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Abstract

The Cassini Spacecraft will be launched on an expedition to Saturn in October 1997. The mission is an eleven year operation, the first seven years traveling to Saturn via a combination of propulsion bums and Venus-Venus-Earth-Jupiter gravity-assist, and the remaining four years orbiting Saturn while exploring the planet, it's moons, rings, and nearby icy satellites. The propulsion module subsystem provides thrust and torque to the spacecraft. Larger Delta-Vs are provided by a primary (with redundant backup) pressure-regulated 490-N engine, which burns nitrogen tetroxide (N-J-O) and monomethylhydrazine (MM}]); total propellant capacity is 3000 Kg. Saturn Orbit Insertion (S01) is accomplished with a 170-minute (maximum duration) continuous firing of the bipropellant engine. Attitude control of the spacecraft is maintained by 1-N thrusters (a total of two redundant pairs per each of four clusters), which operate in a blowdown mode, with the monopropellant tank (containing 132. Kg of hydrazine) recharged once from a dedicated helium pressurant bottle. A significant development program was implemented to provide design verification of major assemblies, and to extend the. performance capabilities of heritage components. The flight hardware is currently in the final integration and test phase prior to shipment to JPL for integration with the spacecraft.

Introduction

Historical Background

Cassini has its roots in the Saturnian system exploration studies that began in 1989 with the CRAF/Cassini Program. That Program involved two separate spacecraft -- the CRAF (Comet Rendezvous and Asteroid Flyby), originally targeted for a 1995 launch to flyby an asteroid and eventually rendezvous with a comet; and Cassini, slated for a 1996 launch to explore Saturn and its many satellites and rings.

Although going through major changes since its inception, Cassini remains an international cooperative effort of NASA, which is producing the main orbiter spacecraft (S/C); the European Space. Agency (ESA), which is providing the Huygens Probe; and the Italian Space Agency (ASI), responsible for the S/C radio antenna and portions of three scientific experiments. The mission is being managed by NASA's Jet Propulsion Laboratory (JPL), where the orbiter is being designed, built and tested.

in keeping with the international flavor of CRAF/Cassini from its inception, the earliest S/C Propulsion Subsystem was to be built by the Federal Republic of Germany (FRG). Technically, the Germans were. contributing one propulsion subsystem for the CRAF Mission and a spare subsystem that was to be. used for the Cassini Mission. From the start, the Propulsion Subsystem consisted of a large, helium regulated bipropellant system, and a much smaller hydrazine system for reaction control and smaller AV maneuvers.

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Due to budget cuts in 1992, the Cassini Program was downsized, and the CRAF S/C was canceled. Following this decision, the FRG elected to end their participation in the Program. At that point, the decision was made at JPL to procure the entire Propulsion Subsystem from industry. This propulsion contract was eventually won by Lockheed Martin Astronautics in Denver and started in April 1993.

Spacecraft Description

The propulsion module forms the core of the Cassini Spacecraft, sandwiched between the upper and lower equipment modules. The Cassini Propulsion Module Subsystem (PMS) features a stand-alone, modular configuration, designed to be assembled, tested, and loaded independent from the remainder of the S/C. Figure 1 shows an isometric view of the spacecraft, delineating the location of the propulsion module.

In addition to interfacing with the upper and lower equipment modules, the PMS provides the structural support interface for the Huygen's Probe. The upper equipment module contains the majority of the spacecraft subsystems and science instruments, while the lower equipment module provides support for the RTG's which supply spacecraft power and waste heat for thermal control of the spacecraft. The PMS is cocooned in an aluminum Kapton thermal blanket between the two equipment modules. This blanket also provides micro-meteoroid protection.

Mission Description

In October 1997, the two-story high Cassini S/C is scheduled to begin an eleven-year odyssey that will include a cruise phase to Saturn, covering almost seven years, followed by a four-year exploration of Saturn's rings, moons, and icy satellites. A Titan IV/Centaur launch vehicle is utilized for injecting the S/C into inter-planetary cruise. Once on its way to Saturn, the S/C flies a VVEJGA trajectory, involving gravity assists from two Venus flybys and one each from Earth and Jupiter before arriving at Saturn in July of 2.004, as illustrated in Figure 2.. A large burn of the bipropellant rocket engine is used to slow the S/C for Saturn orbit insertion (S01).

Once in orbit, the mission explores Saturn for four years: its moons, rings, and the Saturnian magnetic environment. Cassini also carries the Huygens Probe which is designed to study the atmosphere and surface of Saturn's largest moon, Titan. The probe will be released from the S/C some months after SOI; it's targeted to arrive at Titan and begin its parachute descent to the surface in November 2004. The probe will provide the first view of Titan's surface and the first direct sampling of its atmospheric chemistry.

System Design Requirements

Key Design Requirements

Some of the key system design requirements that drove the design of the PMS were:

- Eleven year operational capability
- Standalone design to accommodate off-line testing and servicing
- No single point failures except for the standard structural exemptions
- 3,000 kg bipropellant capacity (MMH and N_2O_4)
- 131 kg monopropellant hydrazine capacity (N_2H_4)
- Common He pressurant supply for the bipropellant and monopropellant systems
- All welded fluid system
- Redundant bipropellant rocket engine capable of up to 200 starts and a continuous burn duration of 170 minutes
- Redundant hydrazine thrusters capable of up to 267,000 pulses and a continuous burn duration of 120 minutes
- Total PMS dry mass less than 512 kg (excluding cabling, engine gimbal actuators, and thermal blankets)
- Tight control on magnetic fields, including use of compensation magnets for valve solenoids.
- Special outgassing requirements requiring vacuum bakeout and/or special handling during fabrication /assembly.

Post-MO Design Changes

The PMS design had progressed to a PDR-level maturity at the time of the Mars Observer (MO) failure. The original design incorporated a single. He pressurant tank and pressure Control Assembly (PCA) that provided regulated pressure to both the. monopropellant and bipropellant systems. As a result of concerns stemming from the subsequent MO failure review, a number of sweeping changes were made to the Cassini PMS design.

One of the leading potential causes of the MO failure was the condensation of propellant vapors in the pressurant system lines. This liquid slug may have reacted in the lines with liquid from the other bipropellant, or may have been forced into the opposite bipropellant tank, reacting violently and rupturing the tank. To preclude a similar problem on Cassini, several major design changes were. implemented between PDR and CDR.

The first significant configuration change. was m separate the bipropellant and monopropellant pressurization systems, as shown in Figure 3. The monopropellant system was changed to a rechargeable blowdown system patterned after the successful Magellan propulsion system.

In order to limit the quantity of oxidizer vapor available in the pressurization system, a burst disk assembly and a "ladder" of eight normally open (NO) and normally closed (NC) pyro valves were added between the PCA and the oxidizer tank. This new hardware combination allows oxidizer vapor isolation for over 90% of the mission. The accumulation of oxidizer vapor poses a triple threat because. it is particularly corrosive, can combine with fuel vapors and form a sticky sludge, and can condense. A similar pyro ladder could not be added to control fuel vapor due. to limitations of the existing pyro system.

During periods when the oxidizer tank is pyro isolated, a leaking regulator would present a serious problem since the leaking helium would flow into the fuel tank. This would lead to mixture ratio problems, and eventually a concern for structural integrity of the tank itself. Therefore, it was necessary to add a ladder of six NO/NC pyro valves between the high pressure helium tank and the PCA. Whenever the oxidizer tank is isolated, the helium tank will also be isolated from the PCA.

