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Final Report
for the period
September 1987 to
May 1990

CONCENTRATOR FLIGHT TEST EXPERIMENT

May 1991

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Prepared for the: **Phillips Laboratory**

Air Force Systems Command
Propulsion Directorate
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FOREWORD

This final report was submitted by L'Garde, Inc., Tustin CA, on completion of Small Business Inovation Research (SBIR) Contract F04611-87-C-0072 with the OL-AC Phillips Laboratory (AFSC), Edwards AFB CA. PL Project Manager was Kristi Laug.

This report has been reviewed and is approved for release and distribution in accordance with the distribution statement on the cover and on the DD Form 1473.

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The goal of this Phase II Small Business Innovation Research (SBIR) effort was to take the conceptual design begun under the Phase I SBIR Flight Test Planning effort and accomplish the preliminary design of a subscale inflatable solar collector system. The preliminary design was then to be experimentally verified and a detail design generated. The inflatable portion of the collector was to be an adaptation of the inflatable collector produced on the Deployable Solar Collector Experiment (DSCE). The entire collector system was to be designed to be packaged into a Get Away Special Canister launched from the space shuttle.

No experimentation was done in this effort. This final report covers the preliminary design and the analysis supporting that design.

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SUMMARY

Some future U.S. space applications will require transporting heavy payloads from low earth orbit to geosynchronous orbit. Current chemical propulsion is a costly and inefficient method to perform this task. Solar thermal propulsion nearly doubles the efficiency in terms of specific impulse -- up to 1000 seconds or more. A solar propulsion system has large collectors that gather the sun's energy and then reflect and concentrate it into a chamber where it heats a gas to a very high temperature. This extremely hot gas expands and is then expelled through a nozzle to produce thrust. To make solar propulsion practical, highly accurate collectors must be available that are lightweight and can be packaged into and deployed from a small volume. An inflatable collector system meets these requirements.

L'Garde worked on a concept for an inflatable solar collector system for a solar rocket as part of the Highly Accurate Inflatable Reflectors (HAIR) program for the Phillips Laboratory (PL) of the Air Force Systems Command. The solar collector system had two major subsystems: the reflector subsystem and the pointing and control subsystem. However, these subsystems must be designed and developed before they can be applied to a real solar rocket.

Much of the development testing can be done on the ground in various government and contractor simulation facilities. However, ultimately the design must be tested in space with a series of flight tests.

PL has awarded five contracts to L'Garde over the years to provide a solar collector system design suitable for solar rocket application and to plan the overall development process leading to and through the space flight experiment. A Phase I SBIR contract (F04611-86-C-0054) defined the overall technical objectives of such a test program, planned the experiment process, and provided a solar collector design concept.

The goal of this Phase II Small Business Innovation Research (SBIR) effort was to take the conceptual design begun under the Phase I SBIR Flight Test Planning effort and complete a preliminary design of a subscale inflatable solar collector system. This preliminary design was then to be experimentally verified and a detail design generated. The inflatable portion of the collector was to be an adaptation of the inflatable collector produced on the Deployable Solar Collector Experiment (DSCE). The entire collector system was to be designed to be packaged into a Get Away Special Canister launched from the space shuttle.

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1.0 INTRODUCTION

Some future U.S. space applications will require transporting heavy payloads from low earth orbit to geosynchronous orbit. Current chemical propulsion is a costly and inefficient method to perform this task. Solar thermal propulsion nearly doubles the efficiency in terms of specific impulse -- up to 1000 seconds or more. A solar propulsion system has large collectors that gather the sun's energy and then reflect and concentrate it into a chamber where it heats a gas to a very high temperature. This extremely hot gas expands and is then expelled through a standard nozzle to produce thrust. To make solar propulsion practical, highly accurate collectors must be available that are lightweight and can be packaged into and deployed from a small volume. An inflatable collector system can meet these requirements.

The Phillips Laboratory (PL) of the Air Force Systems Command has awarded five contracts to L'Garde over the past several years to work on development of an inflatable solar collector system. They are listed below. This document is the Final Report for the last of these programs.

Program Name	Started	Completed
Highly Accurate Inflatable Reflector (HAIR) Phase I	9/83	2/84
Highly Accurate Inflatable Reflector (HAIR) Phase II	10/84	10/86
Inflatable Solar Concentrator Flight Test Experiment SBIR Phase I Project	6/86	1/87
Deployable Solar Concentrator Experiment (DSCE)	9/86	In progress
Inflatable Solar Concentrator Flight Test Experiment SBIR Phase II Project	9/87	In progress

1.1 DEPLOYABLE SOLAR CONCENTRATOR EXPERIMENT (DSCE)

In September 1986, PL awarded contract F04611-86-C-0112 to L'Garde to provide a fully developed inflatable solar concentrator design for a future flight test experiment that would demonstrate packaging/deployment strategies, sun tracking capability, and one milliradian root mean square (RMS) surface accuracy of the plastic film paraboloidal reflectors.

The DSCE effort is still continuing and includes design, fabrication, and test of a prototype off-axis parabolic solar collector test article that is approximately 7 meter (m) by 9.14 m (23 feet (ft) by 30.3 ft) in size (reflector surface only).

1.2 PHASE II SBIR PROGRAM - INFLATABLE SOLAR CONCENTRATOR FLIGHT TEST EXPERIMENT (SIREX)

In September of 1987, PL awarded contract F04611-87-C-0072 to L'Garde to perform the preliminary and detail design of a future flight test experiment that would demonstrate successful inflation and determine the structural dynamics of the flight item. The inflatable would be packaged in a canister which would also contain an inflation system, instrumentation, telemetry, a TV camera, and battery power. For the inflatable, this program was to use the DSCE (Section 1.1 above) inflatable design with only those design changes needed to interface with the SIREX flight experiment. SIREX had to be designed around the size constraints and environments of the Get Away Special (GAS) Canister on the Space Shuttle.

This Final Report documents the preliminary design and analyses for this Inflatable Solar Concentrator Flight Test Experiment, referred to internally at L'Garde as SIREX (Solar Inflatable Reflector Experiment).

2.0 TECHNICAL REQUIREMENTS

The purpose of this section is to present the technical requirements as specified by the contract Statement of Work (SOW) and the derived technical baseline determined by analysis and/or test. (Since the SOW intermingles both program and technical requirements, this section is not intended to be a verbatim quote of the SOW. Rather it is L'Garde's understanding and summary of the requirements explicitly listed in Appendix D, CONTRACT SOW.)

Solar propulsion concepts have the potential to deliver twice the performance of current chemical rockets. By using large quantities of free solar energy to heat a working fluid and exhaust the fluid for thrust, high specific impulses can be achieved. Harnessing the sun's energy in space results in needing only half of the propellant required for conventional chemical rockets. The solar thermal rocket can harness this vast energy source via lightweight, inflatable, off-axis concentrators. The feasibility of inflatable solar concentrators has been demonstrated through past programs. The SIREX Phase II SBIR project delivered only a preliminary design for a space flight test.

The inflated hardware concept is shown in Figure 1. Note that the dimensions in this figure differ from those in Figure 7 of the Phase I SBIR Report (Ref 11) because the DSCE design is much more refined than the Phase I SBIR design. In addition, the major axis dimension is to different reference points in the two figures.

2.1 OBJECTIVES

The objective of the SIREX Program was to design hardware that will satisfy the flight test objectives:

1. Demonstrate that the reflector erects in space.
2. Determine the time required for the reflector to stabilize after being perturbed by a force similar to that produced on a collector during operation of a solar powered rocket.

2.2 DESIGN REQUIREMENTS

2.2.1 SOW Technical Requirements

SIREX must use the DSCE soft torus, truss, and reflector design (SOW para 3.2.5.2.). In the DSCE design, the reflector and mirror image canopy are off-axis 7 m x 9.14 m (23 ft x 30.3 ft) inflated paraboloids. The edges of the paraboloid are held and supported by an inflated elliptical torus. The truss system consists of three inflated tubes extending from the elliptical torus to the canister. The off-axis paraboloid is defined as follows:

Focal length (f) is 3.186 m (10.46 feet),
Angle of paraboloid with respect to a plane normal to the paraboloid axis (ß) is 40 degrees, and
The center of the off-axis paraboloid is 2f tangent ß from the on-axis paraboloid centerline.

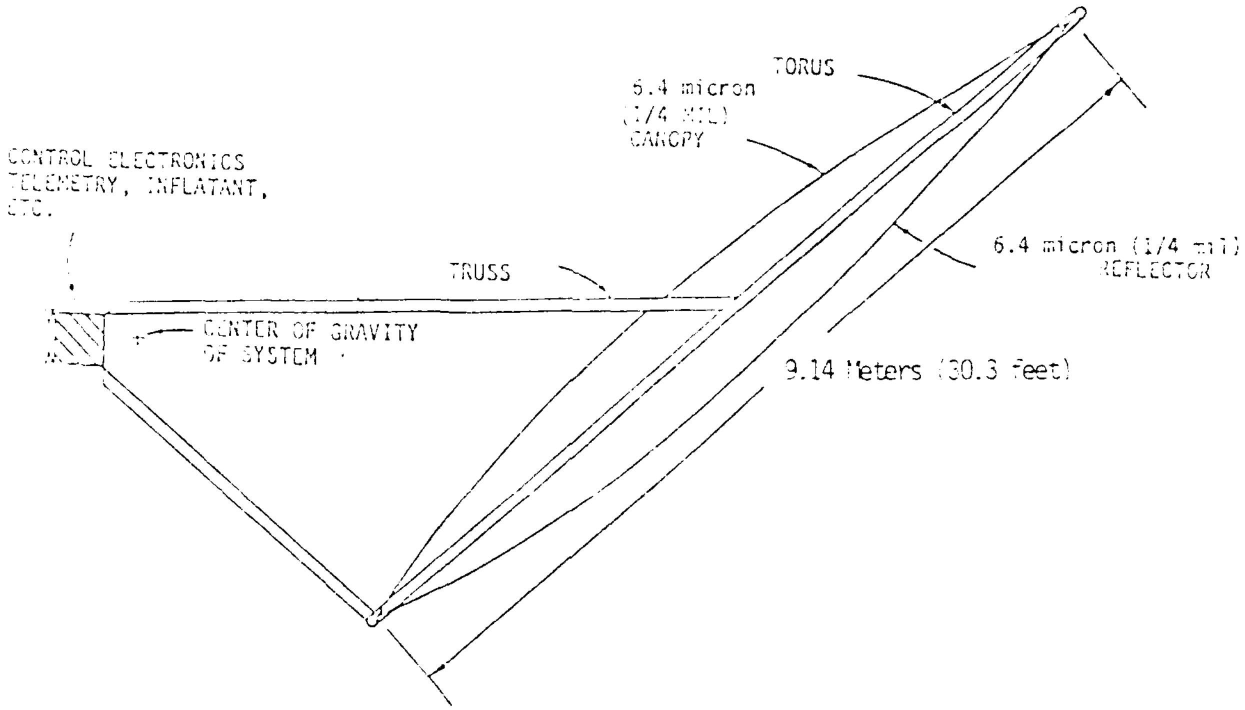


Figure 1. DSCE Off-Axis Flight Test Reflector

The canister is the structural element that holds all components including the packaged inflatable. The canister shall be designed and built to eject from the GAS Canister (SOW para 3.2.4.1). The canister will include doors which open to expose the inflatable, allowing it to be inflated.

Instrumentation shall consist of pressure sensors and linear variable displacement transducers (LVDTs), strain gages, accelerometers, thermocouples, and video cameras (SOW para 3.2.1.1). Telemetry shall consist of a transmitter and an omni-directional antenna or an equivalent configuration for downlinking to the earth (SOW para 3.2.1.1).

Batteries shall be used for power. Lead-acid type batteries are preferred. A list of the candidates and reasons for final choice shall be provided to the PL if a type other than a lead-acid battery is used. (SOW para 3.2.2).

2.2.2 Flight Experiment Description

Figure 2 illustrates the sequence of events. The canister will be carried aloft in a GAS canister aboard a space shuttle and ejected from the shuttle bay at a predetermined time. The altitude of the orbit is not critical, but it is desirable to be as high as possible as this will both minimize drag on the reflector and increase the time that the experiment will be in the line-of-sight (LOS) of any particular ground station. The on-board controller will be activated at the time of ejection and will wait until the (still packaged) experiment is in the LOS of the first ground station. The controller will signal the protective doors to open and latch. About a second later the vent valves will be closed and gaseous nitrogen will be released into the struts and torus,

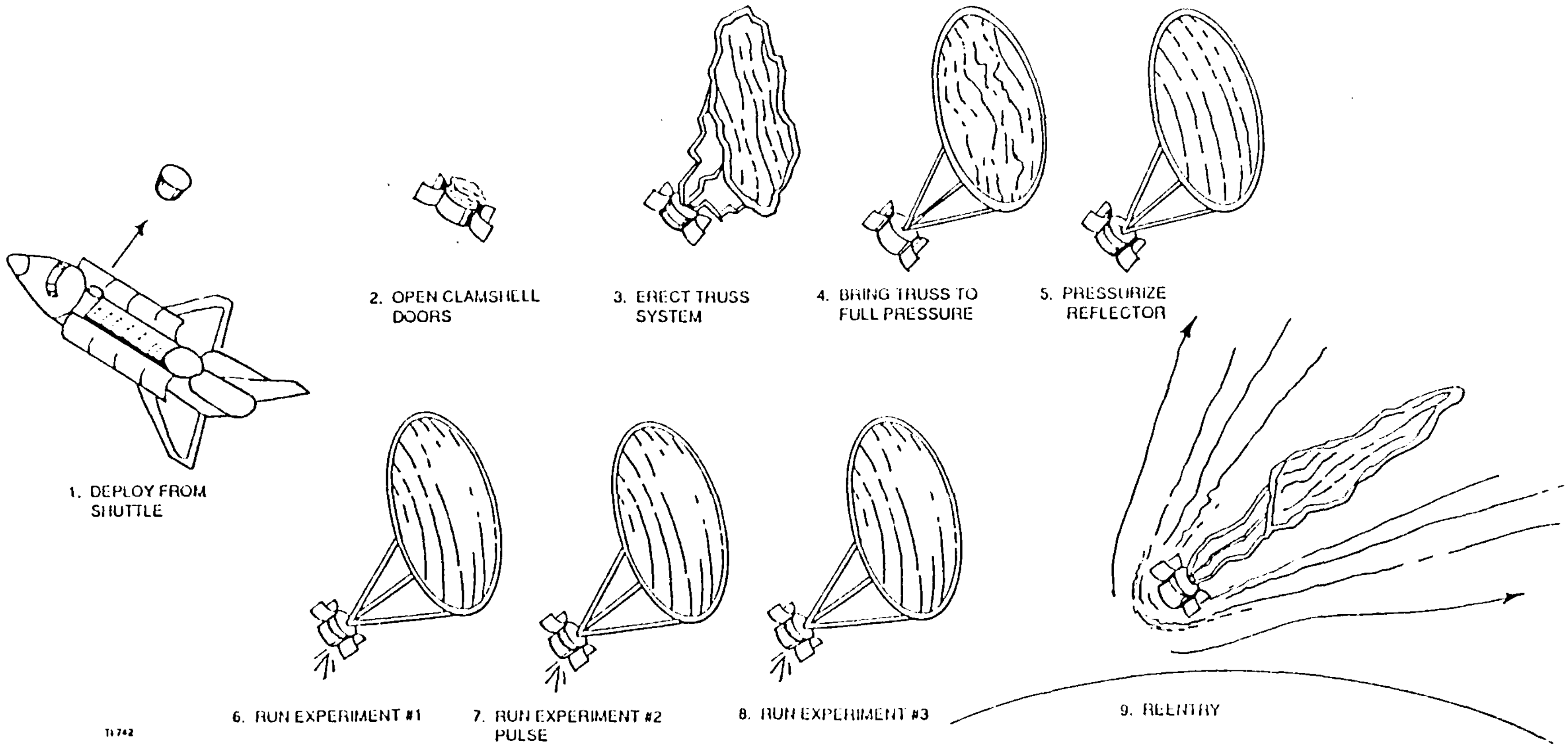


Figure 2. Sequence of Events

inflating the reflector's truss system. Once the truss is inflated and at full pressure, gas will be released into the reflector itself until it reaches the desired inflation pressure. During this entire process both video and sensor data will be transmitted to the ground station. Two minutes after the inflation sequence starts the reflector will be fully erected.

Once the reflector is in place, the perturbation tests will begin. Three tests may be run at any time between erection and 45 minutes later. At this time the location and number of ground stations is unknown, so this criterion is somewhat arbitrary. The limitation of 45 minutes allows all testing to be done while in daylight. This is desirable for three reasons. One, the video camera will not require special light intensifiers. Two, a night experiment would require a design with a wider range of light intensities since the phase of the moon during the flight might not be known until late in the program, possibly not until launch. Three, the daylight temperature (i.e., around 300°K), and thus pressure, of the inflation gas will be twice the night-time temperature (i.e., around 150°K), thus lowering gas requirements by 50%.

A deorbit analysis was run for the inflated reflector and the deorbit profile appears in Figure 3. This shows that even though the unit deorbits quickly, there will be adequate experiment time. For instance, an initial 300 km (160 nm) circular orbit gives approximately 5 hours of experiment time before altitude decays to 220 km (120 nm) where the atmosphere and drag become high.

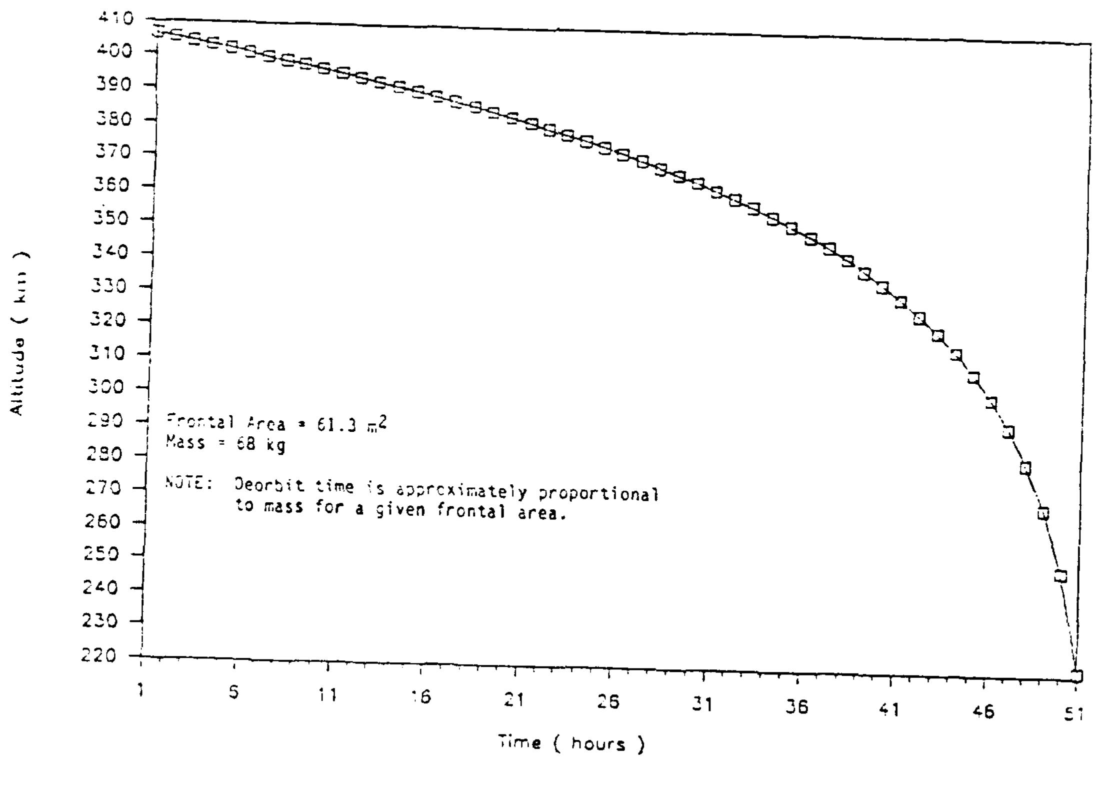


Figure 3. SIREX Deorbit Profile

The experiment timeline is shown in Table 1.

TABLE 1. SIREX PRELIMINARY TIMELINE

Time (Sec)	Delta Time (Sec)	Event
0	0	Timer Started by Signal from Shuttle
1	1	Ejection from GAS Canister
t0	TBD	Turn Main Power ON. (Delay from ejection to start of inflation could be 10 seconds to 45 minutes depending on shuttle requirements and orbit.)
t0+60	60	Power ON to Vent Closing Pyrotechnic Valve
t0+60.1	0.1	Power OFF to Vent Closing Pyrotechnic Valve
t0+60.2	0.1	Power ON to Door Opening Pyrotechnic Cable Cutter
t0+60.3	0.1	Power OFF to Door Opening Pyrotechnic Cable Cutter
t0+62	1.7	Power ON to Inflation Gas Bottle Pyrotechnic Valve
t0+62.1	0.1	Power OFF to Inflation Gas Bottle Pyrotechnic Valve
t0+63	0.9	Start Torus Pressure Regulation
t0+123	60	Start Reflector Pressure Regulation
t0+243	120	Power ON to Pulse Gas Bottle Pyrotechnic Valve
t0+243.1	0.1	Power OFF to Pulse Gas Bottle Pyrotechnic Valve
t0+244	0.9	Trigger Pulse Generator Circuitry
t0+480	236	First Experiment Over
t1	TBD	Wait Time Between Experiments TBD (less than 20 minutes)
t1+60	60	Trigger Pulse Generator Circuitry
t1+480	420	Second Experiment Over
t2	TBD	Wait Time Between Experiments TBD (less than 20 minutes)
t2+60	60	Trigger Pulse Generator Circuitry
t2+480	420	Third Experiment Over

Total experiment time is 24 minutes minimum to 95 minutes maximum, depending on TBD wait times.

2.2.3 Derived Mechanical Baseline

The parameters listed herein are not the only design solutions to the requirements specified. However, as analysis in Section 4 shows, this baseline will meet the requirements.

The canister doors will remain with the system after opening and will be latched in the open position. The doors shall not permanently deform even when subjected to the pressures caused by the air in the packaged balloon during ascent. A 6.35 mm (0.25 inch) diameter orifice vent valve will vent air during ascent. The doors must be able to withstand the 1300 Pascals (Pa) (0.19 pounds per square inch gauge [psig]) maximum internal pressure expected with this vent valve. (See Section 4.1)

The door hinges and latches shall each withstand a 100 Newtons (N) (21 pounds force [lbf]) load from internal pressure. (See Section 4.1.)

The canister shall be capable of being lowered into the GAS canister; a device shall be provided to interface the system to a sling.

The inflation system shall erect the inflated structure slowly enough so the inflatable does not rupture in the process and fast enough so that the experiment can be completed within 0.5 orbit after the start of erection.

The pulse generator shall produce nominal force of roughly 2.2 N (0.5 lbf) for 20 milliseconds (ms) at the canister. This equates to what the reflector might experience on a solar powered rocket. The pulse generator shall consist of a 10 cubic centimeters (cm^3) (0.61 cubic inches (in^3)) bottle pressured with 10.3 MPa (1500 psi) nitrogen, a pyrotechnic valve, a pressure transducer, a solenoid valve, and a nozzle. The volume within components (tubing, pyrovalve, solenoid, pressure gage) between the pressure bottle and solenoid valve shall be less than 5 cm^3 (0.31 in^3). The volume between the solenoid orifice and nozzle throat shall be minimized. The throat diameter shall be 0.75 mm (0.030 inch). The subsystem derived will produce an initial pulse with a 4.4 N (1 lbf) force; subsequent pulses will have lower forces. (See Section 4.4.)

Two 0.8 Newton-meters (Nm) (7 inch-pounds [in-lbf]) springs per door will produce a 5.2 radians (rads)/second (300 degrees/second) velocity at impact with the latches. The doors may permanently deform upon latching but may not break up or unlatch. (See Section 4.2.)

The camera must have a 1.7 rad (100 degree [°]) minimum field of view (FOV). and be tilted 0.09 rad (5°) in the canister in order to see the entire reflector. It must return useful video with the sun, earth, or space in the background.

The torus is designed and developed by the DSCE Program. Its tubular diameter will be 457 millimeters (mm) (18 inches). It will be pressurized to twice the pressure required to prevent buckling. The reflector pressure is 8.3 Pa (0.0012 psi) nominal. This may be varied during the experiment, but may never be allowed to exceed 9.0 Pa (0.0013 psi). (See Section 4.4.)

The pneumatic system is shown in Figure 4.

