

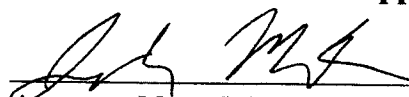


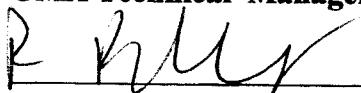
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GRAVITY PROBE B RELATIVITY MISSION

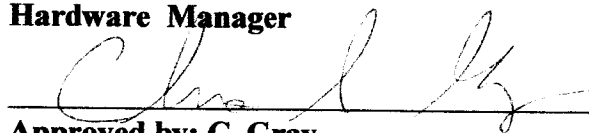
GMA VALVE LEAKAGE MITIGATION PLAN

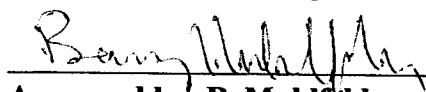
S0701 Rev B


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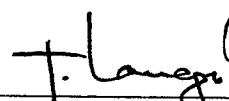

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ITAR Assessment Performed  2/19/03
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Note: Section 'D.10' is
ITAR controlled and
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N O T I C E

GMA VALVE LEAKAGE MITIGATION PLAN

S0701 Revision – (never issued)

S0701 Revision A (never issued)

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3/04/03

REVISION RECORD

Rev	Date	Comments
Rev A	12/12/02	Based on baseline valve leakage data

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A Overview

The Gravity Probe B Gas Management Assembly (GMA) has been documented to have internal valve leakage rates that are not within tolerance and which could, without mitigation, impact mission success. This noncompliance has been detailed in a Discrepancy Report, DR 439. A tiger team of NASA, Lockheed, and Stanford personnel (with Moog support) was assembled to investigate the program implications for GMA latch valves with out of tolerance leakage rates. The team determined that the effect of higher leakage rates can be mitigated without long-term program delays. With mitigation, the GMA will meet all mission needs.

The purpose of this document is to outline the known impact of the GMA issues and to define a Mitigation Plan that will close out the DR. PCB570 has been approved to support the changes required by this Mitigation Plan. This PCB and additional supporting documentation for the plan is included in the Appendices.

No performance observed thus far would in any way impact successful GMA operation on orbit. Rather, the concern is the time between GMA servicing and launch. Valve leakage potentially impacts the system during this ground hold time.

Primary concerns and mitigation issues are as follows:

- Loss of Pressure of Regulator Lockup
Possible regulator damage from launch pyroshock
- Cryo Contamination
Air leakage into spinup lines
Air leakage into GMA
- Helium Gas Leakage into Probe
Increased temperature Rate of Rise of Dewar Main Bath
Increased Guard Tank boil off rate

Secondary concerns and mitigation issues are:

- Loss of Helium from GMA Storage Tanks
- Possible overpressures

This Mitigation Plan Document is arranged as follows:

- Section B defines and introduces the GMA issues of concern that are addressed in the plan.
- Section C provides details of the plan including a description of GMA mitigation operations, a ground and launch operations timeline, and an evaluation of specific program risks after mitigation.
- Section D includes supporting documentation of tests and analyses performed to evaluate GMA performance and to determine mission impact. Details of new flight hardware –a vent line extension manifold– and supporting GSE are also included in this section. Section E addresses range safety issues related to GMA operations.
- Addition supporting documents are included in the Appendices.

B Leakage Impacts

B.1 Latch Valve leakage

Results of the measured leakage rate of the 30 latching solenoid valves in the GMA have been documented and can be found in the Moog GMA Acceptance test (**D.1**), Stanford GMA Acceptance Test (**D.2**), pre-Thermal Vac Test and post-Thermal Vac Test. The data show many valves do not meet mission specifications.

An alternate method of measuring the effective valve leak rates of the GMA pressure zones was recently completed (Rate of Rise Test, **see D.9**). This test recorded GMA pressure sensors values over periods of time with a known starting Helium pressure in each volume. External GSE pressure sensors augmented the GMA sensors. The Rate of Rise Test provides a more accurate measure of the pressure changes within the volumes of each zone in the GMA and is particularly useful to measure the high leak rates of the GMA valves. The current test data available include results with the GMA in the ground state (all outlet solenoid valves closed) and in launch state (only one valve in each pair closed).

Mitigation will not alter the valve leak rates but will limit the effects. The addition of a vent line extension manifold will provide monitoring and control of the leakage effects while the S/V is in VAFB building 1610 and on the MST. Mitigation will be effective even in the event of significant changes in valve leak rates.

B.2 Regulator Lockup

Due to the launch pyroshock environment, it is required to keep a pressure of between 100 and 500 psia (300 psia nominal) on the downstream side of all 4 GMA regulators. This keeps the regulators *locked up* with sufficient force to survive the launch environment. Regulator lock-up is currently scheduled to occur two more times before launch. The next regulator lock-up will occur prior the S/V shipment to VAFB. The second regulator lock-up will occur just prior to solar panel installation in B1610. Regulator lock-up is performed per Stanford procedure P0960. This procedure requires GSE already fabricated plus ECU time of ~ 4 hours. GMA valve leakage can (without mitigation) lead to a loss of pressure to below 100 psi or could alternately lead to an overpressure of greater than 500 psi.

The Mitigation Plan establishes that certain GMA pressures will be monitored in B1610 and on the MST up to 24 hours prior to launch. This will be accomplished with the aid of the vent line extension manifold and GSE detailed in section **D**.

Instrumentation from the GMA Zones IV and V transducers will be railed (over ranged) when the regulators are locked-up. Pressure data from a GSE transducer will be measured and verified to meet launch requirements. Servicing the GMA, if needed, will re-pressurize Zone V to a nominal 300 psi. Servicing of the GMA is scheduled to occur at Guard Tank fills. This frequency is sufficient to ensure proper regulator lock up mitigation even in the event of significant changes in valve leak rates.

B.3 Cryo Contamination

One quad of valves vents the GMA and is exposed to the outside elements. Once in orbit, this provides a vent to space; on the ground, this is a vent to air. If these valves leak, then air may infiltrate the GMA and could migrate into the spinup lines, posing a risk of cryo contamination. This Mitigation Plan calls for Zone V to be monitored and pressurized to 300 psi with Helium (**Section C2 Fig. 1**). This pressure would have to bleed from 300 psia to below 15 psia to allow contamination. Based on current leak rate data, and on the servicing operations discussed above, this is highly unlikely even in the event of significant changes in valve leak rates.

