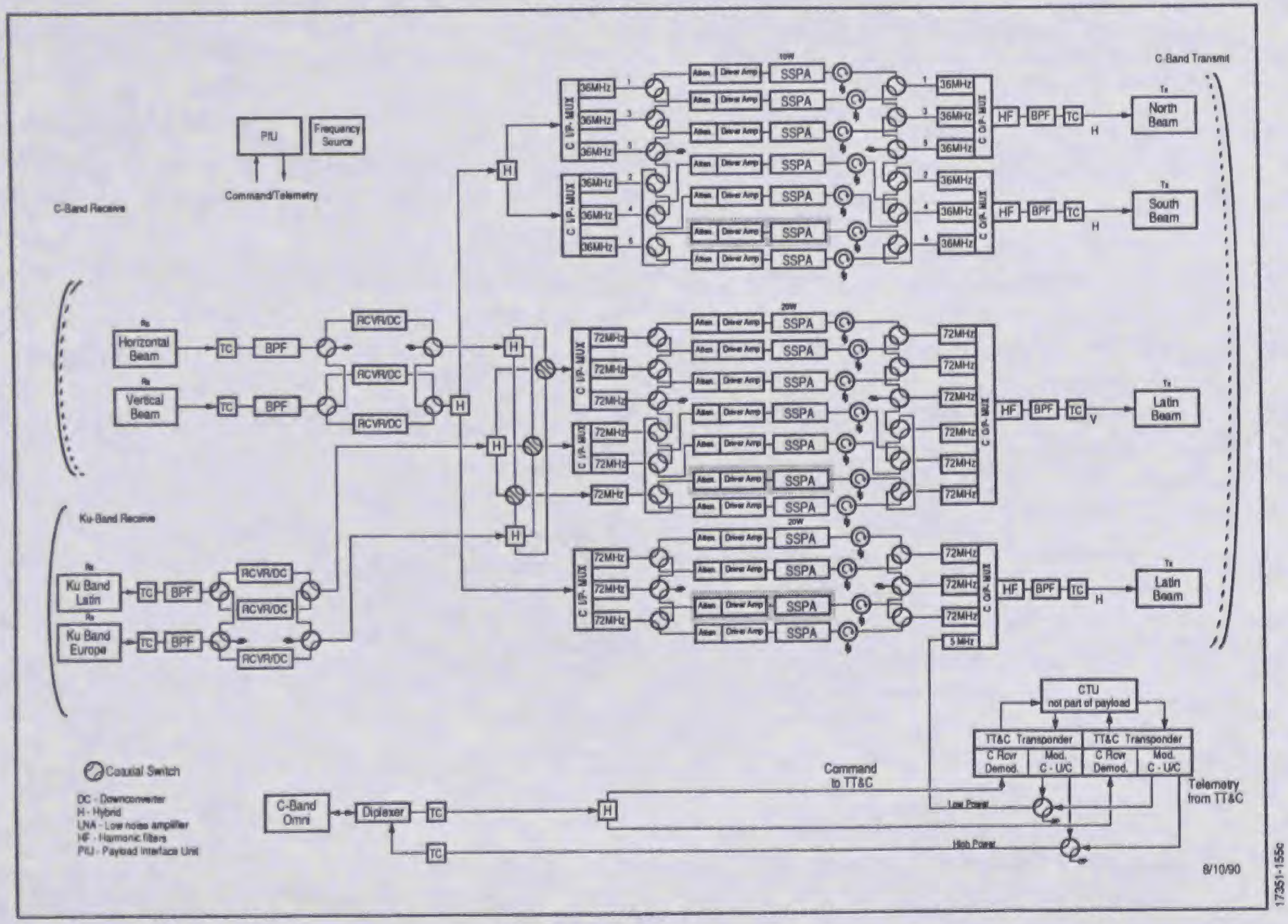


Figure 2.1-1. Payload Block Diagram

UPLINK BEAMS	UPLINK CHANNELS																						
C-BAND LATIN BEAM	6	5		4		3				2				1				0					
KU-BAND EUROPEAN BEAM	0	0	1	0	2	0	1	2	3	0	1	3	4	0	2	3	5	1	2	3	4	5	6
KU-BAND LATIN BEAM	0	1	0	2	0	3	2	1	0	4	3	1	0	5	3	2	0	5	4	3	2	1	0

17361-180

Figure 2.1-2. Switching of Six Latin Beam Transponders to Uplink Beams

The output section comprises four output multiplexers (OMUXs). Each spot beam consists of one 3-channel, even or odd, 36-MHz OMUX. The Latin beam consists of one 6-channel 72-MHz OMUX and one 3-channel 72-MHz OMUX. Harmonic filters and bandpass filters reduce out-of-band spurious emissions and isolate the receive band from SSPA outputs. The C-band transmit antenna uses a 60-inch deployable dual-gridded reflector with multiple feeds, providing spot and Latin coverage with three individual beams.

A separate Ku-band, 17-inch reflector antenna receives uplink beams from southern Europe and Latin America. The Ku-band uplink has one receiver for each beam with a redundancy of 3 for 2; it downconverts to C-band. The two outputs are optionally switchable into the C-band 72-MHz channels for downlink on the Latin beam.

Command reception is via the omni antenna, with dual receivers for either GTO or on-orbit. On-orbit telemetry transmission is via a high-gain Latin beam antenna with low-level output from one of two redundant transmitters. During GTO or in an emergency, the omni antenna transmits telemetry at high power. Tone ranging also is provided.

Telemetry data verify responses to all ground control commands and indicate the status of all payload units. Typical payload functions telemetered include:

- Receiver and power amplifier temperatures
- Transponder gain settings
- Power amplifier output status
- Switch status
- Unit on/off status.

Commands to the payload include individual power amplifier and receiver on/off, transponder gain setting, payload channel configuration, and redundant unit switching.

2.2 FREQUENCY AND POLARIZATION PLAN

The allocated frequency bands for PAS-2 are 5.925 to 6.425 GHz for uplink reception and 3.700 to 4.200 GHz for downlink (Figure 2.2-1). The proposed frequency plan provides six 72-MHz transponders on one linear polarization. The same 500-MHz bandwidth is frequency reused with

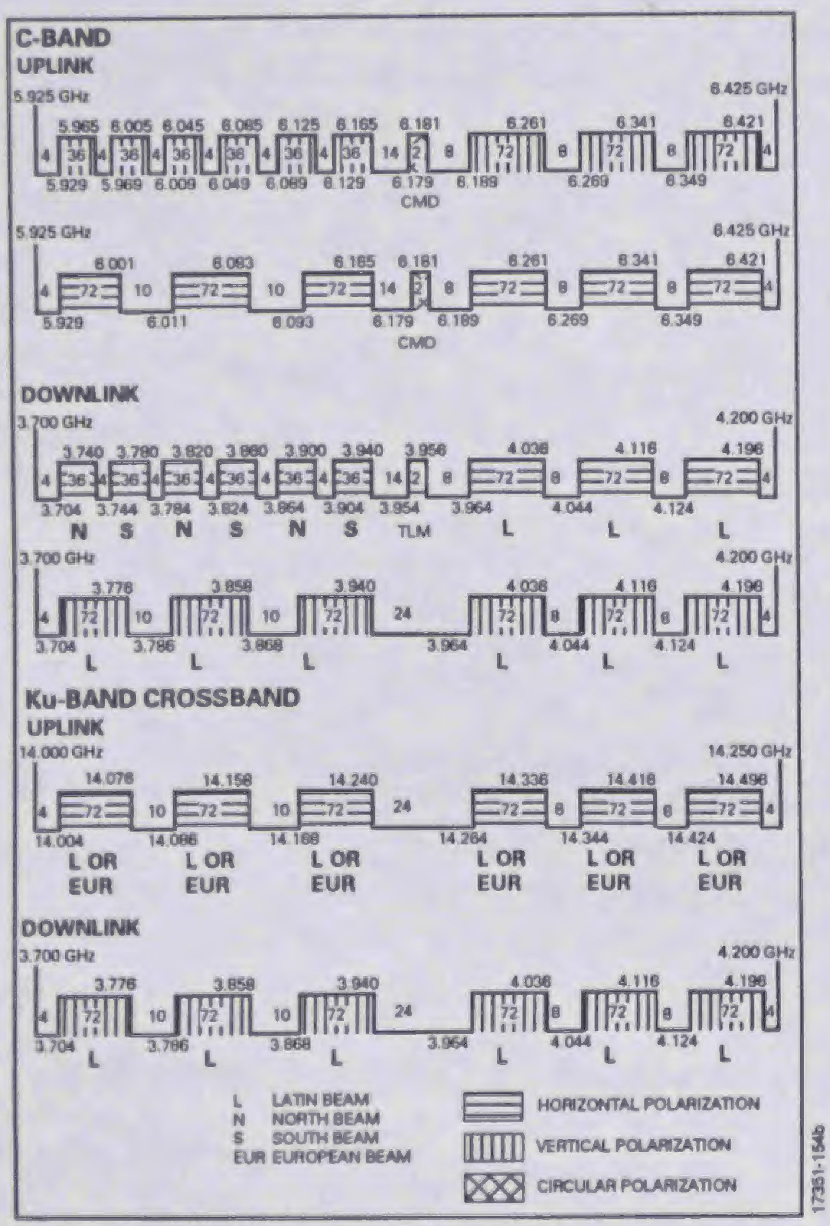


Figure 2.2-1. Frequency Plan

orthogonal linear polarization, providing six 36–MHz transponders plus three additional 72–MHz transponders.

All six 36–MHz transponders receive from anywhere in the combined beam area. Three transponders transmit on the northern spot beam and three transponders on the southern spot beam. Nine 72–MHz transponders receive and transmit to any country in the Latin beam.

The frequency allocation of the transponders is chosen to optimize in–band performance. The 24–MHz guard band in the center allows sufficient space to achieve good rejection between the 36–MHz spot beam transponders and the 72–MHz Latin beam transponders. This rejection is necessary for low passband insertion loss in the antenna diplexers. The north and south spot beam transponders are not contiguous. This simplifies multiplexer design and offers better in–band performance.

Commands are received at 6.180 GHz on the omni antenna using circular polarization. The command frequency chosen prevents signals of adjacent communication transponders from interfering with uplinked commands. During nominal operation, telemetry is transmitted on the Latin beam at 3.955 GHz with linear polarization.

2.3 EIRP AND G/T BUDGET

C–Band G/T

Figure 2.3–1 shows receive noise figures for the C–band. The system noise figure for the C–band front end is 2.5 dB. Waveguide runs from the antenna to the transponder minimize losses. A receiver noise figure of 1.7 dB offers a good balance between cost and performance and is easily achievable with current low noise amplifiers (LNAs). Figure 2.3–2 shows the predicted beam center G/T capability for the C-band receiving system. (Figure 2.4–5 in Section 2.4 shows the predicted receive gain patterns for different locations within the desired coverage area.)

	GAIN (dB)	DEVICE NF (dB)
ANTENNA TO RECEIVER LOSSES		
WAVEGUIDE FROM ANTENNA	-0.10	0.10
TEST COUPLER	-0.05	0.05
BANDPASS FILTER	-0.22	0.22
SWITCH	-0.10	0.10
COAX CABLE	-0.20	0.20
VSWR	-0.10	0.10
RECEIVER (INCLUDING ISOLATOR)	50.00	1.70
REMAINDER OF TRANSPONDER		0.07
TOTAL		2.54

17351 148c

Figure 2.3–1. C–Band System Noise Figure

BEAM	BEAM CENTER RECEIVE GAIN (dB)*	TRANSPONDER NF (dB)	ANTENNA NOISE TEMPERATURE (K)	EFFECTIVE NOISE TEMPERATURE (K)	G/T dB/K
VERTICAL	28.2	2.5	290	516	1.1
HORIZONTAL	28.0	2.5	290	516	0.9

* THE NET ANTENNA GAIN INCLUDES THE EFFECTS OF ANTENNA CIRCUIT LOSSES

17351-151a

Figure 2.3–2. C–Band G/T Predicted Capability

Ku–Band G/T

Figure 2.3–3 shows the receive noise figures for Ku–band. The system noise figure for the Ku–band front end is 3.1 dB. Once again, waveguide runs from the antenna to the transponder minimize losses. The receiver noise figure is 2.4 dB and is easily achievable at Ku–band with current LNAs. Figure 2.3–4 gives predicted beam center G/T capability for the Ku–band receiving system. (Figure 2.4–8 in Section 2.4 shows the predicted receive gain patterns for different locations within the desired coverage area.)

EIRP

Our design uses 20–watt SSPAs for the Latin beam and 10–watt SSPAs for the spot beams. The EIRPs for the spot and Latin beams are approximately the same because the lower power available to the spot beams is offset by higher antenna gain. Figure 2.3–5 gives predicted beam center EIRP

	GAIN (dB)	DEVICE NF (dB)
ANTENNA TO RECEIVER LOSSES		
WAVEGUIDE FROM ANTENNA	-0.20	0.20
TEST COUPLER	-0.05	0.05
BANDPASS FILTER	-0.22	0.22
SWITCH	-0.05	0.05
WAVEGUIDE	-0.10	0.10
VSWR	-0.10	0.10
RECEIVER (INCLUDING ISOLATOR)	50.00	2.40
REMAINDER OF TRANSPONDER		0
TOTAL		3.12

17351 149

Figure 2.3–3. Ku–Band System Noise Figure

for the two spot beams and the Latin beam. (Figures 2.4–4 and 2.4–5 in Section 2.4 show the predicted transmit gain patterns for the various desired locations.)

Figure 2.3–6 shows the losses we expect between the SSPA and the antenna. The output multiplexer (OMUX) suppresses IMs from the adjacent transponder, and the harmonic/bandpass filter provides the required isolation in the receive band as well as suppresses harmonics from the SSPA. Both these filters are necessary but add to the losses between the SSPA and antenna. Again, waveguide runs minimize the loss between the transponder and the antenna.

BEAM	BEAM CENTER RECEIVE GAIN (dB)*	TRANSPONDER NF (dB)	ANTENNA NOISE TEMPERATURE (K)	EFFECTIVE NOISE TEMPERATURE (K)	G/T dB/K
LATIN	26.7	3.1	290	592	−1.0
EUROPE	34.0	3.1	290	592	6.3

* THE NET ANTENNA GAIN INCLUDES THE EFFECTS OF ANTENNA CIRCUIT LOSSES

17351-152b

Figure 2.3-4. Ku-Band Receive G/T Predicted Capability

BEAM	SSPA	SSPA (dBW)	CIRCUIT LOSS (dB)	BEAM CENTER ANTENNA GAIN (DB)*	EIRP (dBW)
LATIN (VERTICAL)	20	13.0	1.3	28.0	39.7
LATIN (HORIZONTAL)	20	13.0	1.3	27.8	39.5
NORTH SPOT	10	10.0	1.3	29.8	38.5
SOUTH SPOT	10	10.0	1.3	29.9	38.6

* THE NET ANTENNA GAIN INCLUDES THE EFFECTS OF ANTENNA CIRCUIT LOSSES

17351-851a

Figure 2.3-5. C-Band EIRP Predicted Capability

Gain Distribution

Figures 2.3–7 and 2.3–8, respectively, are gain distribution budgets for the C–band and Ku–band receive antennas. The transponder has three gain stages: receiver, driver amplifier, and high–power amplifier (HPA). Gains in the C–band and Ku–band receiver are chosen so that the minimum signal levels entering the input multiplexer are at the same level.

The step attenuator in the driver amplifier has a 32–dB range, achievable in 1–dB steps using a 5–bit attenuator. This design accommodates a 15–dB input flux density range from anywhere in the coverage area. For the C–band, approximately 3–dB difference in gain between peak receive and

	NOMINAL LOSS (dB)	SIGNAL LEVEL (dBW)	SIGNAL LEVEL (dBW)
SSPA (20W/10W EOL)	-	13.00	10.00
COAX CABLE	0.25	12.75	9.75
ISOLATOR	0.20	12.55	9.55
SWITCH	0.10	12.45	9.45
OUTPUT MUX	0.30	12.15	9.15
OUT BPF/HARMONIC FILTER	0.20	11.95	8.95
TEST COUPLER	0.05	11.90	8.90
WAVEGUIDE TO ANTENNA	0.10	11.80	8.80
VSWR	0.10	11.70	8.70
TOTAL	1.30		

17351 150c

Figure 2.3-6. C-Band Transmit Loss Budget

UNIT	GAIN (dB) MAXIMUM*	ACCUM XPONDER	MINIMUM*	ACCUM XPONDER	SIGNAL LEVEL (dBW) MINIMUM	MAXIMUM	NOISE FIGURE (dB) UNIT	ACCUM
INPUT FLUX DENSITY TO SATURATE A TRANSPONDER					-90.0 (dBW/m2)	-75.0		
					-127.3	-112.3		
ANTENNA	22.90		28.20					
					-104.4	-84.1		
WAVEGUIDE (50 IN.OF WR137)	-0.10	-0.10		-0.10			0.10	0.10
TEST COUPLER	-0.05	-0.15		-0.15			0.05	0.15
INPUT BAND PASS FILTER	-0.22	-0.37		-0.37			0.22	0.37
SWITCH	-0.10	-0.47		-0.47			0.10	0.47
COAX CABLE	-0.20	-0.67		-0.67			0.20	0.67
VSWR	-0.10	-0.77		-0.77			0.10	0.77
					-105.1	-84.8		
RECEIVER	50.00	49.23		49.23			1.70	2.47
					-55.1	-34.8		
COAX CABLE	-0.50	48.73		48.73			0.50	2.47
SWITCH	-0.20	48.53		48.53			0.20	2.47
HYBRID	-6.00	42.53		42.53			6.00	2.47
SWITCH	-0.50	42.03		42.03			0.50	2.47
INPUT MUX	-6.00	36.03		36.03			6.00	2.47
SWITCH	-0.50	35.53		35.53			0.50	2.47
VSWR	-0.20	35.33		35.33			0.20	2.47
					-69.0	-48.7		
DRIVER AMPLIFIER	57.43	92.76	37.13	72.46			20.00	2.54
					-11.6	-11.6		
COAX CABLE	-0.20	92.56		72.26			0.20	2.54
VSWR	-0.20	92.36		72.06			0.20	2.54
					-12.0	-12.0		
HPA (20 W SSPA) (EOL)	25.00	117.36		97.06			35.00	2.54
					13.0	13.0		
COAX CABLE	-0.25	117.11		96.81			0.25	2.54
ISOLATOR	-0.20	116.91		96.61			0.20	2.54
SWITCH	-0.10	116.81		96.51			0.10	2.54
OUTPUT MUX	-0.30	116.51		96.21			0.30	2.54
OUT BPF/HARMONIC FILTER	-0.20	116.31		96.01			0.20	2.54
TEST COUPLER	-0.05	116.26		95.96			0.05	2.54
WAVEGUIDE (50 IN. OF WR229)	-0.10	116.16		95.86			0.10	2.54
VSWR	-0.10	116.06		95.76			0.10	2.54
					11.7	11.7		
ANTENNA (NORTH BEAM)	26.30		29.80					
EIRP (NORTH BEAM)					38.0	41.5		

17351 1460

NOTE: LEVELS SHOWN DENOTE MINIMUM AND MAXIMUM FLUX DENSITY PER TRANSPONDER TO SATURATE HPA. ATTENUATOR HAS 30 dB RANGE: 15 dB FOR INPUT FLUX VARIATION TO SATURATE A TRANSPONDER; 3 dB FOR RECEIVE GAIN PATTERN VARIATION BETWEEN PEAK GAIN AND EOC GAIN; 12 dB TO BACK OFF HPA DURING MAXIMUM INPUT FLUX DENSITY CONDITIONS.

*REFERS TO MINIMUM AND MAXIMUM DRIVER AMPLIFIER GAIN WHICH OCCURS AT MAXIMUM (BEAM CENTER) AND MINIMUM (EOC) ANTENNA GAIN CORRESPONDINGLY.

Figure 2.3-7. PAS-2 C-Band Gain Budget

UNIT	GAIN (dB) MAXIMUM*	ACCUM XPONDER	MINIMUM*	ACCUM XPONDER	SIGNAL LEVEL (dBW) MINIMUM	MAXIMUM	NOISE FIGURE (dB) UNIT	ACCUM
INPUT FLUX DENSITY TO SATURATE A TRANSPONDER					-100.0 (dBW/m2)	-85.0		
					-144.5	-129.5		
ANTENNA	23.20		34.00					
					-121.3	-95.5		
WAVEGUIDE (50 IN. OF WR 75)	-0.20	-0.20		-0.20			0.20	0.20
TEST COUPLER	-0.05	-0.25		-0.25			0.05	0.25
INPUT BAND PASS FILTER	-0.22	-0.47		-0.47			0.22	0.47
SWITCH	-0.05	-0.52		-0.52			0.05	0.52
WAVEGUIDE	-0.10	-0.62		-0.62			0.10	0.62
VSWR	-0.10	-0.72		-0.72			0.10	0.72
					-122.0	-96.2		
RECEIVER	66.50	65.78		65.78			2.40	3.12
					-55.5	-29.7		
COAX CABLE	-0.50	65.28		65.28			0.50	3.12
SWITCH	-0.50	64.78		64.78			0.50	3.12
HYBRID	-6.00	58.78		58.78			6.00	3.12
SWITCH	-0.50	58.28		58.28			0.50	3.12
INPUT MUX	-6.00	52.28		52.28			6.00	3.12
SWITCH	-0.50	51.78		51.78			0.50	3.12
VSWR	-0.20	51.58		51.58			0.20	3.12
					-69.7	-43.9		
DRIVER AMPLIFIER	58.15	109.73	32.35	83.93			20.00	3.12
					-11.6	-11.6		
COAX CABLE	-0.20	109.53		83.73			0.20	3.12
VSWR	-0.20	109.33		83.53			0.20	3.12
					-12.0	-12.0		
HPA (20 W SSPA) (EOL)	25.00	134.33		85.53			35.00	3.12
					13.0	13.0		
COAX CABLE	-0.25	134.08		83.28			0.25	3.12
ISOLATOR	-0.20	133.88		83.08			0.20	3.12
SWITCH	-0.10	133.78		82.98			0.10	3.12
OUTPUT MUX	-0.30	133.48		82.68			0.30	3.12
OUT BPF/HARMONIC FILTER	-0.20	133.28		82.48			0.20	3.12
TEST COUPLER	-0.05	133.23		82.43			0.05	3.12
WAVEGUIDE (50 IN. OF WR229)	-0.10	133.13		82.33			0.10	3.12
VSWR	-0.10	133.03		82.23			0.10	3.12
					11.7	11.7		
ANTENNA (LATIN BEAM)	22.80		28.00					
EIRP (LATIN BEAM)					34.5	39.7		

17351-147c

NOTE: LEVELS SHOWN DENOTE MINIMUM AND MAXIMUM FLUX DENSITY PER TRANSPONDER TO SATURATE HPA. ATTENUATOR HAS 30 dB RANGE: 15 dB FOR INPUT FLUX VARIATION TO SATURATE A TRANSPONDER; 10 dB FOR RECEIVE GAIN PATTERN VARIATION BETWEEN PEAK EUROPEAN BEAM AND EOC LATIN BEAM; 5 dB TO BACK OFF HPA DURING MAXIMUM INPUT FLUX DENSITY CONDITIONS.

*REFERS TO MINIMUM AND MAXIMUM DRIVER AMPLIFIER GAIN WHICH OCCURS AT MAXIMUM (BEAM CENTER) AND MINIMUM (EOC) ANTENNA GAIN CORRESPONDINGLY.

Figure 2.3-8. PAS-2 Ku-Band Receive and C-Band Transmit Gain Budget

edge of coverage (EOC) yields 18 dB in required attenuator backoff range during maximum flux density conditions. The maximum transponder gain is needed when the lowest flux density is received at a location near the EOC.

For the Ku-band, the peak European receive gain and the EOC Latin beam vary by 12 dB. Added to the 15-dB flux density variation, this gives a total required attenuator backoff range of 27 dB. The 32-dB attenuator range absorbs this variation with a 5-dB margin to back off the HPA during maximum flux density conditions.

2.4 ANTENNAS

PAS-2 has four antennas: two C-band, one Ku-band, and one TT&C. Figure 2.4-1 shows the antenna layout on the satellite. The C-band transmit and receive antennas are mounted on the east and west panels, the Ku-band receive antenna on the nadir panel, and the TT&C antenna on top of the Ku-band feed tower.

C-Band Antennas

The C-band antennas employ two dual-gridded offset reflectors, one for transmit and the other for receive. Wire-gridded reflector surfaces ensure the polarization purity needed for frequency reuse. The transmit antenna employs a 60-inch diameter offset paraboloid with a 48-inch focal length. Two orthogonally polarized gridded reflectors are stacked to form the dual-gridded reflector configuration (Figure 2.4-2). Two feed clusters with identical feed horn layouts, except for their orthogonal polarization, are spaced approximately 10 inches apart in the focal plane. Each feed cluster has 13 pyramidal horns. The front gridded reflector surface is illuminated by the horizontally polarized feed cluster to form three horizontally polarized contour beams – Latin, north, and south. The reflector surface in the back is illuminated by the vertically polarized feed cluster to produce the vertically polarized Latin beam. The cross-polarized field components of both of these feed clusters are directed toward an area outside Latin America.

Generation of shaped contour beams requires multiple feed elements and a low-loss RF distribution network capable of providing precise amplitude and phase excitations to each radiating element. The quality and efficiency of these contour beams depend to a great extent on the feed horn layout, the components used to realize the ideal feed excitations, and the care taken in manufacturing and assembling the hardware. For linear polarization, pyramidal horns are commonly used because of their polarization purity and high aperture efficiency. To use the same feed horns to generate three overlapping horizontally polarized beams requires a feed network (Figure 2.4-3), consisting of two 5-way and two 3-way power dividers and three frequency diplexers. The third diplexer in the Latin beam feed path is needed only to equalize the phase delay in this path with the other feed horns over the entire 500-Mhz frequency band. To reduce the size and weight of the feed network, flat squarax or suspended air stripline power dividers are used to distribute the RF signal to the feed elements. This type of feed circuit

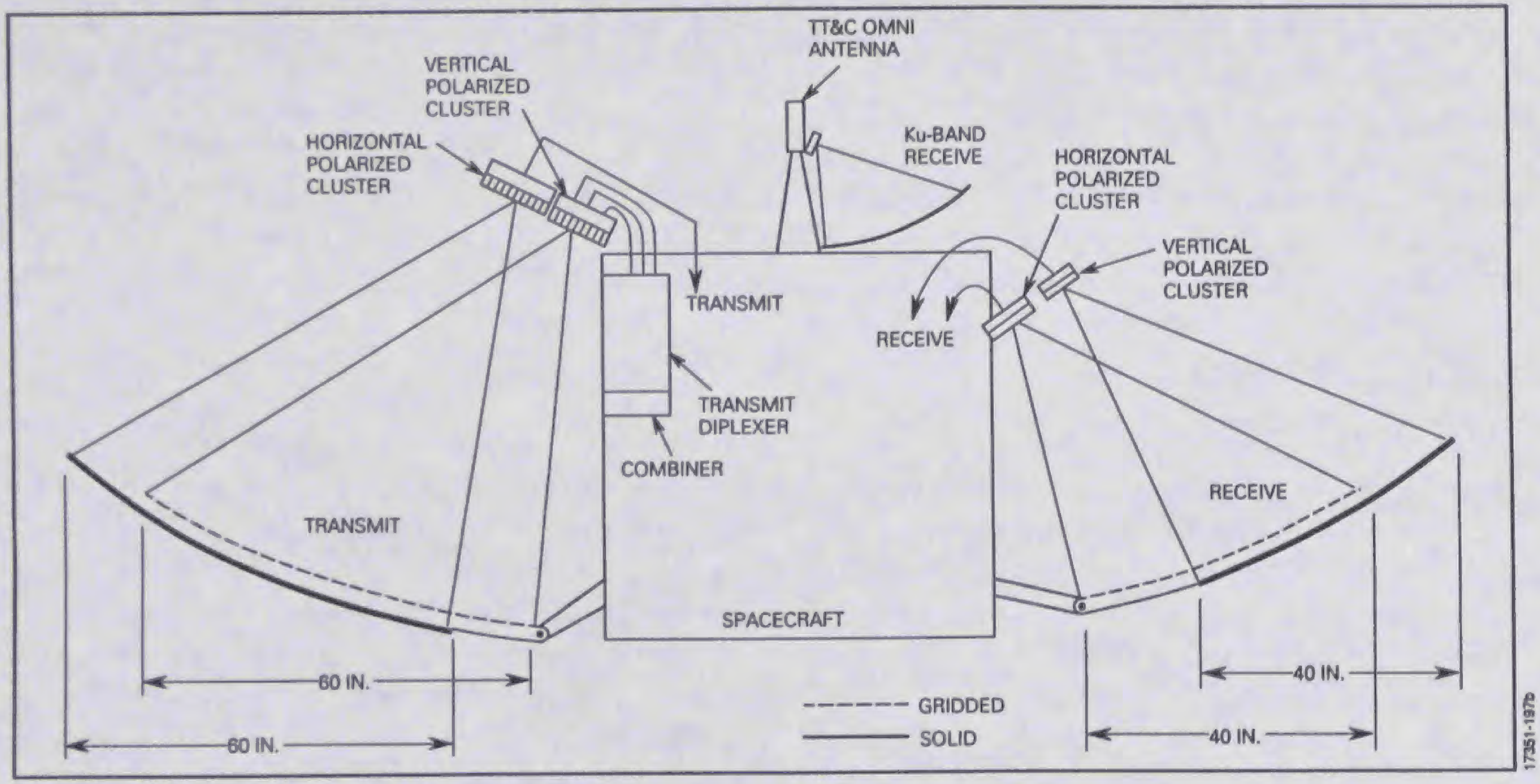
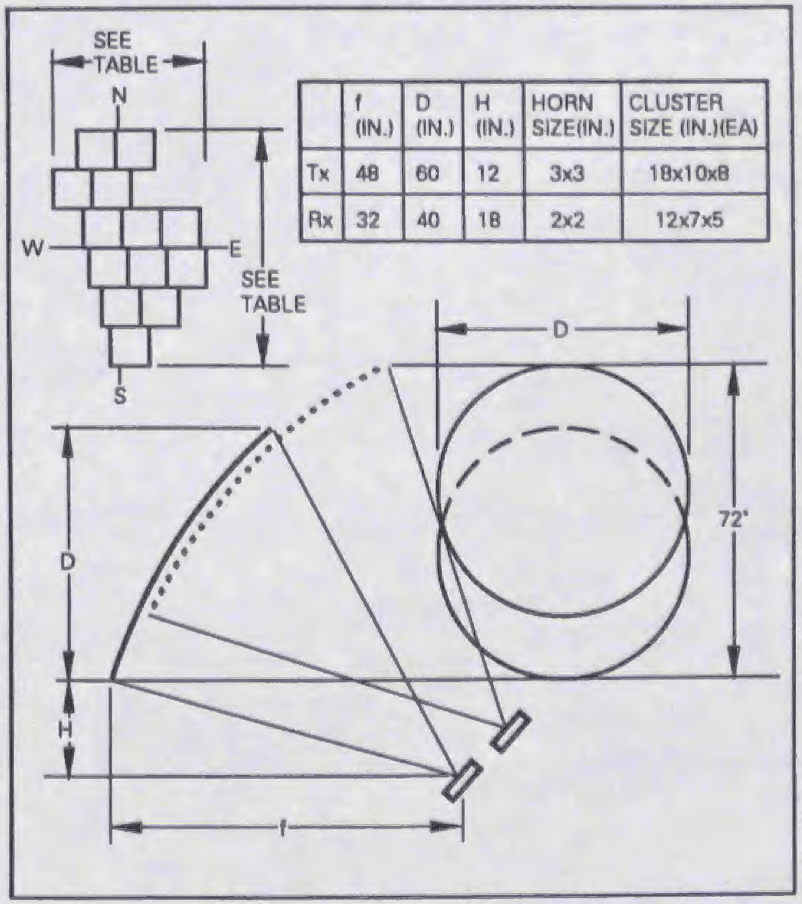


Figure 2.4-1. PAS-2 Antenna Configuration

occupies approximately one third the area and is one third the weight of an equivalent waveguide feed network, with a slightly higher (< 0.2 dB) insertion loss for an entire feed package.

Figures 2.4–4 and 2.4–5 show the computed antenna directivity contours superimposed on a world map. Figure 2.4–6 shows the predicted C-band transmit antenna performance.

The C-band receive reflector is a frequency scale replica of the transmit dual-gridded reflector design. The feed layout is almost a mirror image of the transmit feed, except the horn locations are slightly adjusted to provide a better fit to Latin



	f (IN.)	D (IN.)	H (IN.)	HORN SIZE(IN.)	CLUSTER SIZE (IN.)(EA)
Tx	48	60	12	3x3	18x10x8
Rx	32	40	18	2x2	12x7x5

Figure 2.4-2. C-Band Antenna Configuration

American coverage. The computed receive Latin beam is similar to that of the transmit antenna shown in Figure 2.4–5. Figure 2.4–7 gives predicted C–band receive antenna performance.

Ku–band Antenna

The Ku–band receive antenna is an offset parabolic reflector fed by an array feed of twelve 0.8–inch square pyramidal horns for the Latin beam and a single 1.2–inch square pyramidal horn for the European beam. The reflector has a projected circular aperture of 17 inches and a focal length of 13.6 inches. The feed network follows a septum power divider design used on TDRSS and NASA's Advanced Application and Flight Experiment (AAFE) program.