In order to prevent the formation of liquid in the pressurization system due to propellant vapor condensation, heaters were added to the Pressurant Control Assembly. Also, the PCA mounting structure was changed from aluminum to fiberglass to reduce the heat loss and thereby minimize the required heater power.

Mission.. Requirements

Nominal Mission Scenario

The primary launch period opens on October 6, 1997, and lasts for three to four weeks. Table 1 lists the key propulsion maneuvers required for this long ant] challenging mission. There may be. as many as 100 additional ΔV maneuvers during the Saturn tour.

One of the major challenges for the PMS is to maintain the balance between controlling the migration of bipropellant vapors throughout the pressurization system while still providing sufficient tank pressures at all times [o keep the bipropellant engine operating within its qualified regime. This leads to the desire to perform as much of the mission as possible with the bipropellant tanks regulated. On the other hand, based upon concerns over the harmful effects of bipropellant vapor condensation and mixing, there is a desire m keep the oxidizer tank isolated as much as possible, therefore requiring blow-down operation of the engine, Finally, isolating the high pressure helium source as much as possible is also important to minimize tank pressure increases from a leaking regulator.

The selected bipropellant vapor isolation strategy for the primary mission is shown in the last column of Table 1. As indicated, the primary mission requires three pressurization system open/close cycles to meet the above stated objectives: 1) the first cycle pressurizes the. bipropellant Links shortly before the first trajectory correction maneuver (TCM-1) and pyro isolates approximately a month after 'l-CM- 1 (providing adequate time. m accomplish helium saturation of each bipropellant); 2) the second cycle re-pressurizes the system shortly before the Deep Space Maneuver (DSM- 1) and pyro isolates a day after; and 3) the final cycle Te-pressurize the system around 30 days before the critical Saturn Orbit Insertion (S01) maneuver (to perform an SOI practice maneuver) and pyro isolates a day after the Perijove Raise Maneuver (PRM). For this scenario, the oxidizer vapors are isolated for all but 141 days of the mission (isolated more than 96% of the eleven-year total), and the bipropellant tank pressures fall to only ?.19 psia for the portion of the mission up to SOI and to only 200 psia by end of mission (EOM).

The final pyro isolation following the critical SOI maneuver may be skipped, or at least deferred, as long as the PMS pressurization system performance is nominal. This will maximize engine performance and propellant utilization with little mission risk, since the system can be isolated at the first sign of trouble. Blowdown operations initiated with the. tank ullage conditions existing at that time is acceptable for the remainder of the mission.

Mission Dependency on PMS Design

Considering the pyro valve resources available for pressurization system isolation, the question arises as to the ability of the PMS to meet the previousl y stated objectives for the possible combinations of launch periods and different mission types (primary, secondary, and backup). Since it is not feasible m look at every combination of variables, each of the three mission types were compared for three different launch periods -- early, mid, and late, whit}] bounds the solution. The result of this analysis is shown in Table 2.

As seen in Table 2, the secondary and backup missions both require four pyro isolation cycles (compared to three for the primary mission) to approximate the regulator on-line time of the primary mission. Even with the extra cycle, the cumulative on-line time is greater and the minimum blowdown pressures are lower. As blowdown pressures are. lowered the engine becomes more susceptible to performance degradation (chugging rind loss of Isp), which must be accommodated in mission operations. As in the case of the primary mission, final isolation after PRM is viewed as optional for these mission scenarios, as long as pressurization system performance is nominal.

Propulsion Subsystem Description

The concept and early configuration of the Propulsion Module Subsystem (PMS) had its beginnings at MBB in Germany when the Program included both CRAF and Cassini. After the CRAF mission was deleted JPL began working in-house to further define the propulsion subsystem concept that would deliver the spacecraft and Huygens Probe to Saturn. The decision was made to contract for the subsystem and Martin Marietta Astronautics (later becoming Lockheed Martin Astronautics) was selected to build, test and deliver the PMS, and support it's system testing and servicing through launch. A design transfer process occur-red between JPL and LMA at the beginning of the subcontract, at which point LMA started the process of design development leading to procurement of hardware and parts, fabrication of the subsystem, and subsystem level acceptance testing. During this time JPL personnel worked closely with LMA Integrated Product I'cams, together accomplishing the completed and verified PMS development.

The resulting PMS is configured in a modular approach both with respect to the remainder of the spacecraft, and within the PMS itself, as shown in Figure 4. The central cylindrical core structure supports two large identical Bipropellant Tank Assemblies (BTA) in the center (fuel located above the oxidizer); the remaining propulsion assemblies are located around the exter i or. Major elements attached to the exterior are a High Pressure Tank Assembly (HTA), two Pressurant

Control Assemblies (PCA 1 and PCA?), two Propellant Isolation Assemblies (PIA 1 and PIA2), a Monopropellant Tank Assembly (MTA), a Main Engine Assembly (MEA) and Thruster Cluster Assemblies (TCA) supported via rigid tripod boom assemblies to the core.

The BTAs are 49-inch diameter, cylindrical 6Al- 4V Titanium tanks wit} h passive. vane-type Propellant Management Devices (PMDs), which are similar in configuration to those used in the Viking Orbiter Tanks. Tank volume is a nominal 49 cubic feet. The pressurant tube and liquid outlet line both enter the lower dome of the tank through a common fitting. The tank maximum operating pressure at 45°C is 330 psi. The shells were designed using a Fracture Mechanics Factor of Safety (FMFS) of 1.35 up through the last man-rated pressure cycle of the first service life, and 1.15 through the remainder of the first service life. An FMFS equal [o 1.0 was used for service lives two through four. The MTA is a 6Al-4V Titanium tank with an AF-E-332 diaphragm, designed for a maximum operating pressure at 45*C of 420 psi.

The HTA is a composite vessel with graphite epoxy exterior over an aluminum liner. Maximum operating pressure is 3741 psia at 45°C. The RTA is a small 6AI-4V Titanium sphere of (). 3cubic foot volume., with a maximum operating pressure of 3000 psia. It is used in a continuous flow, single event blowdown mode to resupply pressure (recharge) to the MTA midway through the mission.

The Main Engine Assembly (MEA) consists of redundant Kaiser-Marquardt R4-D 490- N Rocket Engines Assemblies (REAs). Since the entire mission is designed to use the A-side engine only, with the B-side as a backup, a gimbal assembly was incorporated into the mounting of each REA to account for center-of-mass alignment during all mission main engine burns. Heaters are provided on the engine. mounting plates and oxidizer valves for adequate thermal control during times of significant cold temperature excursions.

Spacecraft attitude is provided by 1-N hydrazine thrusters built by Olin Aerospace. A total of 8 thrusters, one each in the Y and Z directions at each of 4 cluster locations provide. maneuvering capability up to 7203 seconds during a single firing. A completely redundant set of thrusters is also provided, for a total allotment of 16 thrusters. These thrusters utilize a fast response Moog valve similar to that used on the Voyager busters to provide minimum impulse bits on the order of 15mN-sec.