B.4 Main Bath Temperature Rise

T003 requires the dewar to have a hold time of 90 days between the time it is last serviced up until launch. A thermal analysis of the Dewar Main Bath heat rates, detailed in section **D.6**, indicates that Helium leaking into the probe from the GMA can increase the heat rate into the main tank, and consequently, decrease the duration to go from 1.65 K to 1.85 K to below 90 days. Therefore, as part of this Mitigation Plan, Top Hat Manual Valve opening and Regulator Lock-up operations have been moved to the latest possible times in the program schedule, i.e. just prior to FEE closure and just prior to Solar Panel integration, respectively. *With this schedule*, if GMA leakage rates remain similar to the Rate of Rise test data, then the time to reach 1.85 K degrades by 9 days to 81 days. While not meeting the 90 day Dewar requirement, this would have no impact on launch operations. If the leakage rates increase markedly to the 10^{-3} sccs or 10^{-4} sccs levels considered in the model, then there is still schedule margin (considering the time between relevant GMA operations and vehicle move to the MST) to accommodate multiple launch attempts and scrubs before reaching 1.85 K main bath temperature. Therefore, this Mitigation Plan is robust with regard to main bath temperature rise issues over the range of foreseeable leakage rates.

Review of the 90 day dewar main bath temperature rise requirement is recommended.

B.5 Guard Tank Boil-Off

An analysis of the effect of leakage of Helium gas into the Probe on Guard Tank boil-off rate is detailed in section **D.7**. The analysis indicates that if probe residual pressures become significant, then Guard Tank boil off rates may increase to levels that would require more frequent servicing than the original baseline 5 day interval. If GMA leak rates remain similar to the Rate of Rise test data (included in this document) probe pressure will remain negligible for at least 55 days after vehicle move to the MST (79 days past regulator lockup) and there will be no impact on Guard tank boil off. If leak rates increase markedly such as to the 10^{-3} sccs or 10^{-4} sccs rates considered in section **C.6**, then a more frequent servicing schedule will mitigate this scenario. No issues have been identified that would prohibit more frequent servicing. Further, scenarios have been identified, such as 2nd shift operations, that would mitigate any possible schedule impacts. Therefore, this Mitigation Plan is robust with regard to Guard Tank boil off issues over the range of foreseeable scenarios.

B.6 Ground Service Operations.

The nine (9) ground service operations procedures planned for the GMA are as follows:

- P0960 Rev - GDS Operating Procedure at VAFB
- P0961 Rev - Internal Leakage Check of the Flight GMA at VAFB
- P0962 Rev - GMA Sleep Procedure at VAFB
- P0968 Rev - Bleed Down of the GMA High Pressure at VAFB
- P0972 Rev - Scrub Launch Recovery Procedure for the GMA
- P0973 Rev - GMA Vent Extension Service Procedure
- P0974 Rev - GMA Rate of Pressure Rise Test Procedure at VAFB
- P0976 Rev - GMA Latch Valve Launch Configuration
- P0977 Rev - Open Gas Inlet Manual (Top Hat) Valves

GMA mitigation includes procedures P0972, P0973, P0974 and P0976. P0972 is a contingency operation. Assuming nominal boil off rates, the guard tank requires servicing every 5 days. Based on test data, servicing of GMA zone 5 at similar intervals will meet requirements with margin.

B.7 Launch Configuration

Depending on valve leakage rates, a reconfiguration of the GMA latch valve launch positions can be manually reconfigured using an existing C-STOL script. This will enable the optimal launch configuration to be set even in the event of significant changes in the latest measured leak rates. This option would require ECU time estimated at ~ 1 hour and have no impact on the flight software. Time is included in the VAFB operations schedule to accommodate this task.

B.8 Launch Scrub Recovery Plan

In the event of a second scrubbed launch it might be required to re-charge the Helium supply in zone V to ensure regulator lock-up. This will be accomplished with the aid of the reconnected vent line extension manifold and GSE detailed in section **D**. This servicing of GMA zone 5 at Guard Tank fill intervals will meet lock-up requirements with margin.

C Mitigation Plan

C.1 GMA Mitigation Philosophy

The key aspects to the mitigation plan follow:

C.1.1 Modification of GMA Hardware

The non-propulsive vent outlet manifold has been redesigned to facilitate a late GMA service capability. (see section **D.10**, **D.11**) The vent extension modification consists of two assemblies.

- 1) The vent extension manifold extends the non-propulsive vent. The manifold extension is routed from the GMA pallet and terminated on the space vehicle truss to incorporate access from a launch vehicle service port. This manifold is approximately 3 feet long and enables access through a launch vehicle fairing door. The outlet of the vent extension incorporates the same design as the GMA pallet configuration. The non-propulsive vent is maintained using the identical 1/4"Ø VCR Tee used on the pallet.
- 2) The second assembly is a GSE manifold that consists of valves and a pressure transducer to monitor zone 5 through the vent outlet. Servicing at the MST using the vent extension supports a maintained regulator lock-up pressure, the monitoring of GMA manifold pressure in zone 5 with an Endevco pressure transducer (GSE), and eliminates the risk for cryo contamination through the vent outlet while installed.

C.1.2 GMA Operations Optimized within the Current Program Baseline Schedule

GMA operations have been strategically placed into the schedule to reduce risk and support the greatest hold times for success.

- Final Rate of Rise evaluation to secure an acceptable launch state in B1610 at VAFB.
- Gyro and P1A inlet manual valves opened as late as possible to minimize helium leakage into the probe.
- Regulator lock-up in B1610 is orchestrated with solar panel installations to ensure that the last solar array to be installed is the array that effects GMA servicing.
- Removal of vent extension GSE (300 psia cover gas in the vent quad) 24 hours before a launch attempt (minimizes regulator lock-up bleed down and probe cryo contamination)
- GMA latch valves configured to ground state (all valves closed except for the vent outlet quad) from T-62 days to T-12 hours (minimizes helium leaking into the probe)

- GMA latch valves configured to launch state at T-12 hours using procedure P0976 and the null.prc C-STOL script.

C.1.3 Gas Leakage Through GMA Outlet Quads into the Probe Optimized

- Launch configuration is evaluated early using the Rate of Rise procedure (P0974) at VAFB in B1610 (T-66 days)
- Once launch configuration is determined, launch configuration valves will remain closed until flight. (minimizes change of latch valve performance due to valve cycling)

C.1.4 Guard Tank Servicing

- Multiple guard tank service intervals can be supported at VAFB (5,4,3,etc. days) by facilitating service operations during the 2nd or 3rd shift
- S/V transported from B1610 to the MST is the only limiting constraint

C.1.5 Scrubbed Launch Recovery

- All GMA latch valves closed as soon as possible
- GSE reconnected to the vent extension manifold, the flexible service manifold is reconnected to the vent extension GSE and the vent extension pump cart manifold.
- Open all the vent quad latch valves and the appropriate “normally open” outlet quad valves to remove any gas trapped in zone 6. This also facilitates the evacuation of zone 5 and the vent manifold to protect the GMA from cryo contamination.
- Close the up stream normally open outlet latch valves after zone 6 has been evacuated
- Re-pressurize zone 5 and the vent manifold to 300 psia helium using the vent extension pump cart and ballast bottle
- T-24 hours, close the vent quad latch valves (V27, V28, V29, and V30), remove vent extension GSE
- T-12 hour, configure latch valves for flight using ECU (P0976)

C.2 Mitigation Operations

The following operations minimize helium from going into the probe, maximize regulator lock-up “hold” time, and protect the probe from potential cyro contamination.