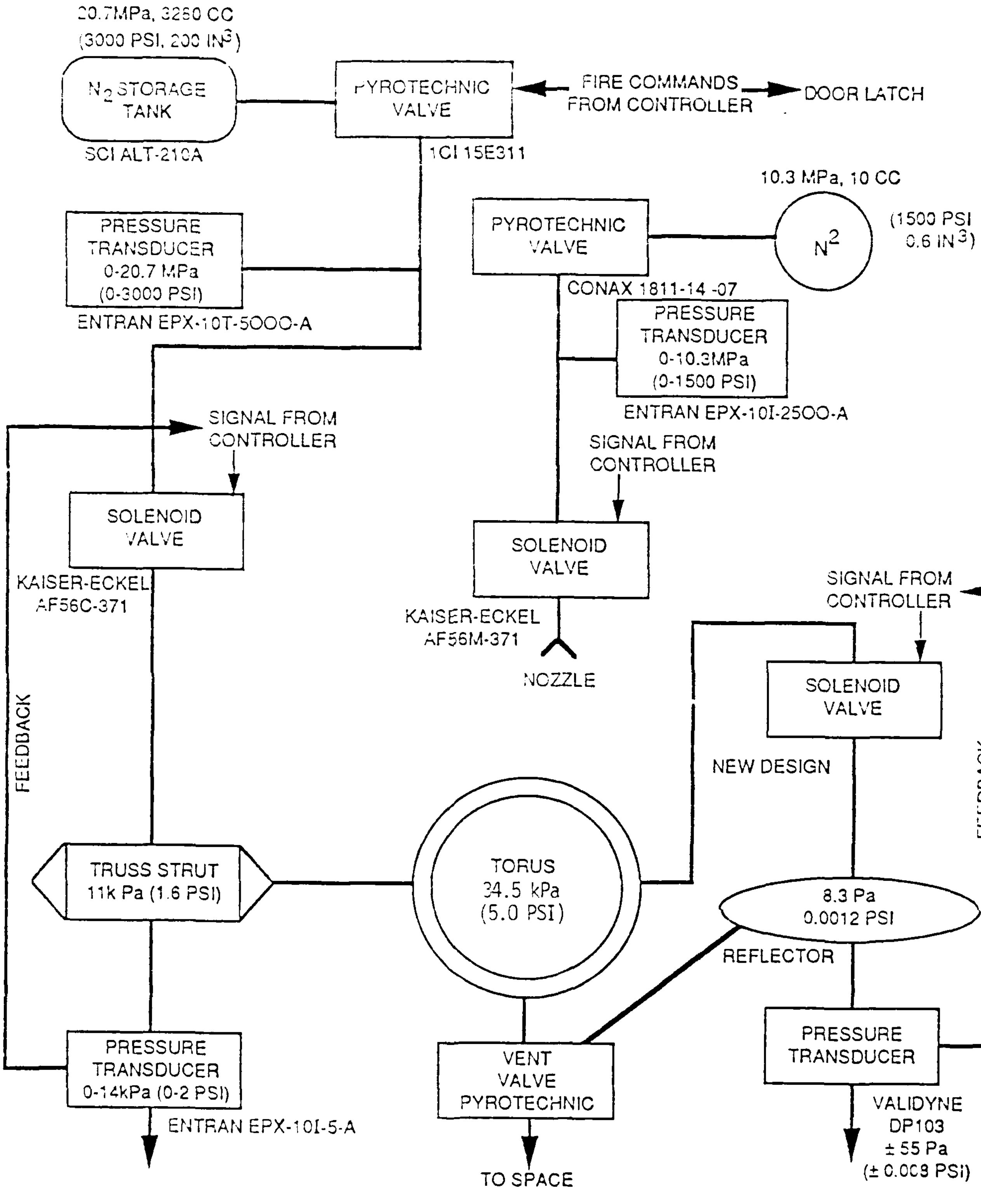


Figure 4. Pneumatic System

2.2.4 Derived Electrical Baseline

The antenna(s) shall be designed to be omnidirectional.

The instrumentation list is shown in Table 2.

2.2.5 Get Away Special Payload Structural Criteria

Definitions

F.S. = Factor of Safety

Limit Load = Maximum expected load

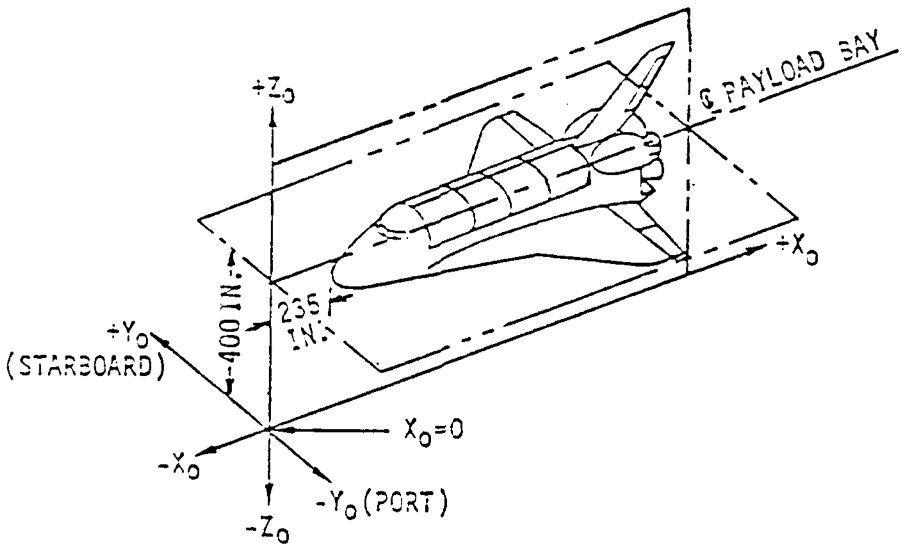
Yield Load = (Limit load) x (Yield Factor of Safety)

Ultimate load = (Limit load) x (Ultimate Factor of Safety)

$$\text{Margin of Safety} = \frac{\text{(allowable stress)}}{\text{(applied stress)}} - 1$$

Design Criteria

1. For design purposes, the X, Y and Z loads are to combined in the worst possible load combinations. The orbiter coordinate system is shown in Figure 5.



Origin: In the Orbiter plane of symmetry, 400 inches below the centerline of the payload bay and at Orbiter X station = 0.
Orientation: The x_o axis is in the vehicle plane of symmetry, parallel to and 400 inches below the payload bay centerline. Positive is from the nose of the vehicle toward the tail.
The z_o axis is in the vehicle plane of symmetry, perpendicular to the x_o axis; positive is upward in landing attitude.

Figure 5. Orbiter Coordinate System

TABLE 2. SIREX INSTRUMENTATION PARAMETERS

ITEM	SIGNAL NAME	SCALE	ACCURACY	SAMPLE PERIOD	RANGE	
1	Torus Pressure	0-14 kPa (0-2 psi)	5%	0.2 Sec	0 - +5V Output	Linear
2	+5V System Monitor				+2.5V Nominal	Linear
3	+15V System				+5V Nominal	Step
4	-15V System				-5V Nominal	Step
5	+13V Battery Tap				+5V Nominal	Step
6	26V Battery				+5V Nominal	Step
7	Inf. Pyro Valve Solenoid	Fire Signal	N/A	As Needed	+5V Nominal	Step
8	Reflector Inflate Valve	On - Off	N/A	As Needed	+5V Nominal	Step
9	Torus Inf. Solenoid Valve	On - Off	N/A	As Needed	+5V Nominal	Step
10	Lid Guillotine	Fire Signal	N/A	As Needed	+5V Nominal	Step
11	Transmitter Power				+5V Nominal	Step
12	Camera Power				+5V Nominal	Step
13	Encoder Power				+5V Nominal	Step
14	Torus Temperature	-50 C to +50 C	5%	5 Sec	-2.975V to +5.08V	Non-linear (corrected on ground)
15	Torus Temperature	-50 C to +50 C	5%	5 Sec	Same as Above	
16	Torus Temperature	-50 C to +50 C	5%	5 Sec	Same as Above	
17	Heater Blanket Monitor				+5V	Step
18	Strain Gauge #1	TBD by Test	5%	0.2 Sec	0 - +5V	Linear
19	Strain Gauge #2	TBD by Test	5%	0.2 Sec	0 - +5V	Linear
20	Strain Gauge #3	TBD by Test	5%	0.2 Sec	0 - +5V	Linear
21	Strain Gauge #4	TBD by Test	5%	0.2 Sec	0 - +5V	Linear
22	Strain Gauge #5	TBD by Test	5%	0.2 Sec	0 - +5V	Linear
23	Strain Gauge #6	TBD by Test	5%	0.2 Sec	0 - +5V	Linear
24	Strain Gauge #7	TBD by Test	5%	0.2 Sec	0 - +5V	Linear
25	Strain Gauge #8	TBD by Test	5%	0.2 Sec	0 - +5V	Linear
26	Strain Gauge #9	TBD by Test	5%	0.2 Sec	0 - +5V	Linear
27	Strain Gauge #10	TBD by Test	5%	0.2 Sec	0 - +5V	Linear
28	Strain Gauge #11	TBD by Test	5%	0.2 Sec	0 - +5V	Linear
29	Strain Gauge #12	TBD by Test	5%	0.2 Sec	0 - +5V	Linear
30	Accelerometer #1	± 1g	5%	0.1 Sec	0 - +5V	Linear
31	Accelerometer #2	± 1g	5%	0.1 Sec	0 - +5V	Linear
32	Accelerometer #3	± 1g	5%	0.1 Sec	0 - +5V	Linear
33	Inf. Bottle Pressure	0 - 21 MPa (0-3000 psi)	5%	0.2 Sec	0 - +5V	Linear
34	Thruster Bottle Pressure	0 - 10 MPa (0-1500 psi)	5%	0.2 Sec	0 - +5V	Linear
35	Reflector Pressure	0 - 55 Pa (0-0.008 psi)	5%	0.2 Sec	0 - +5V	Linear
36	Vent Pyro Valve	Fire Signal	N/A	As Needed		
37	Equipment Module Temp.	-50 C to 100 C	5%	5 Sec	Same as Torus	

2. There are some materials with a yield strength less than 75% of the ultimate strength (e.g., 300 series annealed stainless steel). For these cases the structure should be analyzed using the yield design loads. Yield margins of safety should be computed using the yield strength of the material.

3. Ultimate margins of safety using the ultimate design loads and the ultimate strength of the material should be computed.

4. The flight level environments for GAS payloads is defined in Figure 6.

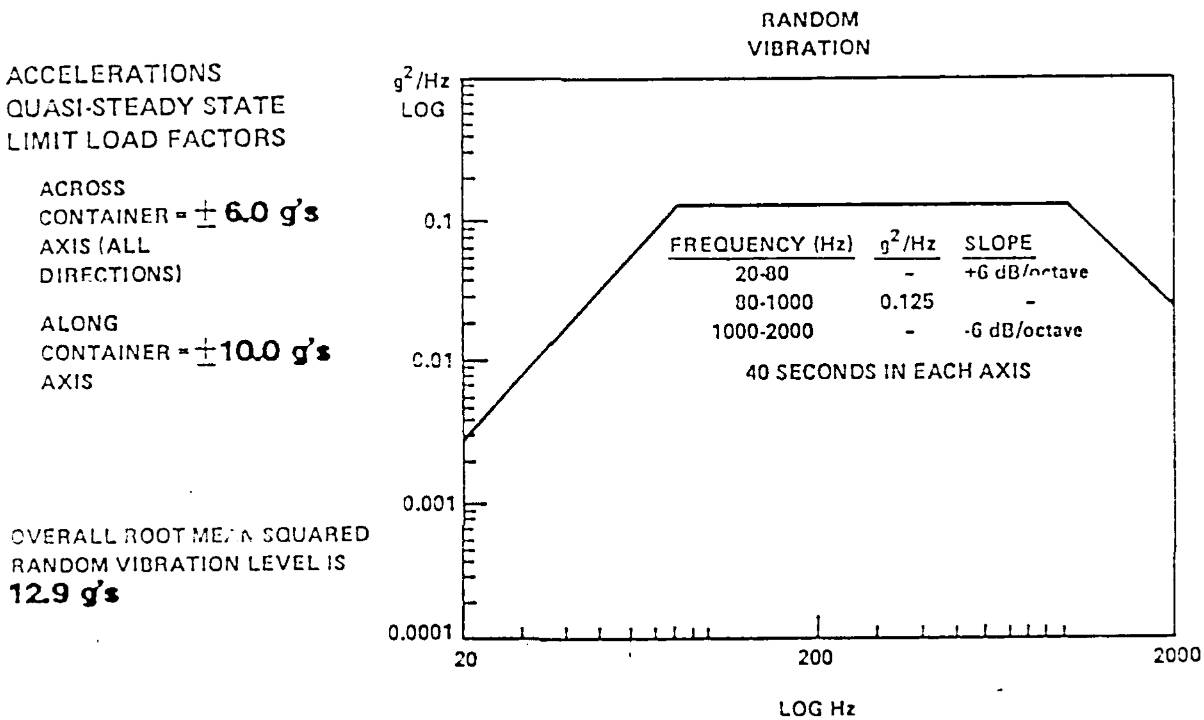


Figure 6. Get Away Special Small Self-Contained Payload Environments

5. The fundamental frequency of the payload about any axis must be $\geq$ 35 Hz. Safety verification can be performed by analysis or test.

Safety Verification Structural Analysis -- Finite element analysis is not required. A written hand analysis using classical techniques appropriate to the structure is required to show the structure will survive the shuttle environment.

Design Verification and Factors of Safety

Assuming there are no tests to verify the structural analysis, the following factors of safety shall be used:

Yield F.S. = 1.5
Ultimate F.S. = 2.0

Table 3 lists the load vectors for payloads where the analysis is not verified by test.

TABLE 3. LOAD VECTORS

Analysis Not Verified by Test

Yield F.S. = 1.5
Ultimate F.S. = 2.0

Dir.	Limit Load (g/s)	Yield Load (g's)	Ultimate Load (g's)
+X	6.0	9.0	12.0
-X	6.0	9.0	12.0
+Y	6.0	9.0	12.0
-Y	6.0	9.0	12.0
+Z	10.0	15.0	20.0
-Z	10.0	15.0	20.0

NOTE: Orbiter coordinate system (Figure 5) is used for defining load direction.

Loads are to be combined using the X, Y and Z loads in the worst possible load combinations.

3.0 MECHANICAL DESIGN

The description of the flight experiment and overall design was given in section 2.0. The mechanical design is divided into the following subsystems:

1) Inflatable
2) Support structure and inflatable enclosure
3) Pneumatics systems, inflation and pulse
4) Controller, connectors, and power supplies
5) Sensors and video camera
6) Encoder, transmitter and antenna
7) GAS Canister and ejector

Descriptions of the first six subsystems can be found in the next six subsections. The seventh subsystem, the GAS canister and ejector, is supplied by NASA (Refs 7 & 8) and is not covered in this report.

Drawings and the drawing tree are found in Appendix A. In the following subsections, figure numbers starting with the letter A are in Appendix A.

3.1 INFLATABLE

Since the inflatable was designed under DSCE, it is only outlined here. Only SIREX-unique details are discussed here. DSCE design details, such as size, focal length, and materials, will be covered in detail in the DSCE report. A computer program, known as "RIMS" within L'Garde, was developed and used for much of the inflatable analysis under DSCE. A RIMS code listing is provided in Appendix C.

The inflatable consists of three main components. One, the off-axis paraboloid reflector whose deployment and dynamics are the focus of this experiment. Two, the elliptical shaped torus which forms a rim to hold the reflector in shape. And finally the three struts which hold the rim/reflector away from the equipment module at a specific orientation.

The DSCE reflector is an off-axis 7 meter (m) x 9.14 m (23 feet (ft) x 30.3 ft) paraboloid which is defined as follows. The focal length is 3.186 m (125 inches) and the angle of the reflector rim with respect to a plane normal to the paraboloid axis is 0.7 rad (40°). The reflector will be made of 6.3 micron (0.00025 inch) thick mylar film and will have a mirror image canopy also made of 6.3 micron (0.00025 inch) thick mylar film. Normally, the film being used as the reflector surface would be metallized to reflect light while the canopy was left transparent. For this design, however, there is no need to metallize the reflector surface since no reflecting will be done. Rather, a pattern will be inked to its surface so that it can be seen by the television. The reflector and canopy will be built from multiple flat pattern gores which will be butt-jointed using 25.4 mm (1 inch) wide tape made of the same material and built into their three dimensional shapes. The reflector's operating pressure is 8.3 Pa (0.0012 psi). This design data is supplied by the DSCE program.

The SIREX reflector will have twelve strain gauges and three accelerometers distributed over its surface. The strain gauges which are mounted on thin film will either be glued to the reflector surface or, if possible, silk-screened directly onto the gores. See Section 5 for a description of the strain gauges and instrumentation. Power will be run to and signal taken from these sensors by thin gauge wires which will be bonded directly into the gore seams.

The elliptical torus is 45.7 cm (18 inches) in diameter and will be pressurized to 34.5 kPa (5.0 psi). Generally, the torus will be composed of 24 cylindrical segments of different lengths joined end to end to approximate the elliptical shape. The DSCE torus will be made of 279 micron (0.011 inch) thick Neoprene coated Kevlar (NCK). Once again, this design data is supplied by DSCE.

Attached to the outside of the torus will be the pyrotechnically operated vent valve, the solenoid fill valve, and the low pressure transducer used to monitor the reflector pressure. Electrical lines will be run to these and the reflector sensors along the outside of the torus underneath a ribbon of 279 micron (0.011 inch) thick NCK. The reflector will be filled using the already inflated torus as a pressure supply. The reflector, torus and struts will all be vented through the above mentioned vent valve.

Three struts will project from the equipment module to the torus. The struts will be made of the same Kevlar composite as the torus and will form a single pressure chamber with the torus. When the system is erected, the gas will be released into the ends of the three struts and then flow into the torus. The electrical lines from the torus and reflector will run down the outside of the struts, divided as equally as possible among the struts. (Figure A-9 shows where the struts attach to the canister, and Figure A-4 shows how they attach.)

The inflatable system will be packaged inside the clamshell doors on the opposite side of the main floor from the electronics equipment. Some packaging tests have been done (see Section 4.3) and a scheme for packaging has been devised. Because high packaging efficiencies are needed, emphasis was placed on tight packaging of the torus which accounts for nearly 80% of the material volume. First the torus is collapsed and the small diameter is folded 2 times to form a flat ribbon pi x 457 mm/6 = 239 mm (9.4 inches) tall. This ribbon is then rolled up like a party favor with the reflector/canopy hanging out one side and the struts hanging out the other. The struts and reflector are then accordion folded on either side of the torus.

3.2 SUPPORT STRUCTURE AND INFLATABLE ENCLOSURE

The main support platform for the SIREX is a 4.75 mm (0.187 inch) thick circular aluminum floor 47.6 centimeters (cm) (18.75 inches) in diameter. On one side of this plate is mounted the inflatable, while on the other are all the electrical, pneumatic, and mechanical equipment with the exception of those few items which are mounted to the torus. Additional rigidity is provided by the three clamp rings, 21.6 cm (8.50") in diameter x 1.9 cm (0.75") high, on the inflatable side of the floor. Sixteen lockscrews hold down each ring. On the equipment side of the floor is a 23.8 cm (9.38 inch) diameter x 19.1 cm (7.50 inch) high x 0.64 cm (0.25") thick interface structure with 8 integral seal screws used for attachment. The interface structure is configured to NASA and the shuttle GAS design specifications; a NASA Marman clamp attaches the SIREX to the GAS canister. See Figure 7.

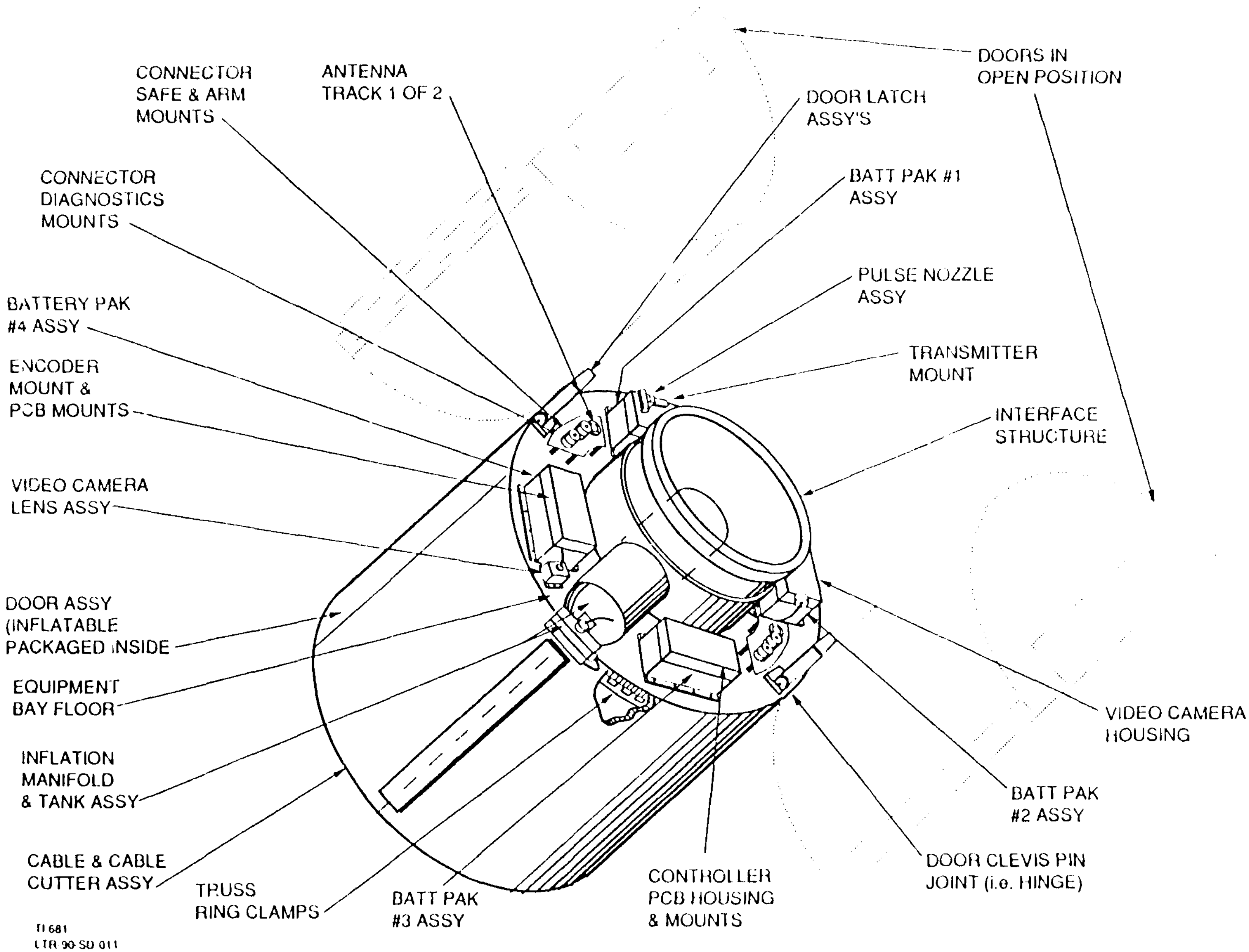


Figure 7. SIREX Structure and Inflatable Enclosure Sketch

In the pre-inflated state a set of clam-shell doors enclosing a volume 33.3 cm (13.1 inches) tall and 47.6 cm (18.75 inches) in diameter surround the inflatable. These doors are held closed by a short length of cable running across the split between the doors. The doors are released shortly before inflation by a pyrotechnic cable cutter allowing them to rotate around the hinge point at the aluminum floor. Two torsional springs at the 0.48 cm (3/16") clevis pin joint of each door provide the opening force. Two small springs located at the top of the doors provide an initial kick to help overcome any static friction which might cause the doors to stick. See Figure A-7, right view.

The door assembly consists of all 6061-T6 aluminum alloy sheet metal welded together. Along the sides where the doors meet when closed are side skirts which both add stiffness and aid in alignment. Along the top edge where the doors meet are 4 pins and mating holes which keep the two semi-circular top plates aligned against shear.

On the equipment side of the floor are two posts which stop and latch the doors after they rotate π radians (180°). In addition to the latch, the torsional springs will still be exerting force to keep the doors open. The post design is a solid machined 6061-T6 aluminum block held by four high tensile socket head screws. A machined out area allows for the compression spring, latch mechanism, 0.79 cm (5/16 inch) diameter chrome steel ball, shaft with retainers, and a locking threaded plug for adjustment. The latch mechanism pivots under contact as the reinforced rectangular hole in the doors strikes the sloping portion of the latch and then returns to its original position thus holding the door open. See Figure A-8.

For convenience in construction and servicing, the equipment side of the floor will not be surrounded by any structure. Before ejection the equipment will be protected by the GAS canister. The equipment section will be wrapped in a thermal blanket. This blanket will consist of sheets of a precoated flexible substrate material such as oxidized silicon monoxide on aluminized film. This composite coating, in which absorbtivity is controlled by the aluminum and emissivity by the thickness of the silicon oxide coating, permits selection of a specific solar absorbtivity to emissivity ratio.

3.3 PNEUMATIC SYSTEMS, INFLATION AND PULSE

Compressed gas is used for two applications in the SIREX experiment. The first is to erect and maintain the stiffness of the inflatable structure, and the second is to provide the perturbing pulse which initiates the structural dynamics under consideration. The two functions will be supplied by independent pneumatic systems.

The inflation system consists of a 3280 cubic centimeter (cm^3), 20.7 mega-Pascal (MPa) (200 cubic inch [in^3], 3000 psi) nitrogen tank, a manifold and polyurethane tubing which leads to the bases of each of the three inflatable struts. The nitrogen tank is Kevlar filament wound around an aluminum liner. It is approximately 38.1 cm (15 inches) long and 12.7 cm (5 inches) in diameter and runs across the length of the floor through a large hole in the interface structure. On the bottle top is a manifold containing a backfill valve to fill the tank, a pyrotechnic puncture cutter to open the tank, a high range pressure transducer for diagnostic purposes, an electric solenoid valve to release gas to the inflatable, and an orifice to restrict the gas flow rate. Downstream of the electric solenoid, polyurethane tubing distributes the gas. Located in the base of one of the struts is a low range pressure transducer which the controller will use to regulate the pressure in the struts/torus. The controller will close the valve whenever the pressure climbs above 11.7 kiloPascals (kPa) (1.7 psi) and open it below 10.3 kPa (1.5 psi). During inflation, this control will have the effect of restricting the flow rate and avoiding the possibility of overpressure which can happen during erection. See Figures A-2 and A-6.

Pressure will be released into the reflector directly from the torus after the torus/struts structure is pressurized. This will be done with a large 6.35 mm (0.25 inch) diameter orifice, low pressure electric solenoid valve which will be controlled in the same manner as the solenoid attached to the main pressure tank. This solenoid is mounted to the outside of the torus and has flexible tubing leading from the torus and to the reflector. The reflector also requires a vent valve for venting continuously during ascent into space. This valve consists of an aluminum manifold with a pyrotechnic piston which moves an O-ring fitted cylinder and closes an orifice. See Figure A-3.

The pulse gas system consists of a small 10 cm^3 (0.61 in^3), 10.3 MPa (1500 psi) nitrogen tank, a manifold, and a nozzle. The tank is a hermetically sealed steel cylinder which arrives from the manufacturer already filled and with a pyrotechnic bottle opener attached. The manifold consists of a small block with three ports, one attached to the bottle, the second to a pressure transducer which is used for diagnostics, and the third to an electric solenoid valve which releases the gas pulses. Immediately following the solenoid valve is an expansion nozzle with a 0.89 mm (0.035 inch) throat and a 2.6 mm (0.102 inch) exit diameter. The nozzle is pointing parallel to the floor and normal to the axis of the canister. See Figure A-5.

3.4 CONTROLLER, CONNECTORS, AND POWER SUPPLIES

The design of the electrical components will be covered in section 5. This section only deals with the mounting of these components.

Four battery packs are mounted to the equipment floor. Each pack holds six "X" cell (2.0 V) batteries protected from shock and vibration by 0.48 cm (3/16 inch) rubber pads on all sides plus packing felt on the bottom. These packs are assembled complete with potting epoxy and then closed with a flat lid. All wiring is through grommets. All four enclosures are constructed of 1.6 mm (1/16 inch) thick aluminum alloy sheet, spot welded on all four sides.