The PMS schematic is presented in Figure 5. The totally separate bipropellant and monopropellant assemblies are included on the schematic. The schematic readily illustrates the high degree of component and system functional redundancy built into the Pressurant Control Assemblies (PCA1 and PCA2) and the Propellant 1 solation Assemblies (PIA 1 and }'IA?.). Also illustrated on the schematic is the significant number of pressure transducers and temperature sensors.

The high pressure portion of PCA1 extends from the HTA to the pyro valves upstream of the redundant regulators; the components and lines are stainless steel with a transition tube interfacing with [he aluminum liner outlet on the HTA. A set of pyro valves and Burst discs isolates the. remainder of the PCAs from the bipropellant tanks. The tanks are launched with a pad pressure of 100 psia, and the PCA pressure between the regulators and the pyro valves/burst discs is held at 50 psia for launch 10 preclude premature activation of the burst discs, which are set for a 70 psi differential. The burst disc assemblies are included primarily for vapor migration control during ground handling since the tanks are scheduled for loading as much as six months before launch (Note: The PMS will be loaded in SAEF2 and then h ansported to PHSF where the remainder of the spacecraft will be assembled around the loaded PMS).

The feed system plumbing downstream of the tanks is launched with a pad pressure of 100 psia also. The feed system plumbing is mostly titanium, the notable exceptions being pyro valves and the. main engine valves. This was selected to preclude significant ferric nitrate formation during the 11- year mission life. Once the Cassini spacecraft reaches orbit, hearers mounted on the BTAs will be activated to increase propellant temperature to control thermal ratchet potential associated with the significant amount of pressurant required for early mission bums, and initial tank pressurization to the nominal 240 psia level.

Once the tanks are fully pressurized the A-side Main Engine feedlines are filled with propellant. A Venturi is included in each line to minimize the water hammer effects. The B-side engine lines are not charged unless a decision is made m activate the B-side engine. After the completion of the first main engine bum and periodically at other times during the mission, the normally open (NO) pyro valves upstream of the oxidizer tank and between the HTA and the regulator are fired closed to prevent oxidizer vapor from traveling upstream and mixing with fuel vapor to form reactant products. Isolating the HTA precludes potential system overpressure conditions from leaky components, since this is normally handled by the large volume potential offered by the propellant tanks. Fault protection for overpressure conditions is a key system design feature. "he main engine can be operated in a blowdown mode for some trajectory correction maneuvers while the isolation system is operative, precluding regulated propellant feed to the engine.

The hydrazine tank is vacuum loaded, the latch valves arc opened and the lines are wetted to the thruster valves. Following stabilization the latch valves are closed for launch after pressurizing to the 400 psi flight level. The bulk of the hydrazine is isolated from the thrusters at launch by two mechanical seats (latch valve and thruster valve), During flight, the monopropellant hydrazine supply is continuously operating in a blowdown scenario. Once approximately a quarter of the 132 Kg of hydrazine has been fed to the thrusters, the MTA pressure can be recharged by firing one of the redundant pyro valves, which allows the RTA to discharge the much higher pressure helium into the MTA for repressurization.

The PMS electrical block diagram is presented in Figure 6. The flight power and telemetry interfaces associated with the PMS flight components are listed along with the number of specific electrical elements interfacing with either the flight PMS Electronic Assembly (PMSEA), which is mounted to the PMS Core Structure., or the other spacecraft subsystems (power and pyro subsystem, attitude and articulation control subsystem and command and data subsystem).

A total of 228 individual interfaces are accommodated. A total of 81 temperature sensors and 18 pressure transducers provide system health status together with 10 latch valve position indicators. Due to the. relatively long (up [090 minutes one way) communication time with the spacecraft, autonomous fault protection is provided for critical mission events. The most significant of these events is the Saturn orbit Insertion (S01) bum, which lasts between 95 and 1-/5 minutes depending on the specific mission operations scenario enacted when the spacecraft arrives at Saturn. If a major main engine failure occurs and REA pressure or temperatures exceed redlines, then the fault protection system automatically terminates the burn. A timer is then set, which will start the second engine after a 60-minute hold programmed to allow for second engine cooldown from radiation heating, prior to its firing to complete the SOI,

The PMS mass and power summaries are itemized in Table 4. The dry masses of the individual assemblies are listed along with other mass numbers for supports, brackets, clamps and other miscellaneous hardware, including all PMS system interconnecting tubing and supports, The significant size of the subsystem flight hardware is indicated by the nearly 500 Kg of dry mass. The propellant and pressurant capacity is over 3140 Kg. This represents by far the largest, highest delta velocity stage designed and built for planetary missions. The power for those components using spacecraft electrical power are also presented in the table. These valves are for worst-cast, steady state operation (except for first 100 msec of REA valve operation). Voltage values range from 29.01030.25

except for [he RFA valve during the first 100 msec, which was activated by 2.6.7 volts.

The PMS has completed fabrication and assembly in Denver. The flight hardware is shown in Figure 7. The fully assembled subsystem is shown in the center of [he. figure, surrounded by views of some of the assemblies. The subsystem is shown standing on a mobile work platform that is used to transport the PMS within handling and servicing facilities at Denver. JPL or the Kennedy Space Center prior to its final integration with the remainder of the spacecraft. Also shown is a breakout box used during final acceptance testing in Denver m status component performance. The hardware is set to be shipped to JPL the end of July or early August 1996, where it will be integrated with the rest of the spacecraft prior to proceeding into system environmental testing.

Summary

A propulsion module subsystem has been designed. built, tested and is now ready for delivery to JPL for spacecraft integration, and environmental and integrated spacecraft functional testing. It will then be disassembled from the spacecraft, and delivered m the Kennedy Space Center, where it will be loaded with propellant, reassembled with the spacecraft and prepared for the October 1997 Cassini launch aboard a Titan IV Centaur.

The PMS represents the largest and most flexible planetary propulsion subsystem yet built. It has the required capability to deliver the spacecraft and science payload to Saturn during the first seven years from launch, and carry out the planned exploration of the Saturian system over the next four years. Extensive hardware and system design development has been accomplished to push the previously characterized performance boundaries to new limits, and to provide sufficient redundancy and fault protection to enhance confidence of mission success in the face of the unknowns that accompany such an aggressive mission to such an interesting part of our Solar System.

Table 4 Mass and Power Summary

Major Assemblies	Mass - Kg
- Structure (core)	111.1
- BTA (ox and fuel)	147.7
- HTA	41.6
- MIA	18.9
- HTA & M-I-A supports	9.7
- PCA - 1	25.3
- PCA-2	7.8
- PIA-1	18.8
- PIA- 2	9.8
- PIA & PCA supports '	10.0
- MEA (including engines)	35.7
- MEA struts & fittings	5,2
- TCA (including thrusters)	13,8
- TCA booms & fittings	19.3
System Interconnect hardware and supports	19.1
TOTAL PMS DRY MASS	491.9
Helium	8.7
Hydrazine	132.0
MMH	1132.0
NTO	1868.0
TOTAL PMS WET MASS	3632.6
Component Power Consumption	**Power - Watts***
- Pressure transducer	0.30
- TVA Catbed heater	?.30
- Thruster valve	4.35
- HP latch valve	11.03
- LP gas latch valve	11.03
- Monoprop latch valve	10.61
- Biprop latch valve	49.92
- REA valve (1 st 100 msec)	83.60
- REA valve (after 100 msec)	
- MEA plate heater (prim&sec)	8.72
- REA Ox valve heater	2.39
- BTA heater (prim&sec)	41.78
- PCA 1 & 2 heater (prim&sec)	9/43
- He line heater	0.55