The primary operation supporting the three concerns is a Rate of Rise evaluation. The Rate of Rise procedure (P0974) verifies the GMA latch valve leakage in volumes instead of each individual valve. This method is most useful because it confirms the health of the GMA as a system over time. This approach also supports the two configurations the GMA will see prior to launch. We call the two configurations *ground state* and *launch state*.

Rate of Rise data is monitored using pressure transducers in all GMA zones except zones 4 and 6. (See schematic figure 1).

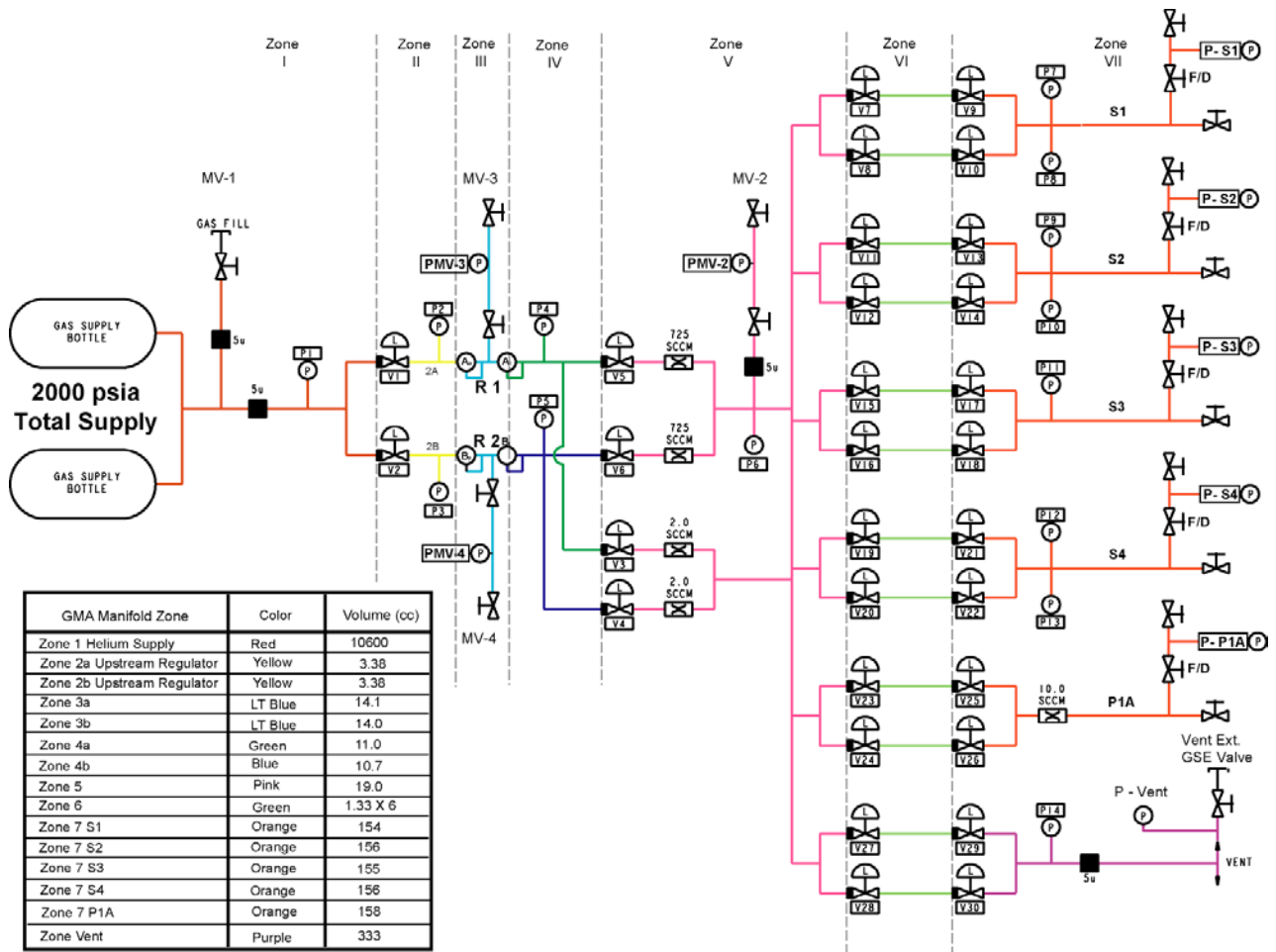


Figure 1

During the Rate of Rise evaluation, the GMA manifold has both pairs of regulators locked-up with 300 psia helium (zones 2, 3, and 4). Zone 5 and the vent manifold are also at 300 psia to support regulator lock-up from bleeding down through the vent outlet and the potential for air contamination from the vent outlet valve quad.

The Rate of Rise evaluation procedure is scheduled for post thermal-vac (if thermal-vac penalty tests is required) in LMMS B156 and at VAFB in B1610. Each Rate of Rise evaluation takes 1 day for GSE set-up and 5 days to take data in various configurations. The first GMA valve configuration to evaluate is the launch state.