On top of battery pack #1 is the pulse bottle and nozzle mentioned above along with the transmitter. On top of pack #2 is the video camera housing. Battery pack #3 has the controller printed circuit boards (PCBs) mounted on top, while pack #4 supports the encoder PCBs. See Figure A-10 and A-11.

The controller consists of two PCBs approximately 8.64 cm (3.4 inch) wide and 12.19 cm (4.8 inch) long. They are supported by battery pack #3 and separated by 1.6 cm (5/8 inch) from each other by standoffs. The boards are shielded by 1.6 mm (1/16 inch) thick aluminum sheet box.

The arm/safe connector is mounted on a sub-floor made of aluminum sheet and separated from the equipment floor with large hollow standoffs. This connector is intentionally kept accessible. The diagnostics connector is panel mounted next to the safe/arm connector.

3.5 SENSORS AND VIDEO CAMERA

The location and mounting of all sensors except the video camera have been covered in previous sections. The video camera, a charge coupled device, is broken up into two parts. A flexible cable 30.5 cm (12 inch) long separates the main camera housing from the smaller remote imager and lens. The main video housing is mounted to the top of battery pack #2 and shielded by a 1.6 mm (1/16 inch) thick aluminum box. This video unit is also padded with 0.64 cm (1/4 inch) thick packing felt. The remote imager is protected in a box of similar construction but is mounted to the equipment floor with the lens pointing through a hole in the floor in order to view the reflector in it's inflated state. The lens has a wide angle ($\pi/2$ rad (90°)) field of view and is pointed (0.087 rad (5°)) outboard, giving it a view of the entire inflatable.

3.6 ENCODER, TRANSMITTER AND ANTENNA

The telemetry down-link consists of signal conditioners on PCBs, an encoder, a transmitter, and finally the two antennas. The signal conditioner PCBs are mounted in a similar structure as the controller PCBs alongside the prepackaged encoder on top of battery pack #4. The encoded signal is passed via cable to the transmitter located next to the small pressure bottle on battery pack #1. The button antennas are located so that they provide maximum coverage. One antenna is mounted on an elevated sub-floor, which acts as a ground plane, 12.7 cm (5 inches) aft of the equipment bay floor and facing aft. The second antenna faces forward and is mounted on the inflatable side of the equipment bay floor.

4.0 ANALYSIS

The details of analyses done in support of the derived requirements and the mechanical design are given in this section.

4.1 INTERNAL PRESSURE LOADING DURING ASCENT

An analysis was done to estimate the pressure differential that will occur between the packaged balloon and the inside of the shuttle cargo bay during ascent into space. The analysis is needed to size the vent valve orifice and to predict internal pressure loading on the clamshell doors enclosing the balloon.

A nominal pressure profile for the shuttle cargo bay during ascent was obtained from the NASA GAS Canister Manual and is reproduced in Figure 8. This profile was modeled for analysis by five line segments, a graph of which appears in Figure 9. It was assumed that the only gas trapped would be in the balloon, (i.e., that the clamshell doors are not air-tight) and that gas leaks from the balloon only through the vent valve. The balloon internal volume was assumed to be the volume of the enclosure minus the balloon material - a worst case assumption. This volume was subject to the external pressure drop of the cargo bay using the reversible adiabatic gas flow equations given in Reference 1. The peak differential pressure over the ascent was noted for various orifice sizes. A orifice diameter of 6.35 mm (0.25 inch) results in differential pressures peaking at 1.3 kPa and averaging well under 1 kPa. This low pressure can easily be resisted by the doors and door latches. Figure 10 shows this differential pressure profile. The sharp peaks are artifacts of the pressure profile model caused by the discontinuities in the slope at the junction of the line segments.

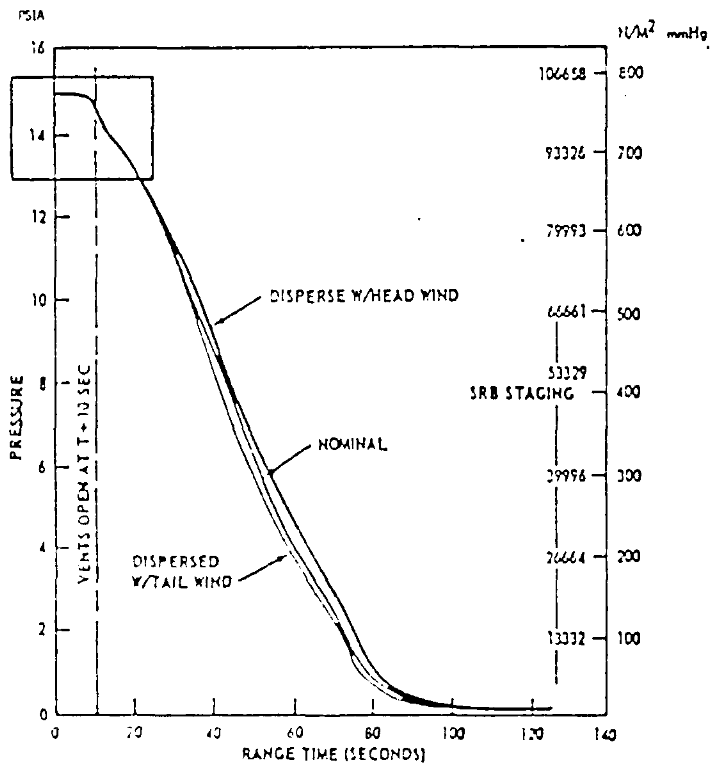


Figure 8. Orbiter Cargo Bay Internal Pressure During Ascent

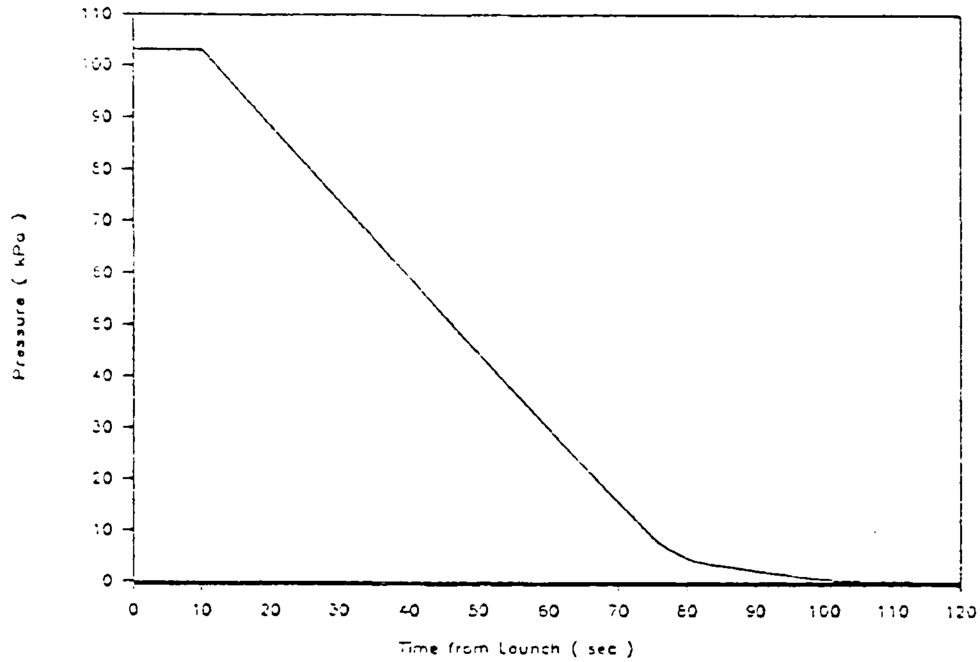


Figure 9. Shuttle Payload Bay Pressure Model

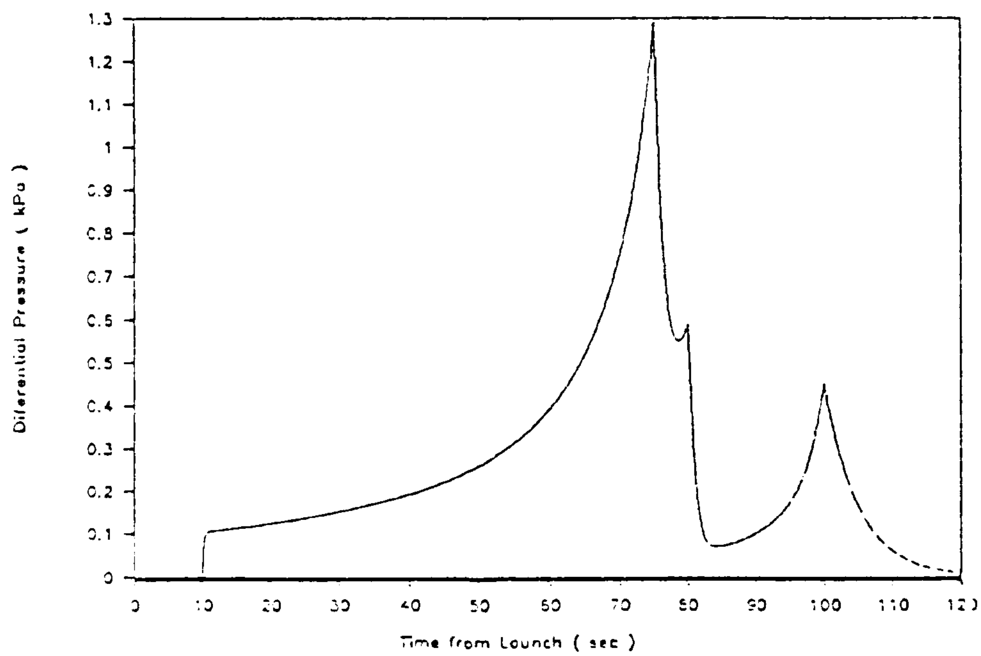


Figure 10. SIREX Pressure Profile in Ascent

The 1300 Pa (0.19 psig) pressure on the doors exerts a force on the doors as shown below:

$$F = P \times (D \times H)$$

where: F = force on doors
P = pressure on doors
D = Diameter of cylinder in which balloon is packaged
H = Height of cylinder in which balloon is packaged.

$$F = 1300 \text{ Pa} \times (47 \text{ cm} \times 30.4 \text{ cm})$$
$$F = 185.7 \text{ N} = 42.2 \text{ pounds force (lbf)}$$

4.2 DOOR OPENING TRADES AND ANALYSIS

Two systems were considered for door opening. In the first system, a shear pin holds the doors in the closed position. The pin is broken by a pyrotechnic actuator which pushes the doors apart, breaking the pin and giving the doors enough energy to move to the latched position. In the second system, the doors are held together by a cable. The doors are released when a cable cutter shears the cable, and they move to the latched position under the force of torsion springs at the hinge.

The shear pin system does not have springs which complicate the hinge and has been flown successfully before. However, the cable/spring approach was chosen for the following reasons. The locking latch requires that the doors impact within a range of velocities. If the doors are moving too slowly, the latch will not engage the doors. If the doors are moving too fast, they will bounce away from the stop before the latch can catch them. The spring system has the advantage that the spring strength can be easily predicted and changed during development testing. With the shear pin system using pyrotechnic pushers, the door velocity cannot be easily predicted or changed. Pyro actuators typically are guaranteed only to produce a minimum impulse and frequently give much greater impulses. Also, since the springs are not consumed during testing, many tests can be run quickly and without great expense. (See Figure A-8)

An analysis was done to size the springs and estimate the door opening time and impact velocity. Only a first order analysis was performed since development testing would firm-up these numbers. The following simplifying assumptions were made: zero friction, initiating springs ignored, torsion springs produce torque linearly with angle. Two 0.79 Newton-meter (Nm) (7 in-lb) springs are used on each door. The door angle and door angular rate vs. time are shown in Figure 11.

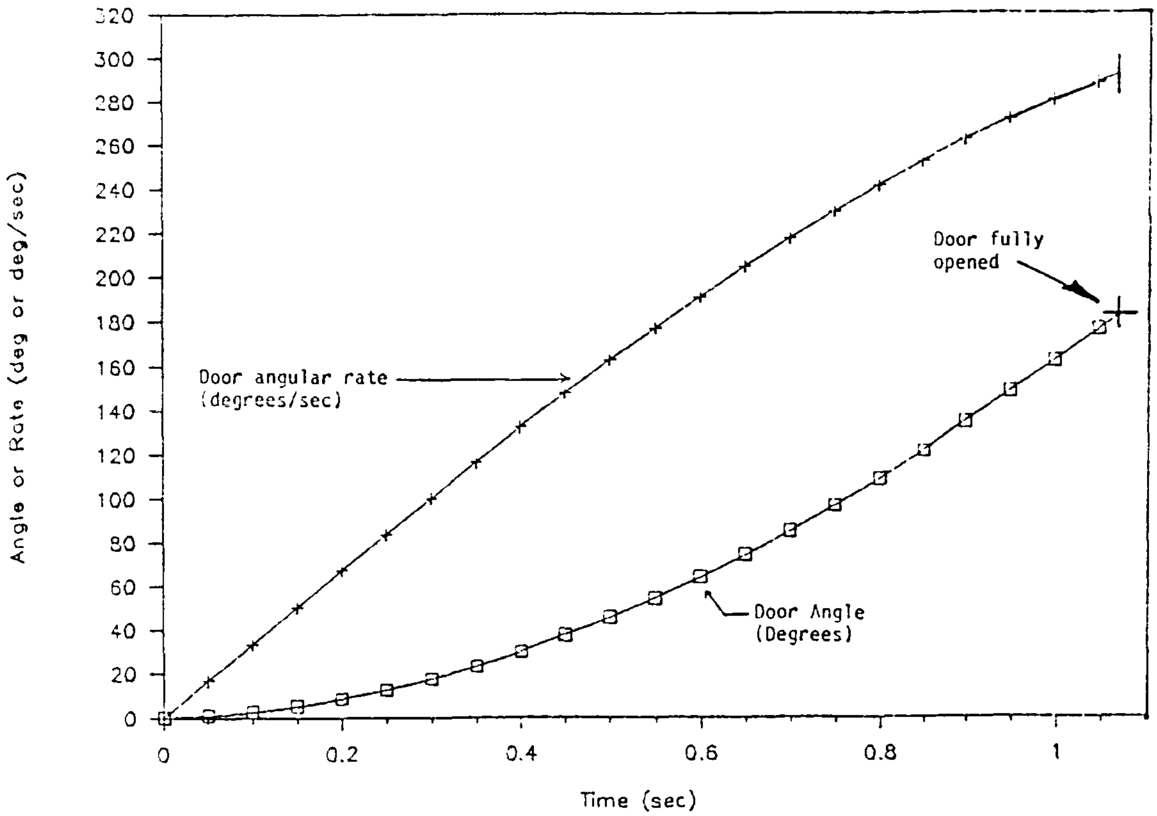


Figure 11. SIREX Door Opening Rates and Angles

4.3 TORUS PACKAGING TESTS

Determining the volume into which a complicated inflatable can be packaged is quite difficult. So packaging tests are done early in programs where space is limited. Since a sub-scale elliptical torus (the primary volume contributor) was available from the DSCE program, several packaging tests were run. That torus was 3m x 4m (9.8 ft x 13.1 ft) with a 30.5 cm (12 inch) diameter.

Three tests were conducted to define the volume required to package the sub-scale torus. First, the deflated torus' small diameter was folded flat so that a continuous ribbon, 47.8 cm (18.8 inches) wide by 10.2 m (400 inches) around by two plies thick, was formed as in Step 1 in Figure 12. Then this ribbon was folded making a long flat ribbon, 47.8 cm (18.8 inches) wide by 5.1 m (200 inches) long by 4 plies thick, as shown in Step 2 in Figure 12. For the first test, this ribbon was folded once width-wise to make a ribbon 23.9 cm (9.4 inches) wide by 200 inches long by 8 plies thick as shown in Step 3 of Figure 12. For the second test, the ribbon from Step 2 was folded once width-wide and once

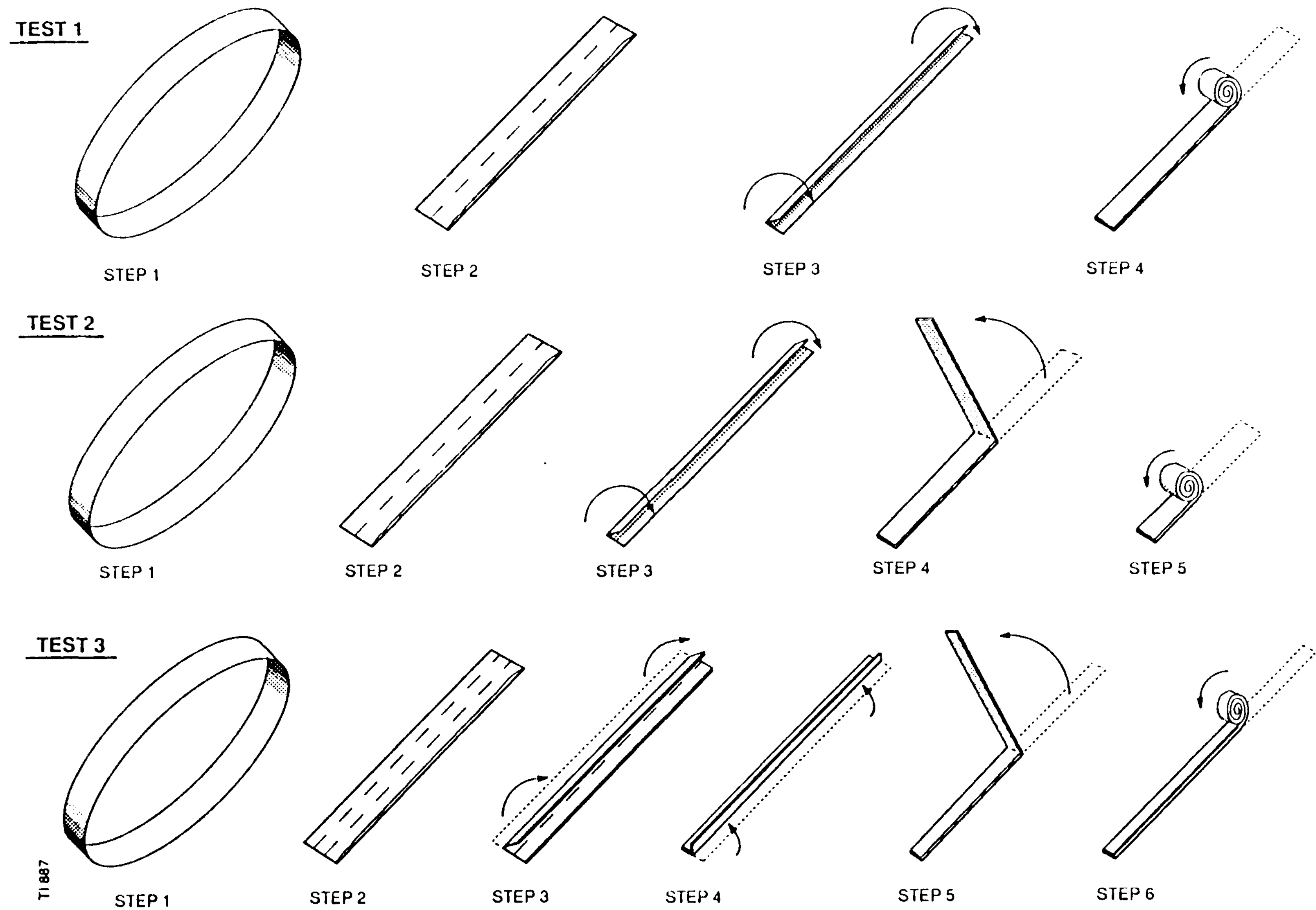


Figure 12. Torus Packaging Test Approaches

length-wise to form a ribbon, 23.9 cm (9.4 inches) wide by about 2.5 m (100 inches) by 16 plies thick, as shown in Steps 3 and 4 for Test 2 of Figure 12. For the third test, we folded the Step 2 ribbon twice width-wise and once length-wise to form a ribbon, 16 cm (6.3 inches) wide by about 2.5 m (100 inches) by 24 plies thick, as shown in Steps 3 through 5 for Test 3 of Figure 12. In all three tests, these ribbons were then rolled up (like a party favor) into a tightly coiled cylinder. The results are shown in Table 4. For the second and third tests, the torus was folded and rolled using considerably more hand pressure. This explains the lower (improved) packaging factors for these tests.

TABLE 4. PACKING TEST DATA

Test No.	Ribbon Dimensions		Cylinder		Packaging Factor
	Width	Length	Diameter	Height	
1	24cm (9.4")	5.1m (200")	22cm (8.6")	25cm (10")	2.9
2	24cm (9.4")	2.5m (100")	19cm (7.5")	28cm (11")	2.4
3	16cm (6.3")	2.5m (100")	23cm (9.1")	19cm (7.4")	2.4

Packaging factor (PF) is defined as packaged volume divided by material volume. In this case, material volume was calculated as material weight divided by material density:

$$9.75 \text{ lb}/(0.0487 \text{ lb/in}^3) = 200.2 \text{ in}^3 = 3281 \text{ cm}^3 .$$

Thus, for example, the packaging factor on the first test is calculated as

$$[\pi(8.6 \text{ in}/2)^2 \times 10 \text{ in}]/200 \text{ in}^3 = 580.6/200 = 2.9$$

These PF figures are for a simple torus and can be applied to the struts and reflector-canopy, as well. However, torus-strut and torus-reflector interface material will create considerable packaging inefficiency which will increase the PF. On the DSCE design, small turnbuckles are used to accurately adjust the reflector within the torus. These are too bulky for SIREX and are unnecessary since the SIREX experiment does not measure reflector accuracy. Therefore, they are replaced by 140 non-adjustable straps in the SIREX design. These straps are 5.08 cm (2 inches) wide by 35.6 cm (14 inches) long by 0.56 mm (0.022 inch) thick.

One can estimate the increased PF from the straps by factoring in their thickness. In the Test 2 folding, the folded torus small diameter ribbon had 4 layers of 279 micron (0.011 inch) thick NCK. The straps will add an intermittent 3 layers -- intermittent because only 140 of the 5.08 cm (2 inches) wide straps are spread over the 25.4 m (1000 inches) torus inner perimeter. The torus PF with straps is estimated at

Total PF = PF x {1 + [SL x SP /(TP)(TL)]}

Where: PF = Packaging Factor = 2.4
SL = Number of strap layers = 3
SP = Strap perimeter = 280 in
TP = Torus inner perimeter = 1000 in
TL = Number of torus layers = 4

Total PF = 2.4 x {1 + [(3)(280)/(1000)(4)]} = 2.4 (1.21)

Total PF = 2.9

Thus, a PF of 2.9-3.0 is the lowest (best) that can be expected of complete packaged inflatable.

At the time of the packaging tests, the DSCE full-scale design had a 24 inch diameter torus and the material volumes shown in Table 5. These were calculated directly from the gore surface areas and NCK material thickness (279 micron, 0.011 in), and they include tapes and bonds.

Table 5. Material Volumes for Early Full Scale DSCE Inflatable

	Volumes	Volumes
Torus	16,026 cm^3	978 in^3
Struts (3)	2,540 cm^3	155 in^3
Reflector Canopy	688 cm^3	42 in^3
Torus-Strut I/F	66 cm^3	4 in^3
Torus-Reflector I/F	1,410 cm^3	86 in^3
Total	20,730 cm^3	1265 in^3

The above volume does not include the DSCE mechanisms that are used to adjust the reflector within the torus.

The volume available for packaging the inflatable is 47 cm (18.5 inches) diameter x 30.4 cm (12 inches) long or 52,850 cm^3 (3225 in^3). Therefore, the needed PF must be less than available volume/material volume = 3225/1265, or 2.5. It must be less than 2.5 because of the interface straps are not included in the 1265 in^3.

The packaging test on the sub-scale DSCE torus shows this is impractical since 2.9 is the best that can be expected. Since the volume available cannot be significantly increased, the volume of material was reduced for the DSCE and SIREX inflatable design.

All of the reduction was in the torus. The torus material is 77% of the DSCE total system inflatable material volume. The total material volume allowed is the available volume of 52,850 cm^3 (3225 in^3) divided by the PF of 3, or 17,620 cm^3 (1075 in^3) Since non-torus components contain 4,700 cm^3 (287 in^3) of material, the torus material volume was limited to 12,910 cm^3 (788 in^3) or less.

Various torus diameters were evaluated until a small enough torus was found. A torus with an 45.7 cm (18 in) diameter has a calculated material volume of 12,600 cm^3 (769 in^3) and was chosen as the final DSCE torus size.

However, since the pressurized torus provides the "rigid" rim on which the reflector is mounted, its diameter cannot be changed arbitrarily. Under the DSCE program, it and its internal pressure were reevaluated to verify that it does not buckle or deform significantly under the loads applied by the reflector. Results of that analysis will be presented in the DSCE final report.

When SIREX work was stopped, the DSCE torus required 14.5 Kpa (2.1 psi) minimum pressure with a tension element to withstand the loads expected. Since that date, the DSCE design has been revised to require 34.5 Kpa (5.0 psi) minimum pressure without a tension element.

Since the detail torus design was done under DSCE (F04611-86-C-0112), its details will be reported in the DSCE final report.

4.4 PULSE GENERATOR

The objective of the pulse generator is to produce an impulse in order to test the dynamic response of the reflector/truss system to mechanical perturbation. The ideal pulse would be a square pulse of at least 2.2N (0.5 lbf) and 20 ms in duration. In past programs such as the Sounding Rocket Measurements Program (SRMP), pulses of this strength and duration have been achieved using a small pressure bottle, solenoid valve, and nozzle; therefore a pulse of this shape was chosen for the design baseline.

The nozzle design was copied exactly from a SRMP design since its performance characteristics are already known. The nozzle and solenoid picked had produced (during SRMP testing) exit velocities of 671 m/s (2200 ft/sec) with a discharge coefficient (C_d) of 0.65.

Similarly, a Conex Inc. 10cm^3 (0.61 in^3) pressure bottle at 10.3 Mpa (1500 psi) was chosen for the pulse generator. This pressure bottle is easily available and known to L'Garde.