Figure 2.4–8 shows the computed antenna coverage and Figure 2.4–9 shows predicted Ku–band antenna performance.

TT&C Omni Antenna

The TT&C antenna is an open–end waveguide with a parasitic element and a conical reflector to improve the radiation pattern of the open–end waveguide and to achieve a hemispherical coverage pattern. By insertion of an orthomode transducer (OMT), the omni antenna can operate in either dual linear or circular polarizations simultaneously.

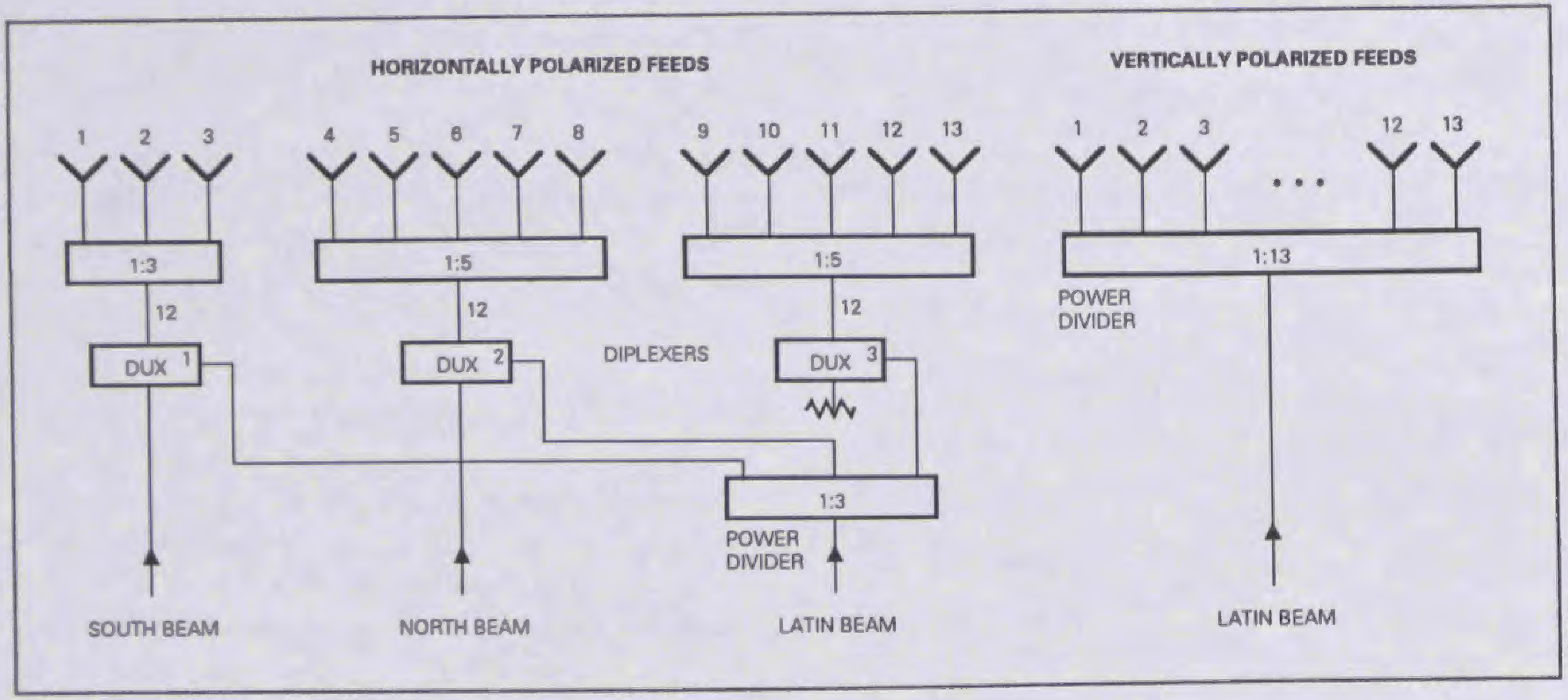


Figure 2.4-3. C-Band Transmit Feed Network

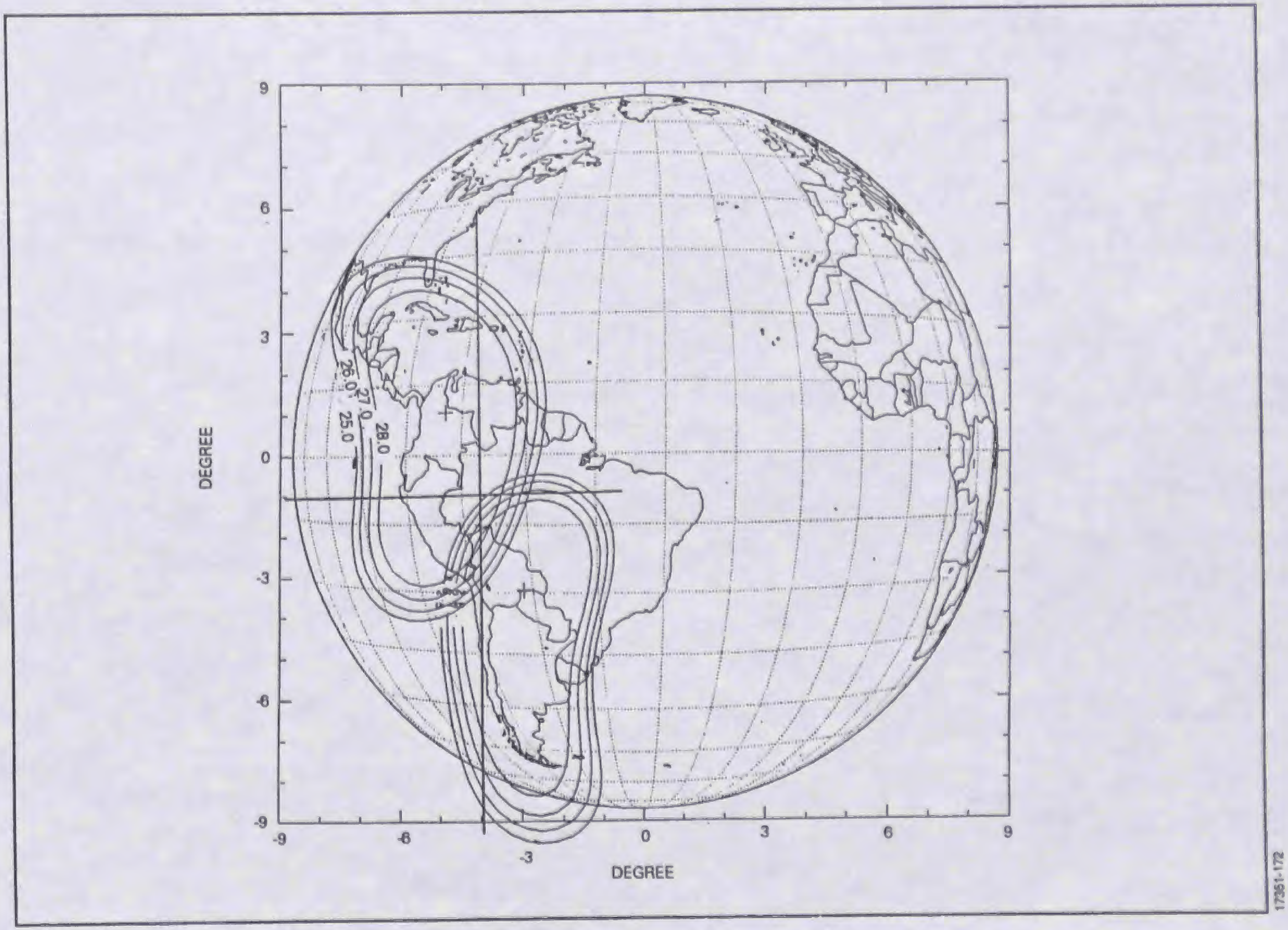


Figure 2.4-4. C-Band North and South Spot Beam Transmit Coverage Pattern (Horizontal Polarization, 4.0 GHz)

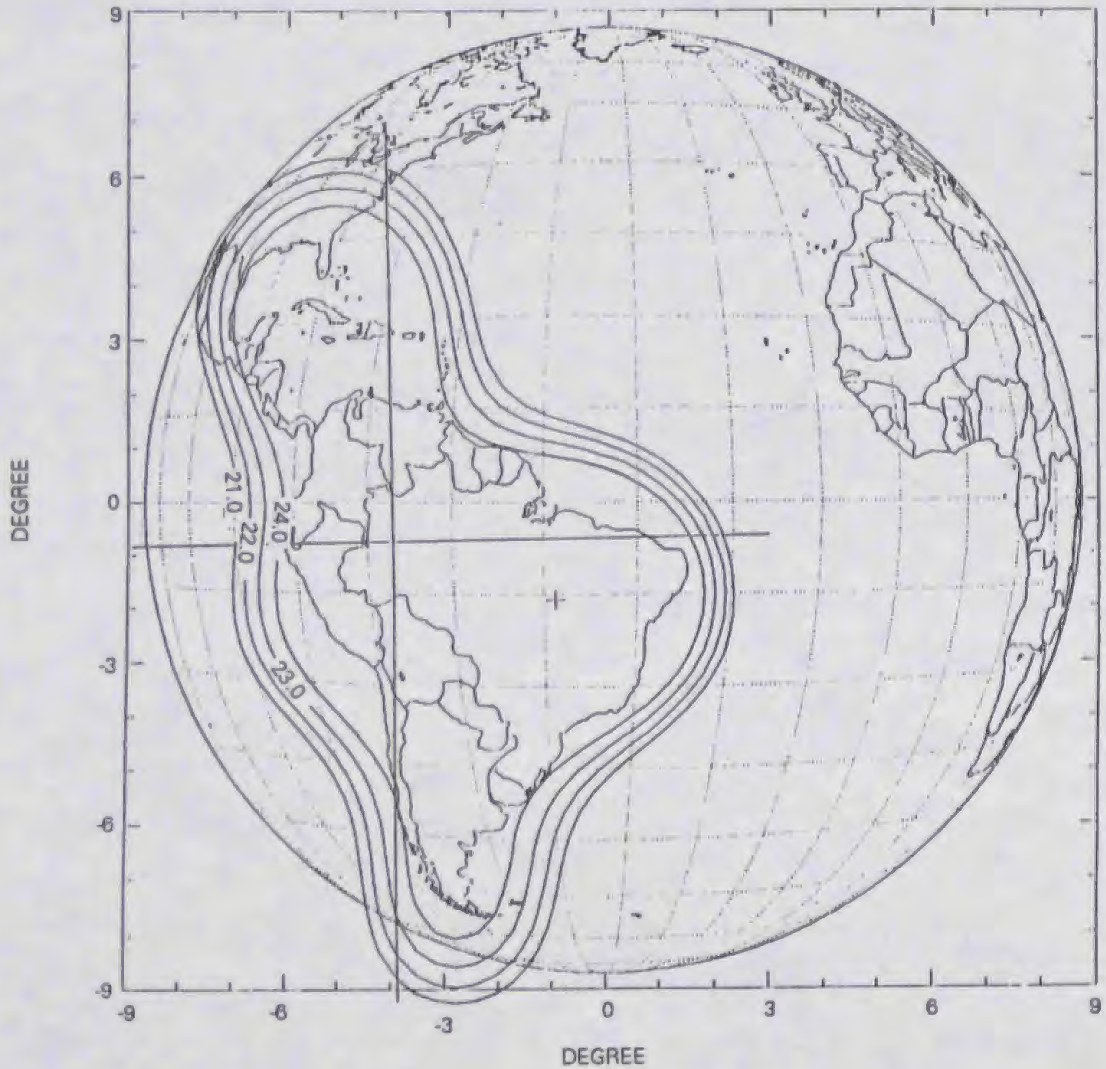


Figure 2.4-5. C-Band Latin Beam Transmit Coverage Pattern (Vertical Polarization, 4.0 GHz)

4 GHz	LATIN - VERTICAL	LATIN - HORIZONTAL	NORTH - HORIZONTAL	SOUTH - HORIZONTAL
ANTENNA PEAK DIRECTIVITY (dBi)	29.1	29.1	31.0	31.5
EOC DIRECTIVITY (dBi)	24.0	24.0	27.5	27.5
FEED UNCERTAINTY (1) (dB)	-0.20	-0.2	-0.2	-0.2
CIRCUIT LOSSES (2) (dB)	-0.50	-0.8	-0.8	-0.8
REFLECTOR LOSS (dB)	0.30	0.1	0.1	0.1
WAVEGUIDE LOSS (dB)	0.10	0.1	0.1	0.1
TOTAL LOSS (dB)	1.10	1.2	1.2	1.2
EOC GAIN (dBi)	22.9	22.8	26.3	26.3
POLARIZATION ISOLATION (dB)	-30.0	-30.0	-30.0	-30.0

(1) DEVIATION FROM THEORETICAL FEED
(2) INCLUDES LOSSES OF COMBINERS, MULTIPLEXERS, AND COAX

17351 169b

Figure 2.4-6. C-Band Transmit Antenna Predicted Performance

6 GHz	LATIN VERTICAL	LATIN HORIZONTAL
PEAK DIRECTIVITY (dBi)	29.1	29.1
EOC DIRECTIVITY (dBi)	24.0	24.0
FEED UNCERTAINTY (1) (dB)	-0.2	-0.2
CIRCUIT LOSS (dB)	-0.5	-0.5
REFLECTOR GRID LOSS (dB)	-0.1	-0.3
WAVEGUIDE LOSS (dB)	-0.1	-0.1
TOTAL LOSS (dB)	-0.9	-1.1
EOC GAIN (dB)	23.1	22.9
POLARIZATION ISOLATION (dB)	-30.0	-30.0
SIDELOBE LEVEL (dB)	-25.0	-25.0

(1) DEVIATION FROM THEORETICAL FEED

17351-170b

Figure 2.4-7. Predicted C-Band Receive Antenna Performance

Figure 2.4–8. Ku–Band Receive Antenna Directivity Coverage Pattern

	LATIN	EUROPEAN
PEAK DIRECTIVITY (dBi)	27.50	34.40
EOC DIRECTIVITY (dBi)	24.00	31.00
CIRCUIT LOSSES (dB)	-0.40	0
FEED HORNS (dB)	-0.10	-0.10
MISCELLANEOUS LOSS (dB)	-0.30	-0.30
TOTAL LOSSES (dB)	-0.80	-0.40
EOC GAIN (dBi)	23.20	30.60
SIDELOBE LEVEL	<-25	<-25

(1) EOC DIRECTIVITY INCLUDES ALL REFLECTOR LOSS, SPILLOVER, ILLUMINATION, ETC.

17351-170(2)b

Figure 2.4-9. Predicted Ku-Band Antenna Performance

2.5 PAYLOAD HARDWARE

The payload block diagram and key transponder units are shown in Figure 2.5-1.

Input Test Couplers

Test couplers are incorporated into the input and output bandpass filters for use in integration and test and are terminated and capped for flight. These units have been used on the DSP satellite for 10 years.

Input Bandpass Filters

The input bandpass filters screen the uplink receive frequencies, reject the image frequencies, and limit the noise and interfering signals to the receiver. The filter, from TDRSS, consists of a ten-section evanescent mode waveguide. The Ku-band filters have waveguide input and output. The C-band filters have waveguide input with coaxial output. The filters are fabricated from aluminum and silver plated for low insertion loss. Silver conductive epoxy is used on all joints and to seal the tuning screws to eliminate stray electromagnetic emissions.

C-Band and Ku-Band Redundancy Switches

Redundancy switching is used on the front end of the receiver. The Ku-band and C-band receivers employ latching-type waveguide and coaxial switches, respectively, with a switching time of 50 ms at 28 Vdc. Telemetry outputs are provided for each switch position. Isolation between ports is > 60 dB. Similar switches are used on TDRSS, INTELSAT VII, ERS-1, SCS-1, ANIK-E, and other satellite programs.

Receivers

The receivers include a low-noise amplifier (LNA), mixer, local oscillator amplifier, and an IF amplifier. The designs for both the Ku-band and C-band receivers have been used on TDRSS, MILSTAR, DSP, and ERS-1.

The Ku-band LNA has waveguide input and coaxial output, and uses hermetically sealed amplifier gain stages as an integral part of the assembly. The LNA features waveguide-to-microstrip transition with a maximum insertion loss of 0.3 dB and GaAs HEMT devices in the amplifiers. The input gain stage has a noise figure of less than 1.5 dB at room temperature. The receiver meets the EOL noise figure of 2.4 dB maximum. Similar performance has been recorded for the C-band receiver.

The HEMP devices, which have been tested extensively on TDRSS, withstand overdrive conditions without

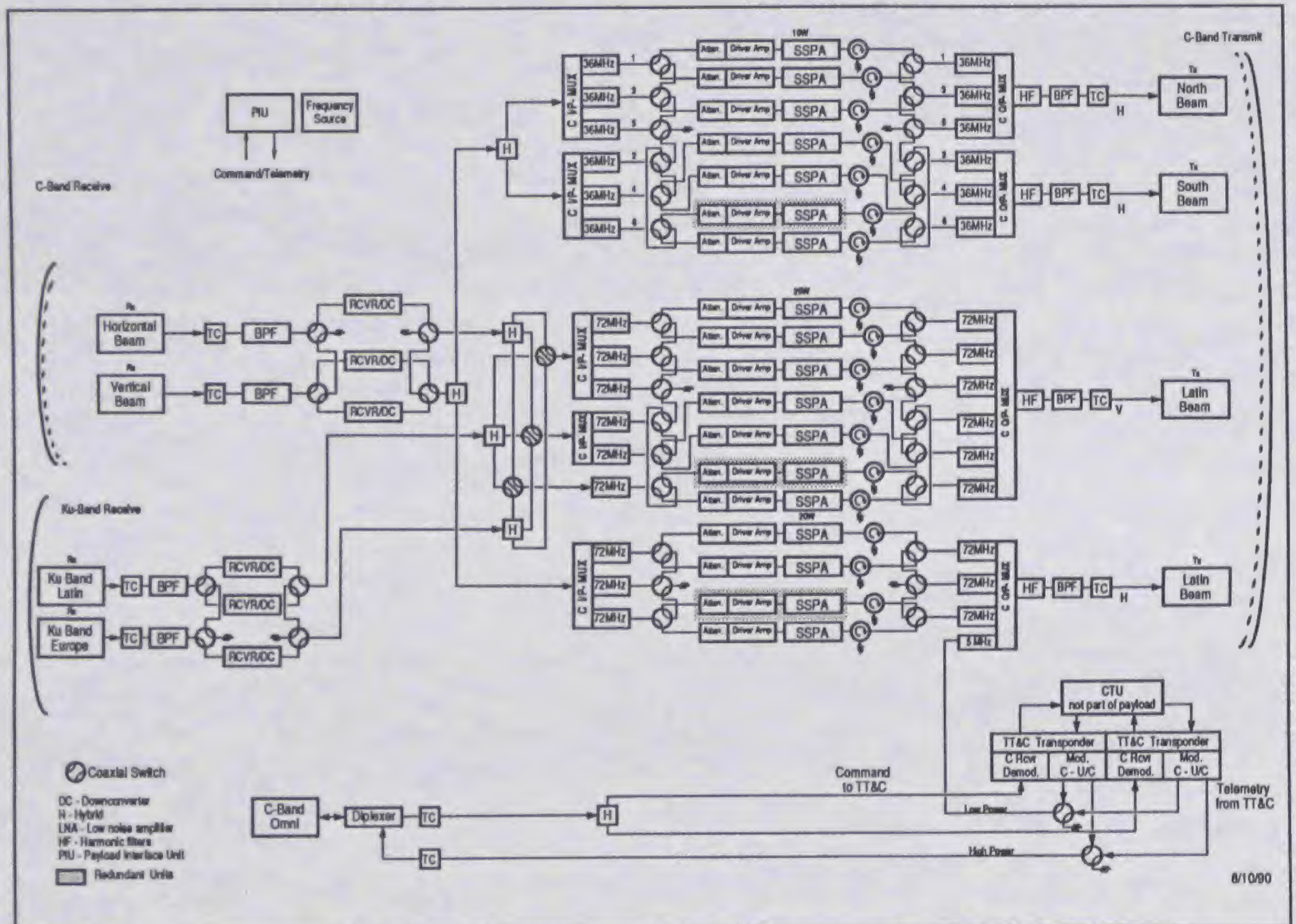


Figure 2.5-1 Payload Block Diagram

performance degradation. Gate currents are controlled during overdrive conditions to ensure long-term reliability.

The downconverter consists of an LO amplifier, a mixer, and an IF amplifier. The unit has been used on TDRSS. The prepackaged devices, including GaAs FETS and MESFETS, are bonded to Kovar carriers and use alumina substages. The mixer and mixer isolators are configured as an iso-mixer assembly with hermetically sealed quad diodes. This technique minimizes interface discontinuities that affect phase and group delay in the operating passband and eliminates the need for hermetic sealing between the case assembly and cover. EMI gaskets are used between the lid and housing, a packaging design that has proven successful on both the TDRSS and DSP (MDM) programs.

The bandpass filter in the IF chain is of a mechanical combline structure. The advantages are low insertion loss, excellent out-of-band rejection, skirt selectivity, and low phase and group-delay variations.

Amplifier temperature compensation is accomplished by using prepackaged PIN diodes on a microstrip circuit.

Input Multiplexers

The input multiplexers (IMUXs) separate the channels prior to input into the power amplifiers. Each multiplexer consists of the appropriate channel filters combined with a coupling manifold. The filters, mounted on a common manifold, consist of quasi-elliptical function cavities with group-delay equalization. The design has been modified for this frequency range from IMUXs flown on TDRSS and DSP, among others.

The IMUX uses a thin-wall Invar design to minimize weight. The input manifold and output cavities have an SMA transition for compatibility with the interconnecting coaxial cabling. Each of the filters are mechanically assembled with high compression seals and silver plated to produce low insertion losses. The use of silver-conductive epoxy assures electro-magnetic compatibility.

Driver Amplifier Input Switch Assembly

The switched driver amplifier assembly utilizes hybrid microwave integrated circuits, similar to those on TDRSS, DSP, and MILSTAR. The inputs to the driver amplifier are switched for redundancy by solid-state PIN diode switches. These are of a C-transfer configuration. The switch states are controlled by TTL-compatible drivers internal to the switch. The switch circuits and diodes are placed in a below cutoff waveguide channel to meet the 60-dB isolation requirement. The transfer function is accomplished by a three-shunt diode design. Semi-rigid cables interconnect the transfer switches. Passageways in the housings allow the cable to pass beneath the RF sections. The driver circuits are located in a cavity below the RF switch sections. Each driver is controlled by a TTL parallel word. Two drivers used simultaneously provide the C-transfer switch configuration. Where it is appropriate, only one path may be turned on at any one time. The C-transfer configuration allows more flexibility than mechanical switches in selecting a RF path. This switch design has been used extensively on several satellites where high-order switching functions are required. The reliability is equal to mechanical switches by using series/parallel diode configurations and redundant driver circuits. These devices are packaged in the driver amplifier modules to eliminate external interconnecting cables, thereby enhancing their reliability.

Driver Amplifier

The driver amplifier design uses conventional hybrid microwave integrated circuits (HMIC), similar to an integrated driver amplifier that has been qualified and flown on many TRW programs (TDRSS, DSP, and MILSTAR). The HMIC driver amplifier is a well-established TRW product line, and its low-power consumption enhances the performance of our high-efficiency SSPAs. PIN diode attenuators situated between a pair of Lange couplers set the signal level and provide temperature compensation in the driver amplifier, guaranteeing stability over the temperature range. The driver network for the attenuators utilizes a five-bit parallel digital word from the PIU to set the attenuators to the required values.

Solid State Power Amplifiers

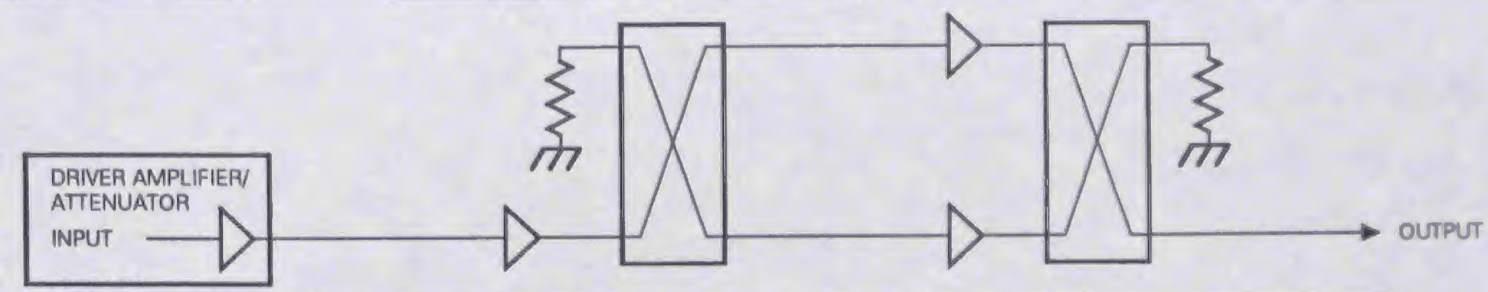
The SSPAs use Fujitsu (FLM3742-10) 10-watt devices for the final output stages and are driven by a 2-watt Fujitsu (FLM3742-2) with a demonstrated power added efficiency of 47.7% (Figure 2.5-2). A breadboard model of the 20-watt amplifier has been tested for efficiency and IM products as a function of backoff. The efficiency of the SSPA is over 41.5% with a power gain greater than 14-dB and a maximum output of 12 watts for each transistor. The SSPA efficiency includes a minimum converter efficiency of 89%. The converters will be bought from FEI, which has a full line of qualified units. The Fujitsu devices are also fully qualified and have been flown on multiple satellite programs. The other components of the SSPA (couplers, bias networks, substrates, and the mechanical layout) are derived from a C-band SSPA used on DSP.

SSPA Breadboard

We breadboarded the proposed SSPA using typical Fujitsu devices that were not screened. The breadboard used a pair of FLM-3742-10s driven by a 2-watt device. The two-stage amplifier produced 43.69 dBm at the output with 46.3% added efficiency at the 1.5-dB gain compression point (Figure 2.5-3). The driver amplifier included a temperature-compensation network that kept the driver level to the SSPA constant irrespective of the temperature. An output level of 43.69 dBm provided a 0.7-dB margin, ensuring more than 20 watts of power at EOL. Figure 2.5-4 shows the test set used to measure breadboard performance. All power and IM data were taken with the baseplate at 40°C (Figure 2.5-5).

Output Multiplexers

The output multiplexers (OMUXs) combine the individual channels into the appropriate beams for downlinking with a low insertion loss. The OMUXs set the transmit frequency



	FLK022WG		FLM3742-1			FLM2342-10			
GAIN/LOSS (dB)	15		14	-3.2		12.5		2.8	
POWER LEVEL (dBm) 1.9		16.9	30.9		27.7/DE		40.2/DE		43.0
POWER LEVEL (W)		0.049	1.23		5.88		10.41		20
EFFICIENCY			50%			50%			
POWER (dc) (W)			2.36			39.5			41.86
IM3 (dBc)			20			20			

OUTPUT POWER = 20 WATTS

EFFICIENCY = 47.7% (WITHOUT CONVERTER)
= 41.5% (87% CONVERTER) (EOL)
= 43% (90% CONVERTER) (BOL)

17351 191

Figure 2.5-2. 20-Watt SSPA Power and Efficiency

bands for the transmitters, provide rejection at the receive frequencies, and limit noise and interference signals. Each OMUX is a complete and tested assembly with coaxial inputs and outputs, similar to those used on SCS-1, ANIK-E, and SATCOM-K.

The output from the multiplexers is followed by a corrugated waveguide low-pass filter in cascade with a passband filter to provide the required rejection at the harmonic frequencies. The OMUXs and bandpass filters are constructed from thin-wall Invar for light weight with a low coefficient of thermal expansion across the required temperature range. Extensive testing, along with careful manufacturing attention, assures that no problems exist due to thermal variations and eliminates multipaction. We have solved problems of this nature on such programs as DSCS II, TDRSS, MILSTAR, and many others.

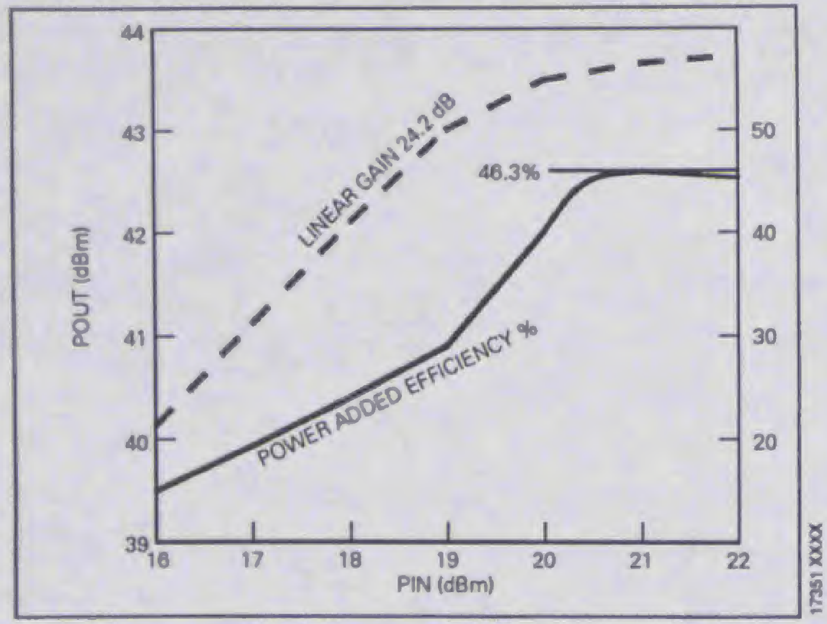


Figure 2.5-3. 20-Watt SSPA Breadboard Testing

Master Oscillator

The master oscillator supplies the basic frequency source for the local oscillators and other timing devices of the satellite. TRW has procured master oscillators from FEI, New York, for such programs as FLTSATCOM, MILSTAR, and DSP. On-orbit performance of this design has been excellent for over 15 years. The modified Pierce crystal oscillator uses a fifth overtone SC-cut premium Q-swept quartz crystal to achieve circuit stability and to minimize the effects of natural radiation. The oscillator is enclosed in a dewar flask and the temperature maintained in a dual oven for stability. The oscillator output is buffered, amplified and used to drive the direct synthesis frequency multipliers, which, in turn, create the local oscillators for the receivers. The prime output is used to provide timing to the TT&CS. Dual redundant units ensure the 12-year design life.

Payload Interface Unit (PIU)

The PIU is redundant and serves as the interface between the communications payload and the spacecraft telemetry and command system. It receives a serial input for commands and outputs a serial bit stream for telemetry. The serial format is a programmable interface utilizing a developed serial command controller (SCC). Serial input commands are stored, buffered and used to develop the binary commands for redundancy switching and the serial-to-parallel words for the driver amplifier attenuator settings. The telemetry section stores and formats the payload telemetry data and outputs it to the PCTU on command. The design is similar to that of the units used on TDRSS, but sized to be compatible with PAS-2 requirements.