* worst case

Table 3 Cassini PMS Components

Component	Supplier	Flight Heritage / Similarity
Bipropellent Tanks (BTA)	Lockheed Martin Astronautics	New Design (Qualified)
Monopropellant Tank (MTA)	Pressure Systems Inc (PSI)	Shuttle APU, Magellan
Helium Tank Assembly (HTA)	Lincoln Composites	New Design (Qualified)
Recharge Tanks Assembly (RTA)	Arde	New Design (Qualified)
Rocket Engine Assembly (RCA)	Kaiser Marquardt	IABS, Mars Observer (Qualified for expanded operational envelope)
Main Engine Assembly (MEA	Lockheed Martin Astronautics	Dew Design (Qualified
Thrusters	Olin Aerospace Corporation (OAC)	Voyager (0.2 lb thruster with Moog valve)
High Pressure Latch Valve	Eaton	EURECA Intelsat VI COBE, DSP (Delta Qualified)
Low Pressure Latch Valve	Eaton	EURECA Intelsat VI COBE, DSP (Delta Qualified)
Propellant Biprop Latch Valve (Ti)	Vacco	Numerous commercial / military spacecraft (Delta Qualified)
Filters	Vacco	Numerous commercial / military spacecraft (Delta Qualified)
Pyro valves (all SS)	OEA	Numerous spacecraft staring with Viking (requalified)
Services valves (SS & Ti)	OFA	Numerous spacecraft
Pressure Regulator	Mu Space Components	Heritage design (Requalified)
Check valves *Quad package	Sterer	Heritage design from Galileo - requalified as individual valve and quad assembly
Flexline (Titanium)	Avica	New Design (Qualified)
Venturi (Titanium)	Flow Systems	New Design (Qualified)
Burst Disc Assembly	Hydrodyne	Heritage Design (New Supplier . Requalified)
Temperature Sensors	Rosemount	Numerous spacecraft
Pressure Transducers	Gulton-Statham	ACTS, DMSP (requalified for design modifications)
Heaters (tanks, plates, engine valves)	Tayco	Numerous spacecraft

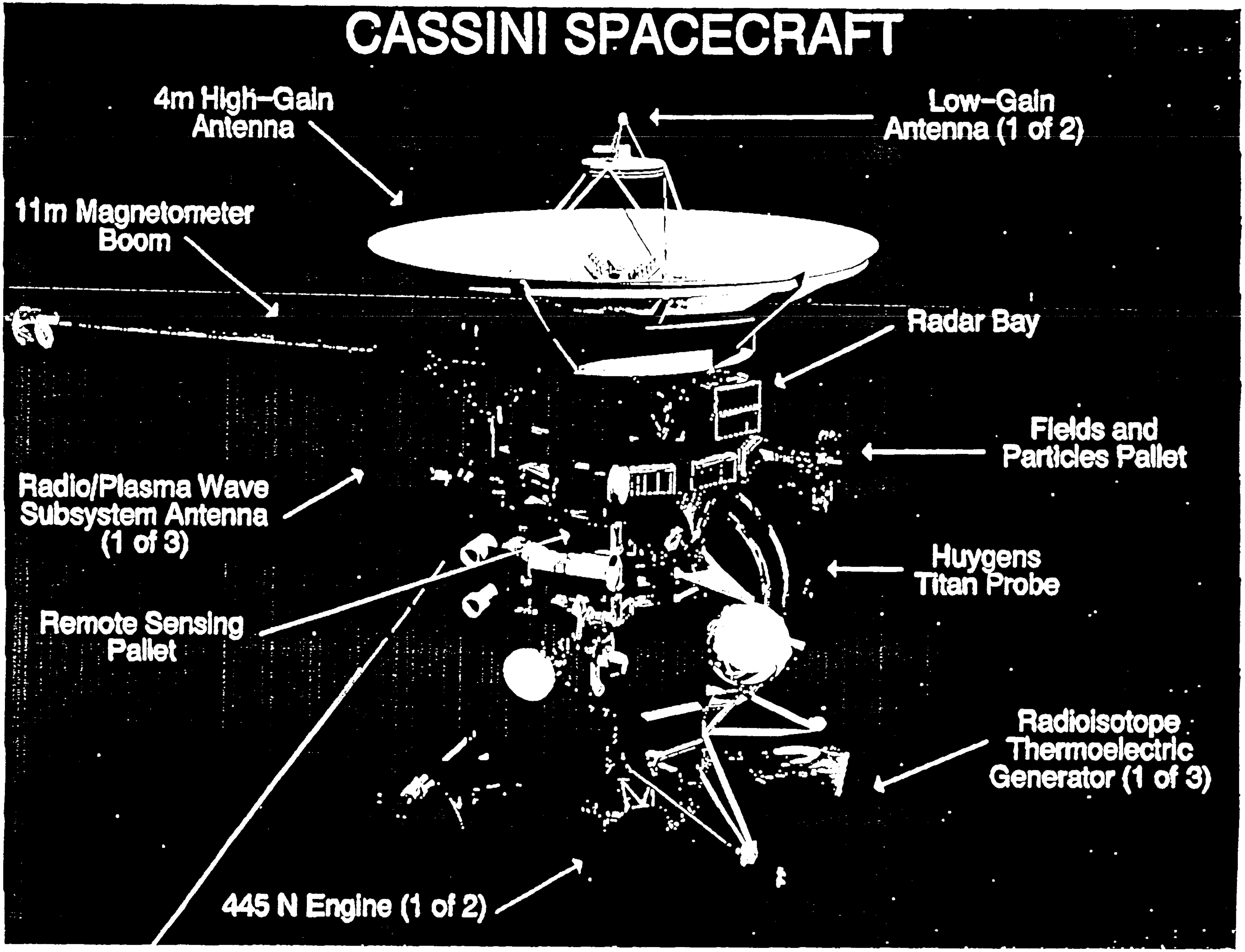


Figure 1 Cassini Spacecraft

FIGURE 3-2

CASSINI TYPICAL BASELINE "
TRAJECTORY

CASSINI OCT 1997 VVEJGA

Figure Z 1NTERPLANETAR% TRAJECTORY , "