To determine the thrust level for this assembly, all that is needed is the mass flow rate from the nozzle. The relationship is Force = (mass flux) x (exit velocity). The mass flux for a hypersonic flow is determined by the orifice size and associated discharge coefficient. The governing equation is given in Reference 9 and is (for Nitrogen):

$$M = 0.6847\ p\ C_d A/(RT)^{1/2}$$

where

M = mass flux (kg/sec)
T = upstream temperature (Kelvin)
R = gas constant ($m^2/sec^2/K$)
p = upstream pressure (Pa)
A = throat area (m^2)

Setting the throat diameter at 0.89 mm (0.035 inch), a thrust of 4.4 N (1 lbf) is produced by an upstream pressure of 6.9 Mpa (1000 psi). Using the Conex bottle, 6.9 MPa (1000 psi) pressure can be achieved if the manifold volume between the pyrotechnic bottle opener and the solenoid valve can be designed to be 5 cm^3 (0.31 in^3) (or less) in volume. Since this is an unregulated blowdown system, each successive pulse will be weaker as the pressure drops. For each 20 ms pulse the upstream pressure will drop by 17%. The experiment design calls for three pulses, so by the end of the third pulse the force produced will be 2.5 N (0.57 lbf), which is still greater than the ideal pulse of 2.2 N (0.50 lbf).

4.5 REFLECTOR INTERNAL PRESSURE

The reflector was designed under the DSCE program, so its details will be presented in the DSCE report.

4.6 SYSTEM MASS

The SIREX contract mass requirement was 90.7 kg (200 lb mass (lbm)). However, since the SIREX was to have been ejected from the GAS canister, a design goal of 68 kg (150 lbm) was used. The GAS canister ejection system uses the other 50 of the 200 lbm allowed for a GAS canister payload. Preliminary mass property work (see Table 6) indicates the system is approximately 55 kg (121 lbm), which is well within the mass limitation.

TABLE 6. SIREX SYSTEM MASS TABLE

	Mass (kg)	Mass (lbm)
INFLATABLE		
Reflector	1.17	2.57
Torus	19.75	43.53
Reflector/Torus Interface	0.45	1.00
Long Struts (2)	2.81	6.19
Short Strut	0.87	1.92
Struts/Torus Interface (3)	0.45	1.00
Reflector Pressure Xducer [Validyne DP103]	1.11	2.44
1/4" Solenoid Valve [KIP 351018]	0.45	1.00
Venting Manifold	0.09	0.20
Wiring	0.22	0.48
EQUIPMENT BAY		
Floor	2.34	5.16
Strut Ring Clamps (3)	0.50	1.10
Interface Structure	3.76	8.30
Battery Pack Enclosures (4)	1.22	2.70
Sub-floors/Standoffs (2)	0.20	0.45
Multi-layer Insulation	0.05	0.10
CLAMSHELL DOORS		
Door Shells (2)	1.54	3.40
Cable Cutter [Holex 11696-02]	0.03	0.06
Cable Blocks/Cable	0.09	0.20
Separation Spring Blocks (2)	0.02	0.04
Clevis Pin Joint (2)	0.05	0.10
Latch Posts (2)	1.05	2.32
ELECTRICAL SYSTEMS		
Battery Packs [Gates 0800-0004] (4)	8.85	19.51
Safe/Arm Connector [Bendix PT07P-10]	0.05	0.10
Diagnostic Connector [Bendix PT07P-14]	0.05	0.10
Video Camera System [Pulnix TM-540]	0.91	2.00
Remote Imager Box	0.11	0.25
Encoder [Loral PCM 440B]	0.45	0.99
Transmitter [Emhiser EVTC-09E1D103-05]	0.34	0.75
Antenna Beacon Track [Telcom 108013]	1.31	2.88
Controller PCBs	0.34	0.75
PNEUMATIC SYSTEMS		
Inflation Tank [SCI ALT-210]	3.00	6.61
Inflation Puncture Cutter [ICI ISE311]	0.04	0.08
Inflation Manifold	0.23	0.50
Inflation Solenoid Valve [Eckel AF56C-371]	0.24	0.53
Inflation Tank Brace	0.11	0.25
Flexible Tubing	0.07	0.15
Pulse Inflation Tank [Conex EP 181114107]	0.13	0.29
Pulse Manifold	0.07	0.15
Pulse Solenoid Valve [Eckel AF56C-371]	0.24	0.53
Total	54.76	120.68

5.0 ELECTRICAL DESIGN

During the operation of the SIREX, it is necessary to execute mission timing and control events, instrument the structure to collect status, communicate status and camera video to the ground stations, and supply required power.

A microprocessor controls the timing of events and manages event functions. These functions consist of such things as applying and removing power to devices as required, inflation, opening and closing vent and pressure valves, door opening, maintaining correct pressure, changing pressure, firing squibs, etc.

To determine the status of the SIREX in space, an instrumentation system is needed to sense vibration, acceleration and pressure. Strain gauges and accelerometers located at strategic locations detect movement in the structure.

A telemetry system communicates instrumented data and camera video signals to ground. Instrumented data is acquired by a sampled data system and is formatted into a serial data stream for transmission using a standard IRIG 106 format. (Reference 6.)

A 28 volt battery, comprised of Gates 2 volt lead acid "x" cells arranged in two 14 volt groups, supplies power to the electronics. This power is conditioned to meet the requirements of the various electronics circuits.

Figure 13 shows a block diagram of the SIREX instrumentation system design.

5.1 REQUIREMENTS

5.1.1 Mission Timeline

The event times and functions performed are found in the SIREX Timeline given in Table 1, Section 2.

5.1.2 Parameters

Table 2 in Section 2 shows instrumentation parameters which will be monitored and transmitted to earth stations.

5.2 SYSTEM DESCRIPTION

Instrumentation electronics are required to handle two types of signals. These are low level signals in the ±5 millivolt range and higher level signals in the 0 to 5 volt range. The low level signals are from strain gauges, pressure transducers and accelerometers. These will be supplied reference power for excitation. Higher level signals are from valves, squibs, power supplies, temperature monitors and event monitors.

Because this is a sample data system, anti-aliasing filters are required to limit the signal bandwidth before the signal is sampled by the analog to digital converter. Both types of signals are then routed to a pulse code modulation (PCM) encoder where they are conditioned for output to the telemetry transmitter.

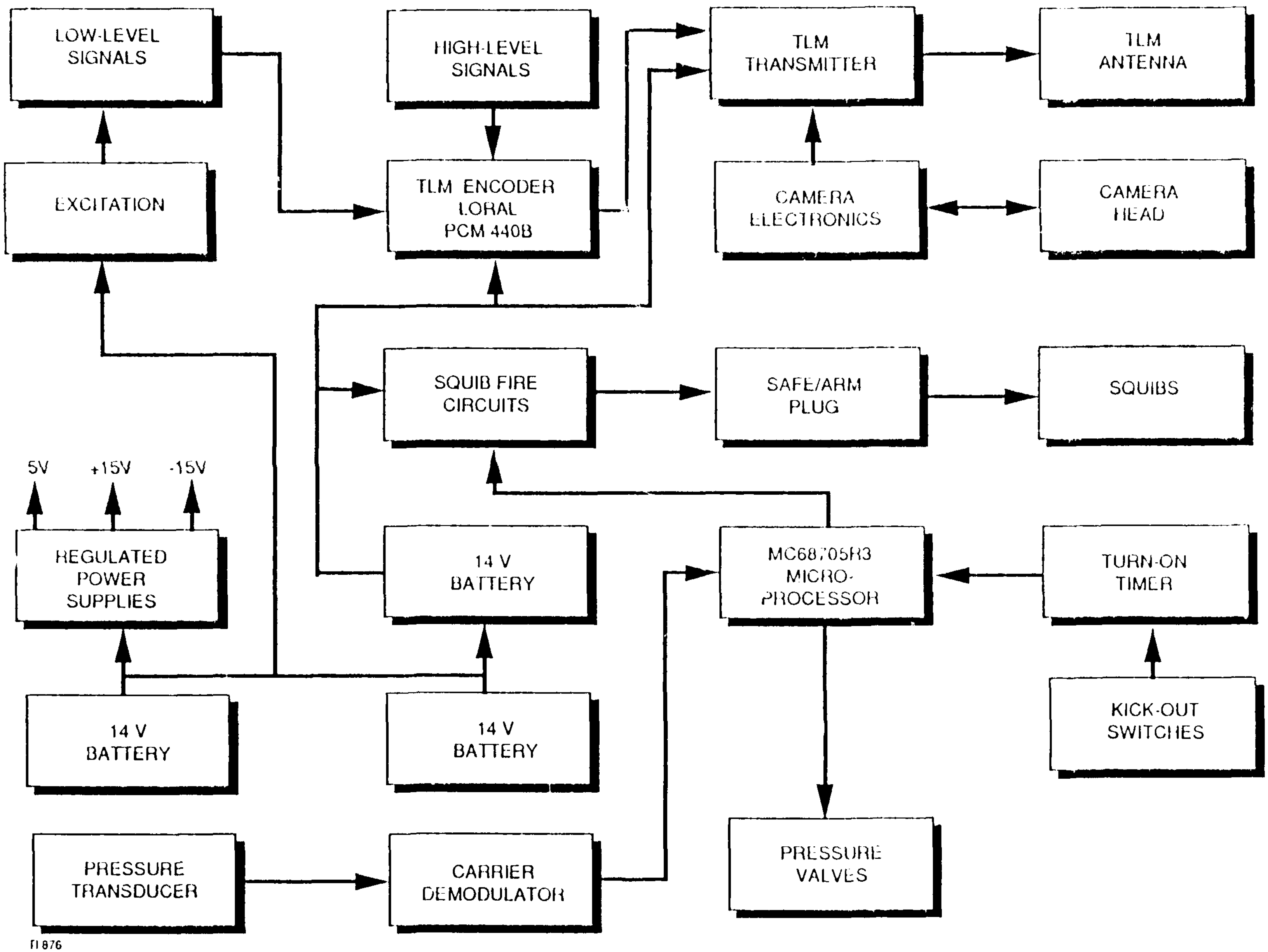


Figure 13. Current Instrumentation System Block Diagram

A Loral PCM Encoder PCM-460A was chosen that will amplify, multiplex and format the instrumented data and output this data to the telemetry transmitter. This encoder is an off-the-shelf unit that requires only initial setup by the manufacturer. It will handle bit rates up to 1 million bits per second and contains a 10 bit analog-to-digital converter (ADC). The unit will accept a variety of input signal levels which are compatible with sensor outputs.

Three timing and sequencing options were evaluated for system control. One option used a counter timer control system. The second used an EPROM controlled sequencer. A third option used microprocessor control.

Counter Timer. This concept employed a system of counters to time events and control operations. In addition, an analog pressure control scheme was used to control component pressure.

EPROM Control. This concept used an EPROM to control functions by clocking the EPROM through its addresses sequentially and allowing unique bit outputs to control individual functions. This alternative provides a better way to incorporate changes and uses less hardware than the first option.

Microprocessor Control. This option is the most versatile. Several microprocessors were investigated:

MC68705R3 - This processor seemed the most likely for use because we have used it on other projects, and it required no initial learning curve. Also existing code could be easily modified for use in this environment. This is a major advantage because programming time would be reduced greatly. The major drawback of this processor was power consumption. With the anticipated time line, the batteries did not contain the capacity to support this chip.

MC68HC705B5 - This processor is almost identical with the 68705R3, but is a lower power CMOS version. The code modification would not be so easy, because the source code is not 100% compatible with the MC68705R3. It also contained some hardware and software enhancements.

MC68HC11 - This processor is considerably more powerful and versatile in both hardware functions and in software versatility. And a considerable amount of "canned" routines and programs are available for this device.

Microprocessor control was chosen after a mission time line was established that required very long timers. Also an existing program was available that could be modified. The last two microprocessor choices were determined to be too costly in terms of funds and schedule so the MC68705R3 was chosen with a modification: a low power timer. Because of the MC68705R3's high power consumption, a low power turn-on timer was added to start the microprocessor operating after a set period of time. The microprocessor control begins when the turn-on timer times out.

The Telemetry Transmitter is an Emhiser Research Inc. model EVTC-09E1D103-05 with a 2200.0 to 2299.0 MHz range and 10 watt output. It has an input for both camera video and a telemetry subcarrier.

Originally two transmitters, one for data and one for video, were to be used. Early analysis showed that one transmitter would be sufficient for both signals.

The TV Camera is a Pulnix TM-540R/560R remote imager CCD device. It is a 510 pixel high-resolution imager with a low light sensitivity of 2 lux. It has a miniature imager head of 1-1/4 inch x 1-1/2 inch x 1-1/4 inch which attaches to the main camera body by a flexible cable.

The camera will be mounted to give information about inflation and erection and provide visual knowledge about the performance of the structure.

The antennas will be button antennas as shown in Figure 7 and described in section 3.6.

5.3 TEST AND ANALYSIS

This section describes the analysis and testing done in support of critical aspects of the electrical design.

5.3.1. Thin Film Strain Gauges

Because of the discontinuity in the reflector film caused by standard strain gauges, thin film strain gauges were evaluated. They were mounted on DSCE's test 3 meter off-axis paraboloid. A 207 Pa (0.03 psi) vacuum was established on the "outside" to duplicate the shape and pressure of a solar reflector. Data was collected at 100 Hertz (Hz) (except as noted) and then smoothed using a 10 point moving average. Test runs were conducted as described below:

Run 002 - Reflector excited by a single gentle thump of a finger on the mylar surface. See Figure 14.a.

Run 003 - Reflector excited by a single medium thump of a finger on the mylar surface. See Figure 14.b.

Run 004 - Reflector excited by a single harder thump of a finger on the mylar surface. See Figure 14.c.

Run 005 - Reflector excited by a single gentle flick of the index finger from the thumb onto the mylar surface. See Figure 14.d.

Run 006 - Reflector excited by a single hard flick of the index finger from the thumb onto the mylar surface. See Figure 14.e.

Run 008 - Offset drift caused by an incandescent lamp held initially at a distance of 8 feet from the mylar surface. Lamp was moved gradually toward the thin film strain gauge to a final distance of 25.4 cm (10 inches). Data was collected at 50 Hz; test time was 20 seconds. See Figure 14.f.

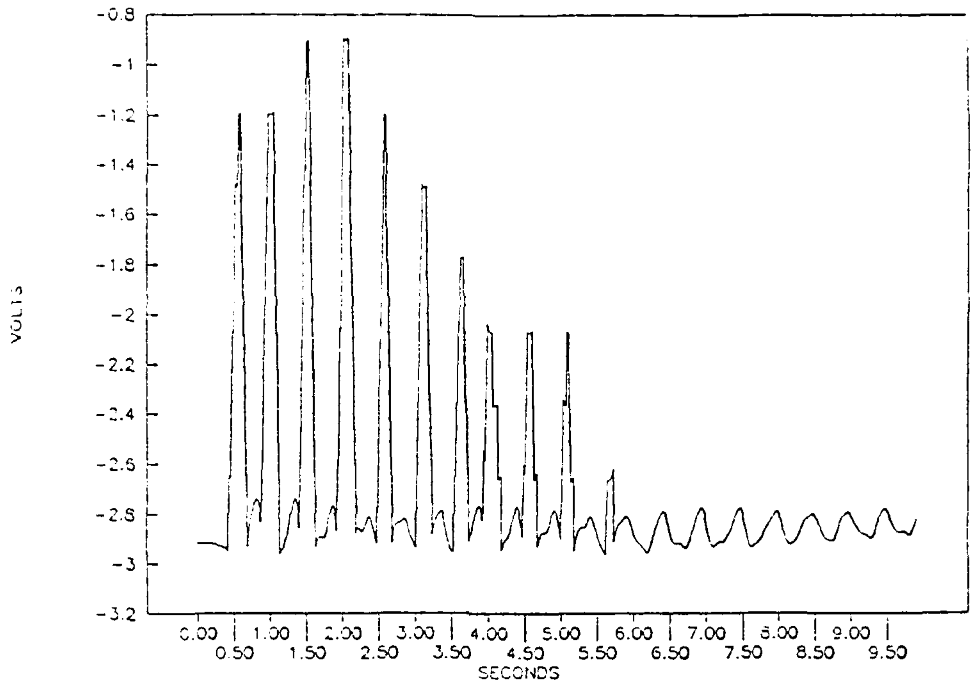


Figure 14a. <u>Thin Film Strain Gauge Test Run 002</u>

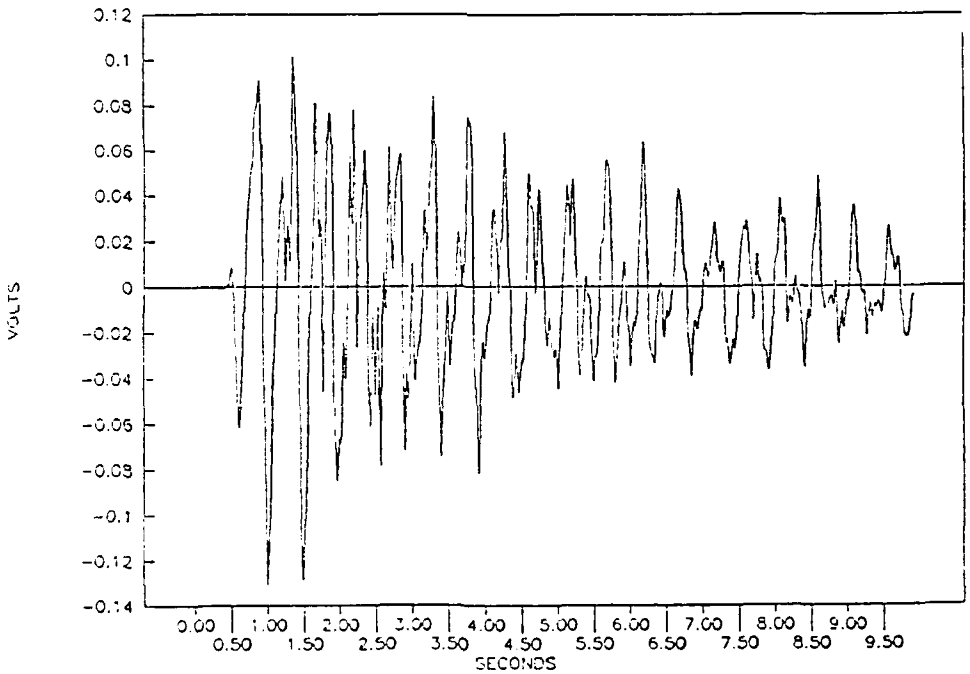


Figure 14b. <u>Thin Film Strain Gauge Test Run 003</u>

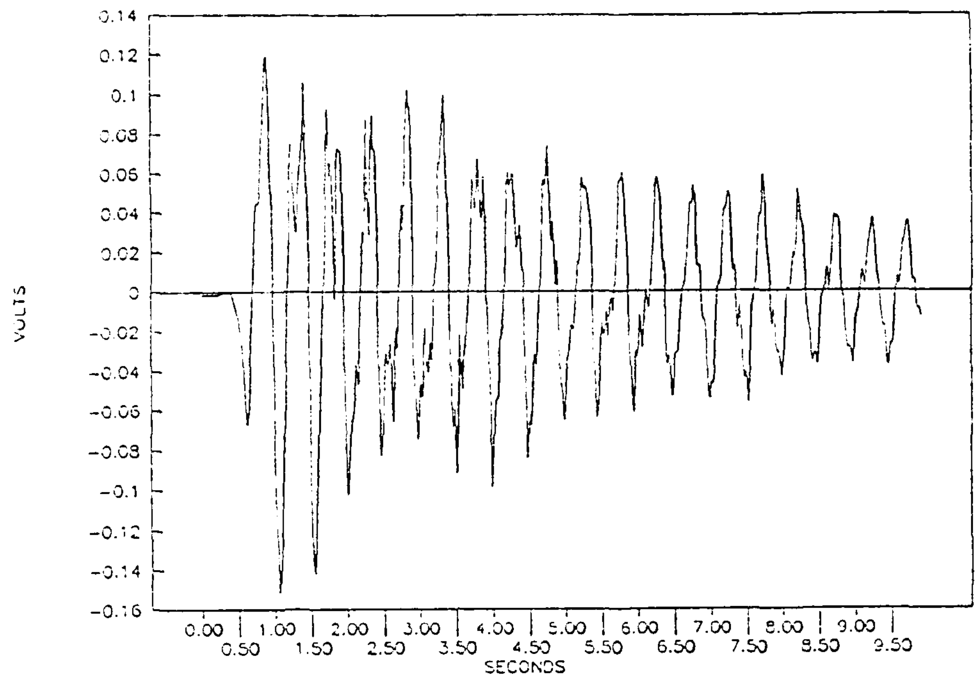


Figure 14c. Thin Film Strain Gauge Test Run 004

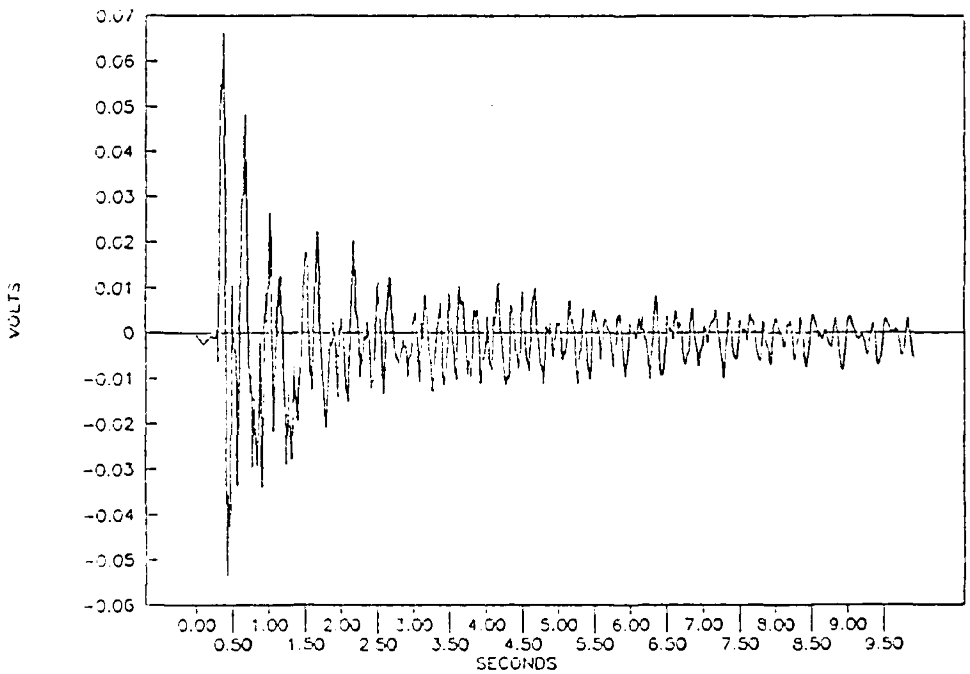


Figure 14d. Thin Film Strain Gauge Test Run 005

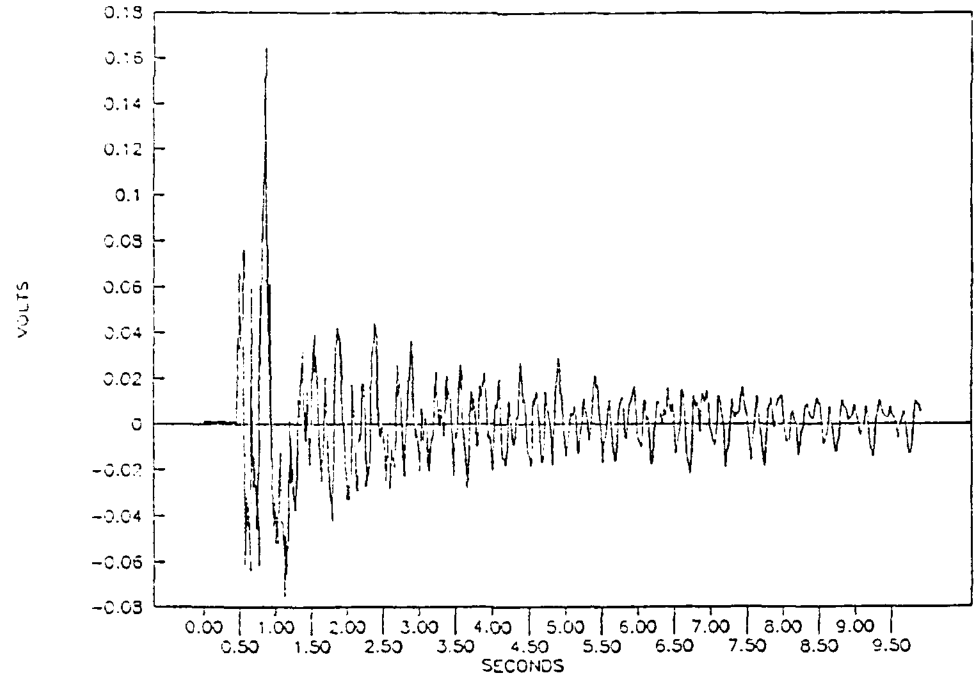


Figure 14e. Thin Film Strain Gauge Test Run 006

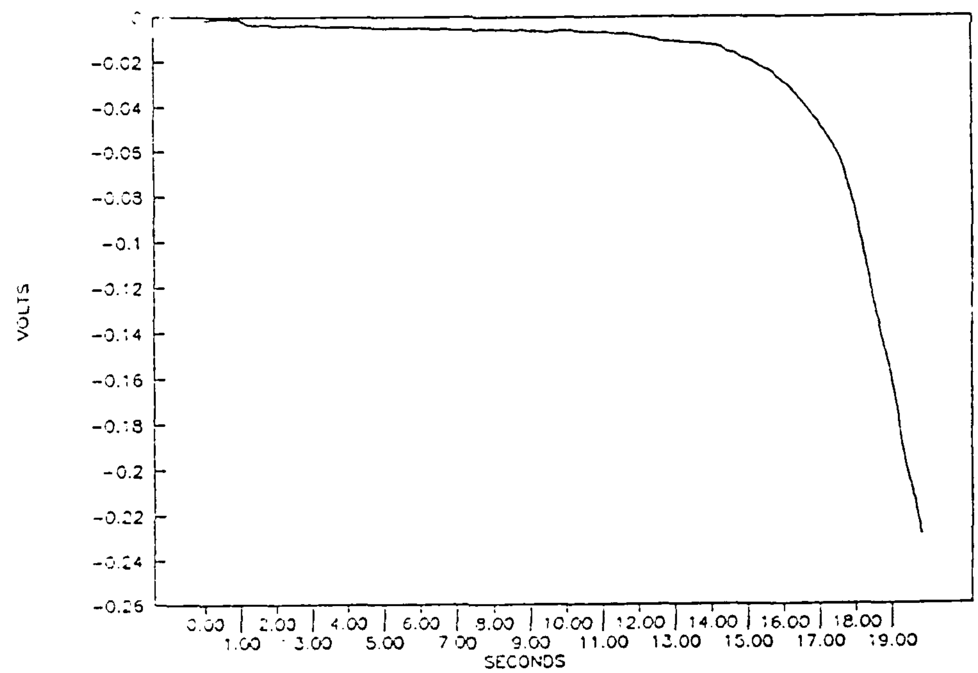


Figure 14f. Thin Film Strain Gauge Test Run 008

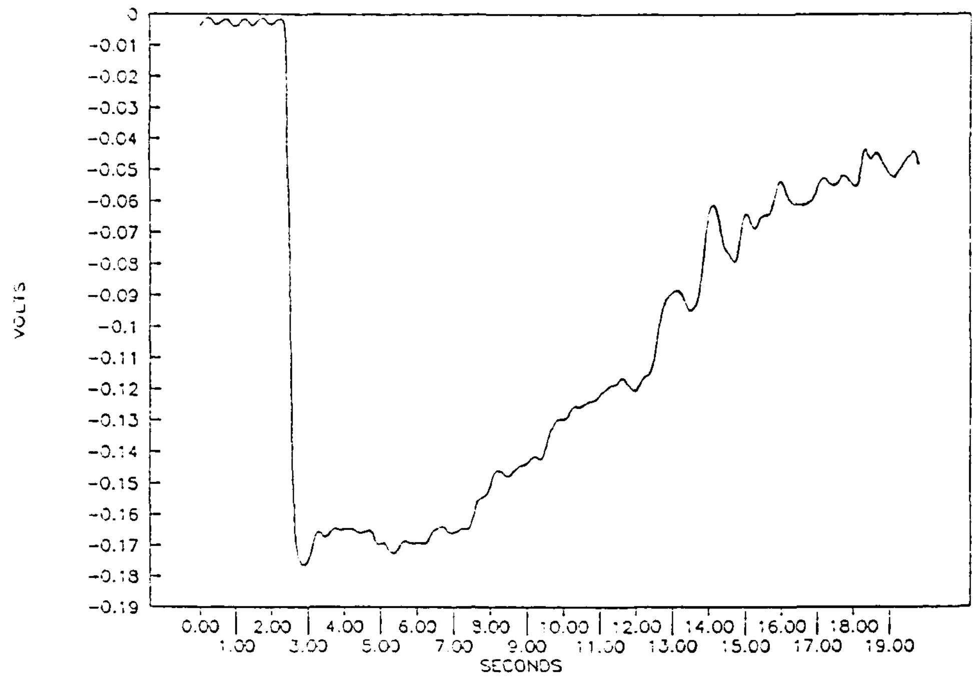


Figure 14g. Thin Film Strain Gauge Test Run 009

Run 009 - Offset drift caused by an incandescent lamp placed 30.5 cm (12 inches) from the strain gauge. Data collected at 50 Hz; test time was 20 seconds. See Figure 14.g.