Power Converters

The power converters used in the SSPAs and to supply power to the receivers, driver amplifiers, and master oscillators will be provided by FEI. These hybrid high frequency converters have been qualified and are presently being flown on ERS-1 and will be flown on LOCSTAR and DSP Block 23. The main control of the converters is an S-level hybrid switching regulator using pulse-width modulation (PWM) techniques to switch the input dc to high-frequency pulses to control the output voltage for the specified requirements. PWM is particularly beneficial in improving efficiency and

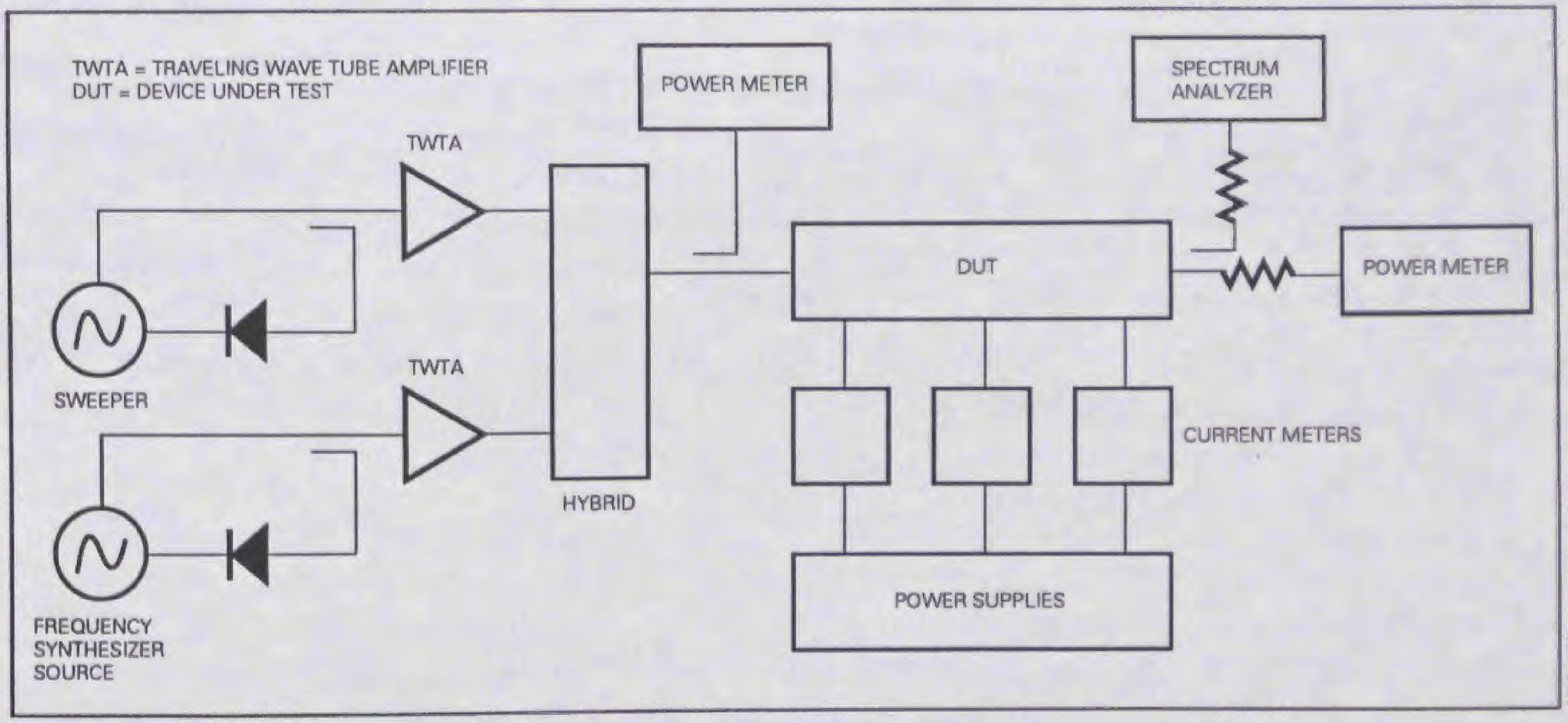


Figure 2.5-4. 20-Watt SSPA C-Band Test Set Block Diagram

PIN dBm	PIN MW	POUT dBm	POUT Watts	GAIN dB	Pdc Watts	POUT-PIN Watts	EFF %	PSAT dB
16	39.8	40.20	10.47	24.20	66.82	10.43	15.6	0
17	50.1	41.20	13.18	24.20	66.82	13.13	19.6	0
18	63.0	42.20	16.59	24.20	66.82	16.52	24.7	0
19	79.4	43.00	19.95	24.00	66.01	19.81	30.1	0.20
20	100.0	43.48	22.28	23.48	56.29	22.18	39.4	0.72
21	125.8	43.69	23.39	22.69	50.17	23.26	46.3	1.51
22	158.5	43.81	24.38	21.87	54.66	24.22	44.3	2.33

TWO-TONE MEASUREMENTS

PIN dBm	POUT dBm	IM3 dBc
18	41.1	18.8
19	41.9	17.4
20	42.4	16.5

17351 194

Figure 2.5-5. 20-Watt SSPA C-Band Data

reducing converter weight. The converters incorporate circuit protection both for the converter itself and the applied loads.

2.6 TRACKING, TELEMETRY, AND COMMAND (TT&C) TRANSPONDER

Figure 2.6–1 shows the RF portion of the TT&CS. Two receivers are always turned on to receive commands. There are two transmitters but only one is active. The units are redundant to avoid single–point failures. The digital portion of the TT&CS is discussed in Section 3.1.

Commands

The omni antenna receives commands at all times. One antenna with two active receivers prevents lock–out and improves reliability by avoiding the use of switches.

The RF transponder receives circularly polarized signals at 6.180 GHz and has a G/T of –41.5 dBi/°K. This value corresponds to an antenna coverage of ±100 degrees. During on–station operation, spacecraft attitude is tightly controlled and the G/T increases by about 3 dB. In either case, system margin is adequate (Figure 2.6–2).

The receiver operates with input flux densities between -90 dBW/m^2 and –65 dBW/M^2. The demodulator accepts three different frequency command tones and demodulates them as a *1*, *0*, or *execute*. The receiver also accepts ranging tones and turns them around for downlink transmission.

Telemetry

A 1–watt transmitter sends telemetry through the omni antenna during GTO with an EIRP of –5 dBW. This EIRP corresponds to a coverage area of ±100 degrees. An additional 3 dB is obtained when the spacecraft attitude is kept within ±70 degrees. During on–station operation, telemetry and ranging tones are transmitted via the Latin beam to prevent interference with other satellites. In this case, power from the transmitter is lower (0.1 watt) since the Latin beam gain is so much higher than the omni antenna gain.

The transmitter accepts bits from the command and telemetry processing unit (CTPU), and BPSK–modulates them on a subcarrier, along with turned–around range tones. The range tones and telemetry are phase modulated and transmitted on a 3.955 GHz carrier.

Ranging

The receiver and transmitter are similar to existing designs for compatibility with existing ground stations. Four ranging tones are possible: 27.777 KHz, 3968.2 Hz, 283.4 Hz, and 35.4 Hz. The accuracy of the 27.777 KHz tone determines range resolution while the three lower frequencies resolve ambiguities.

Receiver/Demodulator

The receiver demodulates the input command signal and ranging tones. The command tones are then FSK–demodulated and sent to the CTPU for processing. The range tones are turned around and sent to the transmitter for downlink transmission.

The proposed receiver uses the RR–500 C–band dual receiver developed by Cubic and flown on SATCOM.

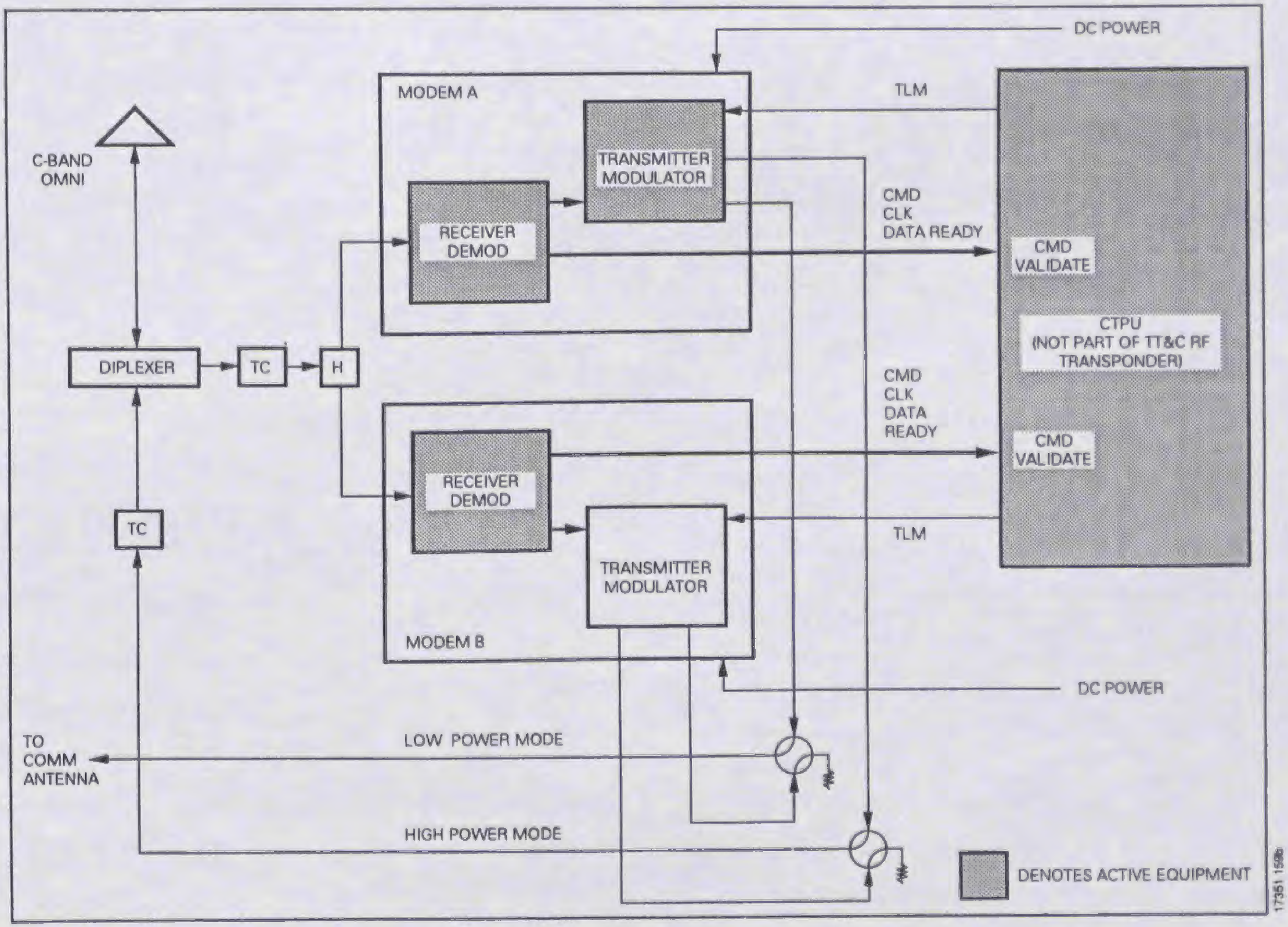


Figure 2.6-1. Tracking, Telemetry, and Command Subsystem RF Block Diagram

	COMMAND UPLINK	TELEMETRY DOWNLINK (OMNI)
FREQUENCY (GHz)	6.180	3.955
TRANSMITTER POWER (W)	300	1.0
CIRCUIT LOSS (dB)	1.5	2.0
TRANSMIT ANTENNA GAIN (dBi)	50.4 (1)	-3 (2)
EIRP (dBW)	**73.7**	**-5**
PATH LOSS (dB)	200.8	196.9
RECEIVE ANTENNA GAIN (dBi)	-3 (2)	46.5 (1)
RECEIVE NOISE FIGURE (dB)	14	2.5
G/T (dBi/K)	**-41.5**	**21.8**
DATA RATE (bps)	1000	1000
IMPLEMENTATION LOSS (dB)	4	4
REQUIRED Eb/No (dB)	**14.5 (3)**	**9.8 (4)**
MARGIN (dB)	**11.6**	**4.7**

(1) CORRESPONDS TO A 55% EFFICIENT 7-METER ANTENNA
(2) CORRESPONDS TO A ±100° ANTENNA COVERAGE ANGLE
(3) CORRESPONDS TO A BIT ERROR RATE OF 10 (-6) FOR NONCOHERENT FSK DEMODULATION
(4) CORRESPONDS TO A BIT ERROR RATE OF 10 (-5) FOR COHERENT PSK DEMODULATION

17351 1576

Figure 2.6-2. PAS-2 Command and Telemetry Link Budget Summary

Transmitter/Modulator

The transmitter BPSK-modulates telemetry on a subcarrier and sums it with the turned-around ranging tones. The telemetry and ranging then are phase modulated in the RF carrier and transmitted.

The proposed transmitter also uses existing equipment. Cubic originally developed and flew the TT-401 dual C-band transmitter on the SATCOM program starting in 1974. Some modifications were made to the transmitter in 1980, resulting in the T-404.

3. SPACECRAFT

Six subsystems comprise the spacecraft, each of which is described in this section.

3.1 TRACKING, TELEMETRY, AND COMMAND

The tracking, telemetry, and command subsystem (TT&CS) encompasses C-band tracking, telemetry and command. Fully redundant equipment ensures no single point failure can compromise mission success. C-band command processing operates in active redundancy, ensuring command and control availability. Figure 3.1-1 is the TT&CS block diagram. The TT&C transponder design is discussed in Section 2.7.

The TT&CS complies with its requirements (Figure 3.1-2). It receives and processes commands for spacecraft control and processes and transmits spacecraft data. The TT&C also controls the spacecraft onboard computer (OBC) and its interfaces to telemetry data and command control.

Subsystem Description

The C-band antenna is omni-directional righthand circularly polarized with a coverage of ±100 degrees at the 3-dB point.

The C-band diplexer routes the uplink signal from the antenna through a bandpass filter, a 3-dB hybrid coupler, and separate isolators to the two receivers. The downlink signal passes from either transmitter through a transmit bandpass filter to the antenna.

The phase-locked C-band receiver acquires the uplink signal frequency modulated with digital command signal and ranging tones. A redundant receiver operates at 6.180 GHz frequency. The receiver demodulates the digital commands and ranging tones, and applies the ranging signal to the C-band transmitter and 1 kbps command data to the redundant command telemetry processing unit (CTPU).

The transmitter biphase modulates in an internal subcarrier oscillator and accepts formatted NRZ-M PCM data. The subcarrier is summed with the ranging tones from the companion receiver to form a composite baseband signal that is phase modulated on a stable RF carrier. The carrier frequency is 3.955 GHz. The omni-antenna transmits during GTO, and the Latin beam high-gain antenna is used during on-station operations.

As an option, the KIR-123 module will decrypt and authenticate cipher text commands using the KIR-23A cryptographic algorithm. We will configure the PAS-2 module for a commercial binary format with authentication. A keyway KIV-123A VLSI circuit developed by Motorola will be used for decryption and authentication. The design provides a nonvolatile, programmable read-only memory (PROM) to store up to 64 cryptovariables (key index). Selection of a specific key index is by ground command. A decryptor bypass is provided by a critical command to enable clear text command processing. The false command probability with

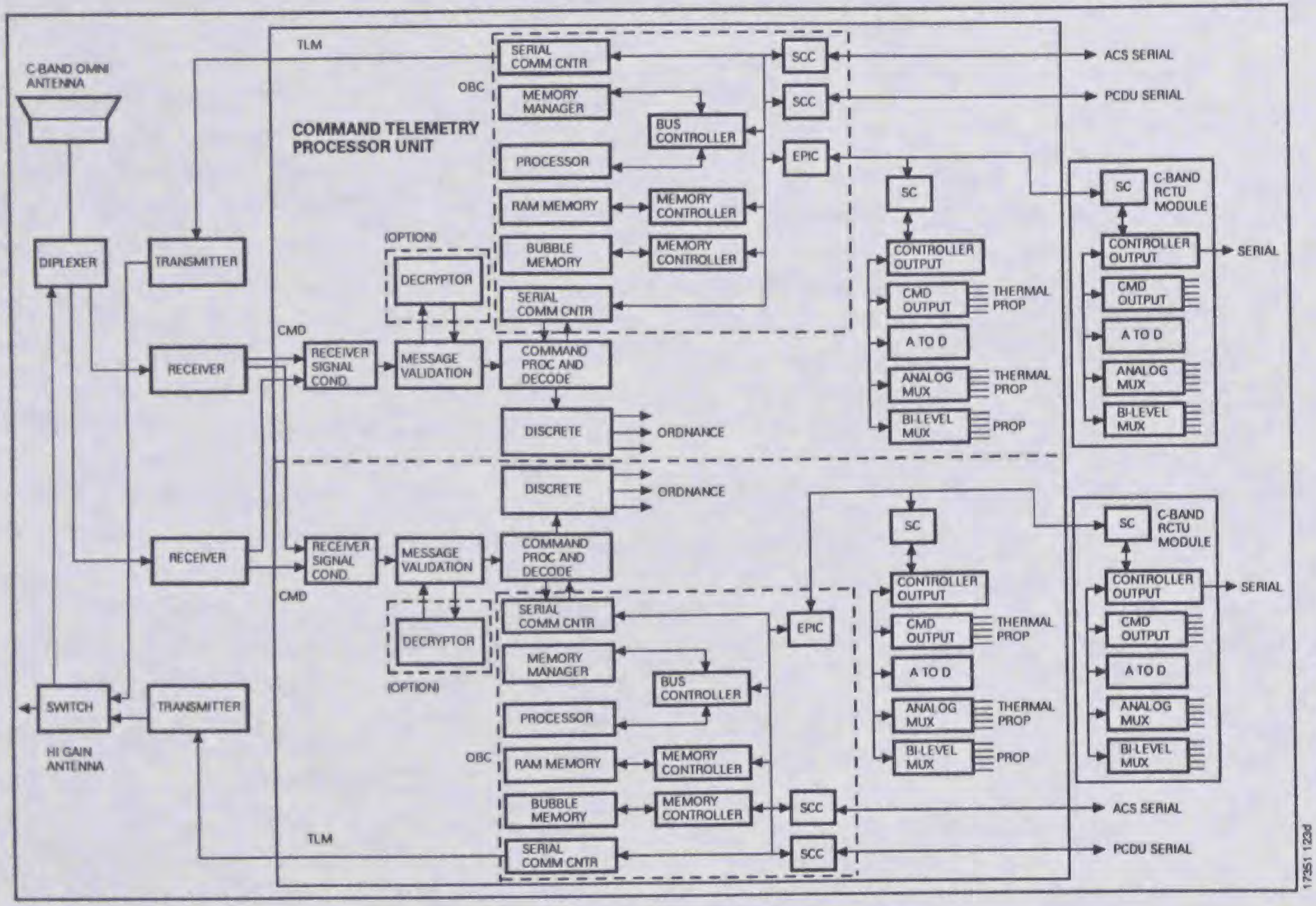


Figure 3.1-1. Tracking, Telemetry and Command Subsystem

REQUIREMENT	DESIGN COMPLIANCE
COMMAND	
ANTENNA COVERAGE: ALL MISSION PHASES, ± 100 DEGREES	± 100-DEGREE COVERAGE, -3 dB POINTS
RANGE TRACKING	FOUR RANGING TONES RECEIVE AND RETRANSMIT TO GROUND STATION
RECEIVE FREQUENCY: 6.180 GHz	6.180 GHz RECEIVER
1×10^{-6} BIT ERROR RATE	6.0 dB MARGIN AT 1.0 kbps
NO SINGLE-POINT FAILURE	COMMAND EQUIPMENT PROVIDES REDUNDANCY FOR EACH UNIT
CONTROL OF ALL SPACECRAFT OPERATING MODES	299 COMMANDS PROVIDED TO CONTROL THE SPACECRAFT
UNIQUE SPACECRAFT COMMAND ADDRESS	DECRYPTOR VERIFIES EACH COMMAND BY PROVIDING A UNIQUE CODE FOR EACH COMMAND. A SPACECRAFT ADDRESS ASSIGNED TO EACH SPACECRAFT
COMMAND AUTHENTICATION	A 21-BIT UNIQUE AUTHENTICATION CODE TRANSMITTED WITH EACH COMMAND MESSAGE AND DECODED BY THE DECRYPTOR
REDUNDANCY AND CROSS-STRAPPING	REDUNDANCY PROVIDED FOR EACH UNIT AND INPUTS AND OUTPUTS CROSS-STRAPPED
OVERRIDE OF ANY AUTOMATIC COMMAND FUNCTION	ALL AUTOMATIC FUNCTIONS PROVIDE OPERATION PAUSES FOR OPERATOR ASSESSMENT AND CONTROL. UPLINK COMMANDS HAVE PRIORITY OVER INTERNAL AUTOMATIC COMMANDS
COMMAND DATA FORMAT	DECRYPTOR FORMAT – PRE-AMBLE: 9-1s – VCC: 21 – FILL: 1 – DATA: 32 COMMAND FORMAT – BARKER CODE: 8 – SPACECRAFT ADDRESS: 5 – OP CODE: 6 – DATA: 12 – PARITY: 1
COMMAND DATA BIT RATE: 1000 bps	COMMAND DATA BIT RATE: 1000 bps
DECRYPTION	KIR-123 DECRYPTS COMMAND MESSAGE

17351-127c (1 of 2)

Figure 3.1-2. TT&C Subsystem Requirements and Performance (1 of 2)

REQUIREMENT	DESIGN COMPLIANCE
NO DECODER PRIMARY POWER SWITCHING	COMMAND VERIFIER AND DECODER, BOTH PRIME AND REDUNDANT, CONNECTS TO SPACECRAFT POWER BUS WITHOUT SWITCHING
HAZARDOUS COMMANDS	HAZARDOUS COMMANDS ROUTED THROUGH DEDICATED COMMAND VERIFIER/DECODER (DOES NOT USE THE COMPUTER); BOTH AN ENABLE AND EXECUTE COMMAND REQUIRED
10% SPARE CAPACITY	A 10% SPARE CAPACITY PROVIDED FOR EACH TYPE OF COMMAND OUTPUT
TELEMETRY	
TRANSMIT FREQUENCY 3.955 GHz	3.955 GHz TRANSMITTER
NO SINGLE-POINT FAILURE	TELEMETRY EQUIPMENT PROVIDES REDUNDANCY FOR EACH UNIT
MONITOR, CONTROL, EVALUATE SPACECRAFT PERFORMANCE	503 MEASUREMENTS PROVIDED TO MONITOR, CONTROL, AND EVALUATE THE SPACECRAFT
REDUNDANCY AND CROSS-STRAPPING	REDUNDANCY PROVIDED FOR EACH UNIT AND INPUTS AND OUTPUTS CROSS-STRAPPED
TELEMETRY FORMAT	TELEMETRY FORMAT – MINOR FRAME: 64 WORDS (8 BITS) – SUB COMMUTATION: 64 WORDS (8 BITS) – MAJOR FRAME: 64 MINOR FRAMES
TELEMETRY BIT RATE SHALL BE 1000 bps	TELEMETRY BIT RATE: 1000 bps
MULTIPLE TELEMETRY FORMATS	TELEMETRY FORMATS STORED IN BUBBLE MEMORY TO SUPPORT GROUND TESTING, TRANSFER ORBIT OPERATIONS, ON-ORBIT OPERATIONS, AND ON-ORBIT SPACECRAFT CHECKOUT. THESE FORMATS CAN BE ALTERED BY GROUND UPLOADS
TELEMETRY DWELL MODE	TELEMETRY PROVIDES A DWELL MODE FOR TWO MEASUREMENTS; ANY TELEMETRY MEASUREMENT CAN BE SELECTED FOR DWELL FROM THE PREPROGRAMMED BUBBLE MEMORY OR CHANGED BY UPLINK DATA
THE TELEMETRY ACCURACY SHALL BE 5%. THE A/D RESOLUTION SHALL BE 8 BITS	TELEMETRY ACCURACY LESS THAN 5%, WHICH INCLUDES ERRORS CONTRIBUTED BY TRANSDUCERS, A/D CONVERSION , CROSSTALK, OFFSET TEMPERATURE, AGING DRIFT, VOLTAGE VARIATIONS, EMI, SIGNAL-SOURCE STABILIZATION, AND IMPEDANCE VARIATIONS
THERMISTOR CALIBRATION	THERMISTOR RESISTANCE VARIATION WITH TEMPERATURE NOT STANDARDIZED. THEREFORE, TRANSFER FUNCTION OF EACH THERMISTOR DETERMINED BY TEST AND CALIBRATION USED FOR DATA REDUCTION
10% SPARE CAPACITY	10% SPARE CAPACITY PROVIDED FOR EACH TYPE MEASUREMENT

17351-127c (2 of 2)

Figure 3.1-2. TT&C Subsystem Requirements and Performance (2 of 2)

authentication is 5.9×10^{-19}; in the clear mode, it is 7.0×10^{-11}.

The CTPU's dedicated command processor has four primary functions:

- Validate uplink commands and route them to dedicated critical outputs or the OBC
- Provide discrete and serial digital commands for system configuration
- Validate uplink data to the onboard computer
- Provide onboard computer access to the command processor.

The redundant serial communication controller (SCC) buses tie the system together. Commands are fed to all remotes simultaneously.

The CTPU may execute a number of critical commands without transmission through the redundant data bus. These hazardous or configuration commands operate critical functions and configure the TT&CS. The RCTUs handle all other command functions.

The CTPU includes an OBC as a second command source (Figure 3.1-1). The OBC can acquire telemetry data and issue commands without impacting uplink or downlink TT&C functions. Uplink commands take precedence over OBC commands.

The OBC has four primary functions:

- Provide ACS, EPDS, thermal, and propulsion control
- Route commands to RCTUs
- Downlink telemetry formatting and data acquisition control of RCTUs
- Issue onboard stored commands.

The OBC features computation capability, active memory, nonvolatile memory, and input/output circuits.

The central processing unit (CPU) is an existing 1750A processor chip set and an application-specific integrated circuit (ASIC) that interfaces the microprocessor to the Nu-bus parallel intermodule interconnect. A watchdog timer detects faults and performs redundancy switching, and a start-up read-only memory (ROM) initializes code and data. The ASIC extends the memory addressing of the processor to include all of the capabilities of the 32-bit Nu-bus. Throughput is approximately 500,000 instructions per second using the Defense Avionics Instruction Set Mix.

A serial input/output (I/O) bus serves spacecraft interfaces. The SCC consists of a receiver and transmitter, providing duplex operation. It is programmable for compatibility with many interface circuits. The direction and polarity of the interface handshake signals are programmable, as are word and message lengths, data rates, and interface protocol. Additionally, optional use of parity or a cyclic redundancy check (CRC) detects errors.

The OBC, which controls all data acquisition from the RCTU, performs telemetry processing and control. Ground command can alter fixed formats in the bubble memory. The RCTUs provide signal conditioning, multiplexing, digitizing, and bi-level and serial digital interfaces for acquiring spacecraft data. A versatile system, CTPU telemetry can be configured to suit spacecraft needs. Modular construction and OBC programming allow easy expansion of, or format changes to, telemetry capability. Four formats, all of which can be altered by ground uploads, provide unlimited flexibility.

The telemetry system master unit is the OBC, which gathers telemetry data from remote units for generation of output format or for spacecraft computations. The OBC combines telemetry data with fixed synchronous words, status words, and vehicle time information. Furthermore, it is capable of dwelling on any telemetry input preemptable word slots under control of serial command from the command decoder. The serial command provides the OBC with operation and channel byte codes. The telemetry format contains 64 bytes of minor frame words and 64 bytes of subcommutation words, while the major frame format has six subcommutation words. The telemetry bit rate is 1000 bps.

Spacecraft Software

The PAS-2 software for ACS functions, EPDS management, thermal management, propulsion pressure regulation, and telemetry processing is based on existing algorithms developed in Ada and implemented in hardened bubble memory.

The software interface to the PAS-2 is through programmable I/O ports provided by the OBC. The software accesses telemetry data for information and controls satellite functions through the satellite command unit.

A system-service top-level computer software component provides support utilities, including a programmable priority table (that reconciles scheduling conflicts) and a task scheduler. A functionally modular software design ensures traceability. Using Ada results in early identification of errors in requirements and design and reduces schedule risk. Ada also expedites software integration through strict data-type consistency checking and interface isolation.

Verification testing will satisfy all software and interface requirements and specifications. The verification process begins with the development of test procedures, a requirements test matrix, and thread tests for the ACS, telemetry, EPDS, and thermal functions. Tests employ simulated operational scenarios.

Software will be exercised in the 1750A processor interfaced with PAS-2 vehicle simulation, which consists of models of relevant satellite elements and physical processes (power, attitude control, redundancy switching, thermal, sensors, and actuators) and interfaces with command and telemetry data. The processor simulator features symbolic debugging capability, simplifying the verification process.

3.2 ATTITUDE CONTROL

The attitude control subsystem (ACS) provides three-axis control during transfer and in GEO throughout the 12-year design life. A pitch momentum bias reaction wheel assembly (RWA) controls on-orbit pitch/roll to a 0.10-degree pointing accuracy (1 sigma), similar to FLTSATCOM. Functionally redundant electrical and mechanical systems provide for avoidance of single-point failures. Our design includes a safe-haven mode for backup protection.

Subsystem Operation

Booster Separation. Before separation, the booster orients the vehicle so that the omni antenna can communicate with earth and the earth is visible to the conical scan earth sensors. The reaction wheel is then activated. After separation, the earth sensors, reaction wheel, and the reaction control system (RCS) maintain vehicle attitude.

Earth/Sun Acquisition. After solar array deployment, the solar arrays are commanded to the desired sun vector orientation to receive solar power throughout GTO. The reaction wheel and RCS thrusters maintain attitude control with earth/sun sensor data used for attitude reference. Proper orientation of the conical scan earth sensor allows continuous earth viewing from GTO to GEO (Figure 3.2-1).

Geosynchronous Transfer Orbit. During GTO coast phases, the earth sensors, reaction wheel, and RCS thrusters maintain attitude control. Fine sun sensors mounted on the spacecraft body at proper orientations provide accurate yaw data for control during apogee burns. The main liquid apogee engine (LAE) is used to accomplish apogee burns. Sun and earth sensors provide the reference to orient the vehicle and engine in the desired velocity vector direction. The sensors, in conjunction with the RCS system, achieve velocity vector pointing to within 0.3-degree accuracy (requirement is 0.5 degree or less). Apogee burns occur over several orbits, and after the final burn the vehicle is reoriented to nadir pointing.

Sixteen RCS thrusters provide redundant pitch, yaw, and roll control as well as momentum dumping and stationkeeping (Figure 3.2-2A). Four canted west-stationkeeping thrusters provide fine pitch momentum dumping. For north-south stationkeeping, four south-facing thrusters fired at appropriate GEO phases maintain orbital inclination. These four thrusters also control attitude during stationkeeping maneuvers.

Figure 3.2-2B compares control torque capabilities to expected maximum disturbances during apogee burn firings. A center-of-gravity offset of 0.5 inch and thrust misalignment angles of 0.25 degree were employed in computing disturbance torques. The design satisfies control requirements.

Normal Mode. After GEO insertion using the LAE, the vehicle is rotated to the normal on-orbit orientation with the yaw axis pointing toward nadir and the pitch axis normal to the orbit plane. The antennas are deployed after satisfactory achievement of the normal mode. Pitch control is maintained using the RWA pitch wheel control, with 0.1-pound RCS thrusters used for momentum dumping. Pitch momentum bias stiffness controls roll and yaw, with 0.1-pound unloading thrusters removing accumulation of momentum (Figure 3.2-3). This well-proven and low-cost method of attitude

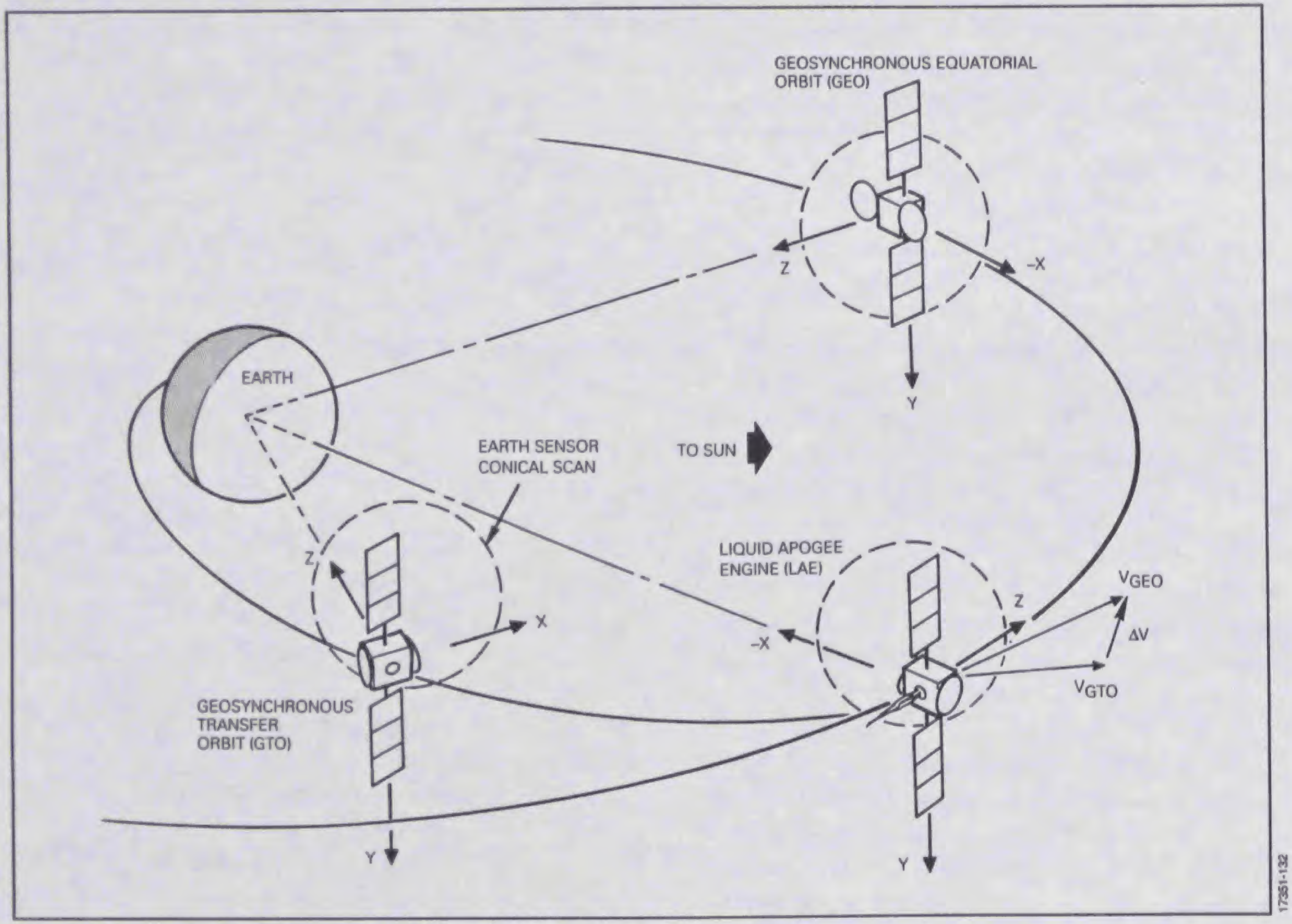
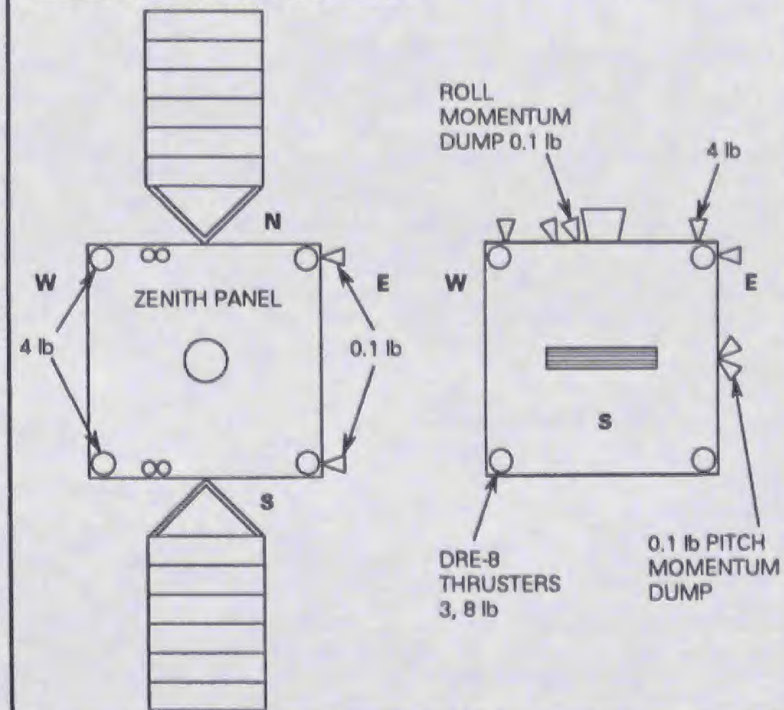


Figure 3.2-1. Satellite Orientation During GTO and GEO

A. LOCATION OF 16 THRUSTERS



B. CONTROL TORQUES

APOGEE BURN		
	DISTURBANCE TORQUES* (ft-lb)	CONTROL TORQUE (ft-lb)
PITCH	5.5	24
YAW	0.1	24
ROLL	5.5	24

*ASSUMES 0.5 INCH CENTER-OF-GRAVITY OFFSET PLUS 0.25 DEGREE THRUST MISALIGNMENT

17351-124b

Figure 3.2-2. RCS Thrusters

control has been used for over a decade on FLTSATCOM satellites.

