TRW

Total Ozone Mapping Spectrometer Earth Probe (TOMS-EP)

Critical Design Review Data Package

Day 2
4 August 1992

CDRL No. SE-22
Contract No. NAS5-31488

TOMS-EP CDR Agenda
Day 1   3 August 1992

TRW

Time	Subject	Presenter
8:00	**Mission Objectives**	
8:30	**Project Overview**	D. Stager
	PDR Actions/Open Issues	
	Subcontractors	R. Hlavaty
	Performance Assurance Implementation	E. Starr
9:30	**Key Requirements Vs. Capabilities**	B. Dobrotin
10:30	**System Implementation**	
	System Description	B. Dobrotin
	System Design Integration:	
	Mechanical Integration	D. Nicolson
	Electrical Integration, Command and Telemetry	W. Jhang
12:00	LUNCH	
1:00	**Interfaces:**	
	Launch Vehicle Interfaces and Integration	J. Giglio
	Spacecraft Bus to Instrument	B. Dobrotin
	Spacecraft/Ground	T. Watson
2:30	**Spacecraft Modes/Redundancy Management**	L. Fesq
3:30	**System Performance**	
	Mass Properties	L. Petty
	Alignment Budgets	W. Akle
	Electrical Power Energy Balance	D. Muleady

TOMS-EP CDR Agenda
Day 2 4 August 1992

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Time	Subject	Presenter
8:00	**TRW Eagle Test Bed (ETB) - M2 High Bay**	T. Petersen
	Subsystem Design and Verification	
9:00	Structure and Mechanisms Subsystem (SMS)	J. Castan
10:00	Thermal Subsystem	D. Wanous
11:00	Orbit Adjust Subsystem (OAS)	A. Alicastro
12:00	LUNCH	
1:00	Communications and Data Handling Subsystem (C&DHS)	J. Kinney
2:00	Electrical Power & Distribution Subsystem (EPDS)	S. Foroozan
3:00	Attitude Control and Determination Subsystem (ACDS)	H. Schmeichel
4:00	Flight Software	D. Stuart

TOMS-EP CDR Agenda
Day 3 5 August 1992

TRW

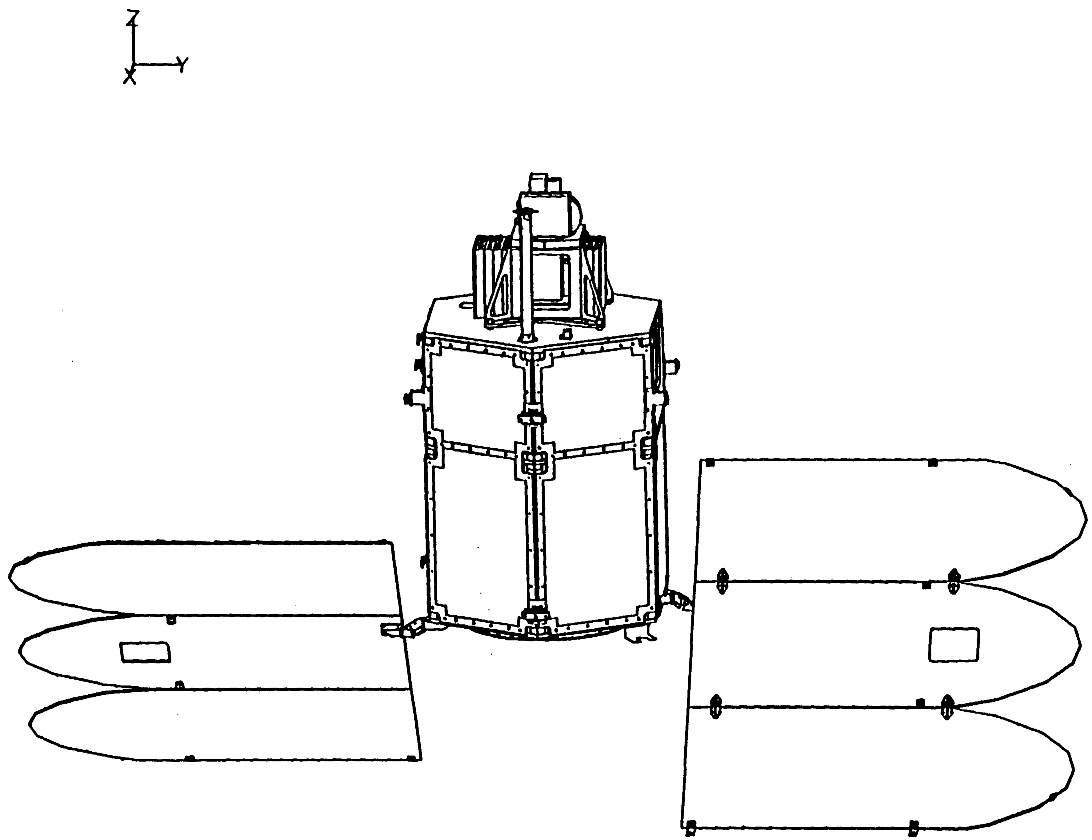
Time	Subject	Presenter
8:00	**System Verification**	B. Dobrotin
8:30	Spacecraft Verification	J. Giglio
9:30	EMC/EMI Verification	R. Bal
	Spacecraft Integration, Test, Launch and Mission Operations	
10:30	System Integration, Test and Launch	J. Durschinger
12:00	LUNCH	
1:00	Mission Operations	T. Watson
2:00	**Performance Assurance**	E. Starr
2:15	Reliability/FMEA	W. Woerner
2:40	System Safety	D. McGraw
3:10	Contamination Control	K. Henderson
3:40	Materials and Processes	M. Hirsch
4:05	EEE Parts	G. Penney
4:50	Hardware Quality Assurance	L. Irwin
5:15	Software Quality Assurance	G. Walsh

TOMS-EP
Subsystem Design and Verification

TOMS-EP
Structure and Mechanisms Subsystem

J. Castan

General Configuration



Subsystem Description

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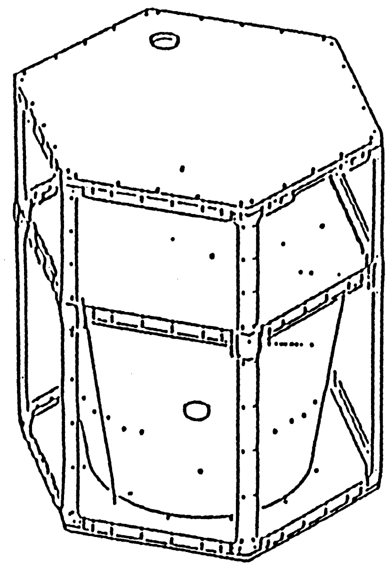
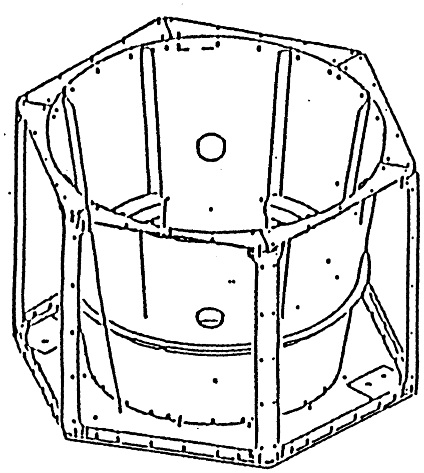


TOMS/ETD SPACECRAFT STRUCTURE



- Nadir platform equipment carried by honeycomb sandwich panel (through bending) to outer rails and down longerons to middle platform.
- Loads from longerons carried across outer edge of middle platform through shear and bending in mid platform and support rail to central cone.
- Loads from Nadir and middle platforms carried by central cone to separation system.
- Tank loads reacted by bathtub fittings to cone skin and stringers.

System Overview - Deployment Sequence

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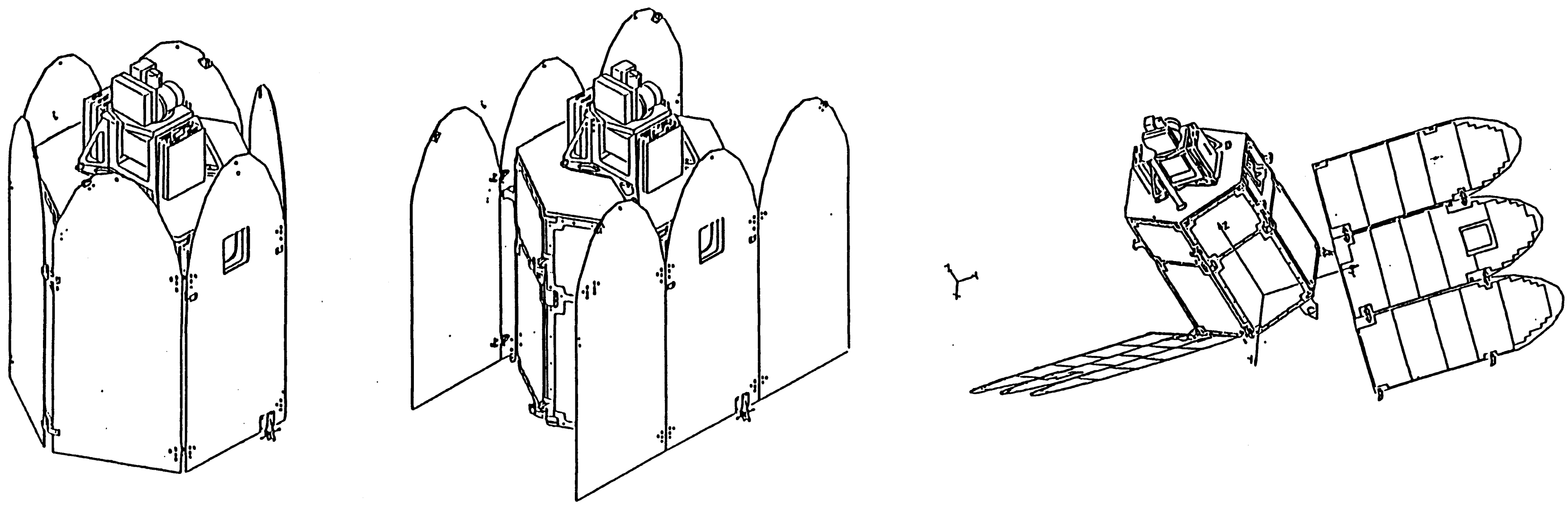

Key Requirements Versus Capabilities

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REQUIREMENT	CAPABILITY	VERIF.* METHOD T	A	I	D
		T	A	I	D
SPACECRAFT INSTRUMENT INTERFACES	COMPLIES WITH ICD 305506			X	
STRUCTURE SHALL BE DESIGNED TO LOAD FACTORS STATED IN D19249 AND D19250 (REF. IOC L122.2.91-060) DOCUMENTS	ALL MARGINS OF SAFETY AGAINST DESIGN LOADS POSITIVE	X	X		
STRUCTURE SHALL BE DESIGNED TO MEET THE FOLLOWING FACTORS OF SAFETY o 1.25 AGAINST YIELD o 1.4 AGAINST ULTIMATE (REF. SPEC: SS1-0021)	ALL M.S. $\geq$ 0.0 AGAINST REQUIRED SAFETY FACTORS		X		
STRUCTURE SHALL BE DESIGNED TO MEET THE FOLLOWING STIFFNESS REQUIREMENTS o PRIMARY STRUCTURE $\geq$ 32 Hz o SOLAR ARRAYS STOWED $\geq$ 22 Hz o SOLAR ARRAYS DEPLOYED $\geq$ 1 Hz (REF. D19252)	o SPACECRAFT FIRST BENDING MODE = 32 Hz o SOLAR ARRAY STOWED FIRST BENDING MODE = 24 Hz o SOLAR ARRAY DEPLOYED, FIRST MODE = 1.16 Hz	X	X		
INSTRUMENT MOUNT SHALL MEET THE REQUIREMENTS STATED IN SPEC: SS1-0021	COMPLY		X	X	
INSTRUMENT ALIGNMENTS SHALL COMPLY WITH ICDS; ALIGNMENT BUDGET SE-18	COMPLY		X	X	
DEPLOYMENT SYSTEM MUST COMPLY WITH SPEC: SS1-0021	COMPLY	X			X
ALL MATERIALS MUST MEET STRESS CORROSION REQUIREMENTS, PER MSFC-SPEC-522A, TABLE 1	ALL MATERIALS SELECTED ARE FROM MSFC-SPEC-522A, TABLE 1		X		

*VERIFICATION METHOD: T = TEST; A = ANALYSIS; I = INSPECTION; D = DEMONSTRATION

Structural Design Requirements

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- Structure Design Weight = 680 lbs
  - 77 lbs TOMS Instrument
  - Full propellant tank
  - Heavy battery and solar cells
  - Contingency on all units

- Design limit load factors, obtained from PEGASUS User Guide, and direct communications with OSC/NASA and from Base Shake analysis.

- Stiffness requirements, obtained from PEGASUS User Guide.

- Stiffness Requirements
  - Primary structure minimum frequency $\geq$ 32 Hz
  - Solar arrays stowed minimum frequency $\geq$ 22 Hz
  - Deployed solar arrays, minimum frequency $\geq$ 1 Hz

- Mechanism requirements (loads and stiffness), obtained from dynamic analysis.

- Factors of Safety
  - 1.25 for Yield
  - 1.40 for Ultimate

- Minimum Margins of Safety
  - Strength $\geq$0.0
  - Stability $\geq$0.15

Structural Design Requirements (Continued)

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o LAUNCH LOADS

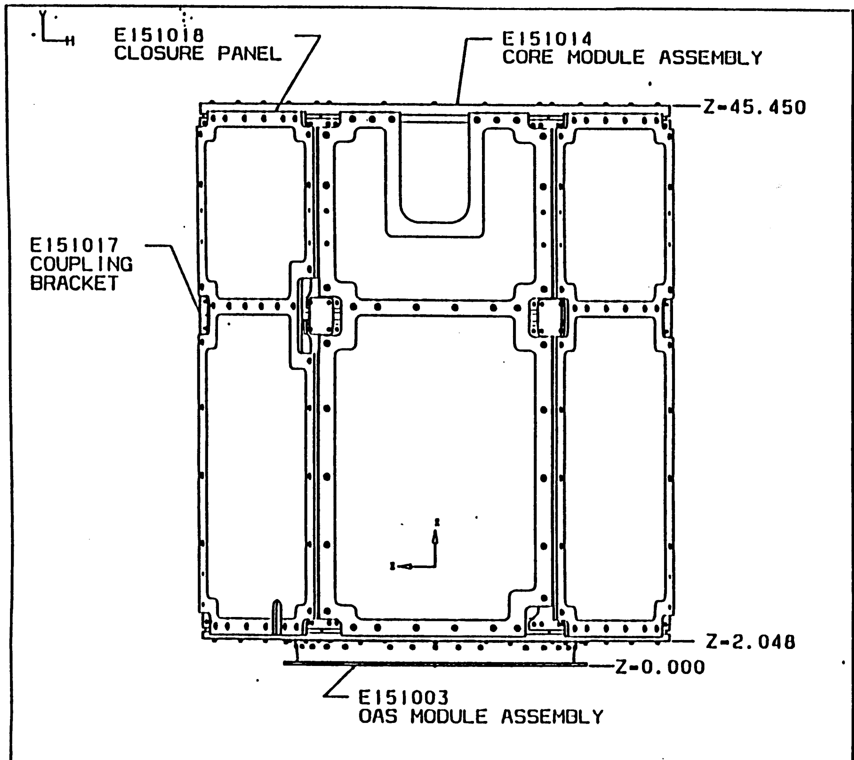
- FROM IOC L122.2.91-160, "TOMS/ETB DESIGN LIMIT LOADS ASSOCIATED WITH PEGASUS XLC", 15 OCTOBER 1991, BY K. S. ANDERSON, AND ICD: IS3-0008.

- DESIGN LIMIT LOAD FACTORS

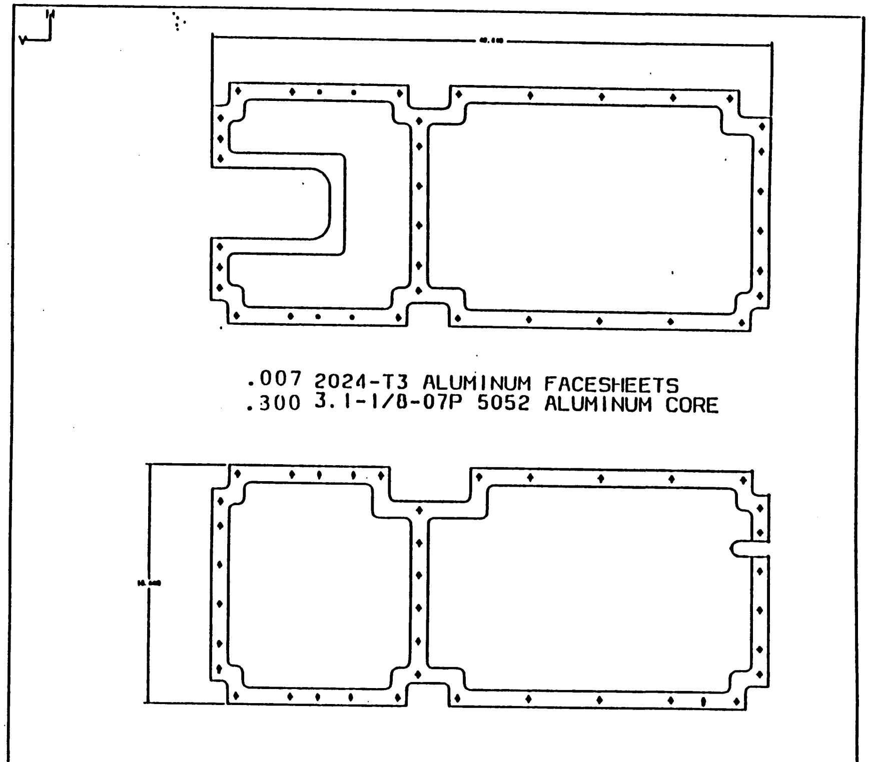
COMPONENT	AXIAL, $Z_{S/C}$	LATERAL	EVENT
SPACECRAFT STRUCTURE	± 1	± 4.5 $X_{S/C}$ ± 1 $Y_{S/C}$	CFR
	-12.5	± 1.2	2ND STAGE
PLATFORMS	-14	± 2	PF*
BLACK BOXES	± 20	± 12	-
TOMS INSTRUMENT	± 1	± 6 $X_{S/C}$	CFR
	-13.5	± 2	PF
PROPELLANT TANK	-14	± 2	PF
SOLAR ARRAY	+15	± 11.2	LAUNCH

CFR: CAPTIVE FLIGHT RELEASE
PF: POWERED FLIGHT
*PLATFORM AXIAL LOADS ARE 1.5G LESS AT EDGES

Closure Panels

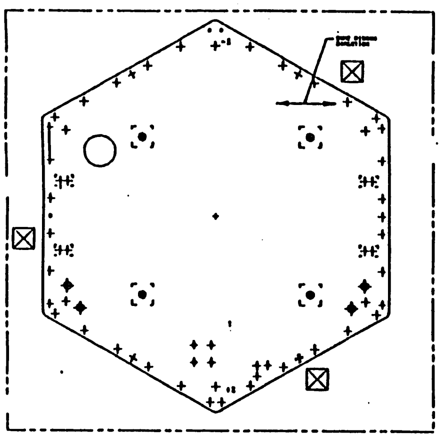


E151002 SPACECRAFT BUS



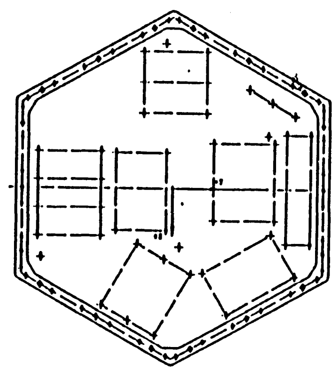
E151018 CLOSURE PANEL

Platforms



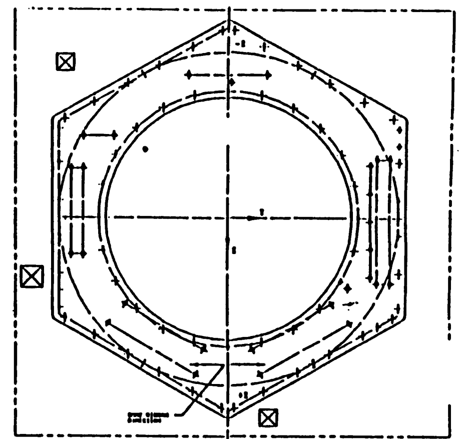
.040 2024-T81 ALUMINUM FACESHEETS
.750 6.1-1/8-15P(5056)E ALUMINUM CORE

E151015 NADIR PLATFORM (TOP)



.063 2024-T81 ALUMINUM FACESHEETS
CHEM MILLED TO .055 AT EDGE AND .025 IN CENTER
.500 8.1-1/8-20P(5056)E ALUMINUM CORE

E151016 CENTER PLATFORM (TOP)

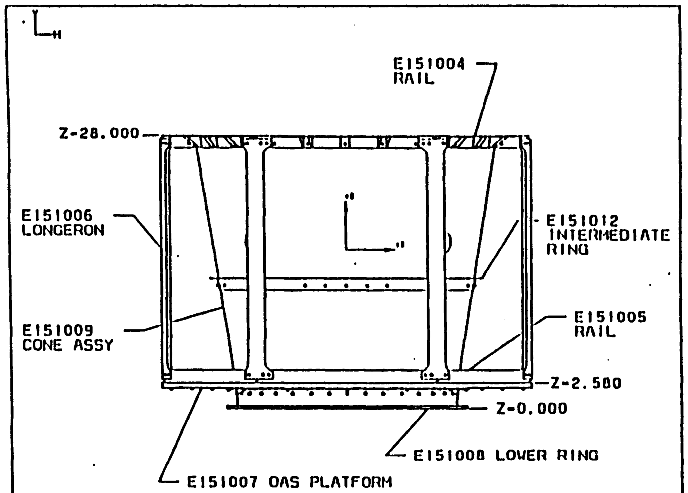


.016 2024-T81 ALUMINUM FACESHEETS
.500 4.5-1/8-10P(5056)E ALUMINUM CORE

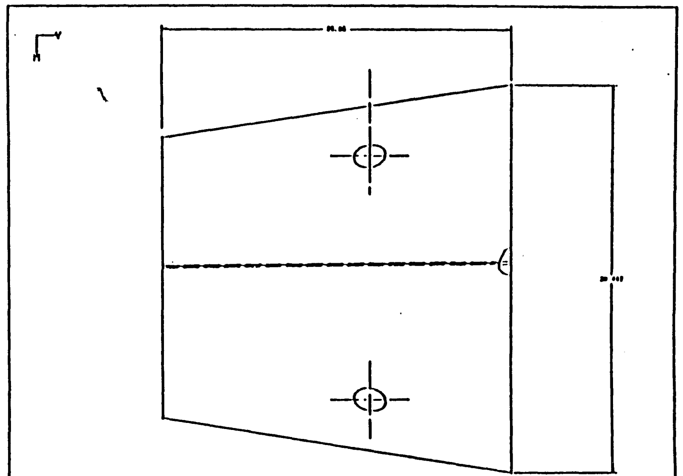
E151007 OAS PLATFORM (TOP)

OAS Module

TRW



E151003 OAS MODULE



.050 2219-T31 ALUMINUM SHEET

E151009 CONE ASSY

Solar Arrays

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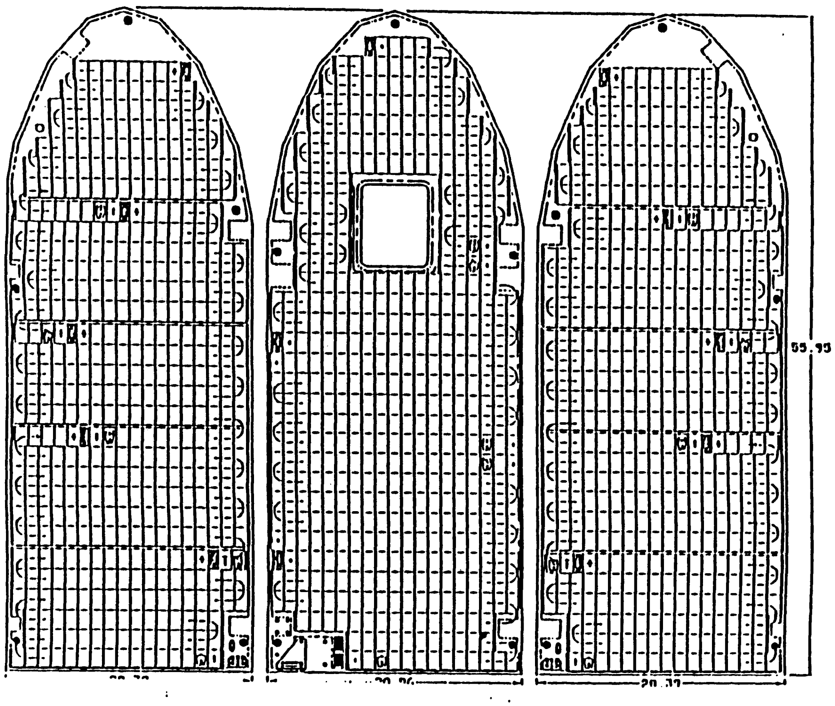
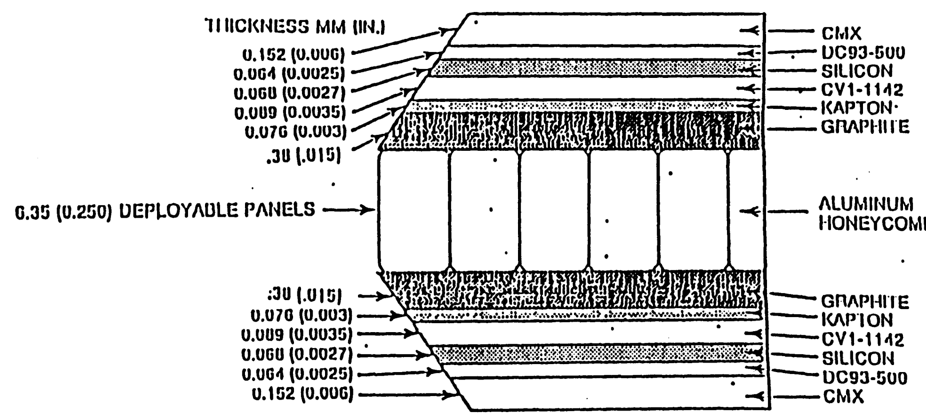
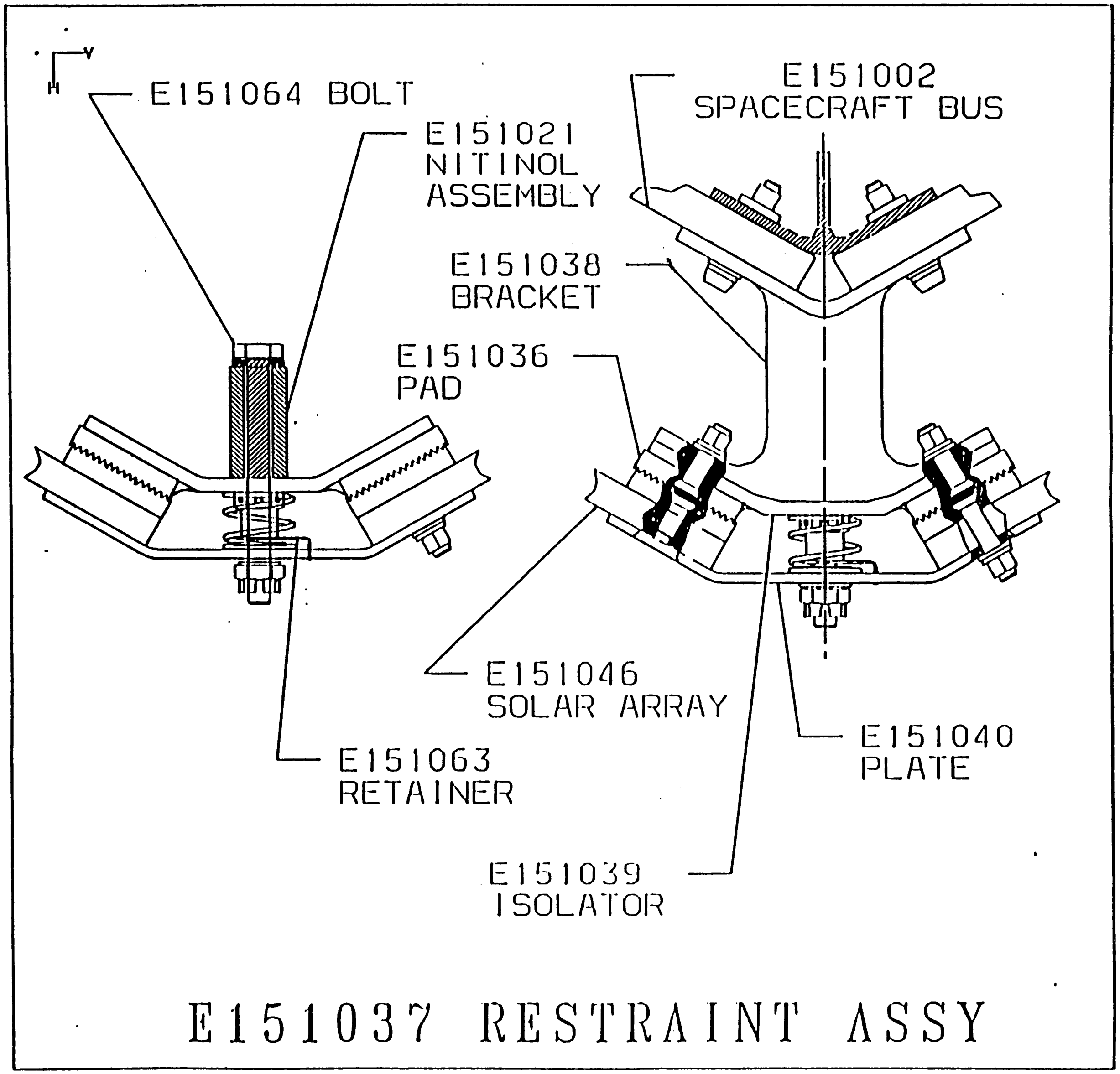
Panel Layouts



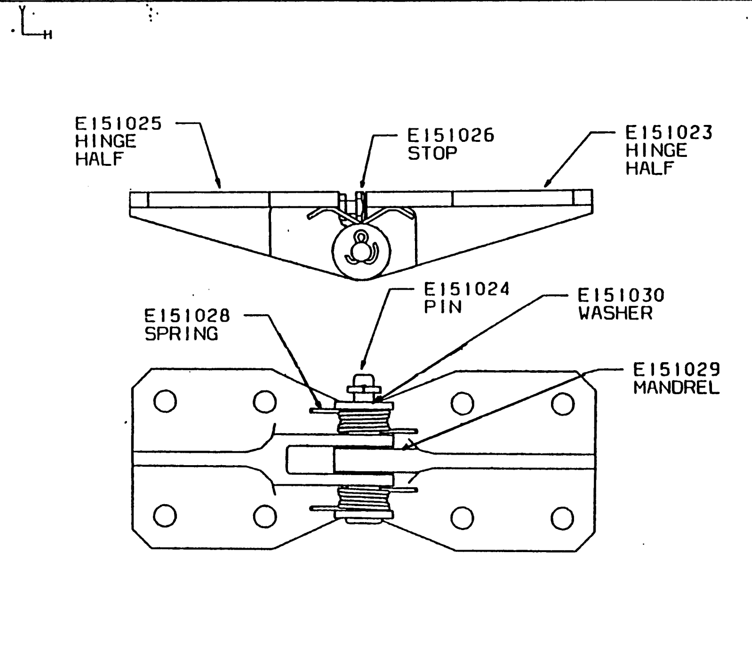
Solar Panel Composition



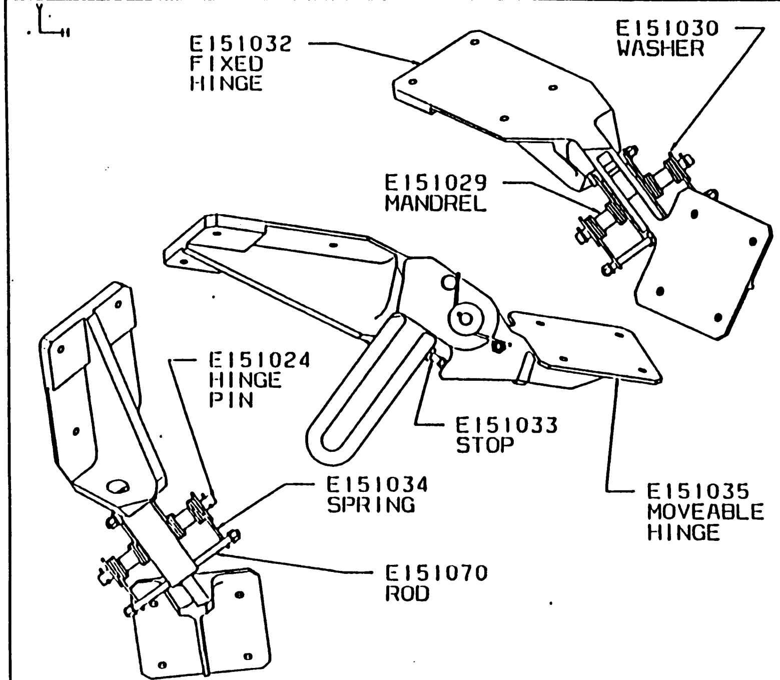
Solar Array Release Mechanisms



Solar Array Hinges

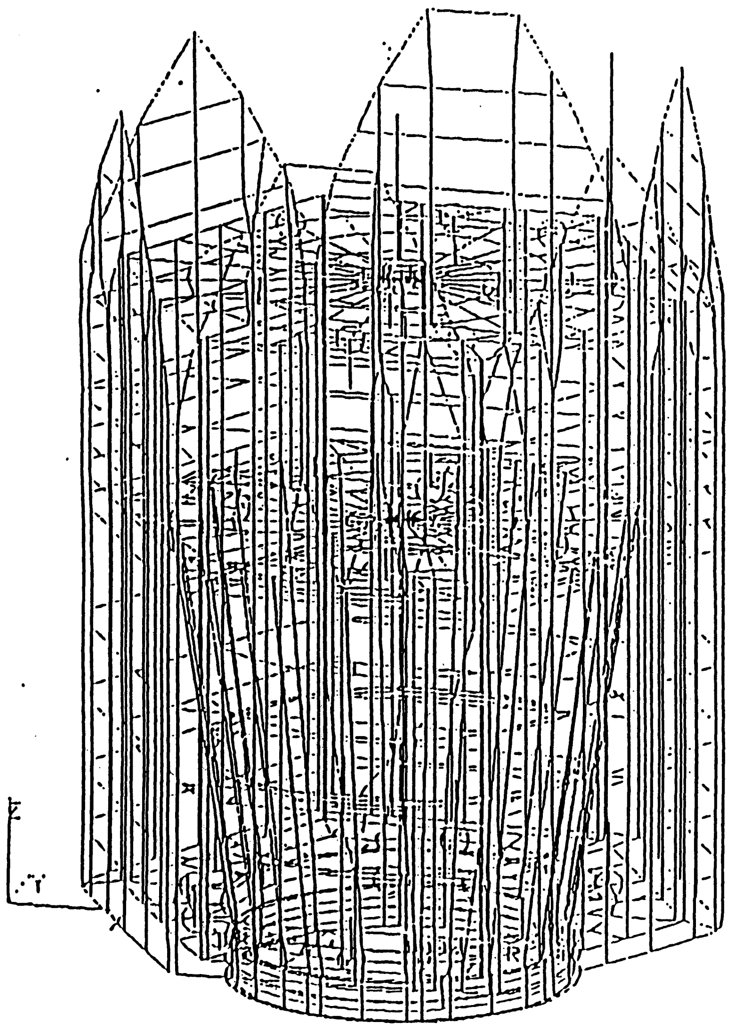


E151022 PANEL HINGE ASSEMBLY



E151031 PRIMARY HINGE ASSY

Finite Element Model



FINITE ELEMENT MODEL PARAMETERS

- 1300 GRID POINTS
- 412 BEAM ELEMENTS
- 1094 PLATE ELEMENTS
- DENSITY USED FOR STRUCTURAL MEMBERS
- NSM USED FOR MISCELLANEOUS WEIGHT (INSULATION, HARNESS, ETC.)

DYNAMICS ANALYSIS

• ON-ORBIT MODES

	DESCRIPTION (SEPARATION TO EOL)		FREQUENCIES (Hz)
NO.	PRIMARY MOTION	SECONDARY MOTION	SEPARATION TO EOL
1	SYMMETRIC FLAPPING	SYMMETRIC TORSION ABOUT Y	1.16
2	ASYMMETRIC FLAPPING	ASYMMETRIC TORSION ABOUT Y	1.30
3	SYMMETRIC TORSION ABOUT Z	ASYMMETRIC FLAPPING	2.12
4	SYMMETRIC TORSION ABOUT Y	SYMMETRIC FLAPPING	2.19
5	ASYMMETRIC TORSION ABOUT Z	ASYMMETRIC FLAPPING	2.33
6	ASYMMETRIC TORSION ABOUT Y	SYMMETRIC FLAPPING	2.98
7-12	ARRAY HINGE TRANSLATION		> 9.90

• STOWED MODES

MODE NUMBERS	MODE DESCRIPTION	FREQUENCY (Hz)
1 2 3 4 5 6	ARRAY 1ST ORDER BENDING	23.7 24.0 24.1 24.1 24.2 24.5
7 8	SPACECRAFT 1ST ORDER BENDING	32.4 33.2
9 10 13 14 16 17	ARRAY DOUBLE CURVATURE BENDING	35.9 37.1 37.4 37.5 47.1 47.5
11 12	THRUSTER SUPPORT BENDING	37.3 37.4
15	CORE MODULE BREATHING	42.7

Margins of Safety

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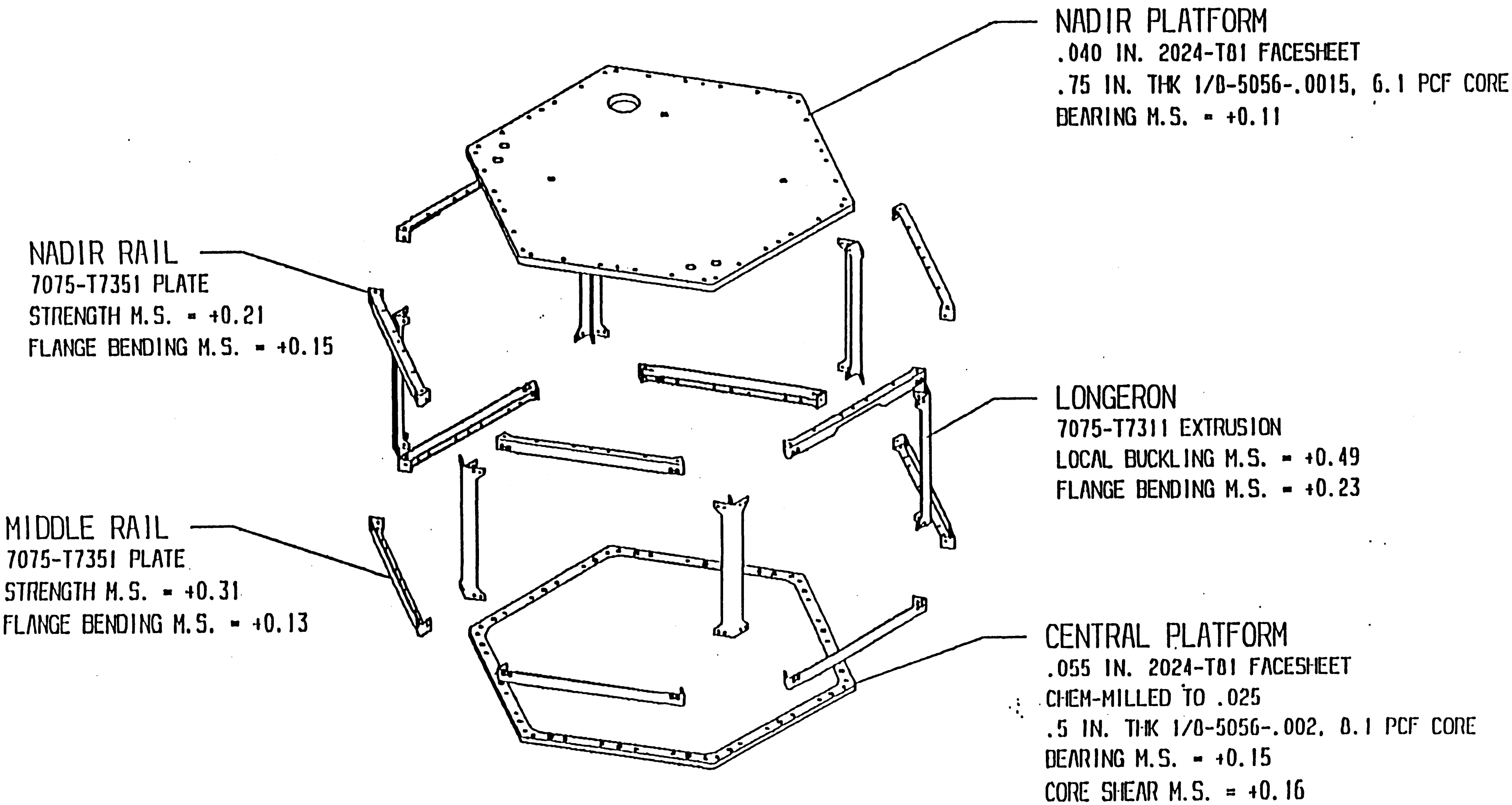
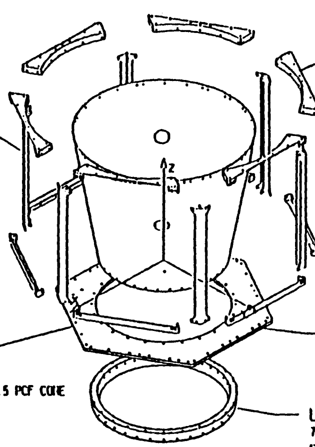
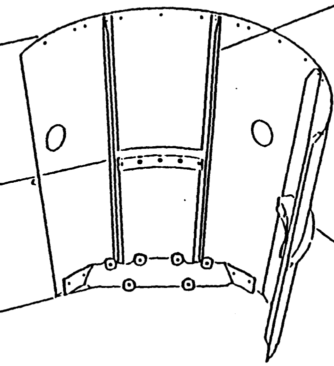
Core Module



Margins of Safety (Continued)

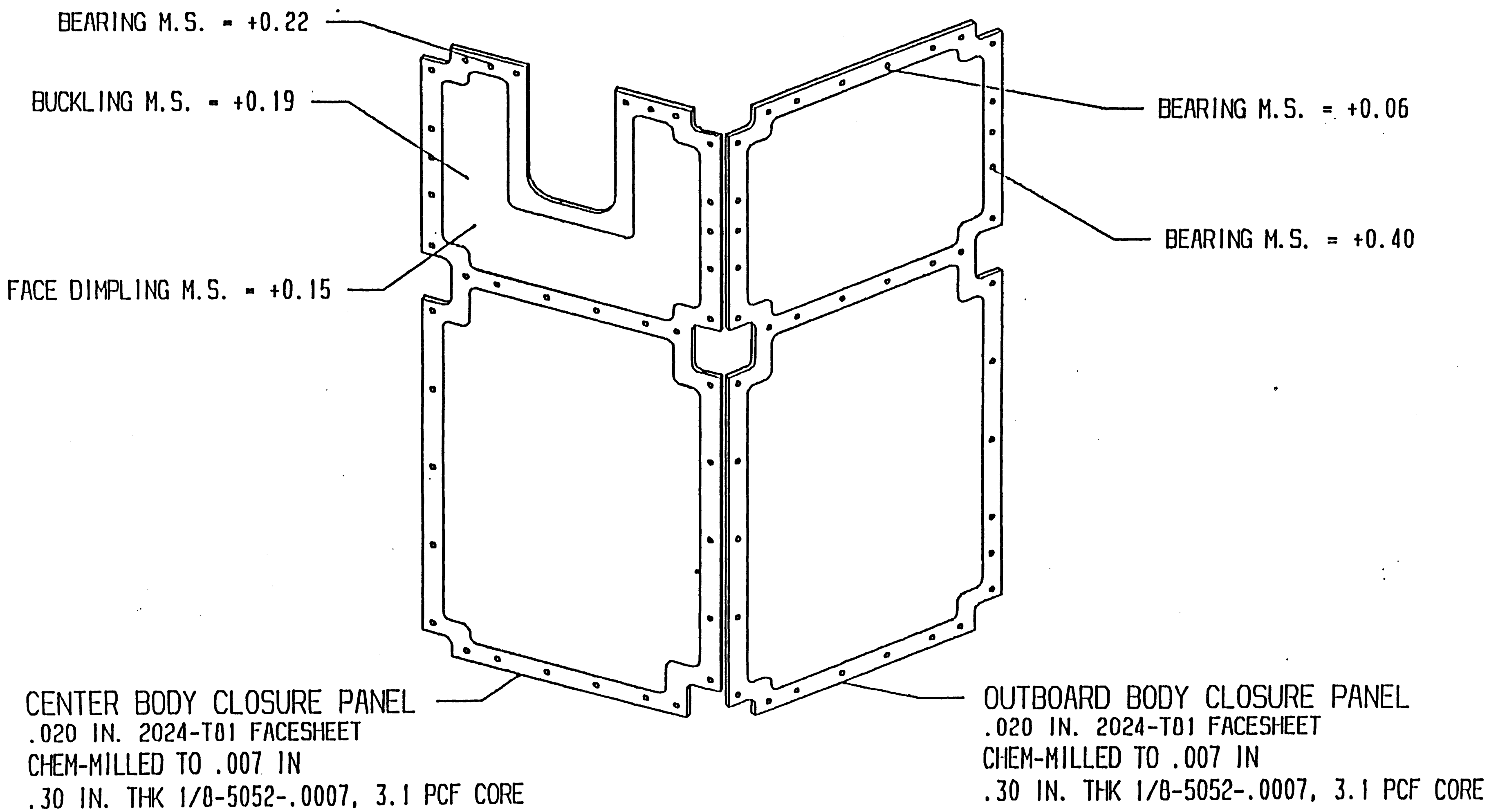
OAS Module





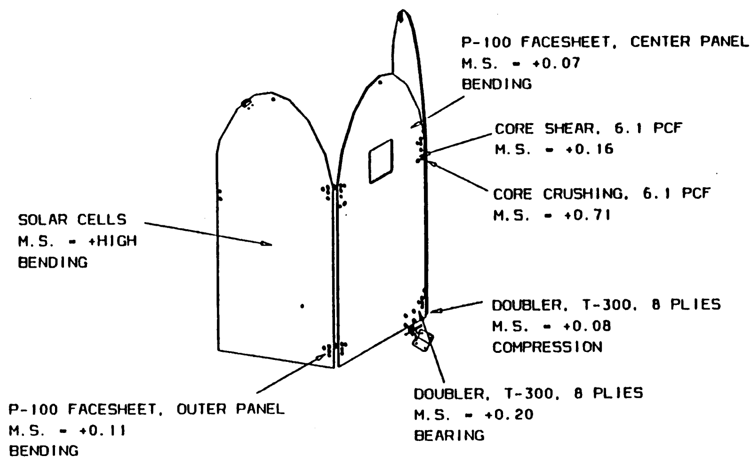
Margins of Safety (Continued)

Closure Panels

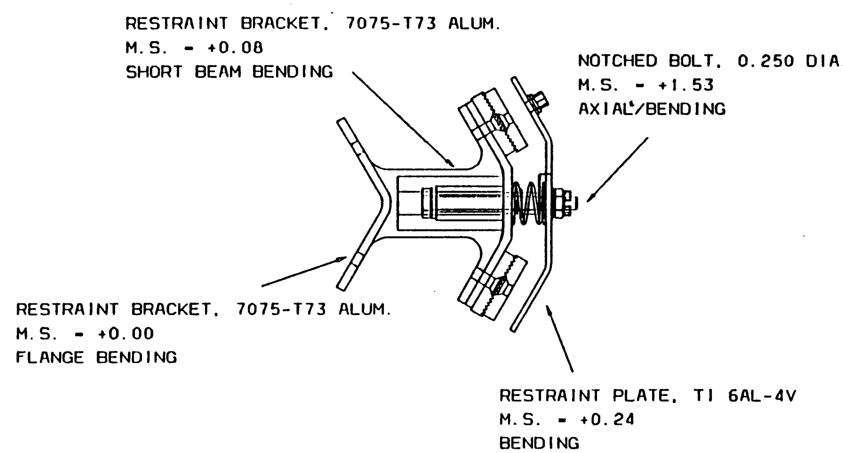


Margins of Safety (Continued)

Solar Array Substrate



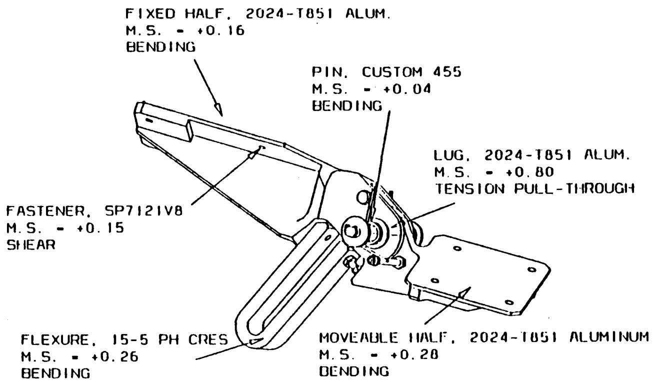
Restraint Assembly



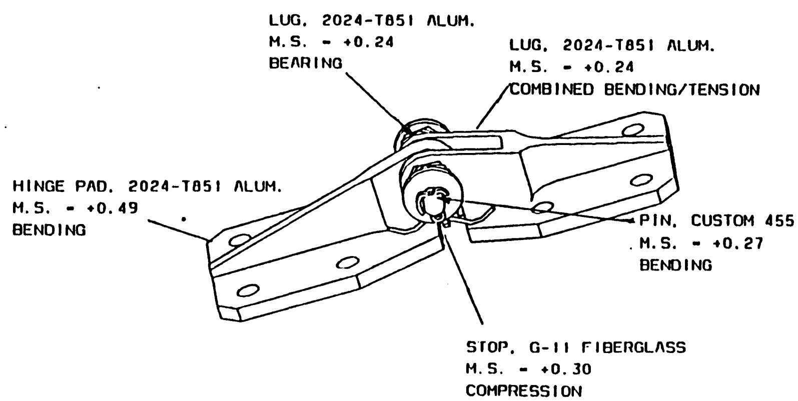
Margins of Safety (Continued)

TRW

Primary Hinge



Panel Hinge



On-Orbit Alignment

TRW

Solar Array Hinge Thermal Distortion from OAS Platform to Solar Array Surface	0.082 Deg.
Hinge Pin Freeplay	0.538 Deg.
Requirement (Satisfied)	0.680 Deg.