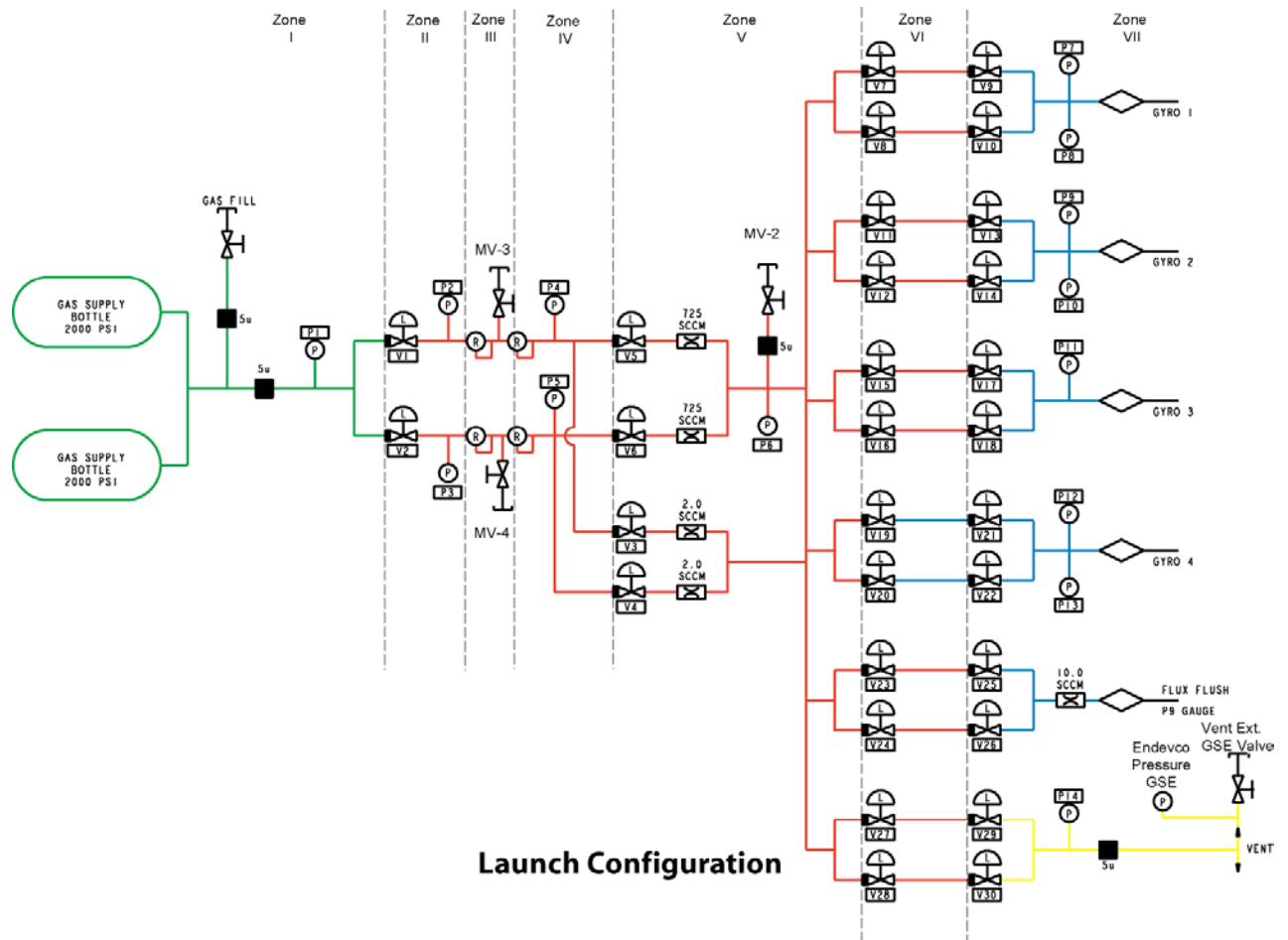
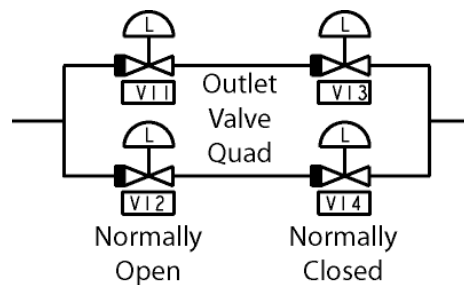


Figure 2

Launch configuration is evaluated first, due to the dynamics of the latch valves. Past performance of the latch valves has proven some “personalities” within latch valves behaviors (see section C.2 Moog Latch Valve FAR and C.8 Latch Valve Leakage for valve leakage history). Most valves are consistent, but some have intermittent performance. We are not overly concerned with this issue since valve cycling has demonstrated that a valves performance can improve from cycle to cycle. We also have the option to swap the normally open valves in an outlet valve quad with the normally closed valves.



C.2.1 Launch Configuration

Launch state configures the outlet quad valves (S1, S2, S3, S4, P1A, and Vent) to minimize leakage. Launch configuration is determined in B1610 at VAFB 62 days prior to launch by Rate of Rise evaluations.