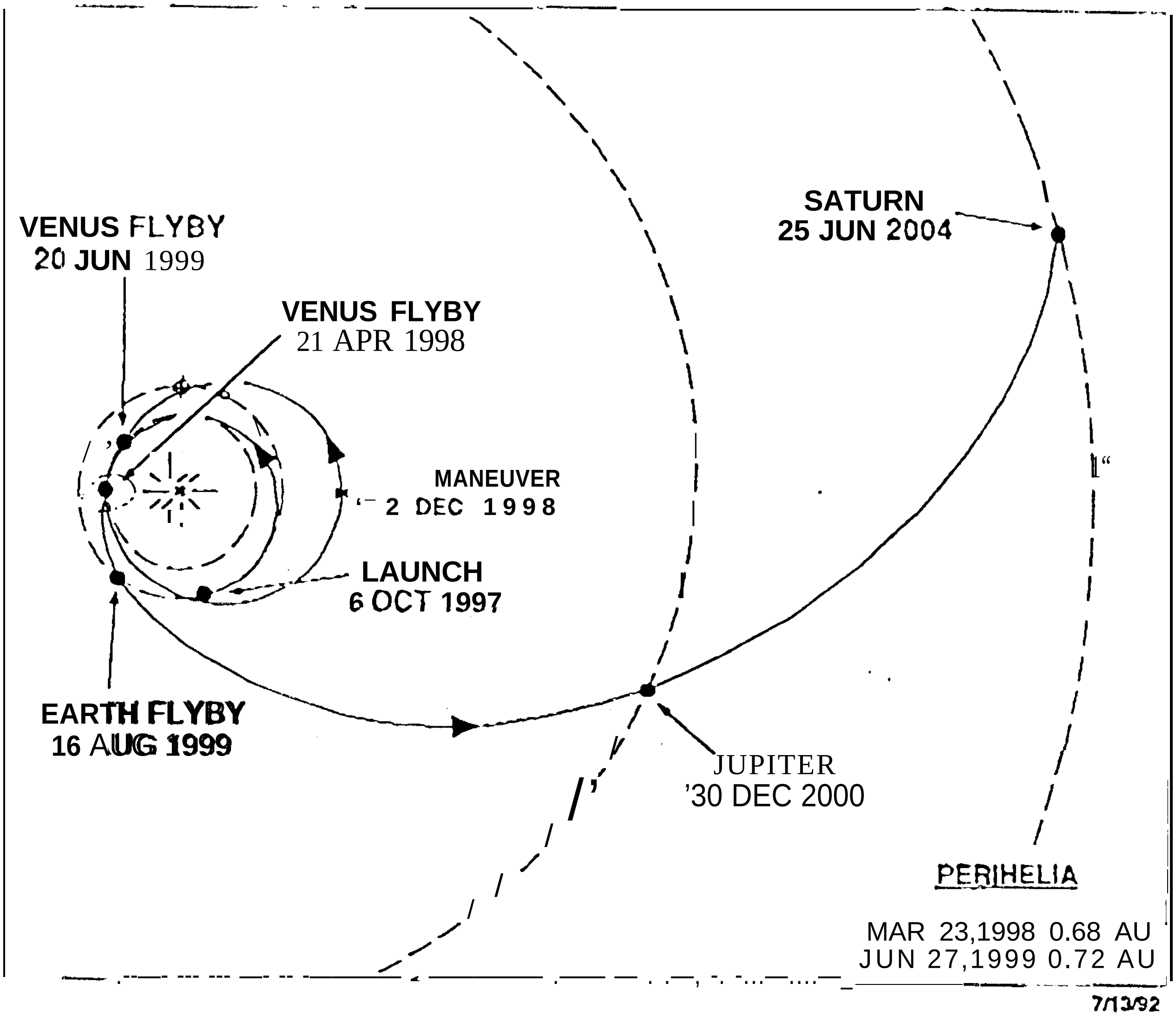
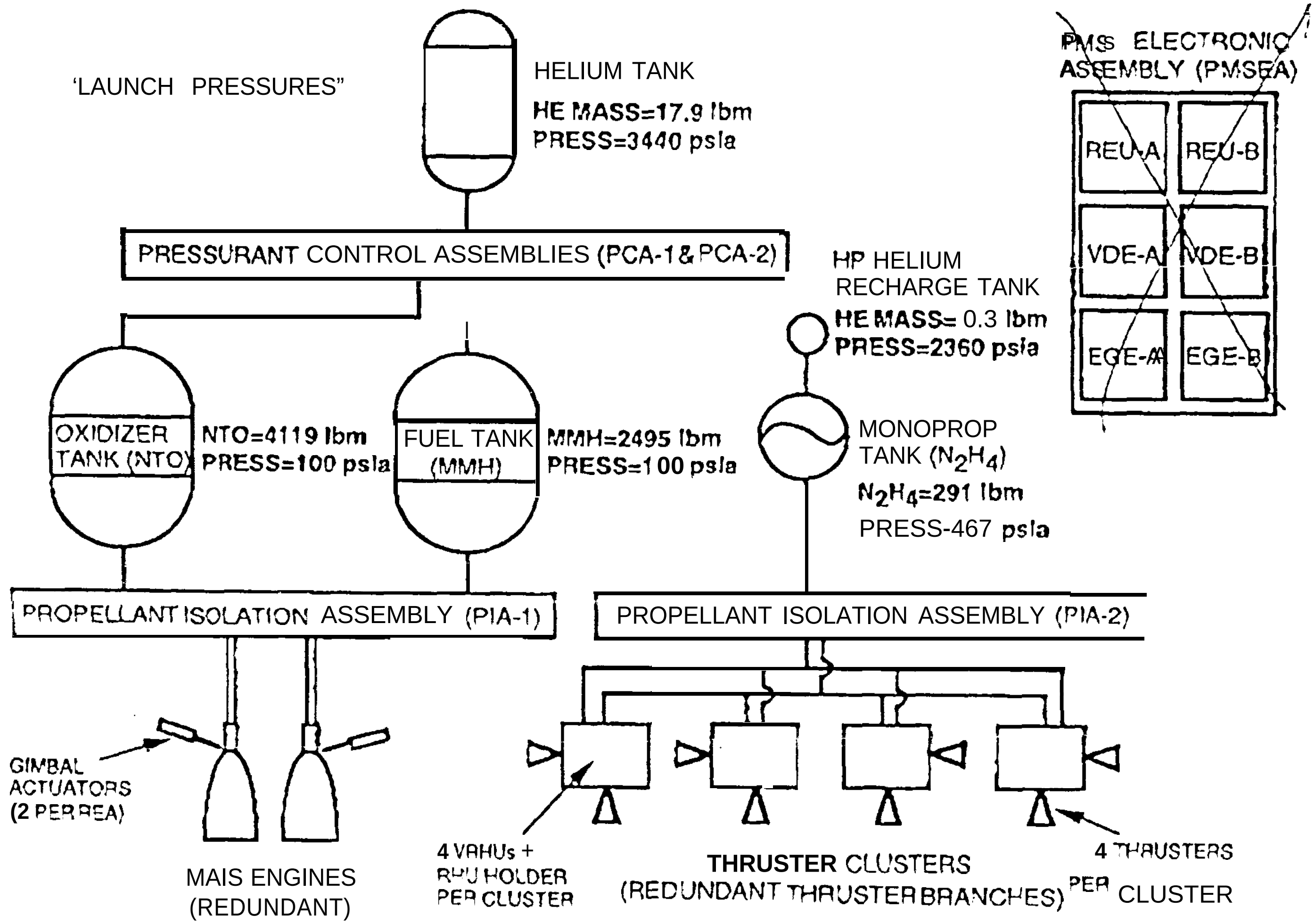


Figure 3

Simplified

CPMS Functional Block Diagram



LOCKHEED MARTIN / Jet Propulsion Laboratory

PMS

Cassini

February 19, 1996

Table 1 Primary Mission Sequence (High Delta V case)