- o Solar Array Panels

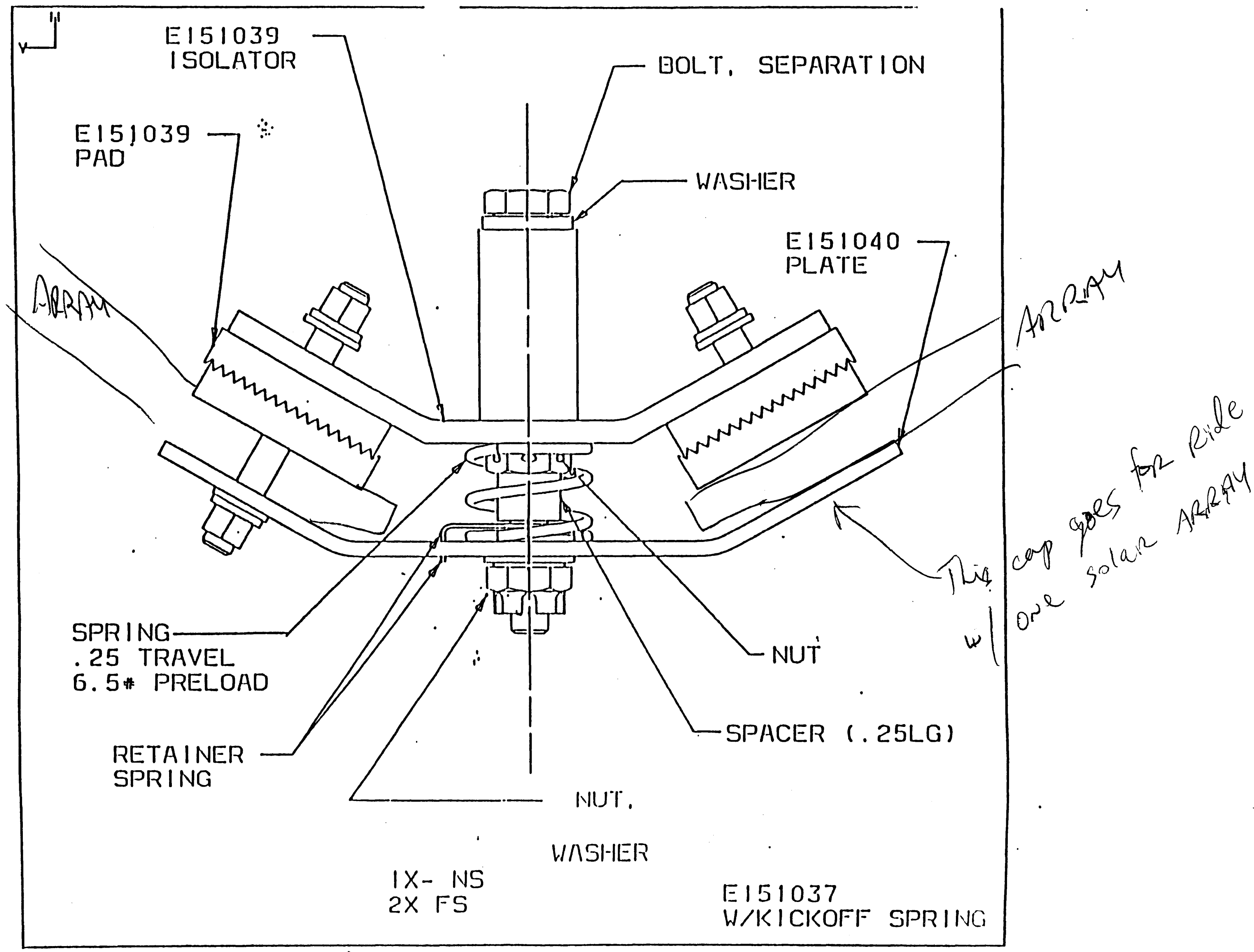
Panel Distortion	0.001 Deg.
Requirement (Satisfied)	0.010 Deg.

ALIGNMENT BUDGET vs. ON-ORBIT THERMAL DEFORMATIONS

ITEMS	ALLOCATION*	PREDICTION
TOMS INSTRUMENT RELATIVE TO THE SCANWHEEL ASSEMBLIES	.0270°	.0246°
TOMS INSTRUMENT RELATIVE TO THE FINE SUN SENSOR ASSEMBLY	.0460°	.0418°
THRUSTERS RELATIVE TO THE CONTROL AXES	.245°	.100°

*ALLOCATIONS ARE FROM D19254, "ALIGNMENT BUDGETS REPORT", 11 MARCH 1992, BY W. AKLE.

Frangibolt Deployment System



Frangibolt Deployment System (Continued)

TRW

– 195°F Nitinol self actuates
– Heaters bring this to 400°F

Features

Lightweight

Testable/Reusable

Lower shock

No explosive hazard

Unlimited shelf life

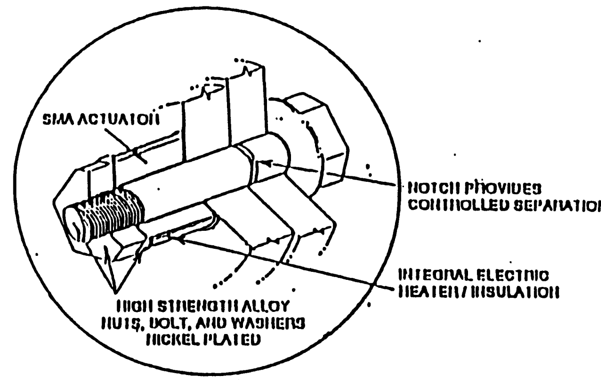
Simplicity/reliability

System Elements

NITINOL ACTUATOR
- Nitinol Cylinder
- Heater Element
- Outer Insulation
- Heater Wires

BOLT
- Notched Bolt
- Washer (2)
- Nut

INSULATION



Frangibolt Deployment System (Continued)

TRW

Testing

Test	Result
Bolt Characterization	Selected bolt configuration: 1/4" dia. bolt, V-notch, .140" dia. at notch
Fatigue Cycling	1M cycles with 1000 lb. preload $\pm$ 200 lb cycle
Insulation/adhesive material properties	Contamination outgassing currently being worked.
Shock Output	$<$ 800 G's at 1000 Hz
Thermal-Vacuum Actuation	Actuates within 40 sec. from -40°F

Qualification Test Plan

- o Vibration
- o Thermal Cycling
- o Thermal Vacuum

Materials

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STRUCTURE MATERIALS

MATERIAL	SPECIFICATION	APPLICATION
7075-T7351 AL PLATE	QQ-A-250/12	RINGS, BRACKETS, RAILS
7075-T73511 AL EXTRUDED BAR	QQ-A-200/11	LONGERONS, STIFFENERS, BRACKETS
2219-T81 AL SHEET	QQ-A-250/30	CONE ASSEMBLY
6061-T6 AL SHEET, PLATE TUBING	QQ-A-250/11 WW-T-700/6	BRACKETS, ANTENNA SUPPORT

PLATFORM AND PANEL MATERIALS

MATERIAL	SPECIFICATION	APPLICATION
2024-T81 ALUMINUM SHEET	QQ-A-250/5 (CLAD) QQ-A-250/4 (UNCLAD)	FACESHEETS
5052 AND 5056 ALUMINUM HONEYCOMB, PERFORATED	MIL-C-7438	HONEYCOMB CORE
ADHESIVE, EA9628	MT5-13-1	BOND FACESHEET TO CORE
ADHESIVE, EA9394	MT5-19-2	BUSHING AND INSERT BONDING
FILLER, FR 8231/540A	MT3-58-2	CORE AND EDGE FILLER

SOLAR ARRAY MATERIALS

MATERIAL	SPECIFICATION	APPLICATION
GRAPHITE TAPE, P100/1901	MT3-112-2-3-5	FACESHEET
GRAPHITE CLOTH, T300/934	MT3-99-1	DOUBLER
ALUMINUM HONEYCOMB, 5052	MIL-C-7438	CORE
ADHESIVE, FM96U	C405791-2	BOND FACESHEET TO CORE
ADHESIVE, FM-37	MT5-14-2	CORE SPLICING
FILLER, FR 8231/540A	MT3-58-2	CORE AND EDGE FILLER
ADHESIVE, EA 9394	MT5-19-2	BONDING
POLYIMIDE FILM	MIL-P-46112, TYPE I	INSULATOR

TOMS Structural Test Model (STM)
General Description

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- Flight-like TOMS spacecraft bus structure.

- All fabrication techniques, components, materials, will be identical to those used on the flight article.

- Flight-like solar arrays (structure).

  a) Solar cells will be mass simulated using lead tape.
  b) Glass cells will be positioned near release device attachment points and hinges.
  c) Arrays will be mounted on the STM for specific tests.

- Flight-like array hinges on the STM.

- Flight-like panel hinges solar arrays.

- All significant components, such as the payload, propellant tank and black boxes, will be mass simulated, and mounted on the STM.

Structural Test Summary

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- Array Hinge Release - Verify array initial release after STM Environmental Test.
- STM Shock Test.
- Low Level Frequency Response.
    - To determine natural frequencies and responses shapes.
    - Structural model validation - tune finite element model to test results.
- Sine Burst Test - To determine capability of structure to withstand design loads.
- Random Vibration Test - (STM) Validate test procedures and determine possible overtest.
- Array Hinge Attachment Strength Test - Verify strength of hinge and panel interface.
- Instrument/spacecraft Attachment Static Test.

CDA Action Items

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EVENT: SAM CDA (TOMS-EP)

NUMBER	RESPONDER/SUBJECT	CREATE DATE	DUE DATE	STATUS
SAM-1	D. WALDIE	5/6/92	6/5/92	
	INSERT BONDING FULLY FILLED (VERIFICATION)			
SAM-2	B. DOBROTIN/NASA/D. WALDIE	5/6/92	6/5/92	
	PAYLOAD INSERT SAME MATERIAL FOR NUT AND BOLT (GALLING)			
SAME-3	L. MELE	5/6/92	5/29/92	COMPLETE
	FITTING FACTOR CRITERIA RATIONALE			
SAM-4	D. WALDIE	5/6/92	6/12/92	
	HINGE ASSEMBLY (WASHERS BETWEEN LUG AND CLEVIS)			

Subsystem Status

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- o All STM drawings released (61).
- o Seven (7) remaining drawings are flight boxes interface hardware.
- o STM fabrication and assembly is 95% complete.
- o STM solar array panels currently being manufactured - estimated completion date is end of August 1992.
- o General Structural Test Plan completed, and submitted to NASA.
- o Detail Test Plan is in work.
- o STM delivery date; August 14, 1992.
- o STM Assembly to be completed on August 30, 1992.
- o STM Vibration Test
  - Spacecraft Structure Test, to be completed, on September 30, 1992.
  - Solar Array Deployment Test, to be completed on October 30, 1992.

Subsystem Status (Continued)

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- o Flight article delivery date to I&T is November 6, 1992.
- o Remaining tasks after STM Test
  - Document STM Test results.
  - Convert all experimental (E) drawings to flight drawings.
  - Generate Flight I/F drawings.
  - Generate LTM and support coupled loads analysis.
  - Stress support to release of flight drawings.
  - Manufacturing sustaining of flight article.

TRW

TOMS-EP
Thermal Control Subsystem

D. Wanous

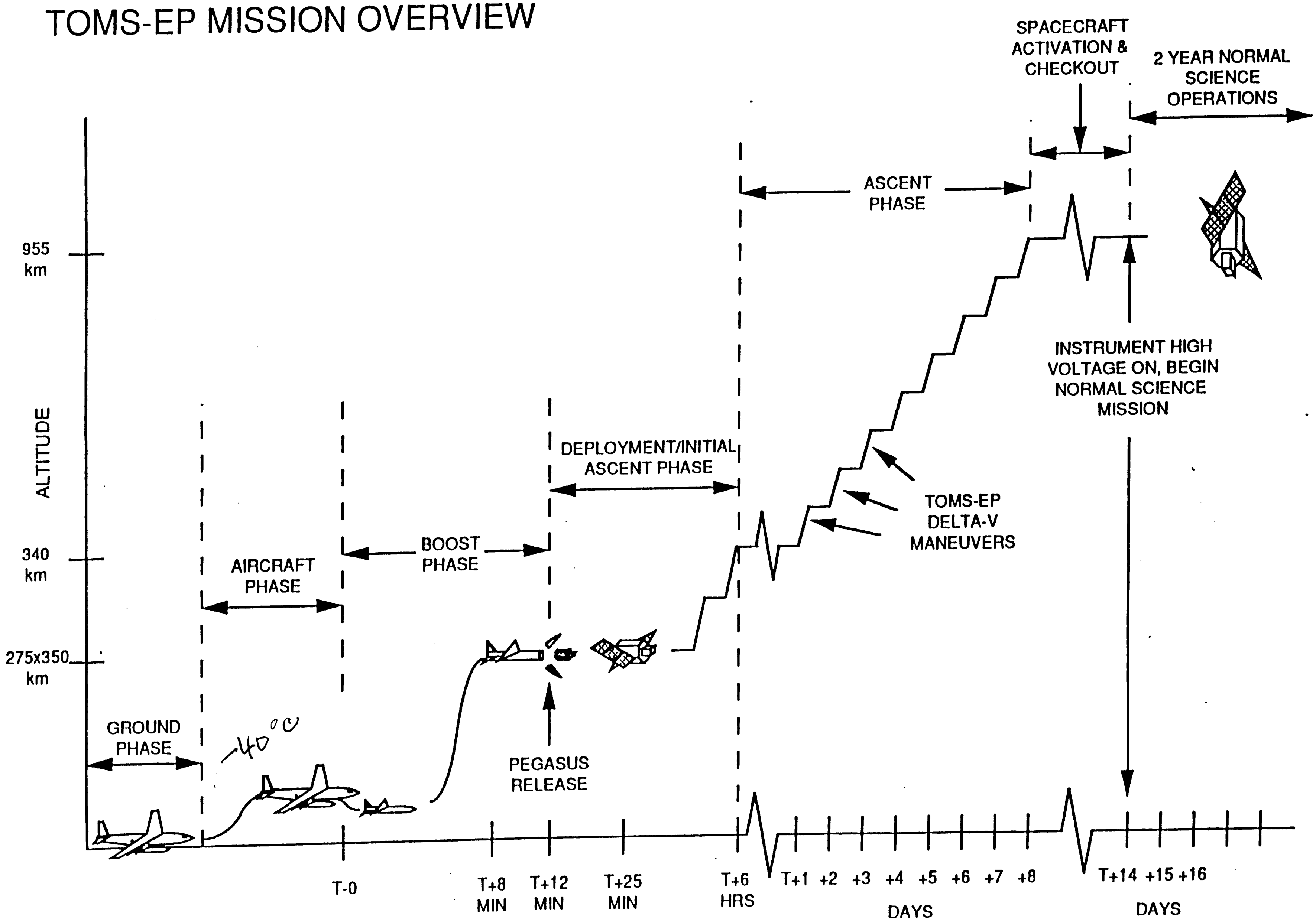
TOMS THERMAL CONTROL CDR AGENDA

- THERMAL ENVIRONMENT
- DESIGN DESCRIPTION
- REQUIREMENTS VS CAPABILITIES
- ANALYSES
- VERIFICATION
- STATUS/CDA ACTION ITEMS

THERMAL ENVIRONMENT

TRW

TOMS-EP MISSION OVERVIEW



LAUNCH MODE THERMAL ENVIRONMENT

GROUND OPERATIONS:

- BEFORE FAIRING ATTACHMENT: TRW SUPPLIED AIR CONDITIONING THROUGH HOLE IN NADIR PLATFORM
- AFTER FAIRING ATTACHMENT: OSC SUPPLIED AIR CONDITIONING MAINTAINS COMPONENTS WITHIN ACCEPTANCE LIMITS,
  INTERNAL DISSIPATION = 23 WATTS

CAPTIVE FLIGHT:

- AIR CONDITIONING SUPPLIED BY OSC MAINTAINS COMPONENTS WITHIN ACCEPTANCE LIMITS
  INTERNAL DISSIPATION = 53 WATTS

POWERED FLIGHT:

- WITH FAIRING: FAIRING TEMPERATURE RISES TO 100°C, RELEASE AFTER 157 SECS
- WITHOUT FAIRING: AERODYNAMIC HEATING UP TO 0.34 BTU/SEC/FT^2

TRW

ON ORBIT THERMAL ENVIRONMENT

ORBIT ADJUST PHASE

- TOMS PROPULSION TAKES VEHICLE FROM INJECTION ALTITUDE (≈ 300 KM) TO OPERATIONAL ALTITUDE OF 955 KM IN EIGHT DAYS

OPERATIONAL ORBIT

- ALTITUDE 955 KM IS ABOVE HEIGHT FOR SIGNIFICANT ATOMIC OXYGEN EFFECTS

- INCLINATION = 98 DEG, CHARGED PARTICLE FLUX FOR TWO YEARS IS $4X10^{-4}$ OF VALUE WHICH CAUSED SIGNIFICANT ABSORPTION INCREASES IN IR&D TESTING

- ORIENTATIONS: EARTH POINTING, SCIENCE MODE
  SUN POINTING, SAFE POWER MODE, ORBIT ADJUST MODE
  ROTATION AROUND Y AXIS AT 1-2 TIMES ORBIT RATE, SAFE HOLD

- INTERNAL DISSIPATION = 74 WATTS

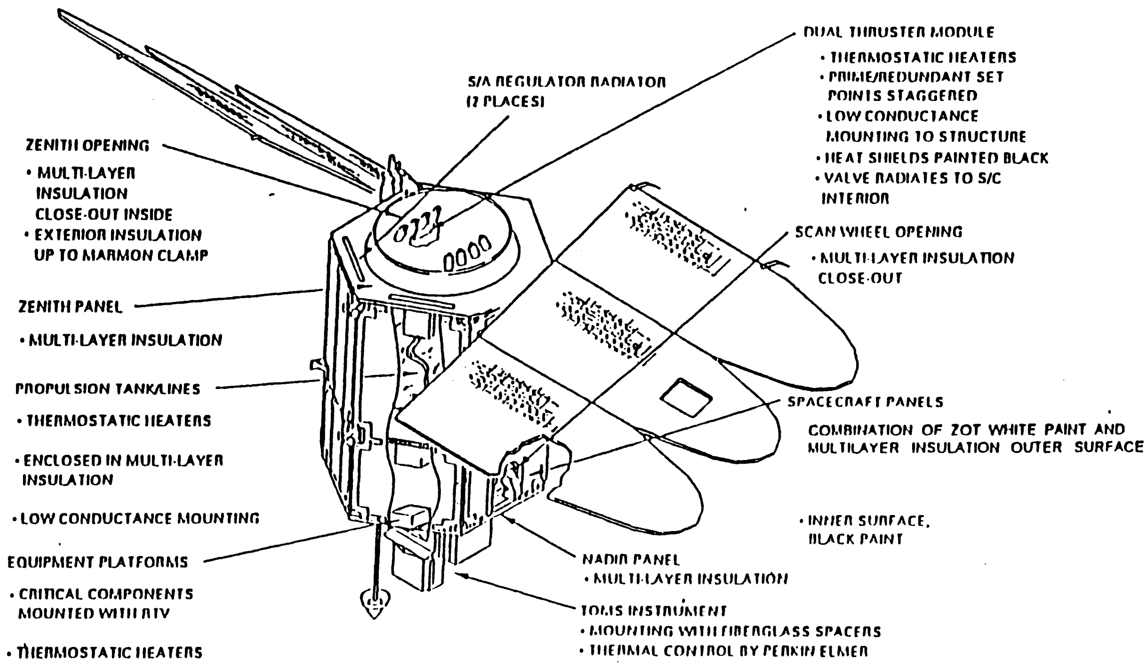
- CONTAMINATION DEPOSITION PER SOURCES AND EFFECTS ANALYSIS
  -Y PANEL, 339 ANGSTROMS, $\Delta\alpha_s = 0.034$
  OTHER PANELS, 128 ANGSTROMS, $\Delta\alpha_s = 0.013$

DESIGN DESCRIPTION

THERMAL CONTROL SUBSYSTEM (TCS)

KEY REQUIREMENTS:

- MINIMIZE HEATER POWER USAGE
- BIAS BATTERY TEMPERATURE TOWARD LOW END OF 0 TO 20^{o} C OPERATING RANGE



THERMOSTAT SPECIFICATION (^{o} F):				
NADIR (2)	OPEN	35 TO 43	CLOSE	17 TO 25
CENTRAL (2) (BATTERY)		42 TO 50		29 TO 35

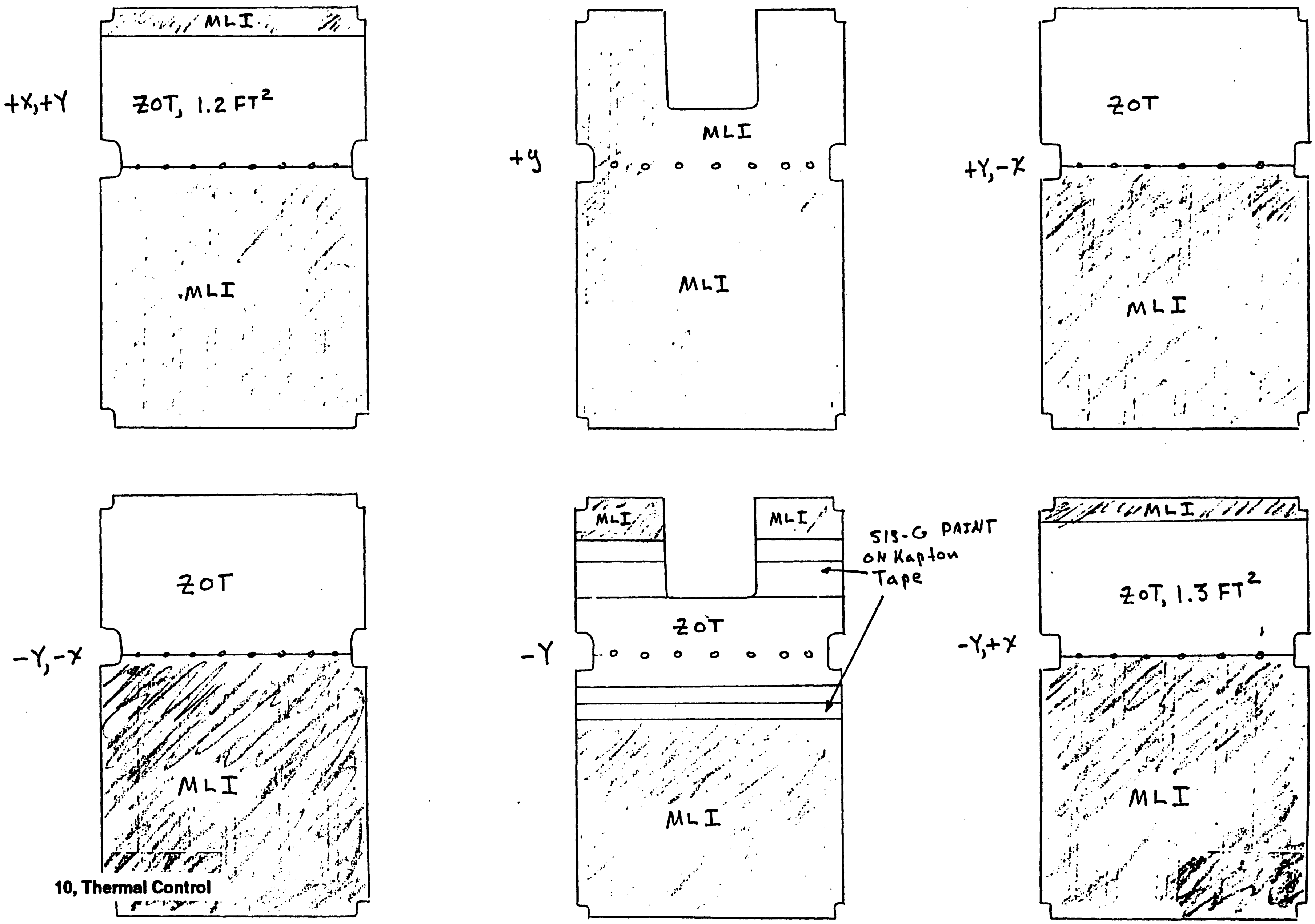
TRW

DESIGN CHANGES SINCE PDR

- ADDED MULTI-LAYER INSULATION TO OUTSIDE OF NON-RADIATOR BODY PANELS
- ADDED RADIATORS TO -Z PLATFORM FOR SOLAR ARRAY REGULATOR HEAT REJECTION
- ADDED OPTION TO DISABLE PROPULSION TANK AND PLATFORM HEATERS DURING ECLIPSE USING TIME SEQUENCED COMMANDS
- LEAVE BODY PANEL TEST HEATERS ON FOR FLIGHT

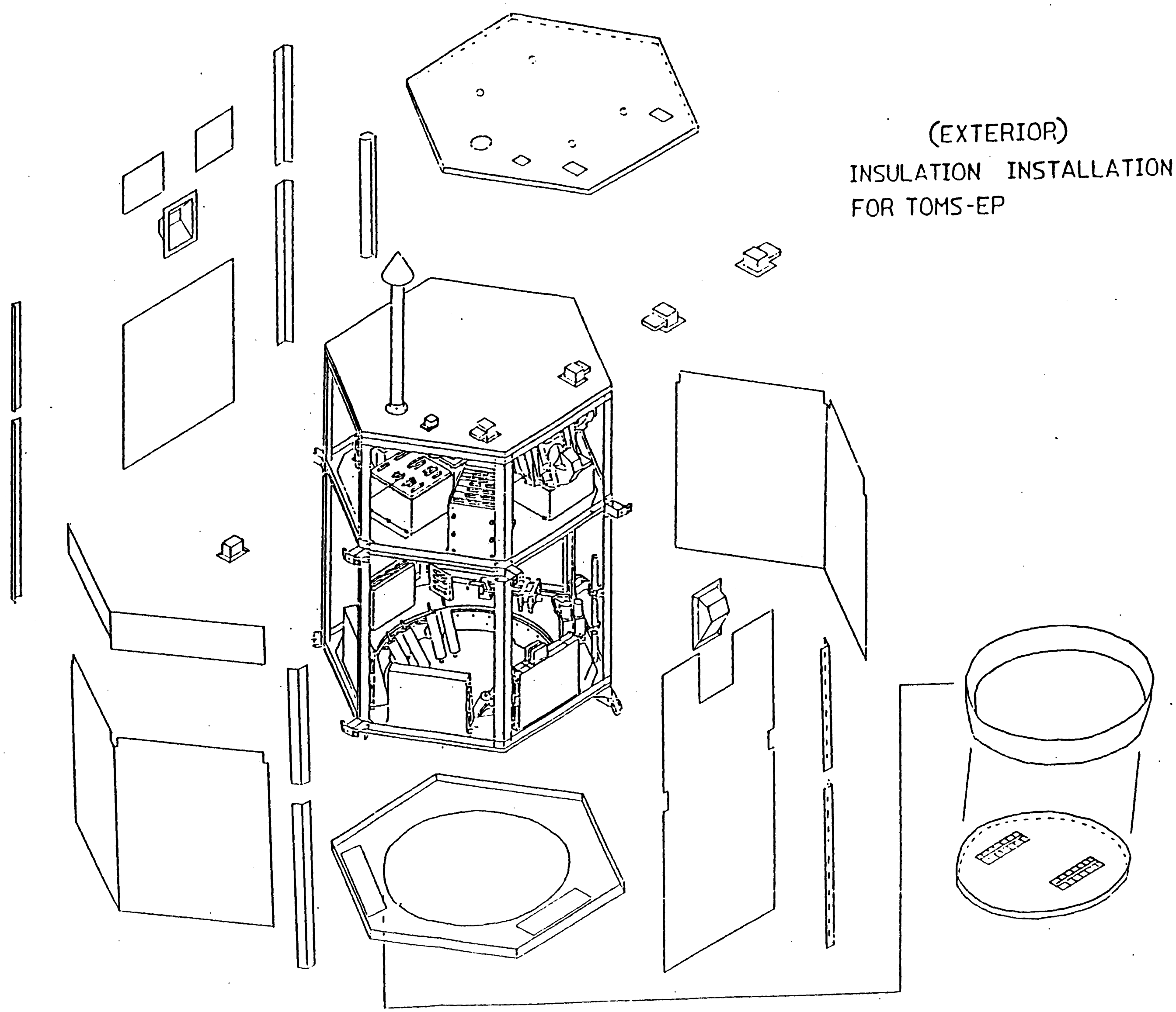
TRW

TOMS-EP BODY PANEL THERMAL COATINGS



TRW

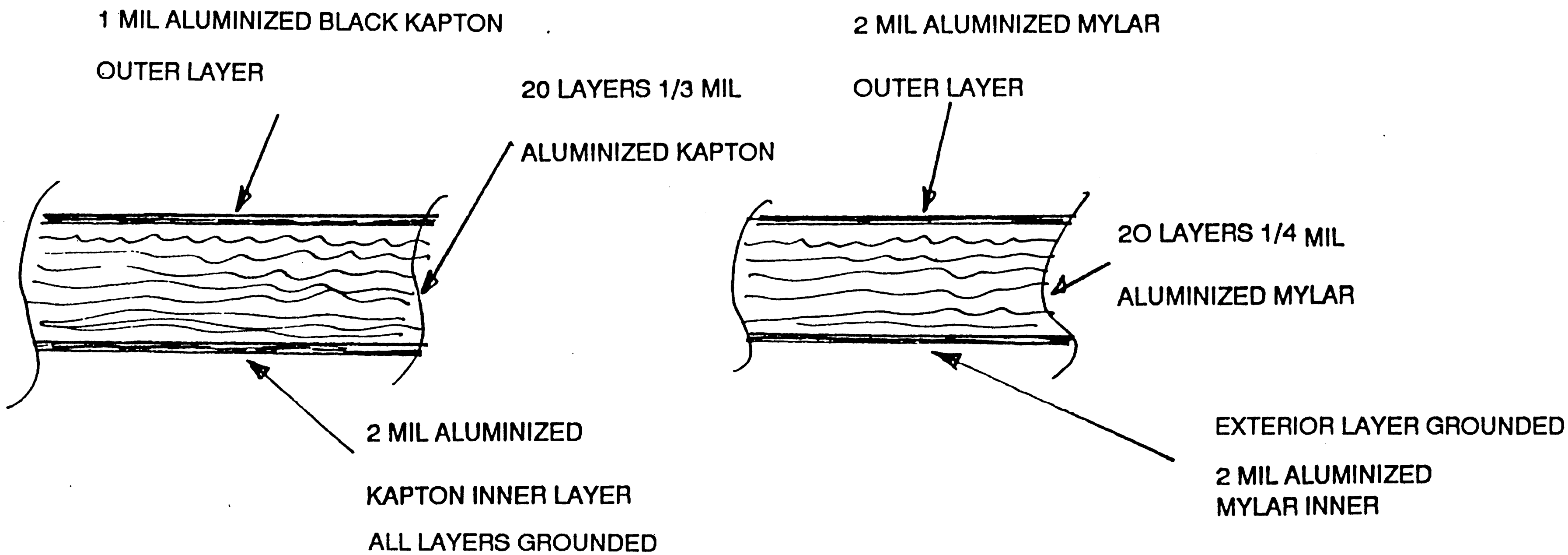
EXTERIOR INSULATION INSTALLATION



MULTI-LAYER INSULATION DESIGN

PERFORMANCE

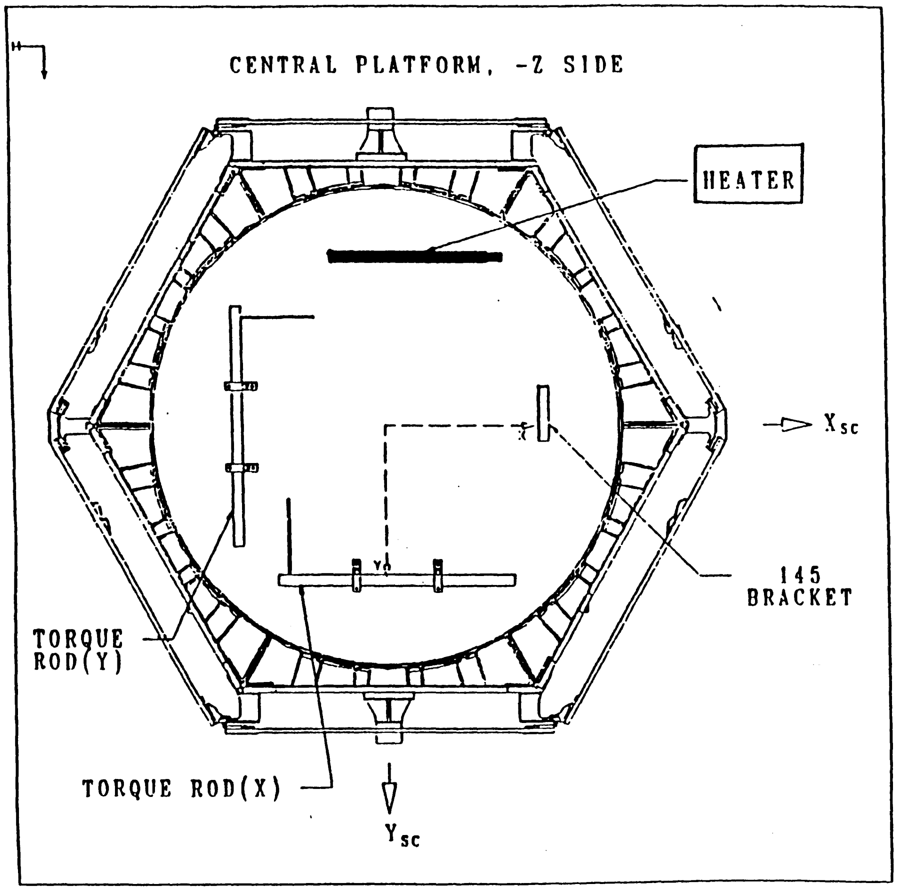
E-STAR = 0.005 TO 0.03

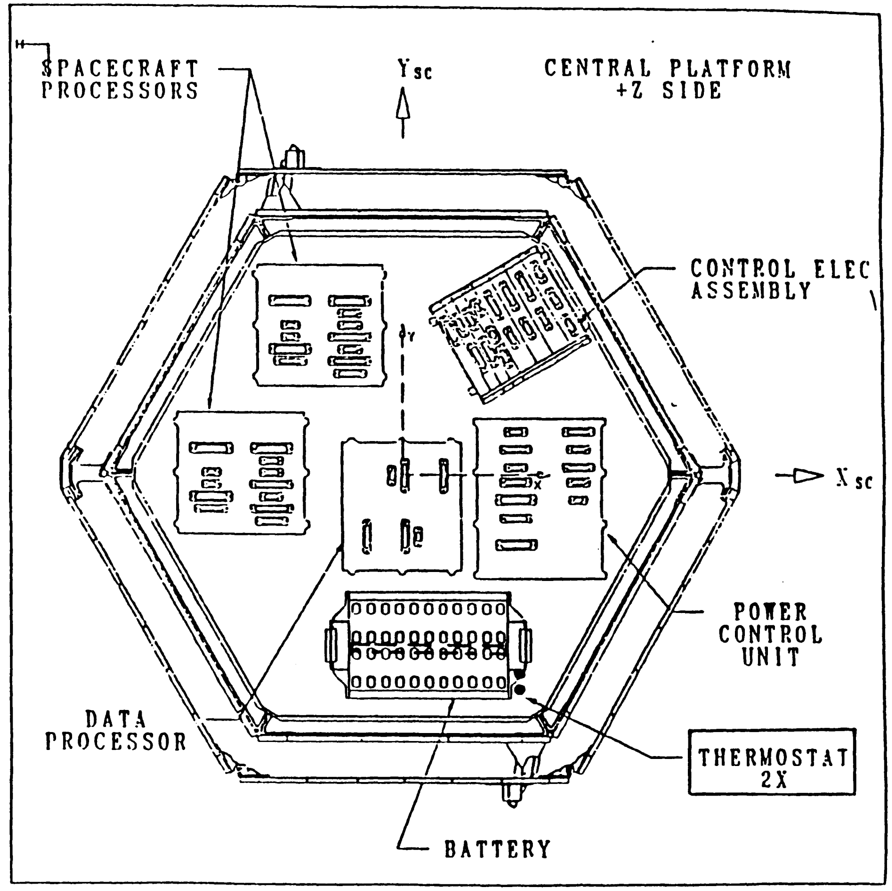


EXTERIOR BLANKETS

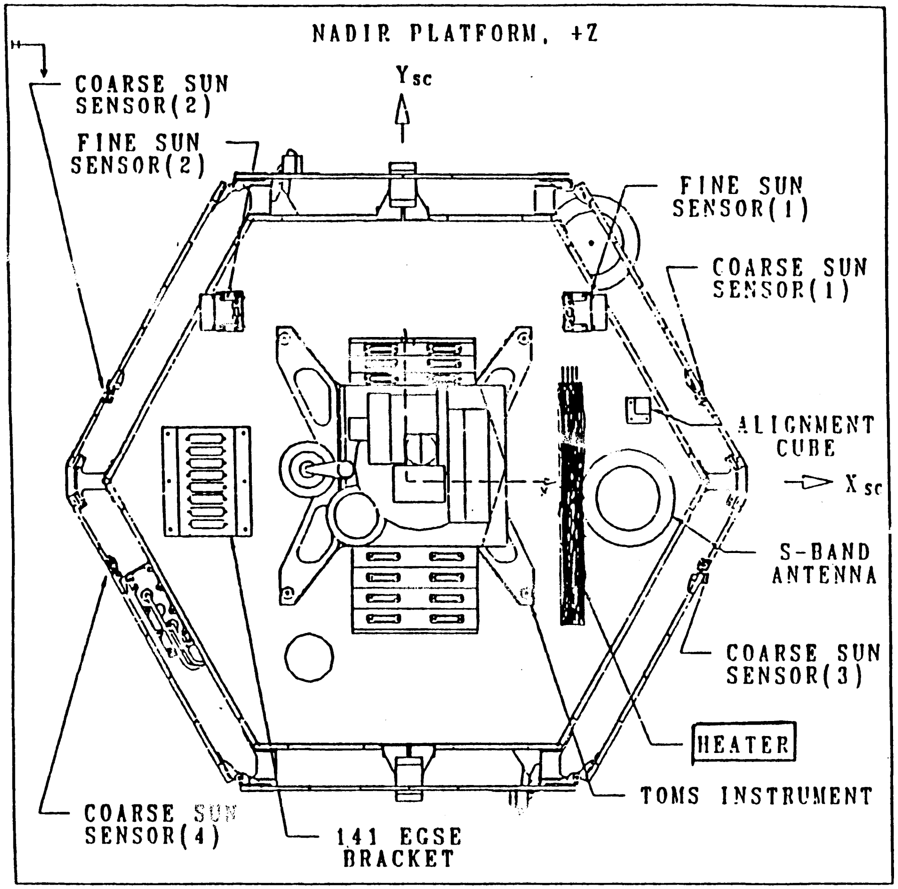
INTERIOR BLANKETS

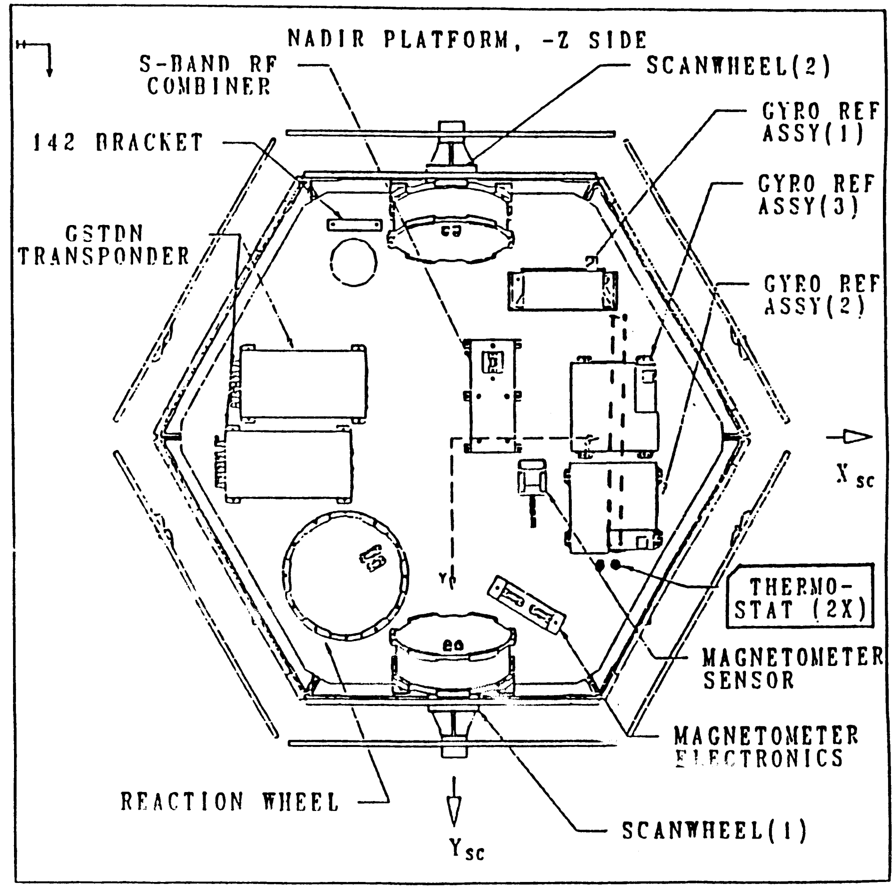
HEATER AND THERMOSTAT LOCATIONS CENTRAL PLATFORM