Backup Velocity Increment Mode. The RCS thrusters are oriented to furnish backup velocity increments if the apogee engine malfunctions. Multiple orbits and apogee burns using onboard dual-reaction engines (DRE-8) can be activated to attain GEO if a malfunction occurs late in the burn.

Block Diagram

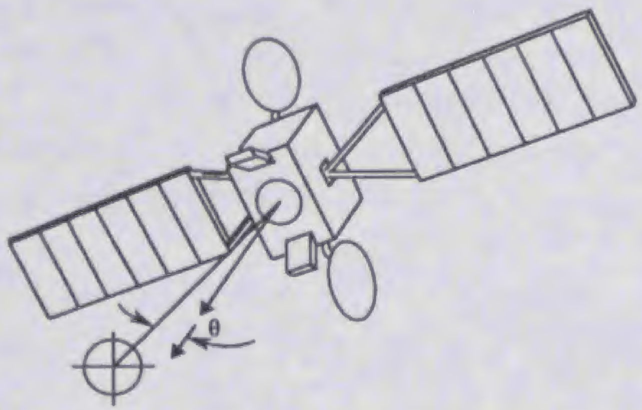
Functionally redundant electrical and mechanical subassemblies of the ACS system provide for elimination of single-point failures. Two conical scan earth assemblies are included, a primary sensor for on-orbit operations and a redundant unit as a backup. A single conical scan sensor provides pitch/roll sensing with an automatic sun/moon interference rejection operation (Figure 3.2-4). . The OBC of the TT&CS CTPU (Section 3.1) estimates yaw attitude using ACS algorithm and logic operations and attitude determination equations.

A pitch momentum bias RWA by Honeywell controls on-orbit spacecraft attitude. A second RWA is included for redundancy. This fully developed and qualified assembly has flown for over a decade on FLTSATCOM.

3.3 ELECTRICAL POWER AND DISTRIBUTION

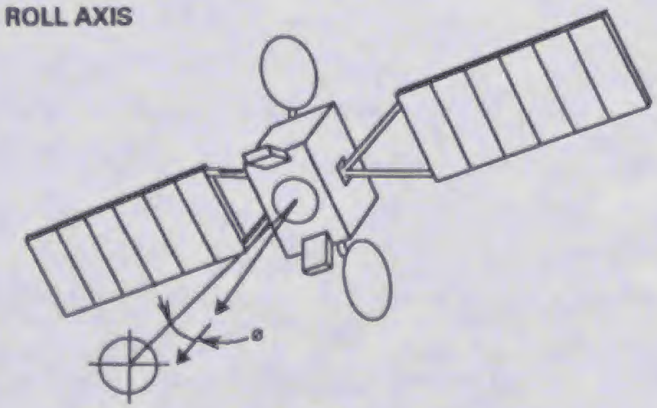
The electrical power and distribution subsystem (EPDS) generates, stores, and distributes the electrical power for the spacecraft (Figure 3.3-1). A silicon photovoltaic solar array generates power during sunlight to support spacecraft

A. PITCH AXIS



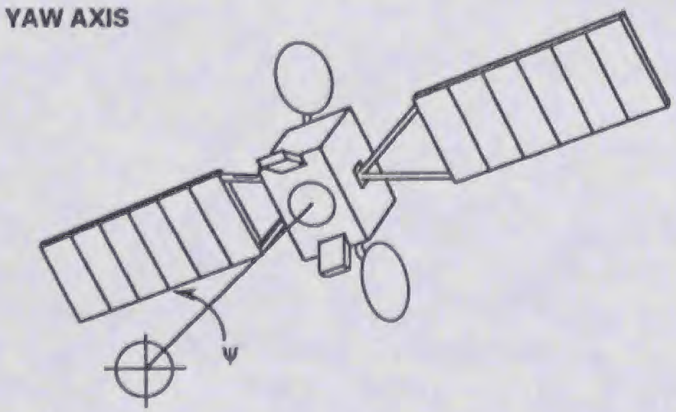
- PITCH ERROR (θ) DETECTED BY EARTH SENSOR
- REACTION WHEEL ACCELERATES TO PRODUCE CORRECTIVE TORQUE
- REACTION WHEEL SPEED VARIATIONS CEASE WHEN ERROR RETURNS TO NULL
- SECULAR PITCH DISTURBANCES CAUSE REACTION WHEEL SPEED CHANGE FROM BIAS VALUE
- PITCH THRUSTERS FIRE PULSE AT WHEEL SPEED LIMIT TO UNLOAD ACCUMULATED MOMENTUM

B. ROLL AXIS



- PITCH MOMENTUM BIAS STIFFNESS MAINTAINS GYROSCOPIC ROLL STABILITY
- EARTH SENSOR DETECTS ROLL ERRORS (ø) CAUSED BY DISTURBANCE TORQUES
- ROLL MOMENTUM DUMP THRUSTERS PRECESS MOMENTUM VECTOR RESULTING IN ROLL ERROR REDUCTION

C. YAW AXIS



- PITCH MOMENTUM BIAS STIFFNESS MAINTAINS GYROSCOPIC YAW STABILITY
- YAW ERRORS (ψ) CAUSED BY DISTURBANCE TORQUES TRANSLATE INTO ROLL ERRORS AFTER A QUARTER ORBIT AND ARE REMOVED BY THE ROLL SYSTEM

17351 1296

Figure 3.2-3. On-Orbit Error Corrections

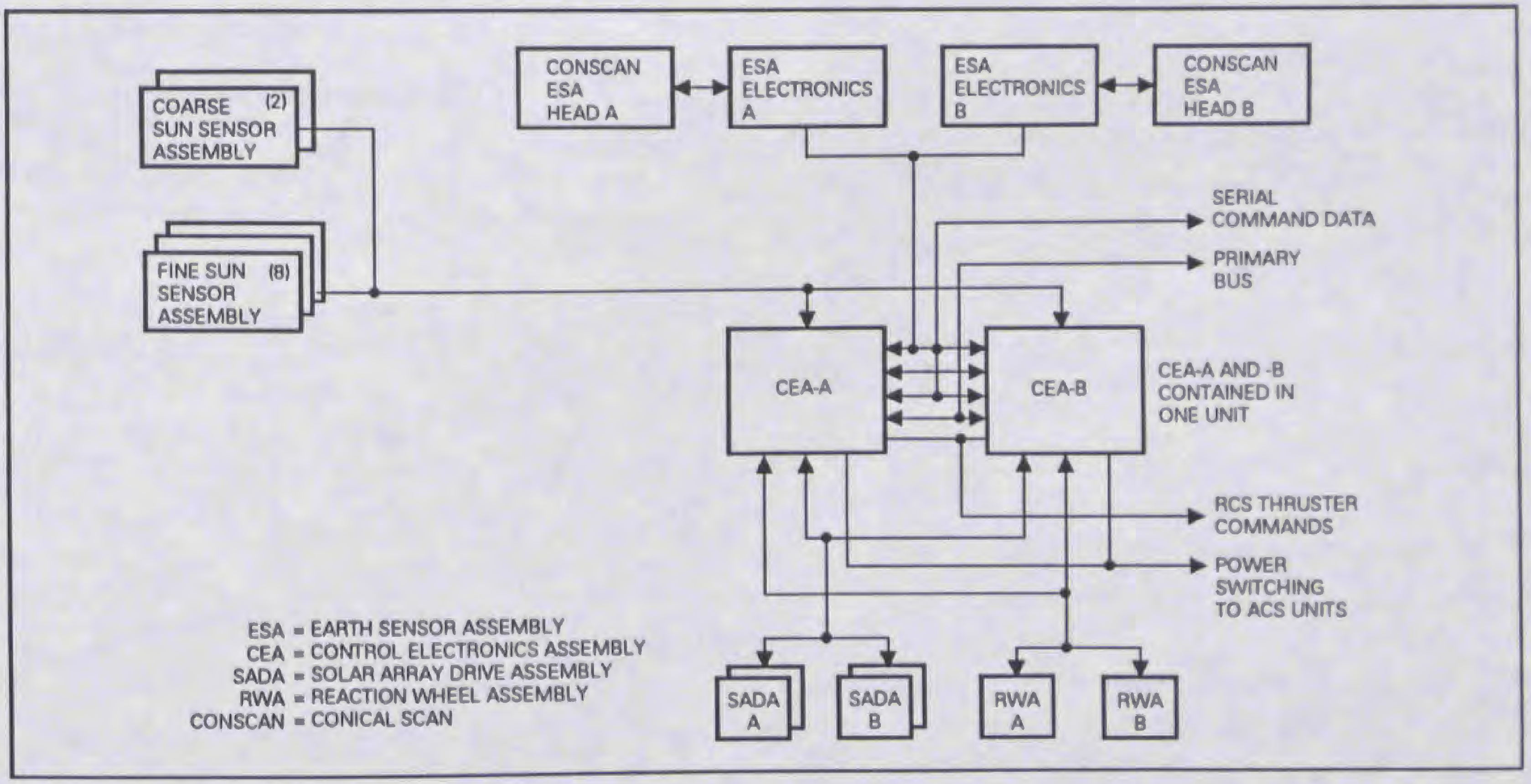


Figure 3.2-4. Attitude Control Subsystem Block Diagram

electrical loads and to recharge the nickel-hydrogen (NiH2) battery, which stores energy for operation during eclipses, power transients and momentary overloads, and fault clearing. A battery-regulated bus, which operates at battery voltage, provides stable, uninterrupted power and bus voltage control regardless of momentary overloads, equinox season eclipses, or lunar eclipses. The normal battery voltage from end of eclipse discharge to full charge ranges from 25 to 35 volts, providing 23 to 35 volts at the payload interfaces. The latter value allows for one NiH2 battery cell failed (and bypassed) and a 1-volt worst-case harness distribution loss between the battery and users. The OBC monitors and controls EPDS operations for spacecraft thermal and power subsystems; the command and telemetry subsystem provides ground control override.

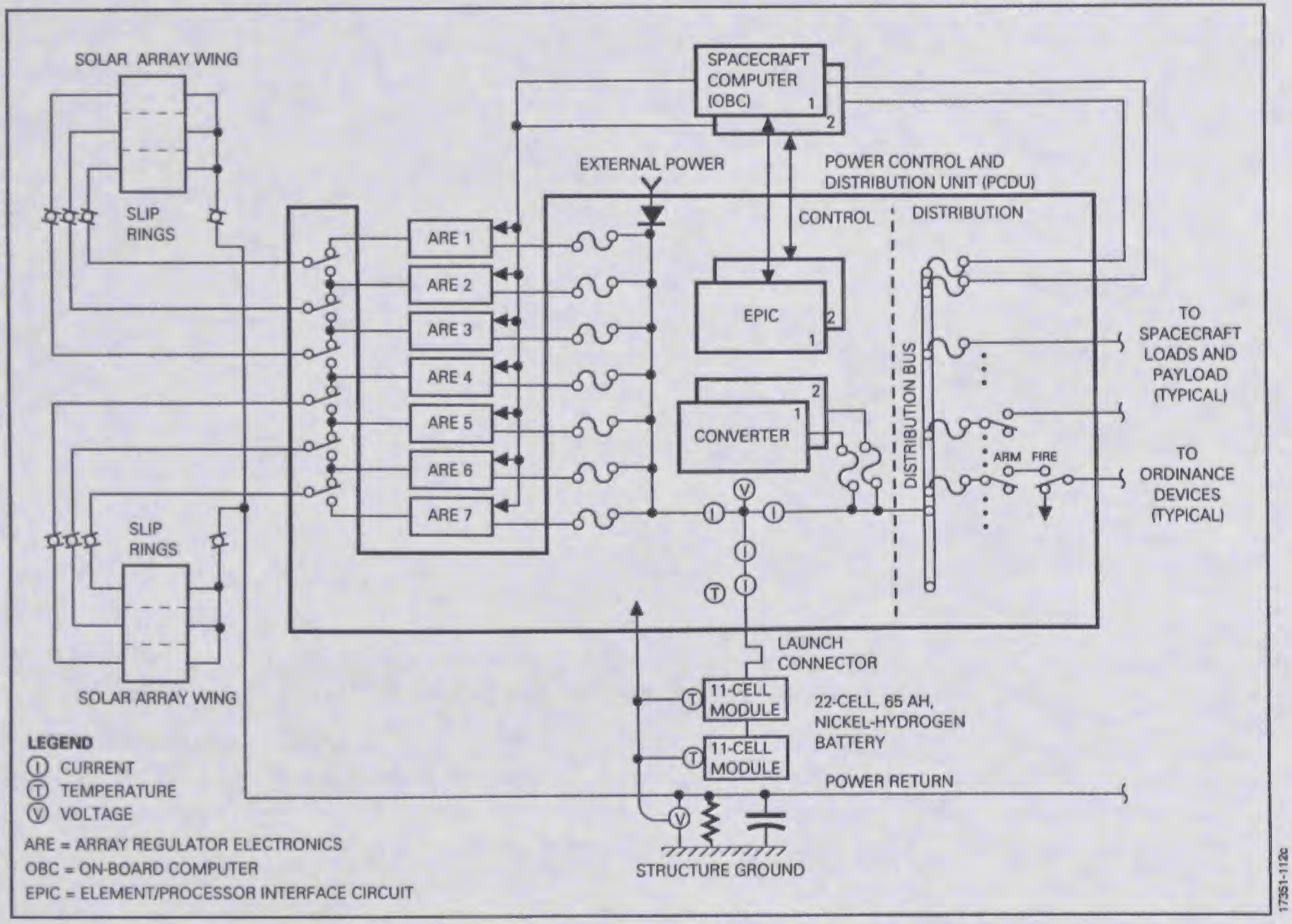


Figure 3.3-1. Electrical Power and Distribution Subsystem Architecture

Subsystem Description

The EPDS consists of two flexible, fold-out solar-array wings, one NiH2 battery, seven array regulator electronics (ARE) units, a power control and distribution unit (PCDU), and spacecraft electrical power and signal distribution harnesses. The battery features two 11-cell modules for better satellite mass balance.

The solar array is sized to generate payload, housekeeping, and battery recharge power during normal sunlight operation. It is subdivided into six electrically isolated sections (~200 watts each, end of life). Solar array open-circuit output range is 37 to 85 volts, depending upon solar array temperature. To transform output into the lower voltage and higher current levels required for battery charging, each array section connects to one ARE, which functions as a buck regulator to control bus voltage. The spacecraft computer controls pulse-width modulation of the parallel AREs, monitoring battery charging current and adjusting ARE operation accordingly. The computer also performs ampere-hour integration and selects the transition from battery charging mode to trickle charge mode.

The EPDS is single-fault tolerant. Fuses protect and isolate the main power bus from load and ARE faults. Careful attention is paid to the main bus wiring within the PCDU during manufacturing to ensure against potential internal fault modes. In addition, the structure is isolated from the primary power return wiring to further ensure that a power bus fault to structure is not catastrophic. Isolating the secondary power network from primary power input prevents fault propagation in the system. Battery cells are doubly insulated from the structure, and cell bypass diode circuitry assures continued battery operation in the event of an open cell failure. AREs are connected in a 7-for-6 configuration to accommodate failure. They are reconfigured by ground command.

Subsystem Equipment

Solar Array. Two identical solar array wings incorporating a flexible foldout photovoltaic blanket produce 1207 watts of power during the equinox seasons. This power supports a 1003-watt system load (including 111 watts for battery charging) with a 20.3% margin at EOL (12 years). At solstice, when the sun angle is offset by 23.5 degrees due to the seasonal movement of the sun-spacecraft vector, the solar array produces 1118 watts of power, more than enough to support a 914-watt spacecraft load (including 21 watts for battery trickle charging) with a 22.3% margin at EOL.

The solar array wings fold against the spacecraft during launch. They are deployed after separation from the launch vehicle to provide power for the transfer orbit.

On-orbit solar array drive assemblies (SADAs) provide a single axis of rotation to track the sun. Dual motor windings in each SADA give full electrical redundancy. The OBC monitors the sun sensors and controls SADA motor operation. Slip rings in the SADAs transfer power generated by the solar array wings to the spacecraft.

Battery. One battery is used for energy storage for PAS-2. It consists of 22 series-connected 65-Ah NiH2 cells configured into two 11-cell modules for improved spacecraft mass balance. The battery will supply 1080 discharge-recharge cycles during the 12-year design life of the spacecraft. Batteries currently in use have successfully operated for 4000 test cycles at 80% depth of discharge (DOD).

The battery includes one cell for redundancy and power diodes within each cell to bypass open-circuit cell failure. The battery is conservatively designed for full eclipse operation at 71% DOD, and with one cell failed (and bypassed) at 74% DOD.

Array Regulator Electronics (ARE). TRW developed ARE architecture for the SUPER program. Eight AREs were breadboarded and operated successfully in a power control demonstration. We are currently developing ARE flight packaging with TRW funds.

Power Control and Distribution Unit (PCDU). The power control section of the PCDU accepts combined ARE and battery inputs and forms the primary power bus. Circuitry monitors array, battery and bus load currents, and interfaces with the OBC and the TT&CS via redundant serial digital data buses. The power distribution section provides primary power bus fault protection and isolation (fusing), and controls switching of spacecraft primary power loads in response to OBC or ground commands.

Figure 3.3-2 compares subsystem requirements and design capabilities.

PARAMETER	UNITS	REQUIREMENTS	CAPABILITY
EQUIPMENT VOLTAGE	VOLTS	28 +7/-6	23-35
SYSTEM POWER GROWTH	%	≥10	19
	WATTS	≥91	196
ENERGY STORAGE			
BATTERY CAPACITY	Whr	≥1497	1788
CELL CAPACITY	Ahr	≥54.4	65
CELL QUANTITY		NR	22
DEPTH OF DISCHARGE	%	≤80	71-74
CHARGE RATE		≥C/20	C/6-C/20
	AMPS	3.25	10.8-3.25
TRICKLE CHARGE RATE		C/80-C150	C/100
	AMPS	0.81-0.43	0.65
DISCHARGE RATE	WATTS	≥1003	≤1192
GROWTH CONTINGENCY	%	≥10	31
	WATTS	≥91	285
POWER GENERATION			
SOLAR ARRAY VOLTAGE	VOLTS	≥37;≤150	37-85
SOLAR ARRAY POWER			
EQUINOX (EOL)	WATTS	≥1003	1207
SOLSTICE (EOL)	WATTS	≥914	1118
GROWTH AND MARGIN			
EQUINOX	%	≥15.5	19
SOLSTICE	%	≥15.5	21

EOL = END OF LIFE
NR = NO REQUIREMENT

17351-131b

Figure 3.3-2. EPDS Requirements Versus Capabilities

3.4 PROPULSION

The propulsion subsystem (PS) provides velocity and controls attitude throughout the design life. Specifically, the propulsion subsystem provides impulse in increments for apogee insertion from GTO, for north–south and east–west stationkeeping, and for satellite disposal at EOL.

In the attitude control mode, the propulsion subsystem provides three–axis thrust vector control during apogee engine firing and three–axis attitude control during all stationkeeping burns, momentum wheel dumping, and disposal burn.

The propulsion subsystem uses hydrazine thrusters in a catalytic monopropellant mode for attitude control, and hypergolic nitrogen tetroxide (NTO) oxidizer and hydrazine fuel in a bipropellant mode for velocity adjustment. Figure 3.4–1 gives the key propulsion subsystem requirements and corresponding capabilities.

Subsystem Description

Figure 3.4–2 is a schematic diagram of the propulsion subsystem. All–welded construction ensures against leakage. During ground operations and launch, normally closed pyrotechnic valves seal off the propellant tanks from each other and the thrusters. After separation from the launch vehicle, the valves are opened to activate the subsystem.

Fuel and oxidizer tanks have separate helium supplies to prevent propellant vapors from mixing in the helium. The command and telemetry processing unit (CTPU) electronically controls the pressure to each tank using data from the pressure transducers. Such regulation permits precise control of the fuel/oxidizer mixture ratio, maximizing the amount of propellant delivered as impulse.

After completion of apogee insertion, propellants to the apogee engine are sealed off by closing the normally open pyrotechnic valves on the lines to the engine.

The propulsion subsystem is one–fault tolerant for all on–orbit operations, with primary and redundant thrusters for stationkeeping, attitude control, momentum wheel dumping, and disposal. Switching from primary thruster branches to redundant branches is done with latching isolation valves.

Thrusters. Figure 3.4–3 shows the locations of the various thrusters. The apogee engine in the center of the zenith face operates in a bipropellant NTO/hydrazine mode with a nominal thrust of 100 lbf and a specific impulse of 320 seconds. Four monopropellant hydrazine thrusters with 4 lbf of thrust in the corners of the zenith face control pitch and roll during apogee and stationkeeping burns. In the corners of the south face are four DRE–8s. In the monopropellant mode, these thrusters provide 4 lbf of thrust for roll and yaw control. In the bipropellant mode, they perform north–south stationkeeping with 8 lbf of thrust and a nominal specific impulse of 285 seconds.

Two pairs of 0.1–lbf monopropellant hydrazine thrusters at the center of the north and south edges of the east face are canted 20 degrees in the pitch direction to provide the control impulse needed for pitch momentum wheel dumping. Two additional pairs of 0.1–lbf monopropellant hydrazine

REQUIREMENT	SOURCE	CAPABILITY
STORE REQUIRED AMOUNTS OF PROPELLANTS AND GASEOUS HELIUM	ANALYSIS, PROTOFLIGHT TESTS	ALUMINUM-LINED, GRAPHITE/EPOXY OVERWRAPPED PROPELLANT AND PRESSURANT TANKS STORE PROPELLANTS AND HELIUM DURING LAUNCH AND ON-ORBIT AT MINIMUM WEIGHT
PROVIDE MINIMUM APOGEE INSERTION THRUST OF 97 lbf	ANALYSIS (ACCEPTANCE FIRING DATA ON MANY ENGINES)	LIQUID APOGEE ENGINE HAS 99 lbf THRUST (3 σ LOW) USING NTO AND HYDRAZINE
DELIVER A MINIMUM APOGEE INSERTION IMPULSE OF 2.54×10^5 lbf - sec	ANALYSIS	APOGEE ENGINE NOMINALLY CONSUMES 378.0 lbm OF FUEL AND 415.8 lbm OF NTO IN DELIVERING 2.54×10^5 lbf - sec IMPULSE
PROVIDE A MINIMUM NORTH-SOUTH STATIONKEEPING THRUST OF 2.5 lbf	ANALYSIS	DRE-8 THRUSTERS PROVIDE 8.0 lbf THRUST
PROVIDE MINIMUM NORTH-SOUTH STATIONKEEPING IMPULSE OF 52,400 lbf - sec	ANALYSIS	DRE-8 THRUSTERS NOMINALLY CONSUME 87.5 lbf OF FUEL AND 96.3 lbf OF NTO IN DELIVERING 52,400 lbm - sec IMPULSE
PROVIDE A MINIMUM THRUST OF 0.1 lbf DURING EAST WEST STATIONKEEPING	ANALYSIS (ACCEPTANCE FIRING AND QUALIFICATION DATA)	RCS THRUSTERS PROVIDE A MINIMUM THRUST OF 0.14 lbf DURING EAST-WEST STATIONKEEPING
PROVIDE A MINIMUM EAST–WEST STATIONKEEPING IMPULSE 2043 OF lbf - sec	ANALYSIS	0.1 lbf THRUSTERS CONSUME 9.5 lbm OF FUEL IN DELIVERING 2043 lbf - sec OF IMPULSE
PROVIDE A MINIMUM RCS THRUST OF 2.5 lbf DURING NORTH–SOUTH STATION-KEEPING AND APOGEE INSERTION	ANALYSIS (ACCEPTANCE FIRING AND QUALIFICATION DATA)	RCS THRUSTERS PROVIDE THRUST OF 3.0 lbf FOR NORTH–SOUTH STATIONKEEPING AND APOGEE INSERTION
PROVIDE A MINIMUM IMPULSE BIT OF 0.020 +0, -0.008 lbf - sec IN PITCH, ROLL, AND YAW DURING MOMENTUM WHEEL DUMPING	ANALYSIS (QUALIFICATION DATA)	0.1 lbf - sec THRUSTERS CAN PROVIDE MINIMUM IMPULSE BIT OF 0.005+0, – 0.002 lbf - sec
EXPEL GAS-FREE PROPELLANTS	ANALYSIS	SURFACE-TENSION, VANE-TYPE PROPELLANT MANAGEMENT DEVICE (PMD) IN BOTH FUEL AND OXIDIZER TANKS DELIVERS GAS-FREE PROPELLANTS AT ALL TIMES
MEET ALL GUIANA SPACE SAFETY CENTER REGULATIONS	ANALYSIS	SUBSYSTEM IS TWO-FAULT ON LOSS OF LIFE OR DAMAGE TO OTHER PAYLOAD. NO KNOWN SAFETY AREAS WITH WHICH WE DO NOT COMPLY
NTO = NITROGEN TETROXIDE		

17351 128c

Figure 3.4-1. Propulsion Subsystem Requirements Versus Capabilities

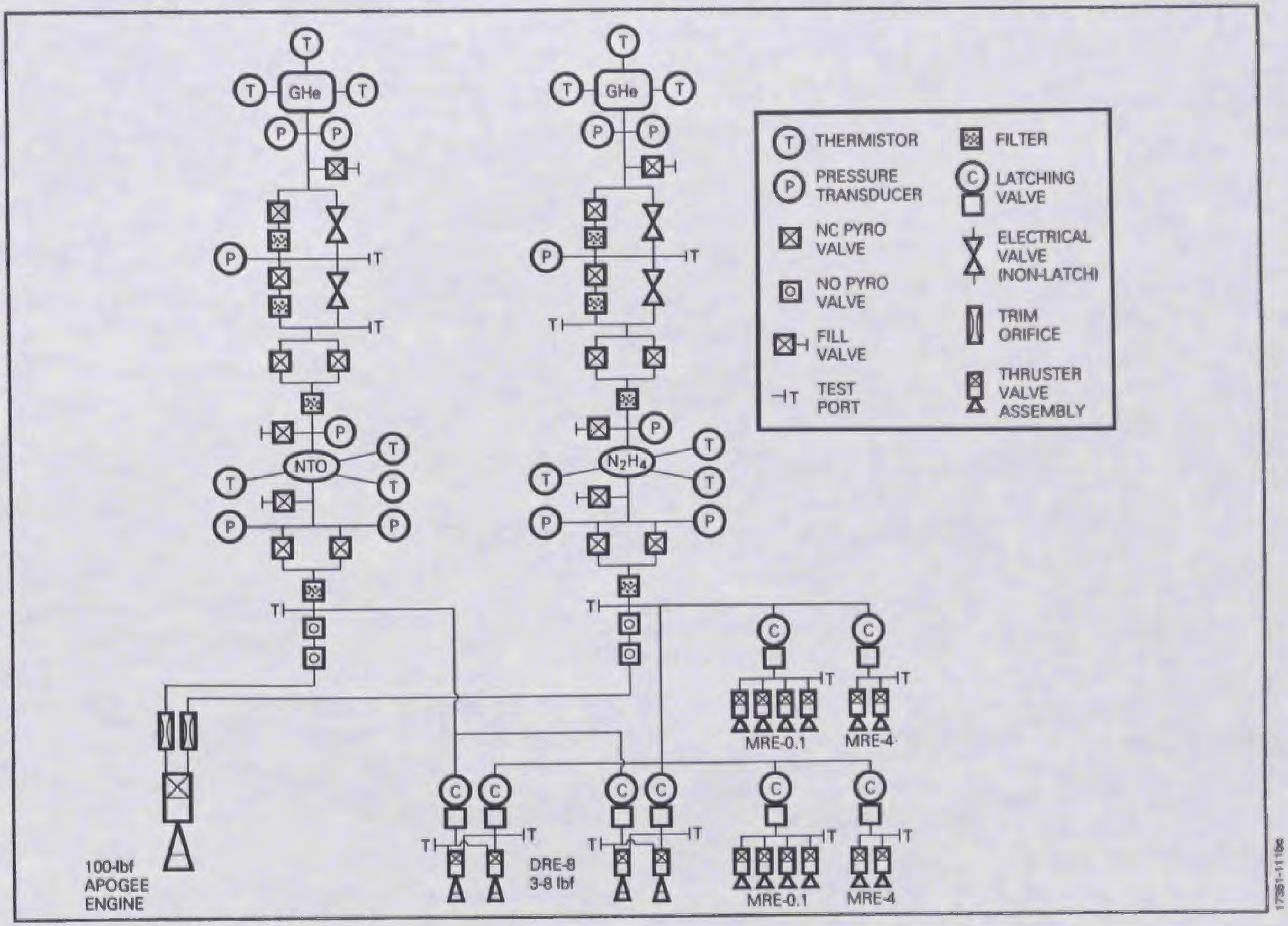


Figure 3.4-2. Dual-Mode Propulsion Subsystem With Bi-Level ACS and DRE-8s

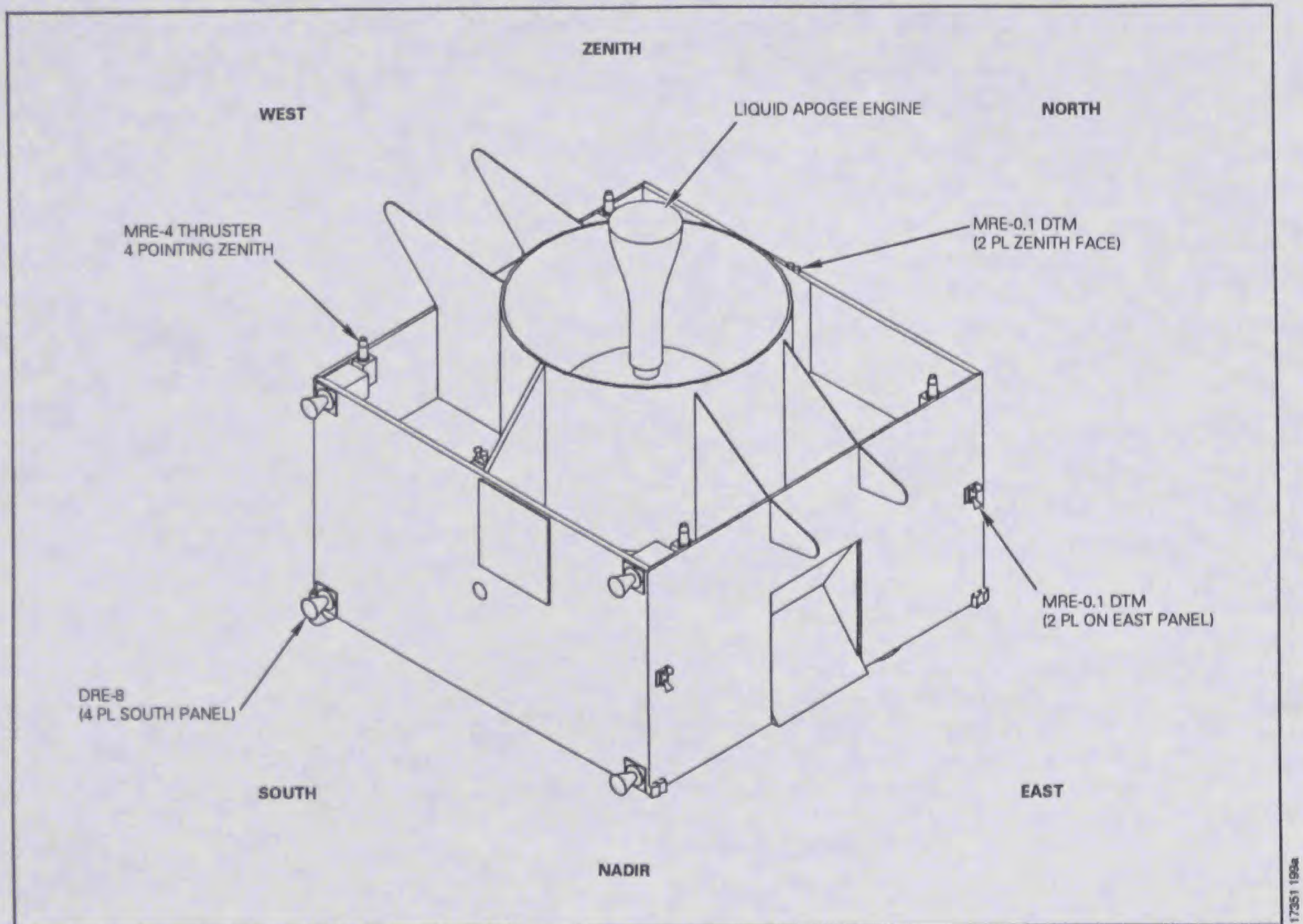


Figure 3.4-3. Thruster Locations

thrusters in the center of the north and south edges of the zenith face provide roll momentum dumping capability.