The tests, while very qualitative, showed that thin film strain gauges will work to show the vibration motion of the reflector surfaces. They also showed that the strain gauges are IR sensitive. However, if the collector assembly is tumbling in space and the gauges are moving into and out of direct sunlight, they will be doing so very slowly and the resultant signal offset changes should be easily discernable from the reflector vibration motion data.

5.3.2 Anti-Aliasing Filters

Because this is a sample data system, anti-aliasing filters are required to limit the signal bandwidth before the signal is sampled by the analog to digital converter (ADC). Signals will be distorted by aliasing if any component of the sampled signal is above ½ the sampling frequency called the Nyquist frequency ($f_s/2$). Aliasing is described by some energy of frequencies (f) above the Nyquist frequency ($f_s/2 + f$) being reflected as a difference frequency by the sampling process to $f_s/2 - f$. This places this energy, and therefore distortion, within the spectrum of interest. If aliasing components are of sufficient amplitude, they can make the signals of interest completely unusable.

To prevent aliasing distortion, the input signal is band-limited by low pass filtering to reduce the amplitude of signals above the Nyquist frequency to a level that appears invisible to the ADC. This level ϵ called the rms quantization error for the ADC is $q \div 2\sqrt{3}$, where q is the value of the least significant ADC code bit. ϵ is an irreducible error of the ADC. For a 12 bit ADC with a 5 volt peak input

$$\epsilon_{rms} = (1.22 \times 10^{-3}) \div 2\sqrt{3} = 3.52 \times 10^{-4} \text{ volts}$$

The anti-alaising filters are required then to have the amplitude of signals above the Nyquist frequency reduced by the voltage ratio

$$20 \log_{10} 5 \div (3.52 \times 10^{-4}) \approx -83 \text{ decibels (db)}$$

For an 8 bit ADC with the same 5 volt peak input, the voltage ratio will be ≈ -59 db.

Both passive and active filters are available. Passive filters can be large and bulky to get a high attenuation per frequency interval (roll off). Active filters have, at a cost of higher complexity, sharper roll off which is desirable in this application. One such active filter is a switch capacitor (SC) filter. This filter is chosen here because it has the characteristics of sharp roll off, low power and smallest size for the highest order filter (in one integrated circuit) with few external components required. Another advantage of the SC filter is the cutoff frequency f_c (-3db point on the attenuation curve) is controlled solely by the frequency of the clock. One disadvantage of this kind of filter is that it is a sample data system itself and will exhibit all the characteristics of a sample data system including aliasing. The filter may require an anti-aliasing prefilter to prevent distortion within the SC filter.

The frequencies of interest here are estimated to be in the range to 0 to 10 Hz. This range was chosen because we do not expect high frequencies in structures the size this solar concentrator.

As an estimate for filter response, a LMF60-50 6th order Butterworth active filter was examined. This filter has a roll off -36 db/octave. A simple 1st order passive filter (6 db/octave attenuation) was used for an anti-aliasing prefilter. This type prefilter was chosen because it consumes no power and requires only two components. A higher order filter would need more components and could consume power. The minimum useable cutoff frequency of the SC filter without aliasing will be determined here by the characteristics of this 1st order anti-aliasing prefilter. To have reduced the input frequency components to the calculated ADC ϵ value (called the noise floor) of -83 db, the SC clock/2 frequency will be 14 octaves above the 10 Hz frequency of interest or 163.8 kiloHertz (kHz), making the SC clock frequency 327.6 kHz. The LMF60 filter has a clock to cutoff frequency ratio (f_{clk}/f_c) of 50 so the SC cutoff frequency will be 327.68 Khz ÷ 50 = 6554 Hz. If any alias signal appears within the SC filters stopband, it will be attenuated as though had been applied at the input. At ≈ 11.5 Khz the stopband attenuation of this filter is ≈ 29 db. Adding the prefilter attenuation at this frequency of about 54 db, the $f_s/2$ -83 db point is reached at ≈ 11.5 Khz. 11.5 kHz x 2 ≈ 23 kHz sample frequency. This is not practical.

Changing the circuit to a 2 pole prefilter (12db/octave) will give a sharper roll off which will drop the SC filter output to the -83 db ADC noise floor at a more reasonable value of 1280 Hz. This puts the SC clock at 2560 Hz. Using a sharper roll off LTC1064-1A 8th order Elliptic SC filter with a f_{clk}/f_c ratio of

100, the SC filter cutoff is now at 2560/100 = 25.6 Hz. From the data sheet, this filter output is down -68 db at 1.5 f_c. Adding the 2 pole prefilter attenuation of ≈ 15 db at this frequency, (-68) db + (-15) db = -83+ db. The sampling frequency is then: $f_s/2 = 1.5\ f_c$, $f_s = 76.8$ Hz, a reasonable value. The 2 pole passive prefilter requires one additional capacitor and resistor each over a single pole filter.

Figure 15 shows a diagram of the estimated filter response of a LTC1064-1A 8th order elliptic lowpass switch capacitor filter with a two pole input prefilter.

5.3.3 Telemetry Link Analysis

The link analysis performed for the SIREX telemetry system follows the procedure outlined in the *Telemetry Applications Handbook* (Ref. 5). Tables 6a. through 6f. herein contain link analyses for a number of different transmitter power outputs for several different slant ranges. The data is compiled and plotted as a family of graphs for power outputs of 3,5,10 and 15 watts RF power output in Figures 16a. through 16d. The graphs are link margins as a function of orbital altitude and elevation angle from the ground station. The graphs assume a circular orbital path directly over the ground station for the duration of the observation (which is adequate for this purpose) and assume that observations will be limited to elevation angles not less than 20° above the geophysical horizon. Some other assumptions are:

a. The attitude in orbit will be aligned such that the antenna pattern will not contain any nulls of any significance. The maximum depth of null would be such that the antenna pattern is no worse than -8 decibels, isotropic (dbi).

b. The ground station sensitivity is taken as 20 db/K on the assumption that elevation angles will be limited. This should be somewhat conservative for the potential range receiving stations to be used.

c. The link analysis is performed for a video signal which is bandwidth-limited at the transmitter to no more than 3.5 megaHertz (MHz) with the receiver will be band-width limited to 4.5 MHz. This should be adequate for the intended purpose. It further assumes a video signal-to-noise (SNR) of 6 db, which would provide a somewhat noisy (snowy) picture at the beginning and end of the observation periods.

d. The link analysis was not performed for the digital portion of the link; however, since the digital bandwidth is considerably less than the video, it is assumed that the video is the controlling factor, and, if the video is adequate, the digital link will also be adequate.

e. Since details of the design were not completed, no consideration was given for any effect that the structure would or might have on the transmitter antenna pattern. See assumption a. above.

The graph in Figure 16c is for the selected 10-watt transmitter and shows some margin except at the extremely low elevation angles.

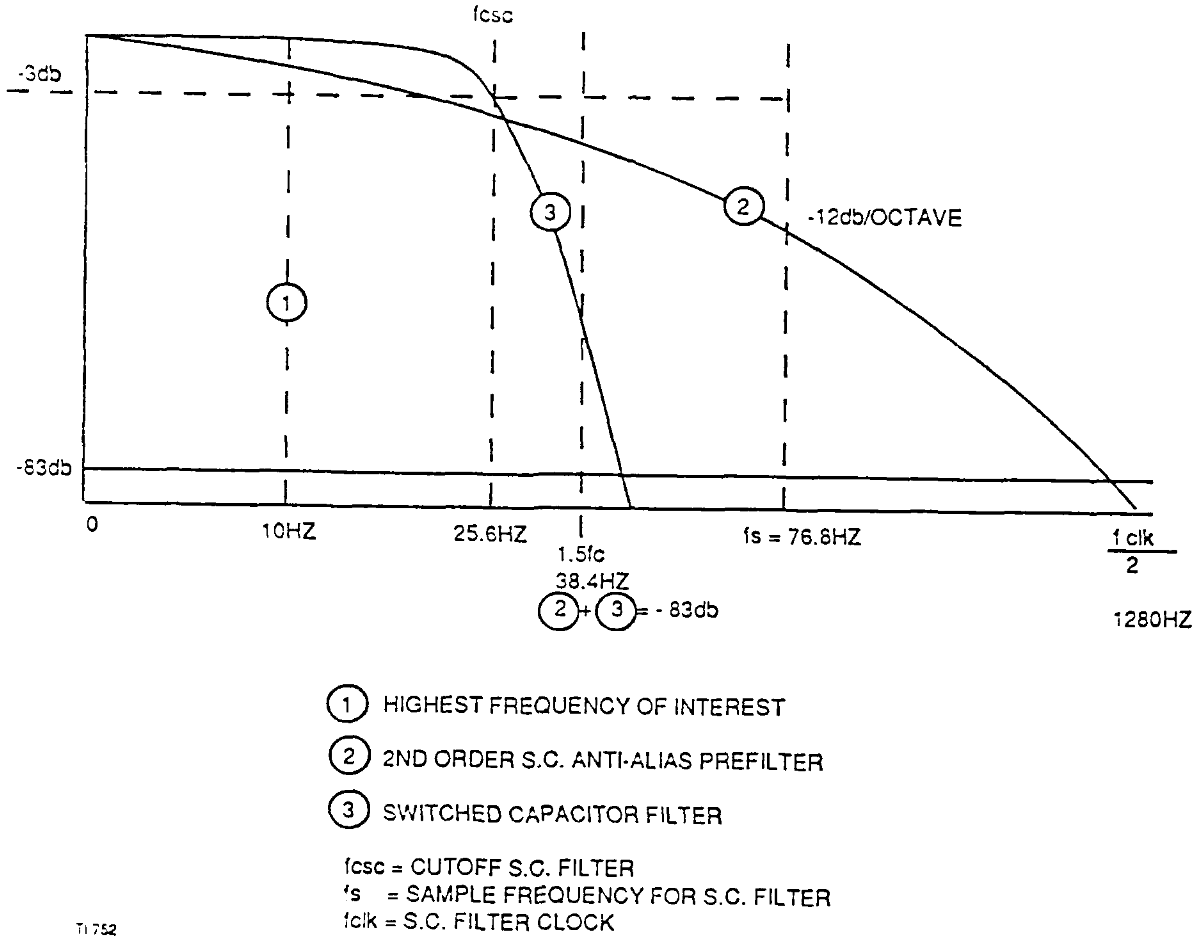


Figure 15. Estimated Filter Response For LTC 1064-1A 8th Order Elliptic Filter

TABLE 7.a. SIREX TELEMETRY LINK ANALYSIS (3 W POWER, 185 km ALT)

EQUIPMENT/MEDIUM	PARAMETER	UNITS	GAIN(db)
FREQUENCY	2.25	GHz	
Wavelength	13.32844	cm	
TRANSMITTER POWER	3.0	Watts	34.77
TRANSMITTER COUPLING			
Cable Length	0.4	Meters	
Cable Loss Factor	85.3	db/meter	-0.338
Diplexer/Hybrid	0.5	db	-0.5
TRANSMITTER ANTENNA	-8.0	dbi	-8.0
CHANNEL LOSS			
Free Space Propagation			
Altitude	185.	km	
Slant Range	656.	km	-155.825
Multipath	3.	db	-3.00
Ducting	0.	db	0.00
Flame Attenuation	0.	db	0.00
Atmosphere (rain, etc.)	1.	db	-1.00
RECEIVER SYS SENSITIVITY (G/T)	20.	db/K	20.00
RECEIVER BANDWIDTH	4.5	MHz	122.07
MODULATION TYPE	Video		
Data Bandwidth	3.5	MHz	
Modulation Method SNR	6.0	db	-6.00

LINK MARGIN			2.176

TABLE 7.b. SIREX TELEMETRY LINK ANALYSIS (5 W POWER, 185 km ALT)

EQUIPMENT/MEDIUM	PARAMETER	UNITS	GAIN(dB)
FREQUENCY	2.25	GHz	
Wavelength	13.32844	cm	
TRANSMITTER POWER	5.0	Watts	36.99
TRANSMITTER COUPLING			
Cable Length	0.4	Meter	
Cable Loss Factor	85.3	db/meter	-0.338
Diplexer/Hybrid	0.5	db	-0.5
TRANSMITTER ANTENNA	-8.0	dbi	-8.0
CHANNEL LOSS			
Free Space Propagation			
Altitude	185.	km	
Slant Range	656.	km	-155.825
Multipath	3.	db	-3.00
Ducting	0.	db	0.00
Flame Attenuation	0.	db	0.00
Atmosphere (rain, etc)	1.	db	-1.00
RECEIVER SYS SENSITIVITY (G/T)	20.	db/K	20.00
RECEIVER BANDWIDTH	4.5	MHz	122.07
MODULATION TYPE	Video		
Data Bandwidth	3.5	MHz	
Modulation Method SNR	6.0	db	-6.00
LINK MARGIN			4.394

TABLE 7.c. SIREX TELEMETRY LINK ANALYSIS (5 W POWER, 370 km ALT)

EQUIPMENT/MEDIUM	PARAMETER	UNITS	GAIN(db)
FREQUENCY	2.25	GHz	
Wavelength	13.32844	cm	
TRANSMITTER POWER	5.0	Watts	36.99
TRANSMITTER COUPLING			
Cable Length	0.4	Meters	
Cable Loss Factor	85.3	db/meter	-0.338
Diplexer/Hybrid	0.5	db	-0.5
TRANSMITTER ANTENNA	-8.0	dbi	-8.0
CHANNEL LOSS			
Free Space Propagation			
Altitude	370.	km	
Slant Range	1224.	km	-161.251
Multipath	3.	db	-3.00
Ducting	0.	db	0.00
Flame Attenuation	0.	db	0.00
Atmosphere (rain, etc.)	1.	db	-1.00
RECEIVER SYS SENSITIVITY (G/T)	20.	db/K	20.00
RECEIVER BANDWIDTH	4.5	MHz	122.07
MODULATION TYPE	Video		
Data Bandwidth	3.5	MHz	
Modulation Method SNR	6.0	db	-6.00
LINK MARGIN			1.032

TABLE 7.d. SIREX TELEMETRY LINK ANALYSIS (10 W POWER, 370 km ALT)

EQUIPMENT/MEDIUM	PARAMETER	UNITS	GAIN(db)
FREQUENCY	2.25	GHz	
Wavelength	13.32844	cm	
TRANSMITTER POWER	10.0	Watts	40.00
TRANSMITTER COUPLING			
Cable Length	0.4	Meter	
Cable Loss Factor	85.3	db/meter	-0.338
Diplexer/Hybrid	0.5	db	-0.5
TRANSMITTER ANTENNA	-8.0	dbi	-8.0
CHANNEL LOSS			
Space Propagation			
Altitude	370.	km	
Slant Range	1224.	km	-161.251
Multipath	3.	db	-3.00
Ducting	0.	db	0.00
Flame Attenuation	0.	db	0.00
Atmosphere (rain, etc.)	1.	db	-1.00
RECEIVER SYS SENSITIVITY (G/T)	20.	db/K	20.00
RECEIVER BANDWIDTH	4.5	MHz	122.07
MODULATION TYPE	Video		
Data Bandwidth	3.5	MHz	
Modulation Method SNR	6.0	db	-6.00

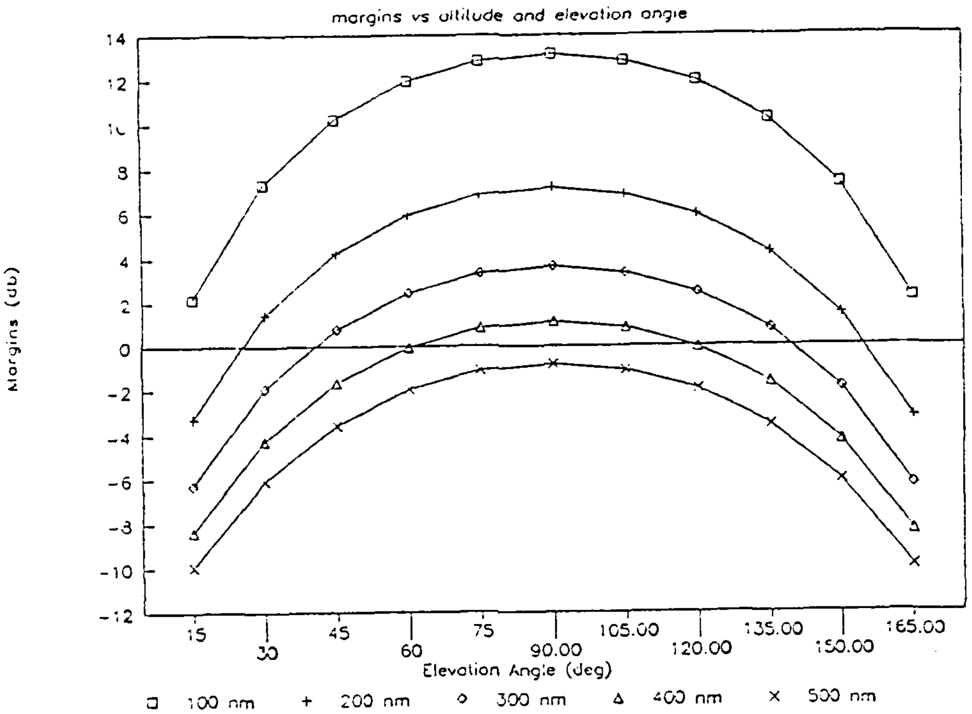
LINK MARGIN			1.978

TABLE 7.e. SIREX TELEMETRY LINK ANALYSIS (15 W POWER, 370 km ALT)

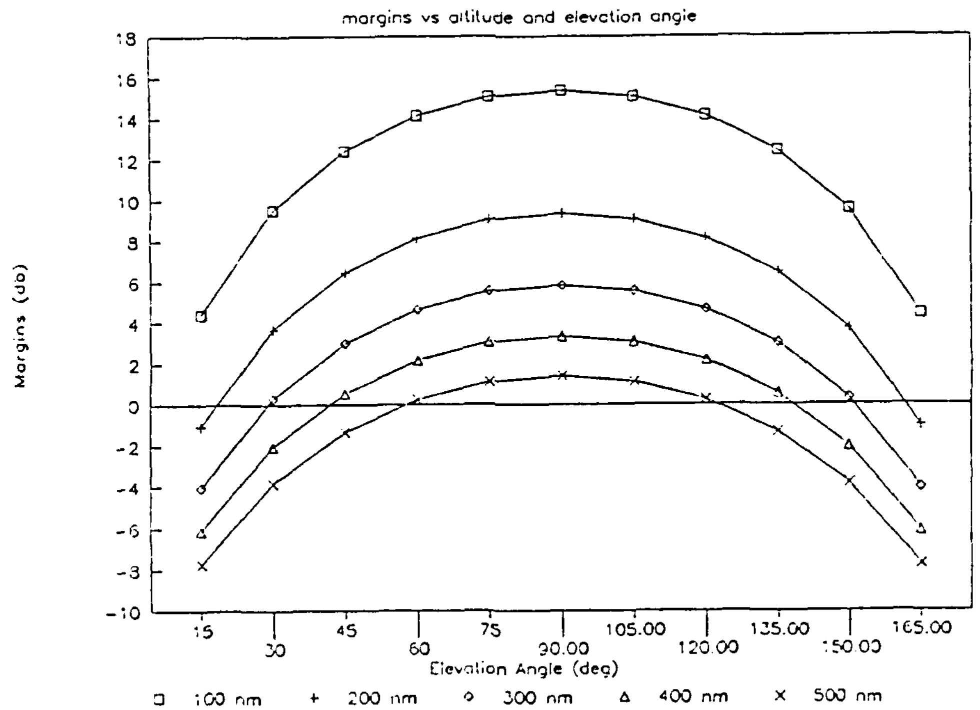
EQUIPMENT/MEDIUM	PARAMETER	UNITS	GAIN(db)
FREQUENCY	2.25	GHz	
Wavelength	13.32844	cm	
TRANSMITTER POWER	15.0	Watts	41.76
TRANSMITTER COUPLING			
Cable Length	0.4	Meters	
Cable Loss Factor	85.3	db/meter	
Diplexer/Hybrid	0.5	db	-0.5
TRANSMITTER ANTENNA	-8.0	dbi	-8.0
CHANNEL LOSS			
Free Space Propagation			
Altitude	370.	km	
Slant Range	1224.	km	-161.251
Multipath	3.	db	-3.00
Ducting	0.	db	0.00
Flame Attenuation	0.	db	0.00
Atmosphere (rain, etc.)	1.	db	-1.00
RECEIVER SYS SENSITIVITY (G/T)	20.	db/K	20.00
RECEIVER BANDWIDTH	4.5	MHz	122.07
MODULATION TYPE	Video		
Data Bandwidth	3.5	MHz	
Modulation Method SNR	6.0	db	-6.00
LINK MARGIN			3.739

TABLE 7.f. SIREX TELEMETRY LINK ANALYSIS (15 W POWER, 741 km ALT)

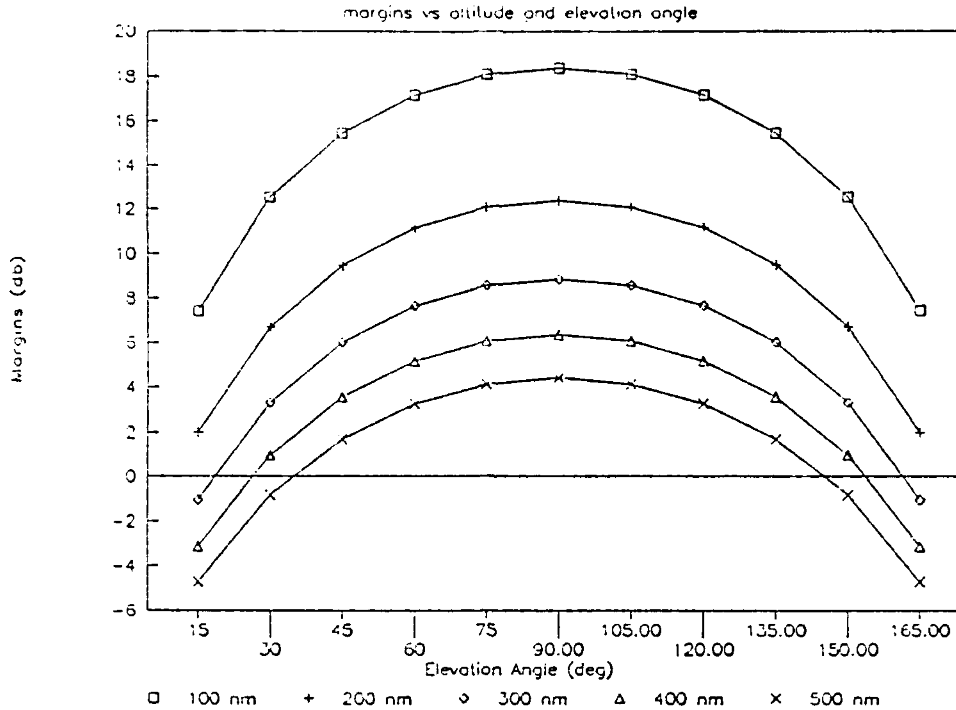
EQUIPMENT/MEDIUM	PARAMETER	UNITS	GAIN(db)
FREQUENCY	2.25	GHz	
Wavelength	13.32844	cm	
TRANSMITTER POWER	15.0	Watts	41.76
TRANSMITTER COUPLING			
Cable Length	0.4	Meter	
Cable Loss Factor	85.3	db/Meter	-0.338
Diplexer/Hybrid	0.5	db	-0.5
TRANSMITTER ANTENNA	-8.0	dbi	-8.0
CHANNEL LOSS			
Free Space Propagation			
Altitude	741	km	
Slant Range	2208.	km	-166.367
Multipath	3.	db	-3.00
Ducting	0.	db	0.00
Flame Attenuation	0.	db	0.00
Atmosphere (rain, etc.)	1.	db	-1.00
RECEIVER SYS SENSITIVITY (G/T)	20.	db/K	20.00
RECEIVER BANDWIDTH	4.5	MHz	122.07
MODULATION TYPE	Video		
Data Bandwidth	3.5	MHz	
Modulation Method SNR	6.0	db	-6.00
LINK MARGIN			-1.377



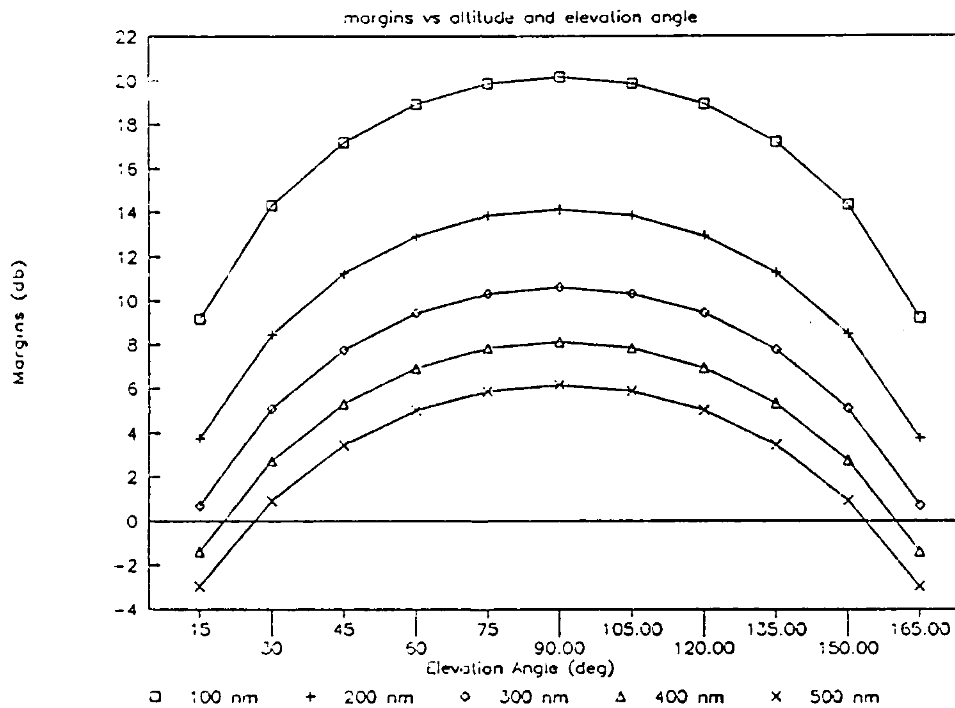
16a. Telemetry Link -- 3 Watt Transmitter



16b. Telemetry Link -- 5 Watt Transmitter



16c. <u>Telemetry Link -- 10 Watt Transmitter</u>



16d. <u>Telemetry Link -- 15 Watt Transmitter</u>

6.0 RECOMMENDATIONS AND CONCLUSIONS

A flight test experiment whose objectives are

- To demonstrate that the reflector erects in space and
- To determine the time required for the reflector to stabilize after being disturbed by a force similar to that produced on a collector during operation of a solar powered rocket is quite feasible.