HEATER AND THERMOSTAT LOCATIONS NADIR PLATFORM





HEATER BUS MANAGEMENT

- USING THE SEQUENCED COMMANDS, PROPELLANT TANK AND PLATFORM HEATER BUSES WILL BE DISABLED FOR ECLIPSE AND ENABLED FOR SUNLIGHT
- THIS ASSURES THAT TANK AND PLATFORM HEATER POWER WILL NOT INCREASE BATTERY DEPTH OF DISCHARGE WHICH IS NEAR THE MAXIMUM ALLOWABLE
- ENERGY COMES DIRECTLY FROM THE ARRAY WHICH HAS SUFFICIENT MARGIN RATHER THAN FROM THE BATTERY
- TANK AND PLATFORM HEATERS CHOSEN FOR TIME SEQUENCING SINCE THEY HAVE SUFFICIENT MASS SUCH THAT TEMPERATURES WILL NOT FALL BELOW MINIMUM ALLOWABLE VALUES AT END OF ECLIPSE

REQUIREMENTS vs CAPABILITIES

TRW

THERMAL CONTROL FUNCTIONAL REQUIREMENTS

- o Maintain S/C Elements Within Acceptable Temperature Ranges (SY1-0012, Paragaph 3.7.2.1)

- o Control Instrument Thermal IF To Allowable Temperature Levels (SY1-0012, Paragraph 3.1.2.2.14)

- o Do Above Within Weight, Power and Alignment Error Budgets (SY1-0012, Paragraph 3.7.2.2, 3.7.2.3, 3.7.2.4)

COMPONENT TEMPERATURES REQUIREMENTS VS PREDICTIONS

COMPONENT	ACCEPTANCE LIMITS				ON-ORBIT PREDICTED (°F)		THERMAL MARGIN (°F)	
	MIN		MAX					
	°F	°C	°F	°C	MIN	MAX	MIN	MAX
BATTERY **	32	0	68	20	32*	63	0*	5
GRA	41	5	131	55	41*	81	0*	50
SCAN WHEELS	23	- 5	131	55	38	62	15	69
SOLAR ARRAY REG	-4	-20	113	45	30	89	34	24
PCU	14	-10	82	28	30	58	16	24
PROCESSOR	-4	-20	131	55	29	55	33	76
EXPERIMENT IC	14	-10	86	30	23	65	9	21
TRANSPONDER	-4	-20	131	55	22	48	26	83

* Heater Turn-On
** At Top of Battery

HEATER POWER REQUIREMENTS

		Predicted Cold Case Average Heater Power (Watts)					
		Orbit adjust Mode		Science Mode		Safe Power Mode	
Heater Location	Power, at 28 volts (watts)	Duty Cycle	Average Power	Duty Cycle per day	Average Power	Duty Cycle	Average Power
Dual Thrust, Module	13.6	43%	5.9	22%	3.0	48%	6.5
Propellant Lines	8.2	22%	1.8	18%	1.5	20%	0.5
Propellant Tank	6.8	57%	2.6[1]	41%	1.8[1]	35%	2.4
F&D Valve	2.5	20%	0.5	20%	0.5	20%	0.5
Isolation Valve	0.6	12%	0.1	15%	0.1	13%	0.1
Filter Module	0.6	13%	0.1	15%	0.1	10%	0.1
Press. Transducer	0.6	13%	0.1	15%	0.1	10%	0.1
Battery	8.7	0%	0	0%	0	64%	7.0
Nadir Platform	12.2	0%	0	0%	0	50%	4.0
			11.1		7.1		23.0

1 = Disabled During Eclipse Periods

MASS PROPERTIES SUMMARY

ELEMENT	WEIGHT (LB)
PLATFORM HEATERS	0.3
PROPULSION INSULATION	1.5
PROPELLANT HEATERS	1.2
RTV	.2
PLATFORM PAINT	.2
EXTERIOR INSULATION	2.6
SCAN WHEEL CLOSEOUTS MLI	.2
TEMP SENSORS	.2
THERMOSTATS	.6
BODY PANEL HEATER	2.1
TOTAL	9.1
ALLOCATION	11.3

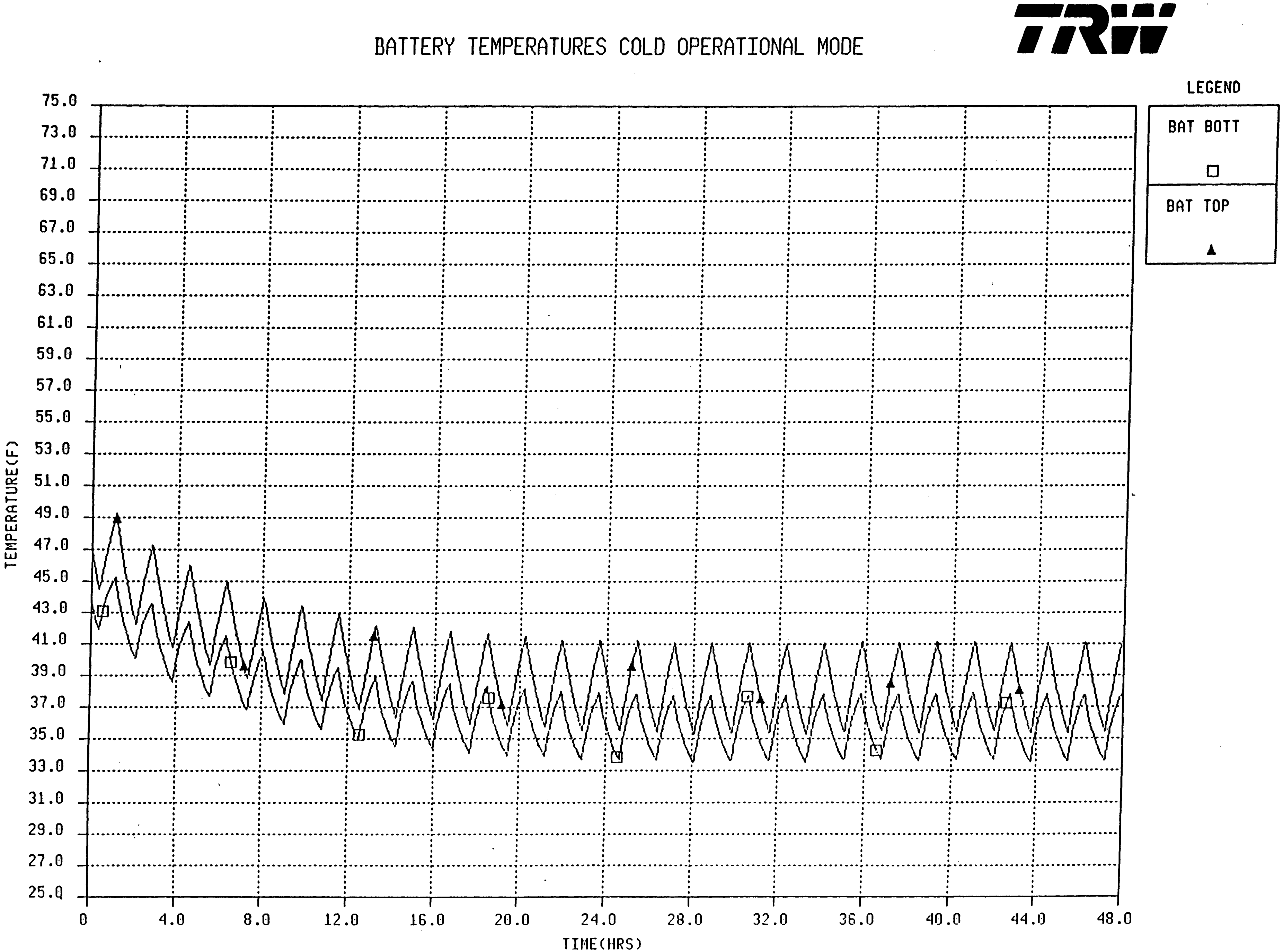
*NOTE: BODY PANEL PAINT IS CARRIED AS PART OF THE STRUCTURE WEIGHT.

ANALYSES

TRW

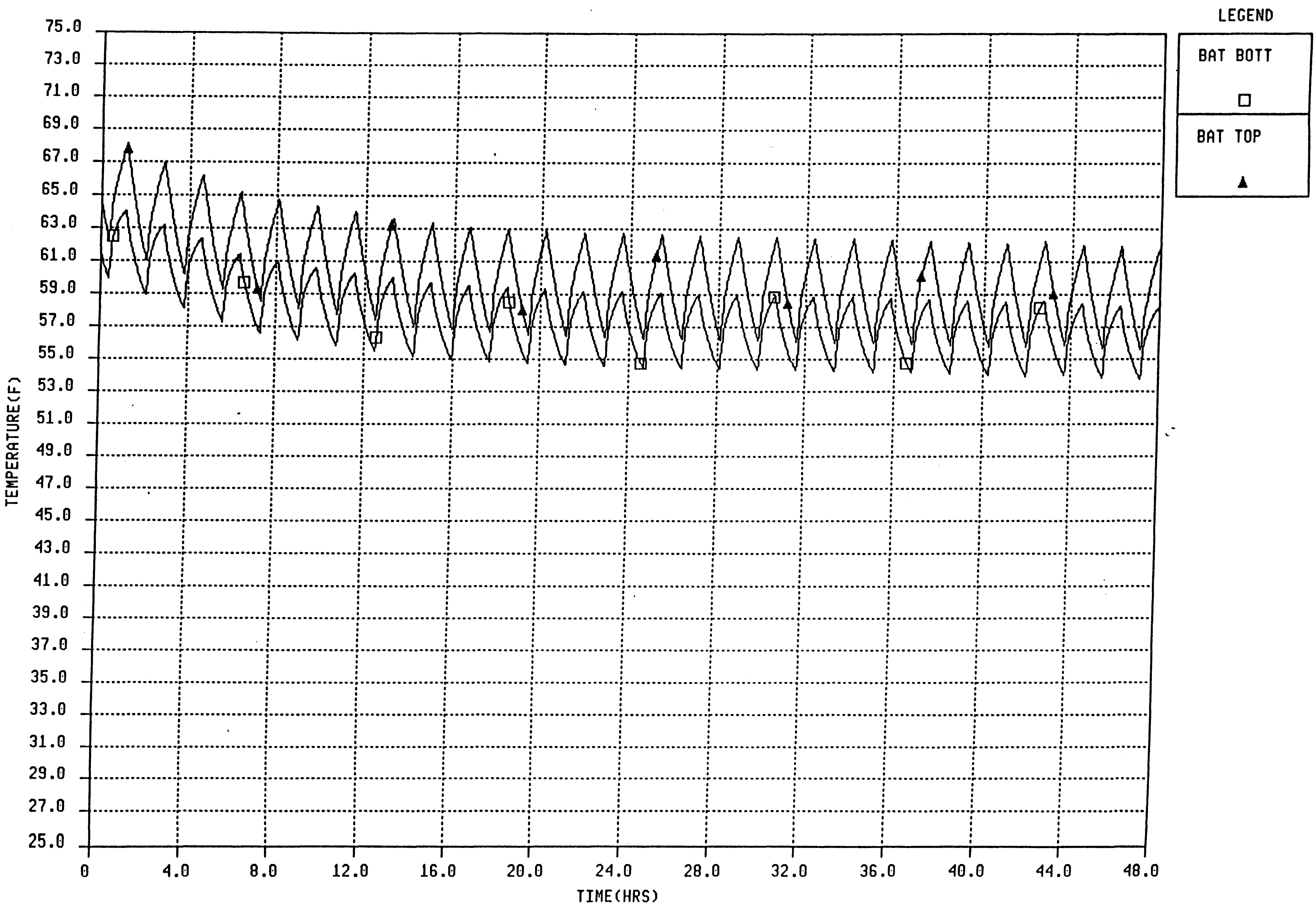
THERMAL ANALYSIS

- THREE MODELS GENERATED
    - A) STOWED S/A IN FAIRING (DELIVERED TO OSC)
    - B) STOWED S/A NO FAIRING
    - C) ON ORBIT DEPLOYED
- DESIGN CASES
    - PRE DEPLOYMENT HOT/COLD
    - ORBIT ADJUST HOT/COLD
    - SAFE POWER MODE COLD
    - SAFE HOLD MODE HOT/COLD
    - OPERATIONAL MODE HOT/COLD
- PRELIMINARY INSTRUMENT MODEL INCLUDED, FINAL MODEL NOT AS YET INCORPORATED (20 JULY). INSTRUMENT HAS MINOR IMPACT ON SPACECRAFT THERMAL BALANCE.
- INTEGRATED S/C INSTRUMENT TRASYS RUN TO BE MADE FOR ON ORBIT HEATING RATE VERIFICATION



23, Thermal Control

BATTERY TEMPERATURES HOT OPERATIONAL



AERO HEATING IMPACTS ON TOMS S/C

- ZENITH PANEL MULTI-LAYER INSULATION BLANKET
  - FOR 0.34 $BTU/FT^2/SEC$, OUTER LAYER TEMPERATURE LESS THAN 500°F. KAPTON ALLOWABLE = 750°F

- SOLAR ARRAY EDGE
  - KAPTON TAPE MAX PREDICTED TEMPERATURE = 330 °F
  - ALLOWABLE TEMPERATURE = 450°F

VERIFICATION

THERMAL SUBSYSTEM TEST REQUIREMENTS

- DURING S/C INTEGRATION

  VERIFY TEMPERATURE SENSOR ALIVENESS
  VERIFY THERMOSTAT AND HEATER ALIVENESS

- DURING S/C THERMAL VACUUM TEST

  VERIFY THERMOSTAT SET POINTS AND HEATER OPERATION
  VERIFY SENSOR FUNCTION AND CALIBRATION
  VERIFY HEATER HAS ENABLE AND DISABLE COMMANDS
  VERIFY SPACECRAFT THERMAL ANALYSIS MODEL

one day T/B test ———— - orbital Avg.
- cycle battery

TRW

THERMAL DESIGN VERIFICATION

THERMAL ANALYSIS MODEL

↓

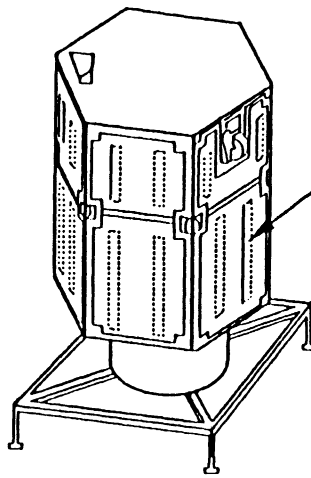
MODIFY MODEL TO MATCH TEST CONFIGURATION

↓

PRETEST PREDICTIONS

→ COMPARE TEST DATA TO PREDICTIONS

THERMAL BALANCE TEST



TEST DATE

↓

COMPARE TEST DATA TO PREDICTIONS

→

CORRECT ANALYSIS MODEL TO CORRELATE TO DATA

→

MAKE SAME CORRECTIONS TO FLIGHT CONFIGURATION MODEL

↑

PERFORM FIGHT ANALYSIS

↑

FLIGHT TEMPERATURE PREDICTIONS

↑

COMPARE WITH ACCEPTABLE LIMITS

↑

VERIFY ACCEPTABLE TEMPERATURES AND MARGINS

THERMAL CONTROL SYSTEM ACTION ITEMS

SUBJECT	ISSUE/CONCERN	ACTION TAKEN
BATTERY THERMAL CONTROL	BATTERY HAS INSUFFICIENT TEMP MARGIN ON LOW END AND HEATER ACTIVATOR WOULD CAUSE HIGH BATTERY DOD.	IMPLEMENT TIME SEQUENCED COMMANDS TO DISABLE HEATER BUS DURING ECLIPSE (BATTERY DISCHARGE), ECR-033.
AIR CONDITIONING VELOCITY IN FAIRING	DYNAMIC EFFECTS OF AIR CONDITIONING FLOW PRIOR TO LAUNCH.	TRW IS WORKING WITH OSC/NASA TO DEFINE AIR CONDITIONING FLOW REQUIREMENTS. ACTION ITEM STILL OPEN.

THERMAL CONTROL SUBSYSTEM STATUS

- DESIGN AND ANALYSIS COMPLETED
- HEATER, THERMOSTAT AND SENSOR PURCHASE ORDERS PLACED
- PRELIMINARY INSULATION INSTALLATION DRAWINGS COMPLETED
- OSC PRE-LAUNCH/LAUNCH THERMAL ANALYSIS PENDING
- REMAINING TASKS:
  - INTEGRATED INSTRUMENT-S/C ANALYSIS
  - INSULATION DESIGN AND FABRICATION
  - ASSEMBLY AND TEST SUPPORT
  - PRE-TV TEST ANALYSIS
  - TV TEST PLAN INPUTS
  - TV TEST SUPPORT
  - CORRELATION OF TV TEST DATA
  - FINAL ISSUE OF ANALYSIS AND THERMAL MODEL DOCUMENTS
  - LAUNCH OPERATIONS SUPPORT

TOMS-EP Critical Design Review
Orbit Adjust Subsystem

A. Alicastro

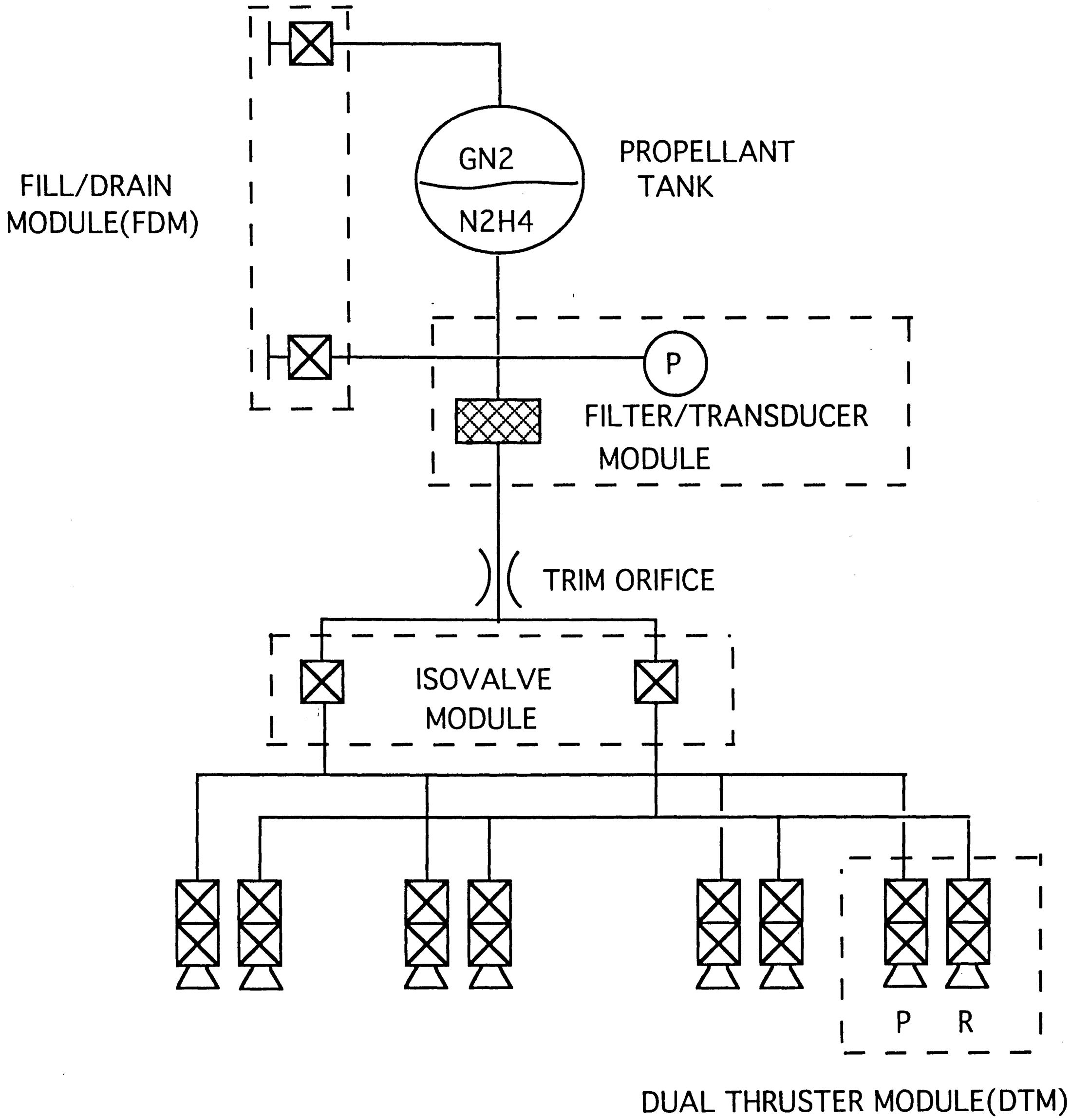
Subsystem Overview and Description

Orbit Adjust Subsystem Description

TRW

- OAS is an all-welded monopropellant blowdown hydrazine system
- Primary and redundant hydrazine thrusters, packaged in Dual Thruster Modules (DTMs), are utilized for delta-V and attitude control
  - Delta-V impulse provided for orbit transfer/insertion
  - Attitude control impulse provided for orbit adjust phase and as backup to ACDS on-orbit
- All OAS components are maintained above freezing utilizing redundant thermostatically-controlled heaters
- Catalyst bed heaters in DTMs are ground commandable
- OAS module, which includes the OAS lines, fittings, structure and components, will be integrated in parallel with the spacecraft core module

Orbit Adjust Subsystem Schematic

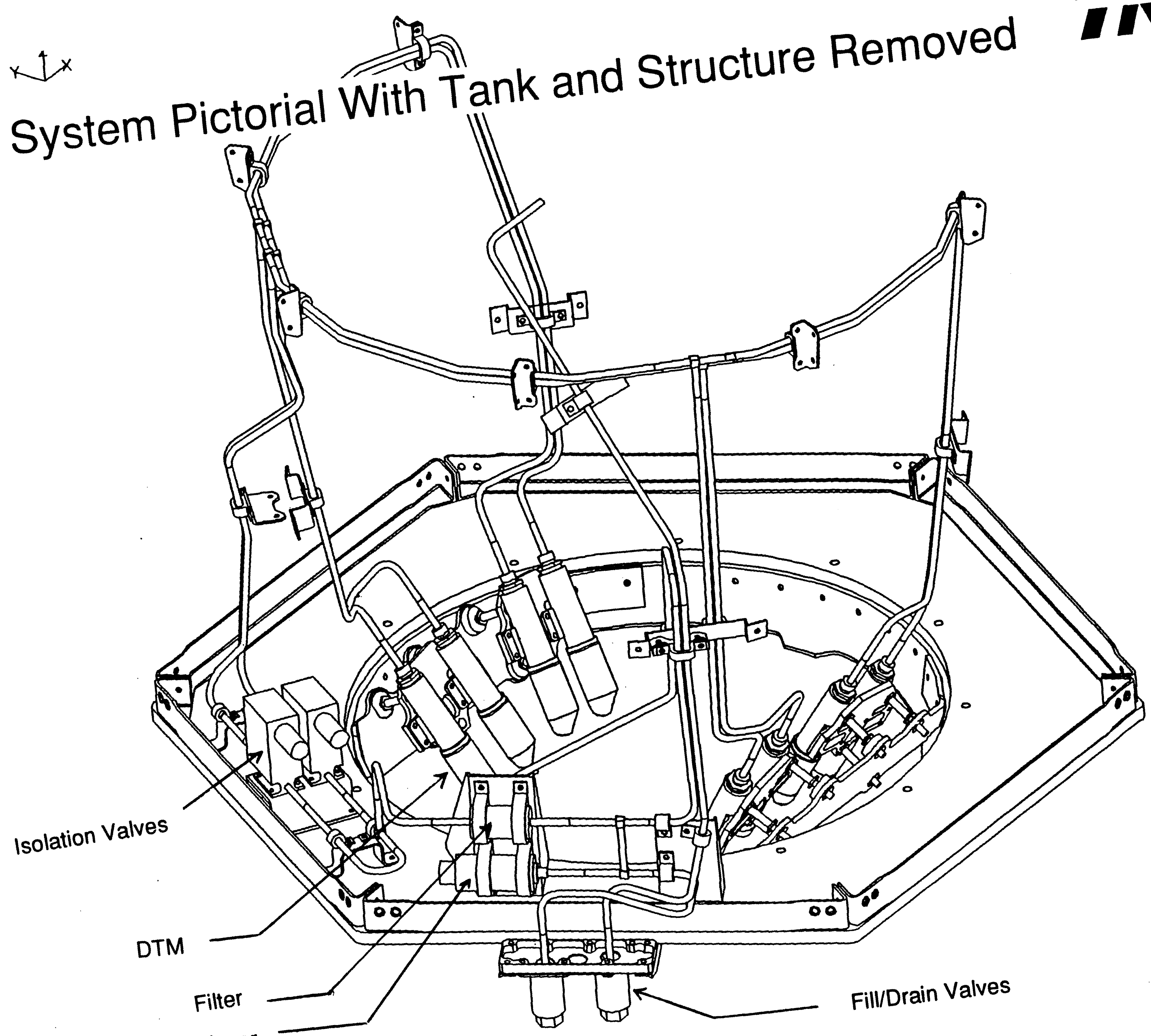


<u>Key Features</u>

- Monopropellant blowdown system 350 psia MOP
- Fully pressurized and wetted down to thruster valves for launch with isovalves closed
- Three mechanical inhibits provided for safety
- All-welded system with 1/4 inch stainless lines

System Pictorial With Tank and Structure Removed

TRW

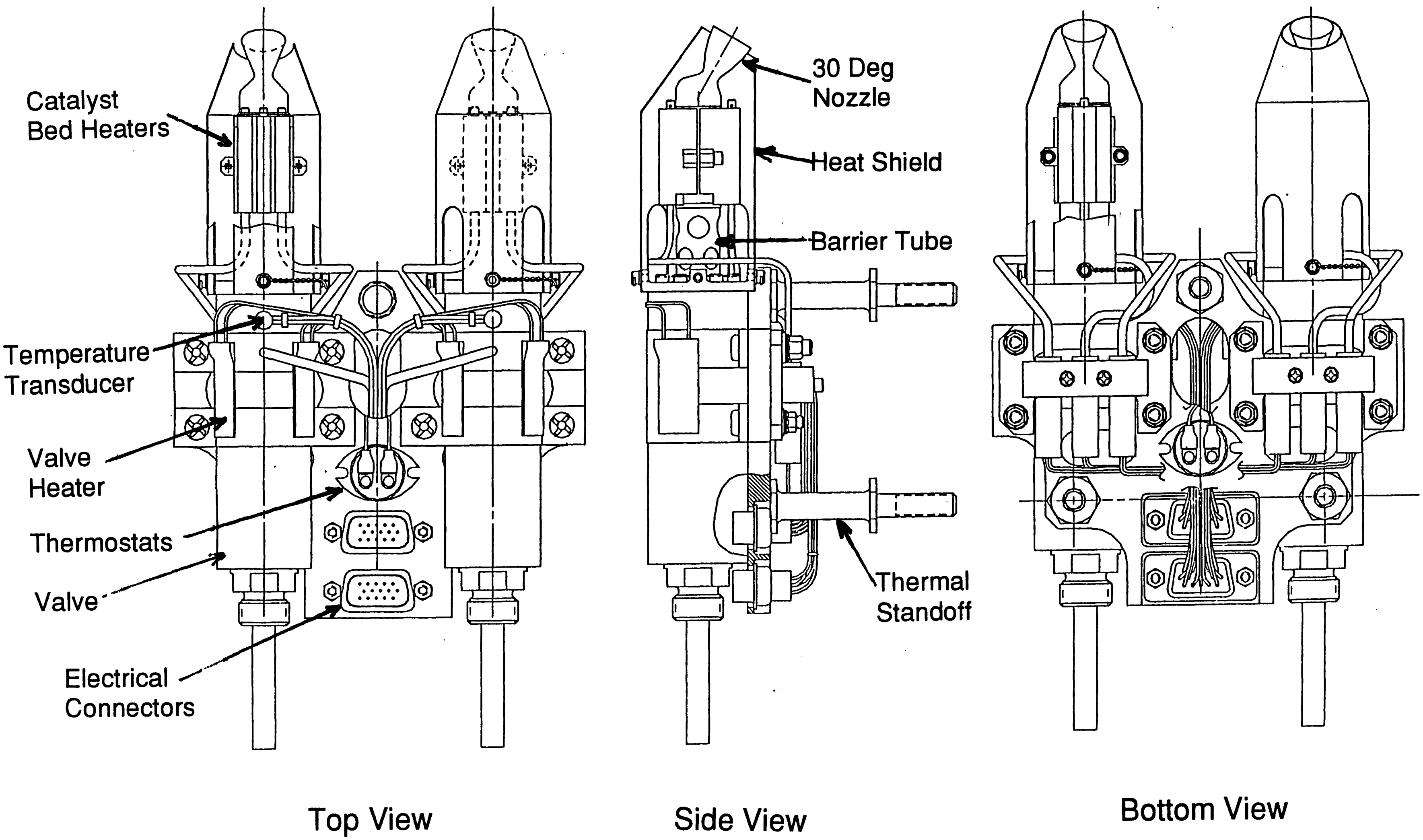


OAS Equipment Summary

Hardware	Supplier	Heritage	Spec No.	Qty/OAS
•Propellant Tank	PSI	FLTSATCOM	EQ8-0023	1
•DTM	TRW	TDRSS	EQ8-0276	4
– Propellant Valve	EG&G Wright	GPS, STEP	EQ8-0024	8
– Catalyst Bed Heater	Tayco	TDRSS	EQ8-0277	24
•Latching Isovalve	Vacco	HS-601 Bus	EQ8-0281	2
•Filter	Brunswick	DSP	EQ1-594	1
•Fill/Drain Valve	Pyronetics	DSP	EQ1-595	2
•Pressure Transducer	Statham	DSP	EQ2-0565B	1
•Heaters	Tayco	Various	1S006,1S016, 1S019	20 Ckts
•Thermostats	Elmwood	Various	2F017	34
•Temperature Transducer	ADI	STEP	AD-590	14

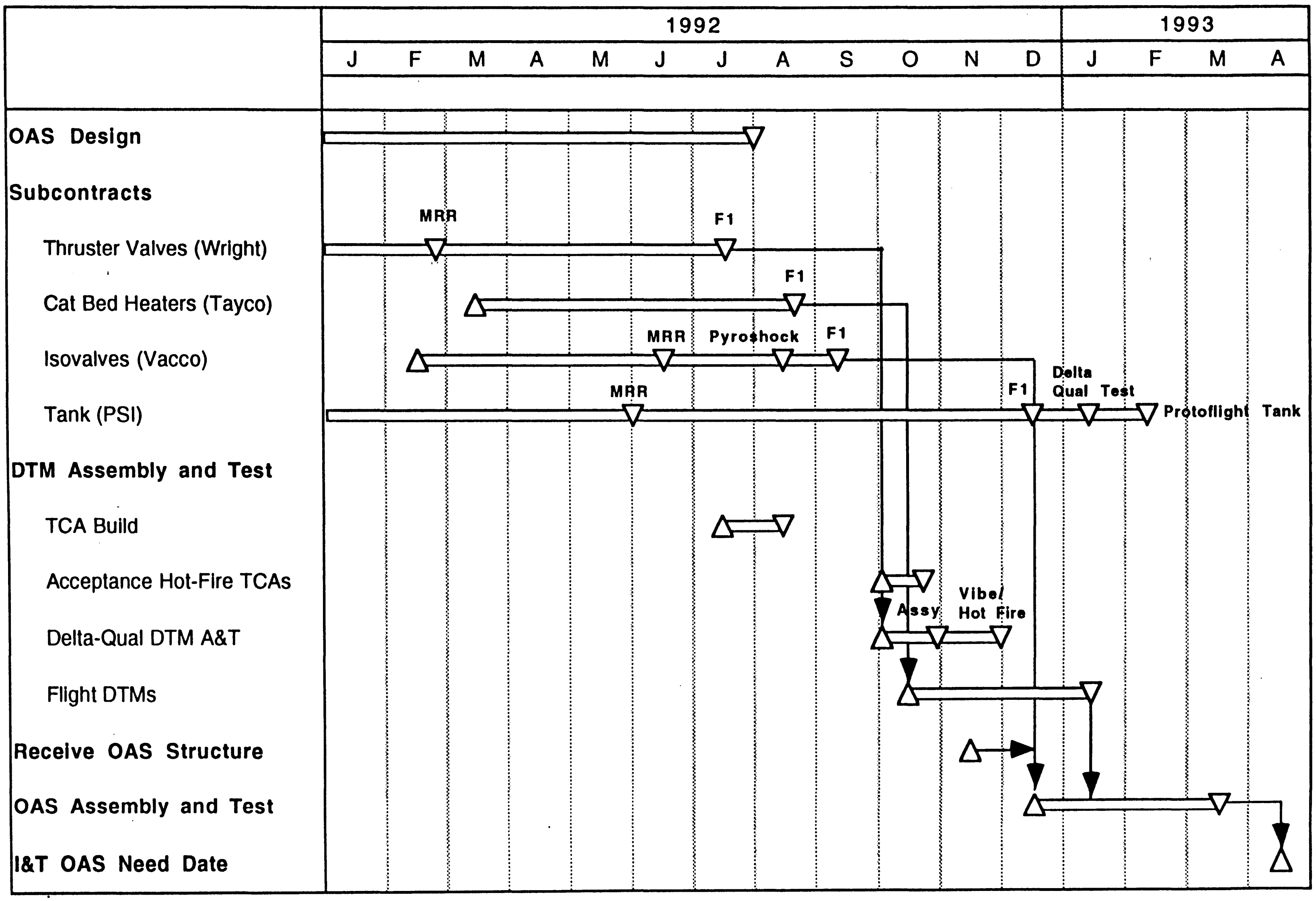
TOMS-EP Dual Thruster Module

TRW



OAS Hardware Status and Key Milestones

TRW



Summary of OAS CDA Action Items

TRW

Action Item	Subject	Response
OAS-1	Redundant Thermostats	o Redundant Thermostats added to Fill/Drain Module and Line Heater circuits o OAS is single-fault tolerant to propellant overheating > 185 deg F
OAS-2	Pressure Transients	o 10 psid trim orifice added to minimize pressure transients when isovalves are first opened o System will be pressurized between isovalves and thrusters
OAS-3	Thruster Delta-Qual Test	o Draft test plan for delta-qual hot-fire test is based on the preliminary mission duty cycle provided by ACDS o Thruster delta-qual hot-fire tests , scheduled for October 1992, will be based on updated mission duty cycle
OAS-4	Tank Loads and Safety Factors	o Loads and safety factors are included in latest revision to the tank equipment spec o Test factor of 1.25 will be applied to protoflight levels for the delta-qual test (sine sweep/sine dwell)
OAS-5	Plume Impingement Torques	o Predicted torques have been assessed by ACDS and incorporated into the latest transfer orbit mission scenario
OAS-6	OAS Proof Test	o OAS will be proof tested to 525 psia (1.5 x 350 psia) o Weld joints will be verified by X-ray inspection o Thruster valves and isovalves will be proof tested to 1.5 x MOP, including back pressure relief

Requirements Vs. Capabilities

OAS Requirements Vs. Capabilities

Source: SY1-0012A, "TOMS-EP System Specification", dated 1 July 1992

3.7.5.4 Performance

The OAS shall provide the following minimum performance:

Mode	Propellant Load (lb)	Deliverable Propellant[1] (lb)	Average I_{sp}[2] (sec)	Total Impulse[3] (lbf-sec)
Delta V	144	139.2	211	29380
ACS	16	15.5	80	1240

Total loaded propellant = 160 lbm

1 Deliverable propellant accounts for unusable propellant due to residuals and loading errors. Verification is by analysis.

2 Nominal I_{sp} based on the average value over the blowdown pressure range from full load to depletion. Verification is by test.

3 Delta-V impulse is based on steady-state I_{sp}. ACS impulse is based on pulse-mode I_{sp} and 30 msec to 80 msec pulsewidth. Verification is by analysis.

OAS Requirements Vs. Capabilities (Continued)

Source: SY1-0012A, "TOMS-EP System Specification", dated 1 July 1992

Paragraph/Requirement	Capability	Verification
3.7.5.7.1 - Impulse Bit • impulse bit $\leq$0.05 lbf-sec for 30 msec pulse and 0.1% d.c.	• $I_{bit} \leq$ 0.05 lbf-sec	• Analysis, test
3.7.5.7.2 - Thrust Duration • Operate at maximum continuous thrust for up to 35 minutes	• Thruster has been qualified for a maximum steady-state firing of 187 minutes	• Test
3.7.5.7.3 - Thrust $\leq$ 1.0 lbf per thruster at BOL $\geq$ 0.15 lbf per thruster at EOL (for 160 lb propellant load)	• Thrust will range from 0.9 to 0.2 lbf over blowdown range	• Analysis, test
3.7.5.8 - Alignment Error Budget • Geometric thrust vector of any thruster shall be aligned to the OAS platform structure to within ±0.71 degree	• Complies. DTM will be adjusted by shimming at OAS level (if required)	• Alignment test • Analysis

Safety Requirements
(Ref: SY1-0012A, paragraphs 3.3.6 and 3.7.5.3)

- Applicable safety documents include:

  MIL-STD-1522A: "Safety Requirements for Pressurized System"

  MIL-STD-1574A: "System Safety Program for Space and Missile Systems"

  GMI1771.1: "Range Safety Policies and Criteria for GSFC/Wallops Flight Facility"

  WSMCR-127-1: "Western Space and Missile Center Range Safety Requirements"

  D19085: "TOMS-EP System Safety Plan"

- Per contract NAS5-31488, Modification Number 18, "Propellant lines and FDM shall be one fault tolerant against overheating to temperatures greater than 160°F"

OAS Safety Compliance

TRW

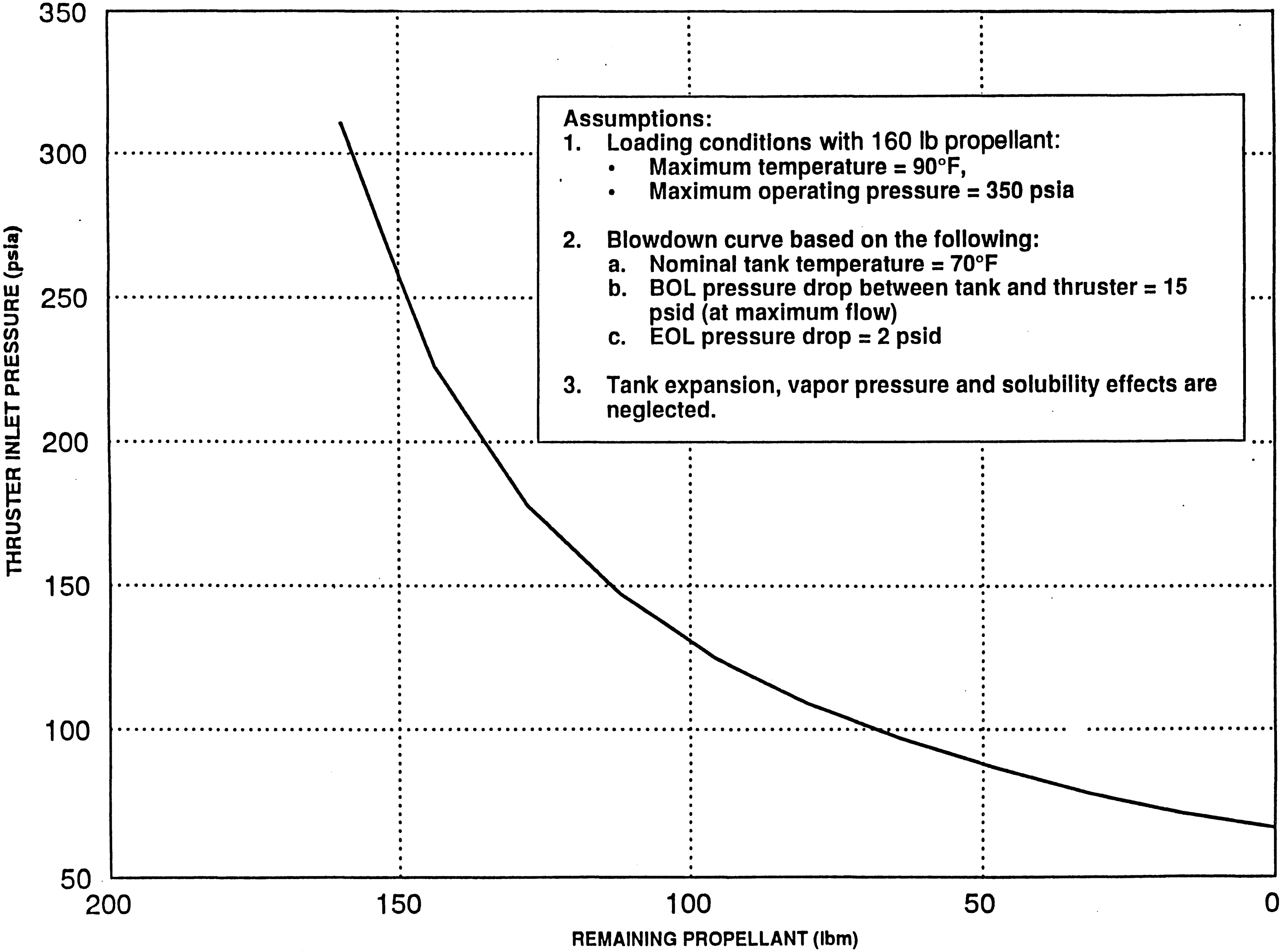
- Three mechanical inhibits (one isovalve and two thruster valve seats) are provided to prevent propellant leakage
- Four electrical inhibits are provided to prevent inadvertent thruster firing
- Single-fault tolerant to propellant overheating
  - FDM, propellant lines ≤ 160 °F
  - Other components ≤ 185°F
- System pressure/temperatures telemetered for ground monitoring
  - Pressure monitoring also provided during pre-launch pressurization
- For launch configuration, OAS is fully pressurized at 300-350 psi, with isovalves closed, and wetted down to thruster inlet
- All-welded design
- Components are designed to meet or exceed the following MIL-STD-1522A safety factors:

	Proof	Burst
– Lines/fittings	1.5	4.0
– Components	1.5	2.5
– Tank	1.25	1.5

TRW

OAS Performance Summary and Analyses

Blowdown Pressure Profile



OAS Propellant Estimates

TRW

Function	Propellant (lb)
Orbit Transfer	104.0
Orbit Injection Errors	2.2
ACDS - Injection	5.4
ACDS - Backup	5.4
Residuals and Loading Errors	2.5
Subtotal	119.5
GN_2 Pressurant (120 lb propellant load)	2.14
GN_2 Pressurant (160 lb propellant load)	1.07

Notes:

1. Pressurant mass based on propellant load, 350 psia MOP, 90°F loading temperature, and 70°F operating temperature.
2. Orbit transfer propellant based on spacecraft weight of 636 lbs and 120 lb propellant load.

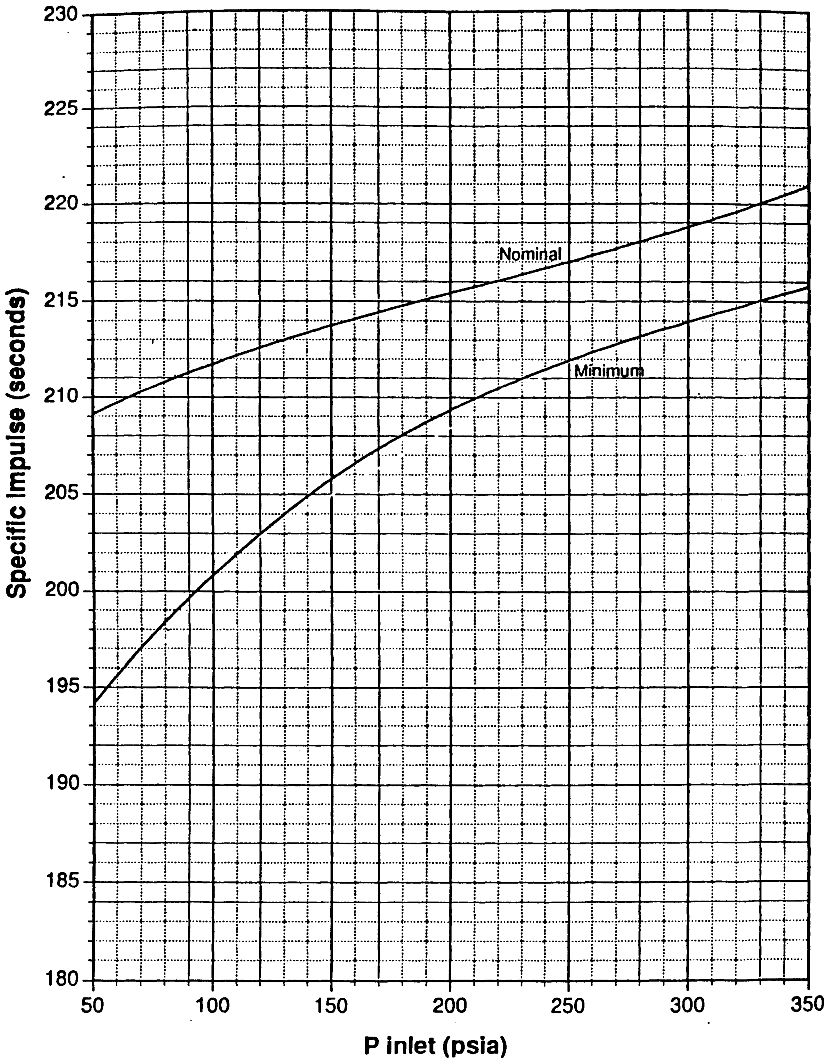
OAS Weight Summary

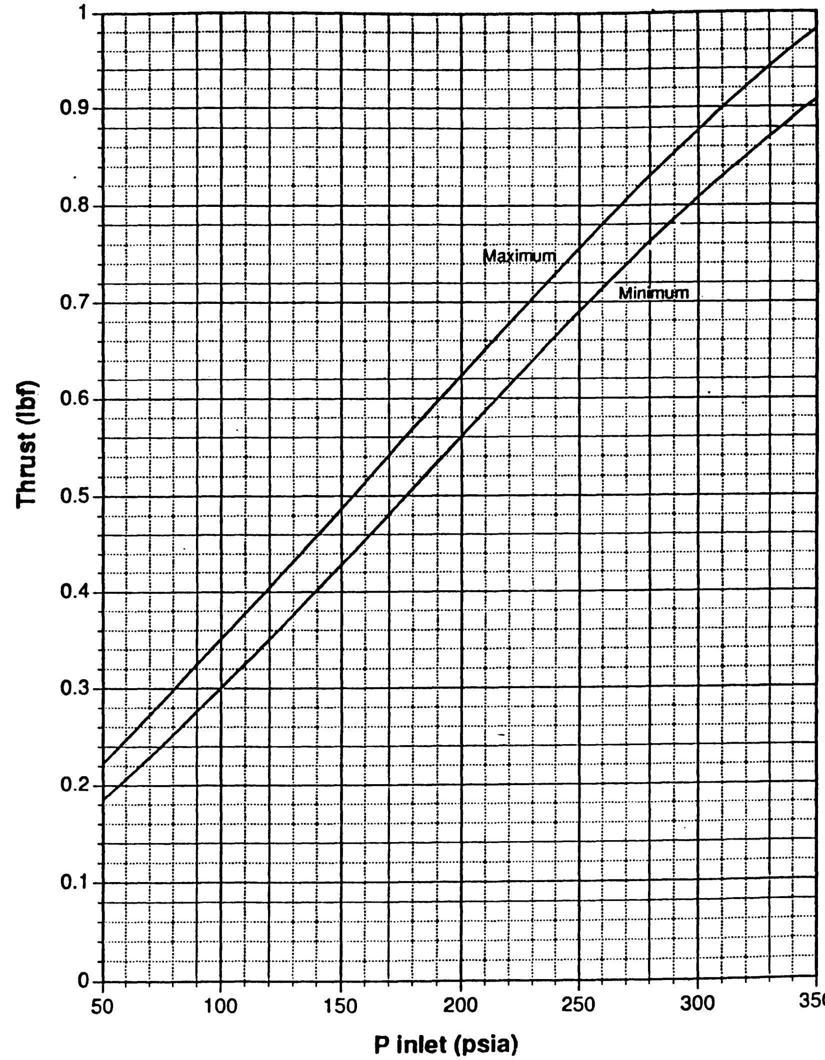
Component	Current Wt (lb)	Contingency Weight (lb)	Weight Budget (lb)
Propellant tank	15.0	0.45	15.45
Fill/Drain valves	1.0	0.08	1.08
Pressure transducer	1.1	0.09	1.19
Filter	0.7	0.06	0.76
Isovalves	1.7	0.14	1.84
DTMs (See Note)	11.0	0.33	11.33
Lines	1.6	0.4	2.0
Support brackets/clamps	0.87	0.07	0.94
Integration hardware	1.68	0.13	1.81
Fill/Drain bracket	0.44	0.04	0.48
Transducer/filter bracket	0.78	0.06	0.84
Isovalve bracket	0.4	0.03	0.43
Total	36.27	1.88	38.15

Note: DTM weight includes DTM thermal and mechanical hardware. Other OAS thermal hardware included in TCS weight allocation.