Firing the 0.1–lbf thrusters on the east face in pairs accomplishes east–west stationkeeping. The nominal specific impulse of these thrusters during east–west stationkeeping is 215 seconds.

3.5 THERMAL CONTROL

The PAS–2 thermal control subsystem (TCS) uses simple, flight–proven semi–passive methods (Figures 3.5–1 and 3.5–2). Thermostatically–controlled heaters maintain minimum temperatures. Body–mounted, second–surface mirror radiators reject heat dissipated from equipment. Multilayer insulation (MLI) on all nonradiating areas of the satellite body minimize environmental loads and other heat leaks. MLI on the rear surfaces of all reflectors reduce temperature gradients, and a diffuse paint on front surfaces minimizes specular focusing of solar energy onto the feeds. The flat–pack solar array requires a pallet to hold the folded array during launch. Studies show that the pallet must be at least 40 inches from the spacecraft sidewall to minimize radiator blockage and reduce radiator–solar array interaction. An aluminized Kapton layer on the pallet surface facing the sidewall reduces infrared energy transfer. Finally, a high–emittance black paint on the rear solar array surface minimizes its temperatures.

The thermal control requirements for PAS–2 are to maintain all equipment between -20° to 50°C and the batteries between -5° to 10°C. Available radiator area on the satellite meets these requirements. Battery radiators are sized at 2.5 ft^2 to account for average battery dissipation and solar array heat inputs. This sizing requires battery heater power of 22 watts during equinox and 16 watts during solstice seasons. The spacecraft and payload equipment requires 28 ft^2 of radiator area and approximately 10 watts of heater power during equinox and solstice for miscellaneous parasitic heat leaks, and up to 20 watts during eclipses. The bulk of the heaters is used to maintain equipment minimum temperatures during GTO.

All thermal control equipment items except insulation are off–the–shelf components with extensive flight heritage. Insulation blankets are tailored to each specific spacecraft, and flight–proven techniques are used in their manufacture, such as grounding inner and outer layers.

The PAS–2 TCS maintains all spacecraft equipment within required limits, with both weight and power budgets within the allocated limits.

3.6 STRUCTURES AND MECHANISMS

The structures and mechanisms subsystem (S&MS) comprises a rigid, lightweight platform that supports all bus and payload equipment and interfaces with the launch vehicle adapter. It includes ordnance and release mechanisms for retaining and releasing the solar array, SADA, and deployable C–band antennas. (The satellite–launch vehicle adapter, band clamp and ordnance, and separation springs and

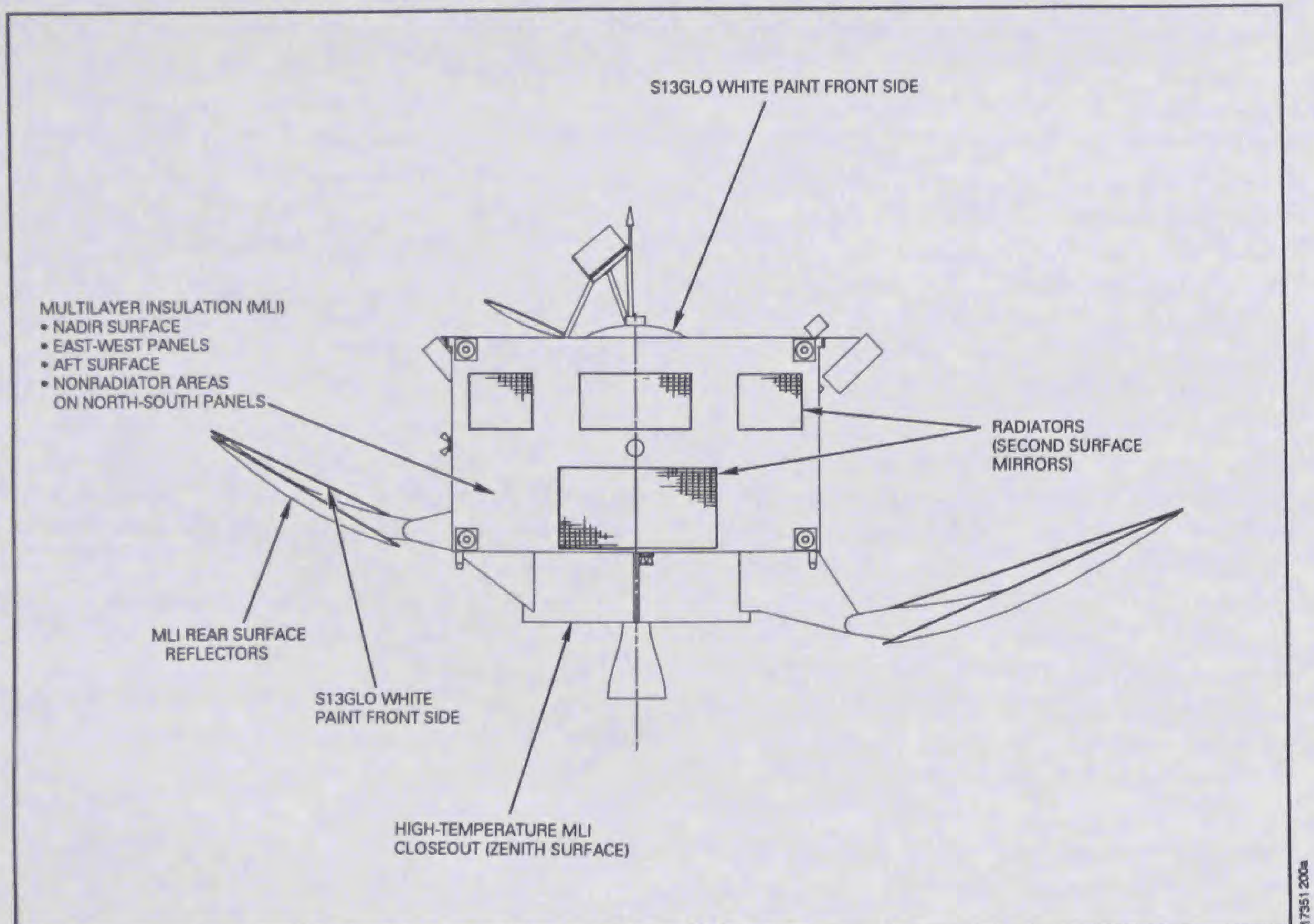


Figure 3.5-1. Thermal Control Features-South Panel

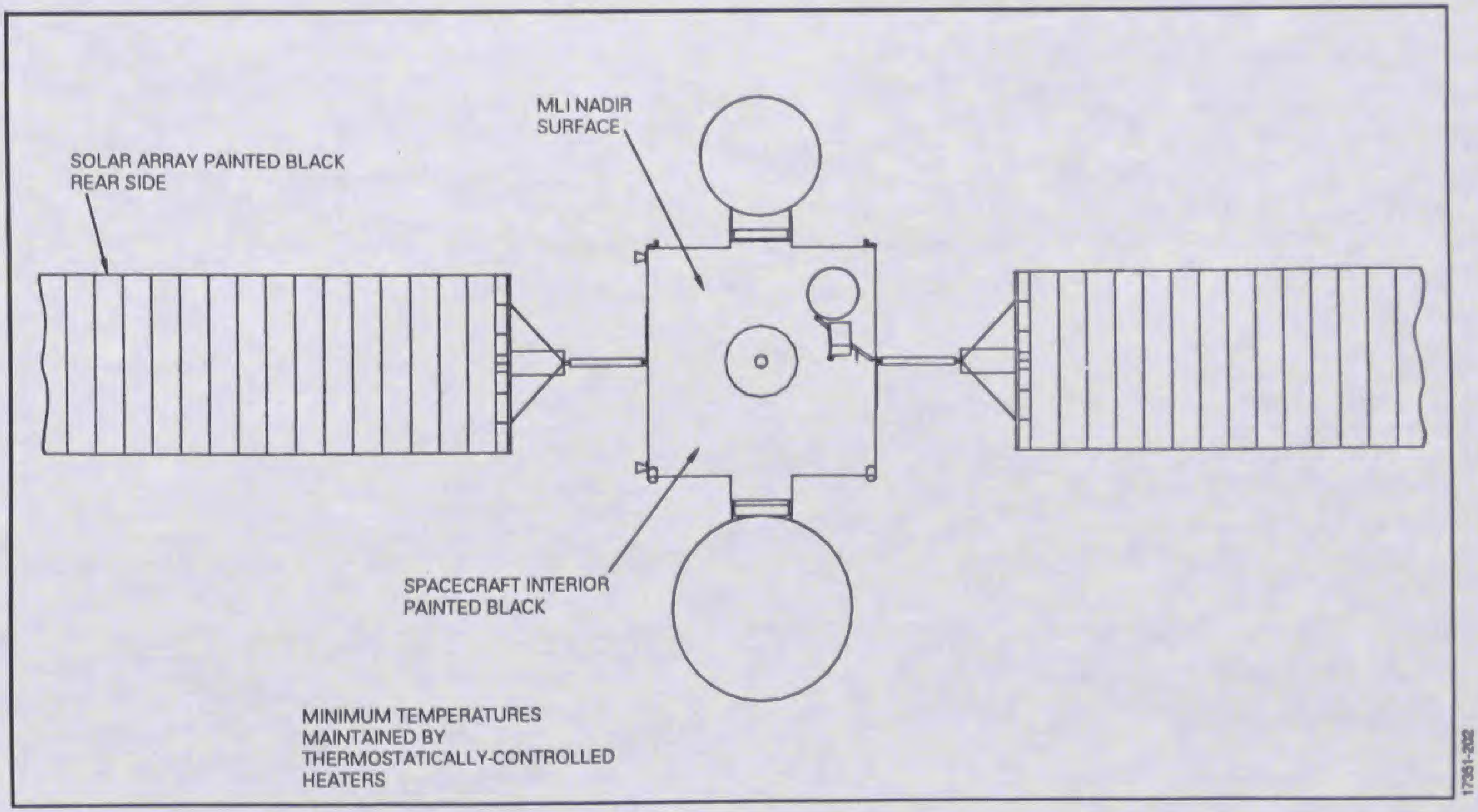


Figure 3.5–2. Thermal Control Subsystem Features – Nadir View

switches are the responsibility of Arianespace as part of launch services.) Use of standard aerospace materials and construction techniques gives an efficient, minimum–weight, low–risk subsystem capable of meeting all requirements.

Figure 3.6–1 summarizes specific structural subsystem requirements and methods of compliance. The use of the Ariane 4 launch vehicle drives the principal requirements.

LAUNCH VEHICLE - ARIANE 4, MINI-SPELDA,
1194A ADAPTER (BY ARIANE)

- LAUNCH LOAD FACTORS (SEE BELOW)
- MINIMUM STIFFNESS REQUIREMENTS:
  - AXIAL = 31 Hz; INTERNAL = 10 Hz
  - EQUIPMENT STOWED = 30 Hz
  - SOLAR ARRAY AND ANTENNAS DEPLOYED = 0.1 Hz

- DESIGN FACTORS OF SAFETY: FS_{yld} = 1.10, FS_{ult} = 1.25
- STATIC TEST TO 1.25 X LIMIT LOAD FACTORS
- MAXIMUM VEHICLE WEIGHT = 2094 lb

CONSTRUCTION
- ALUMINUM HONEYCOMB PANELS
- COMPOSITE CENTRAL CYLINDER
- COMPOSITE HORIZONTAL PLATFORM, SHEAR PANELS, E/W PANELS
- TITANIUM AND STEEL FASTENERS

FLIGHT LIMIT LOADS

FLIGHT EVENT	ACCELERATION (G)	
	LONGITUDINAL	LATERAL
MAXIMUM DYNAMIC PRESSURE	-3.0	±1.5
BEFORE THRUST TERMINATION	-7.0	±1.0
DURING THRUST TAIL-OFF	+2.5	±1.0

THESE LOADS APPLY UNIFORMLY OVER PRIMARY STRUCTURE OF SPACECRAFT AND COMPLY WITH:
- FREQUENCY REQUIREMENTS
- STATIC MOMENTS

ITEM OF REFERENCE TO MASTER CUBE	ANGULAR UNCERTAINTY (DEG)*			CONDITIONS
	YAW(Z)	ROLL(X)	PITCH(Y)	
MOMENTUM WHEEL	0.014	0.014	N/A	MECHANICAL AND THERMAL STABILITY.
	0.010	0.010		ALIGNMENT UNCERTAINTY**
EARTH SENSOR	0.050	0.050	0.050	MECHANICAL AND THERMAL STABILITY.
	0.010	0.010	0.010	ALIGNMENT UNCERTAINTY
FINE SUN SENSOR	0.050	0.050	0.050	MECHANICAL AND THERMAL STABILITY.
	0.020	0.010	0.010	ALIGNMENT UNCERTAINTY
MRE-1 THRUSTERS	0.014	0.014	0.014	MECHANICAL AND THERMAL STABILITY.
	0.050	0.050	0.050	ALIGNMENT UNCERTAINTY
LIQUID APOGEE ENGINE	N/A	0.070	0.070	MECHANICAL AND THERMAL STABILITY.
		0.050	0.050	ALIGNMENT UNCERTAINTY
C-BAND ANTENNAS	0.680	0.340	0.340	MECHANICAL AND THERMAL STABILITY.
	0.200	0.050	0.050	ALIGNMENT UNCERTAINTY
Ku-BAND ANTENNA	0.036	0.022	0.022	MECHANICAL AND THERMAL STABILITY.
	0.010	0.010	0.010	ALIGNMENT UNCERTAINTY

*RELATIVE TO SATELLITE AXIS MASTER CUBE
**INITIAL ALIGNMENT KNOWLEDGE UNCERTAINTY

17351-122b

Figure 3.6-1. PAS-2 Basic Structural Requirements

Subsystem Description

The structure is made of graphite fiber reinforced plastic (GFRP) except for some aluminum–faced honeycomb equipment panels and several struts. The central cylinder supports the major components of the propulsion system (liquid apogee engine and tanks) and transfers all loads from equipment panels to the launch vehicle interface. Ordnance devices at stowed support points for the solar arrays and deployable antennas effect separation after launch. Figures 3.6–2 and 3.6–3 show the structural configuration.

Structural elements are bolted together using standard aerospace fasteners and procedures. Bolts in tight fitting holes in the joints maintain required alignments and provide adequate strength and stiffness during launch.

Solar array and antenna support latches provide needed stiffness and attachment during launch. A pin puller locks out the SADA bearings. Redundant explosive ordnance releases the elements once the vehicle is in orbit. The devices used are identical to those on TDRSS and FLTSATCOM.

Antenna hinges are spring loaded for on–orbit deployment in a design similar to TDRSS. Launch, on–orbit, and thermal loads are considered in mechanism design along with stiffness requirements for both stowed and deployed configurations.

Structure Testing

Flight structure testing will follow Ariane 4 requirements:

- Static test to 1.25 x limit loads
- Modal survey with mass simulated equipment
- Acoustic test of complete flight satellite
- Shock test due to ordnance firing.

In addition to the above, tests will be perfomed to verify mechanisms and latches.

Design Process

The preliminary design includes equipment inputs and arrangements for each subsystem. Structural elements are sized according to Ariane 4 load factors and stiffness requirements. Using the preliminary layouts, detail drawings are prepared from which the structural elements are fabricated and assembled. A load cycle validates Ariane flight load factors and ensures the design is adequate. We then static test the flight structure. Finally, we perform a modal survey test with mass simulated components and other elements, from which we derive a validated dynamic model. All data will be given to Ariane for its integrated load cycle analysis of launch vehicle plus payloads (Figure 3.6–4). Latches and mechanisms are tested separately to verify function, strength, and stiffness.

After integrating all subsystems, we subject the flight system to the required acoustic environment and verify the deployables.

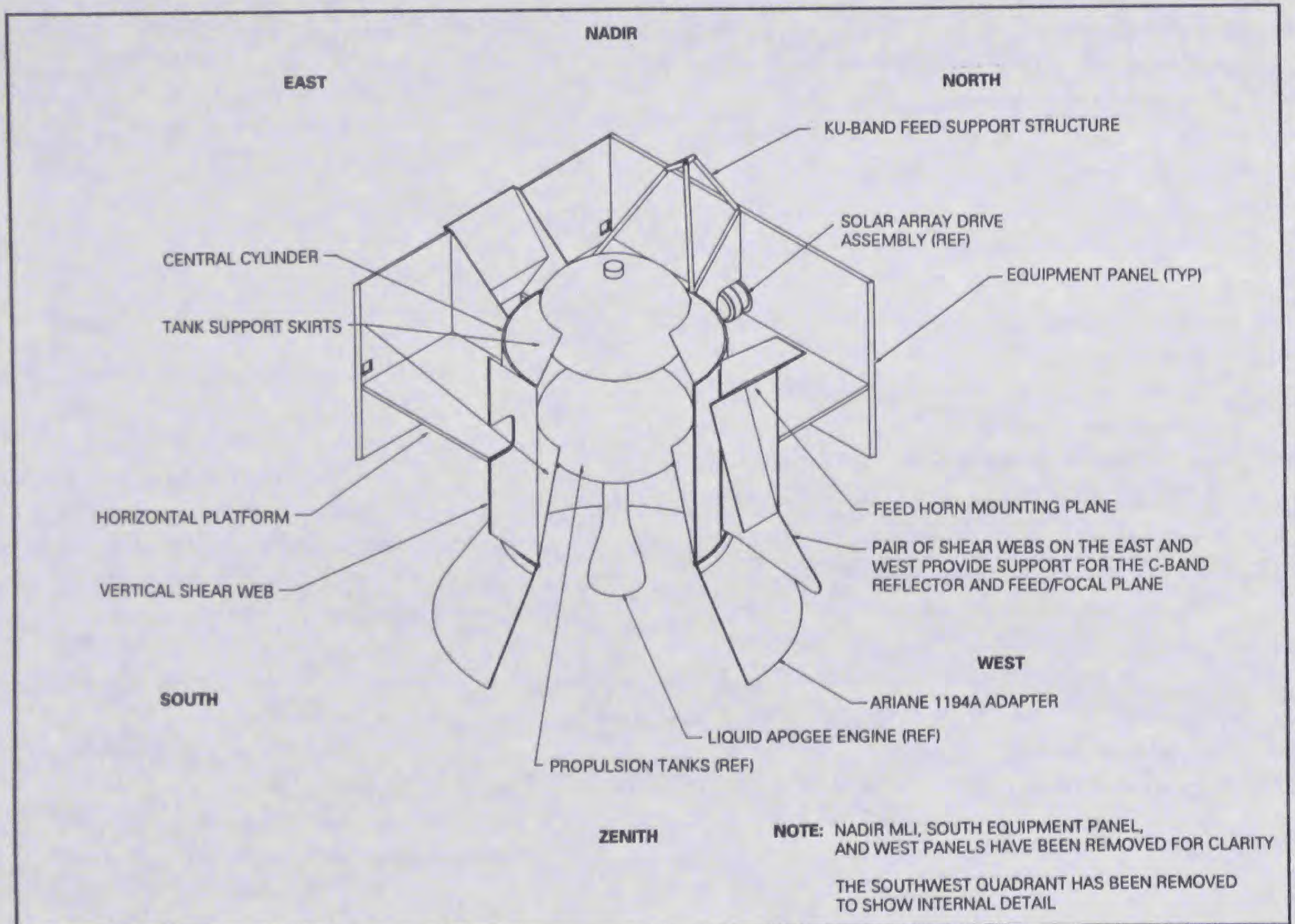


Figure 3.6–2. PAS–2 Structure – Isometric View

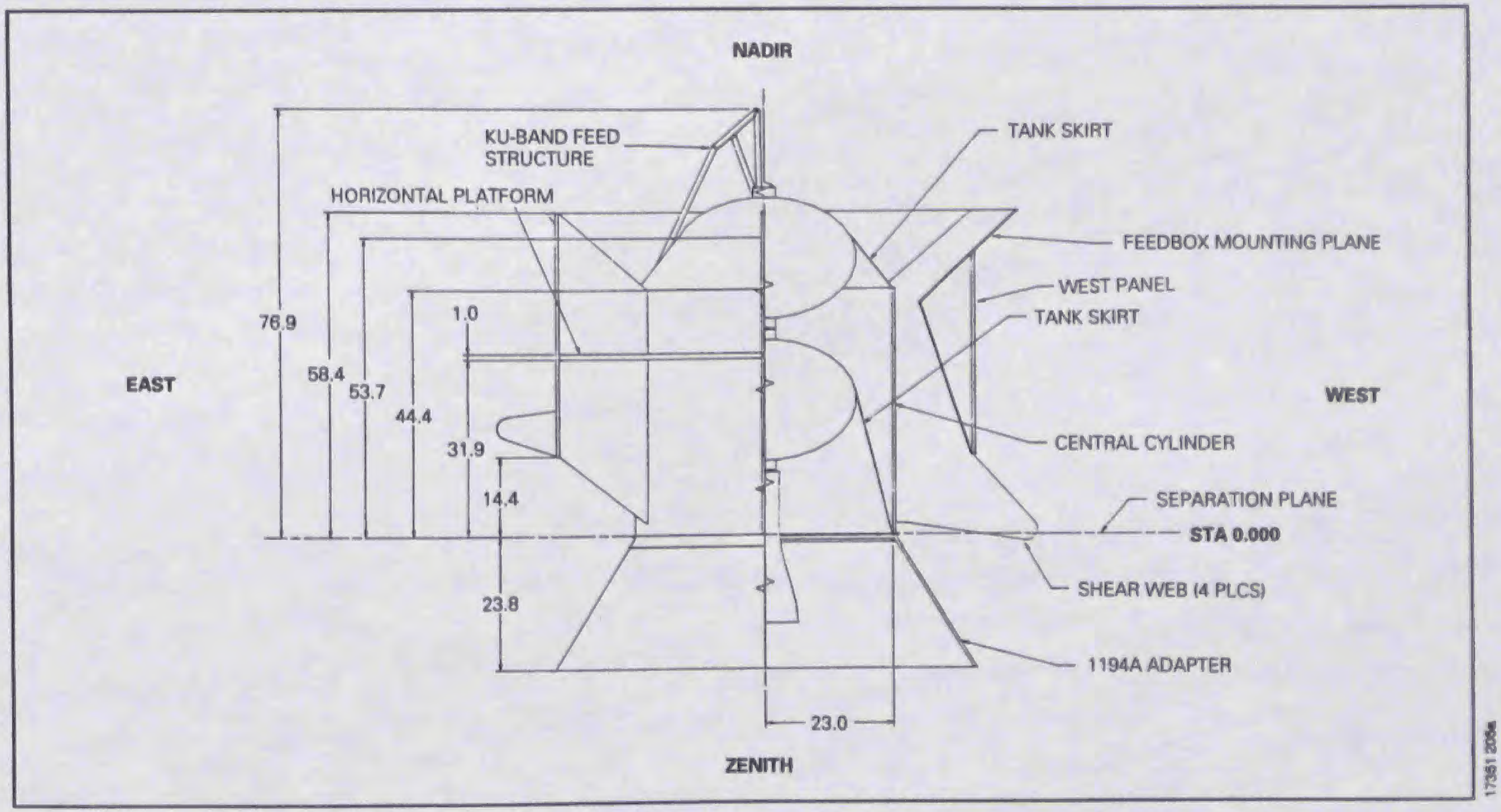


Figure 3.6-3. PAS-2 Structure-Side View

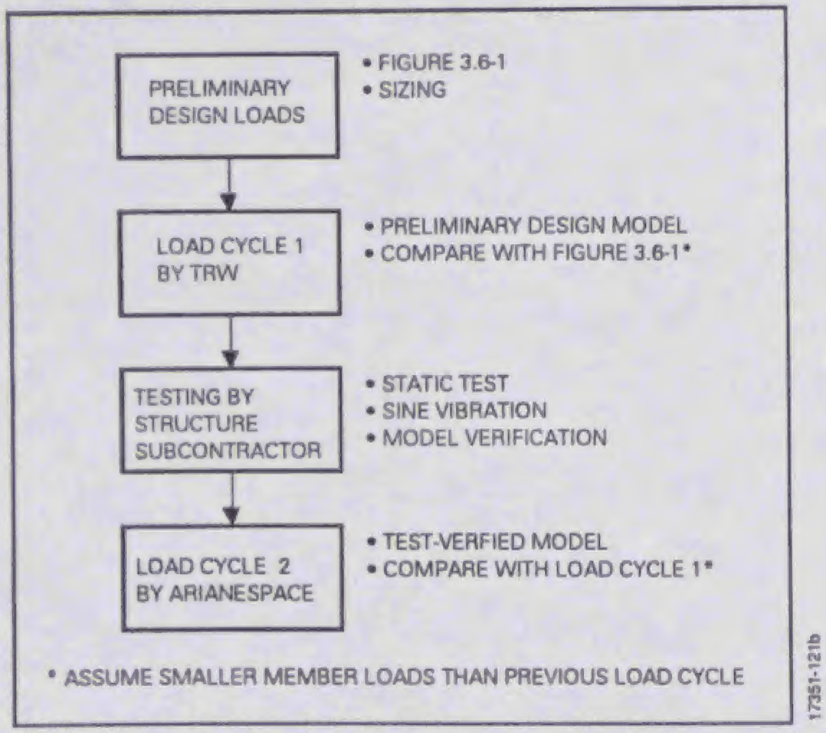


Figure 3.6-4. Structures Design Process

4. INTEGRATION, VERIFICATION, AND TEST

PAS-2 verification relies primarily on testing to substantiate performance according to the requirements of pertinent specifications. Analysis and/or simulations are used in lieu of testing only when the 1-g environment is not feasible or too costly and only when confidence is sufficient in approved analytical verification methods. Figure 4-1 summarizes the verification program.

We have adopted the protoflight concept at all levels of assembly; that is, test levels and durations are adjusted to both qualify the equipment under test and preserve its flight worthiness. Flight hardware testing consists of an appropriate sequence of performance and environmental tests that simulate operational environmental conditions.

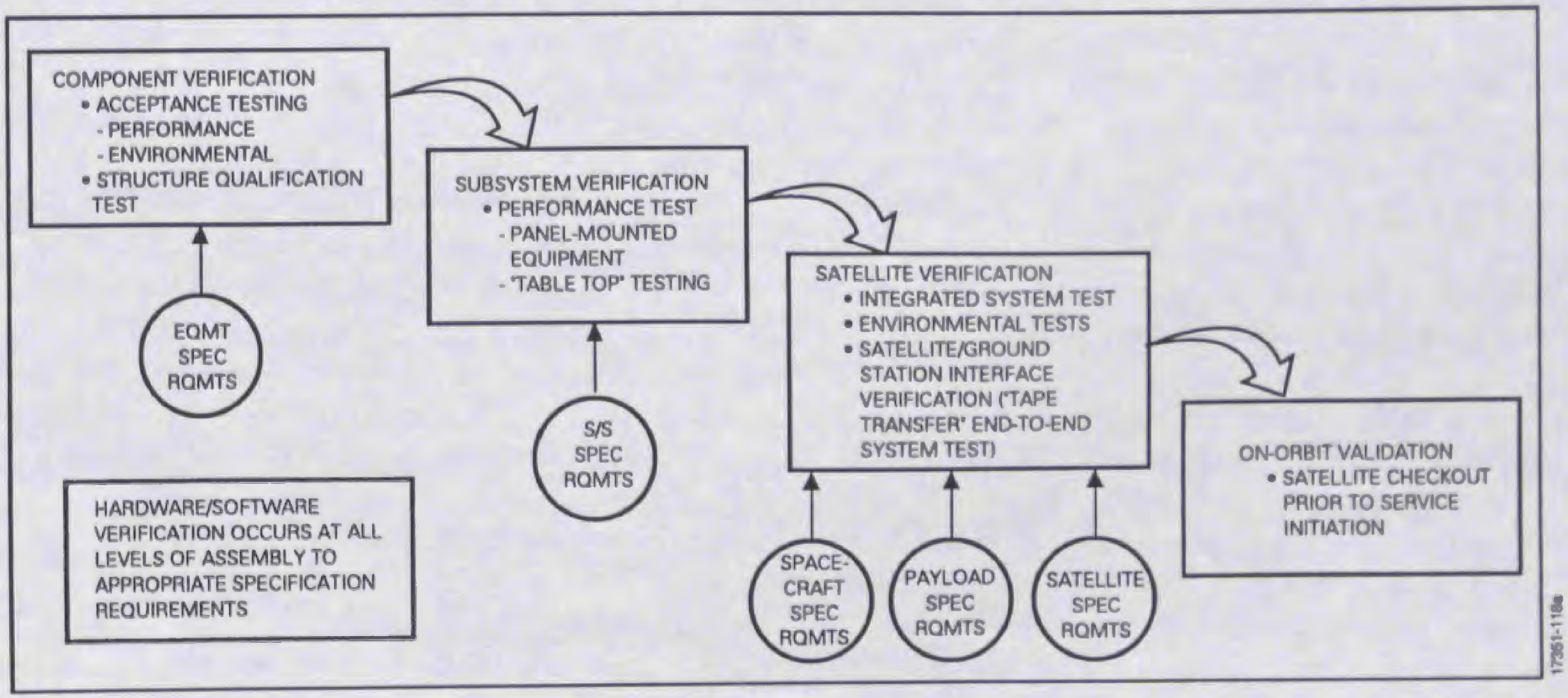


Figure 4-1. PAS-2 Verification Program Summary

4.1 INTEGRATION

The satellite build-up begins with the north and south panels, to which are mounted the payload transponder components. Spacecraft subsystem components, principally ACS and EPDS, are mounted on transfer panels before being fixed on the north and south panels. Propulsion subsystem components are mounted on the central cylinder assembly. Each of these three sets of assemblies are integrated in parallel, and then assembled to complete the north and south panels and finally the total satellite. The first part of Figure 4-2 illustrates this flow.

4.2 SATELLITE TESTS

After satellite assembly, an extensive environmental and functional test program verifies performance, as shown in the remainder of Figure 4-2. Environmental test levels are set sufficiently above launch/flight exposures to assure confidence in the hardware design and workmanship.

A comprehensive system test (CST) performed before and after the environmental exposures demonstrates that the satellite meets its design criteria. The CST is an end-to-end examination of all the integrated subsystems at the satellite level. It verifies that the vehicle is operating in accordance with specifications. Tests are performed before environmental exposure to establish a baseline and after environmental exposure to detect if any degradation has occurred. Payload transponder performance is tested during the CST via RF hardlines to ensure the configuration completes the series of environmental tests without any delays. A pre-ship aliveness test follows the second CST to verify procedures and test setup for the post-ship aliveness test at Kourou.

Electromagnetic and ground station compatibility (tape transfer) tests are performed early in the I&T flow to verify related design issues.

The acoustic test is performed +3 dB above acceptance levels for 1 minute. At this level and duration the satellite can demonstrate margin above maximum flight levels with no refurbishment required due to excessive exposure.

Separation tests, with live ordnance, verify the Ariane adapter release and C-band antennas and solar array releases. These tests demonstrate ordnance circuit integrity, ordnance shock survivability, and initial motion of the satellite deployable elements.

During thermal vacuum testing, an abbreviated CST measures any thermal sensitivity of the payload or satellite electronics at temperature extremes. Thermal balance conditions simulate actual orbital conditions to verify the TCS and adjust the analytical thermal model.

Leak testing, solar array flash, and post-environment deployment and alignment tests are also conducted to verify workmanship before shipping the satellite to Kourou. Mass balance testing using a spin balance machine establishes center of gravity data. At this time, we measure the satellite dry weight.