~~Primary Cassini Mission (High Delta V Case)~~

Event	Event or Phase End Date	Days From Launch	High ΔV (mps)	Pre-Maneuver Pressure (psia)	Pre-Maneuver Mass (kg)	Pyro Isolation Status
Launch	10/22/97	0	0	100	5609	Isolated
Press'n	11/13/97	22	0	250	5609	O-1
TCM-1	11/16/97	25	24	250	5609	Regulated
Post Sat	12/15/97	55	0	250	5564	c-1
TCM-2	3/3/98	132	3.5	250	5564	Blowdown
TCM-3	4/12/98	172	0.3	243	5557	Blowdown
Venus-1	5/2/98	192	0	243	5557	-
TCM-4	5/22/98	212	25.6	205	5557	Blowdown
Repress	11/30/98	404	0	205	5509	0-2
DSM-1	12/2/98	406	435.4	25	5509	Regulated
Isolate	12/3/98	407	0	250	4760	c-2
TCM-5	1/5/99	440	13.8	250	4760	Blowdown
TCM-6	4/25/99	550	0.6	245	4738	Blowdown
TCM-7	6/4/99	590	0.1	245	4737	Blowdown
Venus-2	6/24/99	610	0	245	4737	Blowdown
TCM-8	7/4/99	620	82.7	245	4737	Blowdown
TCM-9	7/19/99	635	6.8	218	4607	Blowdown
TCM-10	8/8/99	655	3.8	216	4597	Blowdown
Earth	8/18/99	665	0	215	45.91	-
TCM-11	9/7/99	685	45.7	204	4591	Blowdown
TCM-12	6/12/00	964	2.2	203	4521	Blowdown
TCM-13	10/10/00	1084	0.7	203	4518	Blowdown
TCM-14	12/9/00	1144	1	203	4517	Blowdown
Repress	6/1/04	2414	0	203	4515	0-3
SOI	7/1/04	2444	594	250	4515	Regulated,
PRM	9/16/04	2521	264	25 Q	3701	Regulated
Isolate	9/17/04	2522	0	250	3387	c-3
ODM	12/3/04	2599	38	250	3387	Blowdown
Tour	7/1/08	3905	497	246	3344	Blowdown
EOM	7/1/08	3905	0	203	2830	-

Table II - Isolation Strategies for Primary, Secondary and Backup Missions

~~Summary of Isolation Events As a Function of Mission~~

	CASSINI MISSION TYPE		
	Primary Mission	Secondary Mission	Backup Mission
1. Number of Nominal Regulator Pyro Isolation Events	3 Opens/3 Closes	4 Opens/4 Closes	4 Opens/4 Closes
2. Regulator On-line Periods			
a. Pre/Post TCM-1	1) Open 2-3 days prior to TCM-1; Close 30 days after TCM-1	1) Same as Primary	1) Same as Primary
b. Deep Space Maneuvers	2) Open 2 days prior to DSM-1; Close 1 day after DSM-1	2) Open 2 days prior to TCM-4; Close 1 day after TCM-4	2) Open 2 days prior to TCM-5; Close 1 day after TCM-5
		3) Open 2 days prior to TCM-9; Close 1 day after TCM-9	3) Open 2 days prior to TCM-11; Close 1 day after TCM-11
c. SOI to FIRM Maneuvers	3) Open 30 days prior to SOI: Close 1 day after PRM	4) Same as Primary	4) Same as Primary
PMS Configuration During Earth Swingby Periods	"Benign State" i.e., blowdown mode with no pyro firings	Same as Primary	Same as Primary
Cumulative Regulator On-line Time (Days)	141	144	169
5. Minimum Blowdown Bipropellant Tank Pressure (psia):			
Prior to SOI	201	206	184
At EOM	180	174	178
Estimated Vapor Reaction Products at EOM (g)	0.0049	0.0095	0.0295

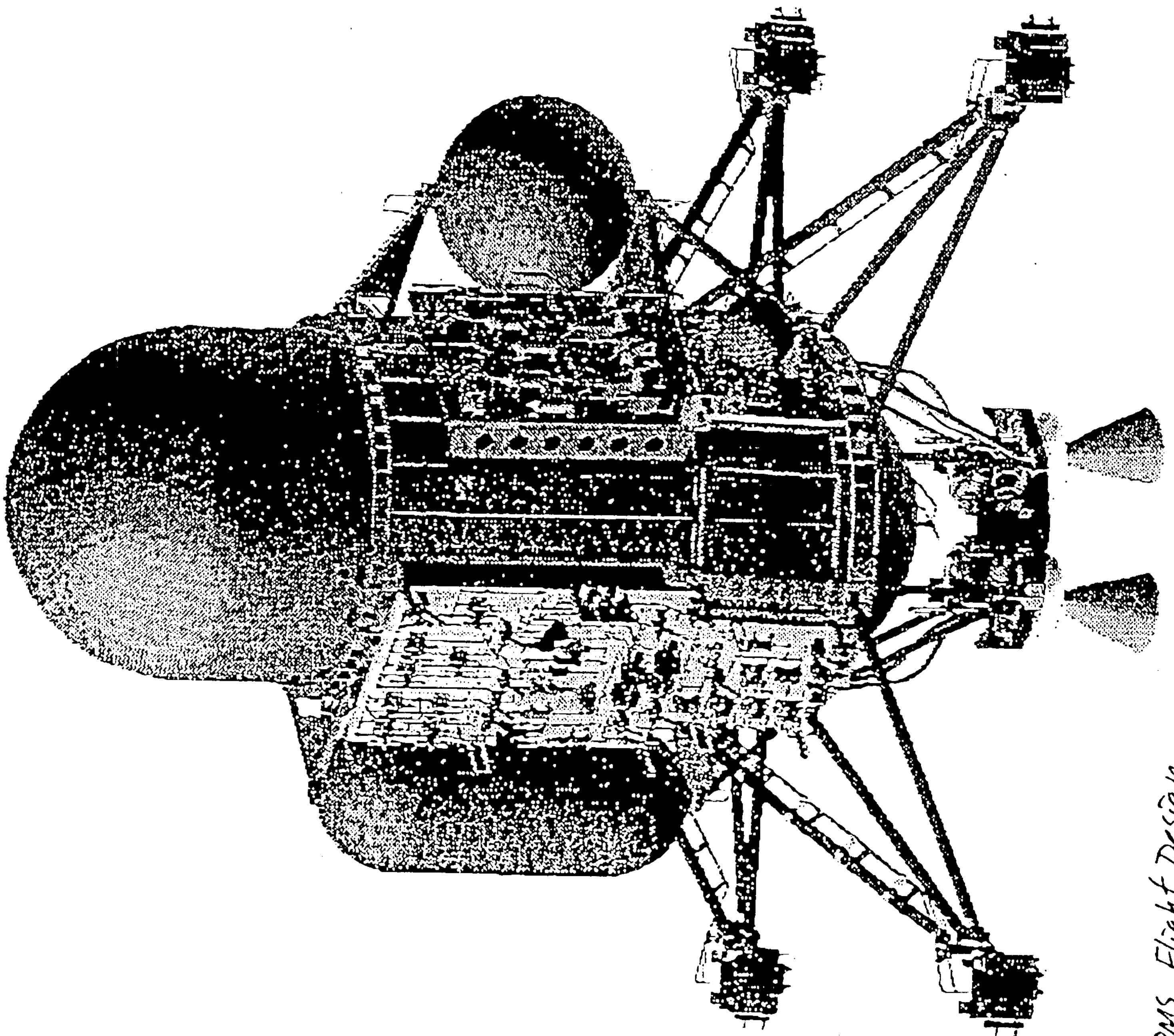
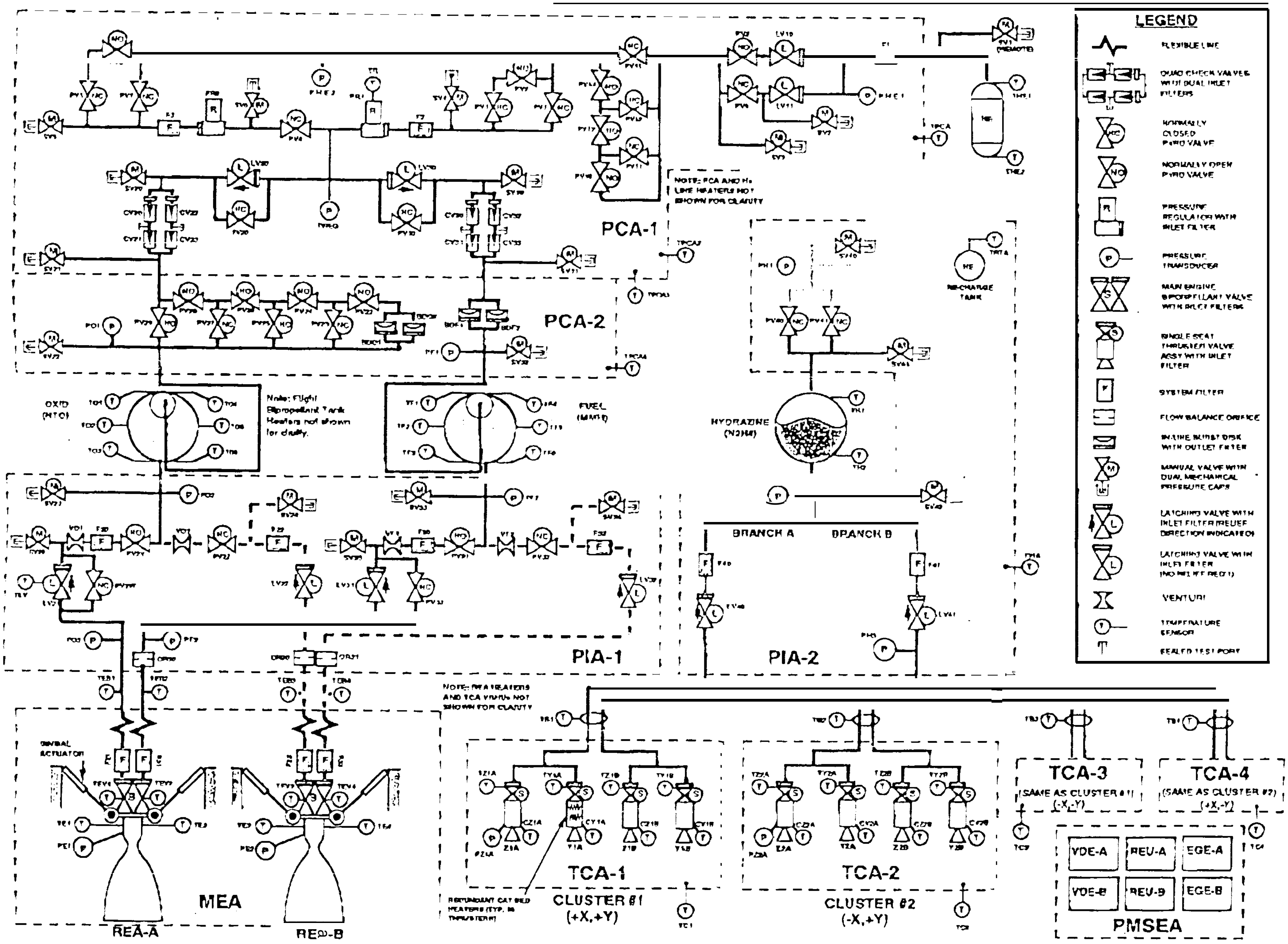