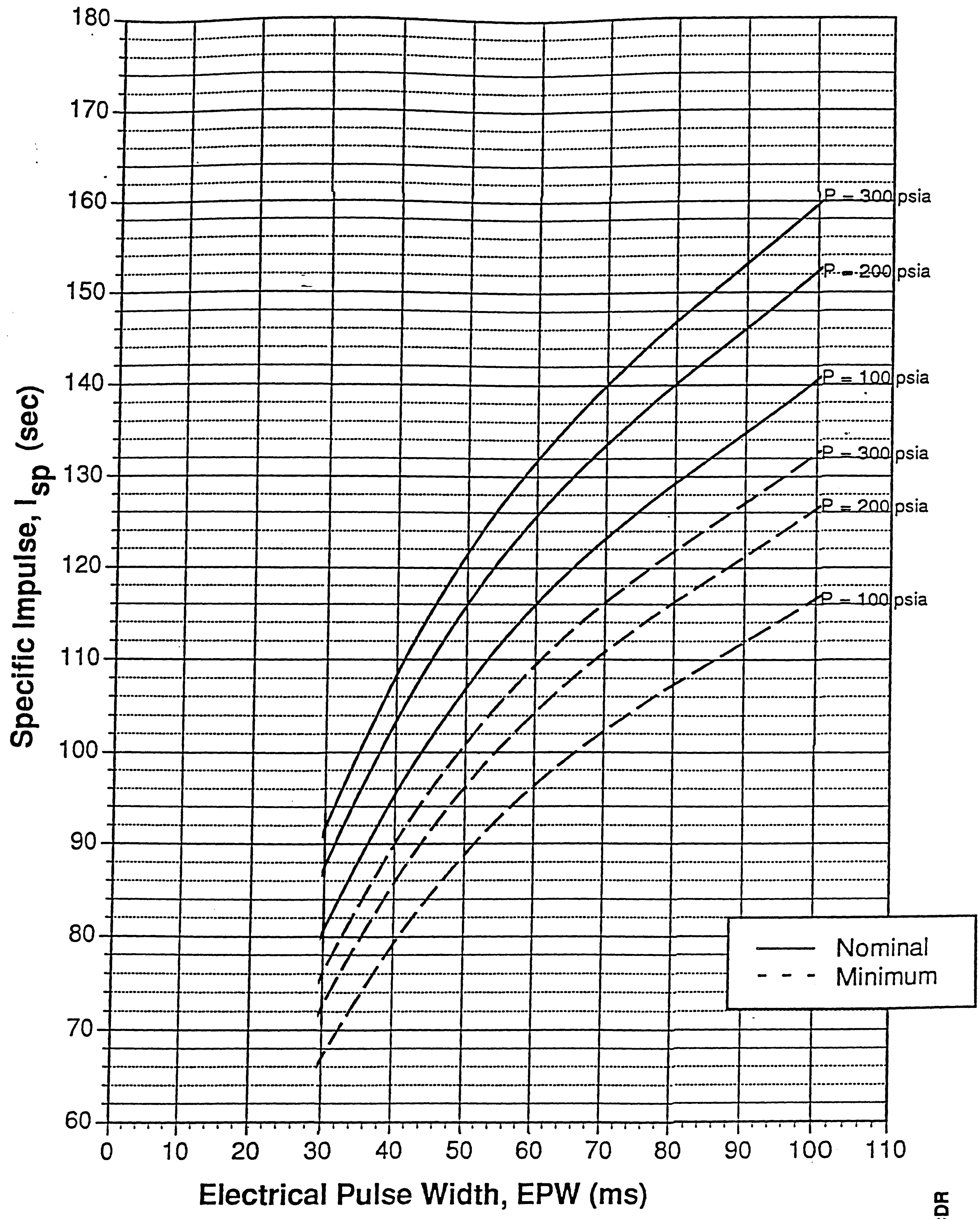
1 lbf Thruster Steady-State Performance

TRW





MRE-1 Pulse Specific Impulse



OAS Analyses Since CDA

TRW

- Pressure Transient Analysis
  - Analysis performed to determine worst-case pressure spike when isovalves are initially opened on-orbit
  - Ten psid orifice and pressurized segment downstream of isovalves minimizes pressure surge
- Tank Stress/Fracture Analyses (PSI)
  - Stress analysis demonstrated positive margin for worst-case loads
  - Fracture analysis demonstrated tank can withstand four times the predicted cycle life
- Catalyst Bed Heating Analysis
  - Transient analysis performed to determine minimum catalyst bed temperature and heating rates for contingency modes
  - Minimum temperature, without heater power, predicted to be -11°F
  - Heating rate = 4.6°F/minute

35°F = Hydrazine freezing

OAS Analyses Since CDA (Continued)

TRW

- Propellant Overheating Analysis
  - Transient analyses performed to predict maximum temperature if a heater fails on (failed thermostat)
  - Analysis showed temperatures above 200°F for FDM and lines and temperatures less than or equal to 185°F for other components
  - Redundant thermostats have been added to FDM and line heater circuits such that OAS is single fault tolerant to propellant heating greater than 185°F

Subsystem Verification and Assembly & Test

Subsystem Verification

TRW

- All components, will demonstrate compliance with Pegasus launch loads either by test (protoflight levels) or similarity to other programs
  - Delta-qual test to be performed on tank for higher launch loads and higher propellant loading
  - Delta-qual test for DTM will include random vibe and hot-fire characterization tests
  - Shock test to be performed on latching isolation valve to verify Pegasus pyroshock levels
  - Thrust chamber assemblies to be verified by hot-fire acceptance

- Integrated OAS will be verified by acceptance testing

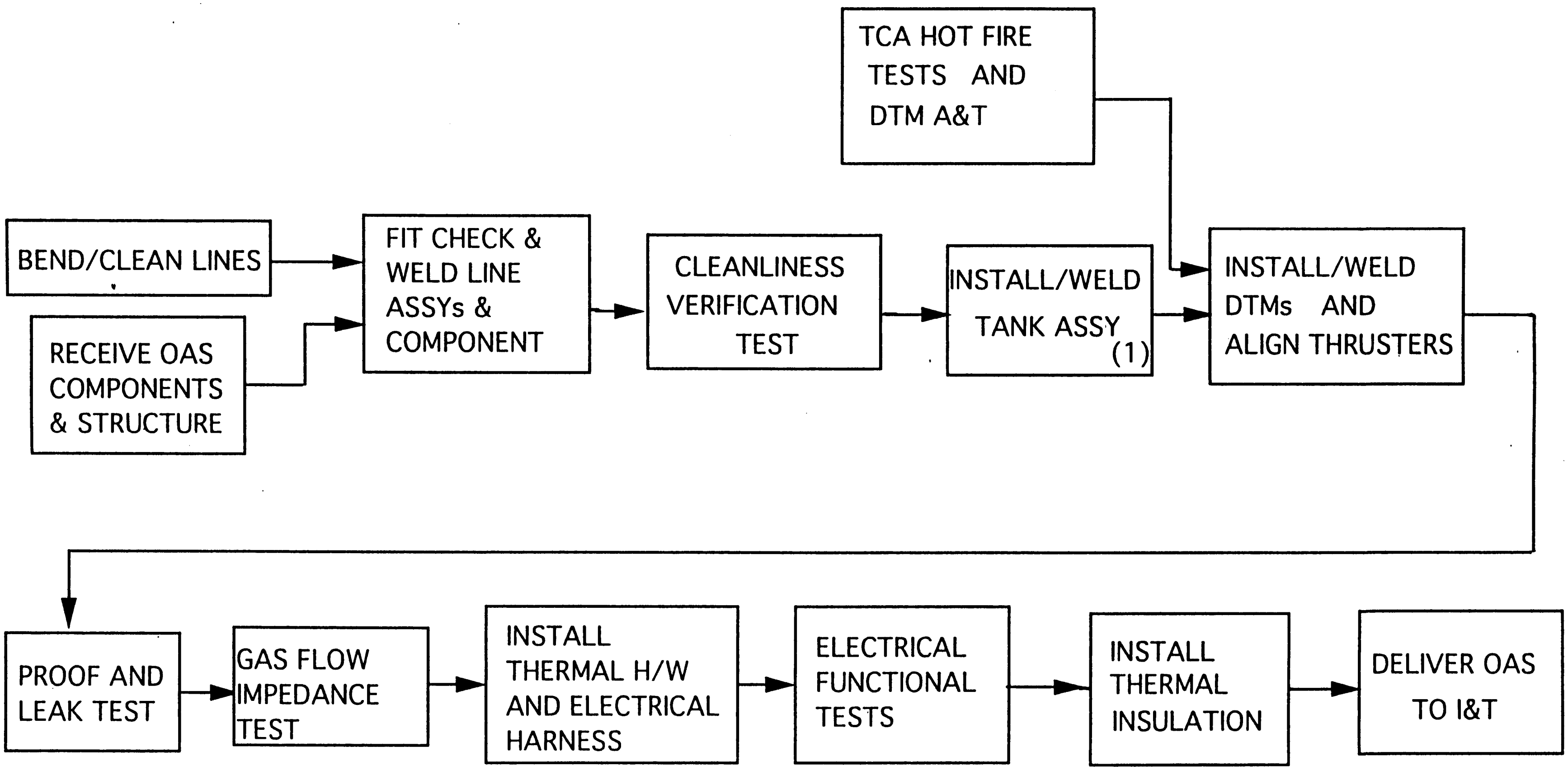
OAS Verification Test Matrix

Item/Level of Assembly	Protoflight Tests							Acceptance Tests							Remarks
	Functional	Random Vibe	Sine Vibe	Pyroshock	Proof	Leak	Hot Fire	Functional	Random Vibe	Sine Vibe	Pyroshock	Proof	Leak	Hot Fire	
Subsystem Level:															
Orbit Adjust Subsystem								X			X	X	X		Pyroshock testing at spacecraft level
Subassembly Level:															
Dual Thruster Module	X	X			X	X	X								• Test unit only
								X				X	X	X	• Hot-fire for TCAs
Component Level:															
Thruster Valves								X	X			X	X		
Propellant Tanks	X		X		X	X		X				X	X		
Fill/Drain Valves								X	X			X	X		See Note 3
Pressure Transducer								X	X			X	X		See Note 3
Filter								X	X			X	X		See Note 3
Isovalves	X			X	X	X		X	X			X	X		• Shock test performed on refurbished qual unit

Notes:
1. Protoflight tests performed on protoflight units.
2. Acceptance tests performed on flight units.
3. Acceptance tests for ICMT hardware (fill/drain valves, pressure transducer and filter) were performed on DSP Program.

OAS Assembly & Test Flow

TRW



Notes:

(1) Thermal hardware and insulation will be installed on the tank prior to tank integration.

TOMS-EP
Communications and Data Handling (C&DH)
Subsystem

J. Kinney

C&DH Digital Components

TRW

- Digital Command and Data Handling Equipment consists of:
  - Spacecraft Processor (SP) responsible for command distribution, timing control, and engineering telemetry acquisition
  - Data Processor (DP) responsible for Instrument telemetry acquisition, telemetry formatting, and data storage
- SP and DP utilize microprocessor-based logic designs
  - Provide centralized real-time and stored command distribution
  - Provide real-time telemetry reporting and storage for later playback
  - Provide platforms for TOMS-EP Flight Software (TFS) execution
- SP and DP are subcontracted to Gulton Data Systems (GDS)

C&DH RF Components

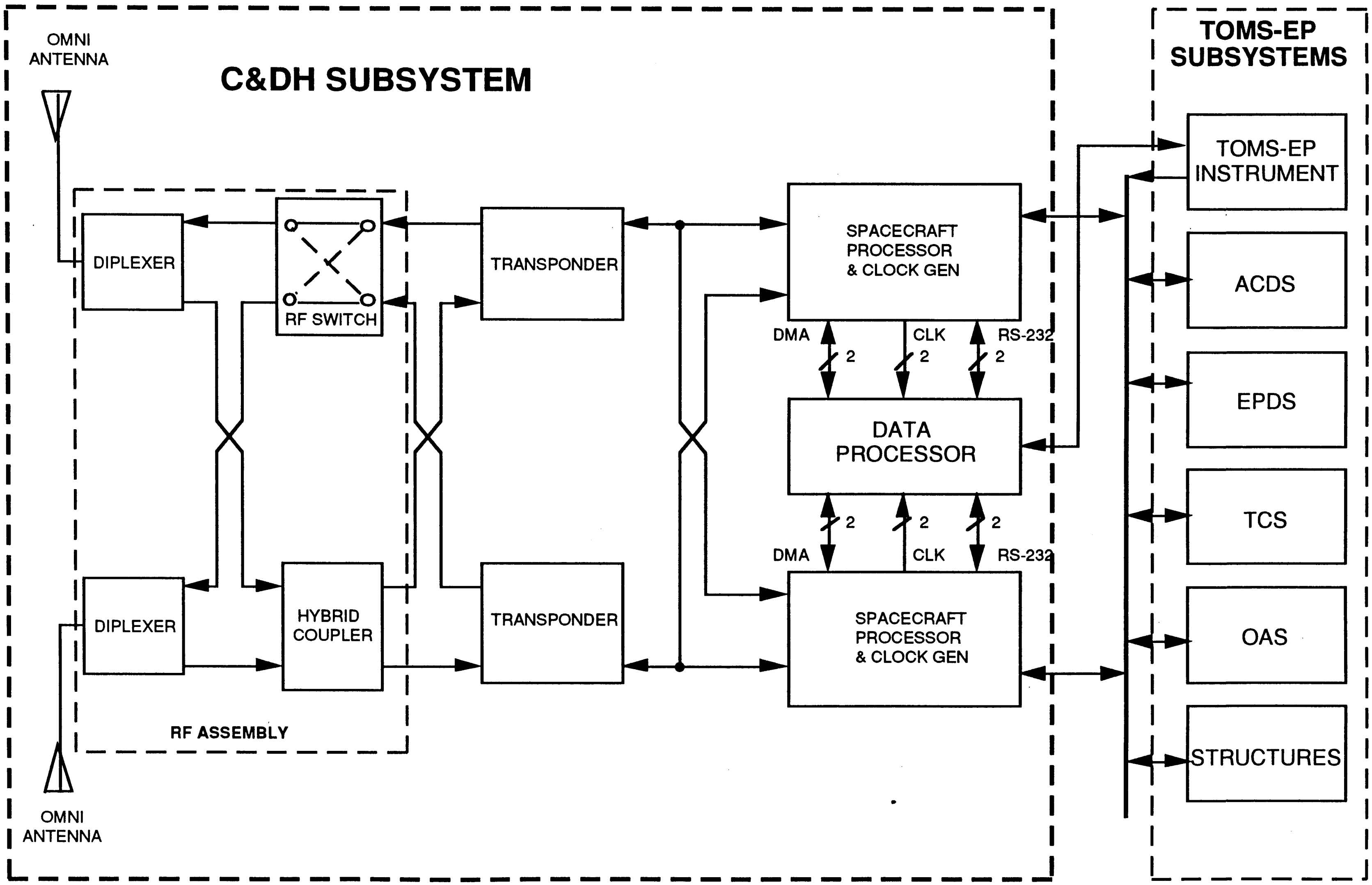
TRW

- OMNI Antenna (2)
  - Zenith and Nadir antennas provide 85% spherical coverage
  - S-Band, Omni directional antenna with 6 inch ground plane
  - Subcontracted to Watkins-Johnson

- RF Assembly (1)
  - Integrated Diplexers, coupler, and RF Switch
  - Performs RF signal routing between antennas and transponders
  - Dual uplink command paths supported
  - Subcontracted to Sage

- Transponder (2)
  - Integrated transmitter and receiver functions
  - S-Band uplink and downlink
  - Subcontracted to Loral Conic

C&DH Block Diagram



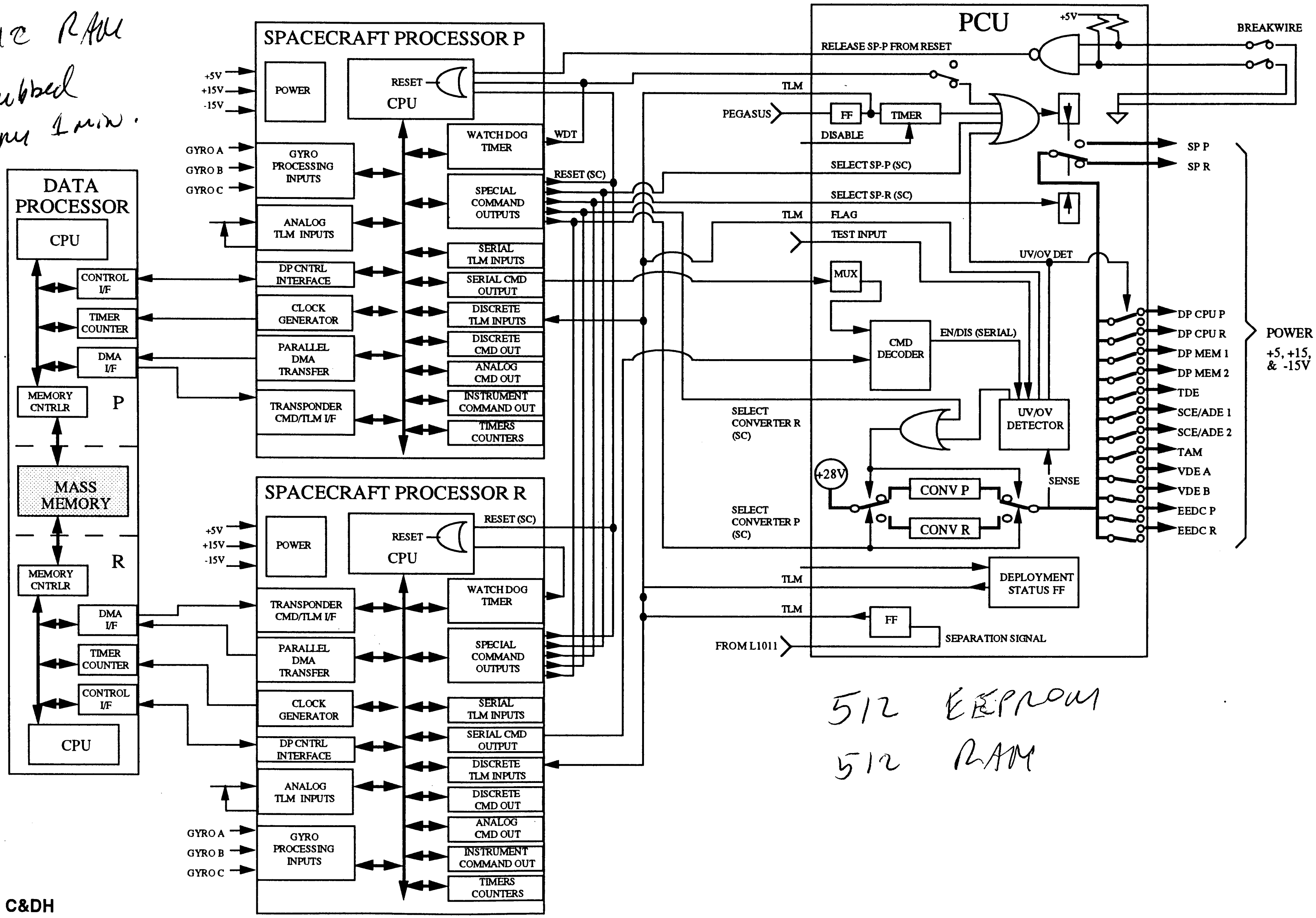
RS232 Test port · upload/Download ability

Command & Telemetry Processing

TRW

UTMC RAM
- scrubbed every 1 min.

256 EEPROM RAM



512 EEPROM
512 RAM

Key C&DH Requirements vs Capability

TRW

PARAGRAPH/REQUIREMENTS	CAPABILITY	HOW VERIFIED
3.1.2.2.11 Instrument Command and Telemetry. Provide command and telemetry service to TOMS Instrument per IF3-0007	SP and PCU provide instrument commanding. DP provides telemetry gathering and formatting	Test at integrated satellite level
3.2.1.6 Communications with Ground Spacecraft shall communicate with the ground as defined in IF3-0009	S-band uplinks up to 2.0 kbps supported with and without ranging. Downlink data at 1125 bps with ranging, 202.5 kbps without ranging.	Test at integrated spacecraft level Link analysis C&DH analysis
3.2.1.6.1 Command Receipt Spacecraft shall receive and decode all GSTDN compatable commands in all mission phases and orientations	> 30 dB margin on uplink, dual command uplink paths with antenna switching and autonomous toggle between paths, opposition mounting of omni antennas	Link analysis C&DH analysis
3.2.1.7.1 Stored Data Playback 24 hours of stored telemetry, together with real-time, shall be transmitted to ground in 8 minutes or less.	202.5 kbps High-Rate Real-Time and Playback telemetry mode, real-time interleaved with playback	Test at Subsystem level (ETB) Test at integrated spacecraft level Link analysis C&DH analysis

C&DH Requirements vs Capability (Telemetry)

PARAGRAPH/REQUIREMENTS	CAPABILITY	HOW VERIFIED
3.7.6.1.2 Data Storage C&DHS shall provide minimum storage of 24 hours of telemetry data.	Data processor mass memory function provides 16 M-bytes of data storage to meet 12.5 M-byte (EOL) requirement	Mass memory function tested at unit, subsystem (ETB), and integrated spacecraft levels
3.7.6.1.3 Simultaneous Data Record and Playback C&DHS shall simultaneously record and playback telemetry data.	Real-Time telemetry always recorded, even in playback modes by Data Processor.	Tested at unit level Test at subsystem (ETB) level Test at integrated spacecraft level
3.7.6.1.6 Telemetry Format Reprogrammability C&DHS shall provide a reprogrammable telemetry format which may be modified by the ground.	Telemetry formatting software executes from Data Processor RAM. All RAM accessable to ground	Test at subsystem (ETB) level Test at integrated spacecraft level
3.7.6.1.7 Telemetry Time Sync C&DHS shall provide sync pulse to intrument to support time tagging and correlation of telemetry data to less than $\pm$ 100 mSec relative to UTC.	Spacecraft time-tagging and instrument time correlatable at 32 sec "Major Frame" sync pulse sent as instrument time sync	Test at integrated spacecraft level C&DH analysis

C&DH Requirements vs Capability (Command)

PARAGRAPH/REQUIREMENTS	CAPABILITY	HOW VERIFIED
3.7.6.2.1 Command Reception C&DHS shall receive uplinked commands from the ground	Commands received, demodulated, decoded, and validated with bit count, address check, and parity checks	Test at integrated spacecraft level Link analysis C&DH analysis
3.7.6.2.2 Command Execution C&DH shall execute and distribute real-time and stored commands	Special commands executed by hardware, real-time and stored commands executed and/or distributed by software.	Tested at unit level Test at subsystem (ETB) level Test at integrated spacecraft level C&DH analysis
3.7.6.2.4 Stored Commands C&DHS shall provide for Absolute Timed and Relative Timed commands as stored commands	Stored commands executed upon match with spacecraft time of day. Resolution is 1.024 seconds	Test at subsystem (ETB) level Test at integrated spacecraft level
3.7.6.12 Synchronous Command Execution C&DHS shall provide command sequencing to enable commands from all sources to execute without interference from each other	Real-time commands execute immediately, stored commands sequenced by time tags and stack position. Software controls command sequencing to avoid interference	Test at subsystem (ETB) level Test at integrated spacecraft level

C&DH Requirements vs Capability (Communication)

PARAGRAPH/REQUIREMENTS	CAPABILITY	HOW VERIFIED
3.1.2.3 Ground Interface The spacecraft shall communicate with the 8-meter GSTDN antenna.	Spacecraft communications with 3-meter antenna for command, ranging, and low-rate playback modes	Link analysis C&DH analysis
3.7.6.3.1 Antenna Coverage C&DHS shall provide ≥ 85% spherical antenna coverage for receiving uplink commands in any orientation.	Farfield antenna coverage > 85%	C&DH analysis
3.7.6.3.2 Communication Modes C&DHS shall provide the following communication modes: Real-Time telemetry Real-Time + Playback telemetry Ranging only Ranging + Real-Time telemetry	Ranging, real-time + ranging, real-time + High rate playback, real-time + Low rate playback. Ranging with playback not precluded	Test at subsystem (ETB) level Test at integrated spacecraft level Link analysis C&DH analysis
3.7.6.3.3.4 Ranging Mode Mod Index Linear modulation shall be provided.	Linear modulation index >0.9 provided	Test at integrated spacecraft level

C&DH Requirements vs Capability (Data Processing)

PARAGRAPH/REQUIREMENTS	CAPABILITY	HOW VERIFIED
	floating gate (anti-fuse)	
3.7.6.3.5.7 Non-Volitile Memory Initialization data, mode transition command sequences, and key parameters shall be contained in ROM	EEPROM in processors contains initial TOMS flight software. Software downloaded to RAM for execution.	Tested at unit level Test at subsystem (ETB) level Test at integrated spacecraft level
3.7.6.3.5.8 Command Processor Anomalies A watchdog timer shall monitor health of primary processor and force transition to redundant unit on processor failure.	Watchdog timer monitor an independent funtion housed within the Spacecraft Processor chassis	Tested at unit level Test at subsystem (ETB) level Test at integrated spacecraft level
(Various) Software Support C&DHS hardware shall support the storage and execution of TOMS Flight Software.	80C86 CPU with control, Address/Data buses, EEPROM and RAM, All commandable functions addressable from the buses.	Tested at unit level Test at subsystem (ETB) level Test at integrated spacecraft level C&DH analysis

RF Performance Summary

TRW

- Command Link meets system requirements with margin

  - 8-meter GSTDN antenna analysis shows > 30 dB margin
  - 3-meter antenna analysis shows > 20 dB margin

- Telemetry and Playback Link meets system requirements with margin

  - High rate Playback to 8-meter antenna analysis shows > 7 dB margin
  - Low rate Playback to 3-meter antenna analysis shows > 5 dB margin

- Command and Ranging wth Real-Time telemetry and 8-meter antenna analysis shows > 37 dB margin

TRW

Command Distribution Key Features

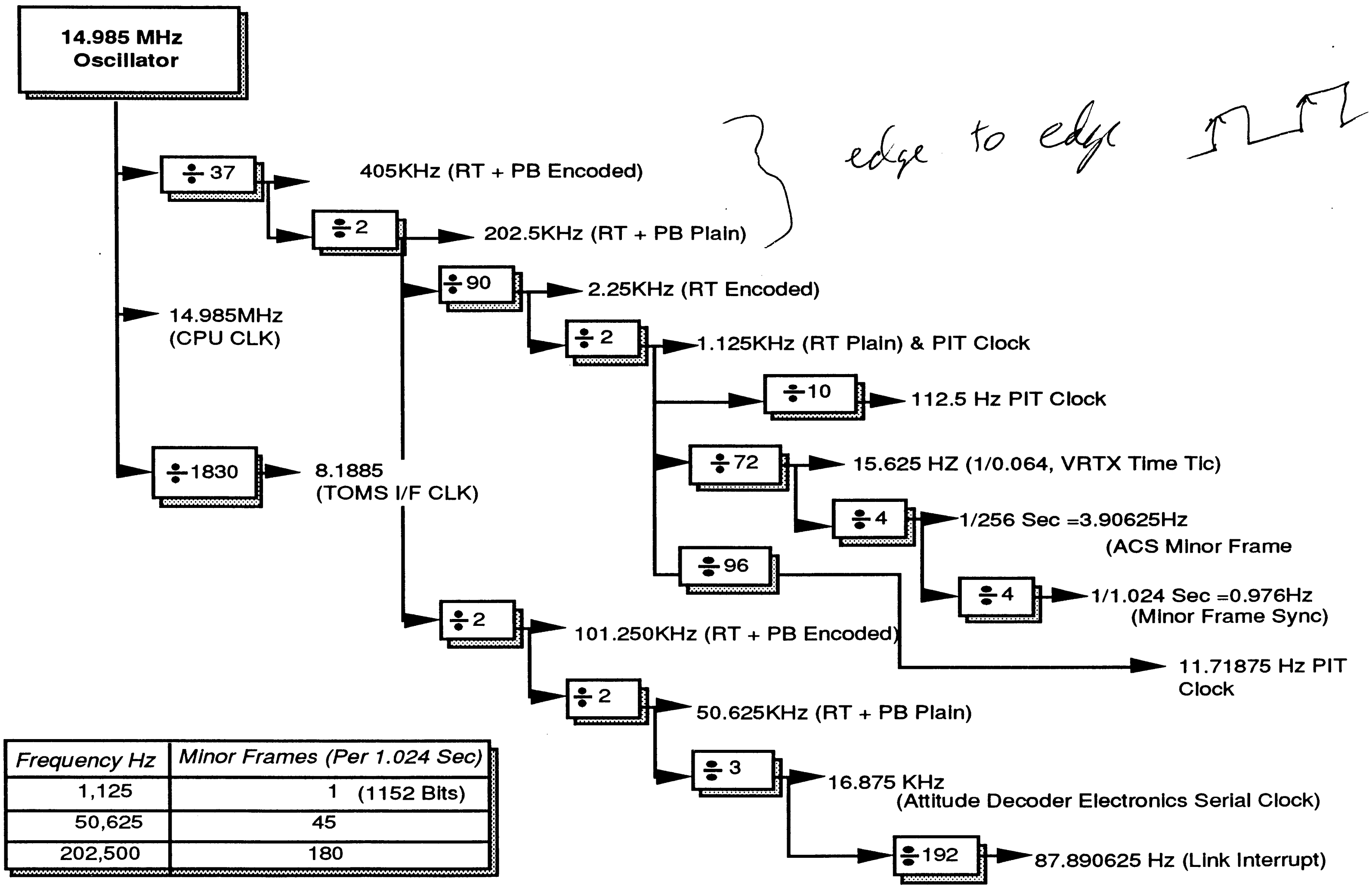
- C&DH Subsystem utilizes centralized command distribution via Spacecraft Processor (SP) unit
  - -- Limited quantity of serial buses
  - -- No protocol based bus systems
- Hardware based special command distribution
- Command validation partitioned between SP hardware and software
- Centralized relay & relay drive service at PCU
- Limited On-board command format conversion

Telemetry Key Features

- Centralized Acquisition of Spacecraft Health and Status (H&S) Telemetry at SP
- Instrument and H&S telemetry input and stored at DP
- Software based telemetry formatting using CCSDS formats
- Combined link formatting and data storage service

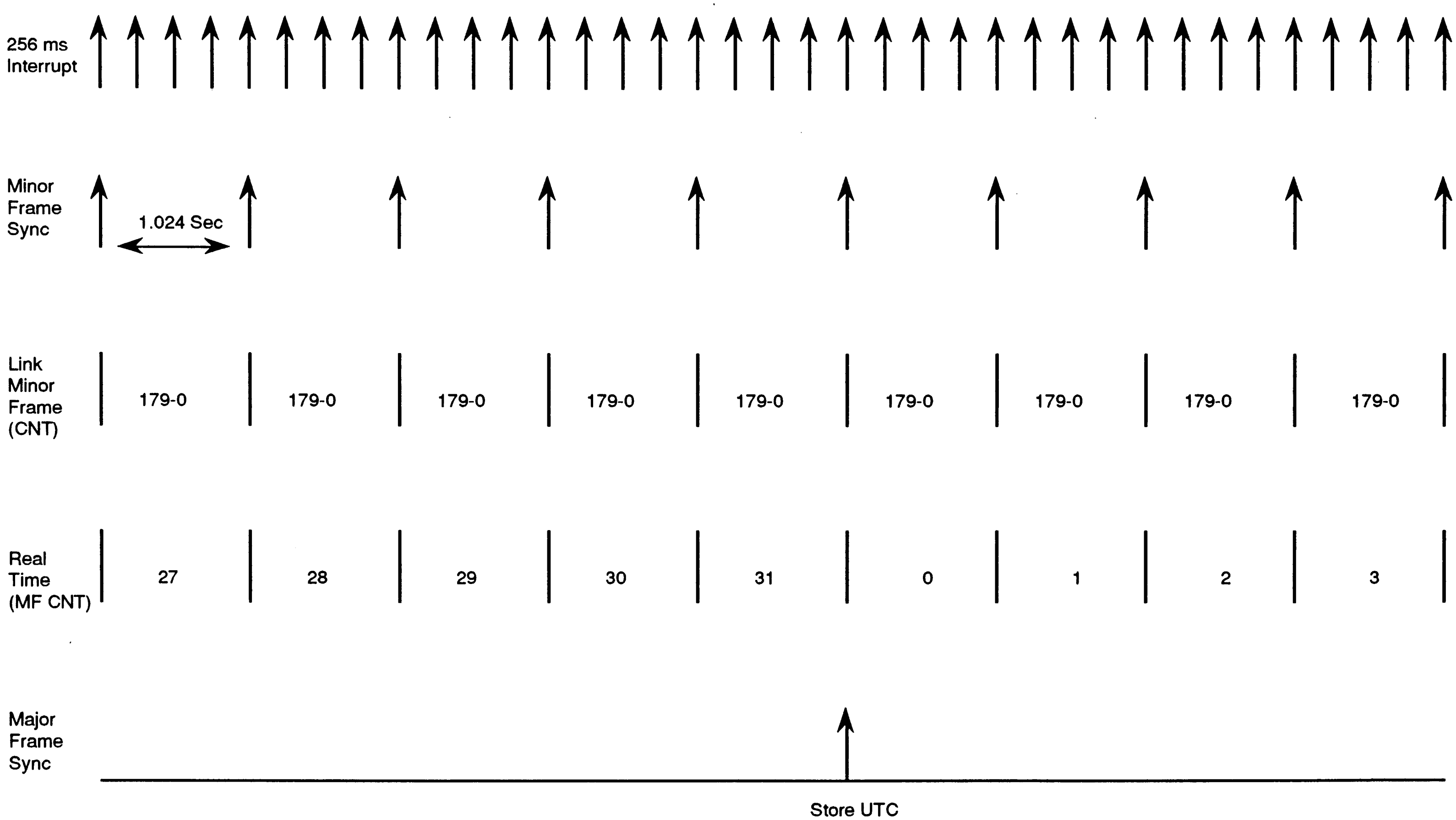
SP Frequency Plan

TRW



Frequency Hz	*Minor Frames (Per 1.024 Sec)*
1,125	1 (1152 Bits)
50,625	45
202,500	180

Top Level Spacecraft Timing

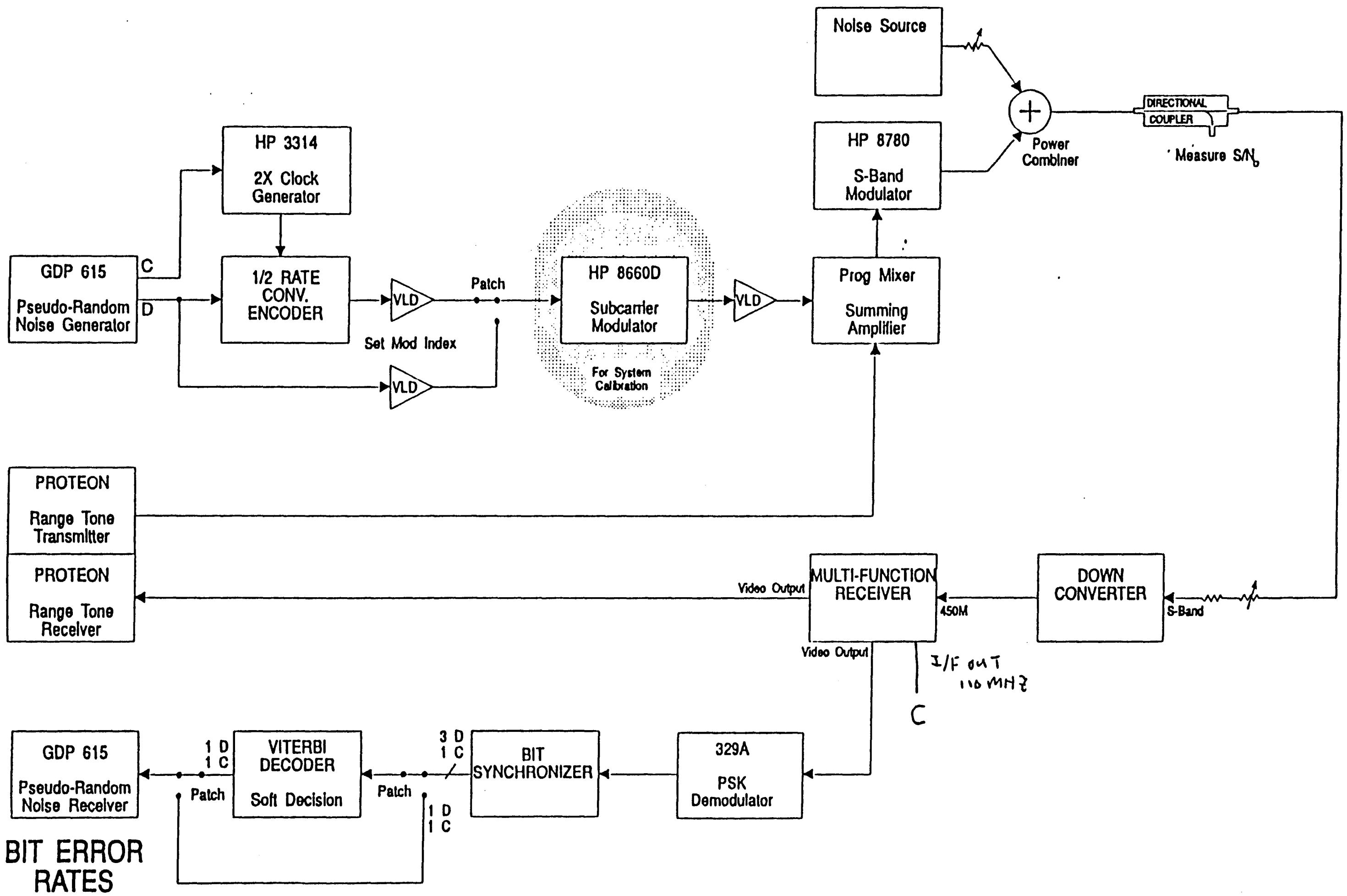


- Instr. MF Pulse
- Timing sync.