Preshipping preparations involve preparing red and green tag items, closing up ground support equipment and the

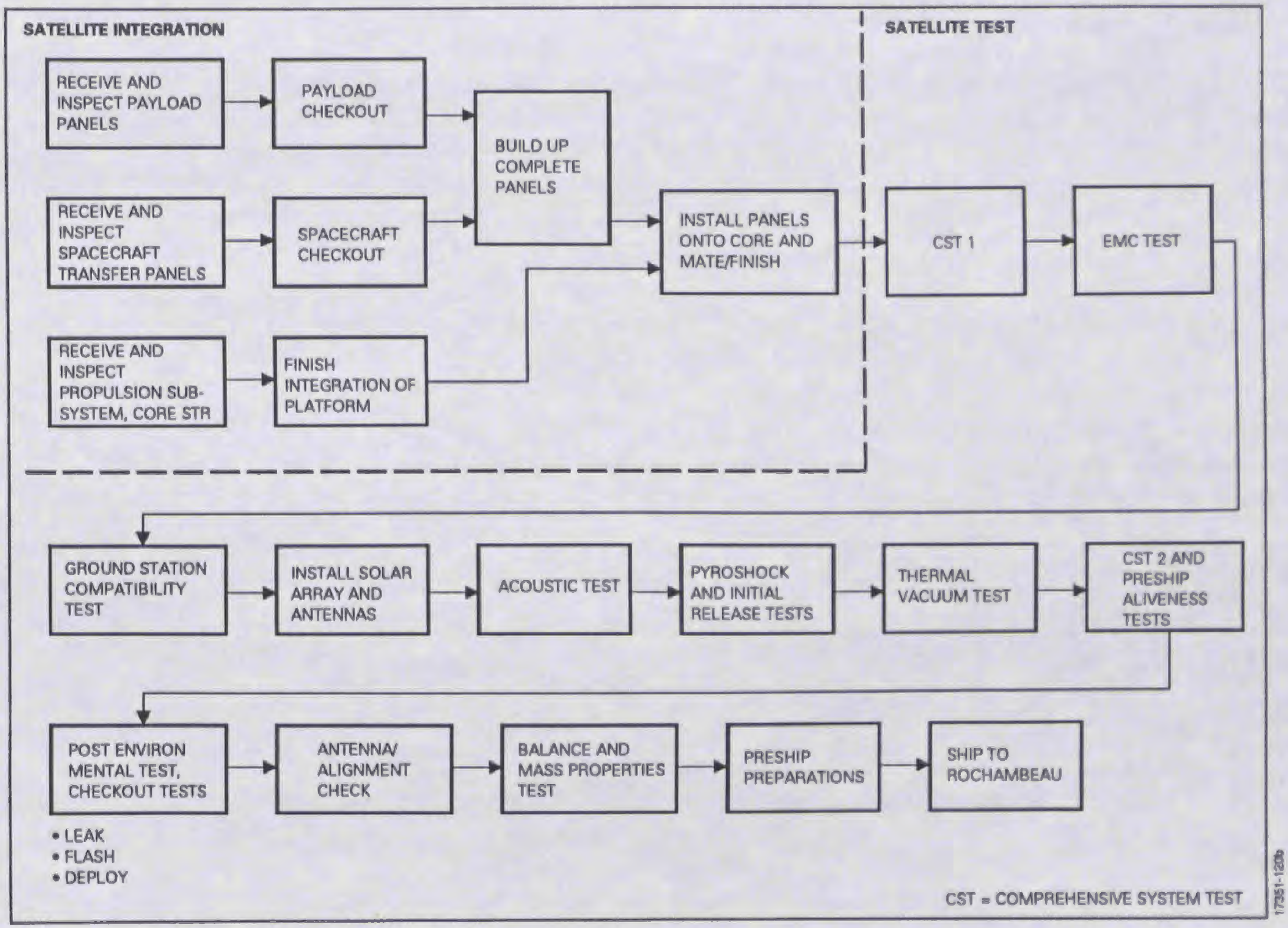


Figure 4-2. Integration and Verification Test Flow

satellite for safe transport, and moving all ground support equipment and flight hardware to the airport. We will use either a 747 cargo plane or a modified C130 transporter to ship the satellite from Los Angeles to the Rochambeau airport.

4.3 LAUNCH OPERATIONS TESTING

After verifying the support equipment at the launch site, quantitative post-ship satellite tests ensure that no damage occurred during transportation.

Finally, the flight batteries are conditioned, and the satellite propulsion system fueled. Propulsion tanks are then monitored for 24 hours to determine if there is any contamination. Before encapsulating the satellite, a configuration and test data review assures the satellite is complete. Launch rehearsals and a practice countdown follow integration of the satellite with the Ariane 4 vehicle.

4.4 ON-ORBIT TESTING

Final verification of satellite performance is made after GEO is attained. Normal operations verify propulsion performance following separation from the launch vehicle through drift orbit injection. Many of the operational functions of the spacecraft subsystems (ACS, EPDS, TT&CS) will be exercised and verified during these same operational sequences. Following injection into the drift orbit, which carries the satellite to its operational longitude, these subsystems are exercised through their on-orbit modes. After the satellite has arrived at its operational station, communications payload performance will be verified according to the Orbital Test Plan.

5. LAUNCH VEHICLE AND MISSION ANALYSIS

Procedures and documentation based on TRW's extensive satellite experience will ensure successful launch and operations of the PAS-2.

5.1 LAUNCH VEHICLE

The PAS-2 satellite is designed to be launched as a shared payload in the mini-SPELDA of the Ariane 4 launch vehicle. TRW will demonstrate flightworthiness of PAS-2 for the Ariane 4 before shipping the satellite to Kourou.

5.2 SATELLITE PRELAUNCH AND LAUNCH OPERATIONS

TRW has extensive experience with expendable boost vehicle launches. We have used the Atlas/Centaur for our low-earth-orbiting HEAO satellites, interplanetary Pioneer satellites, and geosynchronous orbiting FLTSATCOM satellites. Studies have shown Ariane satellite prelaunch and launch operations to be similar to those of the Atlas/Centaur vehicle.

Satellite launch operations begin with prelaunch planning and proceed through prelaunch, launch, and on-orbit operations. The initial tasks include preparing all prelaunch documentation:

- Launch plan inputs to Ariane that define the ascent trajectory requirements
- Procedures to support launch operations
- Contingency plans in case of booster or satellite anomalous behavior
- Post-launch support and analysis.

Prelaunch Planning

First, we perform an ascent trajectory analysis (Figure 5-1), combining the mission requirements and constraints into detailed trajectory requirements. Next, we prepare the satellite launch operations plan and assemble the required range safety data. Targeting conditions are determined based on mission requirements, launch requirements, and satellite and boost vehicle characteristics. In addition, we perform a launch window analysis incorporating the mission requirements and the satellite and launch vehicle constraints.

Mission requirements cover final geosynchronous location for on-orbit operations and limits on the satellite's motion about that location due to orbit perturbations. The on-orbit location will be 43° west longitude, with maximum operational longitude and latitude excursions of 0.1 degrees.

Organizations supplying launch-related equipment and services will jointly conduct planning and analysis of the ascent sequence of events. TRW will be responsible for satellite-related items such as mass properties, dynamic characteristics, and mission requirements and constraints. The launch vehicle contractor will integrate the satellite and launch vehicle and develop a detailed ascent trajectory simulation incorporating launch vehicle and satellite characteristics.

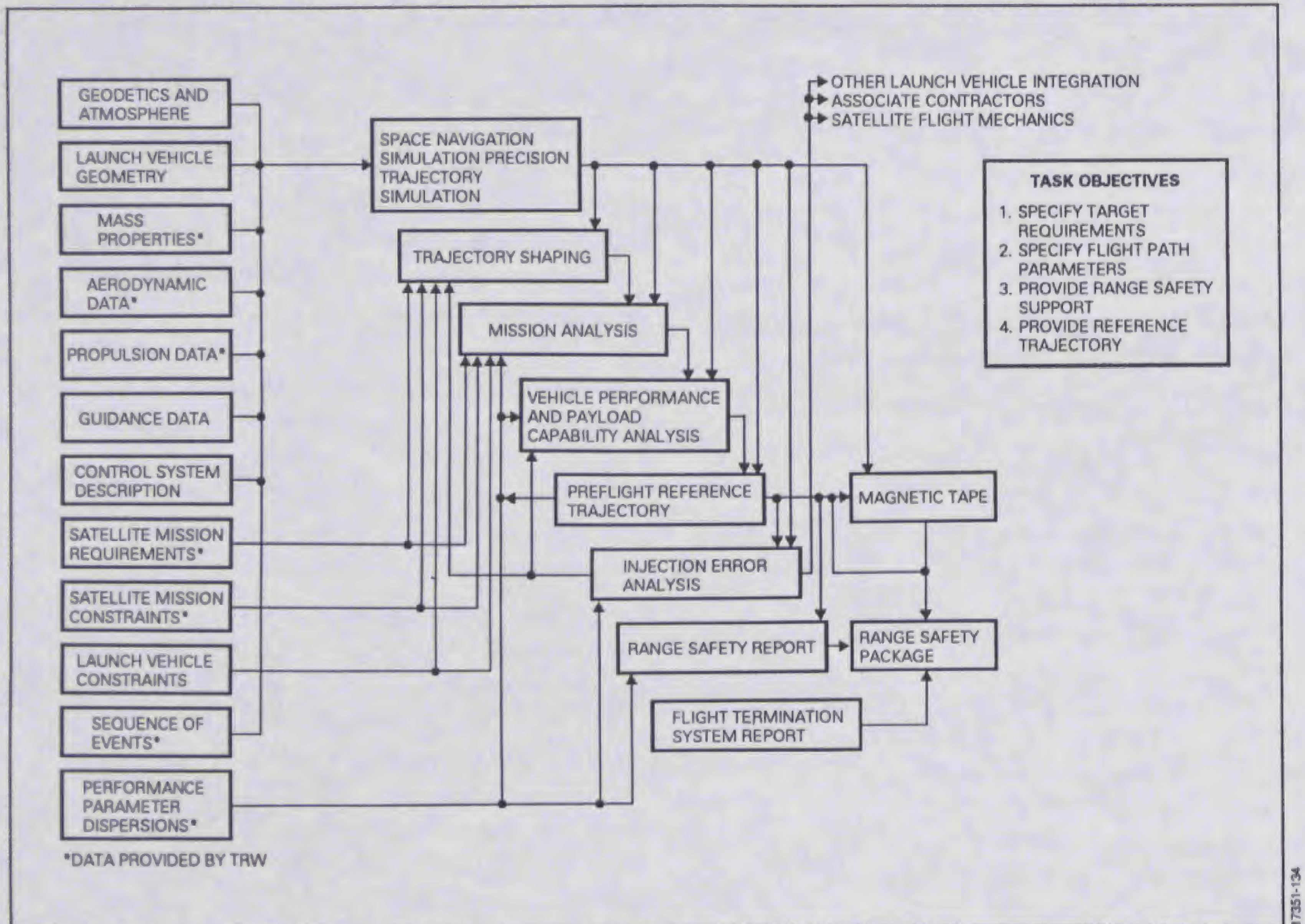


Figure 5-1. Ascent Trajectory Analysis Tasks

Launch Window

Orbit geometry requirements and satellite design dictate acceptable windows. PAS–2 will have a launch opportunity each day of the year. Figure 5–2A shows the effects of attitude determination and eclipse constraints on the launch window. These constraints are compatible with recent Ariane experience with shared payload launches.

During apogee burns, the sun and earth sensors provide the reference to hold the satellite in a constant attitude (see Section 3.2). Sufficiently accurate attitude determination is obtained when the earth–satellite–sun angle is between 40 and 140 degrees. Figure 5–2B shows the values of this angle, and Figure 5–2C shows the effects of the constraint on the launch window.

It is preferable to avoid apogee burns near eclipses. Figure 5–2D shows eclipse occurrences for each launch day in respect to transfer orbit ascending node locations. Figure 5–2E shows the effect on the launch window of excluding apogee burns 2 hours before and 1 hour after an eclipse.

Spacecraft Propulsion Parameters

After injection into the 7–degree inclination GTO by the Ariane launch vehicle, the spacecraft liquid apogee engine (LAE) performs a series of burns near orbit apogee to attain the desired zero–degree inclination geosynchronous orbit. A series of apogee burns rather than a single long burn reduces delta–velocity losses and gives flexibility in retargeting burns. In this way, we can more efficiently correct for dispersions in transfer orbit and apogee burns.

Mission objectives and launch vehicle and satellite performance characteristics determine satellite propulsion and reaction control system error correction requirements. The total propellants required to perform the mission are in Figure 1.2–7 in Section 1.

Launch Operations

During launch operations, TRW's experienced team will support orbit analysis and spacecraft operations.

After injection into the GTO, the launch vehicle reorients and releases the satellite. Communication through the omni antenna to ground starts approximately 22 minutes later, when the satellite becomes visible to the Perth ground station. The solar arrays are then deployed, allowing the satellite to operate in its normal mode with the earth and sun sensors providing reference attitude.

Several burns by the spacecraft LAE inject the satellite into its GEO. Figure 5–3 shows a typical sequence; all of the burns occur within view of North American tracking stations, with several orbit revolutions occurring between burns for tracking and retargeting. Multiple, low–thrust burns, with tracking and retargeting between burns, efficiently compensate for transfer orbit and apogee burn errors.

During the transfer orbit phase, tracking, telemetry, and command stations provide coverage (Figure 5–4). The data collected by these stations is sent to the Satellite Operations Control Center for satellite state–of–health monitoring, orbit determination, and burn targeting.

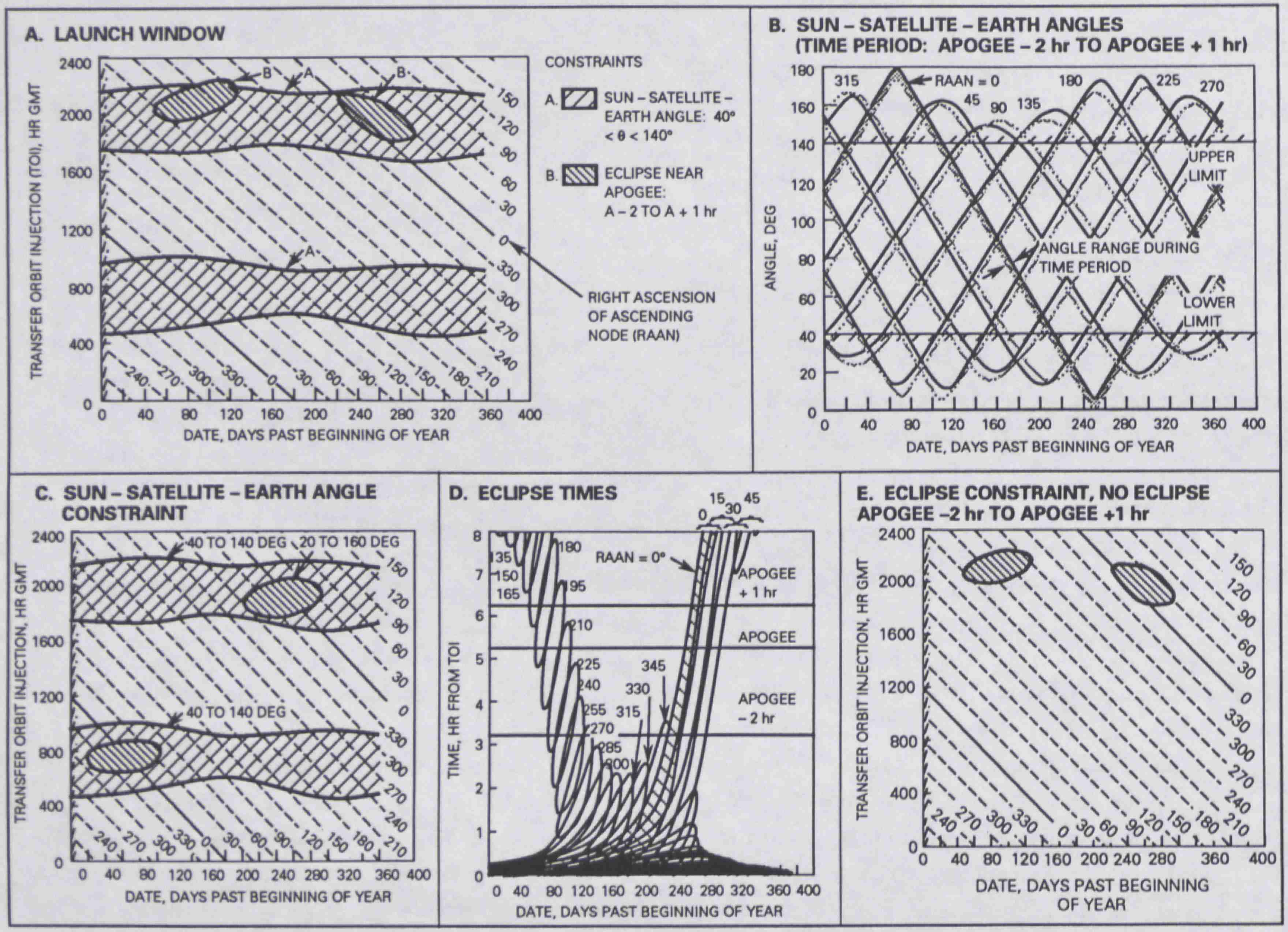
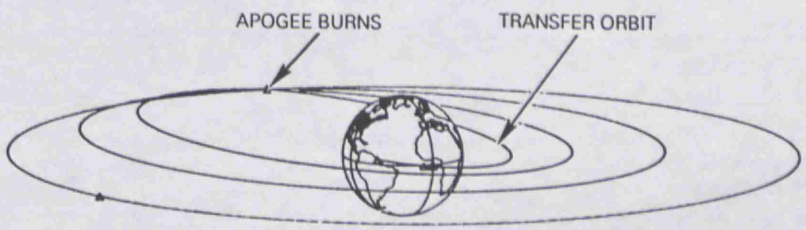


Figure 5-2. Launch Analysis

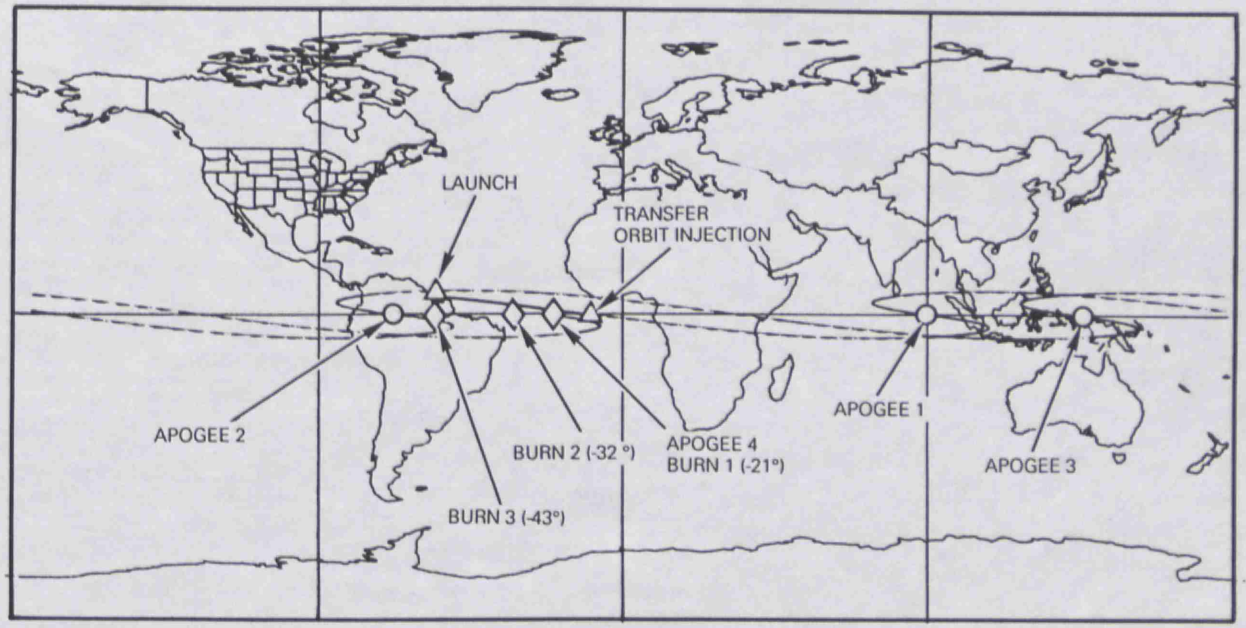
A. TRANSFER ORBIT BURNS



C. TRANSFER ORBIT SEQUENCE OF EVENTS

EVENT	TOI	BURN1	BURN 2	BURN 3
TIME FROM TOI (HOURS)	–	36.8	61.5	110.1
LONGITUDE (DEGREES)	7 W	21 W	32 W	43 W
BURN DURATION (MINUTES)	–	15.5	14.9	12.0
REVOLUTIONS FROM PREVIOUS BURN	–	3.5	2.0	3.0
POST BURN				
APOGEE (nmi)	19,323	19,323	19,323	19,323
PERIGEE (nmi)	108	3,097	8,862	19,323
INCLINATION (DEGREES)	7.0	3.7	1.5	0.0
PERIOD (HOURS)	10.5	12.4	16.2	24.0

B. BURN LOCATIONS



17351-138

Figure 5-3. Transfer Orbit Summary

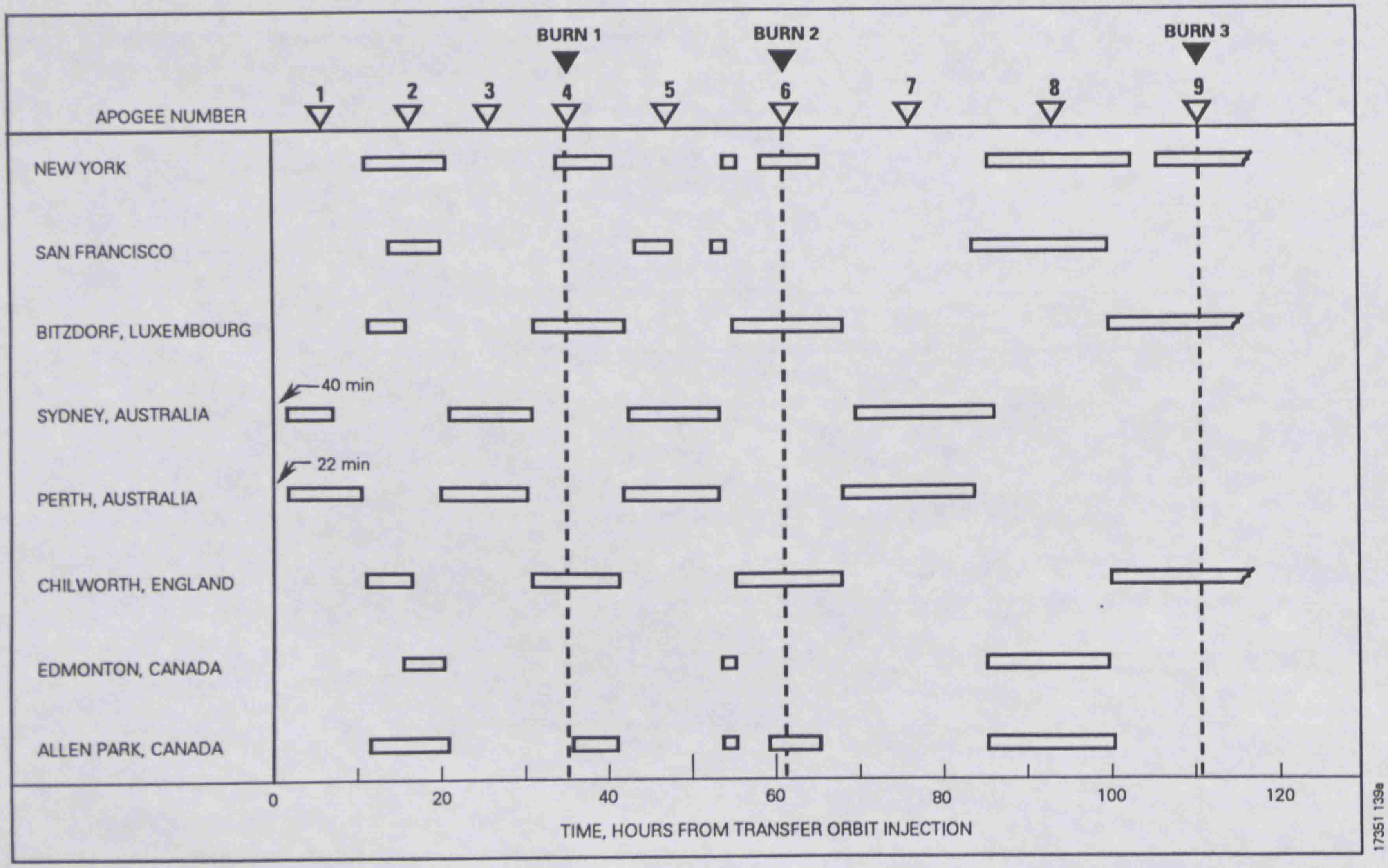


Figure 5-4. Tracking Station Coverage

6. RELIABILITY AND LIFE

TRW conducts rigorous analyses of failures and has in place procedures and methods for reporting and correcting them, ensuring the reliability and life of its satellites.

6.1 RELIABILITY ESTIMATE

Reliability predictions, based on block diagrams, have been established for each spacecraft subsystem. The predictions reflect continuous use over 12 years and currently accepted failure rate data, where available. Standby or redundant channels are assumed to have an equivalent failure rate of 10% of the active failure rate. Reliability predictions have also been established for the three payload elements. Figure 6–1 gives 12–year estimates for the spacecraft and payload.

The 12–year reliability values consider the entire spacecraft operable as well as at least six north–south spot beam transponders, at least six C/Ku–band Latin beam transponders, and at least three C–band Latin beam transponders.

It should be pointed out that the predicted design life is conservative and based upon TRW's prior flight experience. For example, on FLTSATCOM the predicted design life was 5 years. FLTSATCOM Flight 1, launched in 1979, is still in operational service; to date the actual orbital data shows a mean life of 7.8 years with six satellites still operating. On the DSCS II program, the predicted design life was also 5 years. The oldest active DSCS II satellite has been in service in excess of 15 years; to date the actual orbital data shows a mean life of 8.7 years with seven satellites still operating. Since both of these programs have the majority of satellites still operating, the actual operating life durations are expected to be longer than the demonstrated 7.8–year and 8.7–year values.

Thus, the comparison of a design life of 5 years with actual mean values of 7.8 to 8.7 years gives us confidence that the actual mission lifetime for PAS–2 can be expected to exceed the 12 years predicted.

6.2 FAILURE MODES AND EFFECTS ANALYSIS (FMEA)

The objective of FMEAs is to seek, uncover, and correct component and subsystem weaknesses during the design phase, thereby avoiding later modifications and retrofits for problems uncovered during the test validation phase.

SPACECRAFT	
ATTITUDE CONTROL	0.940
ELECTRICAL POWER	0.926
PROPULSION	0.952
STRUCTURES AND MECHANISMS	0.999
THERMAL	0.995
TRACKING, TELEMETRY, AND COMMAND	0.923
PAYLOAD	
NORTH-SOUTH SPOT BEAM TRANSPONDERS	0.899
C-BAND LATIN BEAM TRANSPONDERS	0.930
C/Ku-BAND LATIN BEAM TRANSPONDERS	0.842

17351-141b

Figure 6-1. Subsystem 12-Year Estimated Reliabilities

Initial analyses occur at the functional circuit level. These are followed by product design FMEAs. The latter have the same objective but address details used in converting the functional designs into physical hardware. All FMEAs for PAS-2 will be completed by CDR and included in the CDR data packages. For existing designs and hardware with previous flight background, the majority of the hardware, existing FMEAs will be used.

Functional Level FMEA

First, we identify specific functions of subcircuits within the component; next, we indicate potential modes of failure, and, finally, we determine the effects of postulated modes of failure at the unit interfaces. Additionally, we isolate the means by which these malfunctions are detected and offer provisions in the design for eliminating (or minimizing) any effects on component performance.

A functional flow block diagram, which identifies electrical and active mechanical subunits, signal, power, and command inputs and outputs, and subassembly interfaces, accompanies each FMEA where appropriate. Each input to and output from the equipment is assessed for failure impact. Effects of failure of individual circuitry or elements within procured equipment on signals, power, or command lines are also identified.

Any fault or failure mode condition that could (a) propagate outside the unit and possibly degrade or cause failure of interfacing hardware or (b) prevent resumption of subsystem capability by switching to redundancy provisions is defined as a single-point failure (SPF) and documented in a single-point failure list. When a SPF is suspected, analysis is extended to the piece-part level. To the extent practical, all SPFs are eliminated from the design. The FMEA assures there are no open power daisy chains, converter overvoltages, sneak paths, or premature operations. It also examines test equipment interfaces for fail-safe provisions.

Product Design FMEAs

Product design FMEAs are performed to verify that inherent reliability and integrity are maintained during the product design phase when electrical/mechanical designs are transformed into hardware designs. If there are no adverse findings according to itemized criteria, it is so stated and confirmed at CDR. When adverse findings are identified, remedial actions are taken.

6.3 CRITICAL ITEM CONTROLS

We identify and control critical items. Items considered "critical" meet one or more of the following criteria:

- Single-point failure considered to be "credible"
- Historical record of problem areas in reliability or quality of technology
- Ability of item to meet design life is unproven
- Special handling, packaging, or storage techniques required.

A Critical Item Control Plan (CICP) is prepared that addresses each identified critical item. The CICP includes the following as a minimum:

- Identification of the critical item
- Description of the criticality (for example, long procurement time, temperature sensitivity)
- Description of the plan to be implemented to maintain control and status of the item critical parameter.

Provisions of the CICP are incorporated into design, manufacturing, test, and shipping documentation, to ensure that specified controls are implemented.

Figure 6-2 is a preliminary critical item list. It will be updated for PDR. The critical item control plan will be submitted with the CDR data package.

6.4 FAILURE INVESTIGATION, CORRECTIVE ACTION, AND REPORTING

We use a closed-loop system for failure reporting, analysis, and corrective action. The system goes into effect at first application of power to the unit.

1. APOGEE ENGINE: POTENTIAL SINGLE-POINT FAILURE ELEMENT
2. PRESSURANT TANKS: SAFETY ITEM
3. DEPLOYMENT ORDNANCE: SAFETY ITEM
4. SQUIB ISOLATION VALVES: SAFETY ITEM
5. POWER BUS: POTENTIAL SINGLE-POINT FAILURE ELEMENT
6. BATTERIES: COOL STORAGE REQUIREMENTS (-10° TO +20°C)

17351-142

Figure 6-2. Preliminary Critical Item List

The basic intent of the system is to uncover what went wrong and why it went wrong, and then to recommend corrective measures to be taken to preclude recurrence of any malfunctions. Additionally, the impact on hardware previously built, tested, and/or shipped is addressed. Portions of the failure investigation report must, therefore, relate to hardware effectivity for corrective actions.

Malfunctions encountered during the preformal test phase are documented, analyzed, and controlled internally by the Material Review Board/Failure Review Board.

Formal failure reporting occurs for all flight hardware. This reporting commences with end-item testing according to approved test plans.

A failure is defined as the inability of an item to meet the performance criteria of the equipment specification. If a problem occurs during the formal test phase, the following action is taken:

- Initial notification is provided to the TRW project manager within 24 hours. The notification identifies the unit, time, and nature of failure, and if available, an indication of the cause.
- A preliminary failure report is provided to the TRW project manager within 3 days of failure occurrence. The report contains symptomatic details including:
  - A description of the failure and test conditions prevalent during its occurrence
  - Additional information on possible causes

- Initial hardware disposition and investigation element plans

- A final failure report is provided to the TRW project manager within 20 days of the failure. This comprehensive report contains all information concerning the investigation results, conclusions, corrective actions taken, hardware disposition, and hardware effectivity for corrective actions.

7. PROGRAM MANAGEMENT

TRW's clearly defined program responsibilities and lines of authority ensure successful design, development, test, launch, and on-orbit checkout of Pan American Satellite-2 (PAS-2).

7.1 PROGRAM ORGANIZATION

We have committed key personnel to support the program throughout all phases.

The following organizational objectives will guide the PAS-2 program:

- Rapid response to Alpha Lyracom's requirements
- Precisely defined and highly visible responsibilities
- Clear lines of communication within TRW and with TRW's subcontractors; and between TRW and Alpha Lyracom Pan American Satellite.

TRW's Space & Technology Group (S&TG) will perform the PAS-2 program. It is specifically structured to provide an efficient core team; plus it has access to TRW's broad manpower and experience base on an as-needed basis. S&TG is an operating unit of the Space & Defense Sector (Figure 7-1).

The staff of the PAS-2 program has been carefully selected; their proven experience matches the specific requirements of program assignments. The program manager, Mr. Jack Friedenthal, will be responsible to Dr. Paul Mayhew, deputy group general manager for programs, S&TG, and to Alpha Lyracom for all aspects of the program. His authority is commensurate with his responsibility and equivalent to that of managers of similar programs within S&TG. Mr. Friedenthal previously has held project management positions on TDRSS, Space Station Work Package 3, and FLTSATCOM programs as well as key functional management and new business development positions. His strong

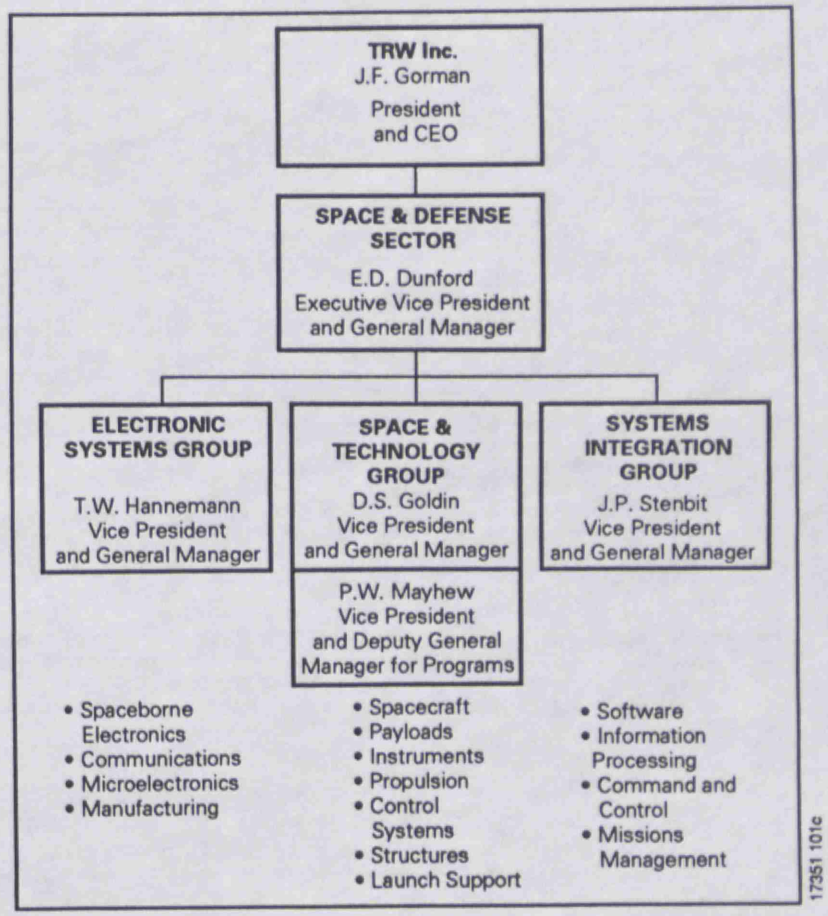


Figure 7-1. TRW Space & Defense Sector

management skills, leadership, and program understanding will enable him to effectively work with Alpha Lyracom and lead the TRW team to successful completion of the PAS–2 program.