A preliminary design of the experiment hardware was completed. This hardware fits within and clamps to the GAS canister per its interface requirements. Calculated payload weight is 55 kg (121 lbm), well below the contractual requirement of 90.8 kg (200 lbm) and the GAS canister ejection system limitation of 68.2 kg (150 lbm).

One major constraint was that the DSCE soft torus, truss, and reflector and the Get Away Special (GAS) canister deployment system were to be used. Testing and analysis showed this is practical if the DSCE torus small diameter is limited to 46 cm (18 inches). The DSCE program accommodated the SIREX Program by adopting this diameter.

A major feature of this design is easy access to all components of the pneumatics, major instrumentation, controller, and telemetry subsystems. The primary instrumentation needed is a video camera which views the inflatable erection and induced dynamics. The dynamics experiment is also supported by strain gages, accelerometers, and temperature sensors. Diagnostic instrumentation is on-board. The experiment could be fully powered for a total of 24 minutes. It is designed such that it can wait essentially unpowered before the inflatable erects to provide shuttle safety. It can also wait between experiments to assure it is within range of a ground station(s) or while it is in the earth's shadow.

The experiment and its hardware are quite practical. We recommend that detail design and development testing be started as soon as possible and that a Inflatable Solar Concentrator Flight Test Program as described in AFAL TR-87-035 be pursued.

GLOSSARY OF ABBREVIATIONS

ADC	Analog to Digital Converter
AF	United States Air Force
AL	Astronautics Laboratory of the Air Force Systems Command
cm	Centimeter(s)
db	Decibel(s)
dbi	Decibel(s), isotropic
DOT	Department of Transportation
DSCE	Deployable Solar Collector Experiment
DTR	Derived Technical Requirement
f	Focal Length
FOV	Field of View
ft	Foot or Feet
GAS	Get Away Special
GHz	GigaHertz
GN_2	Gaseous Nitrogen
GSFC	Goddard Space Flight Center
HAIR	Highly Accurate Inflatable Reflector
Hz	Hertz (i.e., cycles per second)
in	Inch(es)
in-lb	Inch-Pound(s)
IRIG	Inter-Range Instrumentation Group (now part of Range Commander's Council)
kg	Kilogram(s)
kHz	KiloHertz
km	Kilometer(s)
kPa	KiloPascal(s)

lbf	Pound(s) force
lbm	Pound(s) mass
LOS	Line of Sight
LVDT	Linear Variable Displacement Transducer
m	Meter(s)
MHz	MegaHertz
mm	Millimeter(s)
mmHg	Millimeters of Mercury
MPa	MegaPascal(s) (million Pascal(s))
ms	Millisecond(s)
N	Newton(s)
NASA	National Aeronautics and Space Administration
NCK	Neoprene coated Kevlar
N/M^2	Newtons per Square Meter
nm	Nautical Mile(s)
Nm	Newton Meter(s)
PL	Phillips Laboratory of the Air Force Systems Command
P/L	Payload
Pa	Pascal(s)
para	Paragraph(s)
psi	Pound(s) per Square Inch
PCB	Printed Circuit Board
PCM	Pulse Code Modulation
PF	Packaging Factor
psig	Pound(s) per Square Inch - Gauge
RF	Radio Frequency
RMS	Root Mean Square

rad	Radian(s)
SC	Switch Capacitor
SIREX	Solar Inflatable Reflector Experiment
SNR	Signal to Noise Ratio
SOW	Statement of Work
SRB	Solid Rocket Booster
U.S.	United States
V	Volt(s)
W	Watt(s)
°	Degree(s) (angular or thermal)
β	Angle of Paraboloid Rim with Respect to a plane normal to the paraboloid axis

REFERENCES

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6. Telemetry Standards (Document IRIG 106). White Sands Missile Range: Range Commander's Council, May 1986.

7. Thomas, L., Get Away Special Small Self-Contained Payloads Experiment Handbook, NASA/Goddard Space Flight Center, Greenbelt, Maryland, 1985.

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10. Weingarten, et al. "Buckling of Thin-Walled Cylinders." NASA SP-8007, Sep. 1968.

11. Williams, G. T., "Inflatable Solar Concentrator Flight Test Experiment," (AFAL TR-87-035). August 1987.

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APPENDIX A

SIREX DRAWINGS

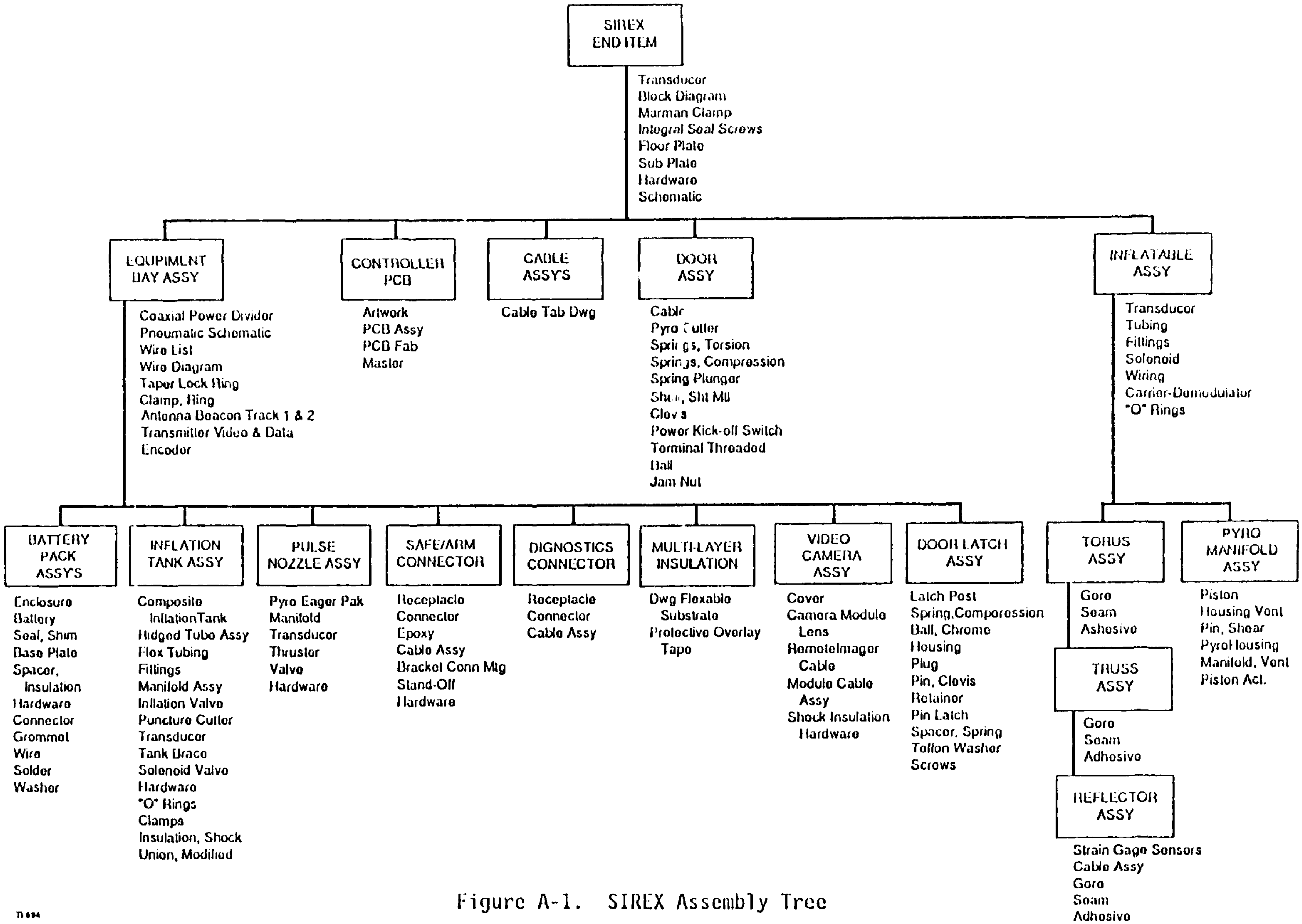
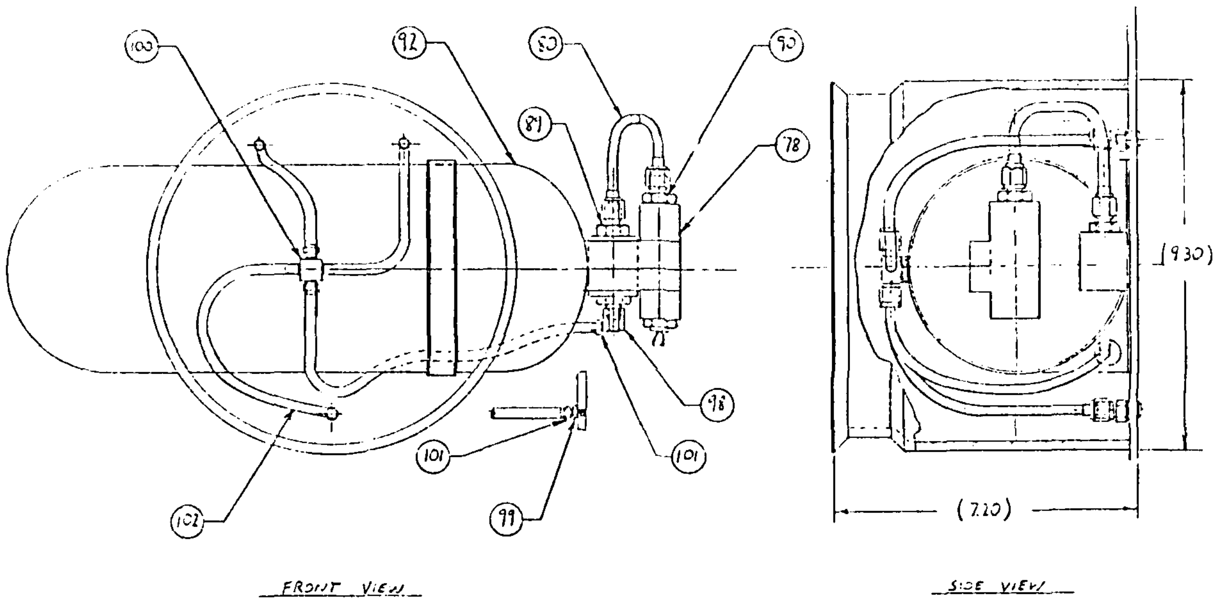


Figure A-1. SIREX Assembly Tree

DWG. NO.	SH	REV.

REVISIONS

REV	DESCRIPTION	DATE	APPROVED



QTY REQD	FSCM NO	PART OR IDENTIFYING NO	NOMENCLATURE OR DESCRIPTION	MATERIAL SPECIFICATION

PARTS LIST

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES TOLERANCES ARE:
FRACTIONS ± DECIMALS .XX ± .XXX ± ANGLES ±

MATERIAL

FINISH

DO NOT SCALE DRAWING

CONTRACT NO.

APPROVALS	DATE
DRAWN	
CHECKED	
ISSUED	

L'GARDE, INC. 15181 WOODLAWN AVENUE TUSTIN, CALIFORNIA 92680

FIGURE A-2

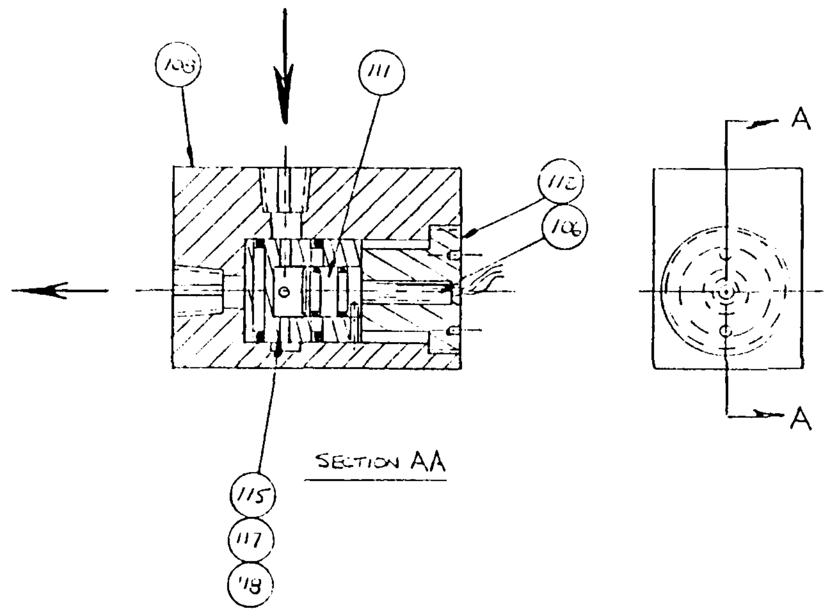
MAIN INFLATION TANK ASSY.

SIZE B | FSCM NO. | DWG. NO. | REV.

SCALE | SHEET

NEXT ASSY	USED ON
APPLICATION	

BISHOP GRAPHICS INC REORDER NO 20510



SECTION AA

DWG. NO.	SH	REV.

REVISIONS

REV	DESCRIPTION	DATE	APPROVED

QTY REQD	FSCM NO	PART OR IDENTIFYING NO	NOMENCLATURE OR DESCRIPTION	MATERIAL SPECIFICATION

PARTS LIST

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES TOLERANCES ARE:
FRACTIONS ± DECIMALS .XX ± .XXX ± ANGLES ±

MATERIAL

FINISH

DO NOT SCALE DRAWING

CONTRACT NO.

APPROVALS	DATE
DRAWN	
CHECKED	
ISSUED	

NEXT ASSY	USED ON

APPLICATION

L'GARDE, INC. 15181 WOODLAWN AVENUE TUSTIN, CALIFORNIA 92680

FIGURE A-3

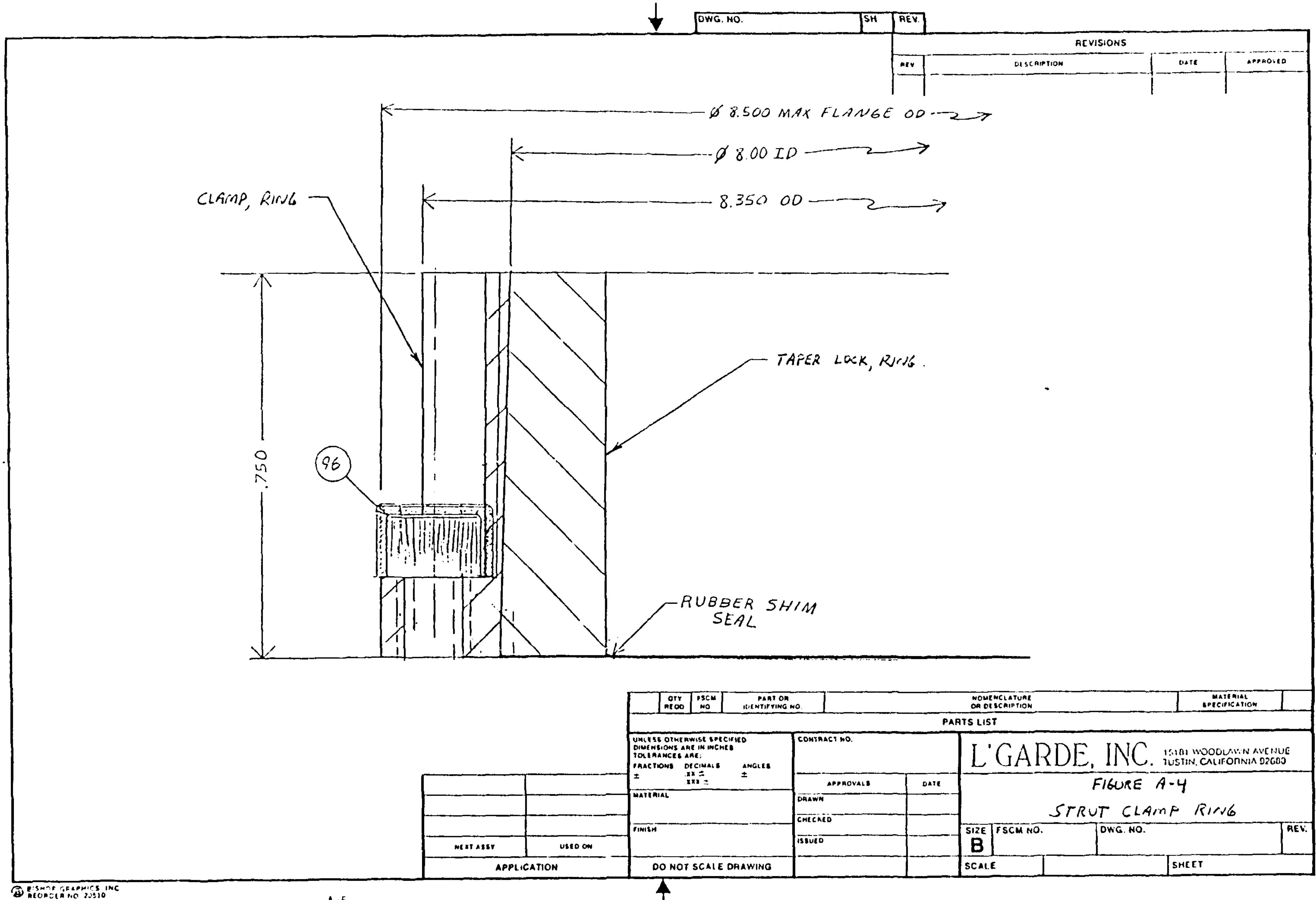
MANIFOLD ASSY, VENT VALVE

SIZE	FSCM NO.	DWG. NO.	REV.
B	1F663		

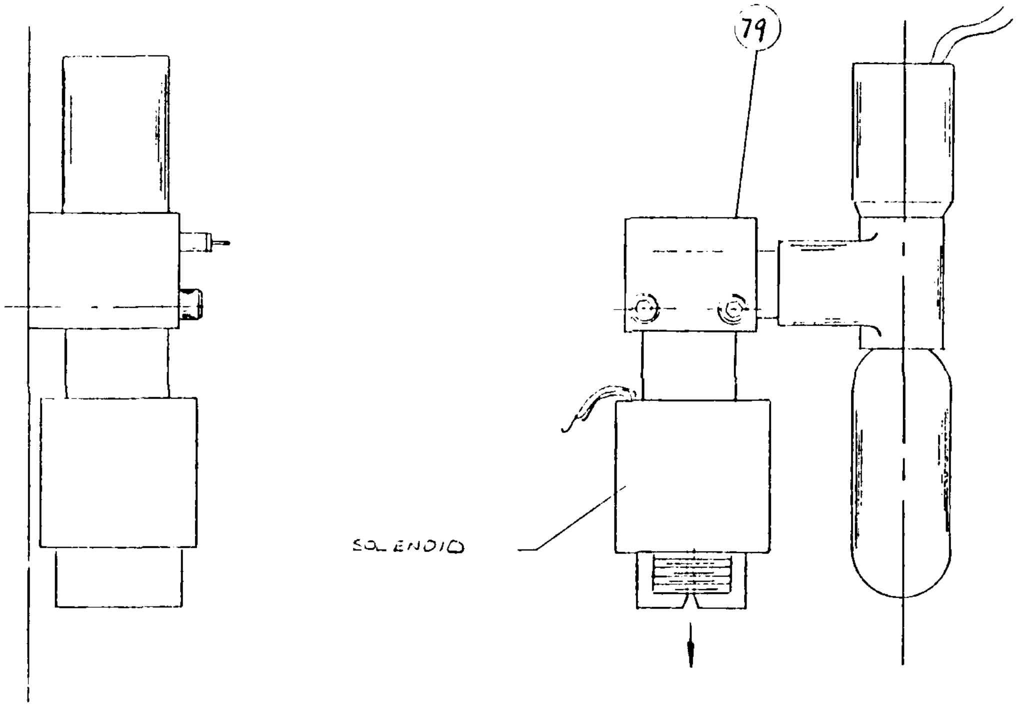
SCALE

SHEET

BISHOP GRAPHICS INC RECORDER NO 20510


DWG. NO.
SH
REV.
REVISIONS
REV
DESCRIPTION
DATE
APPROVED
Ø 8.500 MAX FLANGE OD
Ø 8.00 ID
8.350 OD
CLAMP, RING
TAPER LOCK, RING.
96
.750
RUBBER SHIM SEAL
QTY REQD
FSCM NO
PART OR IDENTIFYING NO.
NOMENCLATURE OR DESCRIPTION
MATERIAL SPECIFICATION
PARTS LIST
UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES TOLERANCES ARE:
FRACTIONS ± DECIMALS .XX ± .XXX ± ANGLES ±
MATERIAL
FINISH
DO NOT SCALE DRAWING
CONTRACT NO.
APPROVALS
DATE
DRAWN
CHECKED
ISSUED
L'GARDE, INC. 15181 WOODLAWN AVENUE TUSTIN, CALIFORNIA 92680
FIGURE A-4
STRUT CLAMP RING
SIZE B
FSCM NO.
DWG. NO.
REV.
SCALE
SHEET
NEXT ASSY
USED ON
APPLICATION
BISHOP GRAPHICS INC REORDER NO 22510

A-5



DWG. NO.	SH	REV.

REVISIONS

REV	DESCRIPTION	DATE	APPROVED

QTY REQD	FSCM NO	PART OR IDENTIFYING NO	NOMENCLATURE OR DESCRIPTION	MATERIAL SPECIFICATION

PARTS LIST

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES TOLERANCES ARE:
FRACTIONS ± DECIMALS .XX ± .XXX ± ANGLES ±

MATERIAL

FINISH

DO NOT SCALE DRAWING

CONTRACT NO.