Compatability Test

TRW

TOMS SUBCARRIER MODULATOR TEST
Compatibility Test Van Equipment Block Diagram

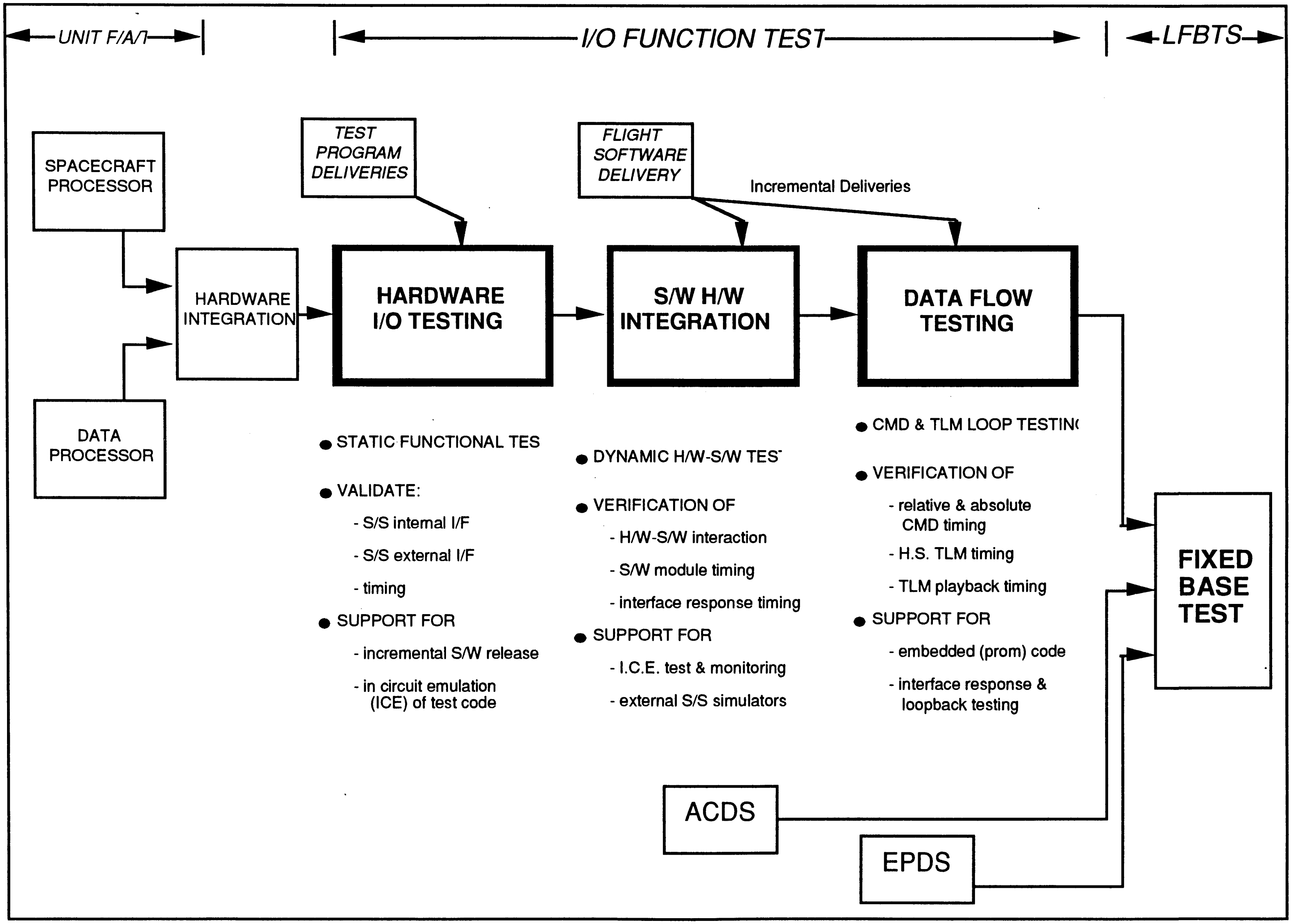


End to End RF Test Results

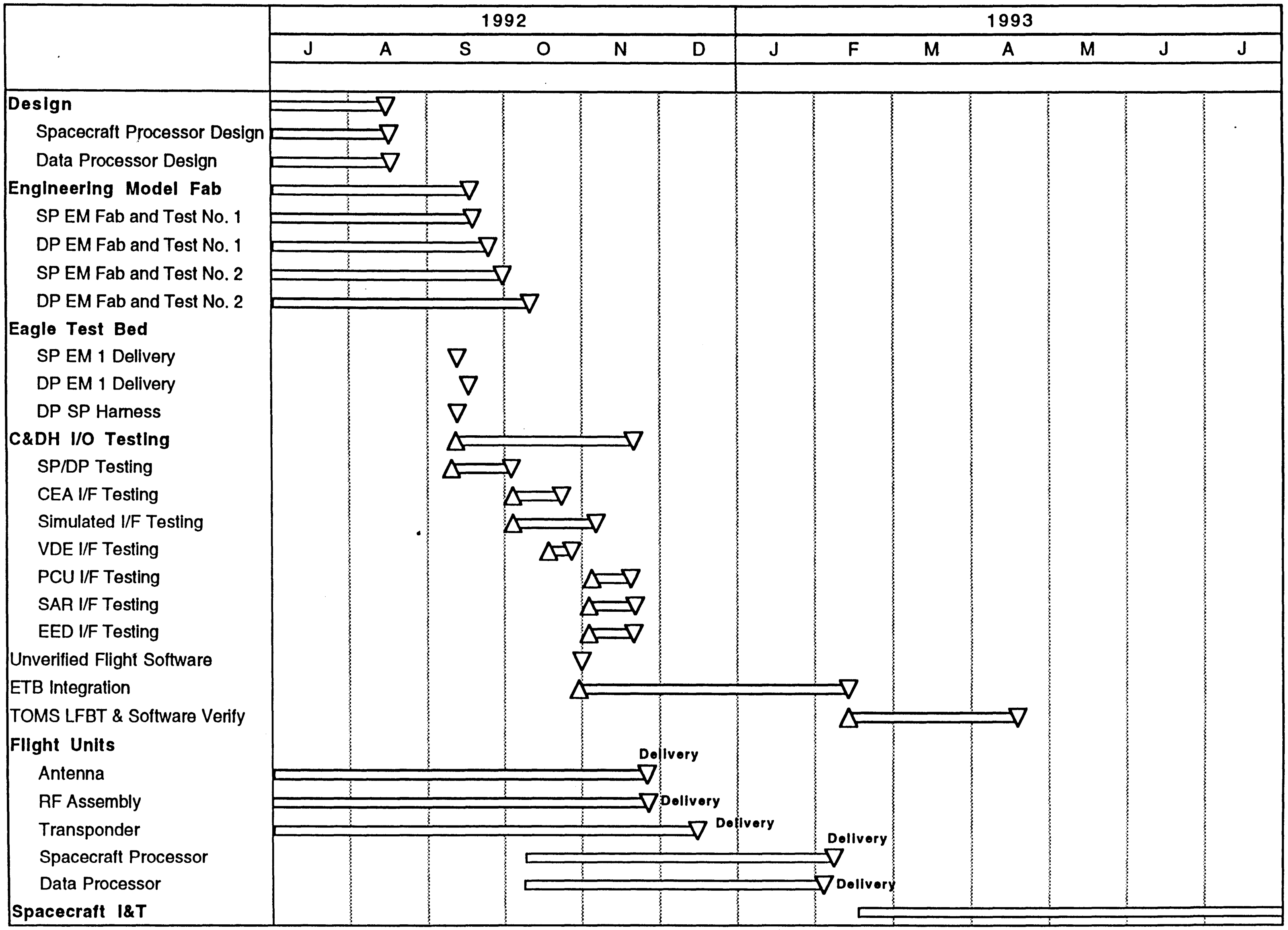
TRW

- Testing performed 27 July to 31 July 1992
- Results unavailable at time of package preparation
- To Be Presented at CDR

Verification Approach



Schedule



1992
1993
J A S O N D J F M A M J J
Design
Spacecraft Processor Design
Data Processor Design
Engineering Model Fab
SP EM Fab and Test No. 1
DP EM Fab and Test No. 1
SP EM Fab and Test No. 2
DP EM Fab and Test No. 2
Eagle Test Bed
SP EM 1 Delivery
DP EM 1 Delivery
DP SP Harness
C&DH I/O Testing
SP/DP Testing
CEA I/F Testing
Simulated I/F Testing
VDE I/F Testing
PCU I/F Testing
SAR I/F Testing
EED I/F Testing
Unverified Flight Software
ETB Integration
TOMS LFBT & Software Verify
Flight Units
Antenna
RF Assembly
Transponder
Spacecraft Processor
Data Processor
Spacecraft I&T
Delivery
Delivery
Delivery
Delivery
Delivery

CDA Action Items

Number	Subject	Responder	Originator	Due	Status
CDHS-01	I/F Reqts Between CDHS and ACDS	Kinney	Dobrotin	6/19/92	Open
CDHS--02	SEU's System Impact - Review Meeting	Fleming	Hogan	6/26/92	Closed
CDHS-03	SP Interrupt 0	Kinney	Tsai	7/1/92	Closed
CDHS-04	SP Premature Wakeup	Fesq	Stuart	6/26/92	Closed
CDHS-05	WDT Enable/Disable Control, Wakeup Function	Dobrotin	Stuart	6/26/92	Closed
CDHS-06	Switch to Redundant SP - Reqts Review	Watson	Dobrotin	7/8/92	Closed
RF-01	RF Assy SMA Connectors Attach to Duroid Board	Kinney	Gross	6/12/92	Closed
RF-02	RF Switch Magnetic	Kinney	Bal	6/19/92	Closed
RF-03	Chanel to Chanel Transponder Isolation	Kinney	Low	6/19/92	Closed
RF-04	RG 400 Cable Suitability	Hirsch	Lyons	6/18/92	Closed
RF-05	Dev. RF Cables Design, Mfg and Test Plan	Kinney	Fleming	7/7/92	Open
RF-06	Omni Antenna Materials Outgassing, Suitability	Argus	Kinney	6/25/92	Open
RF-07	Update FMEA for Loss of Nadir Omni, Coax...	Woerner	Fleming	6/19/92	Closed

TOMS-EP
Electrical Power and Distribution Subsystem

S. Foroozan

EPDS Changes Since PDR

TRW

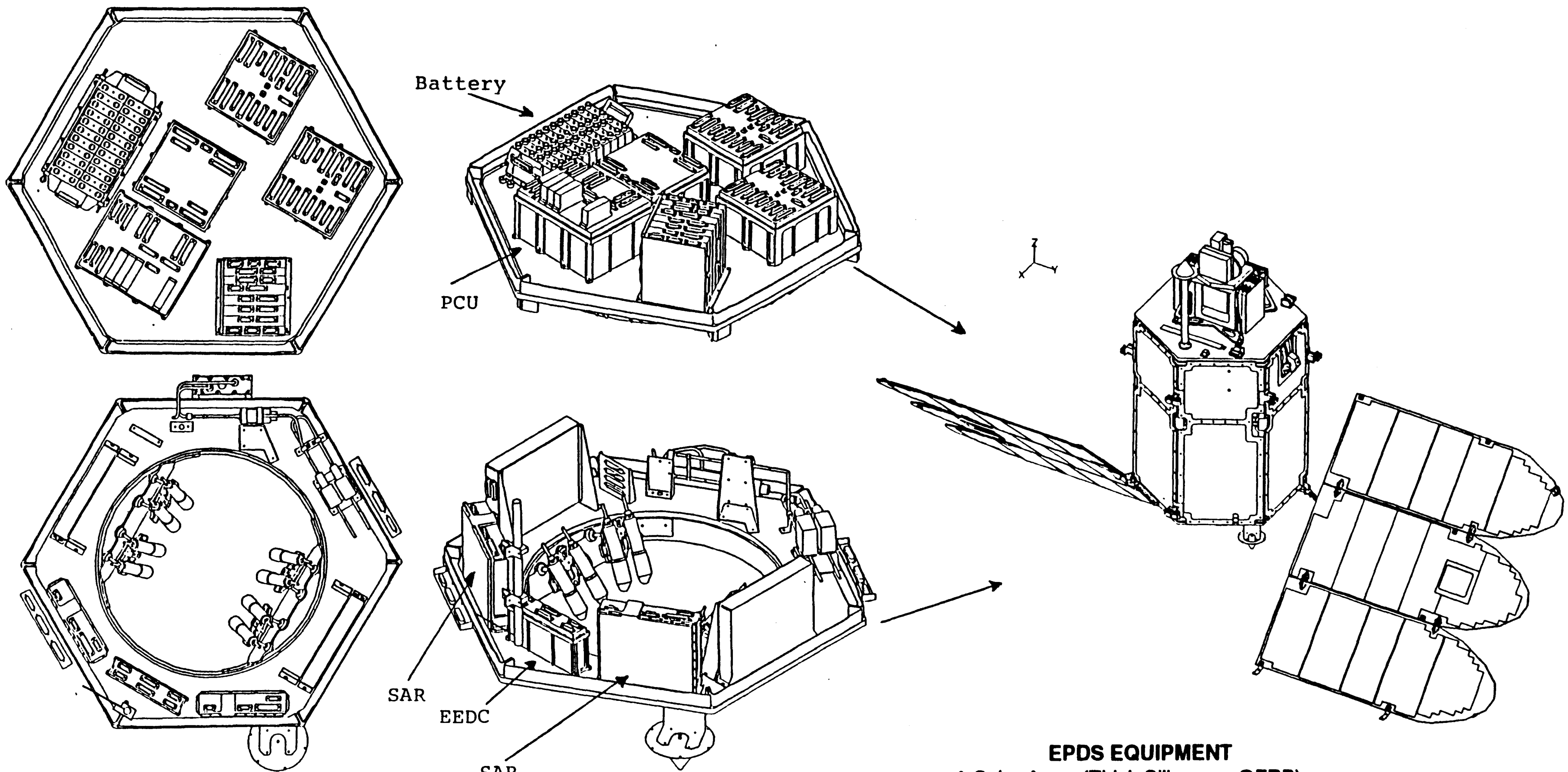
- o Two Solar Array Regulators each with two Array Regulator Modules
- o Dedicated Array Regulator Modules per solar array wing for pseudo PPT
- o TCVL, Ampere-Hour Integration and computer controlled taper schemes are used for battery charge control

Temp. compensated voltage limit

- o Increased the cell mounting area of the wings
- o The wings are at ± 45° to eliminate battery discharge at sub solar point
- o Use only one cell size
- o "Thick" (0.008") silicon solar cells, with higher efficiency (14.6%)
- o Thicker (0.006") cover glass

EPDS Equipment Locations

TRW

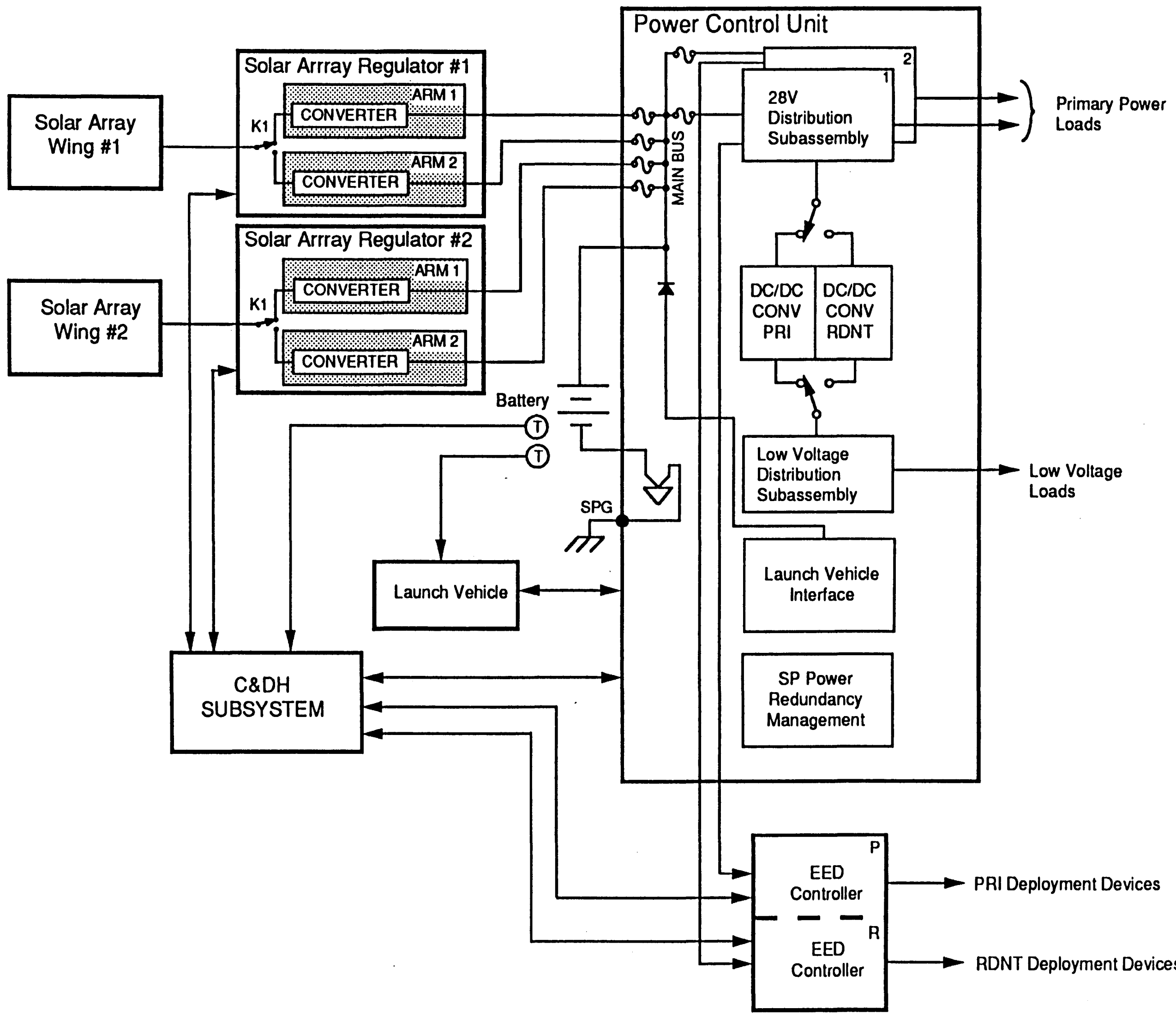


EPDS EQUIPMENT

A Solar Array (Thick Silicon on GFRP);
One Super Nickel Cadmium Battery;
Two Solar Array Regulators;
One Power Control Unit (PCU);
One EED Controller;
Interconnecting Electrical Harnesses

EPDS Functional Block Diagram

TRW



Design Requirements

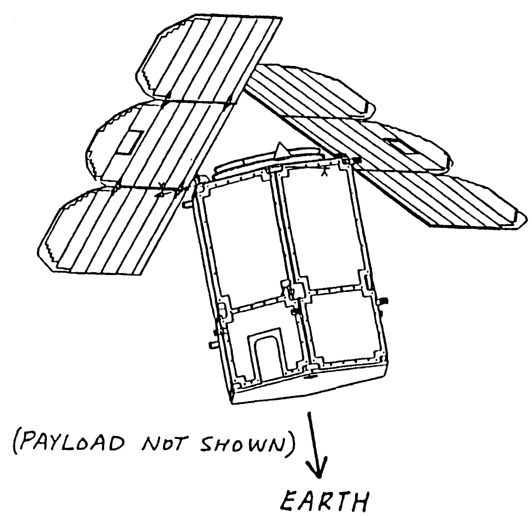
TRW

Orbit:	955 Km, circular
Inclination:	99.3^{o}
Maximum Beta Angle:	18.5^{o}
Life:	2 years, 3 year goal
Period:	69 minutes sun time, 35 minutes eclipse time
Primary Voltage:	23 - 34 V at the load
Battery DOD:	$\leq$35% (Normal Operation) $\leq$70% (Orbital Insertion)
Energy Balance:	Fully recharge battery on each orbit Except launch scenario Except Lunar eclipse orbit Worst case solar array output at end of life: β=18.5^{o}, summer solstice, one string failed open Taper charge rate as battery reaches full charge Provide capability for 108% recharge ratio
Autonomy:	Up to 24 hours of autonomy in the Normal, Safe-Hold and Safe-Power Modes

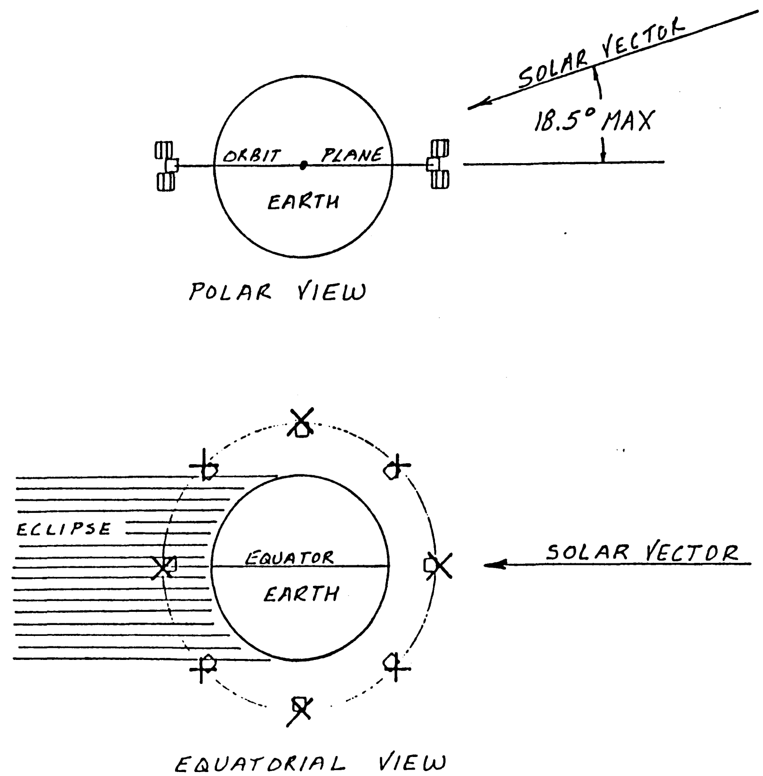
Normal-Mode Operating Conditions

Solar array wings, with cells on both sides, are fixed at $\pm 45^{o}$
Solar array wings "tumble" with respect to sun vector
Major variation in solar array output over each orbit
All primary equipment operational

TOMS BUS



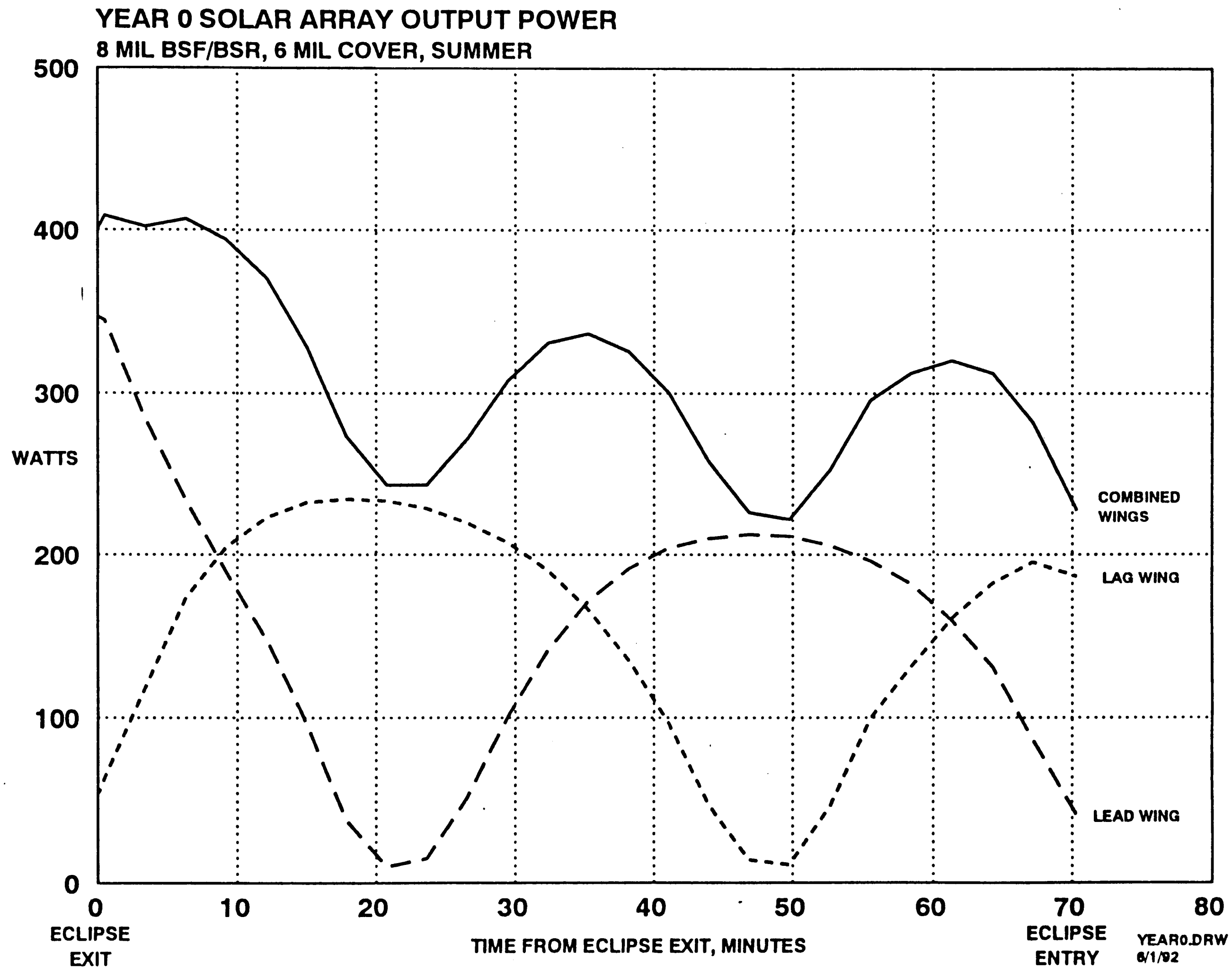
ORBITAL GEOMETRY



Solar Array Output Varies During Each Orbit

TRW

Solar array wings are fixed at $\pm 45^{o}$
2:1 variation in solar array power over each orbit



Design Power Profile

127.9 W average load:

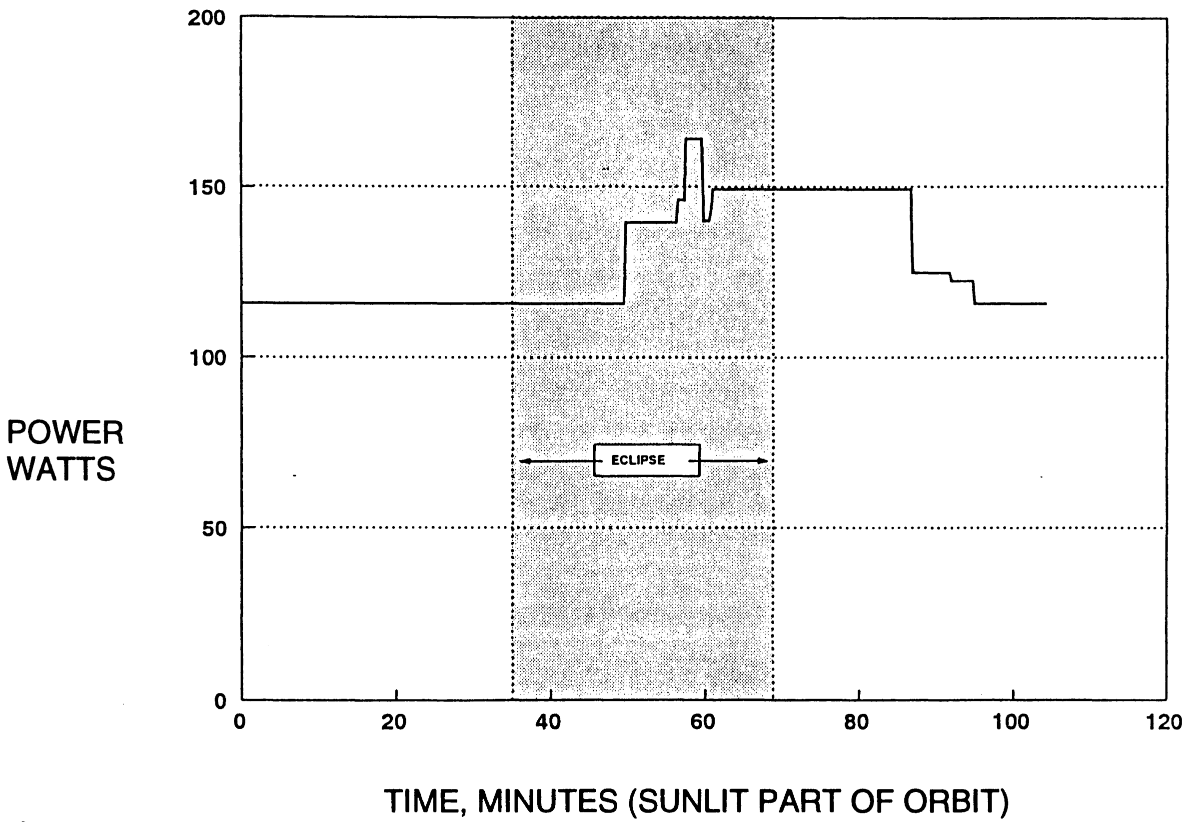
Worst case orbital power usage:

- Transmit during eclipse
- 25 W Payload
- Duty cycle spacecraft heaters

DOD

31.1%:Normal battery

32.6%:One cell failed



Status of CDA Action Items

7 action items were assigned at the EPDS review:		Status
EPDS-1:	Primary charge control (use TCVL along with AHr integration)	Open
EPDS-2:	Fail-Safe monitor embedded in algorithm (ground disable)	Closed
EPDS-3:	Battery reconditioning within 30 days of launch	Open
EPDS-4:	Open circuit solar array measurement time allocation vs performance	Closed
EPDS-5:	Reconcile secondary power levels	Closed
EPDS-6:	Battery discharge circuit current carrying ability	Closed
EPDS-7:	Power bus critical item control protection	Closed

4 action items were assigned at the solar array/battery reviews:		Status
SA-01:	Solar array harness protection (review with system I&T)	Closed
SA-02:	Setup meeting to resolve battery temperature in Pegasus Fairing	Open
SA-03:	Battery heaters in eclipse	Closed
SA-04:	Clarify 35% DOD requirement with GSFC	Open

Spacecraft Processor Controls EPDS

Spacecraft processor provides feedback loop:

Collects EPDS sensor data
Calculates desired solar array operating point
Commands ARM pulse width modulation value
Provides discharge/recharge integration
Temperature compensation of the recharge ratio
Peak power tracking implemented by software

Solar Array Control using the SAR

- Two Solar Array Regulators (SARs)
- Each SAR contains two Array Regulator Modules (ARMs)
- Each SAR is dedicated to one wing
- One ARM operational in each SAR
- Block switch from primary ARMs to redundant ARMs

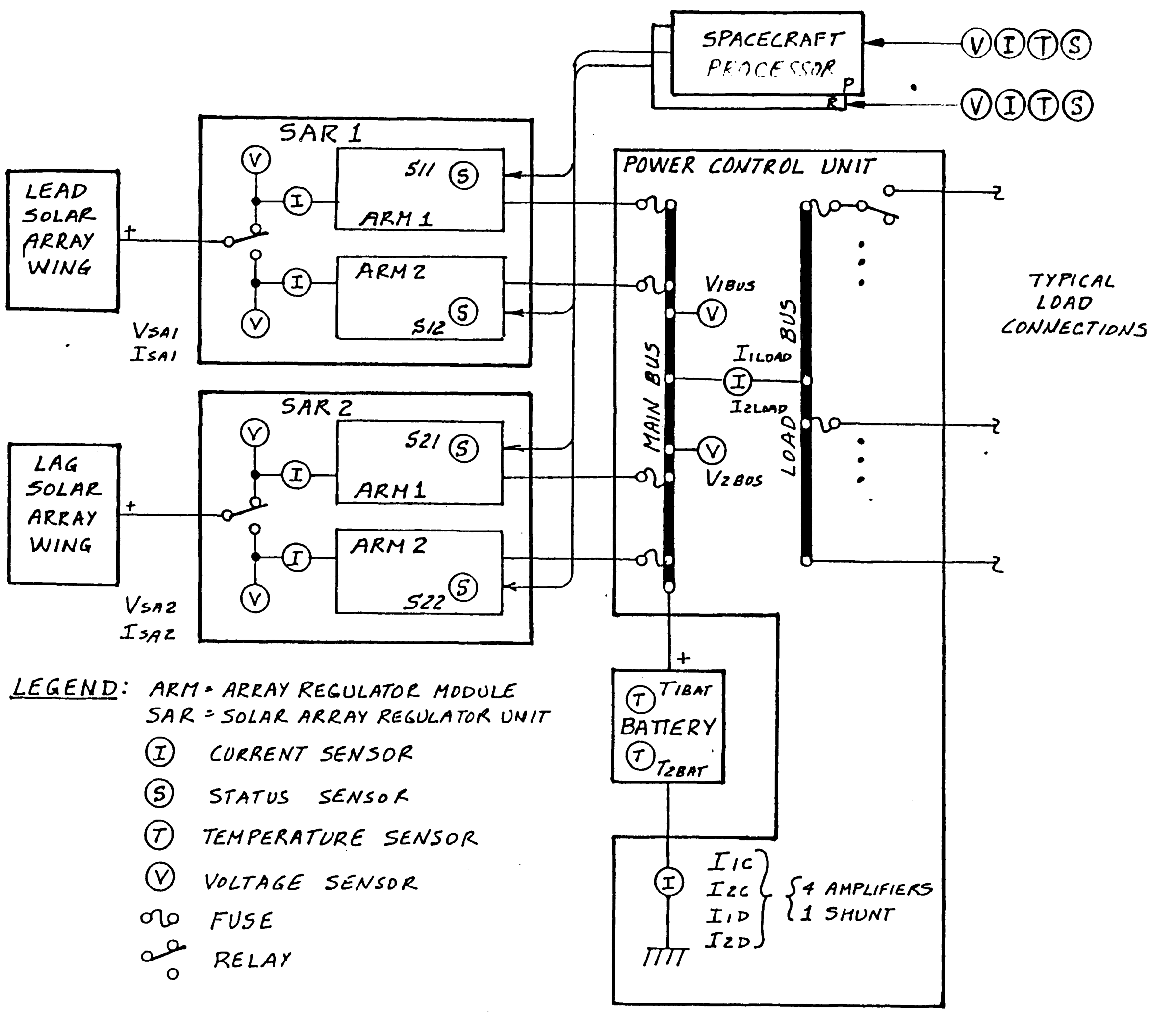
Each ARM provides the following:

- A pulse width modulated buck converter, controlled by the spacecraft processor via a serial data bus
- The capability for peak power tracking of each wing
- Average operating efficiency greater than 95%

Fly back converter ??

Spacecraft Processor Controls EPDS

ARM output current in excess of the load demand charges the battery



Two Algorithms for ARM Control

TRW

Battery Charge Control Algorithm (BCCA) provides:

Peak Power Tracking (PPT) for high-rate charging
Taper charge by temperature compensated voltage limit (TCVL)
Current reference for trickle charging
Battery charge and discharge coulomb integration ($\Sigma i \Delta t$) with SEU correction

Fail-Safe Algorithm (FSA) incorporates:

Direct energy transfer (DET) for high-rate charging
Taper charging at TCVL to end of sunlight
Commandable TCVL equation constants
Diagnostic subroutine for temperature and voltage

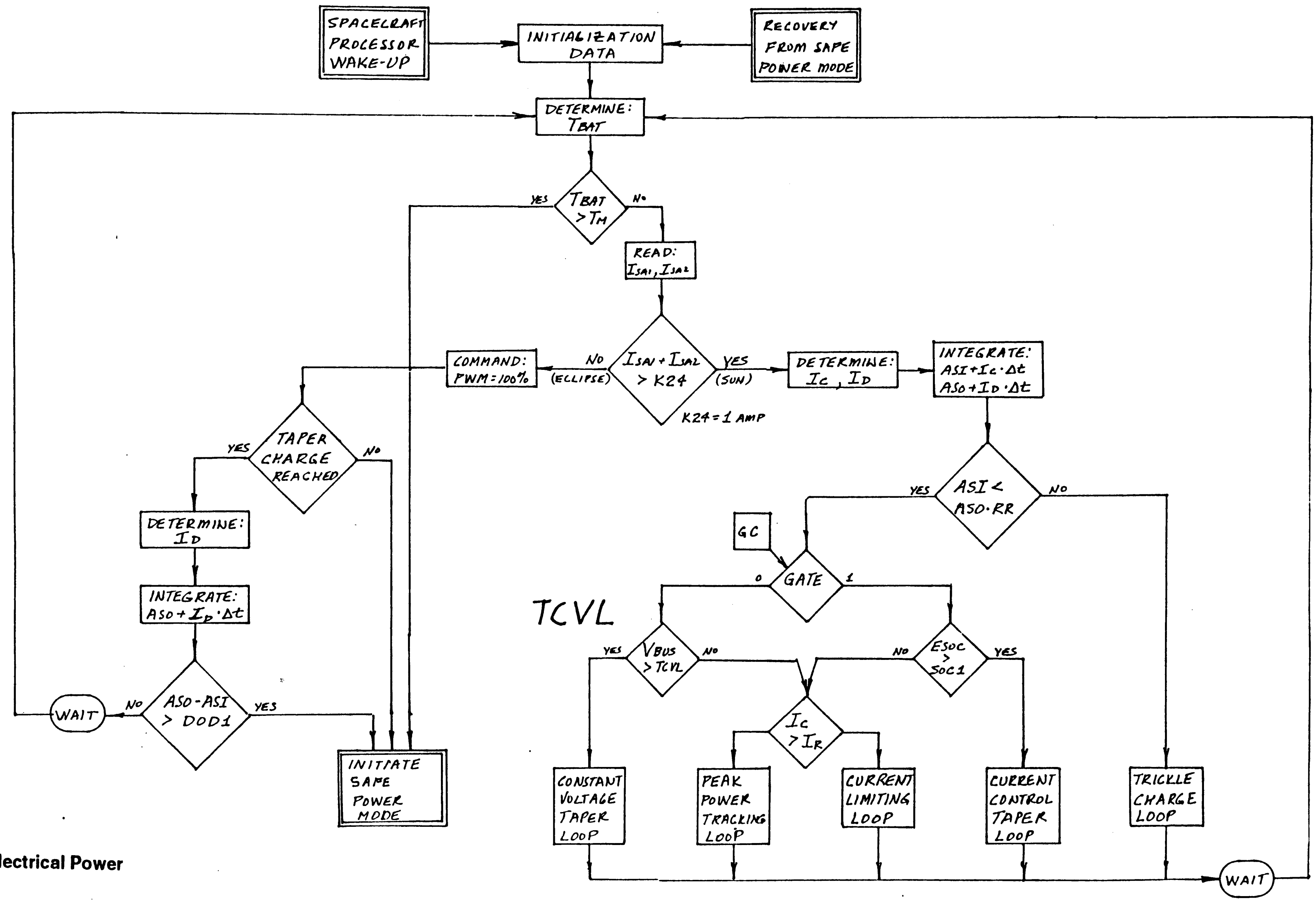
Battery Charge Control Algorithm:

TRW

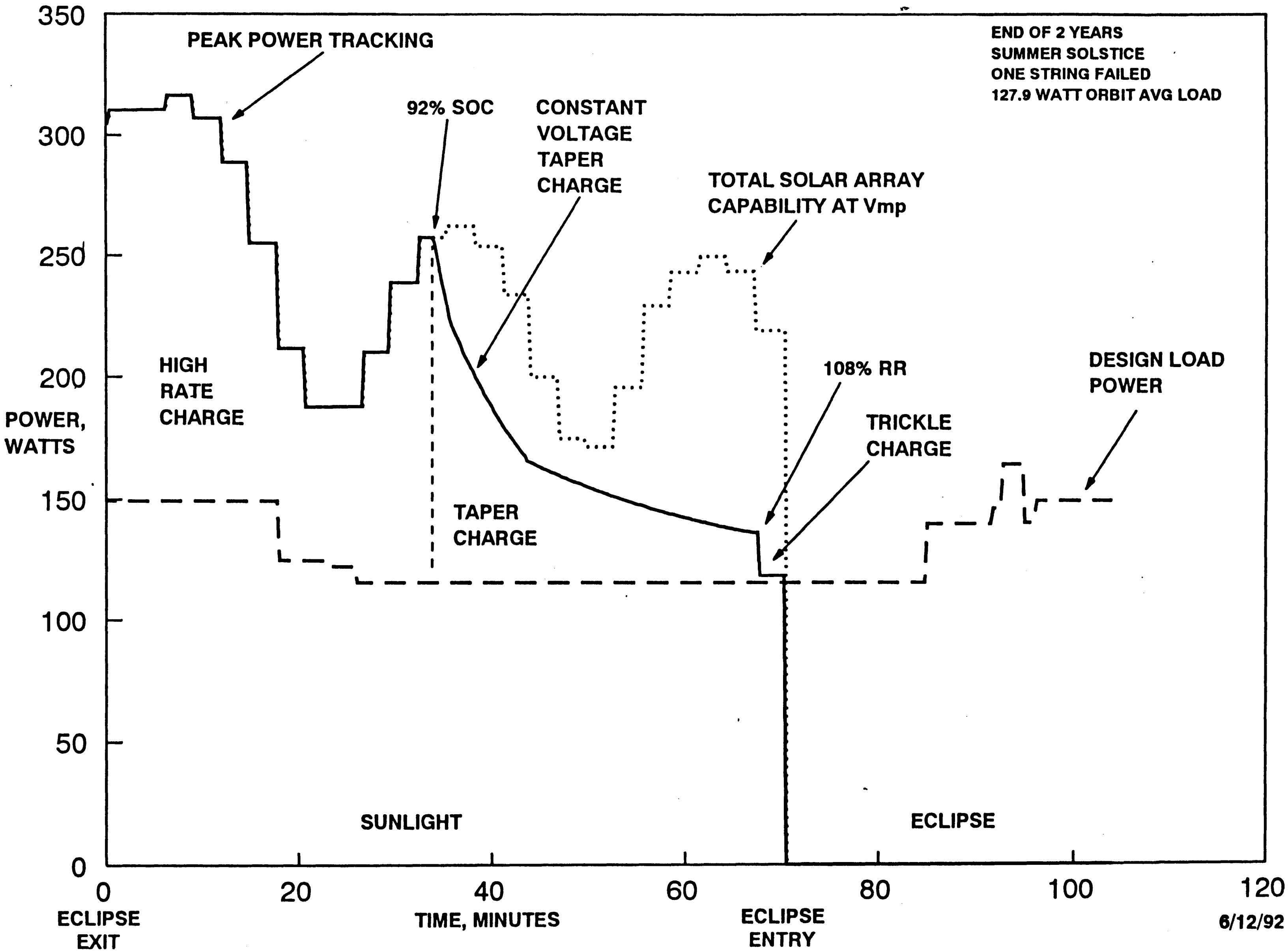
- Coulomb integration of battery charge and discharge currents to determine the equivalent state of charge of the battery
- Peak power tracking for high rate battery charging
- Current limiting during high-rate charging
- Constant voltage mode for taper charging at TCVL
- Alternate taper charging mode at the taper-current limit
- Ground commandable selection of taper charging mode
- Trickle charge operation after reaching the desired recharge ratio
- Temperature compensation of recharge ratio
- 24-hour autonomy
- Anomaly detection and transfer to Safe-Power Mode:
  - Battery discharge over 40% of capacity, except launch
  - Recharge failing to reach taper charge, except during launch
  - Battery temperature exceeding 30^{o} C
- Anomaly detection (**under review**):
  - Significant discrepancy between primary and redundant sensor data
  - Two or more concurrent SEUs in coulomb integration

Battery Charge Control Algorithm Simplified Diagram

TRW



Performance with BCCA



Safe-Power Mode

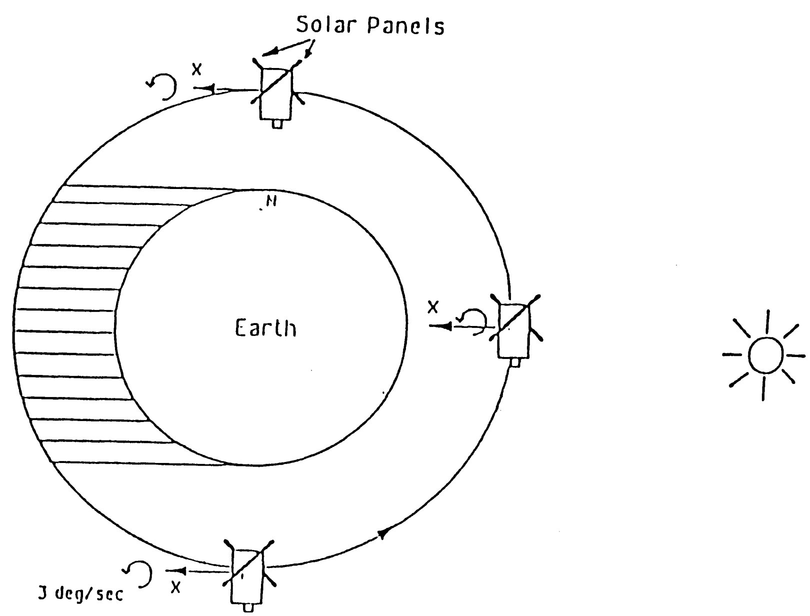
Electrical equipment is switched from primary to redundant units

Non-essential loads are turned OFF

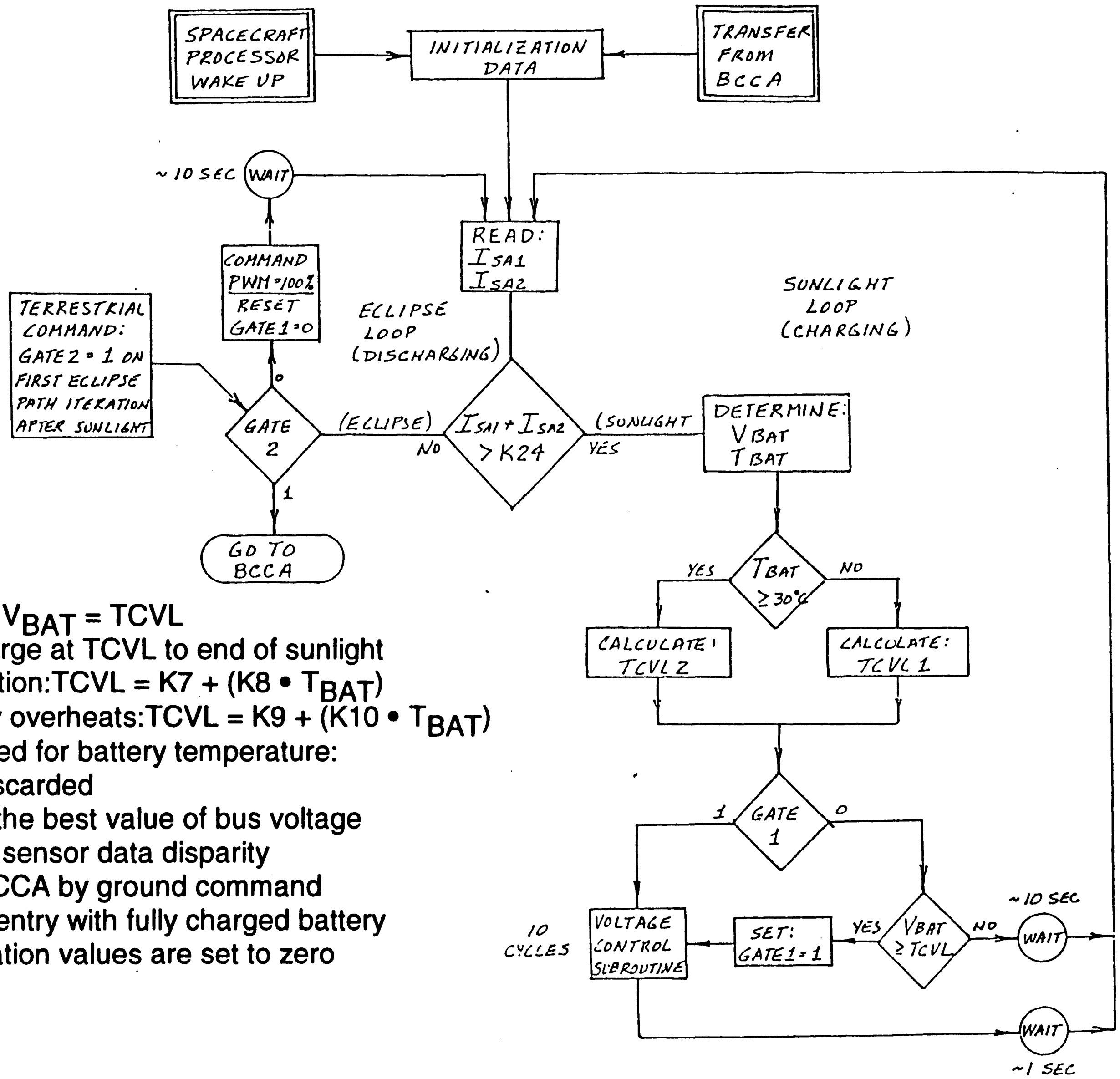
Solar array is oriented towards the sun:

- Constant illumination
- Passive spin stabilization about the maximum inertial axis (no tumbling)
- 233 watts at end of 2 years, Beta = 20°

EPDS operational control is transferred to the **Fail-Safe Algorithm**:



Simplified Diagram of the Fail-Safe Algorithm

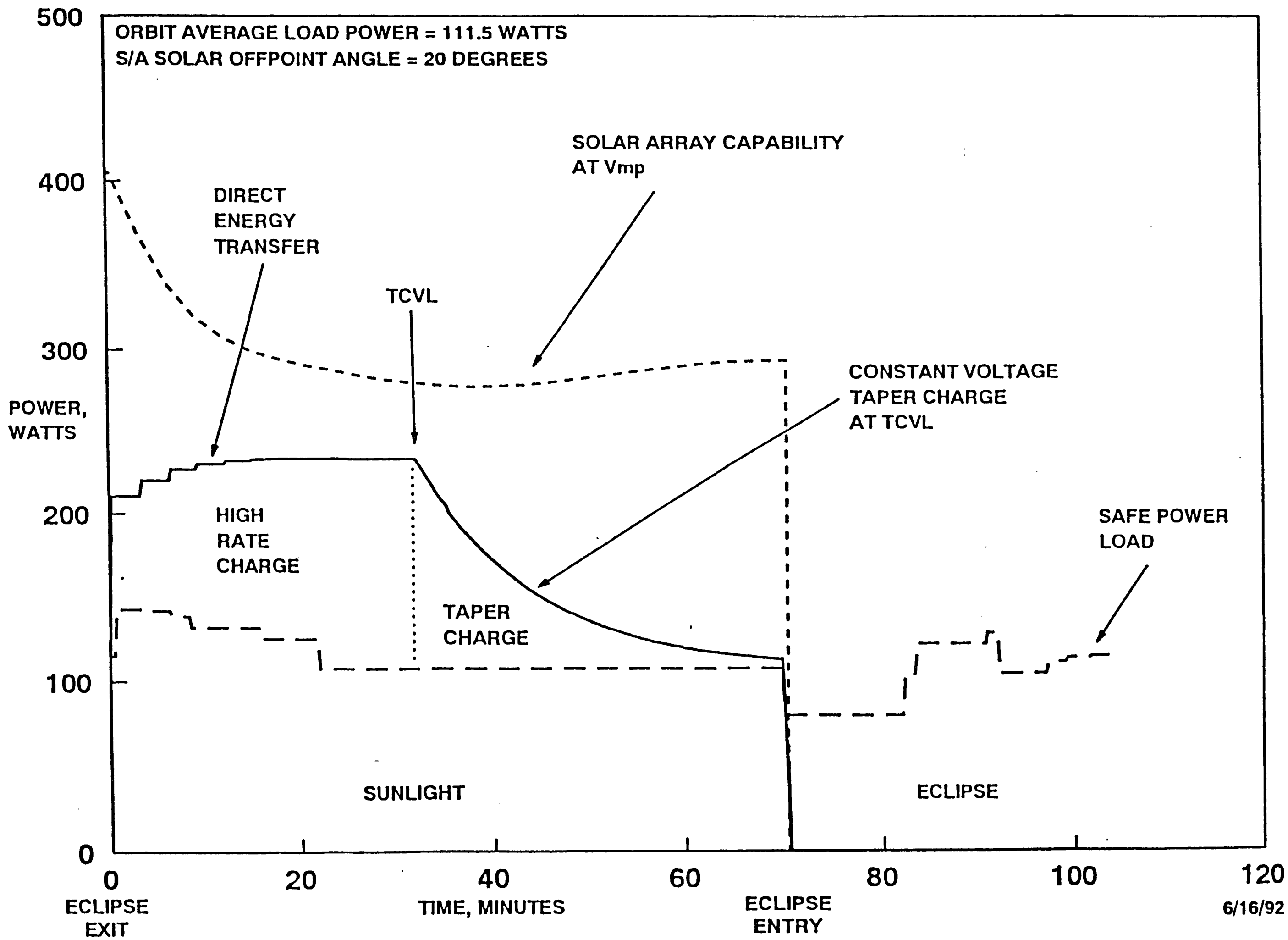


- Direct energy transfer until V_{BAT} = TCVL
- Constant voltage taper charge at TCVL to end of sunlight
- Commandable TCVL equation:TCVL = K7 + (K8 • T_{BAT})
- Lower level TCVL if battery overheats:TCVL = K9 + (K10 • T_{BAT})
- Highest of two readings used for battery temperature: off-scale high reading is discarded
- A subroutine to determine the best value of bus voltage in the event of bus-voltage sensor data disparity
- Operation transferred to BCCA by ground command
- Transfer occurs at eclipse entry with fully charged battery
- Discharge/recharge integration values are set to zero
  - Battery fully charged
  - Eclipse just started