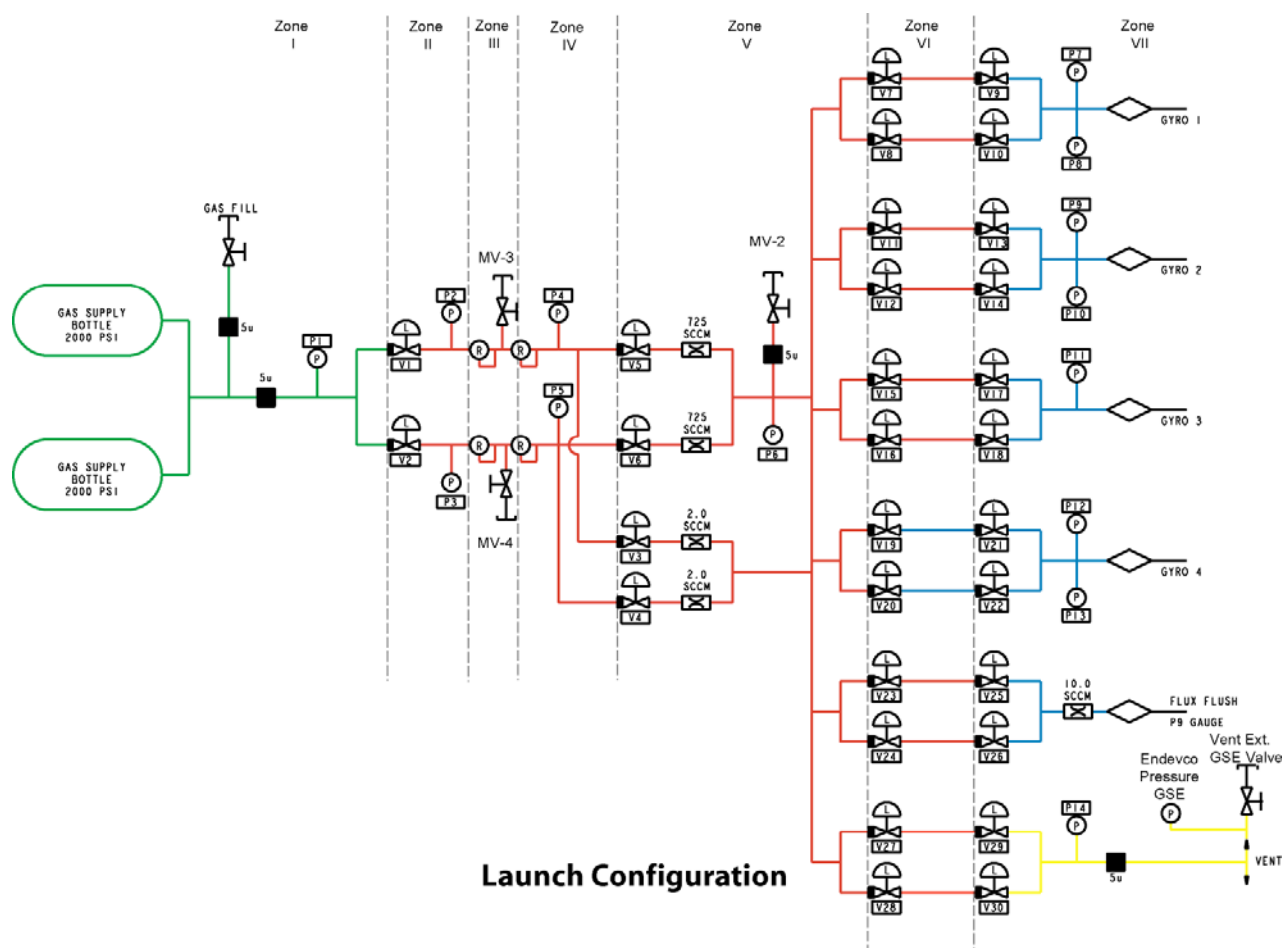


Figure 3

A launch configuration Rate of Rise evaluation can optimize the GMA outlet valves to minimize leakage into the probe. From a past Rate of Rise evaluation, it was demonstrated that a launch configuration scenario could be evaluated for an unacceptable launch configuration in as little as 2 hours. Launch configuration for an acceptable leakage could be determined ~ 4 hours. We feel ~12 hours of data is the minimum for a launch configuration baseline based on previous Rate of Rise evaluations. Within this time frame, many launch configuration scenarios can be monitored and evaluated. It is anticipated that we would *not* have to verify multiple launch configurations, but as stated previously, sometimes a latch valve takes on a personality that gives us a higher leak rate than what is acceptable ($> 1 \times 10^{-4}$ sccs). When this occurs, cycling the valve from close to open and back to close can improve the valve performance. If the valve performance does not improve after multiple valve cycling, then we would select the alternate valves in the outlet valve quad (swap the normally open with the normally closed). Once we have a launch configuration (two normally open valves which could be either the up stream or down stream valves in a quad), we close the normally open valves. We will *not* open the two normally closed valves until flight. This protects us from potential valve personality problems and gives us a known leakage rate of

helium leaking into the probe, which will be determined from the ground configuration Rate of Rise evaluation.

C.2.2 Ground Configuration

Ground configuration Rate of Rise data will be evaluated last. This is useful due to the fact that the worst leakage data first comes from the GMA's launch configuration. To repeat, the worst scenario of latch valve leakage is in the launch state that was previously optimized. So, ground configuration presents a better 'hold' time, due to all the latch valves in a closed state (which further minimizes leakage into the probe) and the vent quad is opened to the 300 psia helium ballast supply (which protects regulator lock-up). The data from this phase of the Rate of Rise evaluation could be passively collected for several days or even weeks with the data logger attached to the vent manifold. GMA pressure transducer data from zone 2 and 7 can be evaluated while functional tests are being run on the space vehicle (see schedule). This data quantifies helium leakage rate into the probe.

Ground configuration (figure 4) has all the latch valves closed except the vent quad. A ground configuration for the latch valves is necessary prior to opening the Gas Inlet Manual Valves at the top hat. This starts to minimize gas leaking into the probe inlets. Ground configuration also has 300 psia in the manifold in zones 2, 3, 4, 5 and the vent as shown in RED in figure 4. This supports regulator lock-up and protects the GMA from potential air contamination through the vent outlet.

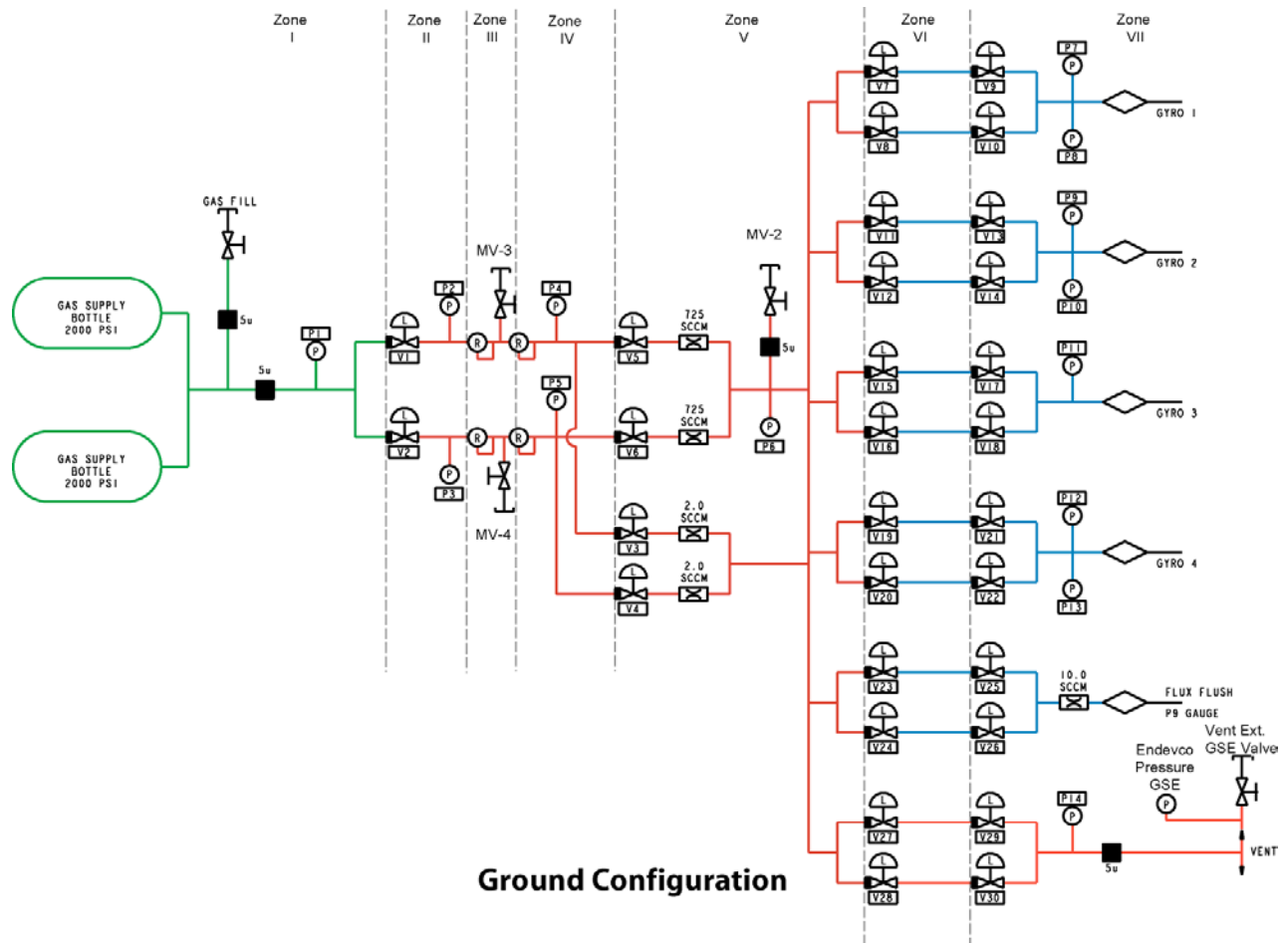


Figure 4

Ground configuration will be the only configuration used for the outlet quads (S1, S2, S3, S4, and P1A) up to T – 12hrs. before launch.