APPROVALS	DATE
DRAWN	
CHECKED	
ISSUED	

L'GARDE, INC. 15101 WOODLAWN AVENUE TUSTIN, CALIFORNIA 92680

FIGURE A-5
PULSE THRUSTER ASSY AND NOZZLE

SIZE	FSCM NO.	DWG. NO.	REV.
B			

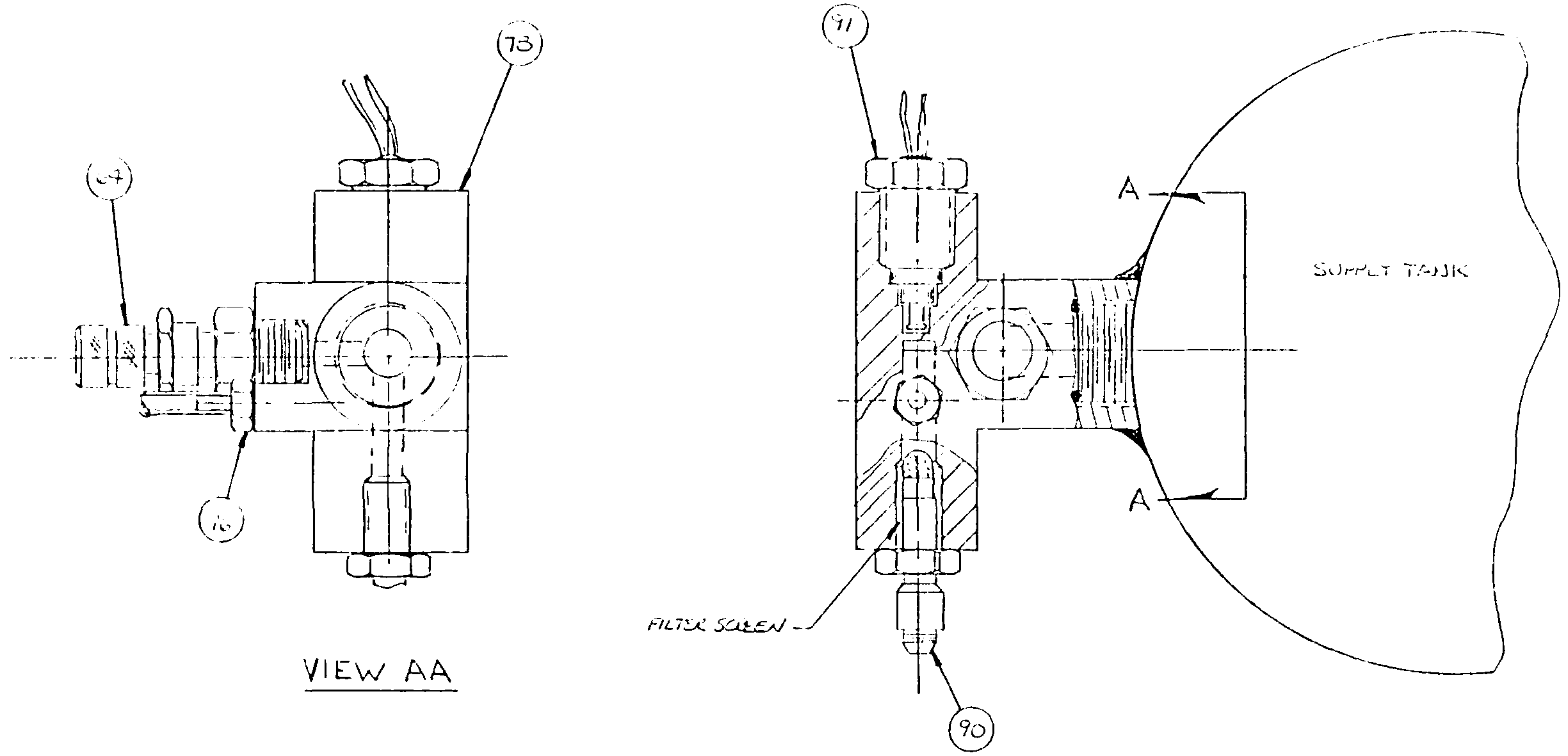
SCALE SHEET

NEXT ASSY	USED ON
APPLICATION	

DWG. NO. | SH | REV

REVISIONS

REV	DESCRIPTION	DATE	APPROVED



QTY REQD	FSCM NO	PART OR IDENTIFYING NO.	NOMENCLATURE OR DESCRIPTION	MATERIAL SPECIFICATION

PARTS LIST

UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES
TOLERANCES ARE:
FRACTIONS ± DECIMALS .XX ± .XXX ± ANGLES ±

MATERIAL

FINISH

DO NOT SCALE DRAWING

CONTRACT NO.

APPROVALS	DATE
DRAWN	
CHECKED	
ISSUED	

NEXT ASSY	USED ON

APPLICATION

L'GARDE, INC. 15181 WOODLAWN AVENUE TUSTIN, CALIFORNIA 92680

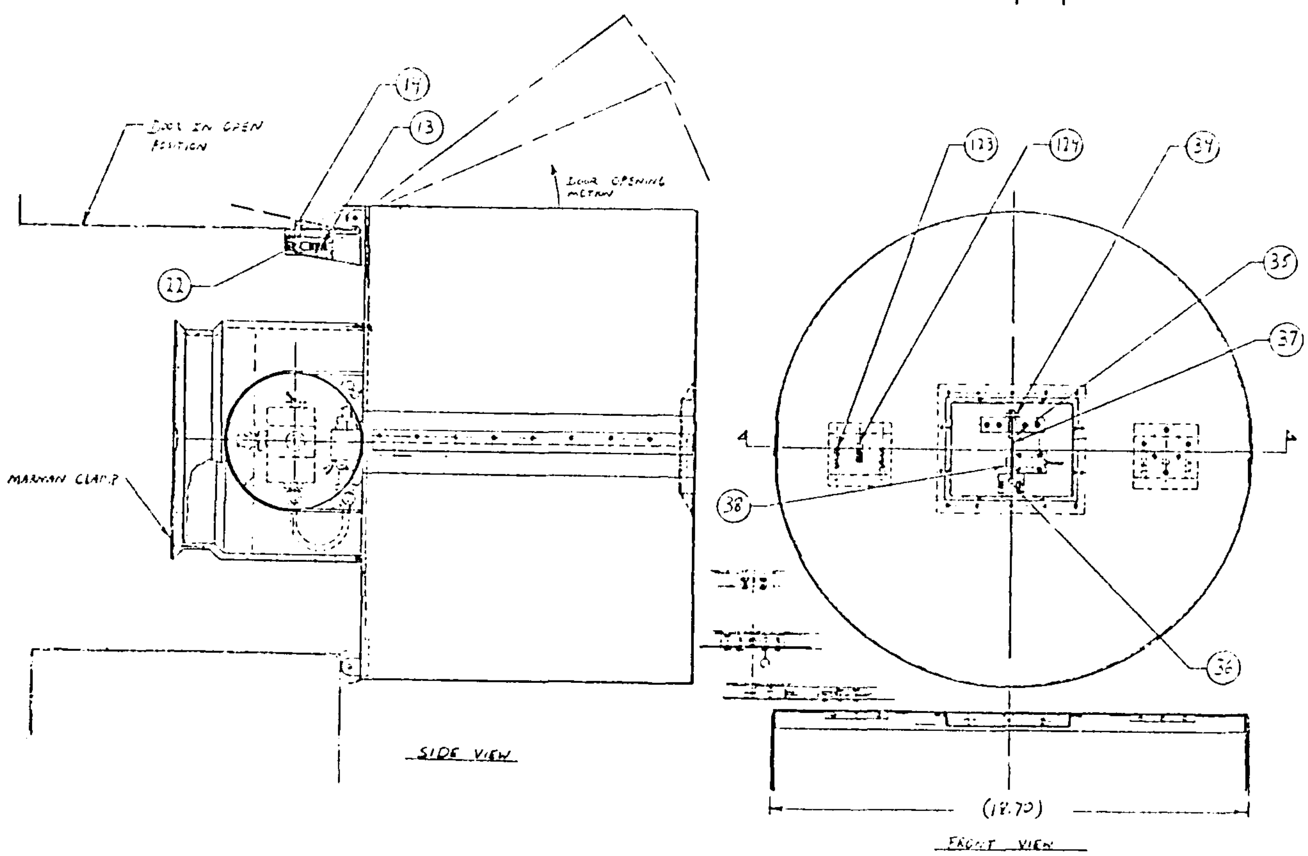
FIGURE A-6

INFLATION MANIFOLD ASSY

SIZE B | FSCM NO. | DWG. NO. | REV.

SCALE | SHEET

BISHOP GRAPHICS INC REORDER NO. 20510



REV	DESCRIPTION	DATE	APPROVED

DWG. NO. | SH | F.

PARTS LIST

QTY REQD	FSCM NO	PART OR IDENTIFYING NO.	NOMENCLATURE OR DESCRIPTION	MATERIAL SPECIFICATION

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES TOLERANCES ARE:
FRACTIONS ± DECIMALS .XX ± .XXX ± ANGLES ±

MATERIAL

FINISH

DO NOT SCALE DRAWING

CONTRACT NO.

APPROVALS	DATE
DRAWN	
CHECKED	
ISSUED	

L'GARDE, INC. 15181 WOODLAWN AVENUE TUSTIN, CALIFORNIA 92680

FIGURE A-7

LAYOUT OF MARMAN CLAMP & DOOR ASSY

SIZE B | FSCM NO. | DWG. NO. | REV.

SCALE | SHEET

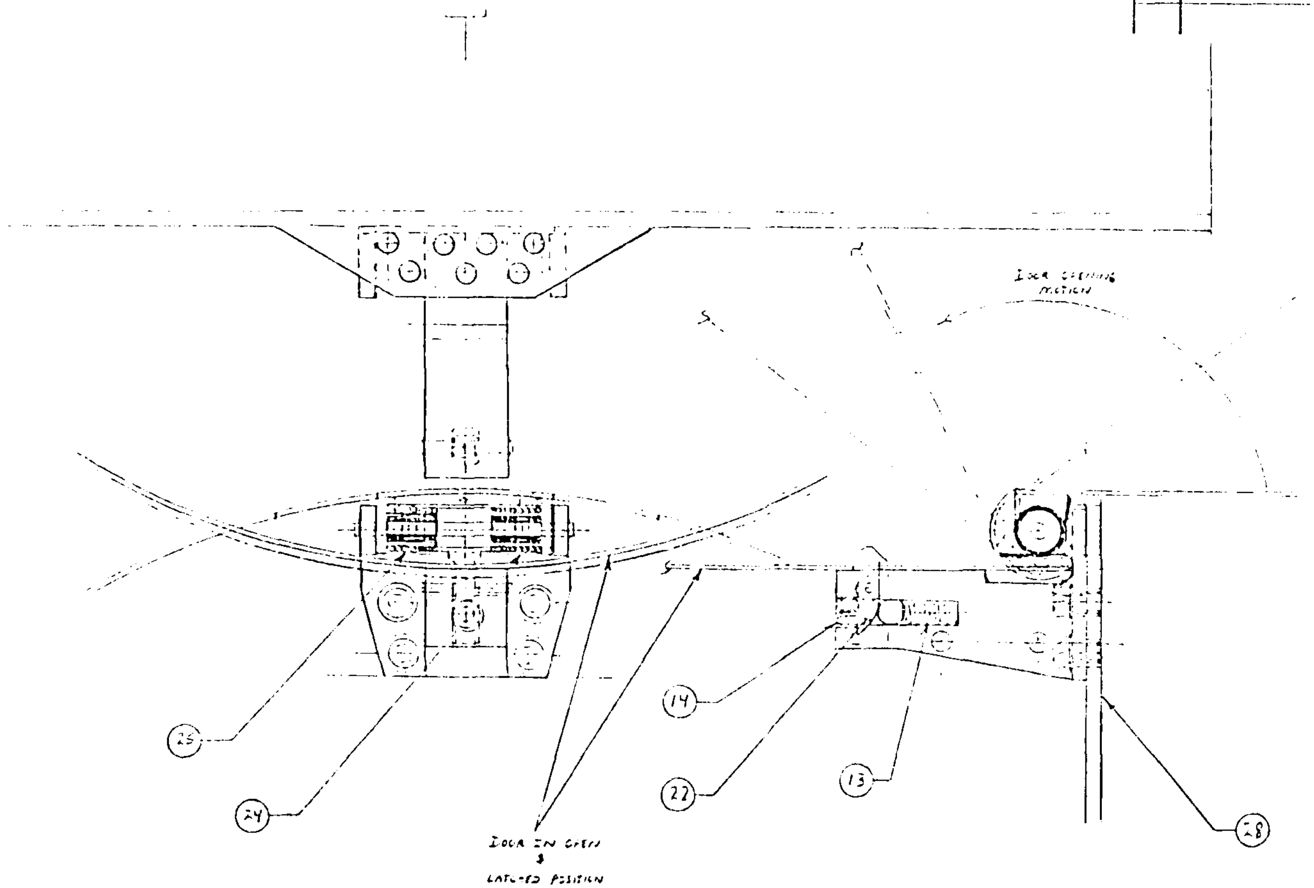
NEXT ASSY	USED ON
APPLICATION	

BISHOP GRAPHICS INC REORDER NO 20510

DWG. NO.	SH	REV.

REVISIONS

REV	DESCRIPTION	DATE	APPROVED



QTY REQD	FSCM NO	PART OR IDENTIFYING NO	NOMENCLATURE OR DESCRIPTION	MATERIAL SPECIFICATION

PARTS LIST

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES TOLERANCES ARE:
FRACTIONS ± DECIMALS .XX ± .XXX ± ANGLES ±

MATERIAL

FINISH

DO NOT SCALE DRAWING

NEXT ASSY	USED ON

APPLICATION

CONTRACT NO.

APPROVALS	DATE
DRAWN	
CHECKED	
ISSUED	

L'GARDE, INC. 15181 WOODLAWN AVENUE TUSTIN, CALIFORNIA 92680

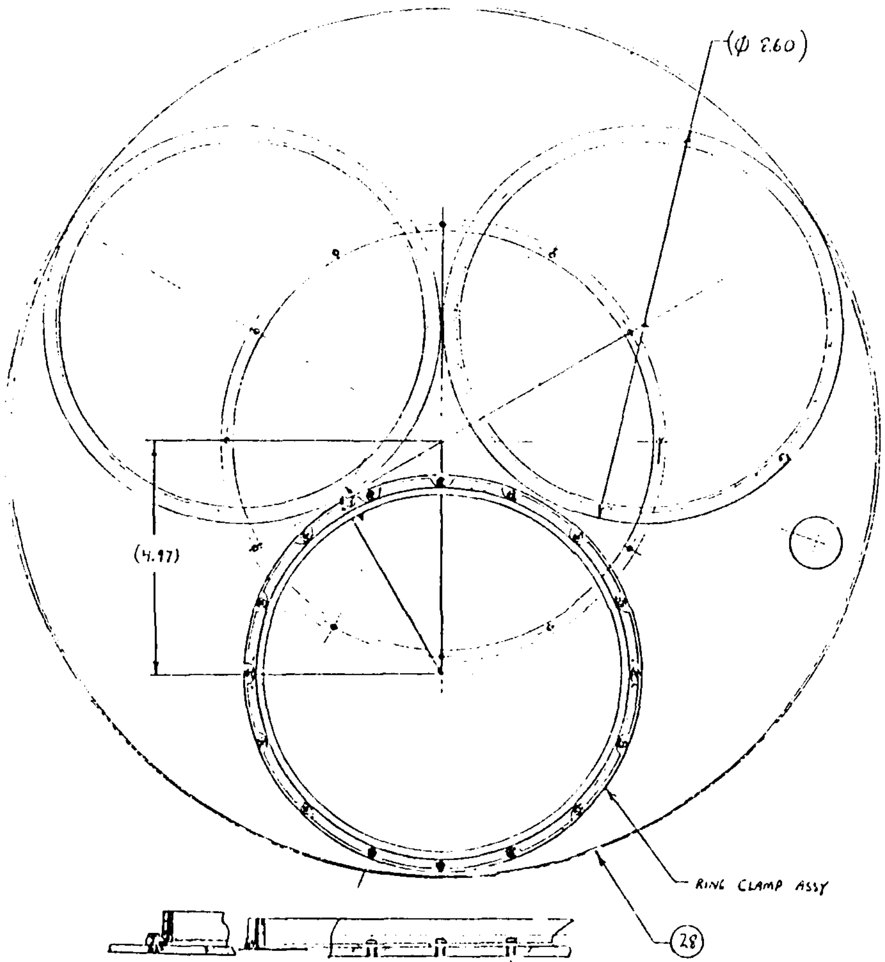
FIGURE A-8

DOOR LATCHING MECHANISM

SIZE B | FSCM NO. | DWG. NO. | REV.

SCALE | SHEET

BISHOP GRAPHICS INC REORDER NO 20510



DWG. NO. | SH | REV.

REVISIONS

REV	DESCRIPTION	DATE	APPROVED

QTY REQD	FSCM NO	PART OR IDENTIFYING NO	NOMENCLATURE OR DESCRIPTION	MATERIAL SPECIFICATION

PARTS LIST

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES TOLERANCES ARE:
FRACTIONS ± DECIMALS .XX ± .XXX ± ANGLES ±

MATERIAL

FINISH

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CONTRACT NO.

APPROVALS	DATE
DRAWN	
CHECKED	
ISSUED	

NEXT ASSY	USED ON

APPLICATION

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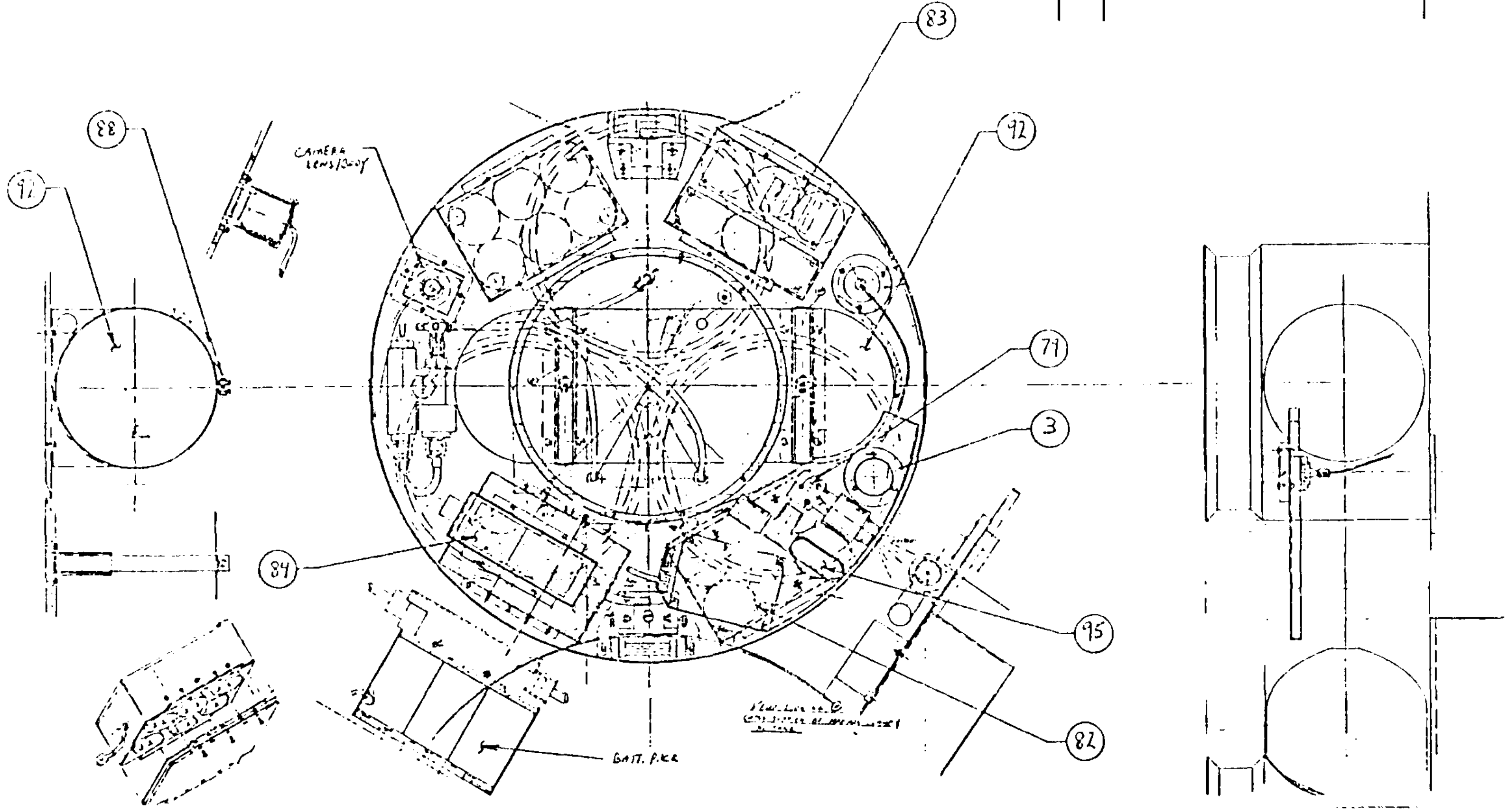
FIGURE A-9

RING CLAMP FOR INFLATABLE TRUSS

SIZE B | FSCM NO. | DWG. NO. | REV.

SCALE | SHEET



DWG. NO.	SH	REV.

REVISIONS

REV	DESCRIPTION	DATE	APPROVED

	QTY REQD	FSCM NO	PART OR IDENTIFYING NO	NOMENCLATURE OR DESCRIPTION	MATERIAL SPECIFICATION

PARTS LIST

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES TOLERANCES ARE:
FRACTIONS ± DECIMALS .XX ± .XXX ± ANGLES ±

MATERIAL

FINISH

DO NOT SCALE DRAWING

CONTRACT NO.

APPROVALS	DATE
DRAWN	
CHECKED	
ISSUED	

NEXT ASSY	USED ON

APPLICATION

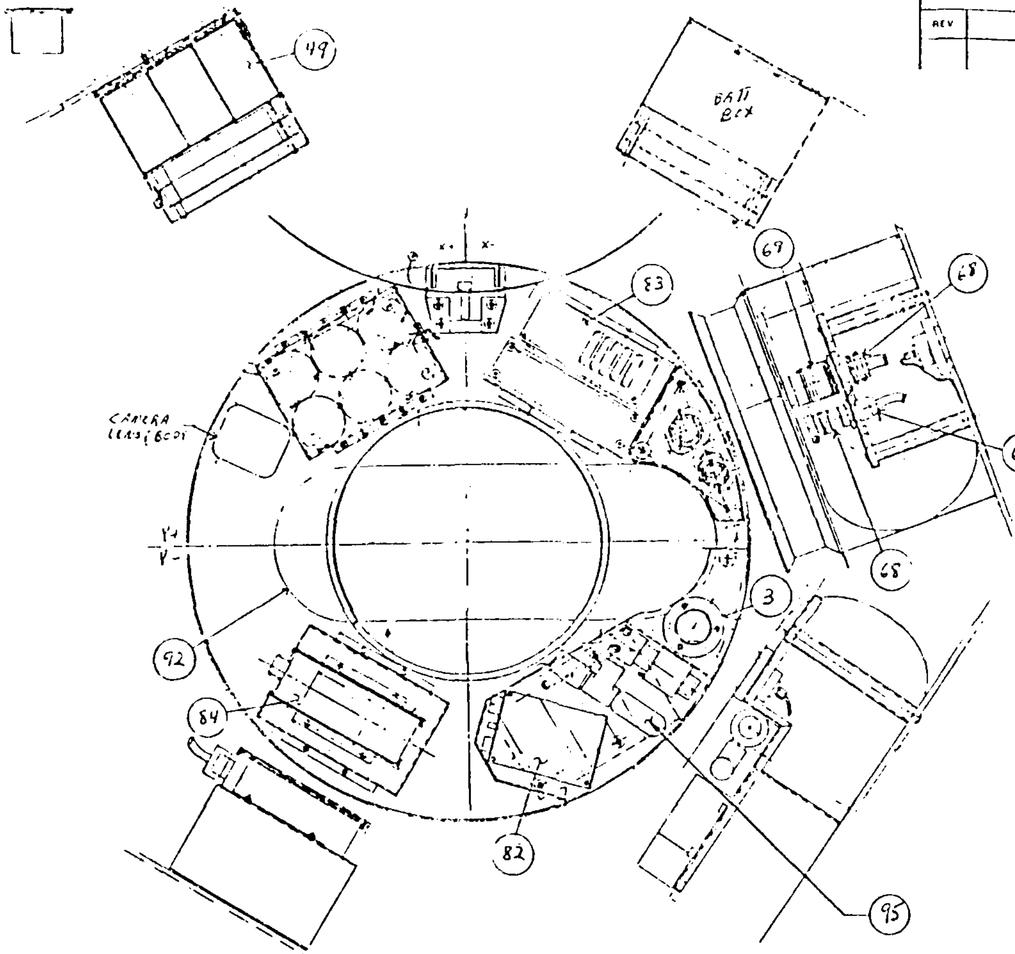
L'GARDE, INC. 15181 WOODLAWN AVENUE TUSTIN, CALIFORNIA 92680

FIGURE A-10

LAYOUT OF EQUIPMENT BAY (VIEW 1 OF 2)

SIZE B	FSCM NO.	DWG. NO.	REV.
SCALE		SHEET	

BISHOP GRAPHICS, INC. REORDER NO 20510



DWG. NO. | SH | REV.

REVISIONS

REV	DESCRIPTION	DATE	APPROVED

QTY REQD	FSCM NO	PART OR IDENTIFYING NO.	NOMENCLATURE OR DESCRIPTION	MATERIAL SPECIFICATION

PARTS LIST

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES TOLERANCES ARE:
FRACTIONS ± DECIMALS .XX ± .XXX ± ANGLES ±

MATERIAL

FINISH

DO NOT SCALE DRAWING

CONTRACT NO.

APPROVALS	DATE
DRAWN	
CHECKED	
ISSUED	

NEXT ASSY	USED ON

APPLICATION

L'GARDE, INC. 15181 WOODLAWN AVENUE TUSTIN, CALIFORNIA 92680

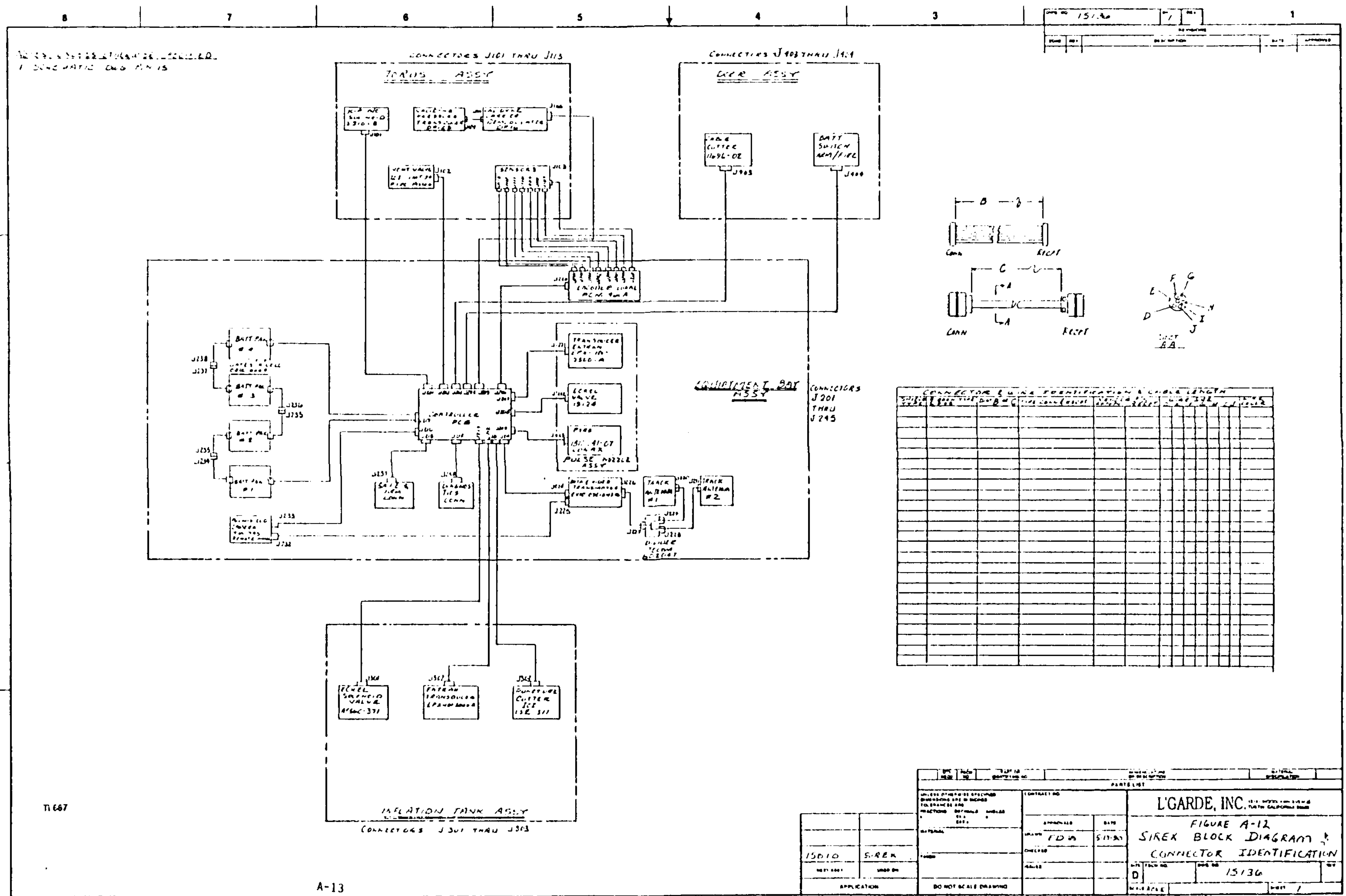
FIGURE A-11

LAYOUT OF EQUIPMENT BAY (VIEW 2 OF 2)

SIZE B | FSCM NO. | DWG. NO. | REV.