Performance with Fail-Safe Algorithm

TRW

Direct energy transfer until TCVL is reached
Taper charging at TCVL to end of sunlight



Subsystem Verification

TRW

- All electronic components will be subject to verification testing at the subcontractors
- Solar array panels will be tested for electrical characteristics at panel level
- There will be a solar array coupon test
- Battery cells are tested prior to battery assembly
- Battery cell life testing is to be performed at Crane under GSFC direction. Anticipated start date: 2/1/93
- There will be a subsystem test prior to spacecraft integration to verify new designs (part of Eagle Test Bed)

EPDS Testing (TOMS/ETB)

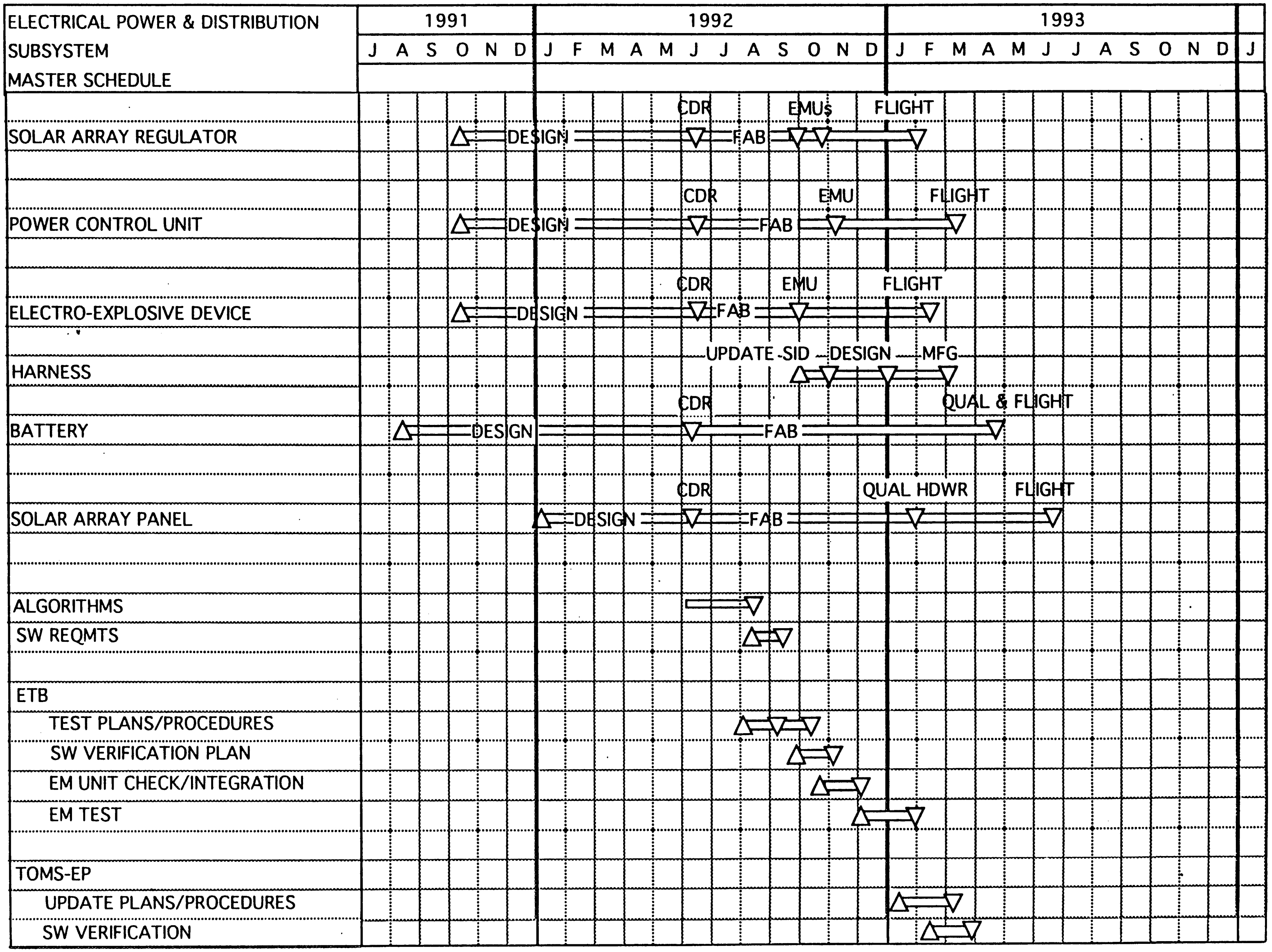
Eagle Test Bed (ETB) will contain non-redundant engineering models:

- Two SARs, one ARM per SAR
- Power Control Unit (PCU)
- Deployment Device Controller (EEDC)
- Auxiliary NiCd battery
- Harness (functionally identical to the TOMS flight harness)

Subsystem test activities will include:

- Verification of interfaces to other test bed subsystems
- Verification of EPDS software
  - Exercise every branch of the algorithms and subroutines
- Verification of commands and telemetry responses
- Power bus dynamic measurements
- Demonstration of redundancy management functions
- Operation with a short-circuited battery cell

Schedules



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EPDS Weight Summary

TRW

UNITS AND OTHER EPDS HARDWARE	QUANTITY	PRESENT ESTIMATE (lbs)	BUDGET (lbs)
BATTERY	1	25.5	
SOLAR ARRAY REGULATORS	2	10.8	
SOLAR ARRAY(ELECTRICAL ONLY)	-	18.3	
EED CONTROLLERS	1	2.6	
PCU	1	15.2	
SUB-TOTAL:		72.4	**75.0**
HARNESS ASSEMBLY	1	34.1	**37.0**

EPDS Requirements vs Capabilities

Source: SY1-0012, "TOMS-EP System Specification"

Paragraph/Requirement		Capability	Verification
3.7.3.1	**Primary Power & Energy Balance**		
	The EPDS shall be sized, during the design phase, to provide for energy balance during each orbit, with no sub solar eclipse and power reserve margin of 10% at end of life (2 years) after including appropriate component maturity factors; The maturity factors applied shall not be less than 5% for measured values on similar units, 10% for calculated values and 15% for estimated values in the power budget	There are two solar array wings at $\pm 45^{o}$	Inspection
		The EPDS provides power to all loads	Inspection, test
		With the current load profile plus 16% (8.3 +7.7) for maturity factors and system margin, and with one battery cell failed, the average load is 128.9 W and the design meets energy balance at EOL (2 years)	Analysis, test
3.7.3.2	**Battery**		
	Use a super NiCd battery for energy storage.	One 9 Ampere-hour super NiCd battery with 22 cells	Inspection
	Battery DOD shall not exceed 70% during spacecraft launch and orbital insertion. DOD shall not exceed 35% during orbital operation, with one cell failed	Maximum battery DOD does not exceed 70% during insertion, 35% during orbital operation with one cell failed	Analysis

EPDS Requirements vs Capabilities (continued)

Paragraph/Requirement		Capability	Verification
3.7.3.3	**Grounding** Use grounds as specified in SR1-0105 for both the primary and secondary power	The EPDS design complies. The design accommodates a Single Point Ground	Inspection,
3.7.3.4	**Fault Propagation** The EPDS design shall protect the main bus by fusing the primary loads and required secondary loads as defined in fusing document D19825	The PCU provides fuses for all primary power loads and selected +5 volt loads	Inspection, Test Analysis
3.7.3.5.1	**Primary Power Voltage Range** The primary voltage at the load shall be 23 - 34 Vdc	The EPDS provides a battery clamped bus and a regulator for charge control to comply	Analysis, test
3.7.3.5.2	**Secondary Voltage** The EPDS shall generate three secondary voltages: +5 V, and $\pm$ 15 Vdc with voltage range limits specified in IF3-0010	The EPDS provides redundant DC/DC converters to comply	Analysis, test

EPDS Requirements vs Capabilities (continued)

TRW

Paragraph/Requirement		Capability	Verification
3.7.3.5.3	**Power Ripple Voltage** The primary and secondary power ripple voltage shall conform to the requirements of SR1-0105	The EPDS design complies.	Analysis, test
3.7.3.6	**Power Switching Control** Provide power switching control to the spacecraft components and to the instrument	The EPDS design complies. PCU provides power control	Inspection, test
3.7.3.7	**GSE Power** Accept power via GSE and the SELV for checkout and battery conditioning prior to launch	The EPDS complies. Inputs are provided at the PCU. There are dedicated IFJs for the battery	Inspection, test
3.7.3.8	**Voltage Protection** Provide the capability to protect against the application of reverse polarity voltages, from power sources external to the spacecraft.	The EPDS contains isolation diode for protection against reverse polarity.	Inspection, test
	Secondary power voltage protection: Over-voltage for the 5V supply, under-voltage protection for 5V and $\pm$ 15V	The EPDS complies. The PCU provides over-voltage for 5V bus, under-voltage for 5V and $\pm$ 15V	Inspection, test

EPDS Requirements vs Capabilities (continued)

TRW

Paragraph/Requirement		Capability	Verification
3.7.3.10	**Interconnecting Wiring Harnesses** Distribute power and signals via wiring harnesses	The EPDS design complies	Inspection
3.7.3.11	**EPDS Allocations & Interfaces** System requirements flowed down to EPDS are shown in: D19589 Power Allocation D19590 Commands Allocation D19591 Telemetry Allocation 57777.505 Mass Properties Report IF3-0010 Electrical Interface Spec. IF3-0011 Mechanical Interface Spec.	The EPDS design complies	Analysis, test Inspection

TRW

TOMS-EP
Attitude Control and Determination Subsystem
Critical Design Review

Topics

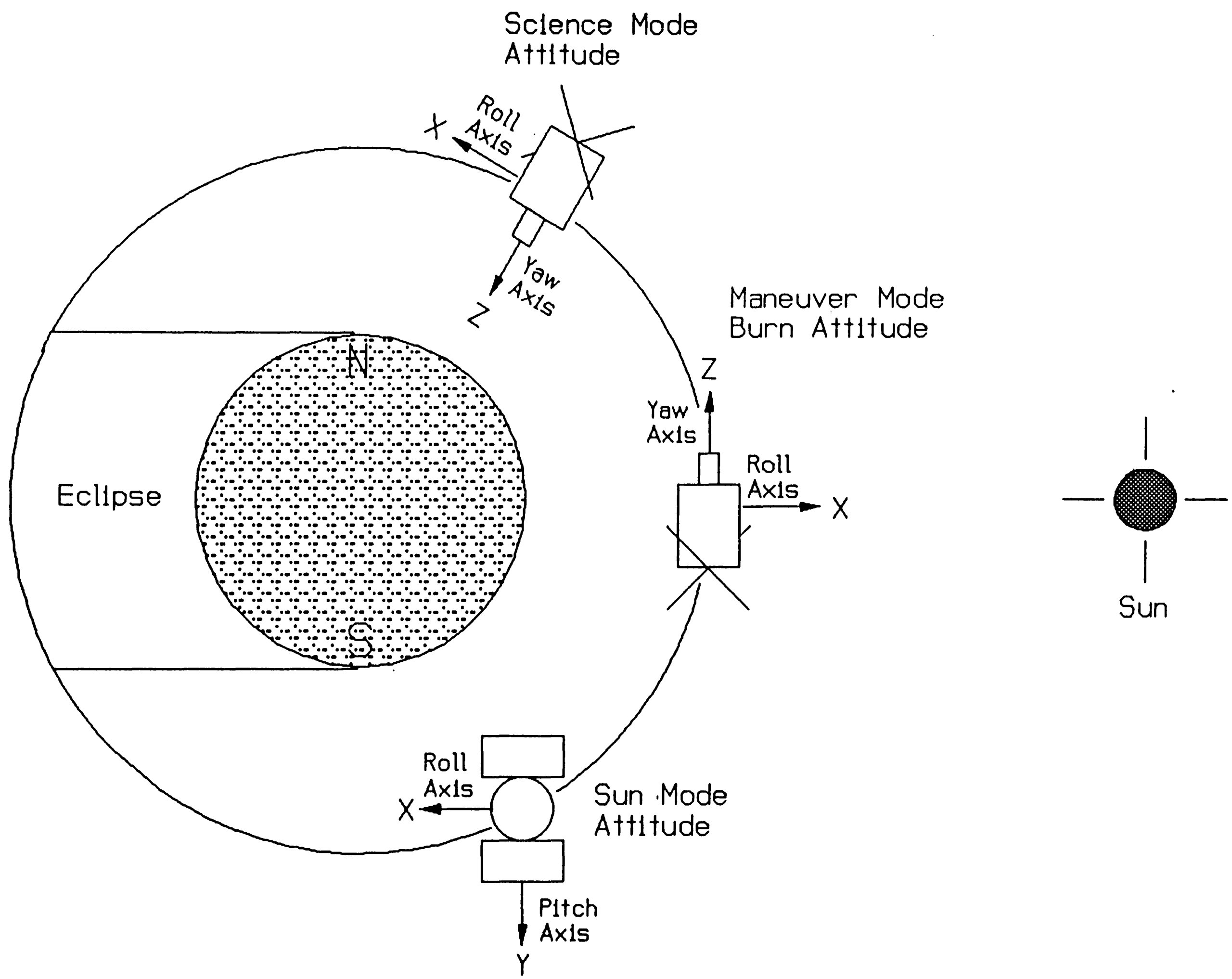
- Performance Requirements
- Design Overview
- Requirements Vs. Capabilities
- Hardware and Software Status
- Subsystem Testing
- CDA Action Items

TOMS-EP
ACDS Performance Requirements

What the ACDS Has To Do

- Provide attitude control during transfer orbit operations (burns, att man, att hold) – Maneuver Mode
- Provide sun and earth acquisition capabilities - Sun Mode
- Provide attitude control and determination during science operations for 2 years – Science Mode
- Provide safe attitude recovery in case of trouble any time after launch vehicle separation – Safe Power Mode and Safe Hold Mode

References for Attitude Control



Attitude Reference Accuracy Requirement

- Overall Attitude Reference Accuracy:

  0.25 deg/axis, 3-sigma

- ACDS Error Allocation (subsystem spec):

  0.12 deg/axis, 3-sigma

Attitude Control Accuracy Requirements

TRW

Mode	Function	Pointing Accuracy (3σ)
Sun	-x toward sun	20 deg per axis
Maneuver	Hold commanded attitude during delta V burn, nadir pointing or inertial hold	1.5 deg per axis relative to command
Science	Maintain LVLH attitude	0.5 deg for roll and pitch 1.0 deg for yaw
Safe Power	-x toward sun	20 deg per axis
Safe Hold	Maintain pitch axis near orbit normal	Within 20 deg of orbit normal

Fail-Safe Requirement

TRW

- After detecting a failure, automatically reconfigure the spacecraft equipment to the appropriate fail-safe mode and acquire a safe attitude
- Hold this safe attitude for seven continuous days without ground intervention

TRW

TOMS-EP
ACDS Design Overview

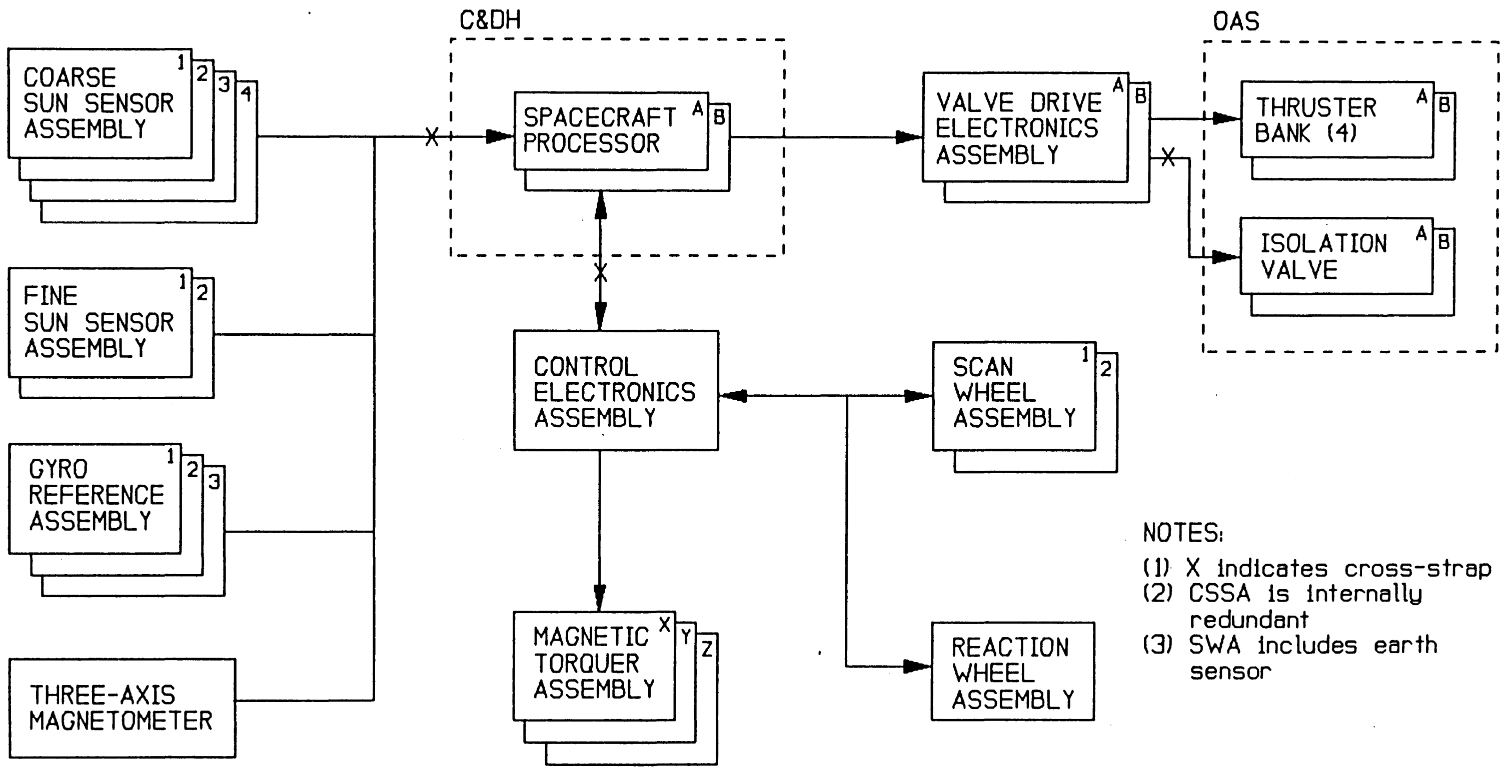
ACDS Design Changes Since PDR

TRW

Change	Design Improvement
1. Added two fine sun sensors	Provides yaw update twice per orbit and permits on-board calibration of gyro rates.
2. Aligned reaction wheel with yaw axis instead of roll axis	Provides backup for scan wheel failure by using pitch momentum bias system. Yaw control relaxed from 0.5 to 1.0 deg.
3. Modified thruster-based fail-safe mode (Safe Power Mode)	Provides spin-stabilization for long-term hold to minimize fuel usage. Uses automatic precession control to stay sun-pointed.
4. Added thrusterless fail-safe mode (Safe Hold Mode)	Provides earth-referenced Safe Hold Mode by using magnetic torquers with a B-dot control law. Permits autonomous operation for at least seven days.

What The ACDS Has To Work With

TRW

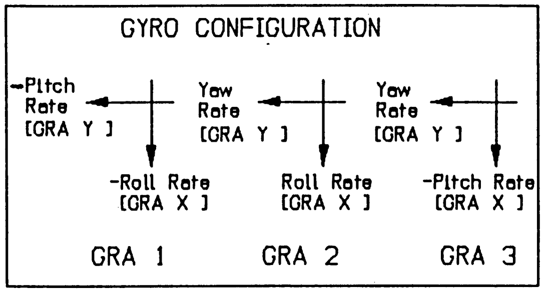


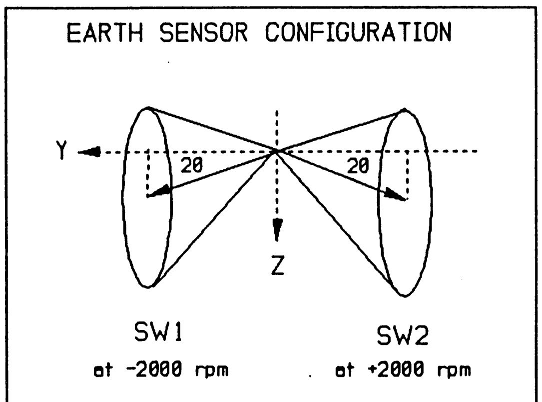
NOTES:

(1) X indicates cross-strap
(2) CSSA is internally redundant
(3) SWA includes earth sensor

Sensor Configurations

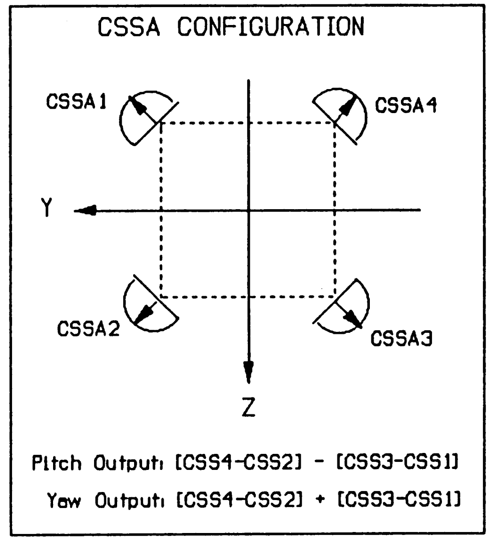
TRW

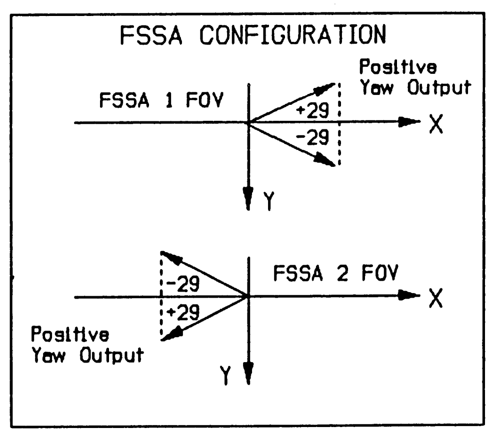




Notes:

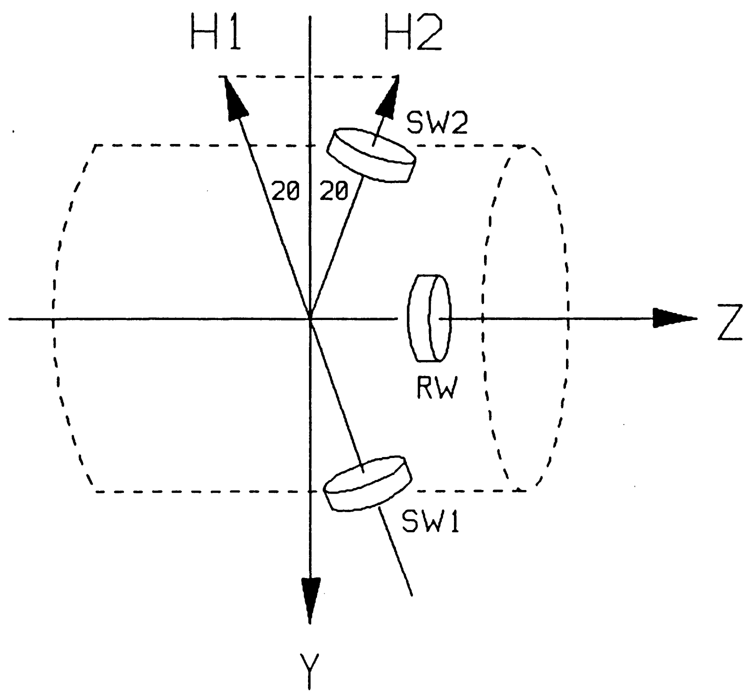
1. Instantaneous FOV is 1.5 deg
2. Half cone angle is 45 deg





Wheel Configuration

TRW



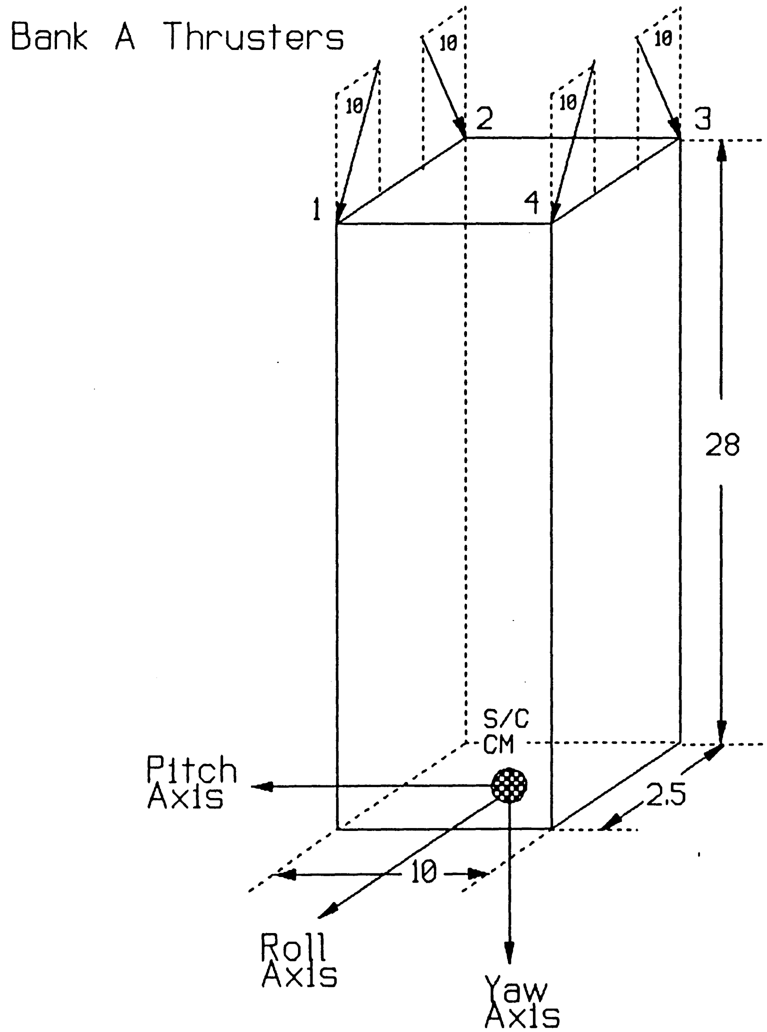
NORMAL MODE MOMENTUM STORAGE

-3.3 < HY < -1.1 ft-lb-sec

-0.4 < HZ < +0.4 ft-lb-sec

Thruster Configuration

TRW



Notes:

1. All dimensions in inches
2. Angles in degrees

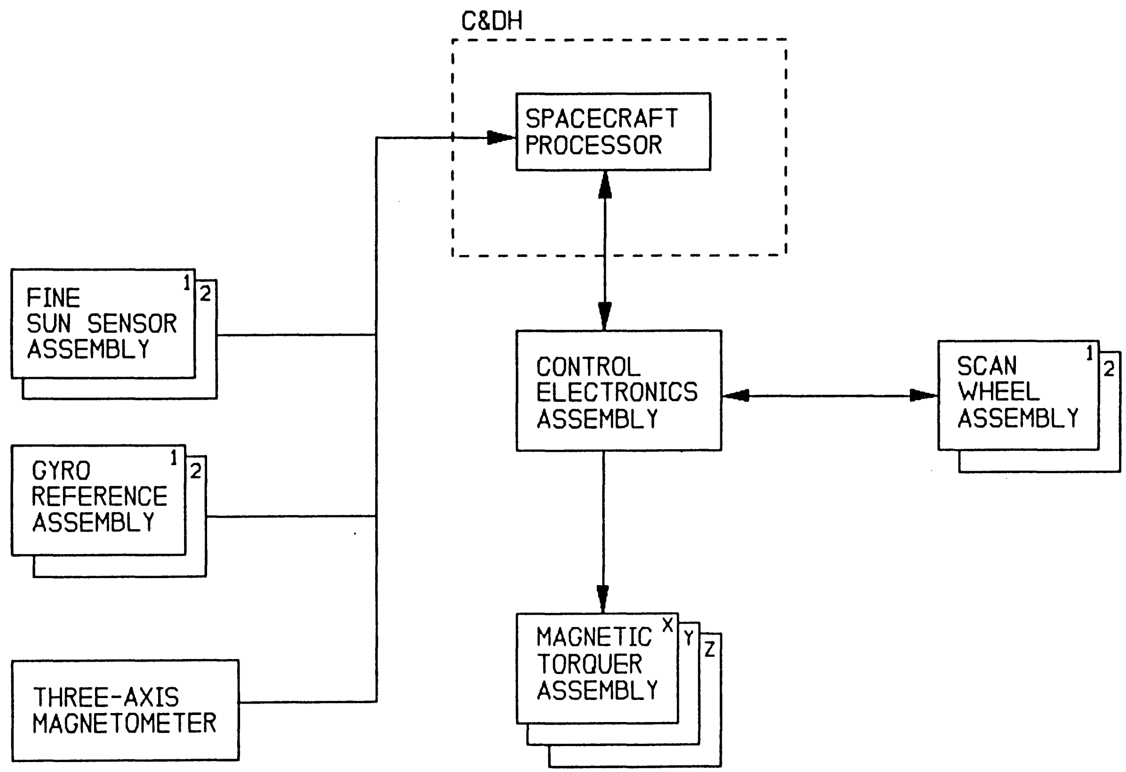
Normal Mode Control Concept

TRW

- Use two scan wheels for pitch momentum bias
  - Effective combination of momentum storage and earth sensing
- Use gyros to provide attitude reference propagation
  - Stable and sensitive high bandwidth sensor
- Use two single-axis sun sensors for yaw updates
  - Simple and reliable
- Use magnetic torquers to unload wheel momentum continuously
  - not limited by expendables

Normal Mode Hardware Configuration

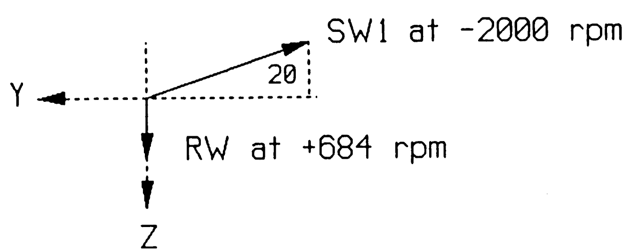
TRW



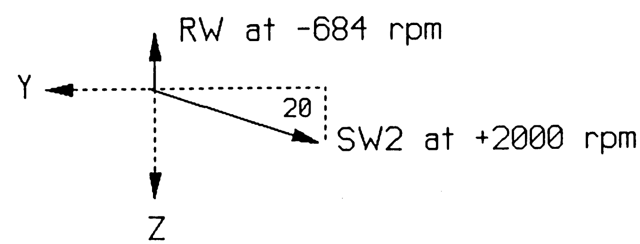
Normal Backup Mode
Control Concept

- Pitch momentum bias provided by one scan wheel and one reaction wheel

- Yaw attitude error is doubled due to reduced momentum bias



Backup 1 Configuration



Backup 2 Configuration

Maneuver Mode Control Concept

TRW

- Gyro-based reference for all attitude capability
- Four hydrazine thrusters to provide delta V thrust and attitude control torques (thrusters are time-shared to produce roll/pitch/yaw torques)
- Scan wheels are spun up to 1000 RPM for earth reference updates when nadir pointed

Sun Mode Control Concept

- Used for sun acquisition and earth search
- Sun acquisition from any initial attitude (similar to GRO and TDRS designs)
- Spin-stabilized for long-term hold to minimize fuel consumption
- Earth search is performed by rolling spacecraft at 2 deg/sec about the sunline (scan wheels spun up to 600 rpm)

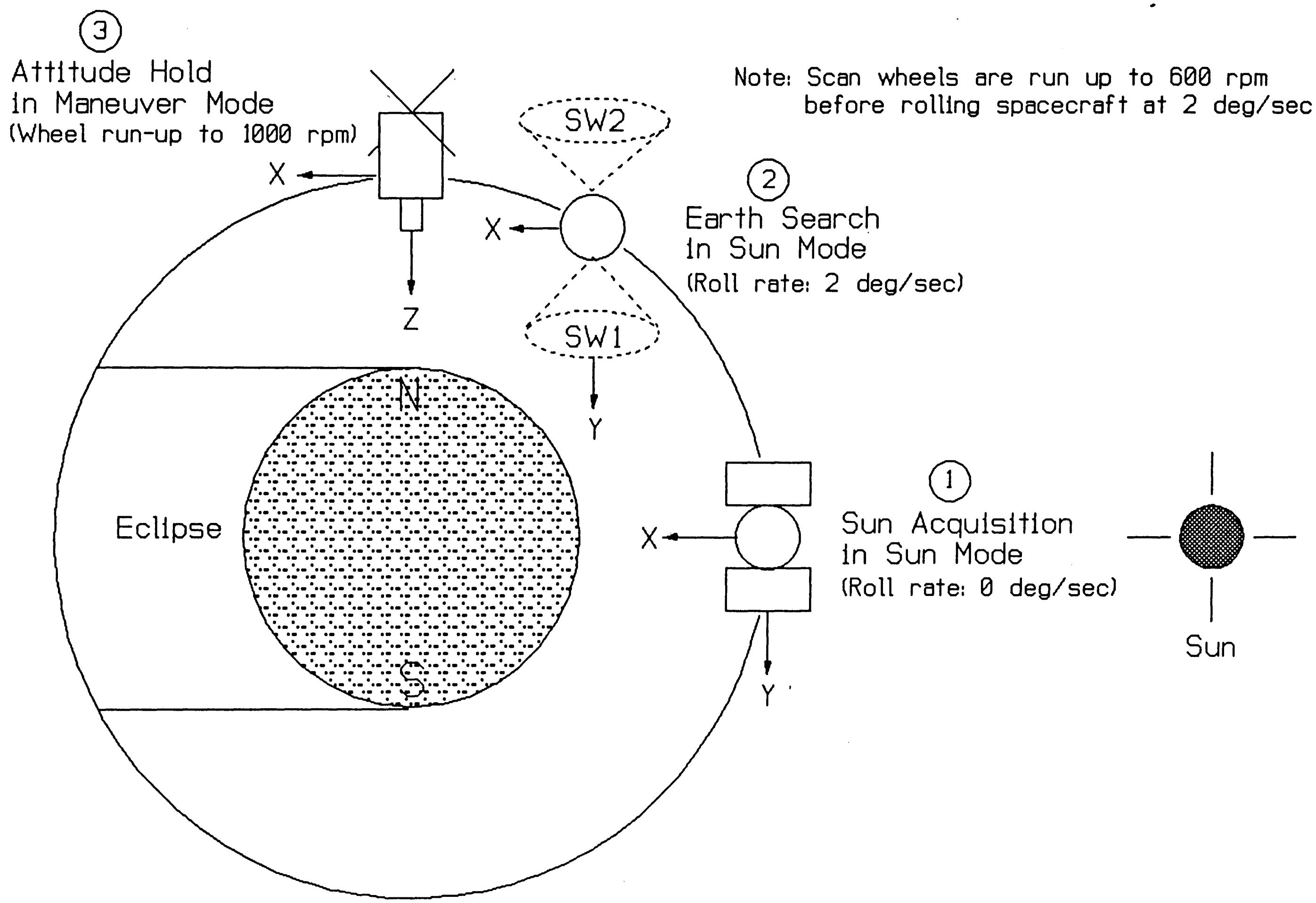
Earth Acquisition Concept

TRW

- Starting point is sun-pointed attitude in Sun Mode
- Ground initiates earth acquisition sequence (two gyros required)
- Near north pole crossing, two scan wheels are spun up to 600 RPM and spacecraft rotates about sunline
- Flight software automatically determines nadir direction from earth sensor outputs and initiates earth acquistion (attitude hold on gyros)

Earth Acquisition Maneuver Sequence

TRW



Safe Hold Mode Control Concept

TRW

- After a fail-safe shutdown in Science Mode, the two active wheels are restored to their nominal bias speeds to keep the pitch momentum bias
- Magnetic torquers are then commanded in accordance with a B-dot control law to provide nutation damping
- The wheel momentum vector is maintained near the orbit normal while the spacecraft rotates slowly about its pitch axis (at twice the orbit rate)

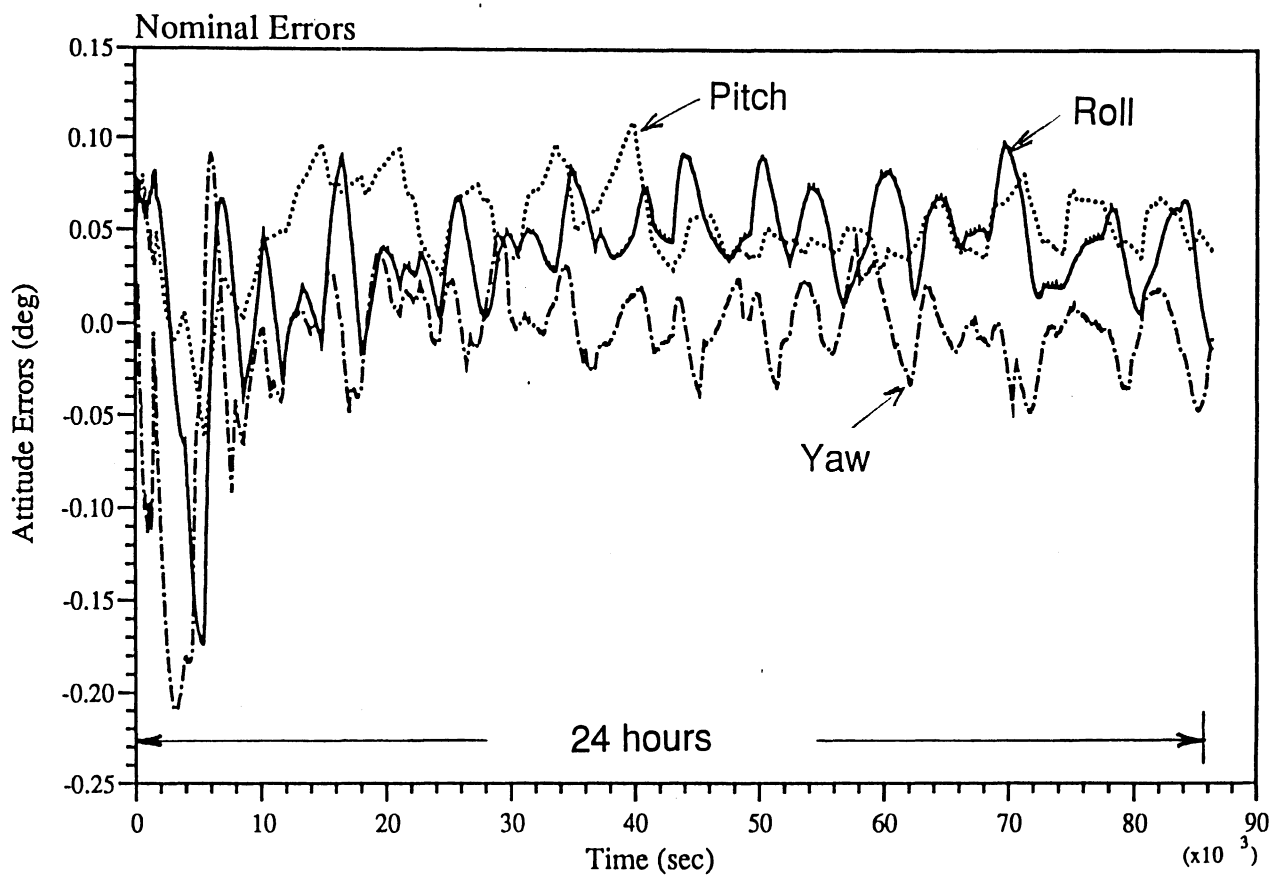
Safe Power Mode Control Concept

- About five minutes after a fail-safe (Group 2 trigger) shutdown in any mode, pitch and yaw rate loops are activated to null the spacecraft rates (mostly about the pitch axis, if wheels are running down)
- Sun acquisition is started 20 minutes after the first eclipse exit. This delay allows the wheels to run down and eliminates earth shine effects for the sun sensors.
- Once the sun is acquired, roll thrusters are fired for a predetermined duration to spin-stabilize the spacecraft
- Based on sun sensor angles and gyro rates, the spacecraft momentum vector is then precessed to stay sun-pointed

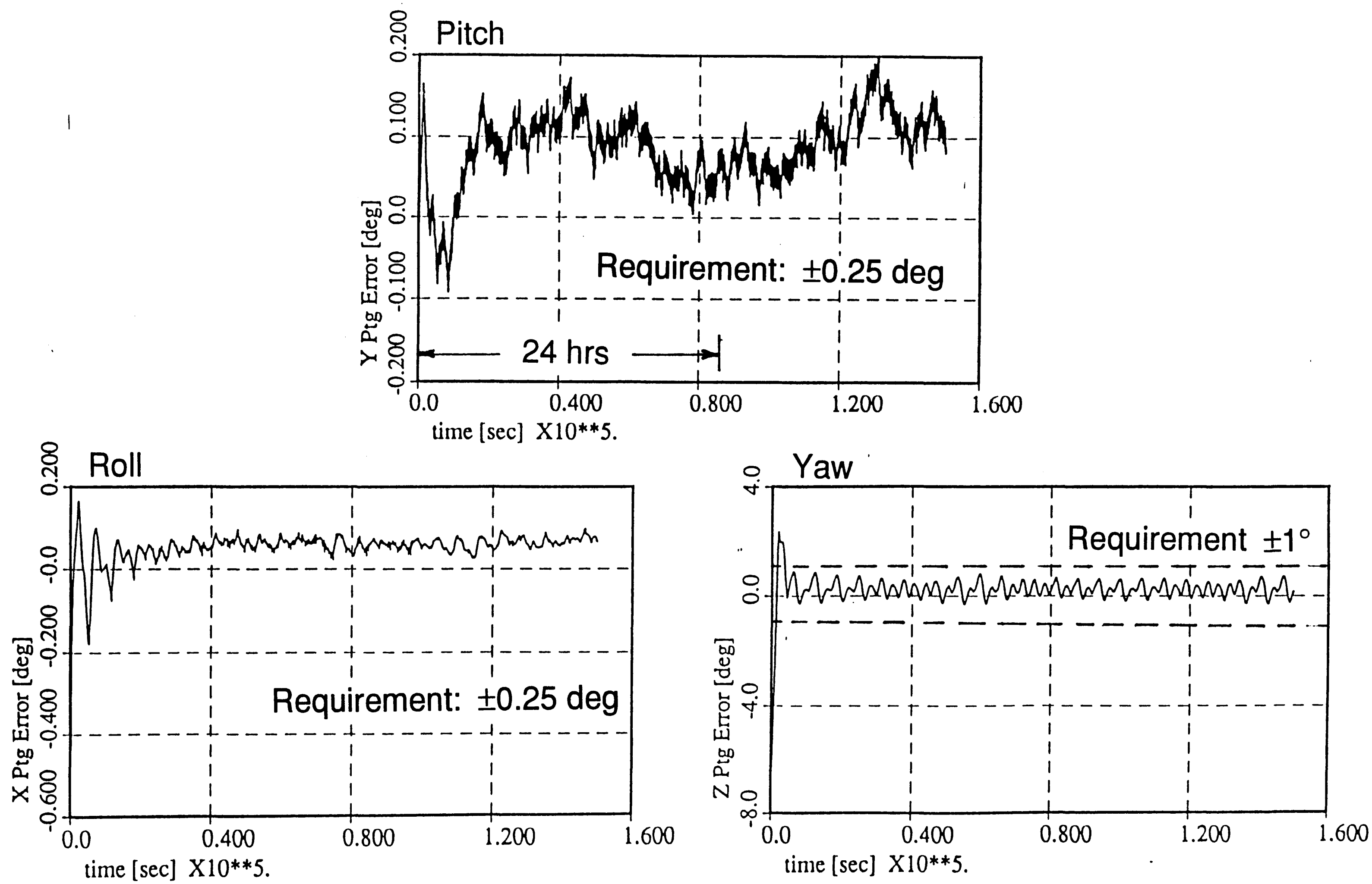
TOMS-EP
ACDS Requirements Vs. Capabilities

TOMS-EP Attitude Determination Results

TRW



TOMS-EP Attitude Pointing Errors



Attitude Reference Accuracy Requirements Vs. Capability

TRW

Function	ACDS Spec Requirement (deg. 3-sigma)	Capability (deg. 3-sigma)
1. Attitude Update		
a. Systematic	0.07	0.06
b. Random	0.02	0.01
2. Attitude Propagation		
a. Systematic	0.06	0.05
b. Random	0.02	0.02
Total Att Det Error RSS(1a+2a) + RSS(1b+2b)	0.12	0.10

NOTE: Nominal operation is with two earth sensors. Capability numbers are shown for the pitch axis. Roll and yaw performance is slightly better.

