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PHASE A REACTION CONTROL SYSTEM DESIGN FOR THE LARGE SPACE TELESCOPE (LST)

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Preliminary Design Office
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16. ABSTRACT

In response to a request from the Office of Space Science, a Phase A study of the Large Space Telescope was undertaken by the George C. Marshall Space Flight Center. The design of a Reaction Control System (RCS) for the LST was a part of this study, the results of which are reported in this document.

The primary requirement for an RCS on the LST is to serve as an emergency backup control system to the LST primary attitude control system. A regulated gaseous nitrogen RCS was selected, and a description of the operation of the system and its individual components is presented. An on-orbit maintenance procedure for the system is also described. The alternate RCS concepts considered during the study are summarized.

Principal design goals of the RCS for the LST were to minimize contamination effects, make use of existing components, and modularize the system to provide ease in manned orbital maintenance.

The RCS described herein will provide a point of departure for a more in-depth Phase B system design study. A summary of this report is presented in NASA TM X-64726, entitled "Large Space Telescope Phase A Report," and reference is made to that report for a description of all aspects of the LST.

17. KEY WORDS Large Space Telescope, Shuttle, Pressure Regulated Gaseous Nitrogen (GN_2), Reaction Control System (RCS), Attitude Control System, Tank, Black Box, Pressure Regulator, Thruster/Thruster Module, Valve/Plumbing, Manned On-Orbit Pressurized Maintenance	18. DISTRIBUTION STATEMENT STAR Announcement Erich E. Goerner Director, Preliminary Design Office

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TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

TECHNICAL MEMORANDUM X-64740

PHASE A REACTION CONTROL SYSTEM DESIGN FOR THE LARGE SPACE TELESCOPE (LST)

SECTION I. INTRODUCTION

The primary requirement for a Reaction Control System (RCS) on the LST is to serve as an emergency backup control system to the LST primary attitude control system. A regulated gaseous nitrogen RCS was selected, and a description of the operation of the system and its individual components is presented. An on-orbit maintenance procedure for the system is also described. The alternate RCS concepts considered during the study are summarized. A summary of this report is presented in NASA TM X-64726, entitled "Large Space Telescope Phase A Report," and reference is made to that report for a description of all aspects of the LST.

SECTION II. REQUIREMENTS, GUIDELINES, AND ASSUMPTIONS

The primary requirement for an RCS on the LST is to serve as a backup control system to the LST primary attitude control system (ACS). The actuators of the primary ACS consist of 4 single gimbaled Control Moment Gyros (CMGs) and 6 magnetic torquers. Each CMG produces a momentum of 678 N-m-sec (500 ft-lb-sec), and the magnetic torquers are used for continuous CMG desaturation. Normally, during the entire LST mission, it is anticipated that there will be no disturbance torques of a magnitude that the CMGs cannot overcome. However, it is envisioned that during certain critical LST maneuvers, abnormal control situations could occur and an RCS on the LST in a standby "go" condition would be highly desirable. For example, during separation of the LST from the Shuttle, the separation transients could be of a magnitude that the CMGs could not immediately overcome. The CMGs would become saturated and the LST could go into a tumble mode. With the LST in a tumble mode close to the Shuttle, a possible collision between the two could result. An RCS on the LST could provide the quick response necessary to bring the LST under proper control, thus avoiding a collision. Even if there were no chance of a collision, the LST could continue to tumble out of control for several orbits. The magnetic torquers would eventually desaturate the CMGs and the LST would be brought under control; however, the solar panels would not have been on line with the sun during this time to provide the needed power for the LST: thus, in the interest of orienting the solar panels on line with the sun as soon as possible after release from the Shuttle, an RCS can provide the quick response necessary to place the LST into its proper orientation.

Other LST RCS functions that could be required during the LST mission include control during misdock recoveries and during the actual docking of the LST to the Shuttle. In the event of a complete or partial failure of the LST primary ACS, the RCS would provide the control torques necessary until the Shuttle can arrive to perform maintenance on the failed system.

Table 1 presents a summary of the projected worst-case LST RCS impulse budget. In arriving at this impulse budget, the RCS is assumed to be required to perform each maneuver under an emergency condition with no assistance from the primary ACS. The total impulse budget was used to size the LST RCS. However, since the requirements for an LST RCS cannot readily be determined, some contingency should be added to this budget by allowing for redundant propellant in designing the RCS.

In designing an RCS for the LST, the following guidelines and assumptions were considered:

- The primary launch vehicle for the LST is the Shuttle with the Titan IIIE as an alternate.

- The CMGs are assumed to be spun-up prior to LST release from the Shuttle.

- The LST is assumed to be released by the Shuttle in such an orientation that minimum maneuvering is necessary to acquire the sun.

- During all LST/Shuttle rendezvous and docking maneuvers, the LST is considered the passive vehicle and the Shuttle the active vehicle.

- The LST RCS must not be a contamination-producing source.

- Components of the LST RCS will have a shelf and operating minimum lifetime design goal of 2.5 years and, where possible, 5 years.

- The LST RCS design will be based on meeting a man-rating requirement.

TABLE 1. RCS IMPULSE BUDGET FOR LST

Function		Impulse	
		N-sec	lb-sec
Compensate LST/Shuttle Separation Transients (0.26 deg/sec — 3 axes)		222.4	50
Emergency control mode (Any One)	• X-POP*; 3 axes control; 29 days • 2 axes control solar pointing with 2 axes estimated secular momentum as disturbance; 16 days • 2 axes control solar pointing with worst-case gravity gradient; 7 days	10 230.9	2300
Misdock (3)		667.2	150
Docking		66.7	15
Total		11 187.2	2515

*Perpendicular to Orbit Plane.

- The Support Systems Module (SSM) will be pressurized so that man can perform orbital maintenance to the LST in a shirtsleeve environment. Limited extra-vehicular activity (EVA) will be allowed for maintenance.

- The LST RCS design will be based on modularization such that RCS maintenance can be easily performed in orbit.

- In designing the LST RCS, efficient use will be made of existing and proven components.

- The LST RCS design will be based on maintaining a low total system weight, low cost, simplicity, and reliability.

- The RCS will not be sized to be used as a backup to the magnetic torquers for CMG desaturation.

SECTION III. CONFIGURATION AND HARDWARE SUMMARY

A functional schematic of the Phase A RCS selected for the LST is shown in Figure 1. The RCS is a pressure regulated, gaseous nitrogen, propulsion system modularized into three basic elements — a propellant tank, a black box, and two major thruster modules. Auxiliary items, most of which are contained in the black box, are latching solenoid isolation valves, filters, pressure regulators, check valves, pressure and temperature transducers, pressure gauges, manual shutoff valves, pneumatic disconnects, propellant fill and drain valve, wire harness, and interconnecting plumbing. The RCS elements are assembled in the SSM of the LST as shown in Figure 2. A mass statement for the RCS is shown in Table 2.

The RCS features of primary significance are as follows:

- Twelve thrusters are used — six are active and six are standby.

- One tank is utilized to store the gaseous nitrogen (GN_2) propellant.

- A dual-level pressure regulator is used. With the regulator operating in the high mode, the thrust level is 44.48 N (10 lbf). With the regulator operating in the low mode, the thrust level is 2.22 N (0.5 lbf).

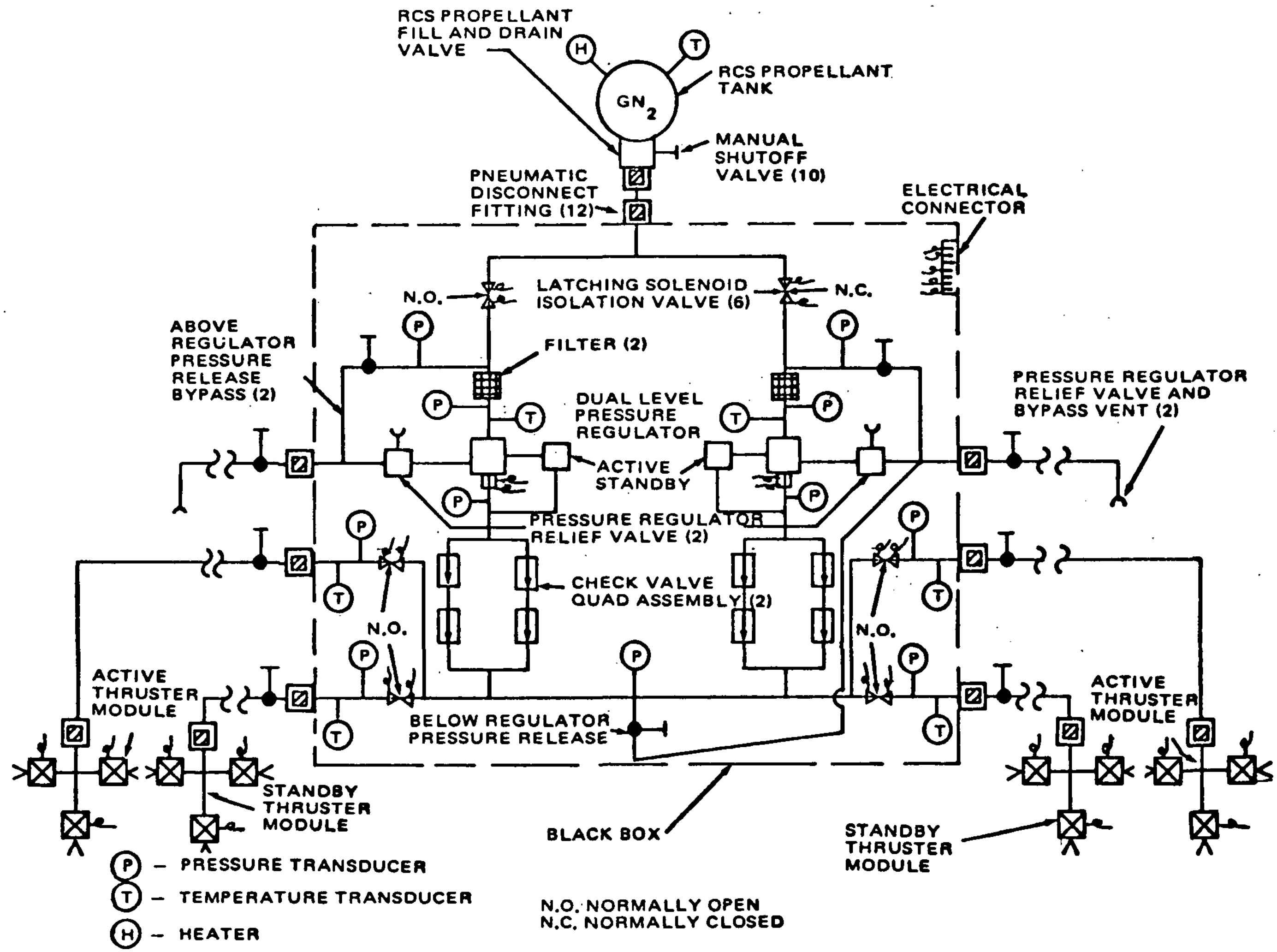

Figure 1. System schematic of the LST Reaction Control System.