For the following event, no latch valve cycling is required:

- “Flight” helium gas fill and gas verification T-59 days (P0960)
- Gyro Inlet Manual Valves Opened (top hat) T-42 days (P0977)

During regulator lock-up operations, the outlet latch valves remain closed. The supply latch valves (V1 – V6 and vent quad valves V27-V30) will need to be cycled in order to perform the final regulator lock-up (replenish the GMA zones 2, 3, 4, 5, and vent with 300 psia). This operation is achieved using the GDS and P0960. This will occur T-26 days before launch. We have performed this operation several times and have a high confidence with the process. This operation obviously requires the Flight ECU and a POD to operate latch valves. We have a successful operational procedure for operating the GMA with a POD by placing a Test Director at the S/V. The Test Director goes through the appropriate procedure and instructs the POD operator (who also has a copy of the procedure) which valve operations to perform. Quality Assurance is also checking every valve command to be performed before the POD operator executes a change in valve’s state. After the regulator lock-up has been replenished, the GMA goes back into ground configuration. We will begin a routine we call “Vent Line

Service” which is P0973. The “Vent Line Service” starts immediately following the final regulator lock-up. The GSE required for the Vent Line Service is a portable turbo pump cart with a helium ballast cylinder and manifold (see diagrams in appendix **D.11**). This system is connected to the vent extension manifold using a flexible 1/4"Ø stainless steel tubing. The flexible tubing is connected to the vent extension GSE outlet port in B1610 and MST. Once the connection to the vent extension GSE outlet port has been made, we will not disconnect at the vent extension until T-1 day. This retires two potential concerns, stressing the GSE hardware connected to the vent extension manifold and capturing the VCR gasket while demating the flex hose. This starts at T-24 days which is the first scheduled guard tank service we will have with the GMA vent extension GSE connected. The Vent Line Service occurs at every guard tank service interval required (~ 5 days). See the timeline for details regarding Vent Line Service intervals.

Stanford will remove the flexible 1/4"Ø stainless hose from the vent pump cart at T-7 days so the MST level 6 can be raised to enable the “Sunshade Cover Removal” procedure. Stanford will reconnect the vent extension service hose to the vent service pump cart at T-5 days. Vent Line Service resumes at T-4 days with the scheduled guard tank servicing.

At T-1 day to launch, the following activities occur (per P0973):

- Verify Zone 5 manifold pressure with data logger and laptop PC
- Close vent outlet quad latch valves (V27, V28, V29, and V30) via the ECU (P0973)
- Vent the GMA “Vent Extension Manifold” to atmospheric pressure of helium.
- Disconnect the vent cart service flexible hose from the vent extension GSE
- Remove the vent extension GSE
- Remove the 1/4" VCR cap from the non propulsive vent tee
- Secure the launch vehicle faring door

At T-12 hrs to launch, configure GMA (latch valves) to pre-determined launch configuration:

- Run P0976 via a POD to configure latch valves for flight
- Use C-STOL script Null.prc per the above procedure

C.2.3 Launch Scrub Recovery (if required)

The GMA latch valves are reconfigured to ground state with the ECU and the POD, as soon as possible.

As soon as the MST is moved back to the launch pad:

- vent service GSE is reconnected
- vent extension manifold is pumped out
- vent quad latch valves are opened with the ECU at a POD while continuing to pump on the vent extension manifold
- the appropriate “normally open” outlet quad valves are opened to remove any gas trapped in zone 6
- After the gas in zone 6 has been evacuated, close the “normally open” outlet quad valves

- Close the valve on the pump cart, and pressurize zone 5 and the vent extension manifold to 300 psia

At T-1 day to launch, the following activities occur (per P0973):

- Pressure with data logger and laptop PC
- Close vent outlet quad latch valves (V27, V28, V29, and V30) via the ECU (P0973)
- Vent the GMA "Vent Extension Manifold" to ATM with helium
- Disconnect the vent cart service flexible hose from the vent extension GSE
- Remove the vent extension GSE
- Remove the 1/4" VCR cap from the non propulsive vent tee
- Secure the launch vehicle faring door

At T-12 hrs to launch, configure GMA (latch valves) to pre-determined launch configuration:

- Run P0976 via a POD to configure latch valves for flight
- Use C-STOL script Null.prc per the above procedure

The following tables show the operations for GMA Mitigations:

GMA and SPACE VEHICLE MITIGATION ACTIVITIES

Location	P Doc	Activity	T- (days)	S0701 Ref.	GSE Required	Hrs. to Install GSE	Hrs.to Remove GSE	S/V Config.	Req'd Test Time	Req'd ECU Time	Personnel Required	Req'd QA	Comments / Valve Configuration
B156	N/A	Spin Balance	N/A		N/A	0	0	Spin Table	0	0	N/A	N/A	
	P0968	Bleed-Down	N/A		GDS, Fill Manifold, LD, Off-Pallet F/D Manifold, Vent Service Pump Cart	8	0	Assy. Stand	4 hrs.	2 hrs.	Dave M. Ken /Chris Rick/Gregg	S/U	
	P0XXX	Install Vent Extension Manifold	N/A		GDS, Fill Manifold, LD, Off-Pallet F/D Manifold, Vent Service Pump Cart	8	4 hrs.	Assy. Stand or Tilt Dolly	2 Days	6 hrs.	Dave M. Ken /Chris Rick/Gregg	S/U, LMMS, DCM	
	P0921	Thermal Vac 15.10.1 Penalty Test	N/A		Fill Manifold, LD, Off-Pallet F/D Manifold, Vent Service Pump Cart	8	4 hrs.	Assy. Stand or Tilt Dolly	8 hrs.	6 hrs.	Dave M. Ken /Chris Rick/Gregg	S/U	
	P0971	Rate of Rise Latch Valve Leakage	N/A	B.1, C.2, C.3	Fill Manifold, LD, Off-Pallet F/D Manifold, EGSE (data logger, ect), Vent Service Pump	8	4 hrs.	Assy. Stand or Tilt Dolly	5 Days	4 events 2 hrs.	Dave M. Ken /Chris Rick/Gregg	S/U	
	P0960	Regulator Lock-up	N/A	B.2, C.2, C.3	GDS, Fill Manifold, LD, Off-Pallet F/D Manifold, Vent Service Pump Cart	8	4 hrs.	Assy. Stand or Tilt Dolly	8 hrs.	6 hrs.	Dave M. Ken /Chris Rick/Gregg	S/U, LMMS, DCM	
	N/A	Move GMA GSE To VAFB	N/A		GDS, Fill Manifold, LD, Off-Pallet F/D Manifold, Vent Service Pump Cart	8	0	N/A	N/A	0	Ken /Chris Rick/Gregg	N/A	