The PAS–2 program organization under Mr. Friedenthal is shown in Figure 7–2.

7.2 PROGRAM MANAGEMENT TECHNIQUES

We will closely monitor the design, development, and test of the satellite, the schedule status, and our subcontractors' progress. Timely status information will be available to TRW management and to the customer. The following paragraphs describe our approach to schedule management, performance measurement, reporting, and internal review procedures. Our aim is to ensure on–time delivery of quality products. A summary PAS–2 milestone schedule and detailed subsystem schedules are provided in Section 7.4.

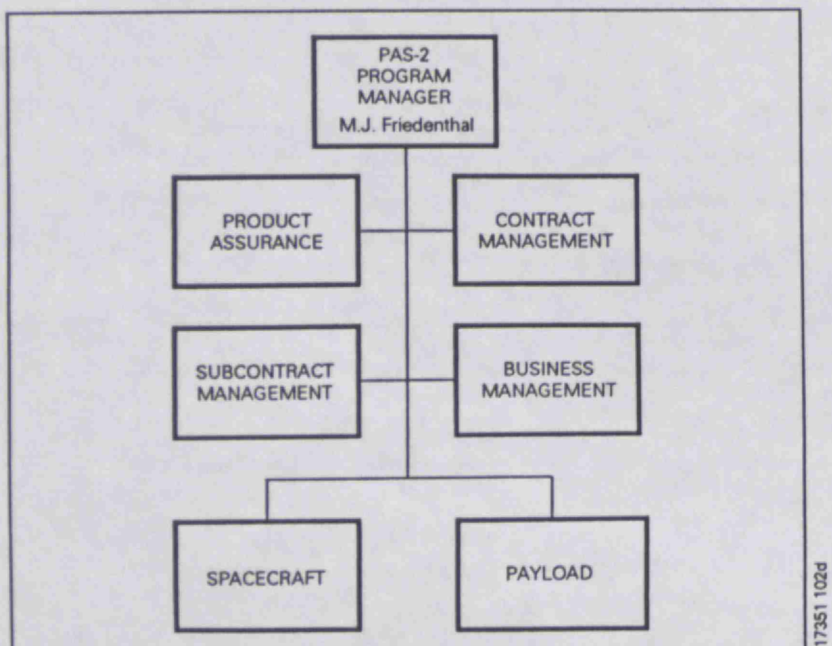


Figure 7–2. TRW's PAS–2 Organization

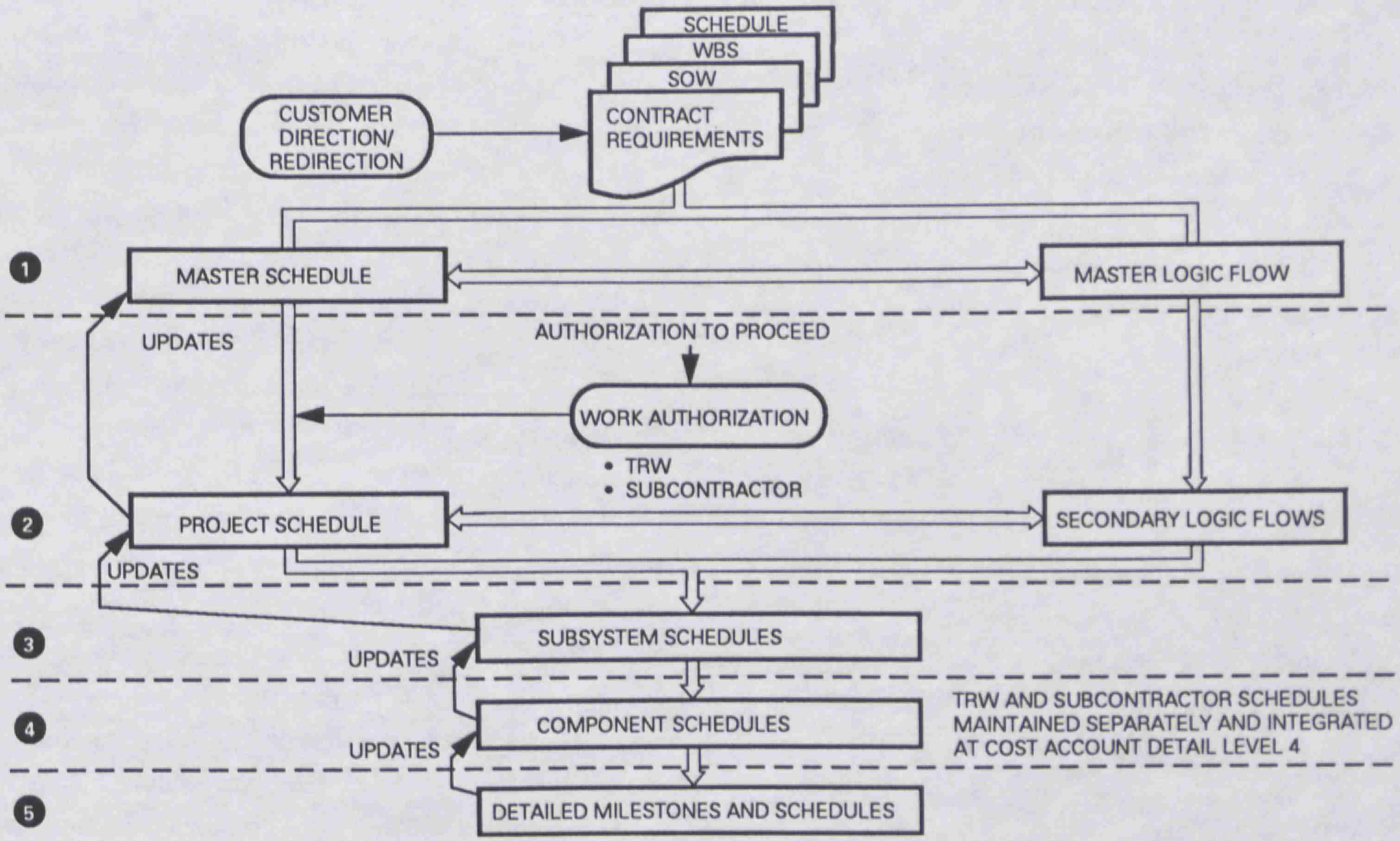
Program Schedule Control

We believe schedule control is a significant factor in reducing risk and realizing program goals. TRW's proven schedule management techniques provide total program visibility with direct integration of subcontractor schedules. Review and control is achieved by weekly milestone statusing and monthly schedule and logic updates. Our system is designed to ensure visibility of scheduling objectives, schedule traceability, and up–to–date program statusing, plus allow for immediate identification and analysis of problems and timely and cost–effective resolution.

The data base for the PAS–2 will rest on clearly established and defined tasks and milestones, subject to revision through review and negotiation with Alpha Lyracom.

TRW's schedule control system, which includes a complete set of logic networks and program schedules, integrates TRW and subcontractor efforts. Schedules are fully traceable, both horizontally and vertically, through the work breakdown structure (WBS) to the cost account level. Logic networks go to the project level.

The system (Figure 7–3) rests on a hierarchy of program schedules that define all SOW tasks and make clear TRW



Notes:

1. Master logic network and master schedule represent the contract requirements and establish the schedule baseline for all lower level schedules.
2. Secondary logic networks and schedules for resource management, systems engineering, etc., identify program and project milestones and show subsystem spans and key subsystem milestones.
3. Subsystem-level schedules identify program, project, and subsystem milestones and show component-level spans and key component milestones.
4. Component schedules identify program, project, subsystem, and component milestones and show detailed cost account level activities. This level of schedule is the basis for schedule control and the focal point for traceability to the WBS.
5. Detailed milestone schedules identify all activities for a mutually agreed-to portion of the program schedule and show all key completions for the period.

17351 103a

Figure 7–3. Integrated Schedule System

and subcontractor organizational responsibilities on all levels of the WBS.

For the PAS-2 program, TRW will rely on "Open Plan," a powerful PC-based scheduling system. Subcontractors will be required to use a compatible system for schedule control, where needed. This will provide full schedule integration and visibility. Prime and subcontractor schedules will be updated and combined on a monthly basis.

Performance Measurement

Our overall approach for performance measurement (Figure 7-4) takes advantage of our extensive automated management system and procedures and will provide PAS-2 project management with timely and accurate data for programmatic decisions. For example, the TRW Performance Measurement System (PMS) will be tailored to specific PAS-2 requirements and concerns to augment the schedule control system described above. The PMS will provide monthly schedule and cost status, plus manpower reporting and variance analysis at each level of the work breakdown structure (WBS). Managers will be able to easily review the status of their respective areas, spot trends early, and apply timely corrective action.

Reporting and Review

Location of the PAS-2 program team in a single area will facilitate communication. The program manager will hold weekly project meetings to ensure dissemination of information and status throughout all levels of the program (Figure 7-5).

In accordance with established TRW procedures, the program manager will meet monthly with the TRW program review authority, Dr. Paul Mayhew, to discuss technical progress and status, and cost and schedule performance data. These reviews will keep senior TRW management up to date on project status and allow the PAS-2 program manager to identify areas where assistance is required. We will also hold weekly telephone interchanges and monthly reviews with Alpha Lyracom to discuss technical and schedule status.

Quarterly program reviews will be held alternately at Alpha Lyracom and at TRW to present technical and schedule status for each subsystem. Where feasible, these quarterly program reviews will be combined with major milestone reviews, such as the preliminary design review (PDR), critical design review (CDR), and preshipment/launch readiness reviews.

The PDR and CDR will be held at TRW during months 5 and 16, respectively. These reviews will feature in-depth presentations on design status. Key TRW technical experts will attend to ensure adequacy and completeness of design.

All other necessary technical reviews, including test readiness reviews and preshipment//launch readiness reviews, will be held at TRW, with complete access afforded to Alpha Lyracom representatives.

We will invite Alpha Lyracom personnel to all reviews with our subcontractors. For critical or high-leverage subcontracts, such as the communications payload, formal monthly technical and management meetings will be held. Schedule

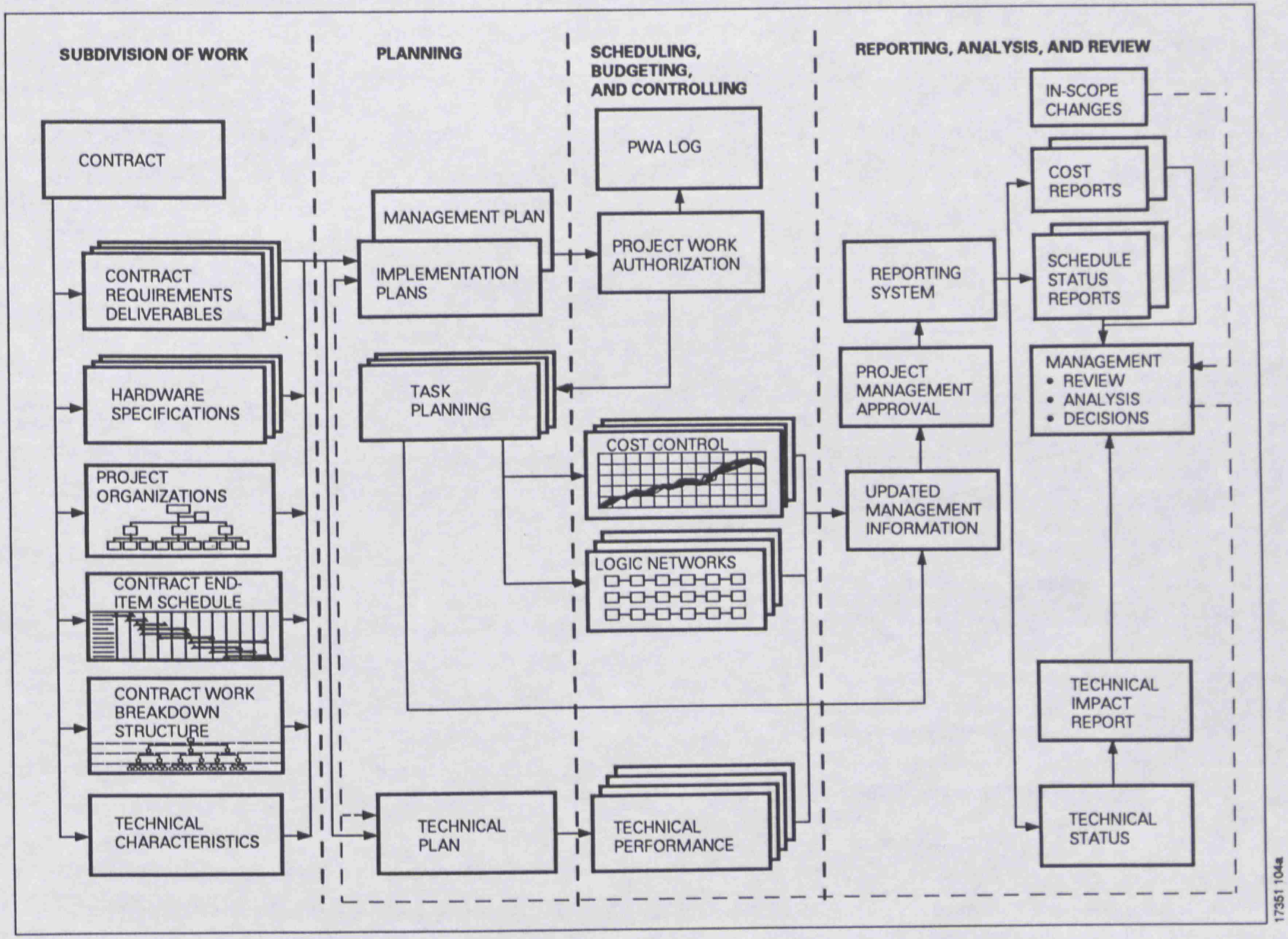


Figure 7-4. TRW Performance Measurement System (PMS)

data from these reviews will be incorporated in TRW's master report.

TRW – CUSTOMER

WEEKLY TELEPHONE INTERCHANGES

TECHNICAL/SCHEDULE STATUS

MONTHLY/QUARTERLY PROGRAM REVIEW
- REVIEW TECHNICAL AND SCHEDULE STATUS FOR EACH SYSTEM
- PROVIDE CRITICAL PROBLEM IDENTIFICATION AND STATUS

DESIGN REVIEWS
- SYSTEM REQUIREMENTS REVIEW
- PRELIMINARY DESIGN REVIEW
- CRITICAL DESIGN REVIEW

READINESS REVIEWS
- TEST READINESS REVIEWS/PRESHIPMENT/LAUNCH REVIEWS

TRW INTERNAL

WEEKLY PROJECT MEETING
- REVIEW CURRENT WEEK'S ACCOMPLISHMENTS
- IDENTIFY CRITICAL ISSUES
- ESTABLISH AND REVIEW ACTION ITEMS
- STATUS NEAR-TERM MILESTONES

MONTHLY MANAGEMENT REVIEW
- SUMMARIZE ACCOMPLISHMENTS AND PROBLEMS
- HIGHLIGHT CRITICAL ISSUES THAT IMPACT TIMELY COMPLETION
- FOCUS ON SPECIAL RESOURCE REQUIREMENTS

TRW – SUBCONTRACTORS
- TECHNICAL INTERCHANGE AS REQUIRED
- MONTHLY FORMAL TECHNICAL/MANAGEMENT REVIEW WHERE REQUIRED

17351 105b

Figure 7-5. PAS-2 Program Reviews

7.3 AUTHORITY AND RESPONSIBILITY

Program Manager's Authority

The program manager is the single-point authority for technical and programmatic management of the PAS-2 program. He has control of all contract funds and the full support of the division and group general managers. He can obtain any additional resources required. Also, he will hold monthly meetings with the Technical and Management Review Committee, consisting of division and group general managers of participating organizations and selected senior technical advisors, to discuss project status.

Lines of Authority and Responsibility

The Program Manager is responsible for all aspects of the contract, assigns tasks and resources, and delegates full authority to manage them to other program members by means of Project Work Authorizations (PWAs), which define scope of work, period of performance, and budget. He establishes priority and direction of contract tasks and resolves conflicts between the program and other TRW organizations and subcontractors.

The Spacecraft Manager is responsible for analysis and validation of all system requirements and development of the baseline system level designs. He directs and coordinates all mechanical and electrical design integration activities. He sees that systems verification plans, software standards and requirements, design reviews, and all deliverable technical documentation are performed on time. He manages satellite/launch vehicle integration. He is responsible for the design, development and test of the spacecraft and its subsystems (electrical power, command and telemetry, propulsion, attitude control, structure and mechanisms, and thermal control). He also directs design, development, and test of flight software and of antenna and solar array deployment mechanisms. Additionally, he is responsible for satellite-level assembly, integration and test of the payload, the spacecraft structure, the spacecraft subsystems, and appendages such as the solar arrays and communications payload and omni antennas. He is also responsible for transportation to and assembly and test operations at the launch site (Kourou, French Guiana).

The Communications Payload Manager is responsible for the design, development, and test of the communications payload and its equipment subcontracts, which include the C-band transponder, Ku-band receiver, and C-band command and telemetry RF equipment. He is also responsible for the design, development, and test of C-band and Ku-band communications antennas and C-band TT&C omni antennas.

7.4 PROGRAM PLAN

TRW's planning for the PAS-2 program capitalizes on our extensive experience in spacecraft design and development. We start by analyzing all the requirements for successful technical performance. This includes preparation of specifications, scheduling, defining the test program, specifying product assurance requirements, and defining other data and document requirements. Only after this extensive preparatory work do we plan our detailed activities.

The WBS (Figure 7-6) divides PAS-2 tasks into three system-level, manageable work packages: Program Level Effort, Spacecraft, and Payload. Each system is subdivided into elements, subsystems, or groups and then each of these is divided into design, fabrication, and assembly and test. Each of these tasks are further divided as required. Detailed plans and schedules, which define the work to be accomplished, start and stop dates, and authorized budget, are based on these WBS tasks.

Figure 7-7 is the PAS-2 program master schedule. It reflects key milestones and activity spans. The master schedule summarizes the detailed subsystem schedules (Figures 7-8 through 7-15).

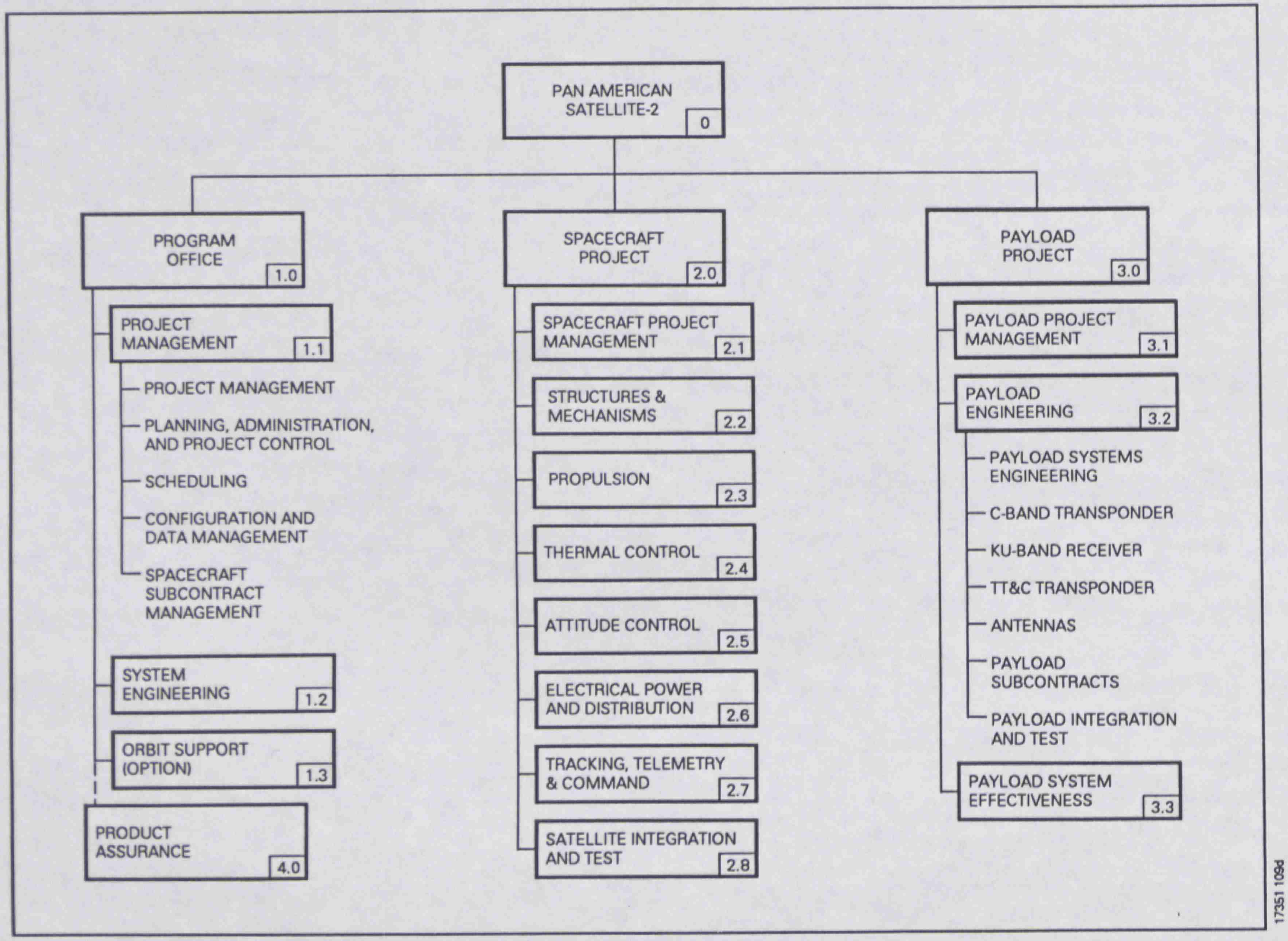


Figure 7-6. PAS-2 Work Breakdown Structure (WBS)