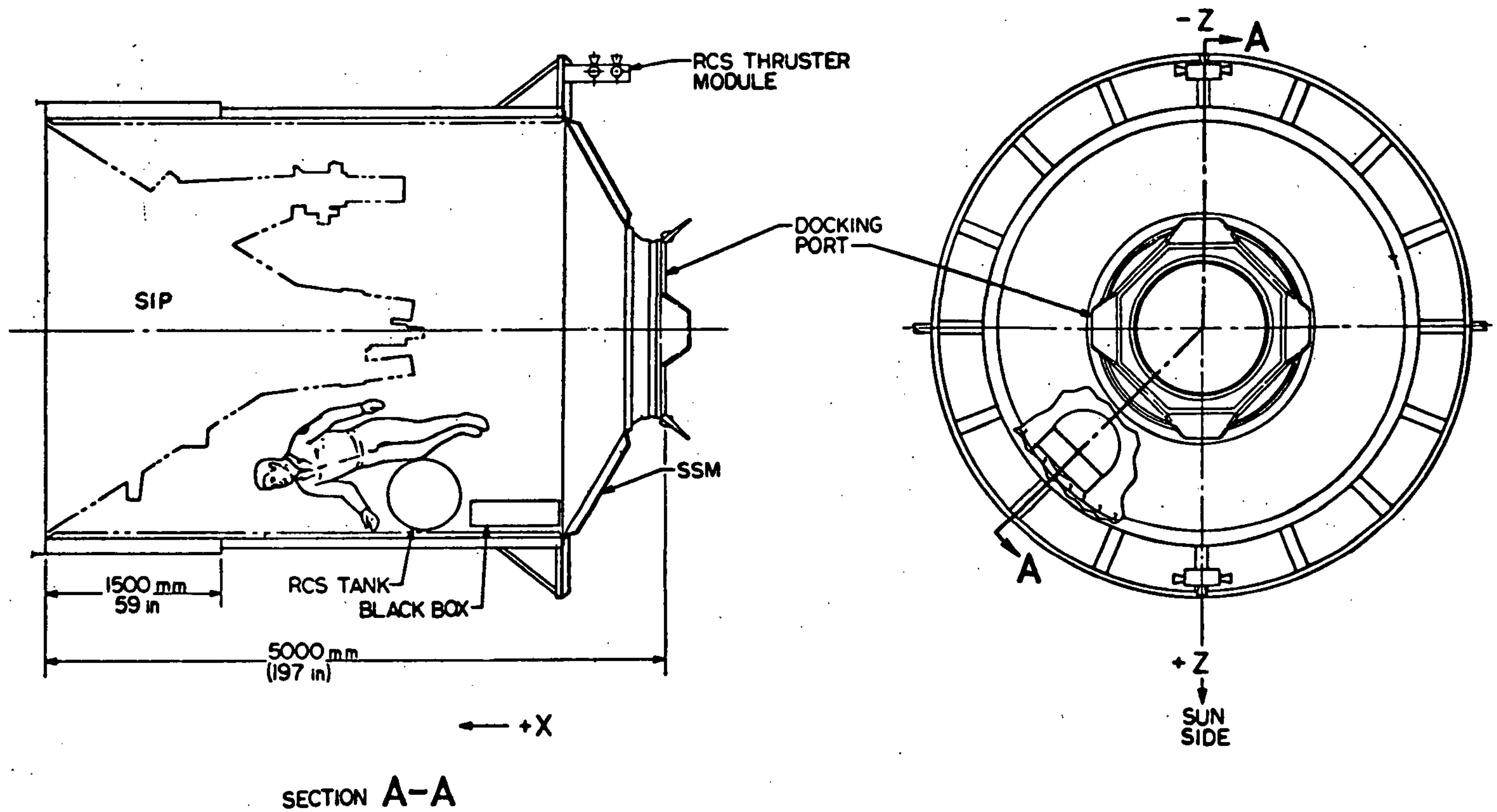

Figure 2. Layout of the LST Reaction Control System major component locations.

TABLE 2. REACTION CONTROL SYSTEM MASS SUMMARY

Item	Mass (kg)	Mass (lbm)
Tank, Including Thermostats and Heaters	25.54	56.30
Manual Shutoff Valve (10)	4.54	10.00
Solenoid Isolation/Shutoff Valve (6)	10.89	24.00
Pressure Regulator, Including Relief Valves and Filter (2)	7.26	16.00
Check Valve, Quad Assembly (2)	0.73	1.60
Pressure Transducer, other than Regulator (6)	0.76	1.68
Pressure Gauge (3)	0.54	1.20
Temperature Transducer, other than Tank (6)	0.41	0.90
Thruster Module, Major (2)	9.07	20.00
Plumbing and Fittings	9.07	20.00
Black Box Structure	9.07	20.00
Tank Retention and other Structure	6.80	15.00
System Dry Mass	84.68	186.68
*Propellant (GN_2)	19.50	43.00
Total System Mass	104.18	229.68
*Redundant Propellant	≈ 1.36	≈ 3.00

- With the exception of the tank, RCS component redundancy is available.

- Modularization of the RCS provides for ease in maintenance.

- Most components are off-the-shelf items.

Using the schematic shown in Figure 1, the operation of the RCS is described as follows. As part of its composition, the black box contains a parallel arrangement of an active gas control loop and a standby gas control loop. Each control loop is made up of a series arrangement of a latching solenoid isolation valve, a pressure regulator, and a quad assembly of check valves. GN_2, stored under a maximum initial pressure of 2.07×10^7 N/m^2 gauge (3000 psig) passes to the pressure regulator in the active control loop. The regulator has a dual level operational capability in that it can reduce the feed pressure down to an average 6.89×10^5 N/m^2 gauge (100 psig) or an average 3.45×10^4 N/m^2 gauge (5 psig). With the regulator operating in the high mode, the steady-state thrust produced is an average 44.48 N (10 lbf), and with the regulator operating in the low mode, the steady-state thrust produced is an average 2.22 N (0.5 lbf) through the same thrusters. The gas passes from the regulator through a quad assembly of check valves to a common manifold which supplies the gas to the two active and the two standby thruster modules. Thrust is achieved by actuating the appropriate active thruster valve(s) as dictated by the ACS control electronics. Details of the propellant line circuitry, failure mode effects, and how the RCS will be maintained are discussed later.

A. Subsystem Operation and Hardware Description

1. <u>Tank.</u> In determining the amount of propellant needed to satisfy the allocated impulse budget for the LST RCS, the GN_2 RCS was assumed to provide an average theoretical specific impulse of 65 seconds. Dividing this number into the allocated impulse budget of 11 187 N-sec (2515 lb-sec) results in 17.69 kg (39 lbm) of GN_2 needed. Since the RCS is to serve as part of a backup control system to the LST primary ACS, the actual RCS requirements cannot readily be projected. Therefore, in choosing a tank for the RCS, it is desirable that volume be available for propellant contingency.

An investigation to determine the availability of existing GN_2 storage tanks revealed two that could be considered for application to the LST RCS.

One is a GN_2 tank used in the Skylab Thrust Attitude Control System (TACS), and the other is a cold gas storage tank used in the backup RCS for the Lockheed Satellite Control Section.

The Skylab tank shell is made of 6Al-4V titanium alloy. The tank is spherical with a diameter of approximately 0.61 meters (2 feet), weighs 53.07 kg (117 lbm) empty, and is man-rated. In a fully-loaded operating condition, the tank contains 28.58 kg (63 lbm) of GN_2 at an operating pressure of approximately 2.14×10^7 N/m^2 (3100 psi). The McDonnell Douglas Corporation provides the tank for the Skylab TACS.

The Lockheed Satellite Control Section backup RCS tank is also made of 6Al-4V titanium alloy. The tank is spherical with a diameter of approximately 0.57 meters (22.25 inches), weighs 25.54 kg (56.3 lbm) empty, and has a safety factor of 2.0 (burst pressure/operating pressure). The factor of safety is within man-rating specifications as dictated by Reference 1. In a fully-loaded operating condition, the tank contains approximately 19.50 kg (43 lbm) of GN_2 at an operating pressure of 2.07×10^7 N/m^2 gauge (3000 psig). Pressure Systems Incorporated (PSI) manufactures the tank for Lockheed.

In an effort to minimize RCS complexity, weight, and volume, and since backup subsystems of the LST are not required to have complete redundancy, a single tank concept was selected for the LST RCS. Of the two tanks considered for use by the RCS, the Lockheed Satellite Control Section cold-gas storage tank more nearly meets these criteria and hence was selected. This tank, when loaded to a maximum operating capacity, will contain approximately 19.50 kg (43 lbm) of GN_2 — 1.81 kg (4 lbm) in addition to the projected 17.69 (39 lbm) needed. Of this 1.81 kg (4 lbm) additional propellant, only 1.13 kg (2.5 lbm) is considered usable; therefore, a propellant contingency of approximately 6 percent is available. Assuming no leakage, the additional propellant will provide approximately 725 N-sec (163 lb-sec) of redundant impulse making the RCS total impulse available at approximately 12 000 N-sec (2698 lb-sec). However, the system leakage between maintenance events is assumed to be contained in the 6 percent propellant contingency.