Attitude Control Performance Requirement Vs. Capability

TRW

Function	Requirement	Capability
1. Science Mode:		
a. LVLH pointing accy	0.5 deg roll/pitch 1.0 deg yaw	0.3 deg roll/pitch 1.0 deg yaw
b. Att. stability	≤0.1 deg over 200 msc	<0.01 deg
c. Momentum unloading	0.1 ft-lb-sec/orbit	>0.1 ft-lb-sec/orbit
2. Maneuver Mode:		
a. Rate stabilization	≤2.5 deg/sec/axis	5.0 deg/sec/axis
b. LVLH pointing accy	1.5 deg/axis	1.0 deg/axis
c. Max maneuver rate	2.0 deg/sec	2.7 deg/sec
d. Roll rate control error	≤0.25 deg/sec	0.15 deg/sec

TOMS-EP
ACDS Hardware and Software Status

ACDS Hardware Summary

TRW

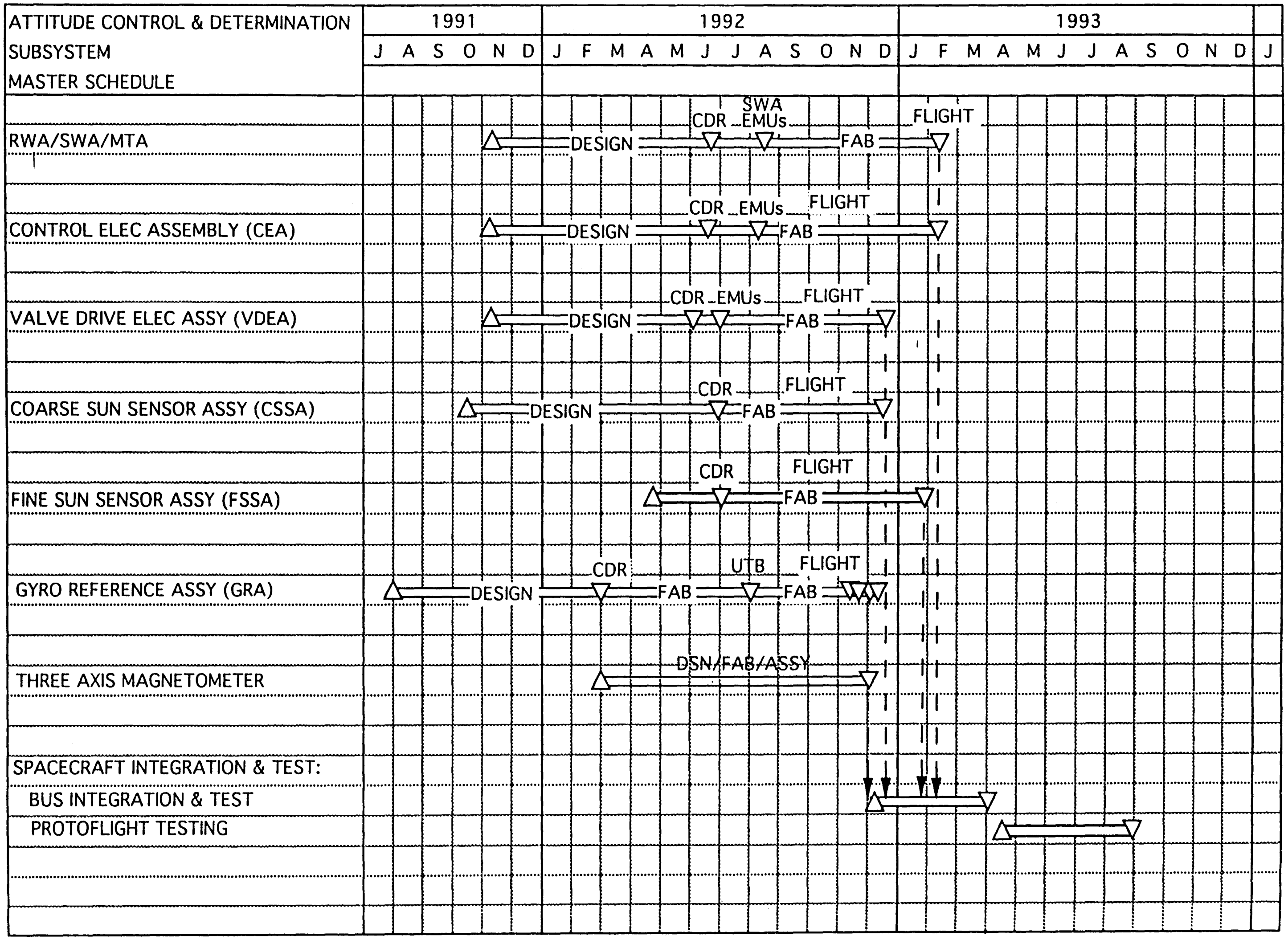
Component	Size (in.)	Weight (lbs)
GRA (3)	3.4x5.7x6.3	3.7
SWA (2)	7.5x8.0 dia	7.2
RWA (1)	2.8x8.0 dia	5.6
TAM Sensor (1)	1.2x1.8x2.3	0.2
TAM Elect (1)	1.5x4.0x6.0	0.9
MTA (3)	12.3x1.0 dia	1.0
CEA (1)	7.0x7.5x8.0	9.9
VDEA (2)	8.0x11.0x2.0	4.3
CSSA (4)	0.4x0.5x1.5	0.1
FSSA (2)	1.5x2.3x2.7	0.3

Note:

Total weight = 54.7 lbs

Allocation = 56 lbs

ACDS Hardware Delivery Schedule



ACDS Software Requirements Status

- 23 functions defined
  - Attitude determination (10)
  - Science mode (5)
  - Maneuver mode (2)
  - Safing mode (3)
  - Miscellaneous (3)

- Processing logic and equations documented in Appendix A of Software Requirements Specification

- Appendix A is in review cycle for CADM release

TOMS-EP
ACDS Verification and Testing

Analyses and Simulations

TRW

- Analysis document has been delivered
- Full-up controls simulation has been developed and used to verify compliance with specified performance
- Remaining analyses and simulations
  - Wheel momentum unloading with thrusters (backup mode)
  - Nominal maneuver sequence for transfer orbit operations
  - Test cases for CSEO software testing
  - Test cases for ETB software testing

Critical Hardware Component Testing

- CEA/ADE development tests at Ithaco
- Wheel life tests at Ithaco
- Gyro life tests at Kearfott
- Fine sun sensor calibration tests

Subsystem Testing

TRW

- Initial hardware/software integration tests will be performed at Space Park using the Eagle Test Bed (ETB) facility
- ACDS closed-loop tests will be performed in two phases using the ETB fixed-base test configuration
  - Engineering development tests
  - Software verification tests
- Test plan for ACDS software verification testing with the ETB has been released
- Final flight hardware/software testing will occur during spacecraft mechanical build-up and electrical integration

TOMS-EP
ACDS CDA Action Item Status

Status of ACDS CDA Action Items

TRW

Number	Subject	Status
1	Effects of Ephemeris Errors on Attitude Determination	White paper by J. Wilcox (7/8/92) GSF review pending
2	Gyro Reliability	Closed
3	VDEA Software Component	Closed pending delivery of VDEA EQ Spec
4	VDEA Thermal Analysis	Open
5	Failure History of Magnetometer	Open (GSFC action)
6	Table for Oblateness/Radiance Errors	Open (GSFC input received)
7	ACDS Test Traceability to Software Functions	Closed
8	Yaw Error Monitor During Safe Hold Mode	Closed

TOMS-EP

CRITICAL DESIGN REVIEW

TOMS-EP Flight Software (TFS)

Dale Stuart

Outline

- ➤ **Key Requirements and Functional Overview**
- **Functional Operations Descriptions**
- **Design Description**
- **Sizing and Timing Analyses**
- **Development Status**
- **Test Plan Overview**

TFS Key Top-Level Requirements

1) **External Interfaces**
   - TOMS Instrument
   - Ground commands and telemetry
   - Spacecraft bus components

2) **Spacecraft Operations**
   - Spacecraft mode transitions
   - Fault monitoring and contingency responses

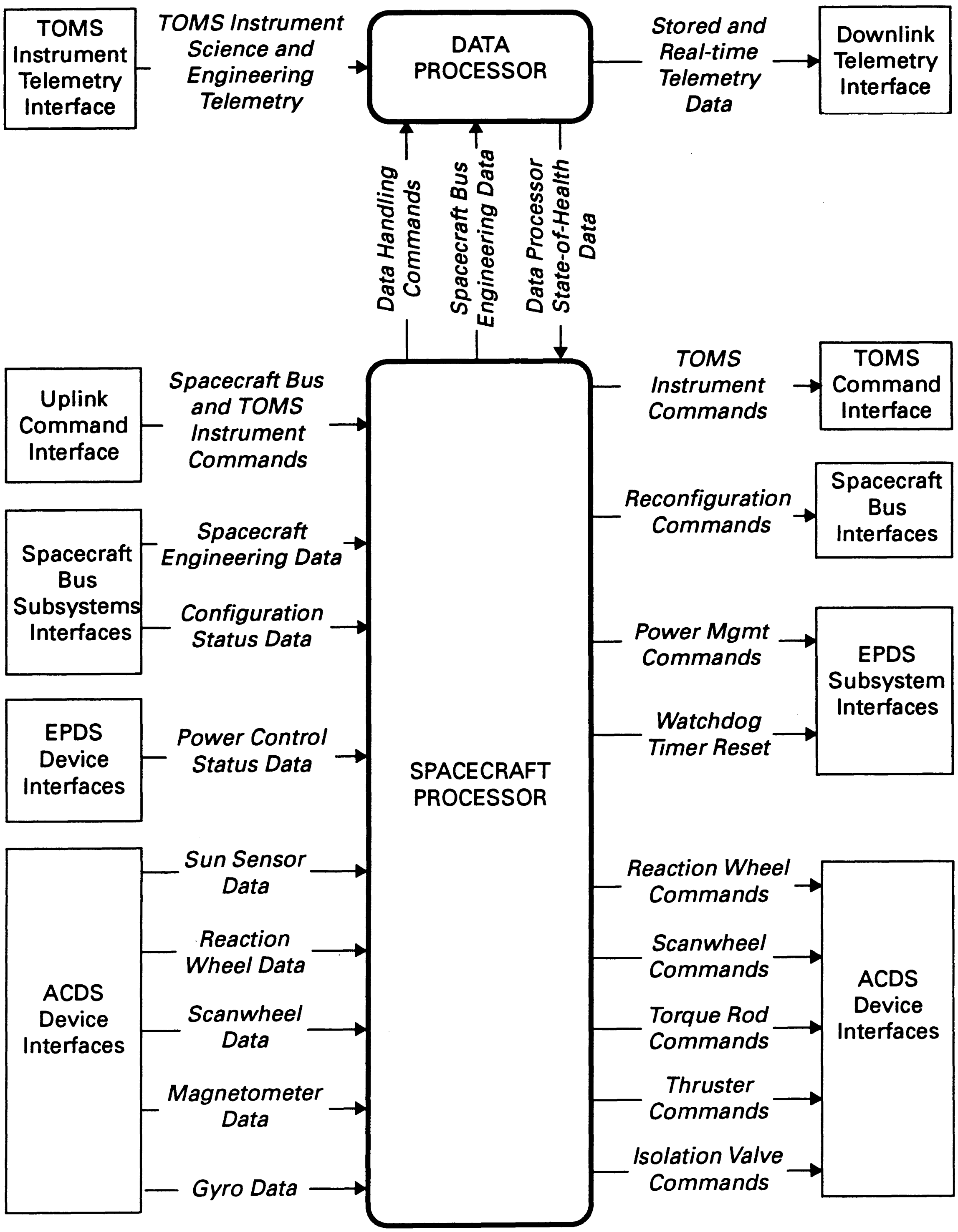
3) **Command Handling**
   - Real-time command processing
   - Stored command processing

4) **Data Management**
   - Telemetry acquisition and storage
   - On-board time
   - Key Parameters Database
   - CODA parameters

5) **Attitude Control and Determination Processing**
   - 13 Spacecraft modes/submodes
   - 23 ACDS functions

6) **Power and Battery Charge Control Processing**
   - Battery charge control algorithm
   - Fail-safe algorithm

TFS Functional Overview



Spacecraft Processor (SP) Functions

Commanding:

- Receives and processes uplinked commands.
- Schedules stored commands (absolute-timed, relative-timed command sequences) for execution, and processes ready commands.

Telemetry Processing:

- Acquires and formats spacecraft telemetry data and transmits it to the data processor.

Attitude Control and Determination:

- Acquires and processes sensor data, executes control and attitude determination logic and issues actuator commands to perform ACDS functions.

Electrical Power and Battery Charge Control:

- Acquires EPDS sensor data, executes logic and issues power control commands to perform battery charge control functions.

Spacecraft Processor (SP) Functions, cont.

Fault Monitoring:

- Monitors spacecraft status and initiates autonomous mode transitions in response to anomalies.

Automatic and Autonomous Mode Transitions:

- Executes automatic sequences for pre-planned mode transitions in support of mission operations.
- Autonomously selects the appropriate contingency mode for fault responses.

Data Processor (DP) Functions

Telemetry Processing:

- Receives TOMS instrument telemetry data from the TOMS instrument interface.
- Receives spacecraft telemetry data from the SP.
- Combines the spacecraft and TOMS telemetry data into a formatted minor frame.

Mass Memory Management:

- Records the completed telemetry frames in mass memory.
- Stores updates to the contingency operations data area (CODA), and forwards CODA status data to the SP.

Downlink Management:

- Downlinks both recorded and real-time telemetry data at the selected rate.

TFS Requirements Responsibility and Status

Topic/Document	Responsible Area	Status
Software Requirements Specification (SRS)	Software System Manager	**Signed June 5,** Minor Markups Expected, *Changes Create Slight Software Impact*
ACDS Processing Logic and Equations (SRS Appendix A)	ACDS Subsystem	**Updates Released June 10,** June 24 Revision in Review Cycle
EPDS Processing Logic and Equations (SRS Appendix B)	EPDS Subsystem	**Final Version Overdue (June 19),** Preliminary Draft Delivered May 29, FORTRAN Code Expected Mid September, *Delay Creates Major Schedule Impact*
Command Function Definitions (SRS Appendix C)	Software System Manager	**Near-Final Draft Released July 27,** Some Markups Expected, EPDS Commands Still Not Defined, *Changes Create Slight Software Impact*
Stored Command Sequences (SRS Appendix D)	Mission Operations	**Final Not Due Until January '93,** Preliminary Draft Delivered April 3
Key Parameters Database (KPD) (SRS Appendix E)	System Engineering	**Near-Final Draft Released June 18,** Some Markups Expected, *Database Changes Create Moderate Software Impact*

Outline

Key Requirements and Functional Overview

➤ **Functional Operations Descriptions**

➤ **Commanding Operations**
- Telemetry Operations
- Spacecraft Modes and Software Initialization

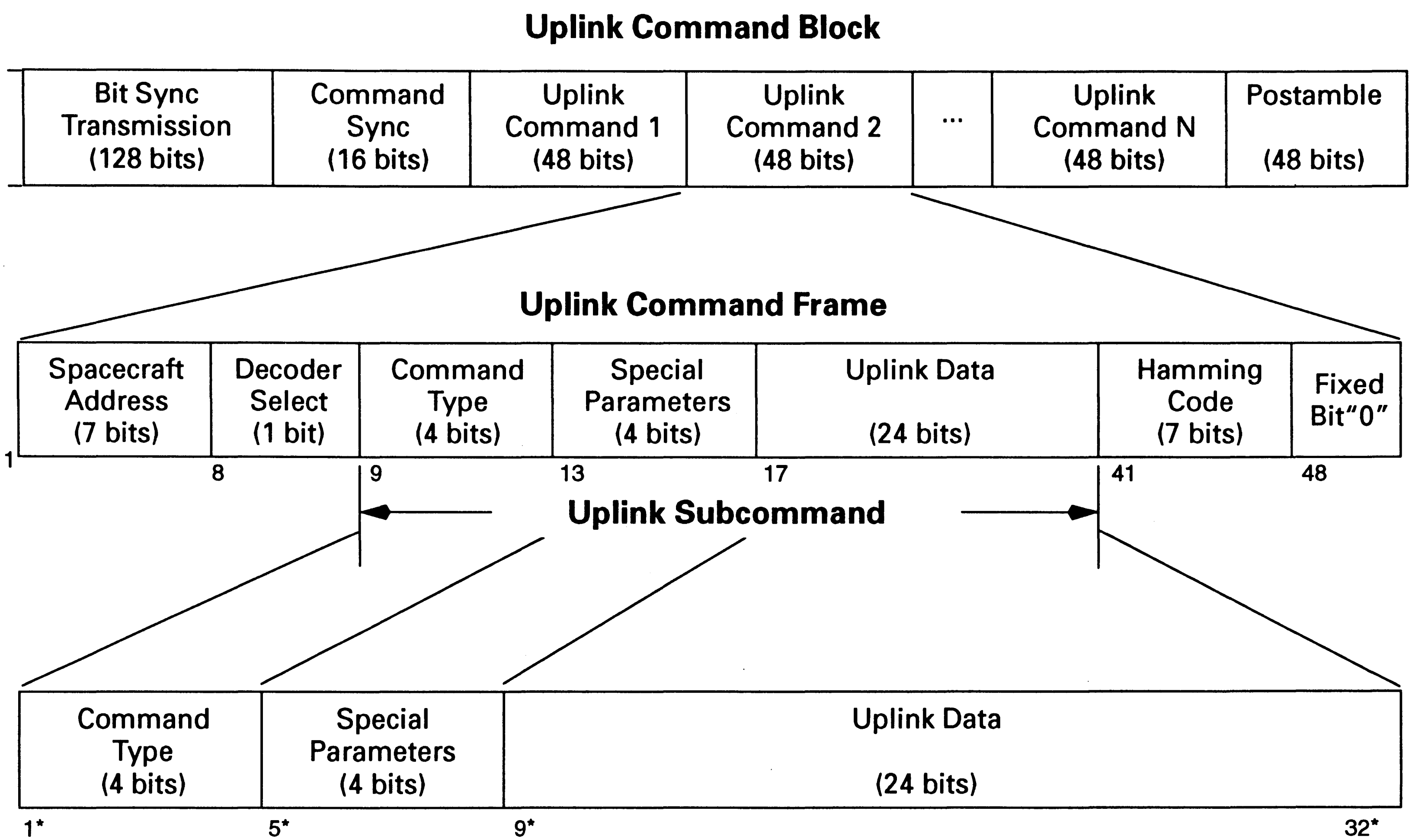
Design Description

Sizing and Timing Analyses

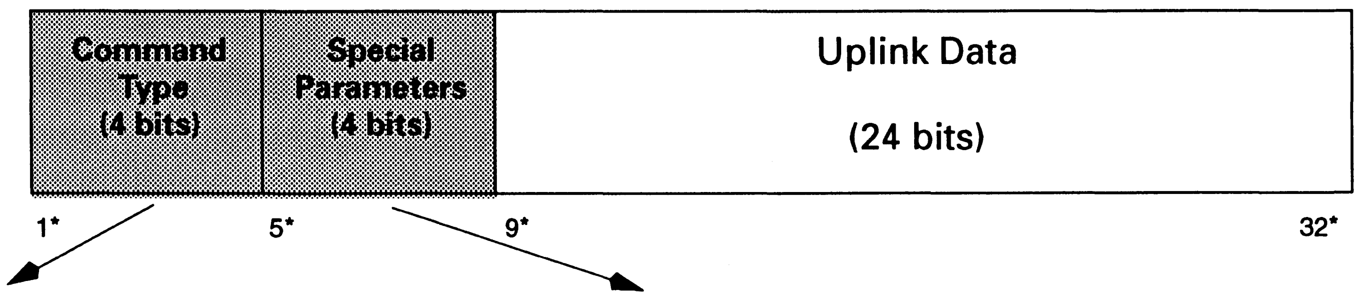
Development Status

Test Plan Overview

Uplink Command Block and Uplink Command Contents



Command Types and Special Parameters



Command Types:

- Real-Time Command
- Absolute-Timed Commands (ATC)
- Relative-Timed Command Sequence (RTCS)
- Key Parameters Database (KPD) Load
- SP Data Load, SP Code Load
- DP Data Load, DP Code Load
- Manage Command Input Buffer (CIB)

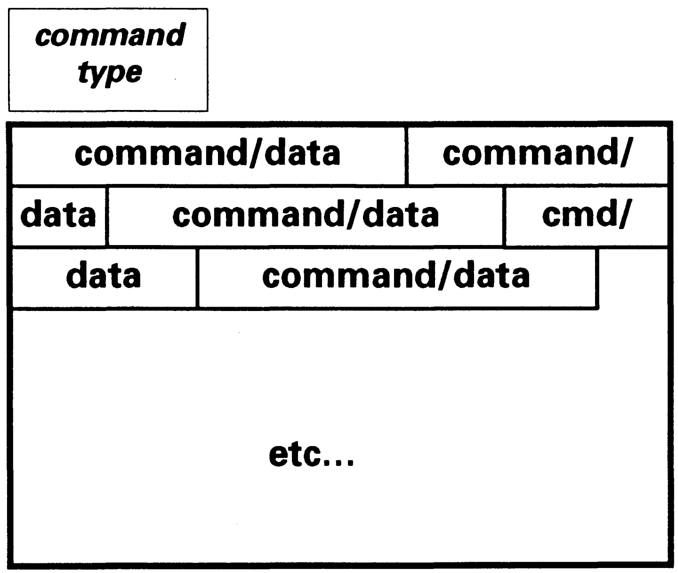
Special Parameters:

- Continue Command
- End of Command
- RTCS Reference
- End of Command with 1 Data Byte
- End of Command with 2 Data Bytes
- End of Command with 3 Data Bytes
- Clear CIB
- Transfer CIB
- Reset Command Counters
- Restart CIB Load

Command Input Buffer (CIB) Definition

Holds all validated commands or data received from the ground which will eventually be stored in memory.

- Allows ground verification of contents before permitting further action.
- Software-controlled size allocation — CIB is currently sized to hold 512 command frames (1536 bytes).



Command Input Buffer

Executable Commands and Data Load Structures

Executable commands and data loads are contained within the uplink data area of one or more command frames.

Command Type (4 bits)	Special Parameters (4 bits)	Uplink Data (24 bits)
1*	5*	9* … 32*

Uplink Subcommand

All executable commands are built from the basic command structure.

Command Number (1 byte)	Command Arguments (5 bytes max)

Basic Command Structure

Command Validation Summary

Upon receipt of the hardware "Uplink Command Ready" interrupt, the software places the command in the circular command uplink buffer (CUB) for EDAC protection.

Command validation is performed before placement of the command in the CIB or IAB.

- The software checks the hardware command accept/reject status bit.
- The command type must be compatible with data already in the CIB.
- The special parameters must be consistent with the command type.
- A command number must correspond to an executable command.
- A memory load address must be within valid boundaries for the load type.
- An ATC time tag must be within 30 days from the current time.
- An RTCS sequence number must correspond to an existing sequence, or be no more than 1 greater than the number in existence.
- An RTCS element number must correspond to an existing element, or be no more than 1 greater than the number in existence.
- There must be room in the CIB to accept the command.

Outline

Key Requirements and Functional Overview

➤ **Functional Operations Descriptions**

- Commanding Operations
- ➤ **Telemetry Operations**
- Spacecraft Modes and Software Initialization

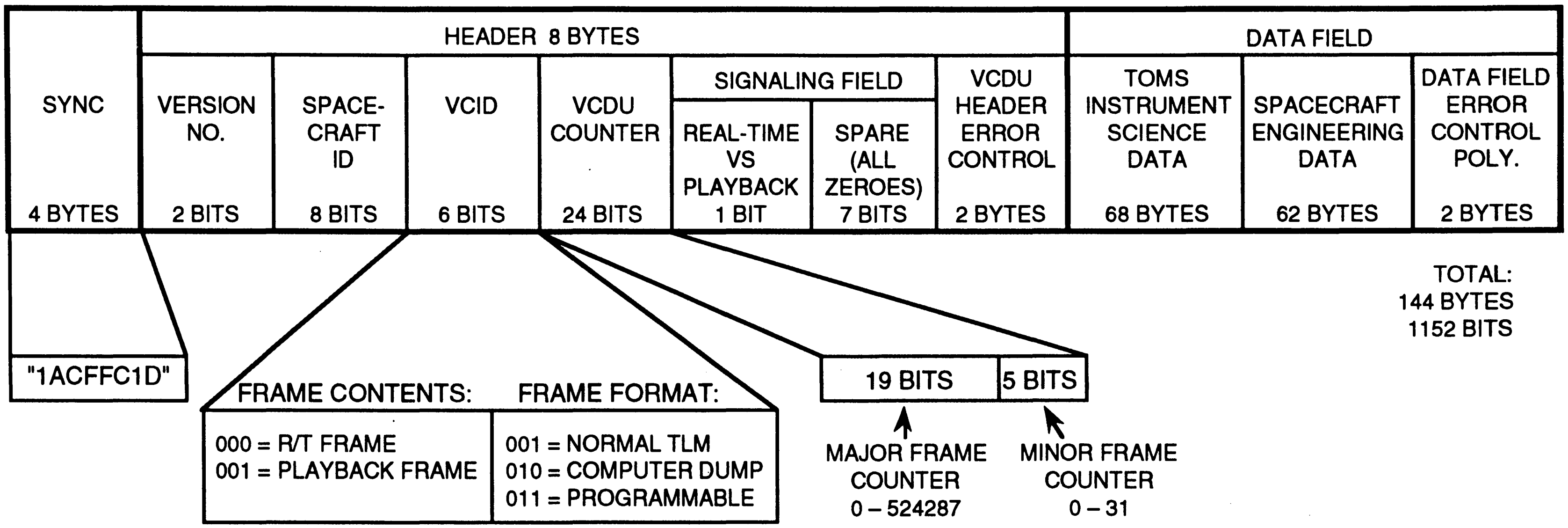
Design Description

Sizing and Timing Analyses

Development Status

Test Plan Overview

Telemetry Format



- The total telemetry frame length remains fixed.
- The partition between the instrument and spacecraft engineering data can be changed in flight.

Telemetry Frame Processing

SP Telemetry Processing:

- SP acquires and formats all parameters in the spacecraft engineering telemetry data area.
- SP sends the formatted engineering telemetry to the DP via DMA.

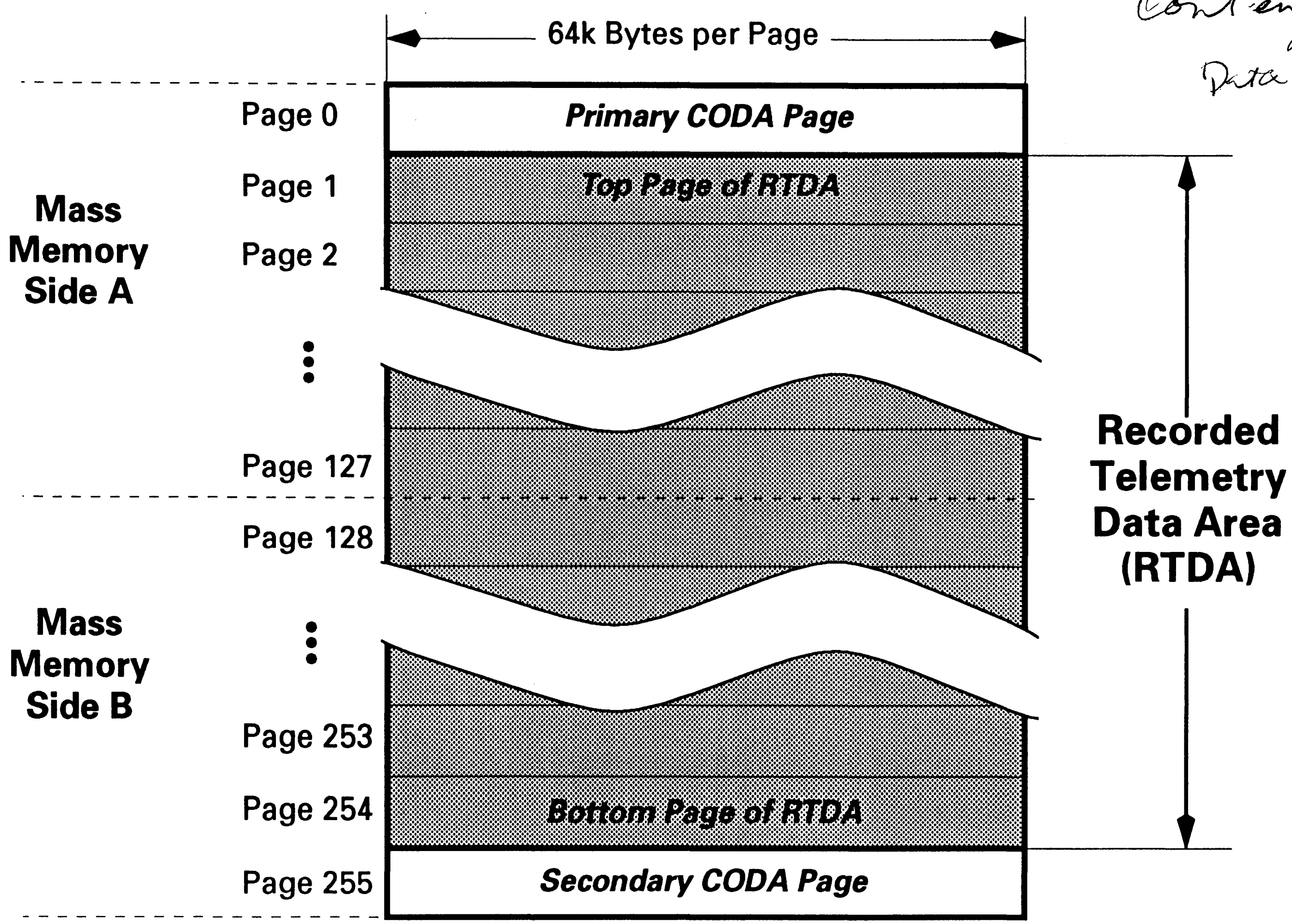
DP Telemetry Processing:

- DP receives the engineering telemetry from the SP.
- DP collects the TOMS instrument telemetry data, appends it to the spacecraft engineering data and completes the formatting of a telemetry minor frame.
- DP sends the current minor frame to the downlink via DMA at the start of the next minor frame cycle (1.024 seconds).
- DP reformats the minor frame header and stores the frame in the "current write" location in the recorded telemetry data area (RTDA) within mass memory.

Telemetry Frame Storage

Stored telemetry is placed in the DP mass memory.

Contingency operations Data Area.



Telemetry Downlink and Playback

Three playback modes are supported:

- Real-time only — one real-time frame per 1.024 seconds.
- Low-rate playback — one real-time frame and 44 playback frames per 1.024 seconds.
- High-rate playback — one real-time frame and 179 playback frames per 1.024 seconds.

Playback options:

- "Playback from end of Last Playback"
- "Playback all Stored Telemetry"
- "Playback Stored Telemetry from Location"

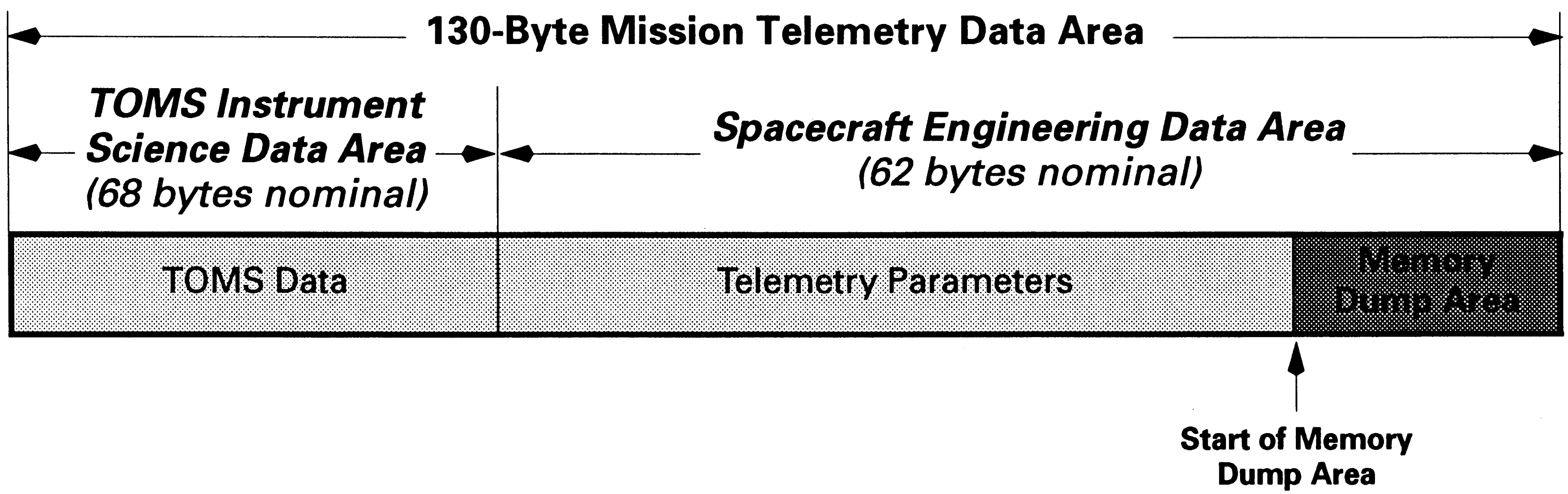
Three telemetry formats are provided:

- "Normal," "Memory Dump," and "Programmable" formats
- All formats can be reprogrammed and are treated identically by software processing.

Memory Dump Operations

Memory dump data is placed in the unallocated space in each telemetry minor frame.

- A memory dump is always active (in every telemetry format).
- Memory dumps of the selected area are continuously repeated until a new dump type is commanded.
- Start of memory dump area may change for each minor frame.



Outline

Key Requirements and Functional Overview

➤ **Functional Operations Descriptions**

- Commanding Operations
- Telemetry Operations
- ➤ **Spacecraft Modes and Software Initialization**

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Spacecraft Modes

"Normal" Modes

Standby:

- (1) Standby

Sun:

- (2) Sun Acquisition
- (3) Earth Search
- (4) Sun Reference Hold

Maneuver:

- (5) Attitude Hold
- (6) Attitude Maneuver
- (7) Delta-V Burn

Science:

- (8) Normal
- (9) Normal Backup #1
- (10) Normal Backup #2

Contingency Modes

Safe Hold:

- (11) B-Dot Hold
- (12) Science Return

Sun:

- (13) Sun Point Recovery
- (14) Long Term Hold

Spacecraft Mode Transition Control

Commanded Mode Transitions:

- Ground commands may cause a mode transition.

Automatic Mode Transitions:

- Automatic pre-defined sequences invoke a planned mode transition.

Autonomous Mode Transitions:

- Detected faults trigger an unplanned transition to a contingency mode.

Software supports mode transitions with high-level software mode transition commands. Hardware reconfiguration must be commanded separately.

Software Fault Monitoring Mechanisms

Critical Parameters

- Selectable from any software variables in the global data area (GDA).
  - Attitude rates
  - Wheel speeds
  - Battery state of charge
  - Battery temperature
  - etc.
- Tested against upper and/or lower thresholds.
- Different sets of parameters can be specified for different modes.
- Different monitoring rates (every 256 msec or every 1.024 secs) can be selected for each parameter, for each mode.
- Group 1 critical parameters trigger a transition to Safe Hold mode.
- Group 2 critical parameters trigger a transition to Safe Power mode.

Software Fault Monitoring Mechanisms, cont.

Time Limits

- Earth and sun acquisition attempt time-outs trigger a transition to Safe Power mode.

EDAC Error

- EDAC double-bit memory error triggers contingency mode transition.

Battery Taper Charge Processing

- Failure to reach taper charge upon eclipse entry triggers a transition to Safe Power mode.

Data Processor Communications

- Sustained absence of communications from DP triggers a transition to Safe Power mode.

Undervoltage Detector - loses Mass Memory

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- ➤ **Task Overview and Execution Timeline**
- – External Interfaces
- – Software Error Conditions and Indicators

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Task Overview

Modular tasks and function libraries perform all the on-board software processing.

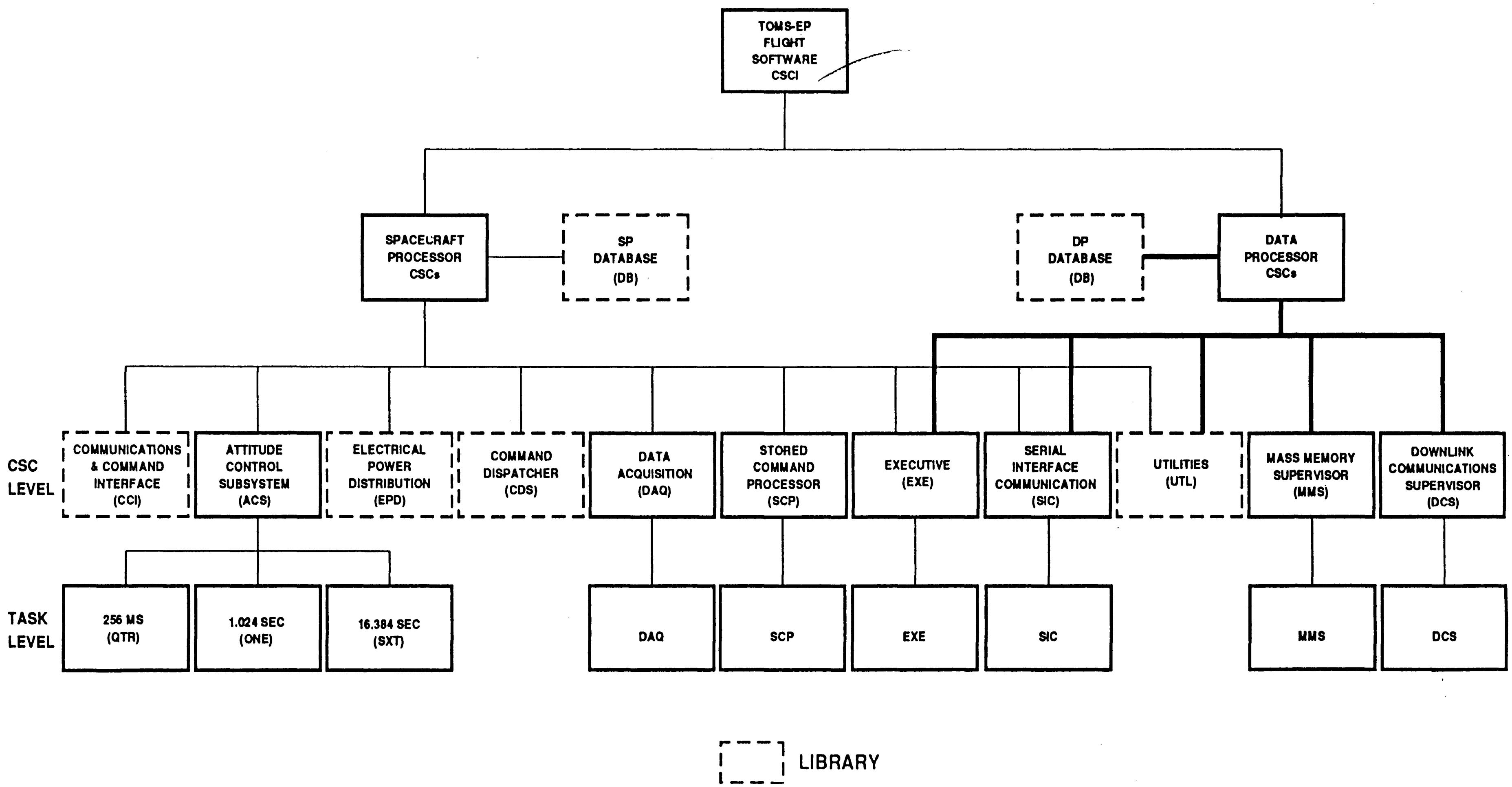
Task processing:

- VRTX operating system handles all task scheduling and switching.
- Task states: executing, ready, pending, or dormant.
- Tasks run (one at a time) to completion unless interrupted by a higher priority task.
- Communications between tasks is handled by VRTX message queues and event flags.

Tasks may be invoked by:

- Hardware interrupts (e.g. alarms, communications events, or timed processing interrupts).
- Another task, via an event flag.
- A time-out of a timed operation.

TFS Hierarchy Diagram



SP Software Tasks

Executive (EXE) [priority = 7]

- Performs initialization and background memory checks.
- Performs memory uploads from ground.

256 Millisecond (QTR) — 256 milliseconds [priority = 1]

- Executes required ACDS functions.
- Receives and processes uplinked commands.
- Dispatches commands to their appropriate destinations, and executes local software commands via the command dispatcher (CDS) library.
- Performs high-rate fault monitoring.

Data Acquisition (DAQ) — 1.024 seconds [priority = 2]

- Acquires and formats spacecraft telemetry, and sends it via DMA to the DP.
- Initiates autonomous mode transitions or DP redundancy management in response to detected anomalies.

SP Software Tasks, cont.

1.024 Second (ONE) — 1.024 seconds [priority = 3]

- Executes required ACDS functions.
- Performs EPDS battery charging and power control functions.
- Performs low-rate fault monitoring and operation timing.

16.384 Second (SXT) — 16.384 seconds [priority = 6]

- Executes required ACDS functions.

Stored Command Processor (SCP) [priority = 4]

- Manages stored commands and schedules ATCs, RTCSs for execution.

Serial Interface Communications (SIC) [priority = 5]

- Receives serial data communications from the DP.

Interrupts Used by SP Software

1) **DP Receive** — triggered by serial data transmission from DP. Invokes SIC task.

2) **256 msec Pulse** — initiates QTR task.

3) **Uplink Command Ready** — triggered by hardware receipt of ground command.

4) **1.024 sec Pulse** (Minor Frame Sync Pulse) — initiates ONE task and DAQ task.

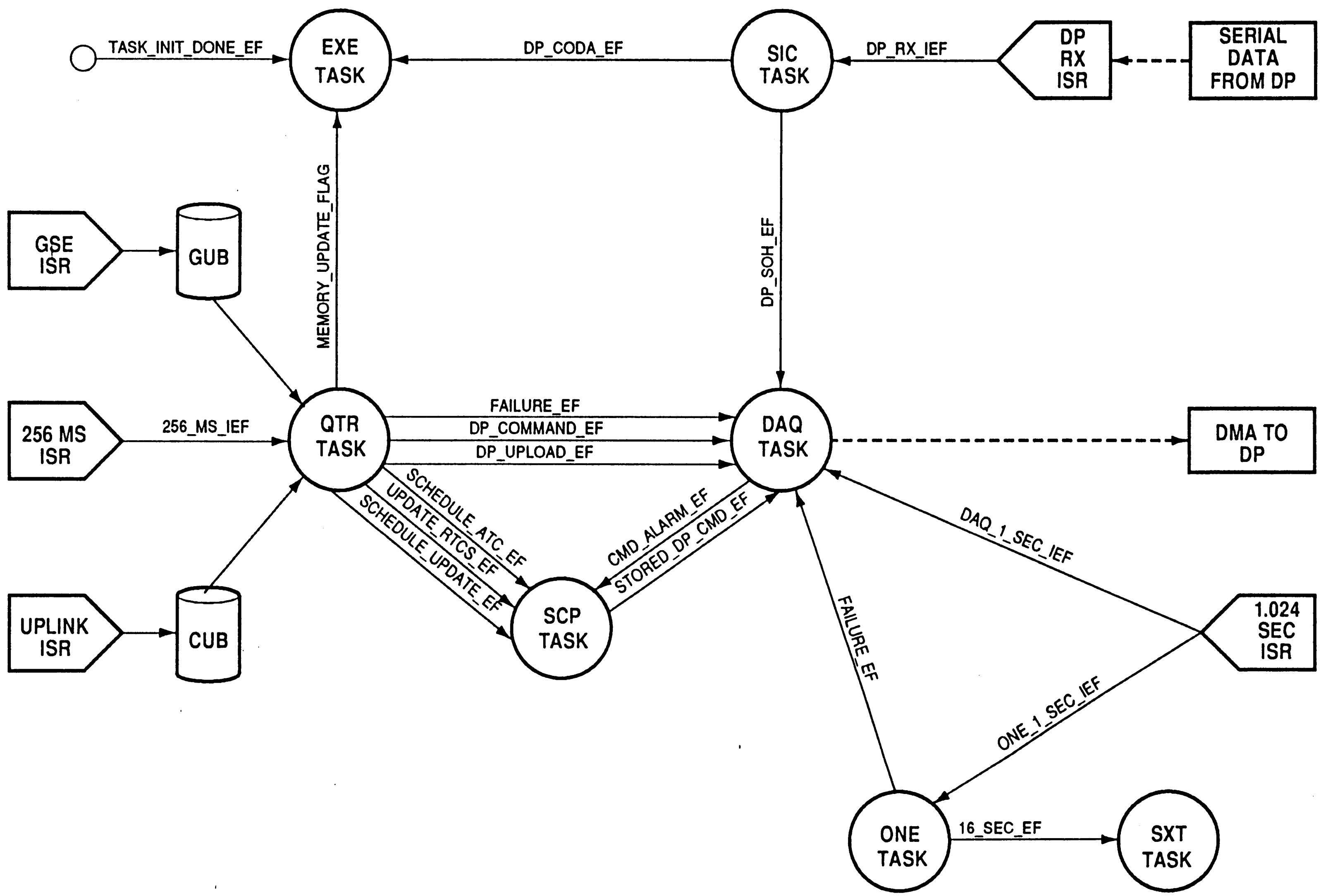
5) **EDAC Error** — triggered by hardware-detected double-bit error.

6) **64 msec Pulse** — used by VRTX for internal clock.

7) **Timer 1** — times the 30 msec bilevel command pulse width.

8) **GSE Receive** — triggered by serial data transmission from the GSE test port.

SP Task Diagram



DP Software Tasks

Executive (EXE) [priority = 4]

- Performs initialization and background memory checks.
- Performs memory uploads from ground.