SCALE | SHEET

BISHOP GRAPHICS INC REORDER NO 20510



CONNECTORS J101 THRU J115
TORUS ASSY
CONNECTORS J403 THRU J414
GER ASSY
CABLE CUTTER
BATT SWITCH ARM/FIRE
SENSORS
CONTROLLER PCB
EQUIPMENT BAY ASSY
CONNECTORS J201 THRU J245
PULSE NOZZLE ASSY
INFLATION TANK ASSY
CONNECTORS J301 THRU J313
CONN
RECPT
SECT A-A
CONNECTOR & WIRE IDENTIFICATION & CABLE LENGTH
L'GARDE, INC.
FIGURE A-12
SIREX BLOCK DIAGRAM &
CONNECTOR IDENTIFICATION
15136
15010
SIREX
APPLICATION
DO NOT SCALE DRAWING
TI 687

APPENDIX B

SIREX PARTS LIST

L'GARDE PARTS LIST, TOP ASSY, MECHANICAL SIREX, PL15100

Item No.	Qty Rqd	Part or ID No.	Nomenclature or Description	Data: Spec., Size, Standard Supplier, etc.
1				
2				
3	2	108013	Antenna Beacon Track	Tecom Industries Inc. Connectors
4	12	Y18-28-A8	8-32 Seal Screw x 1/2 screw	W.F. Berg
5	1	1506	10-32 Elbow x. .170 Barb Fitt.	ADI
6	2	1001	10-32 xx 1/8 bars Fitting	ADI
7	NR	90101A009	Nut, Self Lock 8-32 x .172 high	MCMAS/CARR
8		20097-E-98-C-10-B	SHCS 8-32 x .62 SS	Unbrako Ftr Fasteners
9		20096-E-98-C-12-B	SHCS 8-32 x .75 SS	"
10	NR	98017A125	Washer, SS .032 thk #8	MAS/CARR Cat 95, P#2048
11	8	98D17A155	Washer SS .032 thk 1/4ID	"
12	4	Z2-1	.125 Shaft Ref Retaining Ring	PIC Precision Components
13	2	LC-030D-8	Spring, Compression	Lee Spring Co.

Item No.	Qty Rqd	Part or ID No.	Nomenclature or Description	Data: Spec., Size, Standard Supplier, etc.
14	2	91386A619	Hex Soc Set Screw Nylon Patch 3/8-24 x 3/8 lg.	MCM/CAR of Unbrako
15	2	Z5-2	Retaining Ring .187 Shaft Ref	PIC
16	8	20097-L-10-F-8-8	SHCS 10-32x3/8 Lock-wel Type	Unbrako, p.12
17				
18	1	5391A35	Pliers, Retaining Ring, Standard	MCM/CARR
19	2	15103	Post, Latch	
20	2	15104	Pin, Clevis	
21	2	15107	Pin, Latch	
22	2	15105	Latch	
23	4	5612-19-60	Washer, Teflon	Seastrom .125ID x .317OD, .062 thick
24	2	LT-070M-2MW R.H.	Spring, Torsion Leg Length .50	Lee (Special Ord.)
25	2	LT-070M-2MW L.H.	Spring, Torsion Leg Length .50	Lee (Special Ord.)
26	2	9528K17	Ball, Chrome Steel	MC/MAS/CARR, Page 2234, #95

Item No.	Qty Rqd	Part or ID No.	Nomenclature or Description	Data: Spec., Size, Standard Supplier, etc.
27	2	15109	Spacer, Spr.	
28	1	15106	Plate, Floor	
29	1	15102	Interface Structure	
30	12	9600K27	Grommet	MCM/CARR, Page 2226, #95
31	16	20097-E-96-C-8-B	Soc Hd Cap Screw 6-32 x .50 long	Unbrako
32	28	19509-05	Shim, Rubber	
33				
34	1	90490A029	Nut, Jam 1/4-20	MC/CARR, Pg.2031, #95
35	1	20-619	CMA-20 Terminal, Threaded	CMA Cable Mfg & Assy 201-575-6460
36	1	40-063	CMA-40 Ball	"
37	4-3/4"	5063EA	Cable	"
38	1	11696-02	Cable Cutter	Holex, Hollister, CA
39	16	100°x6-32 x .88	100° Flat HD Screw 6-32x.88 lg Phillips SS	Certified Fasteners Sante Fe Springs

Item No.	Qty Rqd	Part or ID No.	Nomenclature or Description	Data: Spec., Size, Standard Supplier, etc.
40	1	15110	Cover, Batt Pack #1	
41	16	15111	Washer	
42	1	15112	Cover, Batt Pack #2	
43	1	15113	Cover, Batt Pack #3	
44	1	15114	Cover, Batt Pack #4	
45	4	15108	Plate, Base	
46	24	Bulk Stock	4-40x.25 Flt Hd. Screw Scr 100° Grade 8 Blk OX	Certified Fasteners Santa Fe Springs, 213-802-2931
47	1	15120	Cover, Camera Mod	
48	26	Bulk Stock	Washer #4 SS	Certified Fasteners
49				
50	21	0800-0004	"X" Cell 2V, 5.0Ah	Gates, Denver, CO
51	36	15115-01	Shim, Rubber	MC/CAR P. 2165, .020 thick
52	32	15115-02	Shim, Rubber	.030 thick

Item No.	Qty Rqd	Part or ID No.	Nomenclature or Description	Data: Spec., Size, Standard Supplier, etc.
53	4	15116	Shim, Rubber	.050 thick
54	4	8760K2	Felt, Med. Gray 1/4 x 3.54 x 5.34	MCM/Carr, P.2155, Cat #95
55	4	8667K211	Substrate G-10 1/16x3.54x5.46	MC MAS/CARR, P.2155, #95
56	8	1820-632-N-0	Stand-off 3/8 OD x .62 lg. 6-32	RAF Local Sales, p.42,Cat 005
57	4	4033-632-N-0	Stand-off, 1/4 OD x 6-32 Male & Female	" , p.42, Cat 005
58	4	No M/S #	Screw Flt Hd 100°,Phillips 4-40 x 2.0 ss	Certified Fasteners, 213-802-2931, Santa Fe Springs
59	24	90101A005	Nut, Self Lock 4-40 18-8SS	MCM/CARR, p. 2040, Cat #95
60	24	98019A109	Washer MS15795 .125 ID x .250 OD	MCMS/CARR, p.2048, Cat #95
61	8	38030-L-10-8-B	BHCS 10-32 x 1/2 Lock-wel type	Unbrako Ftr Fasteners, p.24 213-946-6464
62	3	15117-01	Standoff	
63	1	15117-02	Standoff	
64	1	1819	Valve Recharge	
65				

Item No.	Qty Rqd	Part or ID No.	Nomenclature or Description	Data: Spec., Size, Standard Supplier, etc.
66	1	PT07P-10	Receptacle	Benoix - Hamilton-Avnet Tempe, AZ, 602-231-5100
67	1	PT06P-10	Plug, Cable Clamp	"
68	1	PT07-P-14-32S	Receptacle	"
69	1	PT07SP-14-32P	Plug, Potting	"
70	A/R	1210AB	Epoxy, Adhesive (Potting)	
71				
72	2	0437TEEN	Tee, Barbed 3/8 ID	ARK-Plas Products 501-453-2343
73	1	15118	Brkt, Conn. Mtg	
74	2	15121	Brace, Tank	
75	1	15122	Door Assy	
76	1	EPX-10I-5000A	Transducer Mini-thrd'd EPS Series	Entran
77	1	EPX-10I-2500-A	Transducer Mini-Thrd'd EPS Series	"
78	1	15123	Manifold, Tank	

Item No.	Qty Rqd	Part or ID No.	Nomenclature or Description	Data: Spec., Size, Standard Supplier, etc.
79	1	15125	Manifold, Thruster	
80	1	15128	Tube Ridged, Assy	
81				
82	1	EVTC-09E 10103-05	Transmitter,Video	Engliser Research, Inc.
83	1	PCM-460A	Encoder Programmable, PROM	Loral Conic, 619-279-0411
84	1	TM-745/765	Camera, Remote Imager CCD	Pulnix
85	2	38030-L-94-C-16-B	But Hd Cap Screw 4-40 x 1.0	Unbrako, Ftr Fastners
86	1	802047	Coax Power Divider TNC-2 way	Tecom, Type No. 102007
87	2 ft.	8601K11	Rubber Sheet .125 thick	MCM/CARR, p.2165, Cat 95
88	2	5415K36	Clamp, Hose SS 05 1/8-6" range, ½" wide	MCMS/CARR, p.56, Cat 95
89	1	AF56C-371	Valve, Sol. Opr. Shutoff N.C.	Eckel Valve Co.
90	1	15129	Union "Modified"	
91	1	ISE311	Puncture Cutter	ICI

Item No.	Qty Rqd	Part or ID No.	Nomenclature or Description	Data: Spec., Size, Standard Supplier, etc.
92	1	ALT-210A	Tank, Storage	SCI
93	1	TBD	"O" Ring	
94	1	TBD	"O" Ring	
95	1	1811-141-07	Eager-Pak Assy Pressure Rel N,	Conax Corp.
96	48	20097-L-94-C-6-B	Soc Hd Cap SCR 4-40 x .375 lg.	Unbrako
97				
98	1	1520	Elbow, 1/8 NPT to .170 barb	ADI, Numatic Engineering 213-666-5050
99	3	1503	Fitting, Single 10-32 to .170 barb	"
100	1	1511	Cross 10-32 to .170 barb	"
101	8	1408	Clamp, Hose ¼ Steel Crimp	"
102	10 ft	1381	Tubing, .159 ID Polyurethane	"
103	8	6541K38	Hose Clamp 2 Ear Type	MC/MS/CAR, p.55 Cat 95
104	1	6541K67	Clamp Pinchers	"

Item No.	Qty Rqd	Part or ID No.	Nomenclature or Description	Data: Spec., Size, Standard Supplier, etc.
105	1	351018	Solenoid, Valve 1/4 Orifice	KIP, Inc., ISI West, 541-4373
106	1	IMT34	Piston Actuator 1 amp, 1 watt	ICI Aerosapce
107	1	DP103	Transducer, Pressure	Validyne, Elotek, Laguna Hills 830-4856
108	1	15130	Manifold, Vent N/O	
109	2 ft.	5108K56	Tubing, Polyurethane 3/8 ID x ½ OD	MCMAST/CR, P.5 Cat 95
110				
111	1	15131	Piston	
112	1	15132	Housing, Pyro	
113	REF	15133	Assy Vent Manifold	All parts called out on this P/L
114	2	L-34-175	Cable Tie 3/16 to 10.0"	Weckesser, H.W. Eckhardt 714-891-4431
115	1	15134	Housing, Vent	
116	1	15135	Pin, Shear	
117	2	AS568-10	"O" Ring, .375 OD .250 ID	Fluorocarbon

Item No.	Qty Rqd	Part or ID No.	Nomenclature or Description	Data: Spec., Size, Standard Supplier, etc.
118	2	AS568-017	"O" Ring, .812 OD .687 ID	"
119	1	5375K36	Tee 1/4 NPT to 3/8 ID Tube	MC/C, p. 50
120				
121	3	5372K17	1/4 NPT to 3/8 ID NPT Male to Tube	"
122	1	PMC 460A	Encoder	Loral
123	4	NNS-52	Spring, plunger	Vlier
124	2	LC-035C-4	Comp. Press	Lee

APPENDIX C

RIMS CODE LISTING

```
C***************************************************************
C                          RIMS                                *
C***************************************************************
C   PROGRAM TO CALCULATE FORCES, MOMENTS AND DEFORMATIONS IN    *
C   RIM SUPPORT OF ON-AXIS/OFF-AXIS PARABOLIC SOLAR REFLECTOR   *
C***************************************************************
C
C************************************************************
      DIMENSION YY1(10001),TTS(10001),TTT(10001),FFX(10001),
     *  FFY(10001),FFS(10001),FFT(10001),FFB(10001),BMN(10001)
C
C   INPUT DATA
C
      DATA F1/0.697/
      DATA BETA/40.0/
      DATA RIA/0.0/
      DATA RJA/0.0/
      DATA SK/10.0/
      DATA CK/0./
      DATA S1/0.0/
C
      DATA N/10000/
      DATA NPRINT/20/
C
c use read statements here
c
      read(*,*)iflg
      if(iflg .eq. 0) goto456
      read(*,*)vf,vb,vbeta,vr,vt,ve,vg,vk,vp,vs
      vi = 3.1416*vr*vr*vr*vt
      va = 3.1416*( vr*vr- (vr-vt)*(vr-vt) )
      f1 = vf/vb
      beta = vbeta
      ria = vi/(va*vb*vb)
      rja =ve*vi/(vg*va*vb*vb)
      sk = vk*vb*vb*vb/(ve*vi)
      ck = vp*vb*vb*vb*vb/(ve*vi)
      s1 = vs/vb
      goto 457
456   read(*,*)f1,beta,ria,rja,sk,ck,s1
457   WRITE(6,1) F1,BETA,RIA,RJA,SK,CK,S1
  1   FORMAT(6X,'F/B=',F6.3,'  BETA=',F6.3,' DEG  (I/AB2)=',F6.3,
     *'  (SEI/GAB2)=',F6.3/10X,'  (KB3/EI)=',F9.3,5X,'(PB4/EI)='
     *,F6.3,5X,'(S/B)=',F6.3/)
C
C   INITIALIZE
C
      STEP1=2.0/N
      KPRINT=N/NPRINT
      BETAR=BETA*3.14159/180.
      SB=SIN(BETAR)
      CB=COS(BETAR)
      TB=SB/CB
C
```

```
      WRITE(6,2)
    2 FORMAT(2X,' Y/B    Z/B     R/B     TR/PB   TC/PB ',
     *        '  TZ/PB   TX/PB   TY/PB   TN/PB'/)
C
      ICOUNT=0
      FFX(1)=0.0
      FFY(1)=0.0
      FFB(1)=0.0
      D1=0.0
      D2=0.0
      D3=0.0
      D4=0.0
      D5=0.0
      D6=0.0
      D7=0.0
      D8=0.0
      D9=0.0
      D10=0.0
      D11=0.0
      AD5=0.0
      AD6=0.0
      AD7=0.0
      AD9=0.0
      AD10=0.0
C
C   BEGIN CALCULATIONS
C
      DO 100 I=1,N+1
      IF(I.EQ.1) GOTO 25
      ICOUNT=ICOUNT+1
   25 Y1=-1.0+(I-1)*STEP1
      YY1(I)=Y1
      Z1=Y1*SB+F1*TB*TB+CB*CB/(4*F1)
      R1=2*SQRT(F1*Z1)
C
C   MEMBRANE TENSILE FORCES
C
      G1=1.-Y1*Y1*SB*SB
      G2=(1.-Y1*Y1)*SB*SB
C       IN CYLINDRICAL COORDINATES OF PARENT PARABOLOID
      TTR=-(F1*Y1*SB+CB*CB/2)*SQRT(F1/(Z1*G1))
      TTC=-F1*(2*F1/R1+R1/F1)*(G2/G1)**0.5
      TTZ=0.5*TTR*R1/F1
C       IN RIM COORDINATES
      SA=0.5*CB*SQRT((1.0-Y1*Y1)/(F1*Z1))
      CA=SQRT(1.0-SA*SA)
      E1D=Y1*CB+2*F1*TB
      TTX=TTR*SA+TTC*CA
      TTY=TTR*CA*CB-TTC*SA*CB+TTZ*SB
      IF(E1D.GE.0.0) GOTO 65
      TTY=-TTY
   65 TTN=-TTR*CA*SB+TTC*SA*SB+TTZ*CB
C       TANGENTIAL AND NORMAL TO RIM
      CG=Y1*CB/SQRT(G1)
```

```
      SG=SQRT(1.-CG*CG)
      TTS(I)=TTY*CG+TTX*SG
      TTT(I)=TTY*SG-TTX*CG
C
C   INTERNAL FORCES AND MOMENTS
C
C        ARC ELEMENT FOR SIMPSON INTEGRATION
      IF(I.EQ.1.OR.I.EQ.(N+1)) GOTO 20
      DL1=SQRT(G1/(1.-Y1*Y1))*STEP1
      GOTO 30
  20  DL1=SQRT(2*STEP1*CB*CB+STEP1*STEP1*SB*SB)
  30  CONTINUE
C       STORE INTEGRAND VALUES FROM PREVIOUS STEP
      IF(I.EQ.1) GOTO 35
      BFFX=AFFX
      BFFY=AFFY
      BFFB=AFFB
      BD1=AD1
      BD2=AD2
      BD3=AD3
      BD4=AD4
      BD5=AD5
      BD6=AD6
      BD7=AD7
      BD8=AD8
      BD9=AD9
      BD10=AD10
      BD11=AD11
  35  CONTINUE
C        CALCULATE INTEGRAND
      AFFX=-TTX*DL1
      AFFY=-TTY*DL1
      AFFB=((1.+Y1+S1)*TTX-SQRT(1.-Y1*Y1)*CB*TTY)*DL1
      AD1=DL1
      AD2=(1.0-Y1*Y1)*DL1/G1
      AD3=(1.+Y1+S1*(1.+CG))*(1.+Y1+S1*(1.+CG))*DL1
      AD4=Y1*Y1*CB*CB*DL1/G1
      AD8=SQRT(1.0-Y1*Y1)*DL1
      AD11=(1.+Y1+S1*(1.+CG))*DL1
      IF(I.EQ.1) GOTO 40
      FFX(I)=FFX(I-1)+0.5*(AFFX+BFFX)
      FFY(I)=FFY(I-1)+0.5*(AFFY+BFFY)
      FFB(I)=FFB(I-1)+0.5*(AFFB+BFFB)
      BMN(I)=FFB(I)+(1.+Y1+S1*(1.+CG))*FFX(I)-SQRT(1.-Y1*Y1)*FFY(I)
     &   *(CB+S1/SQRT(G1))
C
      H1=BMN(I)
      H2=(RIA-RJA)*SG*CG*FFY(I)-(RIA*CG*CG+RJA*SG*SG)*FFX(I)
      H3=(RIA-RJA)*SG*CG*FFX(I)-(RIA*SG*SG+RJA*CG*CG)*FFY(I)
      AD5=H1*DL1
      AD6=(1.+Y1+S1*(1.+CG))*H1*DL1
      AD7=H2*DL1
      AD9=SQRT(1.-Y1*Y1)*H1*DL1
      AD10=H3*DL1
```

```
      D1=D1+0.5*(AD1+BD1)
      D2=D2+0.5*(AD2+BD2)
      D3=D3+0.5*(AD3+BD3)
      D4=D4+0.5*(AD4+BD4)
      D5=D5+0.5*(AD5+BD5)
      D6=D6+0.5*(AD6+BD6)
      D7=D7+0.5*(AD7+BD7)
      D8=D8+0.5*(AD8+BD8)
      D9=D9+0.5*(AD9+BD9)
      D10=D10+0.5*(AD10+BD10)
      D11=D11+0.5*(AD11+BD11)
  40  CONTINUE
C
C   PRINT RESULTS
C
      IF(I.EQ.1) GOTO 15
      IF(ICOUNT.LT.KPRINT) GOTO 100
      ICOUNT=0
  15  WRITE(6,3) Y1,Z1,R1,TTR,TTC,TTZ,TTX,TTY,TTN
  3   FORMAT(1X,F6.3,8(1X,F7.4))
 100  CONTINUE
C
C   REACTIONS AT LOW AND HIGH ENDS
C
      DD=(D3+RIA*D4+RJA*D2)*D1-D11*D11
      FFL=((D6-D7)*D1-D5*D11)/DD
      IF(SK.GT.0.0) GOTO 70
      PP=0.0
      GOTO 75
   70 DDD=(D1*D1-D1*D3/2-D8*D8/2)*CB*CB+(RIA*D2+RJA*D4)/2+1/SK
      PP=((D5*D8-D1*D9)*CB-D1*D10)/DDD
   75 BML=D5/D1-FFL*D11/D1+PP*CB*D8/(2*D1)
      FFH=-FFL+FFX(N+1)
      BMH=-BML+2*(1.+S1)*FFH+FFB(N+1)
      WRITE(6,5) FFL,FFH,BML,BMH,PP
  5   FORMAT(/5X,'FFL=',F7.4,'  FFH=',F7.4,'  BML=',F7.4,
     *      '  BMH=',F7.4,'  PP=',F7.4)
C
      WRITE(6,4)
  4   FORMAT(/2X,'Y/B     TS/PB   TT/PB  FX/PB2  FY/PB2 ',
     *        ' FS/PB2  FT/PB2  BM/PB3 '/)
C
      ICOUNT=0
C
C   REACTION ADJUSTMENT TO INTERNAL FORCES AND MOMENTS
C
      DO 200 I=1,N+1
      G1=1.-YY1(I)*YY1(I)*SB*SB
      CG=YY1(I)*CB/SQRT(G1)
      SG=SQRT(1.-CG*CG)
      FFX(I)=FFX(I)-FFL
      FFY(I)=FFY(I)-PP/2
      BMN(I)=BMN(I)-BML-(1.+YY1(I)+S1*(1.+CG))*FFL+
     &        SQRT(1.-YY1(I)*YY1(I))*CB*PP/2
```

```
      FFS(I)=FFY(I)*CG+FFX(I)*SG
      FFT(I)=FFY(I)*SG-FFX(I)*CG
C
C   PRINT RESULTS
C
      IF(I.EQ.1) GOTO 45
      ICOUNT=ICOUNT+1
      IF(ICOUNT.LT.KPRINT) GOTO 200
      ICOUNT=0
 45   WRITE(6,6) YY1(I),TTS(I),TTT(I),FFX(I),FFY(I),FFS(I),
     *   FFT(I),BMN(I)
 6    FORMAT(1X,F6.3,7(1X,F7.4))
 200  CONTINUE
C
C   DEFORMATIONS CALCULATION
C
      WRITE(6,7)
 7    FORMAT(/2X,' Y/B    PSI+FI     PSI-FI    FI      (XO-X1)/B
     *   (YO-Y1)/B '/)
C
      ICOUNT=0
      PSIPF=0.0
      PSIMF=0.0
      U=0.0
      V=0.0
      DO 300 I=1,N+1
      IF(I.EQ.1) GOTO 85
      ICOUNT=ICOUNT+1
 85   Y1=-1.0+(I-1)*STEP1
      G1=1.-Y1*Y1*SB*SB
c
      arg=-y1*cb/sqrt(g1)
      if(arg .eq. 1.0)then
        phi = 0.0
      else
      PHI=ACOS(-Y1*CB/SQRT(G1))
      endif
C       ARC ELEMENT FOR SIMPSON INTEGRATION
      IF(I.EQ.1.OR.I.EQ.(N+1)) GOTO 80
      DL1=SQRT(G1/(1.-Y1*Y1))*STEP1
      GOTO 90
 80   DL1=SQRT(2*STEP1*CB*CB+STEP1*STEP1*SB*SB)
 90   CONTINUE
C      STORE INTEGRAND VALUES FROM PREVIOUS STEP
      IF(I.EQ.1) GOTO 95
      BPSIPF=APSIPF
      BPSIMF=APSIMF
      BU=AU
      BV=AV
 95   CONTINUE
C       CALCULATE INTEGRAND
      C=1.0+CK*RIA*FFT(I)
      APSIPF=(CB*(1.+C)/(G1**1.5)-CK*BMN(I)/C)*DL1/C
      APSIMF=(CB*(1.-C)/(G1**1.5)-CK*BMN(I)/C)*DL1/C
```

```
      IF(I.EQ.1) GOTO 96
      PSIPF=PSIPF+0.5*(APSIPF+BPSIPF)
      PSIMF=PSIMF+0.5*(APSIMF+BPSIMF)
   96 CONTINUE
      AU=(-2*SIN(PSIPF/2)*SIN(PSIMF/2)-CK*RIA*FFT(I)*COS(PHI))
     *    *DL1/C
      AV=(2*COS(PSIPF/2)*SIN(PSIMF/2)-CK*RIA*FFT(I)*SIN(PHI))
     *    *DL1/C
      IF(I.EQ.1) GOTO 97
      U=U+0.5*(AU+BU)
      V=V+0.5*(AV+BV)
   97 CONTINUE
C
C    PRINT RESULTS
C
      IF(I.EQ.1) GOTO 86
      IF(ICOUNT.LT.KPRINT) GOTO 300
      ICOUNT=0
   86 WRITE(6,8) Y1,PSIPF,PSIMF,PHI,U,V
    8 FORMAT(1X,F6.3,5(4X,F8.5))
  300 CONTINUE
      END
```