Should the allocated total impulse budget for the RCS increase, or should additional propellant contingency be required due to the uncertainty of the RCS requirements and/or leakage, the Skylab tank would have to be used to stay with the one-tank RCS concept. Should the propellant requirement grow beyond the capacity of the Skylab tank, then a multi-tank RCS should be considered, using either the Lockheed tank or the Skylab tank. A multi-tank

RCS would require a modification to the plumbing scheme used in connecting the tank to the black box inlet manifold. For each tank used, the black box would require a pneumatic disconnect fitting with an associated feed line connected to the manifold. To guard against the potential loss of the total RCS propellant in case of a tank failure, check valves may be necessary for each tank inlet feed line to passively isolate the failed tank from the remainder of the system. As an alternate approach to connecting a multi-tank concept to the black box, a single common manifold can be provided for the tanks, which, in turn, connects to the black box. Modification of the black box would then not be necessary.

The characteristics of the Lockheed tank are listed in Table 3. The shell of the tank, and any necessary closures, are made of 6Al-4V titanium alloy. Two forged hemispheres are tungsten-inert-gas welded to a transition joint to form a sphere. The tank assembly has a thermal management system which includes a flight heating system and a ground heating system each containing two heaters, a thermostat, and an electromagnetic interference (EMI) suppressor. Associated with the thermal management system are two electrical connectors and a temperature sensor. The tank is also covered with multi-layer insulation such as aluminized mylar. In applying the tank to the LST RCS, the ground thermal management system will be deleted.

The purpose of the flight heating system is to maintain the temperature of the gas within the operating temperatures of the regulator and thruster valve. This provides for maximum operating efficiency of the RCS, and also the higher the gas temperature the better the performance and consequently the greater the total impulse derived from the system. Prior to any critical maneuvers to be performed by the LST in which the possibility exists that the RCS may be needed, the tank heating system will be turned on. The thermostat associated with this heating system is mounted in intimate contact with the shell of the tank. The thermostat is closed when the tank shell temperature has stabilized at a minimum of 344.26°K (+160°F) and opens when the tank shell temperature has stabilized at a maximum of 358.15°K (+185°F). The tank thermistor permits monitoring the skin temperature. When the RCS is not expected to be used, the heating system is commanded off.

The flight heating system consists of two 5-watt heating elements mounted in parallel such that if one becomes inoperative, the other can maintain active thermal control. The heaters are encased in a silicone-rubber material. The voltage range of the heaters at a nominal temperature and

TABLE 3. TANK CHARACTERISTICS*

Item	Data
Configuration	P/N 8100017
Volume	8.82×10^{-2} m^3 (5382 $in.^3$)
Maximum Working Pressure	2.07×10^7 N/m^2 gauge (3000 psig)
Mass (Maximum)	28.54 kg (56.3 lbm)
Plumbing Configuration	One port
Flight Heater Rating	5 watt each
Thermostat Range	344.26° K to 358.15° K (160° F to 185° F)
Pressure Cycle Life	500 cycles
Operating Temperature Range	222.04° K to 358.15° K (-60° F to +185° F)
Burst Pressure	4.14×10^7 N/m^2 gauge (6000 psig)
Proof Pressure	3.11×10^7 N/m^2 gauge (4500 psig)
Reliability	0.9879 for 1 year

*Data were taken from Reference 2.

pressure of 294.26°K (+70°F) and 101.35 N/m^2 (14.7 psi), respectively, is from 20 to 37 volts direct current (Vdc). The resistance of each heater is 115 ±8 ohms [3].

The Skylab tank does not have a heating system and should it be necessary to use this tank for the LST RCS, one would have to be added.

The Lockheed tank has been qualified to perform to meet the Satellite Control Section requirements during exposure to orbital conditions for a period of 6 months. How much longer the tank can perform beyond this time period is unknown. There is no known reason why the tank cannot perform under orbital conditions for 2.5 years or beyond; however, testing to prove this would be required. The tank is capable of performing a minimum of 500 pressure cycles after acceptance of the tank by Lockheed. A pressure cycle is defined as increasing the tank pressure from zero N/m^2 (zero psig) to the maximum operating pressure and then back to zero N/m^2 (zero psig). The tank and the thermal management system are capable of performing a minimum of 5000 thermal cycles after acceptance of the tank and thermal management system by Lockheed. A thermal cycle is defined as raising the temperature of the tank until the thermostats open the electrical circuits, and then lowering the temperature until the thermostats close the electrical circuits. The tank has a minimum reliability of 0.999 to perform under orbital conditions for a minimum period of 30 days. The tank reliability for 1 year is 0.9879 [3].

Since the tank has only a single port, an integral manual shutoff/fill and drain valve associated with this port will be required. Associated with this valve will be a pneumatic disconnect fitting to provide an attachment for the propellant supply line which leads to the black box. This same fitting will also be used for filling the tank. The addition of the valve/pneumatic fitting to the tank will be a necessary tank modification.

Since a bump or scratch on the surface of the tank when fully loaded could cause the tank to explode, a protective cover around the tank will also be required. Other necessary modifications to the tank and to what extent the tank should be requalified for application to the LST RCS should be determined in the LST Phase B study effort.

2. Black Box. The purpose of the black box is to house the numerous auxiliary RCS components as well as a few primary RCS components which cannot easily be replaced in orbit on an individual basis. Should a component in the black box fail and cause the successful operation of the RCS

to be in jeopardy, the black box can simply be replaced during an LST maintenance period. Because of the large number and type of components in the black box, and hence the greater probability of a failure, complete redundancy in black box components was provided. The black box consists primarily of a parallel arrangement of an active gas-control loop and a standby gas-control loop. Each control loop is composed of a series arrangement of a latching solenoid isolation valve, a pressure regulator, a quad assembly of check valves, a pressure-release loop, a manual shutoff valve, a pressure gauge, pressure and temperature transducers, and a pneumatic disconnect fitting. Other items contained in the black box include a main manifold for supplying gas to the thrusters, a latching solenoid isolation valve for each supply line leading to the thruster modules, a below-regulator pressure-release loop with an associated pressure gauge and manual shutoff valve, and wire harnesses.

Even though the components in the black box are existing items, the black box does not exist. As a proposed concept, the black box is to consist of two primary structural members — a base plate and a protective cover. The base plate will be designed as the load-carrying structure for the internal and external components. Mounting structure will be provided on the base plate for attaching the individual RCS components and for retaining the plumbing, pneumatic disconnects, and wire harnesses. The base plate will also have the necessary structure for attaching the box to the SSM. A protective cover will fit over and attach to the base plate. This cover can be made of fiberglass or some lightweight sheet metal.

The black box will be designed and configured for minimum weight, volume, and for ease in handling; however, for purposes of this study the box is envisioned as being rectangular, measuring 0.18 m × 0.51 m × 0.71 m (7 in. × 20 in. × 28 in.).

A discussion of the components in the black box follows.

a. Pressure Regulator. The pneumatic pressure regulator selected for use by the LST RCS is a two-stage regulator currently used in the Agena RCS. A functional schematic of the regulator is shown in Figure 3. The purpose of the regulator is to reduce the gas pressure down to a working level that will be acceptable by the thrusters. The regulator is two-staged, in that it has a dual-mode operational capability. The regulator, when operating in the high pressure mode, can reduce an inlet gas working supply pressure as high as 2.48×10^7 N/m^2 gauge (3600 psig) down to an average pressure of 6.89×10^5 N/m^2 gauge (100 psig), or when operating in the low

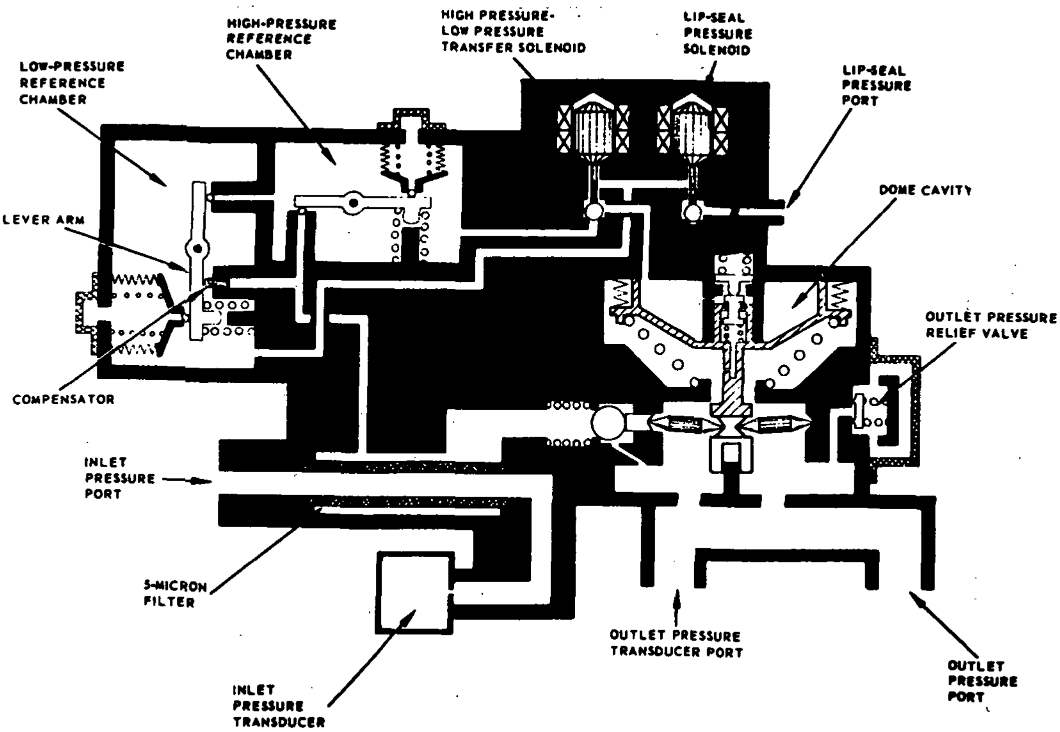

Figure 3. Pneumatic pressure regulator system schematic [4].

mode, the regulator can reduce the same inlet pressure down to an average of 3.45×10^4 N/m^2 gauge (5 psig). The purpose of the dual pressure mode is to have the capability to provide two levels of thrust through the same thruster system. During high mode operation, an average thrust of 44.48 N (10 lbf) is achieved by the thrusters selected for the LST RCS, and during low mode operation, an average thrust of 2.23 N (0.5 lbf) is achieved through the same thrusters.