Downlink Communications Supervisor (DCS) [priority = 1]

- Controls telemetry playback and downlinking.

Mass Memory Supervisor (MMS) [priority = 2]

- Formats and stores telemetry minor frames.
- Processes incoming commands to the DP.
- Manages CODA operations.

Serial Interface Communications (SIC) [priority = 3]

- Sends serial data communications to the SP.

Interrupts Used by DP Software

1) **1.024 sec Pulse** (Minor Frame Sync Pulse) — initiates downlinking of the real-time telemetry frame.

2) **Link-Load** — initiates downlinking of stored telemetry frames.

3) **SP DMA Done** — indicates receipt of an SP DMA data transfer.

4) **SP Transmit** — triggered by serial data transmission to SP. Invokes SIC task.

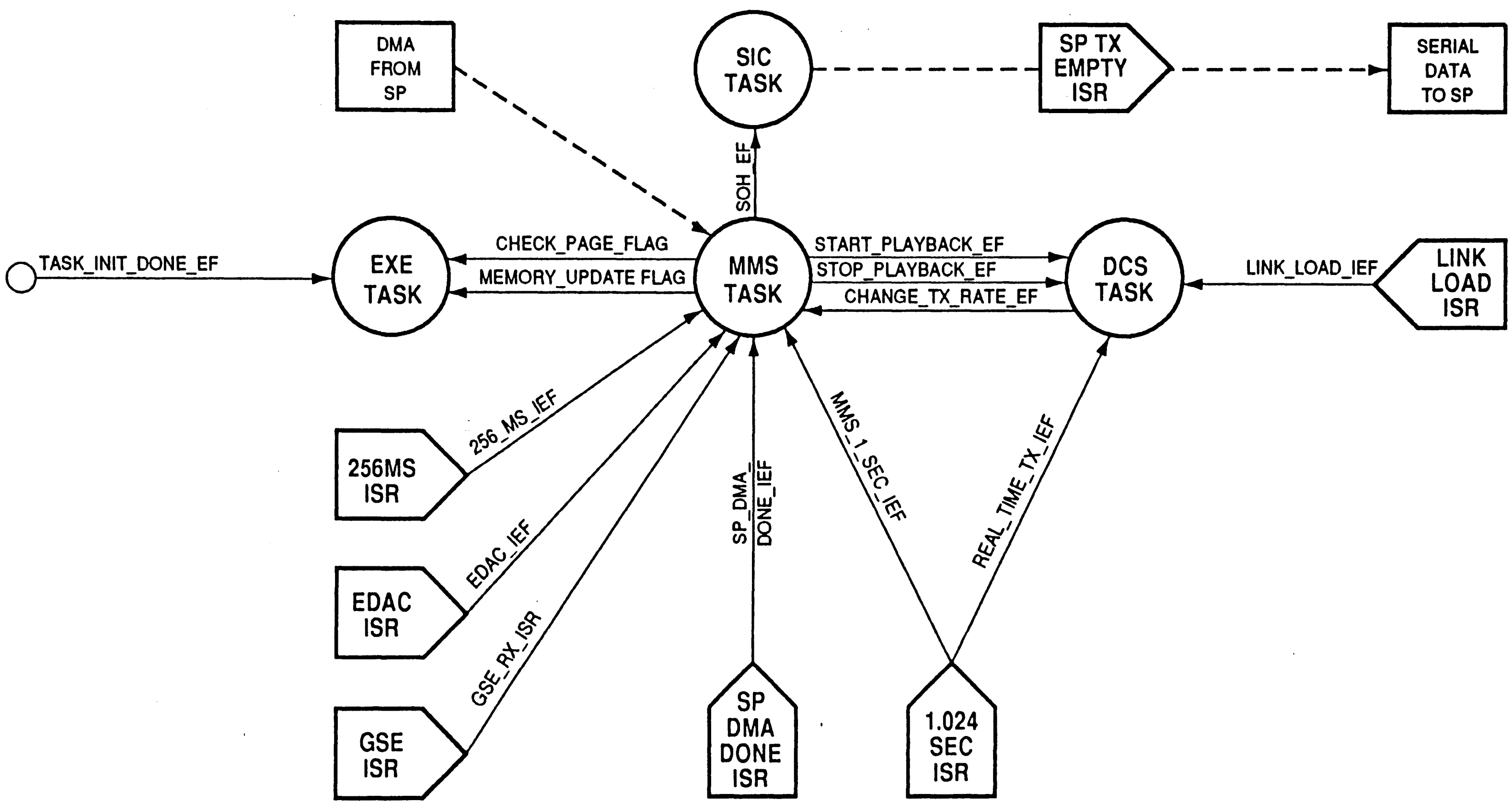
5) **256 msec Pulse** — initiates TOMS instrument telemetry collection on second interrupt in minor frame cycle.

6) **EDAC Error** — triggered by hardware-detected double-bit error.

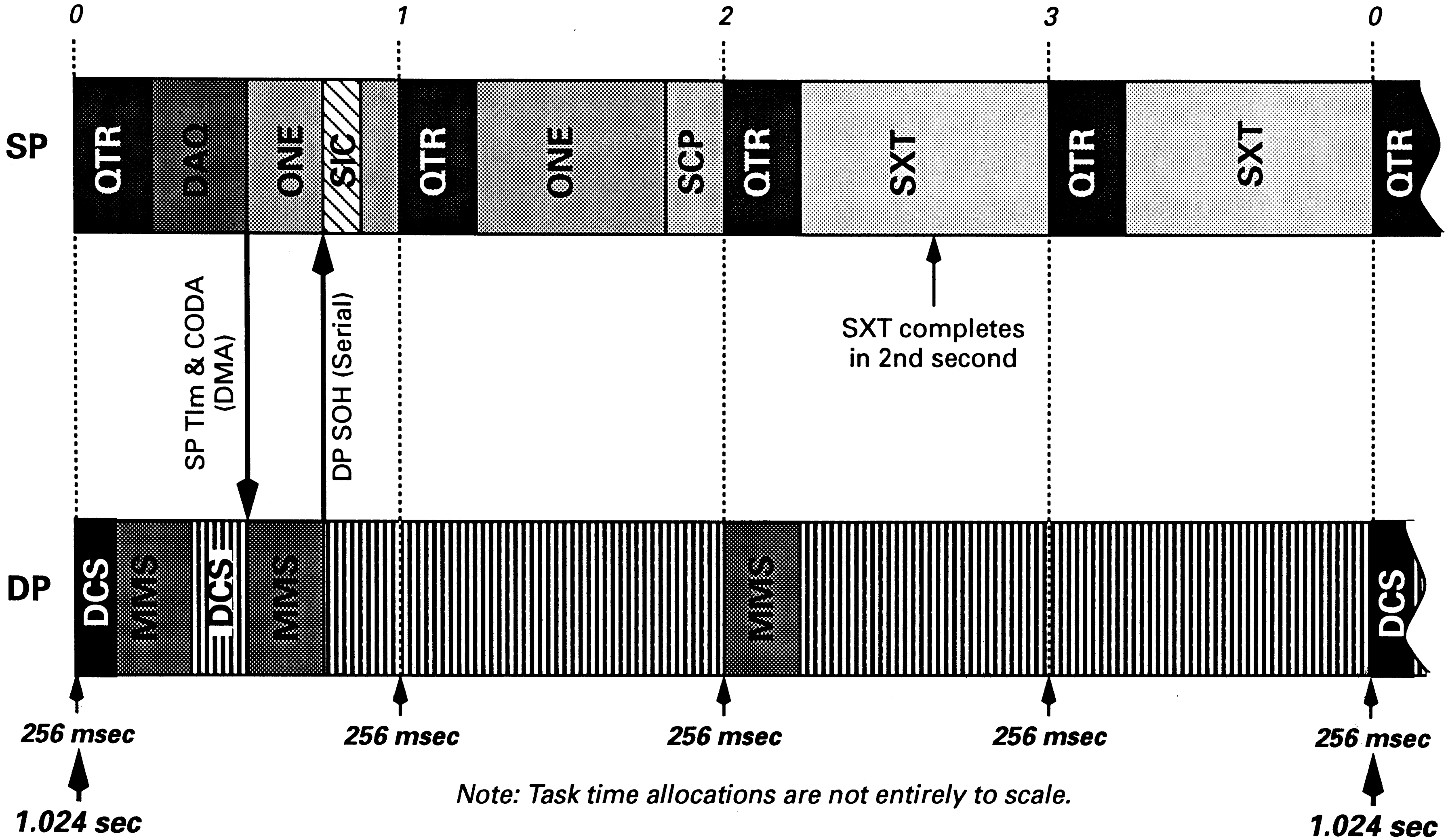
7) **64 msec Pulse** — used by VRTX for internal clock.

8) **GSE Receive** — triggered by serial data transmission from the GSE test port.

DP Task Diagram



Task Execution Timeline — 1st second in 16.384 sec cycle



Note: Task time allocations are not entirely to scale.

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➤ Design Description

- – Task Overview and Execution Timeline
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- – Software Error Conditions and Indicators

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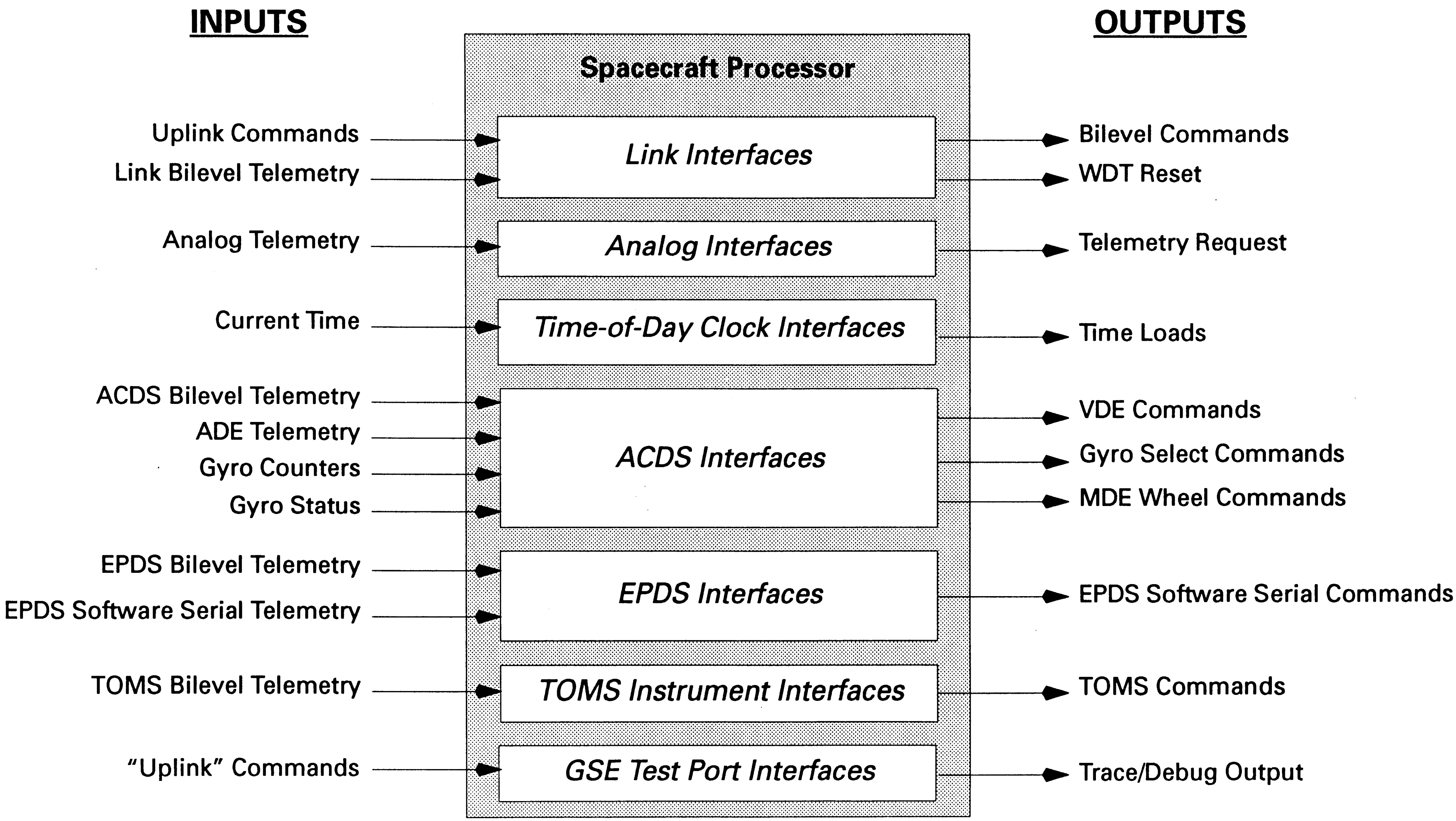
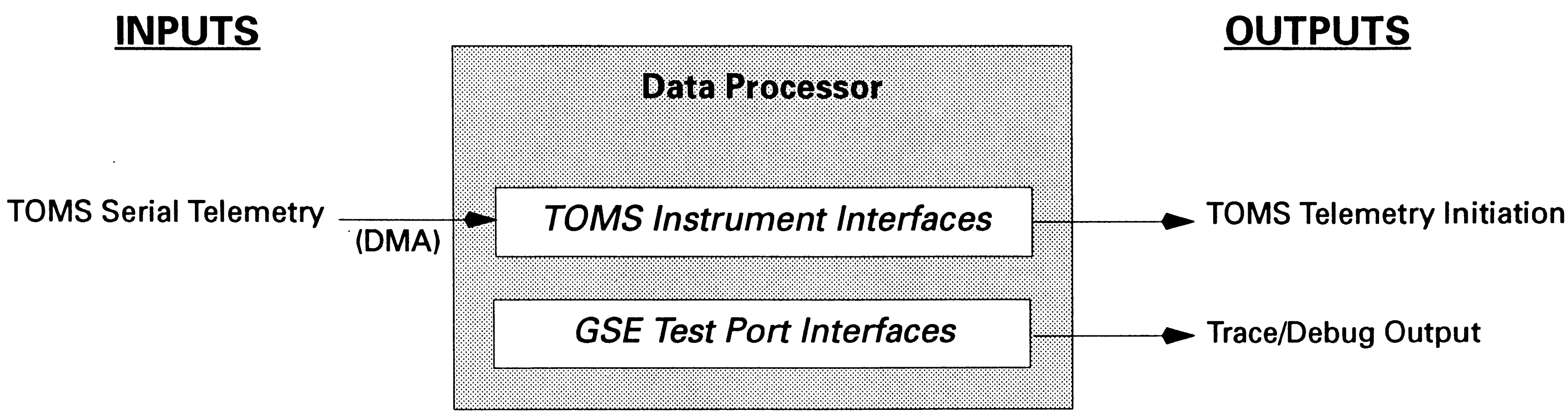
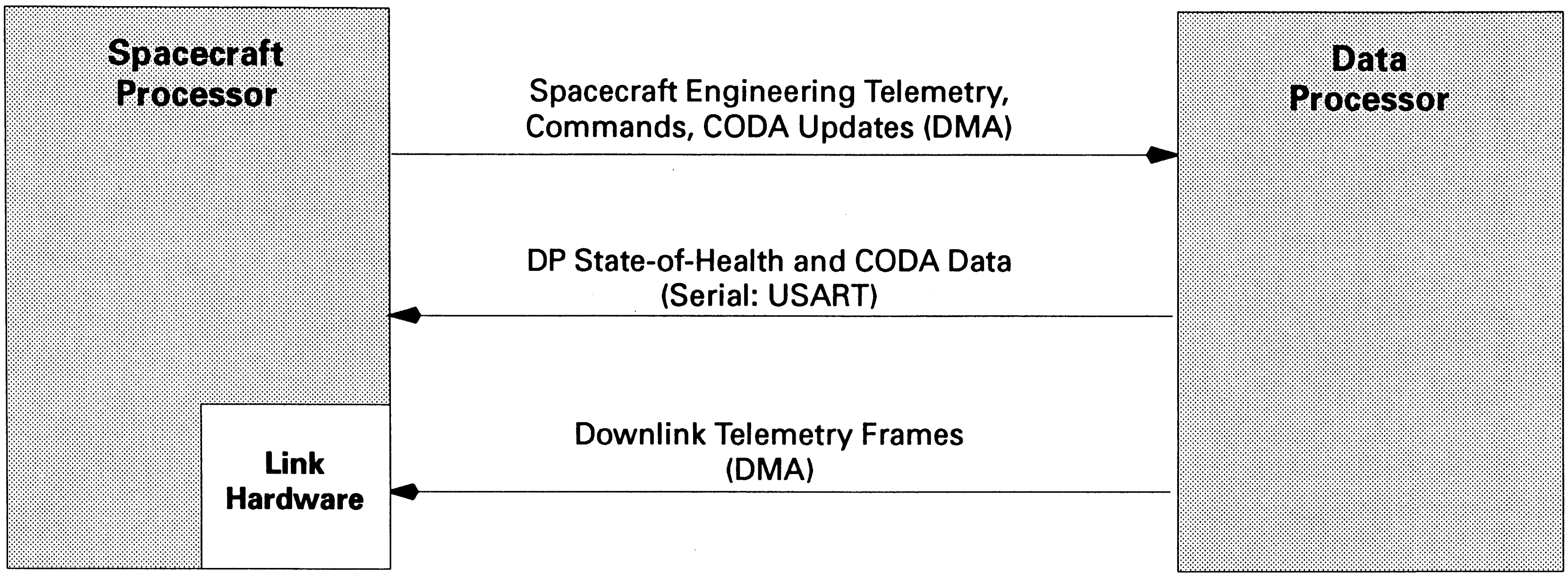
Spacecraft Processor to Bus Subsystem Interfaces



Data Processor to Bus Subsystem Interfaces



SP and DP Communications Interfaces



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Software Error Words

The SP and DP compile a software error word (SEW) to provide notification of processing errors. Each bit is a flag for an error, or class of errors.

SP Software Error Word:

- General SP Software Error
- SP EEPROM CRC Check Error
- Uplink Command Validation Error
- SP/DP Communications Error
- General DP Software Error
- DP EEPROM CRC Check Error
- DP RAM EDAC Error
- Telemetry Playback Error

(The last four items are bracketed together as the **DP Software Error Word**.)

Software Error Tables

SP and DP maintain software error tables (SETs) containing error information:

- Error code identifying exact nature of the error.
- On-board time at which the error occurred.
- Detailed error information for diagnosis and recovery.

General types of processing errors detected and noted by software:

- I/O read errors.
- CIB operations errors.
- Command validation or processing errors.
- Telemetry frame formatting errors.
- DP to SP communications errors.
- CODA operations or read errors.
- SP to DP DMA data transfer errors.
- Telemetry storage or playback errors.

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- ➤ **Sizing Analysis**
- – Timing Analysis

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SP Memory Usage Analysis

Task/Library	CODE (K Bytes)	DATA (K Bytes)	EEPROM Used (KB)	EDAC RAM Used (KB)
ACS	54.7	10.9	54.7	65.6
CCI	18.3	18.3	18.3	36.6
CDS	22.7	2.3	22.7	25.0
DAQ	12.8	12.8	12.8	25.6
EPDS	22.5	2.2	22.5	24.7
EXE	12.7	1.3	12.7	14.0
ONE	7.1	0.7	7.1	7.8
PACLIB	4.0	0.0	4.0	4.0
QTR	2.1	0.2	2.1	2.3
SCP	12.7	15.3	12.7	28.0
SXT	1.8	0.2	1.8	2.0
UTL	42.4	4.2	42.4	46.6
VRTX	8.0	32.0	8.0	40.0
SIC	3.4	0.7	3.4	4.1
Totals	**225.2**	**101.1**	**225.2**	**326.3**
Resources			512.0	512.0
% Used			**44%**	**64%**

DP Memory Usage Analysis

Task/Library	CODE (K Bytes)	DATA (K Bytes)	EEPROM Used (KB)	EDAC RAM Used (KB)
DCS	8.3	1.7	8.3	10.0
EXE	12.7	1.3	12.7	14.0
MMS	22.6	11.3	22.6	33.9
UTL	42.4	4.2	42.4	46.6
VRTX	8.0	16.0	8.0	24.0
SIC	3.4	0.7	3.4	4.1
Totals	**97.4**	**35.2**	**97.4**	**132.6**
Resources			256.0	256.0
% Used			**38.0%**	**51.8%**

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- – Sizing Analysis
- ➤ **Timing Analysis**

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SP Timing Analysis Assumptions

The timing thread is based upon normal on-board operations with active telemetry and commanding operations:

- Ground transmits 43 real-time commands within 1.024 seconds.
  - 8 ATC management commands
  - 27 serial commands
  - 8 RTCS management commands
- One stored command is executed from the schedule per second.
- SP telemetry is collected once every 1.024 seconds: 12 hardware parameters (3 analog, 5 serial, 4 bilevel) and 40 software parameters are read.
- The DP SOH data is received and examined once every 1.024 seconds.
- The ACDS and EPDS processing execute at their scheduled times (dependent upon current spacecraft mode).
- 20 critical parameters are checked every 256 msecs, and 20 every 1.024 seconds (total of 100 checks).

SP Timing Analysis

Mode	Submode	Total Time (μsec)	% of Total Utilization
Standby		207,570	**15.3%**
Sun	Sun Acquisition	566,252	**50.3%**
	Earth Search	679,144	**61.3%**
	Sun-Reference Hold	533,902	**47.1%**
Maneuver	Attitude Hold	737,289	**67.0%**
	Attitude Maneuver	568,609	**50.5%**
	Delta-V Burn	568,587	**50.5%**
Science	Normal	673,087	**60.7%**
	Normal Backup #1	623,088	**55.8%**
	Normal Backup #2	623,088	**55.8%**
Safe Hold	B-Dot Hold	?	**(approx 27%)**
	Science Return	?	**?**
Safe Power	Sun Point Recovery	451,538	**39.1%**
	Long Term Hold	440,900	**38.1%**

DP Timing Analysis Assumptions

The DP works in concert with the SP:

- The SP telemetry is received once every 1.024 seconds.
- The DP SOH is sent to the SP once every 1.024 seconds.
- The TOMS instrument telemetry is collected once every 1.024 seconds.
- The telemetry downlink mode can be:
  - 1 real-time frame per 1.024 seconds, or
  - 1 real-time and 44 recorded frames per 1.024 seconds, or
  - 1 real-time and 179 recorded frames per 1.024 seconds.

DP Timing Analysis

Function/Task	Execution Time for Selected Downlink Mode		
	Real-Time Only (μsec)	Low-Rate Playback (μsec)	High-Rate Playback (μsec)
DCS Task	2,330	140,442	320,036
MMS Task	22,702	22,702	22,702
SIC Task	1,736	1,736	1,736
ISR – SP TX Empty	726	726	726
ISR – 1.024 Sec	1,298	1,298	1,298
ISR – Link-Load	0	92,370	115,842
ISR – SP DMA Complete	919	919	919
ISR – 256 msec	3,677	3,677	3,677
ISR – 64 msec	8,531	8,531	8,531
TOTAL	41,919	272,401	475,467
% of Total Utilization	**4.1%**	**26.6%**	**46.4%**

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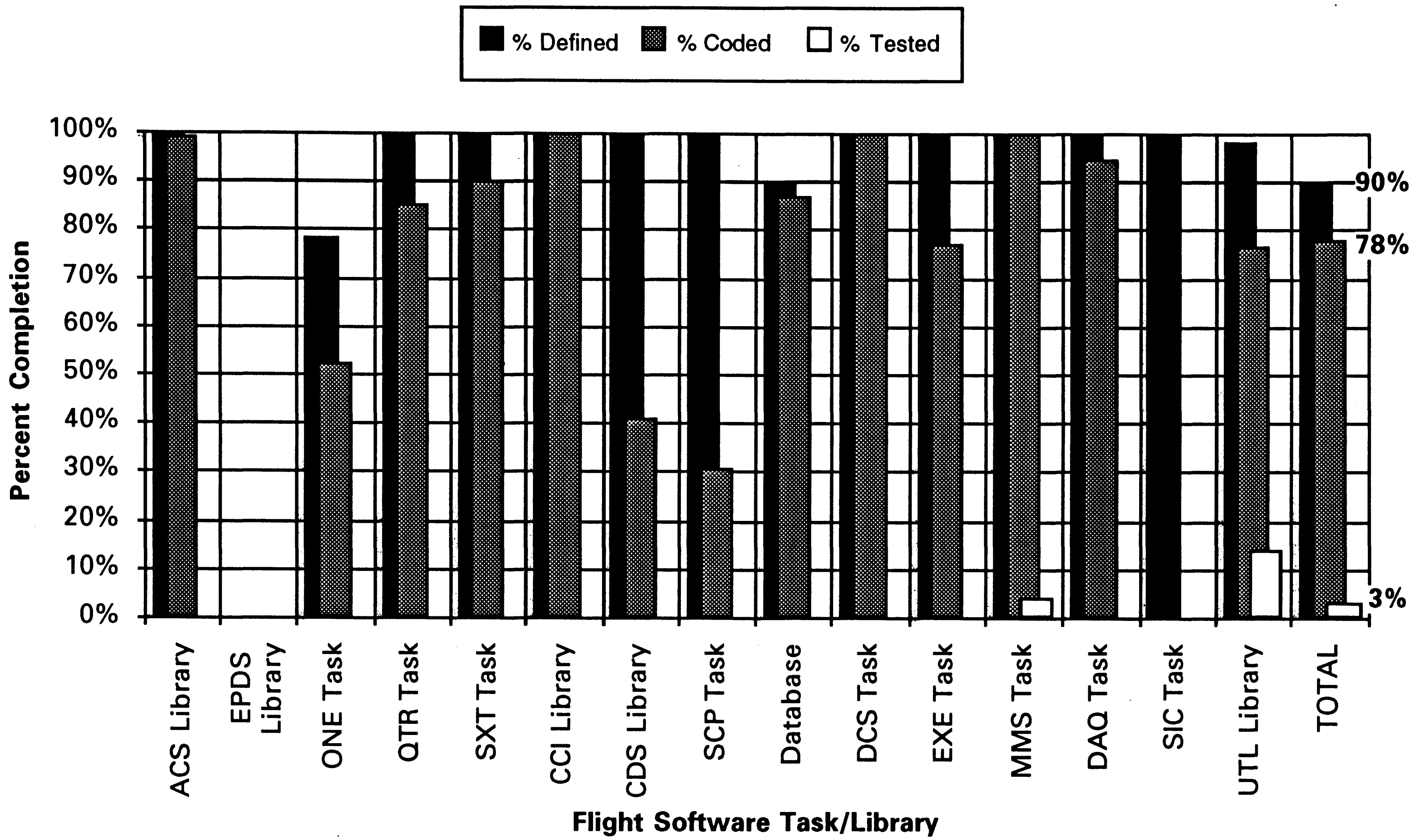
Sizing, Coding and Testing Status

CSC	Task/Library	Number of Functions	SLOCS Originally Forecasted	SLOCS Currently Expected	SLOCS Defined (able to code)	SLOCS Currently Coded	% Defined	% Coded	% Tested
ACS	ACS Library	23	750	1630	1630	1611	100%	99%	0%
	EPDS Library	16	0	657	0	0	0%	0%	0%
	ONE Task	4	250	206	161	108	78%	52%	0%
	QTR Task	2	100	88	88	75	100%	85%	0%
	SXT Task	2	50	61	61	55	100%	90%	0%
CCI	CCI Library	14	200	578	578	578	100%	100%	0%
CPS	CDS Library	27	1350	621	621	255	100%	41%	0%
	SCP Task	9	450	367	367	112	100%	31%	0%
DB	Database	0	0	3219	2897	2795	90%	87%	
DCS	DCS Task	12	100	243	243	243	100%	100%	0%
EXE	EXE Task	8	775	350	350	270	100%	77%	0%
MMS	MMS Task	0	800	704	704	704	100%	100%	4%
DAQ	DAQ Task	11	450	435	435	412	100%	95%	0%
SIC	SIC Task	1	1400	100	100	0	100%	0%	0%
UTL	UTL Library	37	1600	1242	1217	952	98%	77%	14%
	TOTAL	**166**	**8275**	**10501**	**9452**	**8170**	**90%**	**78%**	**3%**

Note: 3219 lines of database structure were not counted in the bookkeeping method used in the original forecast. With the database code, the original forecast would be 11,494 SLOCS.

Coding and Functional Testing Status



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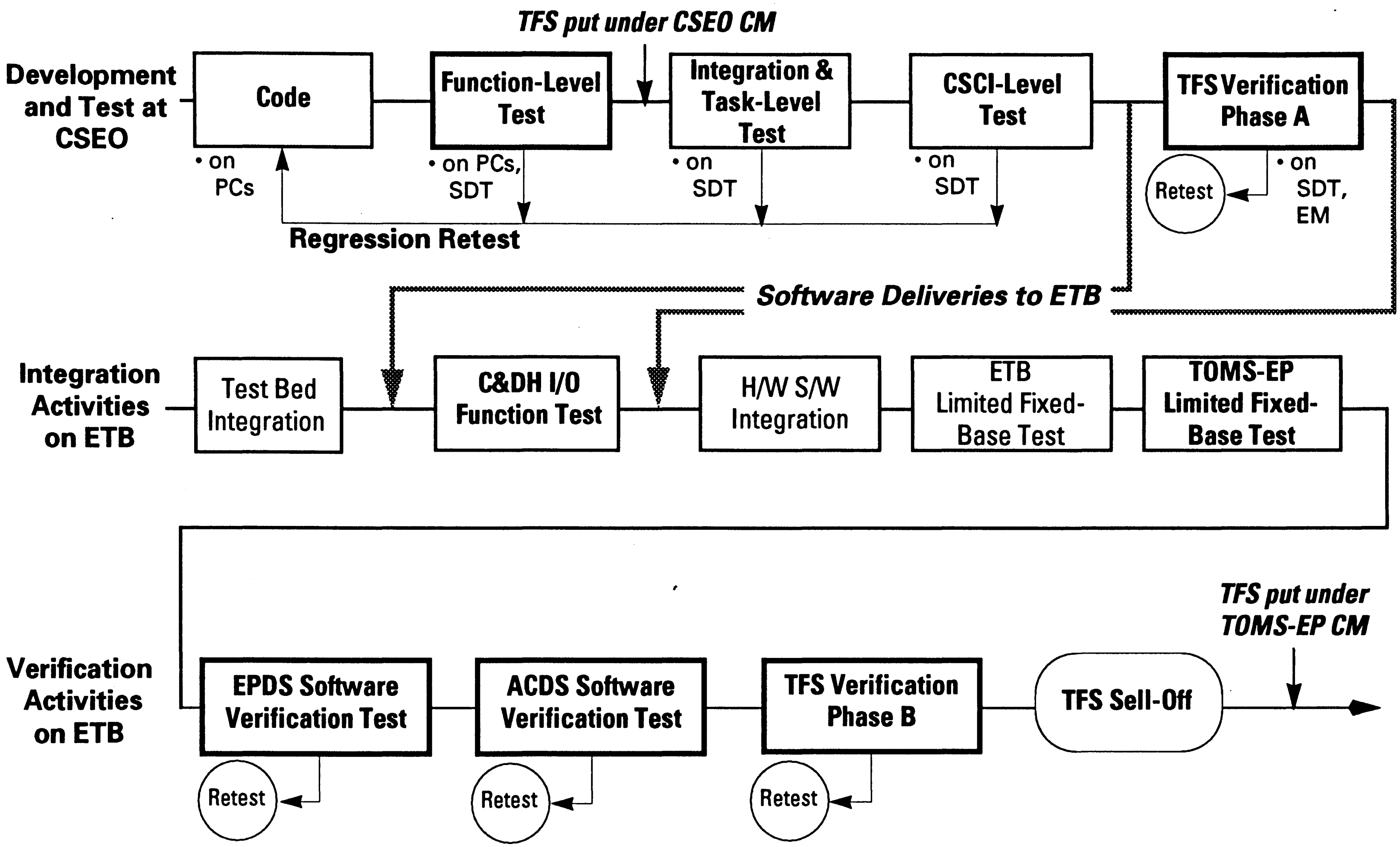
➤ **Test Plan Overview**

TFS Test Responsibility Assignments

Software Test	Test Planning Responsibility	Documentation and Test Status	Test Performance/ Supervision Responsibility
TFS Functional Test	TRW/CSEO	Test Plans Completed, Testing has Begun	TRW/CSEO
TFS Phase A Verification Test	TRW/CSEO	Test Plans & Procedures Completed	TRW/CSEO
ACDS Software Verification Test	ACDS	Test Plans Completed	ACDS, ETB Test Conductors
EPDS Software Verification Test	EPDS	Documentation Not Completed	EPDS, ETB Test Conductors
TFS Phase B Verification Test	TRW/CSEO	Test Plans & Procedures Completed	TRW/CSEO, ETB Test Conductors
System Level Verification Test	*I&T*	*Test Plans Completed*	*I&T*

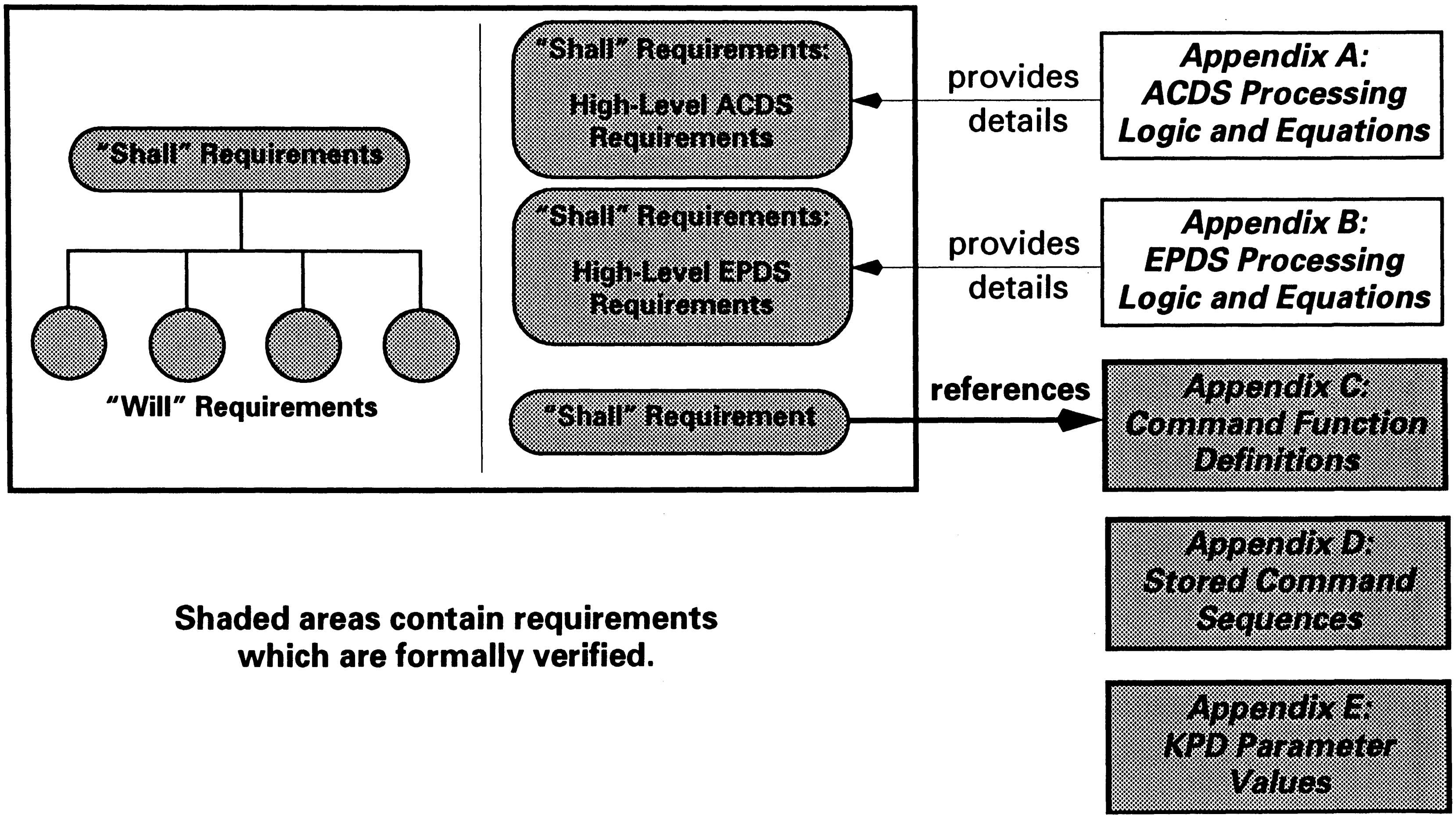
Flight Software Testing and Verification Sequence



TFS Requirements Organization and Verification

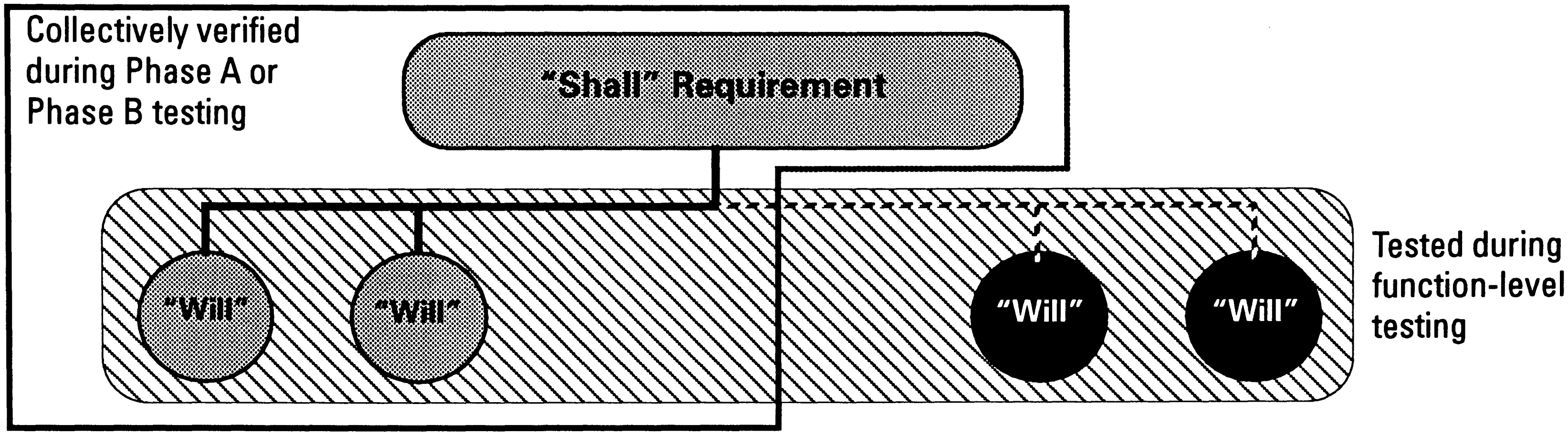
Software Requirements Specification

SRS Appendices



Shaded areas contain requirements which are formally verified.

Testing and Verification of "Will" Requirements



If the procedure for verifying the "shall" requirement also demonstrably tests the "will" requirement, then it is an

<u>ADOPTED</u> "will" requirement,

and it will be tested by the developer in accordance with function test log (FTL) procedures during function-level test.

If the procedure for testing the "shall" requirement does <u>not</u> demonstrably test the "will" requirement, then it is an

<u>ORPHANED</u> "will" requirement,

and it will be tested by the developer <u>with QA witness and SDM monitor*</u> during function-level test.

* Monitor may control or stop the testing if desired.

CDR Acronym List

A&T	Assembly and Test
AC	Air Conditioning (Launch VEhicle)
ACDS	Attitude Control & Determination Subsystem
ACQ	Acquisition
A/D	Analog-to-Digital
ADE	Attitude Determination Electonics
AHr	Ampere Hour
AOS	Acquisition of Signal
ARAR	Accident Risk Assessment Report
ARE	Array Req. Electronics
ARM	Array Regulator Modules
ASA	Aluminum Substrate Assembly
ASTM	American Society for Testing and Materials
ATC	Absolute Timed Commands
ATS	Absolute Time Sequence
BCCA	Battery Charge Control Algorithm
BSF	Back Surface Field
BSR	Back Surface Reflector
C/O	Check Out
CAL	Calibration
CAP	Contamination Analysis Program
CCB	Configuration Change Board
CDA	Critical Design Audit
CEA	Control Electronics Assembly
CFR	Captive Flight Release
CG	Center of Gravity
CIB	Command Input Buffer
CM	Center of Mass
CMM	Configuration Management Manual
CMS	Command Management System
CONV	Converter
CPT	Comprehensive Performance Test
CPU	Central Processing Unit
CSA	Command Storage Area
CSEO	Colorado Springs Engineering Operations
CSSA	Coarse Sun Sensor Assembly
CTV	Compatibility Test Van
CVCM	Collected Volatile Condensible Material
D/L	Downlink
DDLS	Deployment Device Load Simulator
DIU	Diode Isolation Unit
DMA	Direct Memory ACcess
DP	Data Processor
DPA	Destructive Physical Analysis
DPRO	Defense Plant Representative Office
DSN	Deep Space Network
DTM	Dual Thruster Module
EED	Electro-Explosive Device
EEDC	Electro-Explosive Device Controller
EEE	Electrical, Electronic, and Electromechanical

EGSE	Electrical Ground Support Equipment
EM	Engineering Model
EMC	Electromagnetic Compatibility
EMI	Electromagnetic Interference
EMISM	Electromagnetic Interference Safety Margins
EQ	Equipment
ER	Established Reliability
ESD	Electrosstatic Discharge
ETB	Eagle Test Bed
EV	Environmental
FDM	Flexible Data Mux
FMEA	Failure Mode Effect anmd Criticality Analysis
FOV	Field of View
FPGA	Field Programmable Gate Array
FSA	Fail-SAfe Algorithm
FSSA	Fine Sun Sensor Assembly
GFE	Government-Furnished Equipment
GFP	Government Furnished Property
GN2	Gaseous Nitrogen
GRA	Gyro Reference Assembly
GSE	Ground Support Equipment
GSTDN	Ground-Space Tracking and Data Network
H/L	Hard Line
H/W	Hardware
HEX	Base 16 (Hexadecimal)
HQAM	Hardware Quality Assurance Manual
I/C	Interface Control
I/F	interface
ICD	Interface Control Document
ICMT	Intercontract Material Transfer
IFJ	In-Flight Jumper
IGSE	Instrument Ground Support Equipment
IIS	Instrument Interface Simulator
IR	Instrument Review
IVT	Interrupt Vector Table
KBPS	Kilo Bits Per Second
KPD	Key Parameter Database
LDSI	Luna Defense Systems Inc.
LOS	Line of Sight
LPO	Launch Project Office
LV	Launch Vehicle
LVAB	Launch Vehicle Assembly Building
LVI	Launch Vehicle Interface
M&P	Materials and Processes
MDE	Motor Drive Electronics
MGSE	Mechanical Ground Support Equipment
MLI	Multilayer Insulation or Machine Language Instruction
MMS	Mass Memory Supervisor
MRB	Material Review Board
MTA	Magnetic Torquer Assembly

CDR Acronym List (Continued)

MUA	Material Usage Agreement
Mux	Multiplexer
NASCOM	NASA Communication
NDI	Nondestructive Inspection
NHB	NASA Handbook
NiCd	Nickel Cadium
NO-OP	No Operation
NSPAR	Nonstandard Parts Approval Request
NVR	Non-Volatile Residue
OAS	Orbital Adjust Subsystem
OSC	Orbital Sciences Corporation
P-E	Perkin Elmer
P/B	Play BAck
PA	Performance Assurance
PAF	Payload Attach Fitting
PAIP	Performance Assurance and Implementation Plan
PAMPL	Project Approved Materials and Processes List
PAPL	Program Approved Parts List
PAR	Performance Assurance Requirement
PCA	Physical Configuration Audit
PCMTS	Power and Control/Monitor Test Set
PCU	Power Control Unit
PDA	Preliminary Design Audit
PDF	Programmable Data Formatter
PF	Powered Flight
PIL	Parts Identification List
PMPCB	Parts, Materials, and Processes Control Board
POCC	Payload Operation Control Center
PPL	Preferred Parts List
PPT	Peak Power Tracking
PRI	Primary
PWB	Printed Wire Board
QA	Quality Assurance
QCI	Quality Conformance Inspection
QD	Quality Directive
QPL	Qualified Parts List
QPR	Quality Project Requirement
R/T	Receive/Transmit
RAM	Random Access Memory
RDNT	Redundant
RF	Radio Frequency
RFTS	Radio Frequency Test Set
RIU	Remote Interface Unit
RPM	Revolutions Per Minute
RSS	Root Sum Squared
RT	Real Time
RTC	Relative Time Command
RTCS	Relative Timed Command Sequence
RWA	Reaction Wheel Assembly
S&MS	Structure and Mechanisms Subsystem

CDR Acronym List (Continued)

S/A	Solar Array
SAR	Solar Array Regulator
S/C	Spacecraft
SC ADDR	Spacecraft Address
SELV	Small Expendable Launch Vehicle
SEMCAP	Specification Electro-Magnetic Compatibility Analysis Program
SEU	Single Event Upset
SIS	Spacecraft Interface Simulator
SOH	State-of-Health
SP	Spacecraft Processor
SQAM	Software Quality Assurance Manual
SRS	Software Requirements Specification
STC	System Test Controller
STM	Structural Test Model
S/W	Software
SWA	Scan Wheel Assembly
SYNC	Synchronous
T-O	Time Zero
T/C	Telemetry/Command
T/V	Thermal Vacuum
TAM	Three-Axis Magnetometer
TBD	To be determined
TBR	To be Reviewed
TCA	Thrust Chamber Assembly
TCTS	Telemetry and Command Test Set
TCVL	Temperature Compensated Voltage Limit
TDE	Torquer Drive Electronics
TFS	TOMS Flight Software
Tlm	Telemetry
TML	Total Mass Los
TRASYS	Computer Program
U/L	Up Link
USART	Universal Synchronous Asynchronous Receiver Transmitter
UTB	Universal Test Bed
UTC	Universal Time, Coordinated
UV/OV	Under Voltage/Over Voltage
VAB	Vehicle Assembly Building
VAX	Mini-computer
VCM	Volatile Condensible Material
VDC	Volt Direct Current
VDE	Valve Drive Electronics
VDEA	Valve Drive Electronics Assembly
Vp-p	Volts Peak to Peak
WDT	Watch Dog Timer
XMTR	Transmitter
Xponder	Transponder