Figure 4 CPMS Flight Design

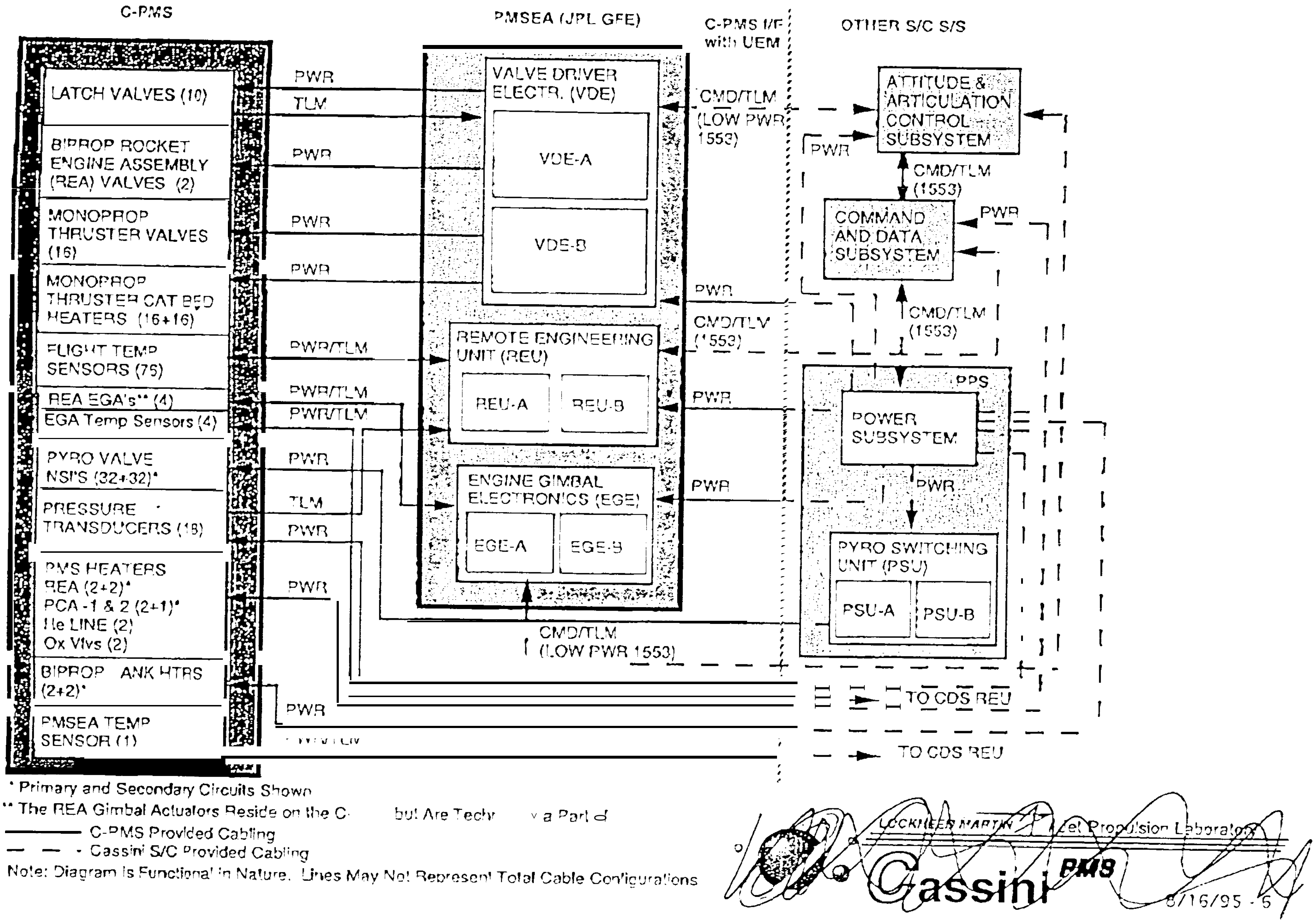
FIGURE ~~[illegible]~~ 5
REVISED 11/11/94