The dual thrust mode capability provides for control versatility and efficient utilization of propellant. For example, during periods of large vehicle disturbances such as might occur during LST/launch vehicle separation or during LST/Shuttle docking and the RCS is needed to help control the LST, the high thrust level can provide the quick response necessary for spacecraft control. However, during an emergency control mode where the LST primary control system has failed and the RCS is used for control, the low thrust level and corresponding Minimum Impulse Bit (MIB) is used to counteract distrubance torques. Operating in this mode minimizes propellant expenditure and maximizes the stay time until the Shuttle can arrive for maintenance.

Referring to Figure 3, the operation of the regulator is described as follows. The regulator is designed for operation with an inlet pressure range between 6.89×10^5 N/m^2 (100 psi) and 2.48×10^7 N/m^2 (3600 psi). The regulator is capable of withstanding a rapid pressurization rate (50 milliseconds) from 0 to 2.48×10^7 N/m^2 (0 to 3600 psi) without regulator malfunction. Gas enters the inlet pressure port and passes through a filter located in the port. The filter is designed to a maximum nominal rating of 1×10^{-5} meters (10 microns), and an absolute cutoff of 2.5×10^{-5} meters (25 microns). Also associated with the inlet port is an integral pressure transducer with a measurement range of 0 to 2.76×10^7 N/m^2 (0 to 4000 psi). From the filter the main gas supply route leads to a check valve, the opening and closing of which is dictated by unbalanced conditions which occur in the diaphragm assembly or main poppet assembly contained in the regulator dome housing. An unbalanced condition occurs as a result of gas being used by the thrusters with subsequent resupply of gas to thruster valves being necessary [4].

Connected to the inlet port within the regulator is a gas supply line leading to the high pressure reference chamber. Here the pressure is regulated to a maximum of approximately 8.96×10^5 N/m^2 gauge (130 psig) to provide the high-pressure dome-cavity reference when the regulator is operating in the high-pressure mode. Connected to the high-pressure reference chamber is the low-pressure reference chamber. Here, pressure fed from the high pressure reference chamber is further regulated to a maximum of approximately 1.38×10^5 N/m^2 gauge (20 psig) to provide the low-pressure dome-cavity reference when the regulator is operating in the low mode. Gas from both reference chambers is fed to a solenoid-operated selector valve. The position of this valve determines from which pressure-reference chamber gas is supplied to the dome cavity which in turn determines the outlet pressure to the thruster valves.

Switching from one pressure mode to another is accomplished by the activation of the selector valve. The valve will move from one position to another in approximately 90 milliseconds after application of the command signal. Incorporated in the valve is a microswitch to permit monitoring of the valve position in flight. The valve is also qualified for 2500 cycles of intermittent operation. A cycle is defined as an opening or closing actuation. When switching from the low-pressure mode to the high-pressure mode, a time period of approximately 2.5 seconds is required before the outlet pressure is brought up to an average 6.89×10^5 N/m^2 gauge (100 psig). This time factor, of course, is dependent on the plumbing volume downstream of the regulator as well as the flow demand of the thrusters. When switching from a high pressure mode to a low pressure mode, a time factor of between 30 to 60 seconds is required before the outlet pressure is brought down to an average 3.45×10^4 N/m^2 gauge (5 psig). Three factors contribute to this time delay: first, the high pressure in the dome cavity is released through a relief valve in the low pressure reference chamber; second, the flow demand of the thrusters; and third, the plumbing volume downstream of the regulator.

Both reference chambers incorporate a pressure relief valve to guard against unexpected over-pressurizations; however, the relief valve in the low-pressure reference chamber has a primary function in relieving the normal over-pressurization which occurs when switching from the high mode to the low mode. The outlet port also has a relief valve designed to open at approximately 1.17×10^6 N/m^2 gauge (170 psig). The purpose of this valve is to prevent over-pressurization from occurring downstream of the regulator which could damage the thrusters. For LST purposes, relief valves on the regulator will have to be connected to a common vent which leads to the exterior of the spacecraft.

When used in the Agena RCS, the regulator, in addition to supplying regulated gas to the thrusters, also supplies low-pressure nitrogen gas to the Agena main engine to pressurize the lip-seal in the oxidizer turbine pump. This seal is pressurized to prevent oxidizer leakage from seeping along the turbine shaft into the turbine gear case. The regulator has a lip-seal port and an associated pressure solenoid valve. This valve can be closed or opened on command and its electrical performance characteristics are the same as the mode-selector valve. The low pressure gas is supplied from the low-pressure reference chamber. For LST application, the lip-seal pressure solenoid valve will remain in the closed position with the lip-seal pressure port capped to prevent leakage. However, further investigation may reveal the lip-seal port to be handy as a supply source of GN_2 for the LST Contamination Control System (CCS). Under operational conditions, the lip-seal port pressure is controlled by means of an orifice between 1.38×10^4 N/m^2 gauge and 9.65×10^4 N/m^2 gauge (2 psig and 14 psig) over the regulator inlet pressure range of 2.48×10^7 N/m^2 gauge and 6.89×10^5 N/m^2 gauge (3600 psig to 100 psig) with a 4.92×10^{-5} m^3 (3 in.^{3}) volume downstream of the port. Also, over this same inlet pressure range, the lip-seal flow demand is between zero to 3.49×10^{-6} kg/minute (zero to 7.7×10^{-4} pounds per minute) of nitrogen [5].

While operating in the high pressure mode, the regulator full-flow capacity is 9.07 kg/minute (20 lbm/minute) of nitrogen to the outlet port with the regulator inlet pressures ranging from 2.07×10^6 N/m^2 gauge to 2.48×10^7 N/m^2 gauge (300 psig to 3600 psig), and a full flow capacity of 4.54

kg/minute (10 lbm/minute) with the regulator inlet pressures ranging from 1.38×10^6 N/m^2 gauge to 2.07×10^6 N/m^2 gauge (200 psig to 300 psig). In the low-pressure mode, the regulator full-flow capacity is 0.45 kg/minute (1.0 lbm/minute) of nitrogen to the outlet port with the regulator inlet pressures ranging from 6.89×10^5 N/m^2 gauge to 2.21×10^7 N/m^2 gauge (100 psig to 3200 psig). The mass of gas expelled as a result of any mode switching operation does not exceed 4.10×10^{-3} standard cubic meters (250 standard cubic inches) with an outlet-flow demand of zero to full flow. The outlet port relief valve has a minimum flow capacity of 0.79 kg/minute (1.75 lbm/minute) of nitrogen at an outlet port pressure of 1.17×10^6 N/m^2 gauge (170 psig). The reseat pressure of this valve is a minimum 9.10×10^5 N/m^2 gauge (145 psig). The outlet port also has a pressure transducer for monitoring the outlet pressure [5].

The internal working pressures of the regulator are as follows:

- Inlet port 0 to 2.48×10^7 N/m^2 gauge (0 to 3600 psig)
- Outlet port 0 to 1.03×10^6 N/m^2 gauge (0 to 150 psig)
- Lip-seal port 0 to 1.38×10^5 N/m^2 gauge (0 to 20 psig)

The burst pressure values for the same are as follows:

- Inlet port 4.96×10^7 N/m^2 gauge (7200 psig)
- Outlet port 2.07×10^6 N/m^2 gauge (300 psig)
- Lip-seal port 2.76×10^5 N/m^2 gauge (40 psig)

Thus the regulator is man-rated [5].

The total external leakage of the regulator is not greater than 10 standard cubic centimeters per hour (scch) with inlet pressures ranging from 6.89×10^5 N/m^2 gauge to 2.48×10^7 N/m^2 gauge (100 psig to 3600 psig) and outlet pressures ranging from 2.41×10^4 N/m^2 gauge to 7.93×10^5 N/m^2 gauge (3.5 psig to 115 psig). The internal leakage is not greater than 60 scch, with inlet pressures ranging from 6.89×10^5 N/m^2 gauge to 2.48×10^7 N/m^2 gauge (100 psig to 3600 psig). The regulator is capable of remaining in the lockup condition with an inlet pressure from 1.03×10^5 N/m^2 gauge to 2.48×10^7 N/m^2 gauge (15 psig to 3600 psig) for a minimum of 30 days. Tests are required to determine its maximum time duration in the lockup condition. Tests are also required to determine the reliability of the regulator for long periods of operational time, 1 year for example.

The assembly life of the regulator is 14 quarters. The regulator has been qualified for a flow life of 141.58 standard cubic meters (5000 standard cubic feet) in 35 000 pulse-type flow demands [5].

Table 4 presents a summary of the major characteristics and qualification specifications of the regulator.

b. Propellant Line Circuitry, Latching Solenoid Isolation Valves, Check Valves, Manual Shutoff Valves, Failure Mode Analysis, and Miscellaneous Items. Seven pneumatic disconnect fittings are located externally around the depth dimension side of the black box (see Figure 1). The GN_2 supply line leading from the propellant tank connects to the black box at one fitting. The two overboard-dump lines for the pressure-regulator relief valves and pressure-release bypass lines connect to two of the fittings. The remaining four fittings connect the black box to the propellant supply lines leading to the thruster modules. The pneumatic disconnect fittings are of the screw-on type which provide a good seal and minimize leakage.