S/V Transported to VAFB

S0701 GMA Valve Leakage Mitigation Plan

2/13/2003

Location	P Doc	Activity	T- (days)	S0701 Ref.	GSE Required	Hrs. to Install GSE	Hrs.to Remove GSE	S/V Config.	Req'd Test Time	Req'd ECU Time	Personnel Required	Req'd QA	Comments / Valve Configuration
B1610	P0968	Bleed-Down	67		GDS, Fill Manifold, LD, Off-Pallet F/D Manifold, Vent Service Pump Cart	8	0	Assy. Stand	4 hrs.	2 hrs.	Dave M. Ken /Chris Rick/Gregg	S/U	Install Fill Manifold & Off Pallet F/D Valve GSE
	P0960	Regulator Lock-up	67	B.2,B.6, C.2,C.3	GDS, Fill Manifold, Vent Service Pump Cart	0	8 hrs.	Assy. Stand	4 hrs.	4 hrs.	Dave M. Ken /Chris Rick/Gregg	S/U, LMMS, DCM	Regulator Lockup for Rate of Rise Evaluation
	P0974	Rate of Rise Evaluation - Launch Configuration	66	B.6,B.7, C.2, C.3	Fill Manifold, LD, Off-Pallet F/D Manifold, EGSE (data logger, ect), Vent Service Pump	0	0	Assy. Stand	2 days	2 events @ 2 hrs. ea.	Dave M. Ken /Chris Rick/Gregg	S/U	Launch Configuration
	P0974	Rate of Rise Evaluation - Ground Configuration	64	B.6,B.7, C.2, C.3	Fill Manifold, LD, Off-Pallet F/D Manifold, EGSE (data logger, ect), Vent Service Pump	0	0	Assy. Stand	2 days	2 events @ 2 hrs. ea.	Dave M. Ken /Chris Rick/Gregg	S/U	Ground Configuration
	P0974	Rate of Rise Evaluation - Complete, All Valves Closed	62	B.6,B.7, C.2, C.3	Fill Manifold, LD, Off-Pallet F/D Manifold, EGSE (data logger, ect), Vent Service Pump	0	0	Assy. Stand	4 hrs.	2 events @ 2 hrs. ea.	Dave M. Ken /Chris Rick/Gregg	S/U	Ground Configuration
	P0960	GMA Helium Fill "Flight"	59	B.2,B.6, C.2,C.3	GDS, Fill Manifold, LD, Off-Pallet F/D Manifold, Vent Service Pump Cart	0	0	Assy. Stand	8 hrs.	8 hrs.	Dave M. Ken /Chris Rick/Gregg	S/U, LMMS, DCM	Ground Configuration
	P0977	Gyro Inlet Manual Valves Opened	42	B.6, C.2	GDS, Fill Manifold, LD, Off-Pallet F/D Manifold, Vent Service Pump Cart	0	4 hrs.	Assy. Stand	8 HRS.	4 hrs.	Dave M. Ken /Chris Rick/Gregg	S/U	Remove off-pallet F/D GSE Ground Configuration
	P0960	Regulator Lock-up	26	B.2,B.6, C.2,C.3	GDS, Fill Manifold, Vent Service Pump Cart	0	8 hrs.	Assy. Stand	8 hrs.	8 hrs.	Dave M. Ken /Chris Rick/Gregg	S/U, LMMS, DCM	Ground Configuration
	P0973	Vent Line Service	26	B.3,B.6, C.2,C.3	LD, Vent Service Pump Cart	4	0	Assy. Stand	8 hrs.	8 hrs.	Dave M. Ken /Chris Rick/Gregg	S/U	GMA zone 5 and vent manifold to 300 psia / Ground Configuration
	P0973	Vent Line Service	24	B.3,B.6, C.2,C.3	LD, Vent Service Pump Cart	0	0	Assy. Stand	8 hrs.	0	Ken /Chris Rick/Gregg	S/U	Verify GMA Zone 5 and Vent Manifold Pressure is ~ 300 psia / Ground Configuration
	P0973	Vent Line Service	17	B.3,B.6, C.2,C.3	LD, Vent Service Pump Cart	0	0	Assy. Stand	8 hrs.	0	Ken /Chris Rick/Gregg	S/U	Verify GMA Zone 5 and Vent Manifold Pressure is ~ 300 psia / Ground Configuration
	P0973	Disconnect Vent Line Service	17	B.3,B.6, C.2,C.3	LD, Vent Service Pump Cart	0	8 hrs.	Assy. Stand	8 hrs.	0	Ken /Chris Rick/Gregg	S/U, LMMS, DCM	Remove Vent Extension Pump Cart / Ground Configuration

S0701 GMA Valve Leakage Mitigation Plan

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Location	P Doc	Activity	T- (days)	S0701 Ref.	GSE Required	Hrs. to Install GSE	Hrs.to Remove GSE	S/V Config.	Req'd Test Time	Req'd ECU Time	Personnel Required	Req'd QA	Comments / Valve Configuration
MST	N/A	Move Vent Service GSE to MST	16		LD, Vent Service Pump Cart	12 hrs.		N/A	0	0	Ken /Chris Rick/Gregg	S/U	
	P0973	Connect Vent Line Service GSE	12	B.3,B.6, C.2,C.3	LD, Vent Service Pump Cart	8 hrs.	0	N/A	8 hrs.	0	Ken /Chris Rick/Gregg	S/U, LMMS, DCM	Reconnect Vent Extension Pump Cart / Ground Configuration
	P0973	Vent Line Service	12	B.3,B.6, C.2,C.3	LD, Vent Service Pump Cart	0	0	N/A	8 hrs.	0	Ken /Chris Rick/Gregg	S/U	Verify GMA Zone 5 and Vent Manifold Pressure is ~ 300 psia / Ground Configuration
	P0973	Vent Line Service	8	B.3,B.6, C.2,C.3	LD, Vent Service Pump Cart	0	0	N/A	8 hrs.	0	Ken /Chris Rick/Gregg	S/U	Verify GMA Zone 5 and Vent Manifold Pressure is ~ 300 psia / Ground Configuration
	P0973	Disconnect Vent Line Service	7	B.3,B.6, C.2,C.3	LD, Vent Service Pump Cart	0	4 hrs.	N/A	8 hrs.	0	Ken /Chris Rick/Gregg	S/U, LMMS, DCM	Remove Vent Extension Pump Cart for level 6 movement(sunshade cover removal)
	P0973	Connect Vent Line Service GSE	5	B.3,B.6, C.2,C.3	LD, Vent Service Pump Cart	8 hrs.	0	N/A	8 hrs.	0	Ken /Chris Rick/Gregg	S/U, LMMS, DCM	Reconnect Vent Extension Pump Cart / Ground Configuration
	P0973	Vent Line Service	4	B.3,B.6, C.2,C.3	LD, Vent Service Pump Cart	0	0	N/A	8 hrs.	0	Ken /Chris Rick/Gregg	S/U	Verify GMA Zone 5 and Vent Manifold Pressure is ~ 300 psia / Ground Configuration
	P0973	Vent Line Service	1	B.3,B.6, C.2,C.3	LD, Vent Service Pump Cart	0	0	N/A	8 hrs.	0	Ken /Chris Rick/Gregg	S/U	Verify GMA Zone 5 and Vent Manifold Pressure is ~ 300 psia / Ground Configuration
	P0973	Close Vent Quad valves with ECU	1	B.3,B.6, C.2,C.3		0	0	N/A	1 hrs.	1 hrs.	Dave M. Ken /Chris Rick/Gregg	S/U, LMMS, DCM	Close V27, V28, V29, & V30 / Ground Configuration
	P0973	Disconnect Vent Line Service	1	B.3,B.6, C.2,C.3	LD, Vent Service Pump Cart	0	8 hrs.	N/A	8 hrs.	0	Ken /Chris Rick/Gregg	S/U, LMMS, DCM	Remove Vent Extension Pump Cart & vent extension GSE for launch / Ground Configuration
	P0976	Configure GMA latch valves for Flight	12 hrs	B.7,C.1, C.2,C.3	POD	0	0	N/A	2 hrs.	2 hrs.	Dave M. Ken /Chris Rick/Gregg	S/U, LMMS, DCM	C-STOL Null.prc / Launch Configuration
LAUNCH													