CASSINI PMS SCHEMATIC MEOP

High Pressure 3742 psia	Thermal Induced 460 psia	Hydrazine N_2H_4 420 psia
Regulated MEOP 330 psia	Thermal Induced 450 psia	Hydrazine Thermal 540 psia



uk6 - CPMS E ectrica Block Diagra n



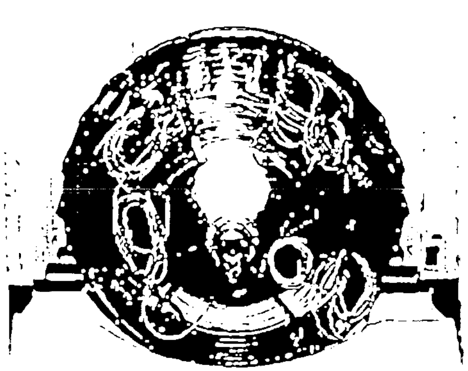
* Primary and Secondary Circuits Shown

** The REA Gimbal Actuators Reside on the C- but Are Techr v a Part of

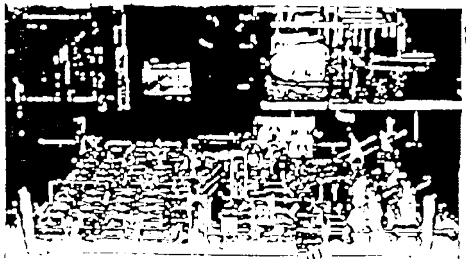
——— C-PMS Provided Cabling

— — - Cassini S/C Provided Cabling

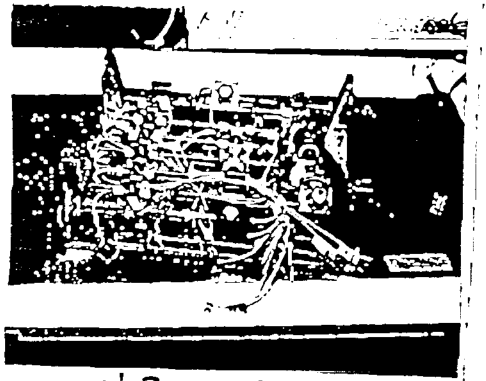
Note: Diagram Is Functional in Nature. Lines May Not Represent Total Cable Configurations



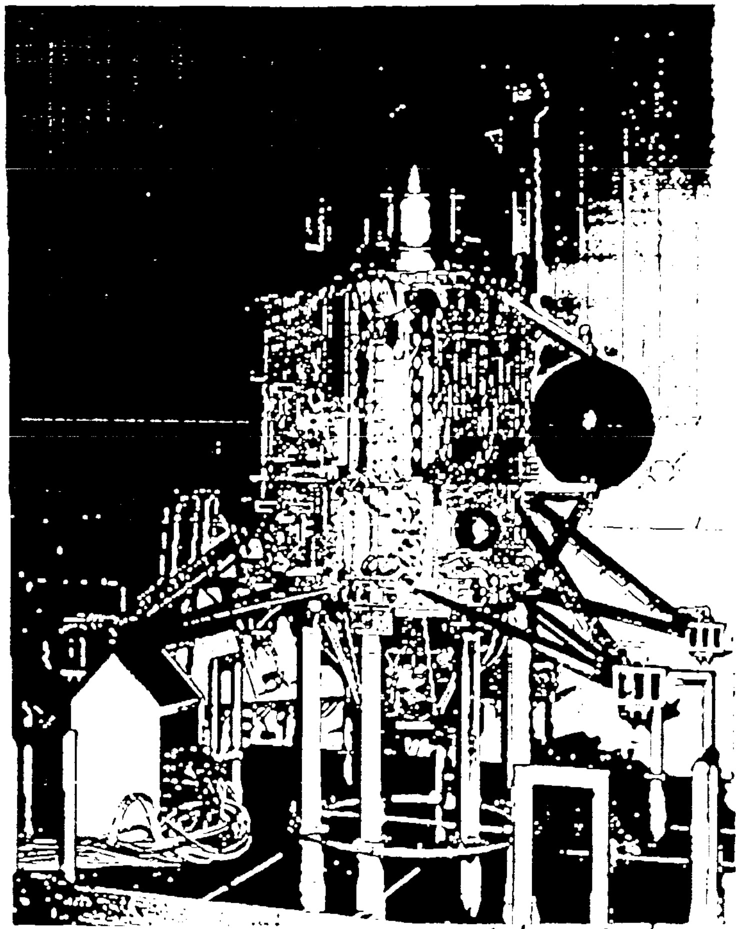
CN 4632-95
Bipropellant Tank Assembly
(Including heaters and instrumentation)



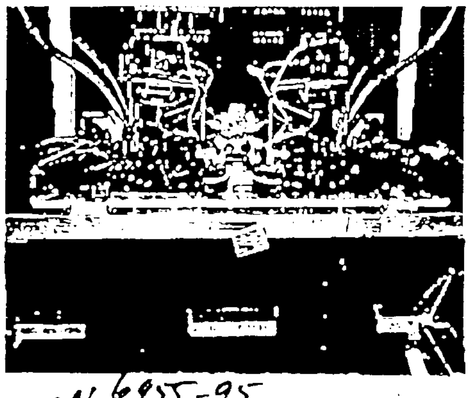
CN 7629-95
PCA 1 Assembly



CN 7020-95
PCA 2 Assembly

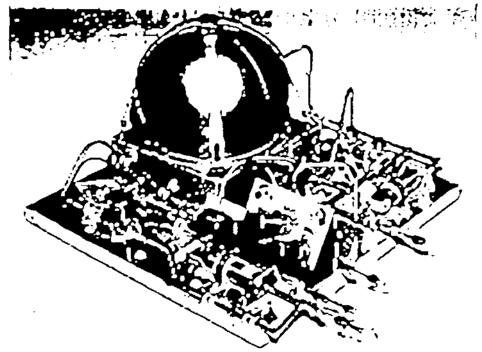


CN 2307-96

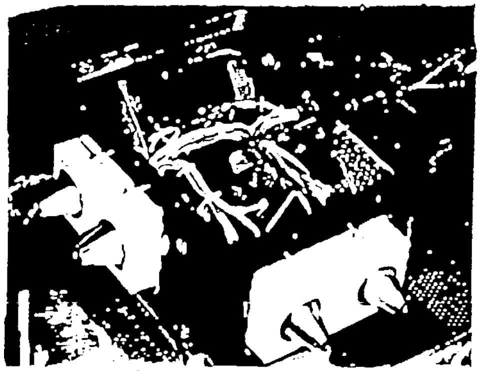


CN 6955-95
Main Engine Assembly

CN 2316-96
PIA 1 Assembly



CN 6799-95
PIA 2 Assembly (with RTA)



CN 5558-95
Thruster Cluster Assembly

Figure 7 CPMS Flight Hardware