Inside the black box, a single gas supply line leading from the propellant tank fitting connects to a common manifold. This common manifold feeds gas to the two gas control loops. Both control loops are then connected to a common manifold which supplies gas to the feed lines leading to the thruster modules. Above the regulator, in each control loop, is a pressure release bypass line and an associated manual shutoff valve. The purpose of these bypass lines is to bleed down the pressure above the regulator during RCS maintenance. The bypass line connects to the regulator relief valve vent line, which in turn leads to an overboard dump. Connected to the common manifold below the gas control loops is a below-regulator pressure-release bypass vent line and an associated manual-shutoff valve. This line is used during RCS maintenance to bleed down the pressure below the regulator. This line also connects to one of the pressure regulator overboard dump lines.

In addition to the three manual shutoff valves associated with the pressure release bypass systems and the one on the propellant tank, there are six others: one in each of the two overboard dump lines, and one in each of the four lines leading to the thruster modules. It is necessary that all pressure lines leading to the exterior of the LST be closed during portions of the RCS maintenance. This is accomplished by simply closing the manual shutoff valve associated with each line. The maintenance procedure for the RCS will be discussed later.

TABLE 4. REGULATOR CHARACTERISTICS*

Item	Data
Configuration	P/N 1462099
Mass	3.63 kg (8 lbm)
Operating voltage	20 - 28 Vdc
Current Drain	1.5A @ 28 Vdc @ 266.48°K (20°F)
Maximum Inlet Pressure	2.48×10^7 N/m^2 gauge (3600 psig)
Minimum Inlet Pressure	6.89×10^5 N/m^2 gauge (100 psig)
Maximum Operating Temperature	344.26°K (160°F)
Minimum Operating Temperature	238.71°K (-30°F)
Flow Cycle Life	35 000 pulses
Solenoid Cycle Life	2500 cycles
High-Mode Regulation Pressure	6.41×10^5 to 7.93×10^5 N/m^2 (93 to 115 psig)
Low-Mode Regulation Pressure	2.41×10^4 to 4.48×10^4 N/m^2 (3.5 to 6.5 psig)
GN_2 Flow Capacity	
High Mode	9.07 kg/min (20.0 lbm/min)
Low Mode	0.45 kg/min (1.0 lbm/min)
Electromagnetic Inductance (EMI) Suppression	Yes
Solenoid Position Switch	Yes
Inlet Filter	Yes
Burst Pressure	4.96×10^4 N/m^2 (7200 psig)
Approximate Dimensional Envelope	0.22 m × 0.20 m × 0.14 m (8-1/2 in. × 8 in. × 5-1/2 in.)

*Data were taken from Reference 2.

All electrically-operated isolation valves associated with the propellant line circuitry are the latching solenoid type. A valve is provided at the beginning of each gas control loop and at the beginning of each feed line leading to each thruster module. With the exception of one, all of these valves are open in the normal mode of operation. The only time that any of these valves will be commanded "closed" is in the event a failure of a part of the RCS demands isolation of that part from the rest of the system. The normally-closed isolation valve is associated with the standby gas-control loop.

Should a failure occur in the primary gas-control loop; for example, a leak occurs in the regulator, the loop can be isolated by commanding its associated isolation valve to close. The pressure transducers associated with the control loop constantly transmit data to the onboard malfunction detection system and the ground as to the well being of the system. This data can indicate the occurrence of an anomaly in the control loop. If an anomaly occurs, the information from the transducers initiates an onboard command to quickly isolate the loop. The loop can also be isolated by ground command. Then, either by onboard or ground command, the standby gas-control loop is brought on-line by opening its associated isolation valve.

Gas is fed to the thrusters in both the active and standby thruster modules. Electrical commands are directed only to the active thrusters to provide the necessary thrust for control. However, should a failure occur in one or more of the thrusters of a given active thruster module, such as a thruster valve which sticks open, providing continuous thrust, or a thruster valve seat which leaks somewhat, then that thruster module can be isolated by commanding its isolation valve to close. Electrical commands can then be directed to the standby thruster module and normal RCS control can continue.

As in the case with the gas control loops, pressure transducers located in the feed lines leading to the thruster modules monitor the well being of the system. Data from these pressure transducers are fed to the onboard malfunction detection system and to the ground. This data coupled with data from the onboard attitude sensing equipment can indicate the occurrence of an anomaly in the thruster system. If an anomaly occurs, the information from the transducers and attitude sensing equipment initiates an onboard command to isolate the malfunctioning thruster module and to switch electrical commands from the active to the standby module. The ground can also provide these same commands.

The latching solenoid valve selected for use by the LST RCS can be closed or opened on command, providing the capability to troubleshoot an anomaly in the system, and if a "fix" is made, the system can be brought on-line again, i.e., a regulator or thruster module. Should a latching solenoid-isolation valve be inadvertently switched out of its normal position, a command can be given to switch it back. Squib valves are not utilized because they are "one shot" devices and would need replacing after use.

The latching solenoid valve selected for use by the LST RCS is used on a Lockheed cold-gas attitude-control system. The unit is a two-way pressure-balanced, direct-acting poppet valve designed for gaseous flow when a differential pressure of 2.48×10^7 N/m^2 (3600 psi) exists across the valve. With either or both ports pressurized, gas flow through the valve is shut off when the poppet is in the closed position. The poppet is held in the closed position by the permanent latching magnet and spring forces. Energization of the opening coil creates a magnetic field opposing, and substantially stronger than, the field of the latching magnet. The flux of the opening coil cancels the magnetic field and provides the pull-in force to overcome the spring-load holding the poppet on the seat. The latching magnet provides the holding force to maintain the valve in the open position after the electrical signal to the opening coil is removed. At approximately mid-point of the valve opening stroke, a microswitch is actuated by the plunger movement, closing a 28-Vdc circuit and thereby indicating the valve open position. The closing sequence is initiated by energization of the closing coil. The magnetic field of the closing coil cancels the field of the latching magnet and the upper armature spring force returns the armature/plunger to the closed position. At approximately mid-point of the closing stroke, the microswitch is actuated to close a 28-Vdc circuit, indicating that the valve is in the closed position [2].

The characteristics of the latching solenoid valve are listed in Table 5.

A quad assembly of check valves is located in each gas-control loop downstream of the regulator. The check valve assembly completes each gas loop by connecting to the common manifold which supplies gas to the thrusters. The primary function of the check valves is to prevent gas from flowing into the standby loop or an inoperable active loop. The active gas control loop could develop a leaky regulator or some other failure and need isolating from the rest of the system. The check valves in the active loop would prevent the possibility of losing gas when the standby loop is activated. Thus, the check valves provide downstream passive isolation of the gas control loops.

TABLE 5. LATCHING SOLENOID VALVE CHARACTERISTICS*

Item	Data
Configuration	1462039
Operating Pressure	Zero to 2.48×10^7 N/m^2 (Zero to 3600 psig)
Response	80 milliseconds
Operating Voltage	20 to 30 Vdc
Current Drain	4.5 amps max
Operating Temperature	260.93° K to 347.04° K (10° F to 165° F)
Mass	1.81 kg max (4.0 lbm)
Pressure Drop	1.83×10^6 N/m^2 max (265 psi)
Burst Pressure	4.96×10^7 N/m^2 (7200 psig)

*Data were taken from Reference 2.

For redundancy purposes, the four check valves are arranged in a quad configuration: two valves in series are connected in parallel (Fig. 1). In the event one of the valves fails closed, the parallel arrangement provides redundancy in opening, and in the event one of the valves fails open, the series arrangement provides redundancy in closing.

Various types of check valves are available from existing GN_2 reaction control systems. One such existing system which utilizes a check valve is the RCS of the Oribital Astronomical Observatory (OAO). The various types of check valves available include the ball, guided poppet, flapper, and others. The type of check valve, their number and arrangement for use on the LST RCS should be considered in further detail in the Phase B study.

Other items contained in the black box include temperature transducers, pressure gauges, and an electrical connector. The function of the temperature transducers is to monitor the GN_2 temperature at critical locations in the RCS. The gas temperature is monitored at the entrance to the regulator and prior to entering the thruster modules. The regulator, thruster valves, and other components are designed to operate within certain temperature limitations, and the performance of some of these components is also a function of gas temperature. Therefore, it is important that the gas temperature in certain locations be monitored. Should the temperature in these certain locations become too low, the information from the temperature transducers can command the tank heaters "on", or the ground can provide this same command.

The pressure gauges are attached to the pressure release bypass vent lines. There are three gauges, one on each vent line. While the RCS is being bled down during maintenance, the astronaut reads these gauges for determination of the internal RCS gas pressure.

The electrical connector located on the side of the black box provides for a common hookup for all electrical equipment internal to the black box.

3. Thruster/Thruster Module. Since the RCS is an LST backup control system, the thrust level and Minimum Impulse Bit (MIB) requirements could vary over a broad spectrum. RCS control requirements for very small LST disturbances as well as for very large LST disturbances could be necessary; therefore, rather than optimize a thrust level, an MIB, and a thruster system for the LST, an existing system was selected that is thought to most nearly satisfy the expected LST thruster requirements.

The Agena RCS thrust-valve cluster is selected as the basic thruster module for the LST RCS. The solenoid-operated thrust valve cluster shown in Figure 4 consists of three identical thrust-valve cartridges mounted on a single manifold containing a pressure port and electrical receptacle common to the three valves. As was mentioned previously, and as shown in Figure 1, four of these modules are utilized by the LST RCS. Two of the modules are active and two are standby. An active module and a standby module are clustered into a single major module for mounting to the LST as shown in Figure 2. The two major modules are mounted to the LST 180 degrees apart, and each module is located 90 degrees from the solar panel support structure. This arrangement minimizes the thruster plume impingement on the solar panels. Also shown in Figure 2 is the thruster orientation with respect to the LST. The thruster modules are mounted to the LST as far aft as possible and as far radially as possible to take advantage of the maximum lever arm distance which in turn minimizes the propellant weight required. The structural makeup of the major module and its design for attaching to the LST should be determined in the Phase B study. However, the method selected for attaching the modules to the LST must be simple enough for man to be able to replace them by means of an Extra-Vehicular Activity (EVA).