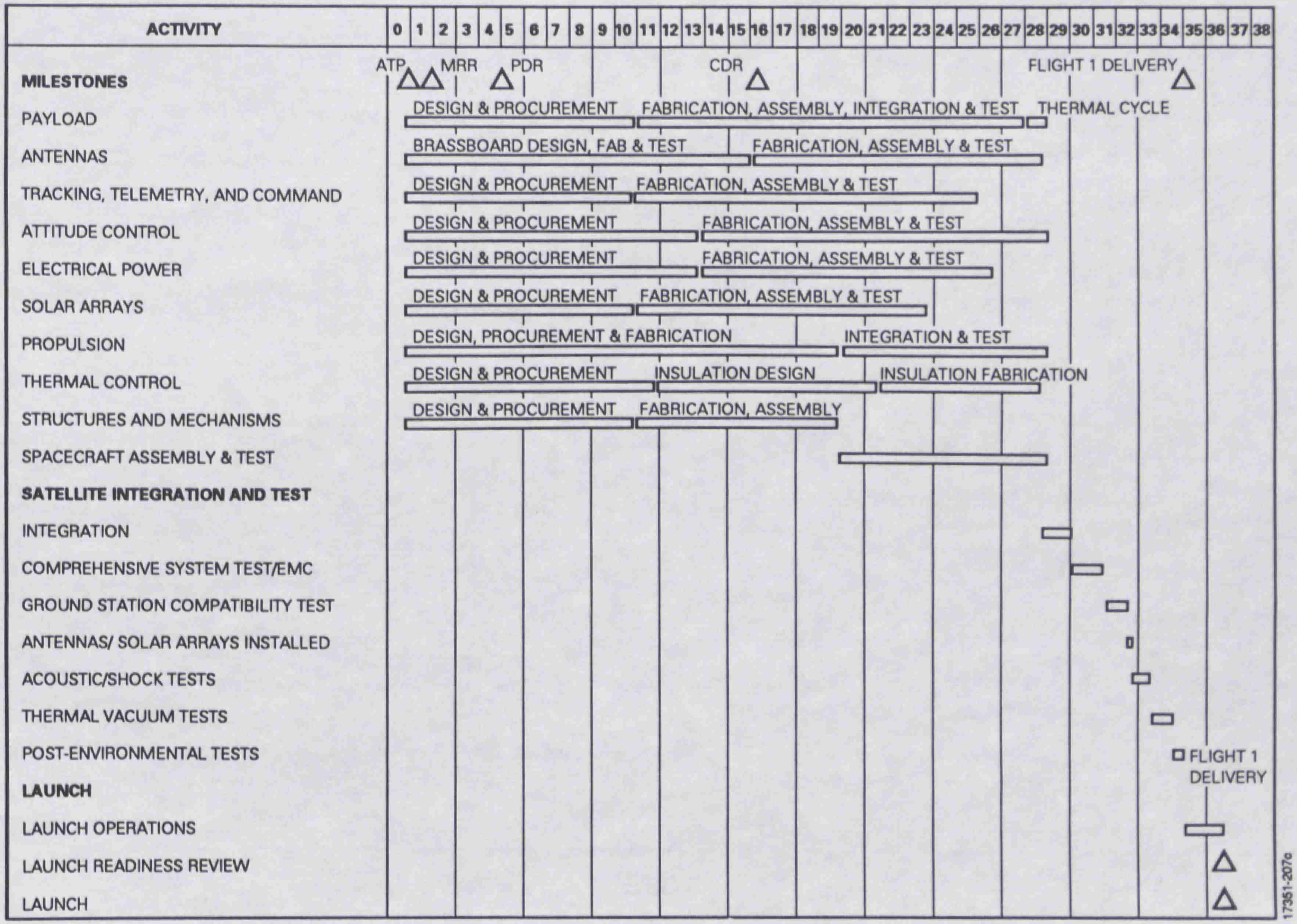


Figure 7-7. PAS-2 Master Program Schedule

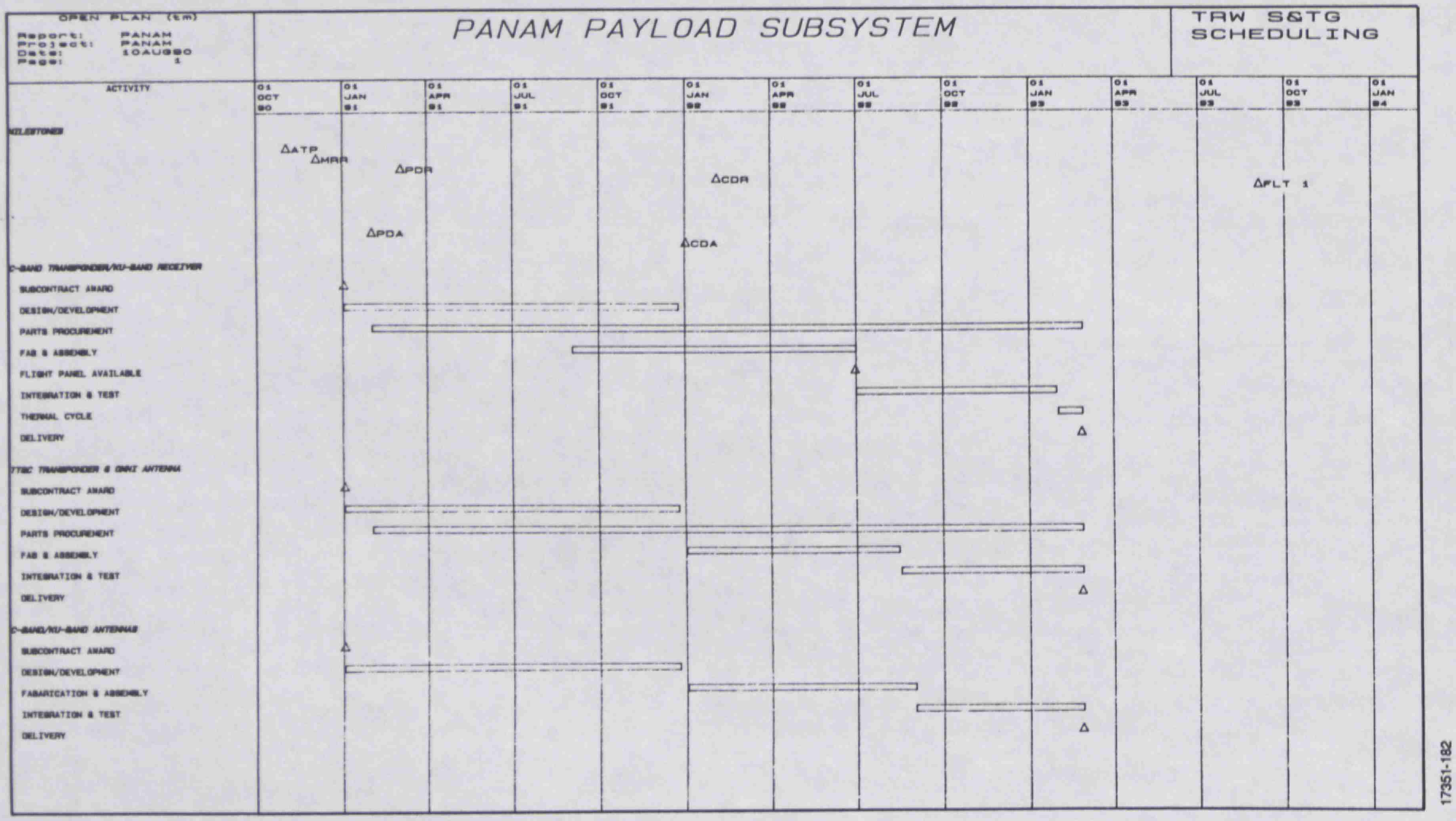


Figure 7–8. Payload Schedule

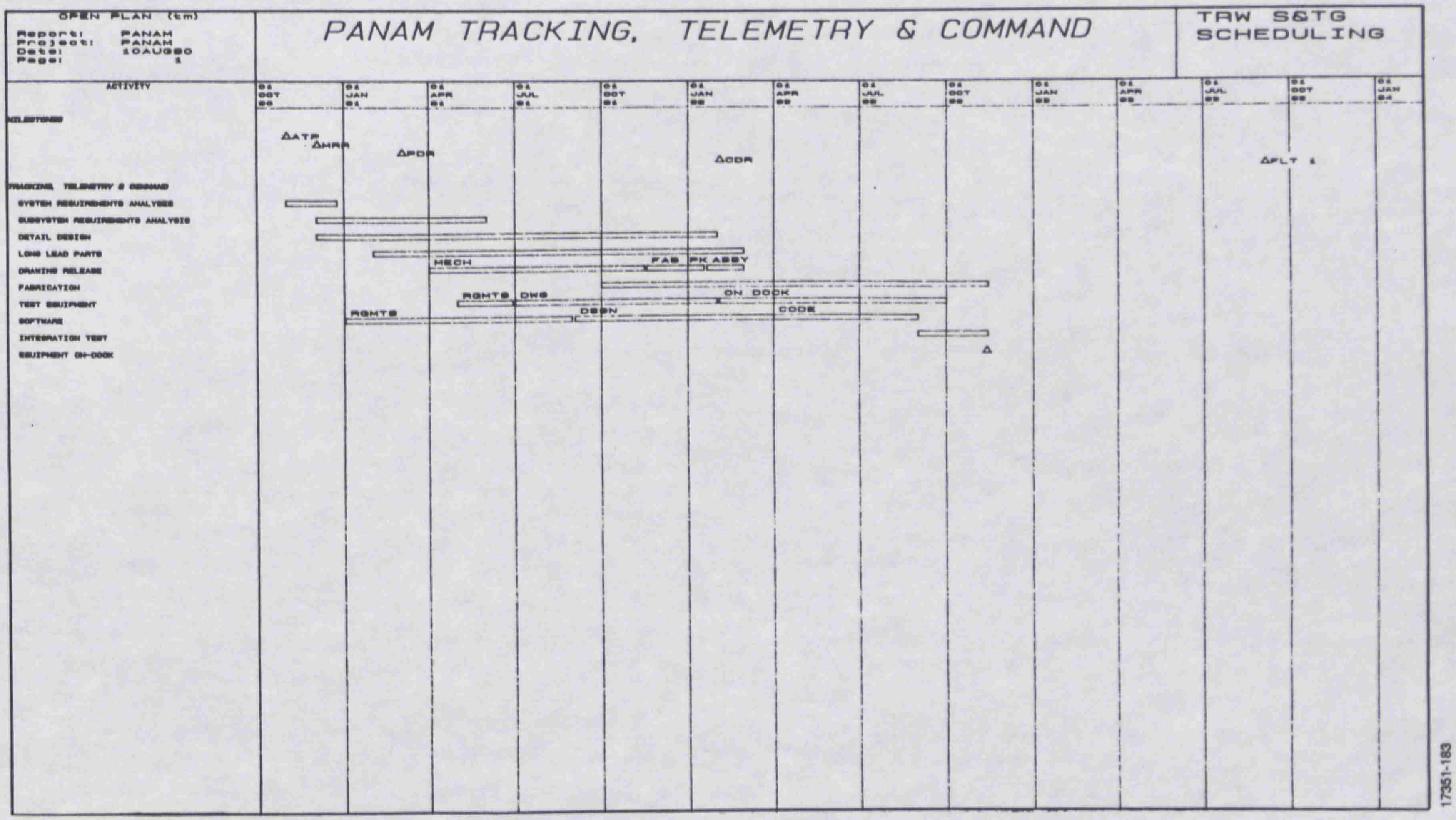


Figure 7–9. Tracking, Telemetry, and Command Subsystem Schedule

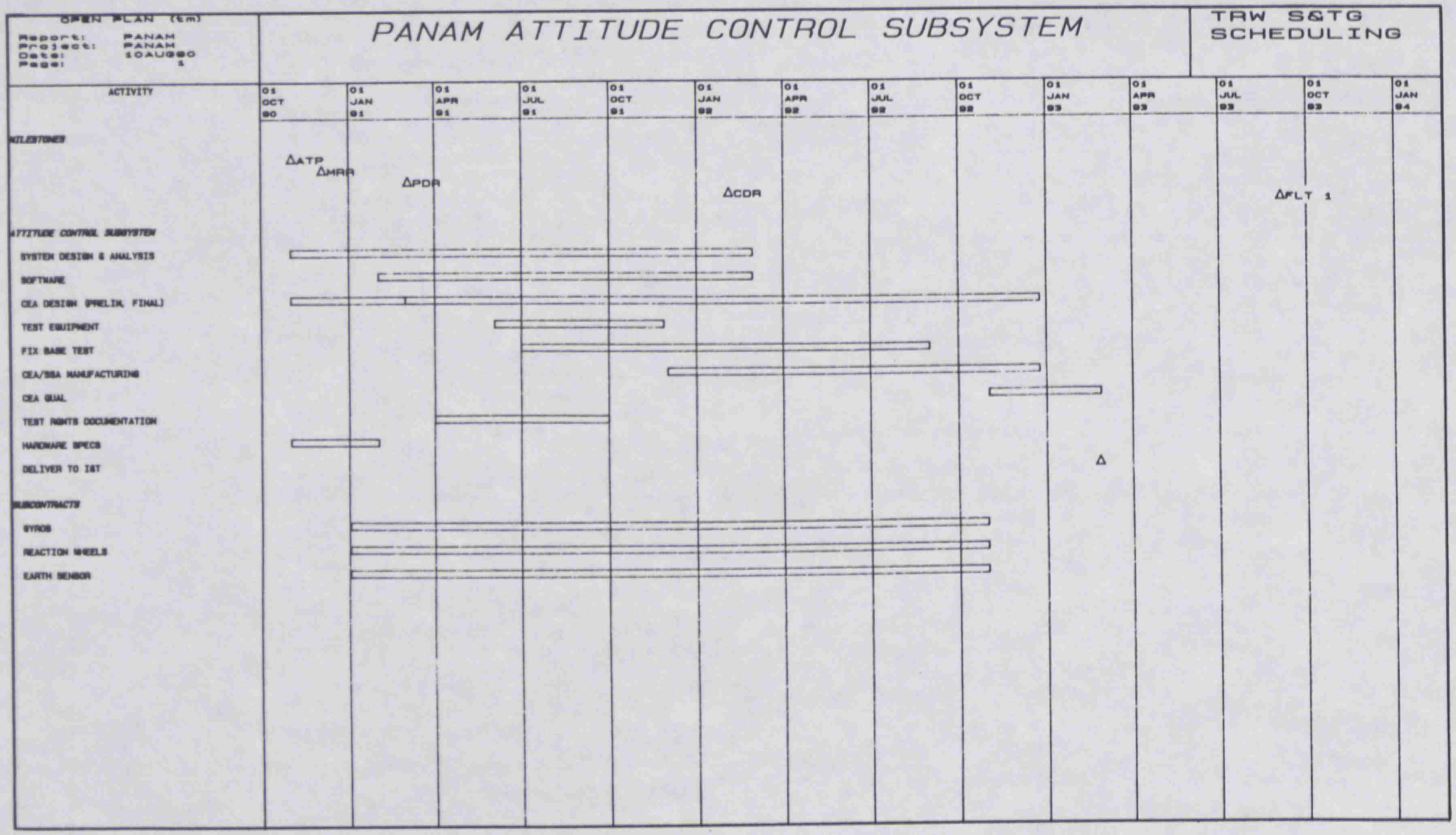


Figure 7–10. Attitude Control Subsystem Schedule

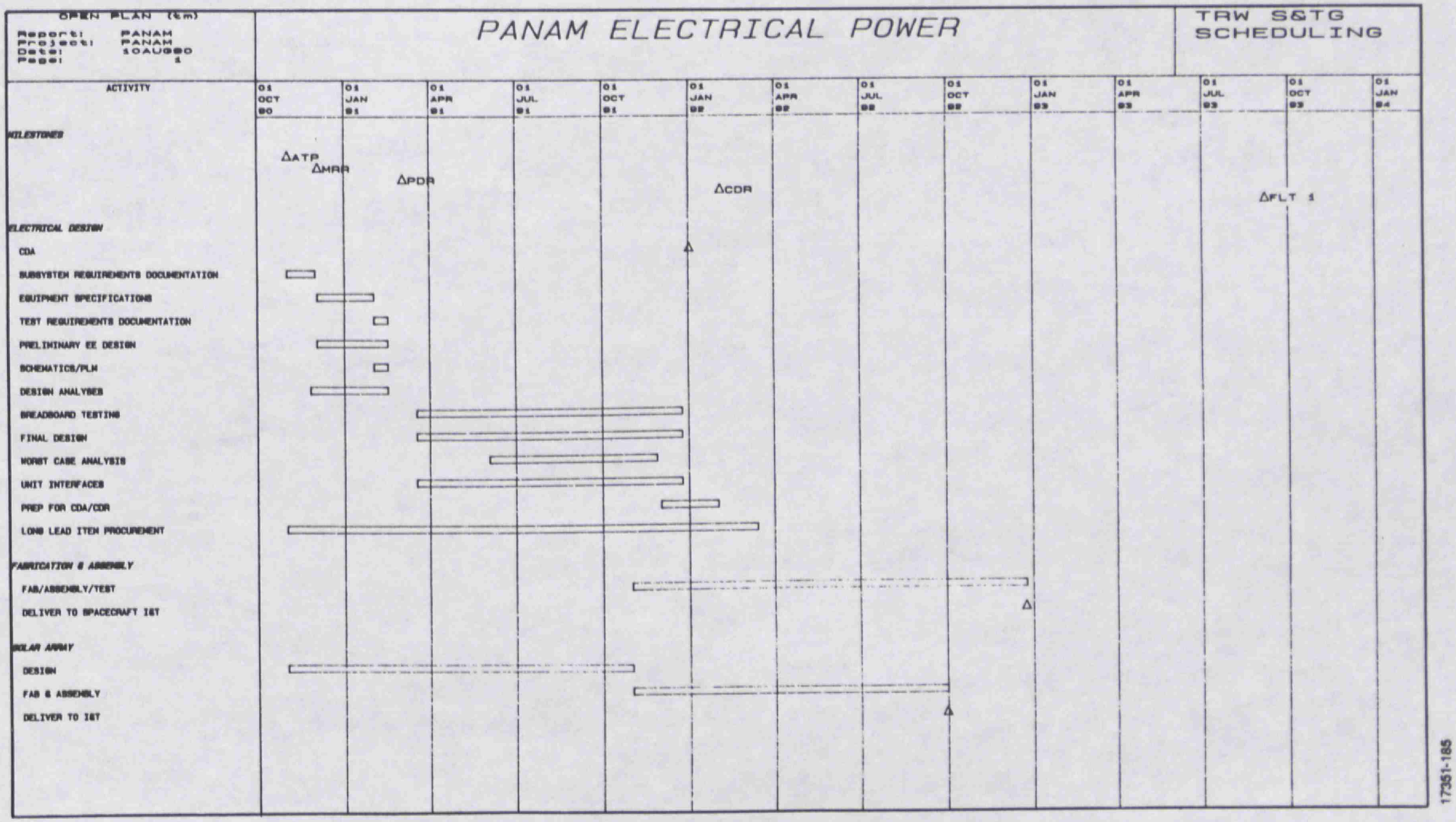


Figure 7–11. Electrical Power and Distribution Subsystem Schedule

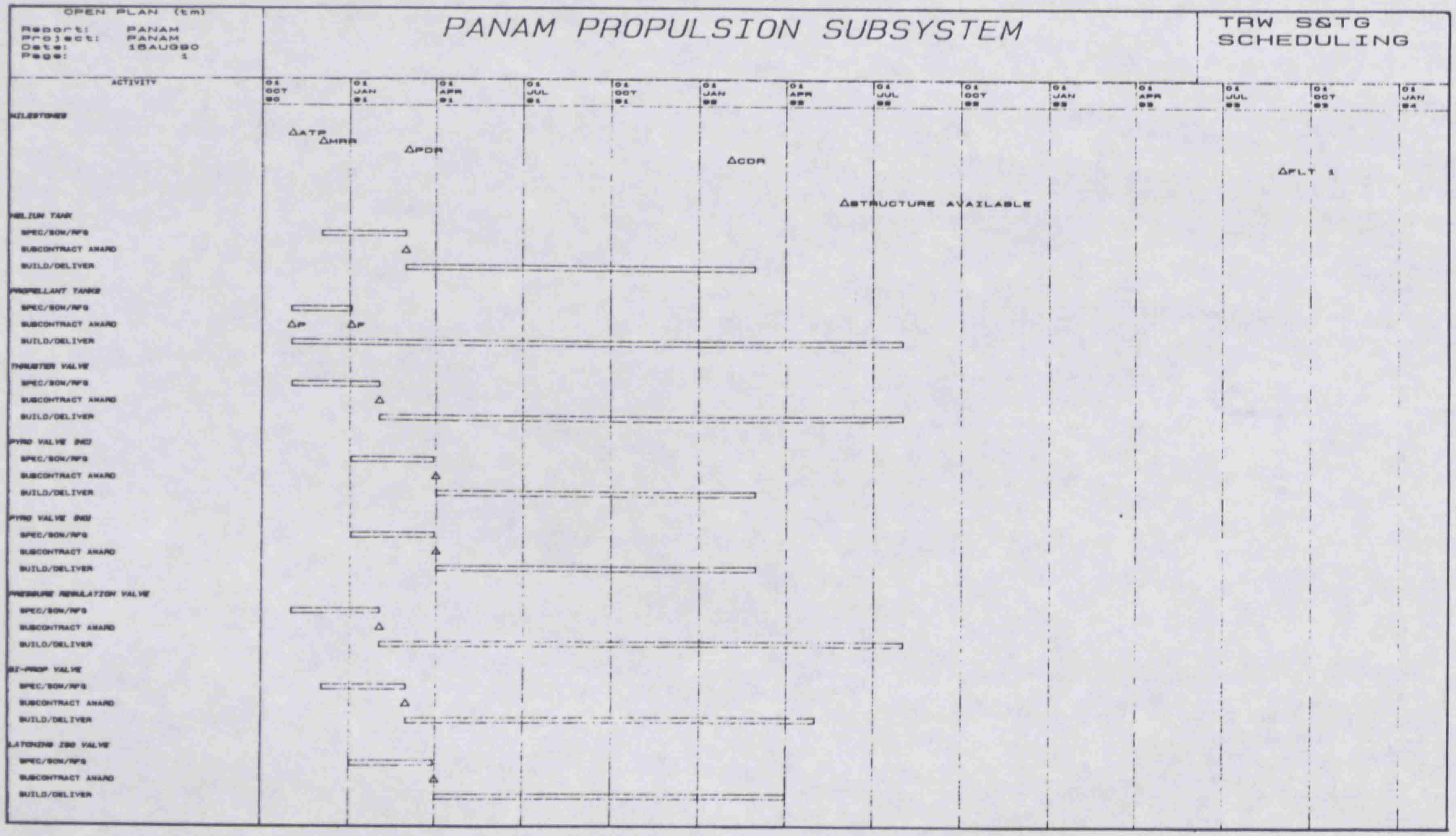


Figure 7–12. Propulsion Subsystem Schedule (1 of 3)

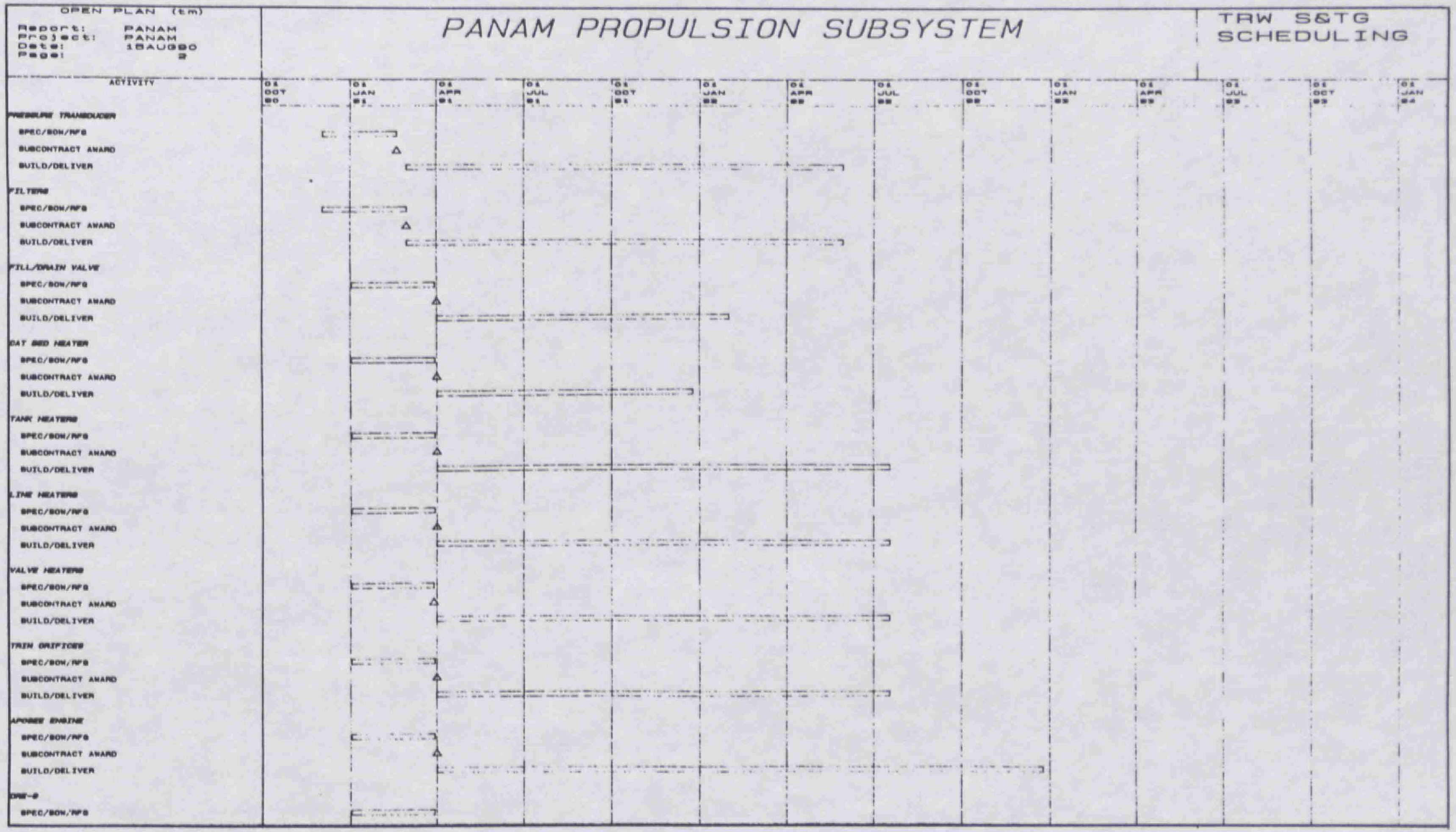


Figure 7–12. Propulsion Subsystem Schedule (2 of 3)

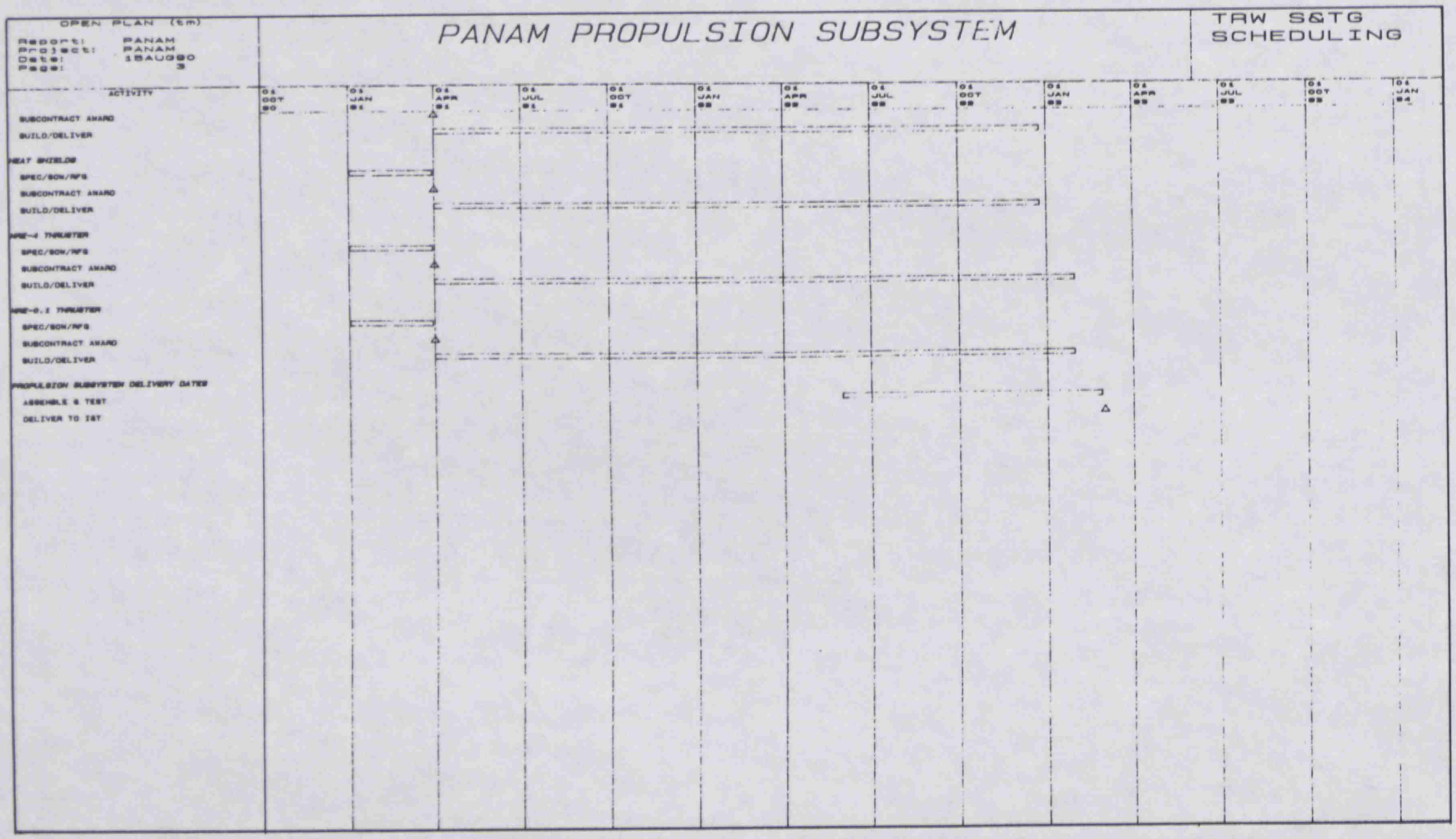


Figure 7–12. Propulsion Subsystem Schedule (3 of 3)

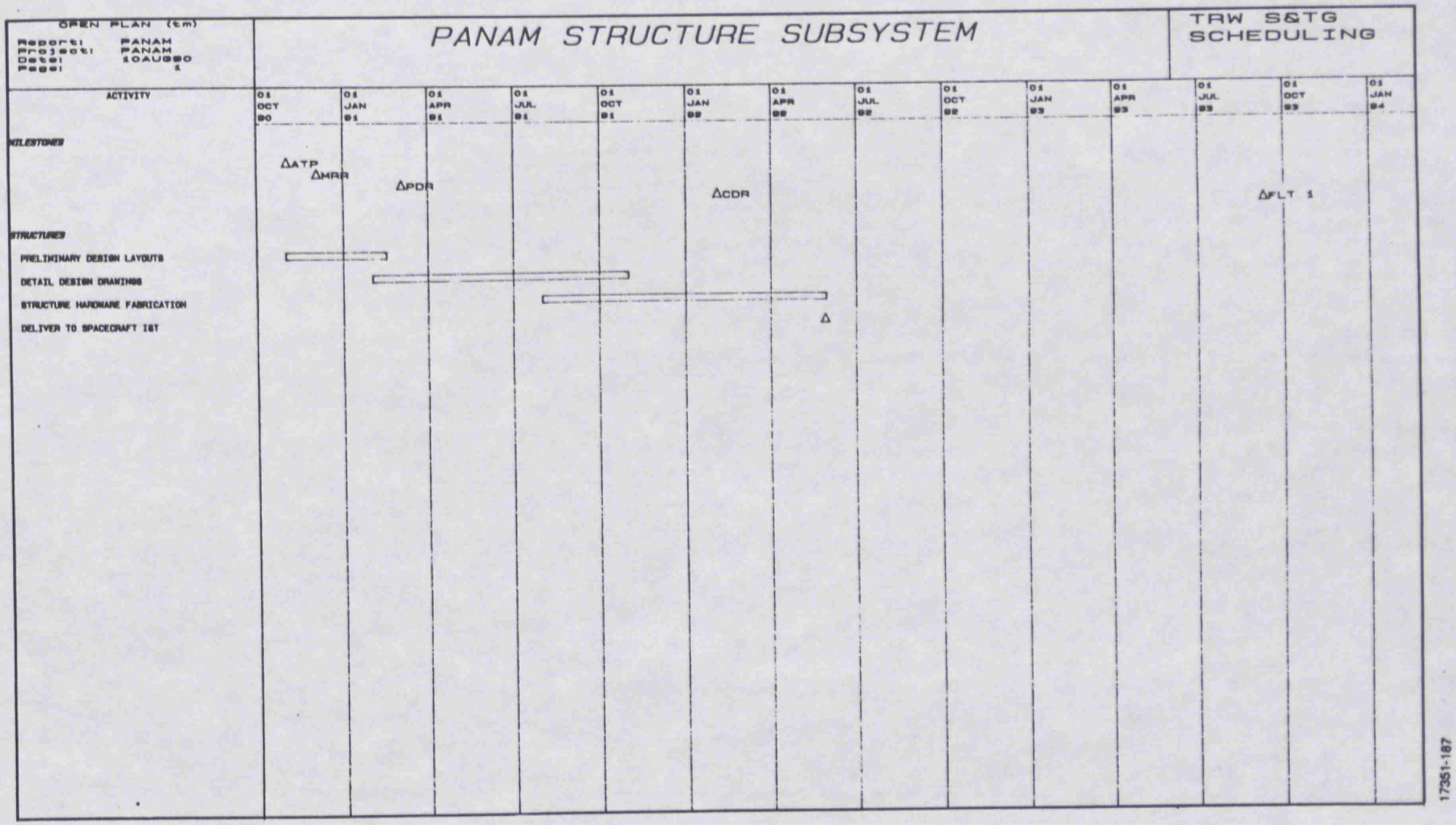
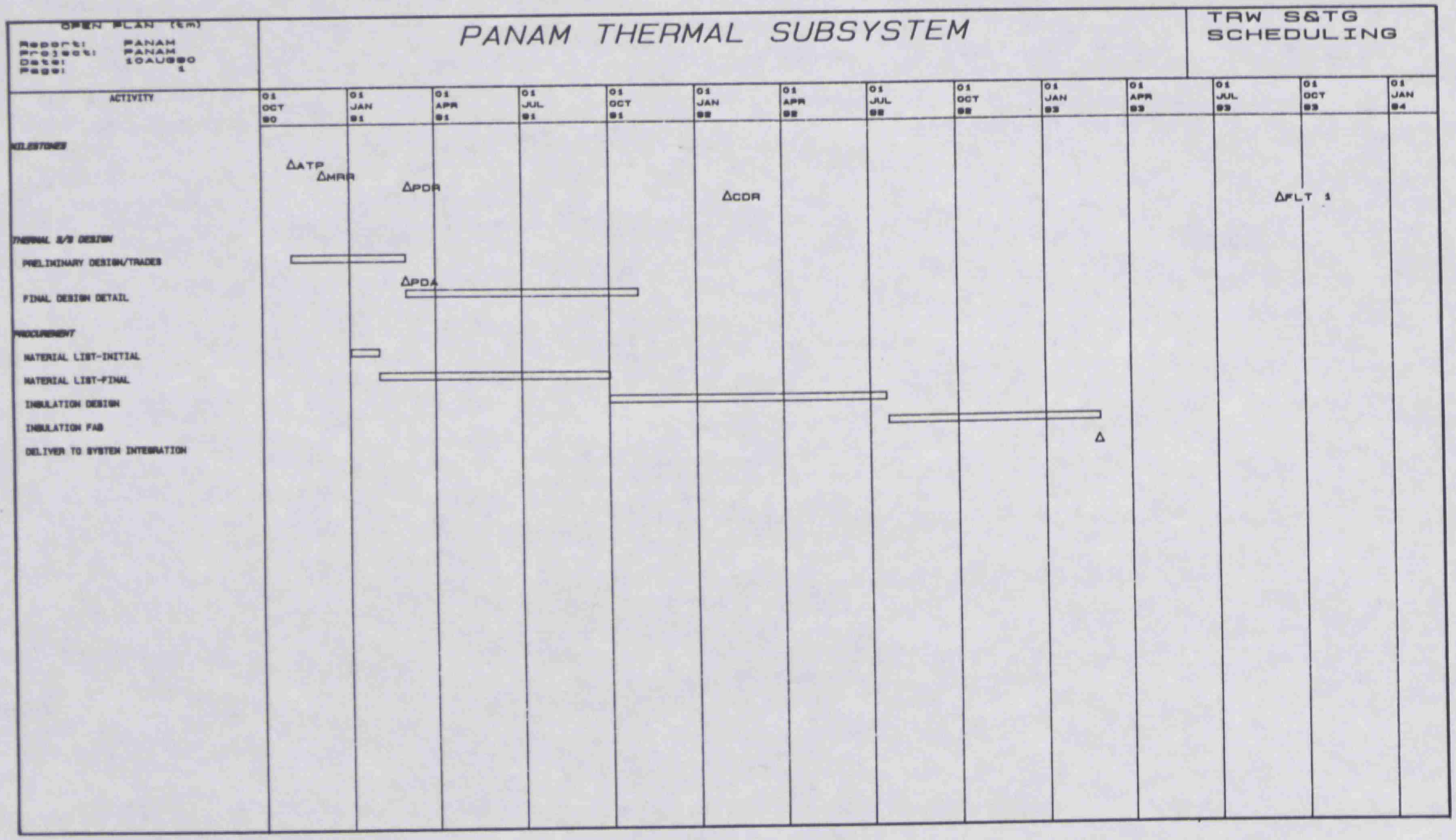


Figure 7–13. Structures and Mechanisms Subsystem Schedule



17351-188

Figure 7–14. Thermal Control Subsystem Schedule

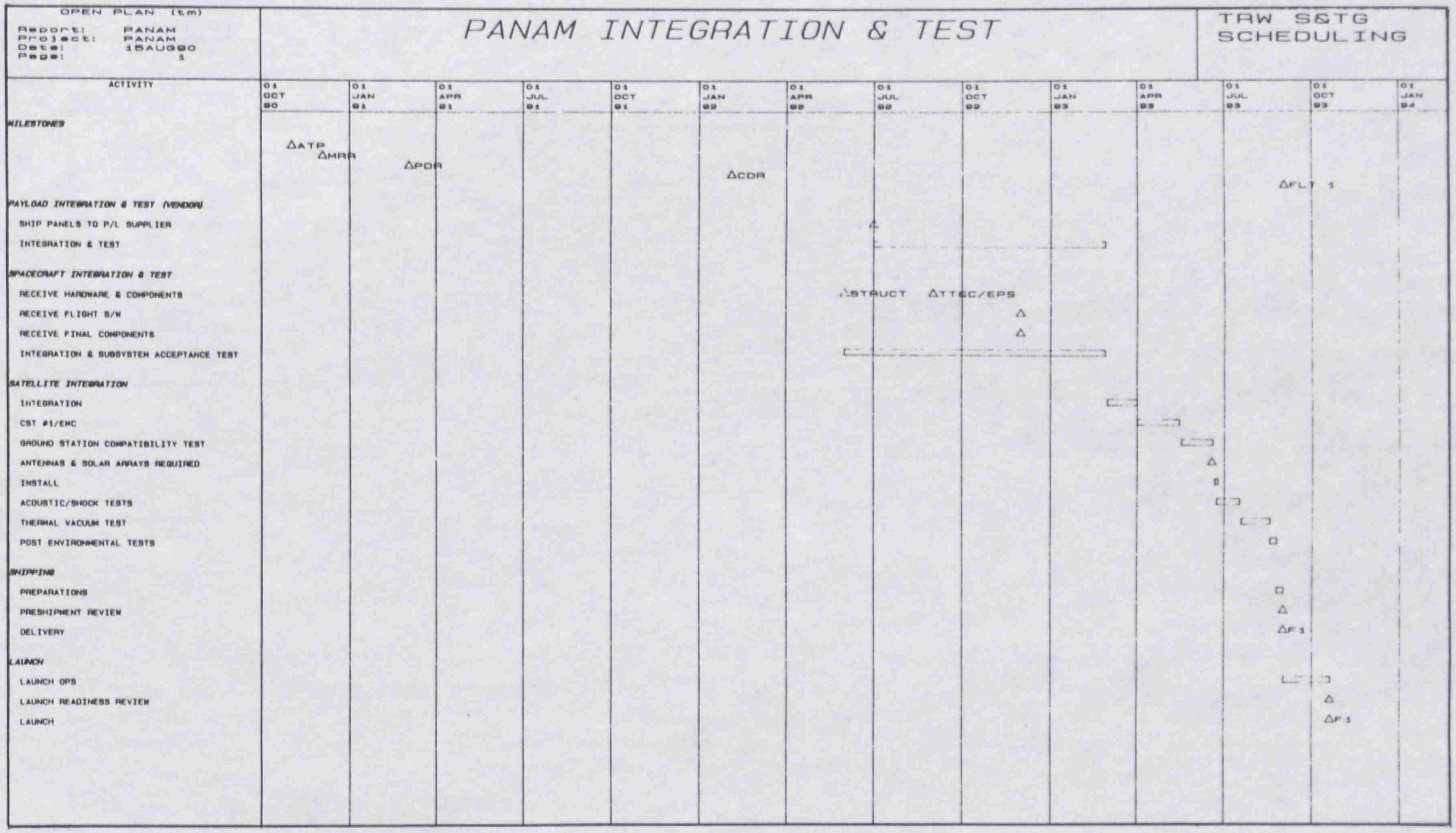


Figure 7–15. Integration and Test Schedule

ILLUSTRATIONS

ILLUSTRATIONS (Continued)

ILLUSTRATIONS (Continued)

ILLUSTRATIONS (Continued)

GLOSSARY

ACS	attitude control system
ARE	array regulator electronics
ASIC	application-specific integrated circuit
BOL	beginning of life
CTPU	command and telemetry processing unit
CDR	critical design review
CPU	central processing unit
CRC	cyclic redundancy check
CST	comprehensive test system
DOD	depth of discharge
DRE	dual-reaction engine
DSCS II	Defense Satellite Communications System
DSP	Defense Support Program
EMI	electromagnetic interference
EOC	edge of coverage
EOL	end of life
EPIC	element/processor interface circuit
EPDS	electrical power distribution subsystem
FLTSATCOM	Fleet Satellite Communications
GEO	geosynchronous equatorial orbit
GTO	geosynchronous transfer orbit
HMIC	hybrid microwave integrated circuit
HPA	high-power amplifier
IMUX	input multiplexer
I/O	input/output
LAE	liquid apogee engine
LNA	low-noise amplifier
MLI	multilayer insulation
NiH_2	nickel-hydrogen
NTO	nitrogen tetroxide
OBC	spacecraft onboard computer
OMT	orthomode transducer
OMUX	output multiplexer
PAS-2	Pan American Satellite-2
PCDU	power control and distribution unit
PDR	preliminary design review
PIM	passive intermodulation products
PROM	programmable read-only memory
PS	propulsion subsystem
PWM	pulse width modulation
RCS	reaction control system
RCTU	remote command/telemetry unit
ROM	read-only memory
RWA	reaction wheel assembly
SADA	solar array drive assembly
S&MS	structures and mechanisms subsystem
SCC	serial communication controller
SPF	single-point failure
SSPA	solid-state power amplifier
TT&CS	tracking, telemetry, and control subsystem
TCS	thermal control subsystem
TDRSS	Tracking and Data Relay Satellite System