As shown in Figure 1, four feed lines lead from the black box to the four thruster modules. A pneumatic disconnect fitting similar to that used on the black box attaches each line to its appropriate module. There will also be an electrical receptacle for each of the four thruster modules.

The major thruster module mounting concept and associated thruster orientation provides for either the active or standby system: two thrusters in pitch, four in yaw, and four in roll. The yaw/roll combination, however, will be a mixed-mode operation. The thruster valves receive compressed gas from the pressure regulator. With the regulator operating in the high mode, gas inlet pressures to the thruster valves range from 6.41×10^5 N/m^2 to 7.93×10^5 N/m^2 (93 to 115 psi) steady state. The resulting output thrust at this pressure level averages 44.48 N (10 lbf). With the regulator operating in the low mode, gas inlet pressures range from 2.41×10^4 N/m^2 to 4.83×10^4 N/m^2 (3.5 to 7.0 psi) steady state, and the resulting output thrust averages 2.22 N (0.5 lbf). With a 4.51 meter (14.8 foot) lever arm, the maximum average torque level capability in the pitch axis is 200.6 N-m (149.0 ft-lbf) when operating at the high thrust level and 10.0 N-m (6.5 ft-lbf) when operating at the low thrust level. The respective maximum average torque level capabilities in the yaw plane are double that of the pitch since two thrusters are available, that is 400.1 N-m (298 ft-lbf) and 20.0 N-m (13.0 ft-lbf). With a 2.0 meter (6.5 foot) roll lever arm, the respective maximum average torque

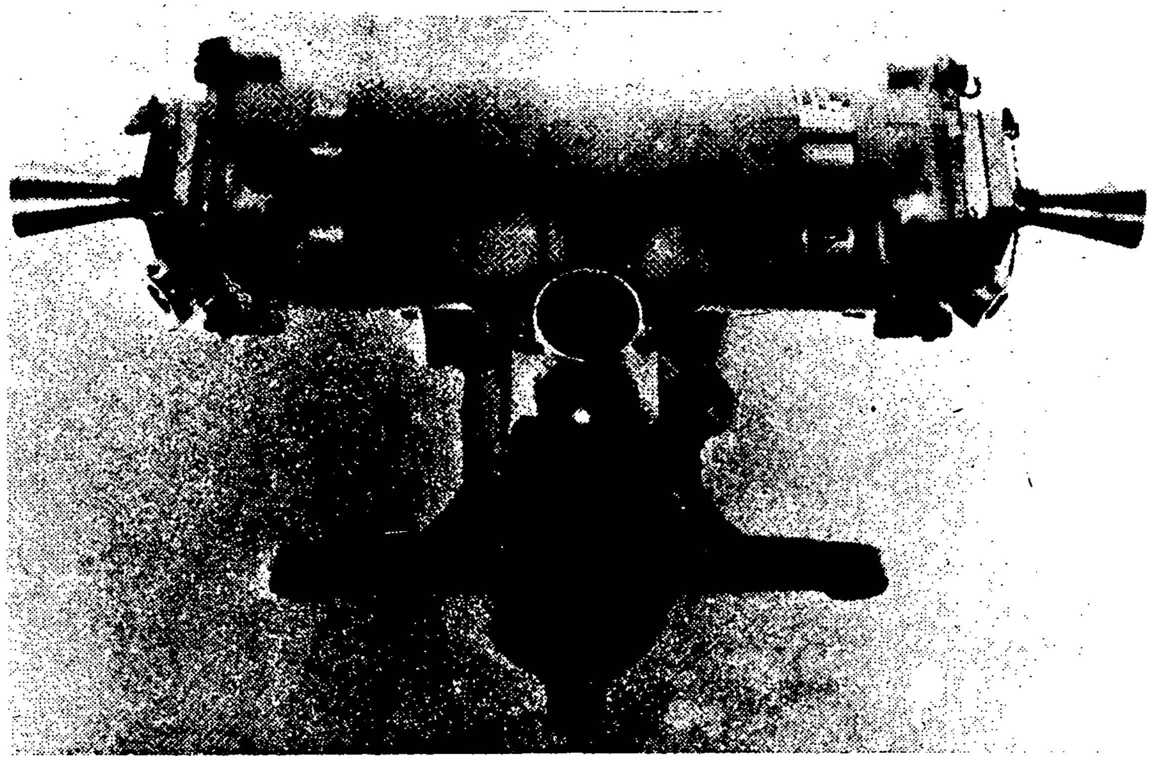

Figure 4. Thrust valve cluster [4].

level capabilities in roll are 177.92 N-m (130.0 ft-lbf) and 8.88 N-m (6.5 ft-lbf). The 44.48 N (10.0 lbf) thrust level is expected to provide sufficient thrust for LST control during large disturbances such as those which could occur during separation from and docking to the Shuttle. Quick recovery is also possible with the high thrust level. The 2.22 N (0.5 lbf) thrust level is expected to provide sufficient thrust for LST control during small disturbances such as those which occur during an emergency X-POP hold-control mode.

Each thruster valve operates independently and Figures 5 and 6 illustrate the typical valve impulse limits when supplied $7.17 \times 10^5 \pm 7.58 \times 10^4$ N/m^2 (104 ±11 psi) and 2.41×10^4 to 4.14×10^4 N/m^2 (3.5 to 6.0 psi), respectively. Figure 6 shows that the thruster, when operating in the low pressure mode, is capable of producing an MIB in the range of 6.67×10^{-3} N-sec to 3.34×10^{-2} N-sec (0.0015 to 0.0075 lb-sec) at a pulse width of 20 milliseconds. This MIB range is highly desirable for desaturating the CMGs; however, the LST RCS is not required, even in a backup capacity, to perform any CMG desaturation and hence was not designed for the propellant capacity to perform such a function.

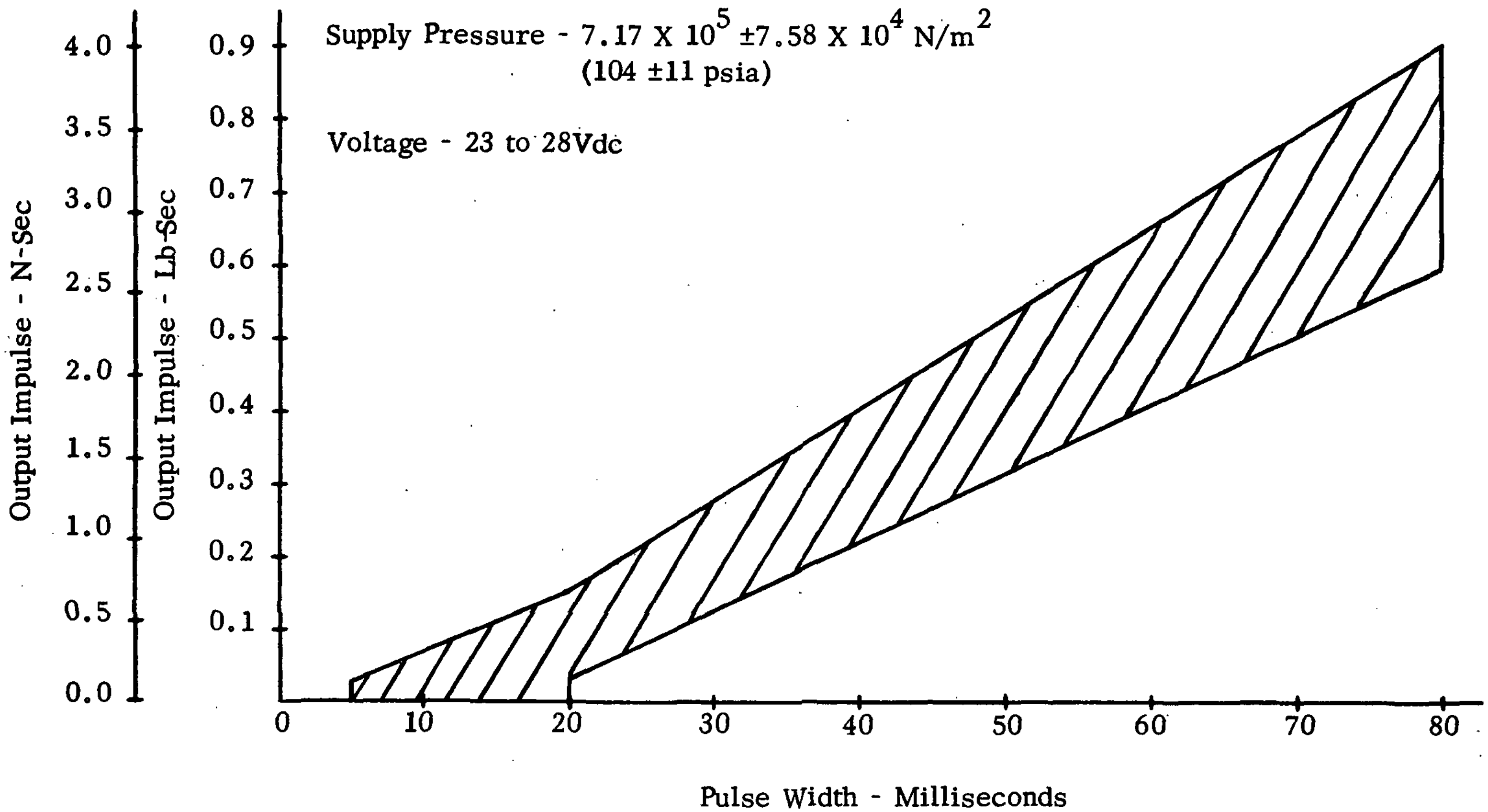

Figure 5. Thruster altitude performance at high thrust [2].

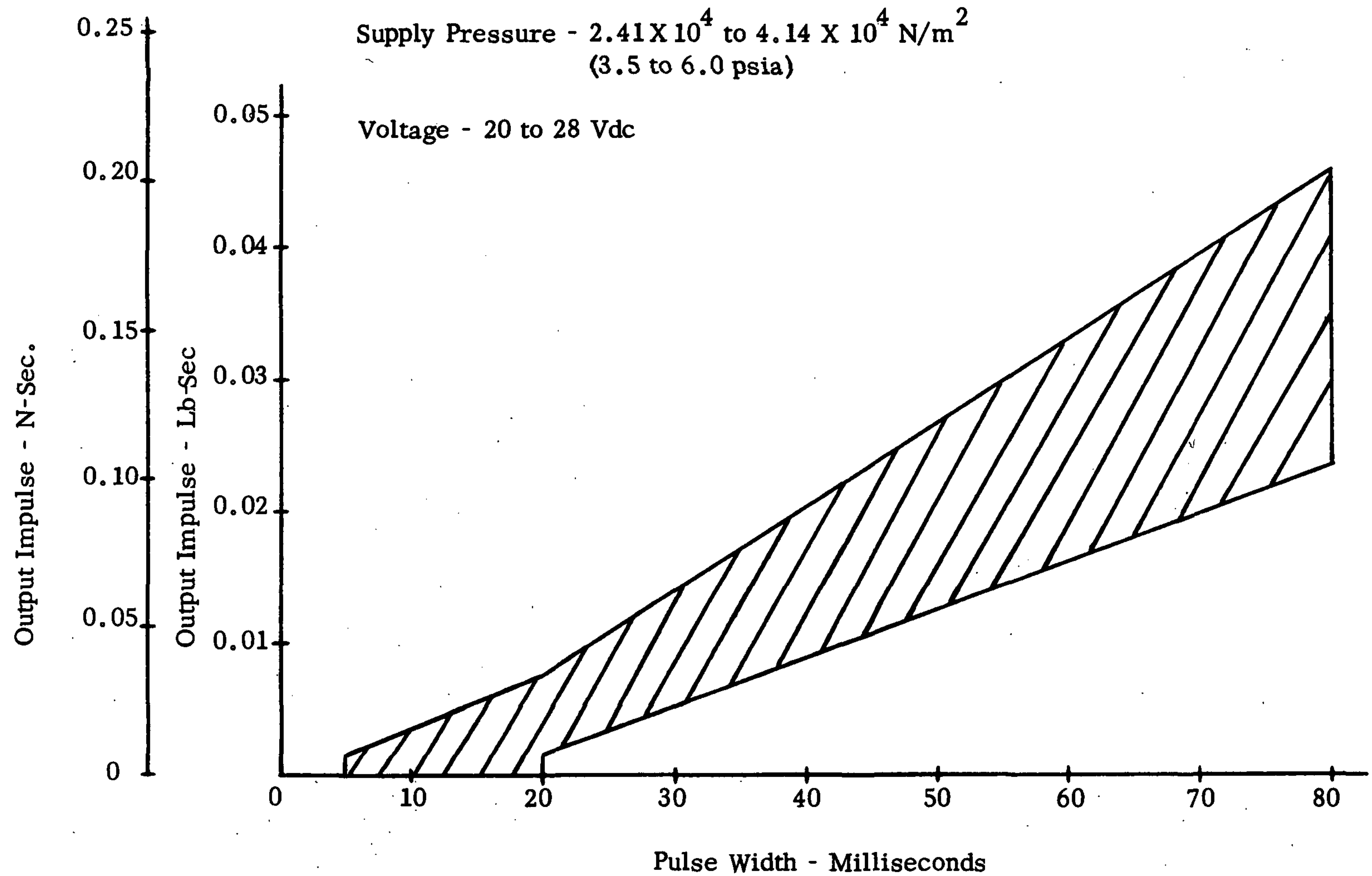

Figure 6. Thruster altitude performance at low thrust [2].

Referring to Figure 7, the operation of the individual thruster is described as follows. Regulated gas pressure passes through an inlet filter with a nominal rating of 1.0×10^{-5} meters (10 microns) and an absolute rating of 2.5×10^{-5} meters (25 microns). After passing through the filter, the gas flows through a port in the plunger and into the bellows, where it remains until the coil is energized. When the solenoid is actuated, the plunger is pulled back, moving the flange away from the O-ring mounted in the seat. This allows gas to flow around the seat and out the nozzle to give the required thrust. De-energizing the coil shuts off the gas flow. A single-pole double-throw microswitch installed on each thruster permits actuation monitoring in flight. Each thruster valve actuates to the full-open position upon application of command signals ranging from 20 to 28 volts dc. The drop-out voltage is 1.0 volt dc minimum at which time the unit returns to the normally closed position [2, 4, 6].

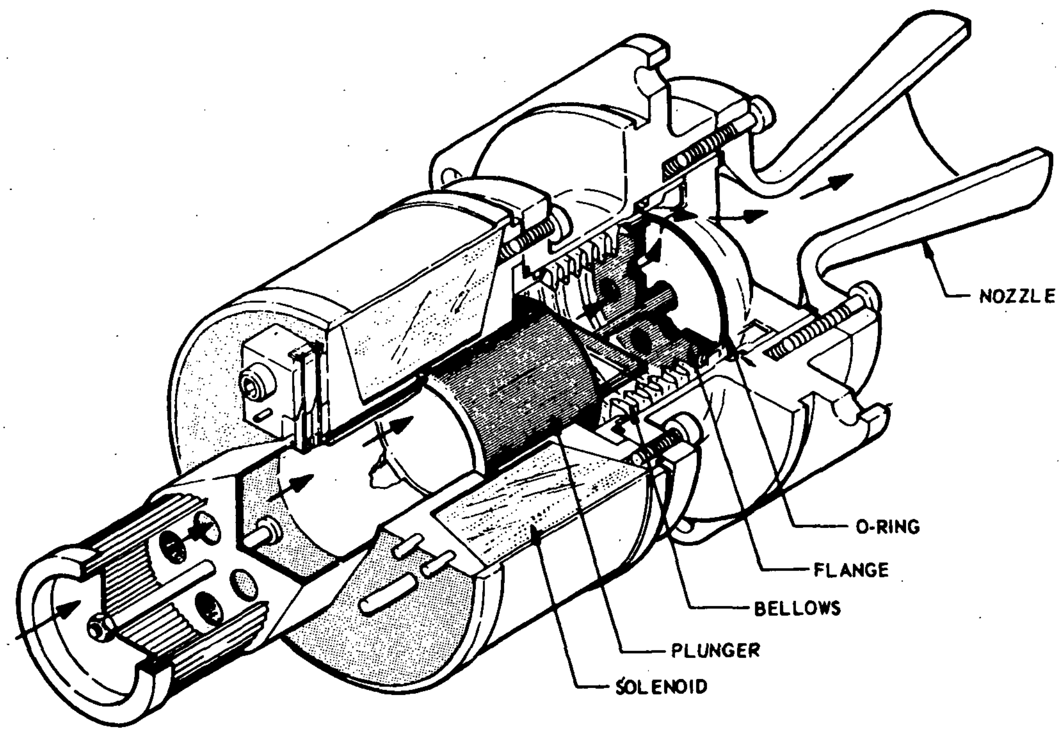

Figure 7. Thrust valve cartridge [4].

The thrust valve cluster internal operating pressure ranges from zero to 1.03×10^{6} N/m^2 gauge (zero to 150 psig) at the inlet port. The cluster is also designed for a proof pressure of 1.55×10^6 N/m^2 gauge (225 psig) and a burst pressure of 2.07×10^6 N/m^2 gauge (300 psig). With a zero command signal applied, the thruster valve is designed such that the external leakage is no greater than 0.17 standard cubic oentimeters per minute (SCCM). The thruster valve is designed for a service life of 950 000 actuation cycles minimum. The operating temperature range for the cluster unit is 238.71°K to 344.26°K (-30°F to +160°F). Each thruster nozzle throat area is 5.87×10^{-5} m^2 (0.091 in^2) and the exit area is 3.48×10^{-4} m^2 (0.54 $in.^2$) [6].

Stainless steel is used for the valve poppet and bellows, and silastic-rubber compounds are used for all static seals and the poppet seat. The filter is made of stainless steel wire mesh [2].

Tests are required to determine the reliability of the cluster unit for the operational lifetime required when used on the LST. Table 6 presents a summary of the thruster valve characteristics.

B. LST RCS Maintenance Procedure

Reference is made to Figure 1 in conjunction with the following description of the LST RCS maintenance procedure. Assume during one of the LST maintenance visits, the RCS propellant is found to be almost depleted, a major component failure has occurred in the black box, and one of the major thruster modules has been switched to its standby system because of a valve failure in the active system. During this maintenance visit, the tank would need to be refilled or replaced with a full tank, the black box would need replacing, and one or both of the thruster modules would need replacing.

As a safety measure to guard against asphyxiation, the GN_2 content in the SSM must be determined before man enters that module. Then, before maintenance to the RCS can begin, a check is made to determine the operating mode of the active regulator. If the regulator is not in the high mode of operation, it will be switched to that mode to ensure that high pressure exists below the regulator. Maintenance of the RCS is initiated by bleeding down the pressure inside the RCS to equal the pressure inside the SSM. With this pressure equivalence, the disconnection of pneumatic fittings is accomplished with ease and safety. The RCS pressure bleeddown is accomplished by opening the manual shut-off valve in each of the above regulator pressure-release bypass-vent lines. This allows the remaining gas in the propellant tank, as well as in the feed lines above the regulator, to be dumped overboard.

TABLE 6. THRUST VALVE CHARACTERISTICS*

Item	Data
Configuration	1462553
Mass (Triple Cluster)	2.04 kg (4.5 lbm)
Minimum Operating Temperature	238.71°K (-30° F)
Maximum Operating Temperature	344.26°K (+160° F)
Service Life	950 000 Cycles
Shelf Life	Unlimited
High Mode Thrust	44.48 ±6.67 N (10 ±1.5 lbf)
Low Mode Thrust	2.09 ±0.58 N (0.47 ±0.13 lbf)
Operating Pressure	0 to 1.03×10^6 N/m^2 gauge (0 to 150 psig)
Operating Voltage	20 to 28 Vdc
Current Drain	0.64 A @ 24 Vdc @ 294.26°K (70° F)
Response Time	0.020 sec Max
Actuation Indication Switch	Yes
Coil Resistance	40 Ohm @ 294.26°K (70° F)
EMI Suppression	No
Coil Dimensions	1.27×10^{-2} m ID $\times$ 3.81×10^{-2} m OD $\times$ 2.54×10^{-2} m long (0.5 in. ID $\times$ 1.5 in. OD $\times$ 1.0 in. long)
Wire Size	No. 29 AWG Magnetic Wire
Number Wire Turns	2100

*Data were taken from Reference 2.

The astronaut can close the valves when the pressure reading on the pressure gauge associated with each bypass vent line approaches the SSM pressure. Both above-regulator pressure-release bypass vent lines are opened to ensure that high pressure gas is not trapped in the standby loop or in the once-active loop that is now isolated because of a component failure.

After the pressure above the regulator is bled down, the astronaut will then open the manual shutoff valve associated with the below regulator pressure release vent line, which allows the excess gas below the regulator to be dumped overboard. By reading the pressure gauge associated with this vent line, the astronaut can close the shutoff valve when the pressure approaches that in the SSM.

An alternate approach to decreasing the pressure below the regulator would be to send a firing command to a thruster. However, rather than provide an electrical override on the black box to send such a command through the command circuitry, the mechanical pressure release method was selected. This method was also selected because electrical power may not always be available to send commands to the thrusters.

With the pressure inside the RCS equivalent to that in the SSM, the manual shutoff valve on the tank and in each line leading to the exterior of the spacecraft is closed. A pneumatic fitting at the tank, which connects the tank to the line leading to the black box, is disconnected. After an electrical connection to the tank has been disconnected, the tank is removed from its support rack structure and placed in the Shuttle supply/spares area.

Next, the black box is removed from the SSM. Removal of the black box consists of disconnecting seven pneumatic fittings — one fitting for each line which leads to the exterior of the spacecraft and the fitting for the line which leads from the tank — the black box electrical connector, and removal of the black box from its support structure. A new black box is placed in proper position in the SSM and connected up following the reverse of the procedure used to remove the old black box. The old black box is secured in the Shuttle to be flown back to earth for repair.

If GN_2 resupply facilities are on board the Shuttle, the tank will be refilled and reconnected to the LST RCS; otherwise, the Shuttle will have to bring a fully-loaded replacement tank up from the ground, and the old tank will be flown back to the ground for resupply and later use. Regardless of the resupply method, the LST RCS tank will have to be protected against bumps and scratches by some type of protective cover. The maneuvering around of a fully-charged GN_2 tank [approximately 2.07×10^7 N/m^2 gauge (approximately 3000 psig)] inside the Shuttle/SSM can be dangerous as a small bump or scratch on the surface of the tank could cause the tank to explode. The protective cover could be some type of thick, lightweight, rubberized material. The tank is placed in its support rack structure and connected up following the reverse of the procedure for its removal; except the tank manual shutoff valve will not be opened until the RCS is together and ready to operate. In the interest of safety during a maintenance visit, it is suggested that the fully-loaded RCS tank be one of the last items to be placed in position prior to the astronaut's leaving the SSM.

The major thruster module will have to be replaced by means of an EVA. The two feed lines leading to the module are easily disconnected by means of a pneumatic disconnect similar to that used on the black box. The two electrical connections to the module are disconnected, and by some simple means, the entire module is separated from the LST. The reverse of this procedure is followed in mounting the new module. The expected life remaining in the other module determines whether or not it should also be replaced during this maintenance visit.

Prior to release of the LST from the Shuttle, the SSM is powered up and checkout tests are initiated. However, prior to the power up, the RCS electrical and pneumatic connections are checked for proper connection. The manual pressure release valves on the black box are closed if they are not already. The manual shutoff valve in each line leading to the exterior of the spacecraft is opened. After power up of the SSM, the shutoff valve on the tank is opened, allowing gas to flow to the black box and to the regulator in the active control loop. The regulator regulates the pressure and the gas passes on to the thrusters. Checks are made to determine whether there are any leaks at the pneumatic connections. Engineering data are then telemetered to the ground for an entire RCS checkout. The operating mode of the regulator is noted, and the thrusters are actuated to be sure they are working properly. The regulator is then commanded to switch to the other mode and the thrust valves are again actuated. Once the entire LST/SSM checkout tests are completed, the LST is ready for release from the Shuttle.

A worst-case RCS maintenance procedure was just described. Of course, any one major element can be replaced without having to replace the others. The described RCS checkout procedure is only suggestive and is subject to variation.

SECTION IV. A SUMMARY OF THE ALTERNATE RCS CONCEPTS CONSIDERED FOR THE PHASE A LST

An alternate RCS considered for the LST during the Phase A study was a monopropellant hydrazine system. A monopropellant hydrazine RCS provides good performance (specific impulse = 120 to 230 seconds), and the total system mass when applied to the LST is low, i.e., 82 kg (180 lbm). A hydrazine RCS is simple and reliable for long periods of operation. However, a hydrazine RCS for the LST is believed to be more expensive than a GN_2 system. The exhaust of a hydrazine RCS is not considered to be a contamination producing source, but hydrazine is toxic and may produce harmful effects due to ingestion, inhalation of vapors, or contact with the skin. The latter two are the more common hazards. The threshold value, which has been adopted by the American Conference of Government Hygienists (1963), is 1 part per million (PPM). The maximum tolerable concentration in air breathed for no more than 10 minutes is suggested as 10 PPM. Because the toxicity effects of hydrazine could prove fatal to man, a hydrazine RCS for the LST was rejected.

The RCS selected for the LST (GN_2) is slightly heavier than the hydrazine system, i.e., 104 kg vs. 82 kg (230 lbm vs. 180 lbm). However, in sizing both systems, existing components were used. The performance of the GN_2 system is less than the hydrazine system (GN_2 specific impulse = 60 to 70 seconds). A GN_2 RCS is simple and highly reliable as the regulated GN_2 RCS of the Mariner 64 spacecraft demonstrated a 2.5-year lifetime. A GN_2 system requires the least cost for reliable hardware. The exhaust gas of a GN_2 RCS is clean, and GN_2 is not toxic unless, of course, the entire environment becomes saturated with nitrogen.

Two types of GN_2 reaction control systems were considered for the LST — a blowdown system and a regulated system. The blowdown system was rejected primarily because the initial high thrust produced by such a system would cause the spacecraft to overshoot its deadband which initiates limit cycling, which in turn results in inefficient utilization of propellant. Also since the thrust level is constantly decreasing, complexity is added to the guidance system in determining the thrust level at all times.

The alternate launch vehicle for the LST is the Titan IIIE. The Titan IIIE is a basic Titan IIID with the Lockheed Orbit Adjust Stage (OAS) used to adjust and refine the orbit of the payload. The OAS is assumed to have its own RCS to provide control until the LST is placed in its proper orbit and separation of the OAS/LST has occurred. Other OAS/LST guidance and control functions are assumed to come from the LST. The RCS considered for the OAS is a hydrazine system which draws its propellant from the OAS main propulsion tank. The dry mass of this RCS is 59.5 kg (131.2 lbm). The RCS on the LST will be the same as that used for the Shuttle-launched configuration. The thruster modules may, however, require an aerodynamic fairing.

Other RCS concepts considered for the OAS/LST configuration included a GN_2 system on the LST only to provide control for the OAS functions as well as for the LST functions, and a hydrazine system on the LST only to provide the same control functions.

SECTION V. CONCLUSIONS AND RECOMMENDATIONS

The RCS described herein is a simple regulated GN_2 system modularized into three basic elements to provide ease in manned orbital maintenance. Most of the components are existing and are used in operational space systems. However, some of the components may need to be modified and quality-tested for application to the LST. The use of these existing components will result in a low-cost RCS for the LST spacecraft.

Modularization of the RCS also provides for growth potential. Should the RCS propellant budget increase substantially, the black box can be modified for the connection of additional tanks or a single common manifold can be provided for the tanks which, in turn, connects to the black box. Modification of the black box would not be necessary with the common manifold approach. Volume is also available in the SSM for additional propellant tanks.

During the LST Phase B study, considerable attention should be devoted to determining the exact requirements for an RCS on the LST. Should the necessity for an RCS on the LST continue to exist, an effort should be made to keep the impulse budget low enough such that the RCS will remain a simple GN_2 system. From the standpoint of reliability, lifetime capability, system cost, contamination effects, and toxicity, it is important that a GN_2 RCS be retained for the LST.

Should a GN_2 RCS be selected for the LST during the Phase B study effort, a detailed study should be performed to determine whether the RCS should be a simple blowdown or regulated system. The reliability needed in RCS components as well as the extent of redundancy in these components should be determined. The feasibility of the RCS maintenance method should also be investigated. Also, since dry nitrogen gas will be used by the LST onboard Contamination Control System (CCS), an analysis should be performed to determine the feasibility of using a common GN_2 supply source for the RCS and the CCS.

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APPROVAL

PHASE A REACTION CONTROL SYSTEM DESIGN FOR THE LARGE SPACE TELESCOPE (LST)

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The information in this report has been reviewed for security classification. Review of any information concerning Department of Defense or Atomic Energy Commission programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

This document has also been reviewed and approved for technical accuracy.

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