SCRUBBED LAUNCH RECOVERY - GMA

P Doc	Activity	T- (days)	S0701 Ref.	GSE Required	Hrs. to Install GSE	Hrs.to Remove GSE	S/V Config.	Req'd Test Time	Req'd ECU Time	Personnel Required	Req'd QA	Comments / Valve Configuration
P0976	Close all latch valves	plus 48 to 72 hrs.	B.8,C.1, C.2,C.3	POD	0	0	N/A	4 hrs.	4 hrs.	Dave M. Ken /Chris Rick/Gregg	S/U, LMMS, DCM	C-STOL Null.prc / Ground Configuration
P0973	Connect Vent Line Service GSE	2	B.8,C.1, C.2,C.3	LD, Vent Service Pump Cart	8 hrs.	0	N/A	8 hrs.	0	Ken /Chris Rick/Gregg	S/U, LMMS, DCM	Reconnect Vent Extension Pump Cart / Ground Configuration
P0973	Open Vent Quad valves with ECU	1		LD, Vent Service Pump Cart	0	0	N/A	1 hrs.	1 hrs.	Dave M. Ken /Chris Rick/Gregg	S/U, LMMS, DCM	Open V27, V28, V29, & V30 / Ground Configuration
P0973	Pump out zone5 and vent ext. manifold	1	B.8,C.1, C.2,C.3	LD, Vent Service Pump Cart	0	0	N/A	8 hrs.	0	Ken /Chris Rick/Gregg	S/U	Verify GMA Zone 5 and Vent Manifold Pressure is ~ 300 psia / Ground Configuration
P0973	Re-pressuize zone 5 and vent ext. manifold	1	B.8,B.2, C.1,C.2, C.3	LD, Vent Service Pump Cart	0	0	N/A	4 hrs.	0	Ken /Chris Rick/Gregg	S/U	Verify GMA Zone 5 and Vent Manifold Pressure is ~ 300 psia / Ground Configuration
P0973	Close Vent Quad valves with ECU	1	B.8,C.1, C.2,C.3		0	0	N/A	1 hrs.	1 hrs.	Dave M. Ken /Chris Rick/Gregg	S/U, LMMS, DCM	Close V27, V28, V29, & V30 / Ground Configuration
P0973	Disconnect Vent Line Service	1	B.8,C.1, C.2,C.3	LD, Vent Service Pump Cart	0	8 hrs.	N/A	8 hrs.	0	Ken /Chris Rick/Gregg	S/U, LMMS, DCM	Remove Vent Extension Pump Cart & vent extension GSE for launch / Ground Configuration
P0976	Configure GMA latch valves for Flight	12 hrs	B.7,C.1, C.2,C.3	POD	0	0	N/A	2 hrs.	2 hrs.	Dave M. Ken /Chris Rick/Gregg	S/U, LMMS, DCM	C-STOL Null.prc / Launch Configuration

C.3 Success Criteria

C.3.1 Scope

This section summarizes the issues known to effect the GMA's ability to sufficiently maintain its internal pressures prior to launch for mission success in flight.

C.3.2 Background

The flight GMA is known to have problems with leakage through some latching valves. Sufficient leakage could cause any of the following problems to occur:

1. Via internal leakage, the main storage tank could lose enough Helium gas to reduce the amount remaining for flight operations below requirements. Although a significantly higher level of loss could probably be tolerated at launch (~10%-20%), the success criterion is conservatively *defined here* to be a 20 psia (~1%) maximum loss of main tank pressure due to leakage. [Note that some main tank gas is consumed during ground operations during regulator lock-up operations (typically 1-3 psia), and that consumption is not part of the 20 psia loss criterion.]
2. Some elements (pressure transducers) of the GMA are MAWP rated to 500 psia. Since the main tanks are at ~2000 psia at launch, it is possible that internal leakage could cause some volumes to exceed the 500 psia rating. Although Zone IV is the first such volume sensitive to this requirement, relevant pressure data are not available for that volume from flight nor ground support equipment. However, it is not possible for Zone IV to exceed Zone III. Therefore, success criterion is conservatively *defined here* to be that Zone III should not exceed 500 psia. [Note that Zone III can not be read during MST operations. This evaluation shall be based upon Rate of Rise evaluations performed when the GMA valves are closed the final time prior to launch.]
3. For safe launch, Zones II, III, and IV should remain above 100 psia to ensure regulator lock-up. Zones II and III will always equal or exceed Zone IV, which will always equal or exceed Zone V. Since relevant pressure data for Zone V will be available during ground state operations from the Vent GSE, success criterion is conservatively *defined here* to be that Zone V should not drop below 100 psia. [Note that some operations (i.e. launch scrub recovery) evacuate this volume and restore it to 300 psia. That intentional evacuation shall not disqualify the 100 psia requirement unless Zone II also drops below 100 psia.]
4. To prevent possible cryo-contamination of the probe from atmospheric contamination leaking in the vent outlet (and later traveling into the probe), success criteria are *defined here* to be that Zone V should always be maintained at a pressure greater than 15 psia when the vent outlet is exposed to air. [The vent outlet is exposed to air only in the final stages prior to launch, after the Vent GSE has been removed.]

5. Helium gas pressure within the probe will increase the thermal transfer rates and cause an increase in the temperature and boil-off rates of the Main and Guard liquid Helium tanks. The effect of the cumulative leakage from the GMA into the probe via the S1, S2, S3, S4, and P1A outlets over time must not cause the Main tank to exceed 1.85 Kelvin nor cause the guard tank to boil-off too rapidly. Although the calculations from leak rate to thermal effect cannot be simply stated within the confines of this paragraph, total leak rates of $<1.0\text{E-}05$ sccs during ground state and $<1.0\text{E-}04$ during launch state will meet launch timeline requirements. Since lower leak rates have been achievable in Rate of Rise operations, significant margin of safety exists. Refer to Sections **D.6** and **D.7** for more detailed analysis.

The data used to calculate the predicted hold times of the GMA in various states is based upon measured leakage rates. These measurements were made by the “Rate of Rise” method.

C.3.3 Calculations

C.3.3.1 “Rate of Rise” Results

Stanford Procedures P0970 and P0971 were used to conduct these tests. More detailed descriptions of the hardware used can be found in those documents. Figure 1 displays a schematic of the GMA with the related GSE hardware. More detailed data can be found in the “Rate of Rise” Test Report (**D.9**).

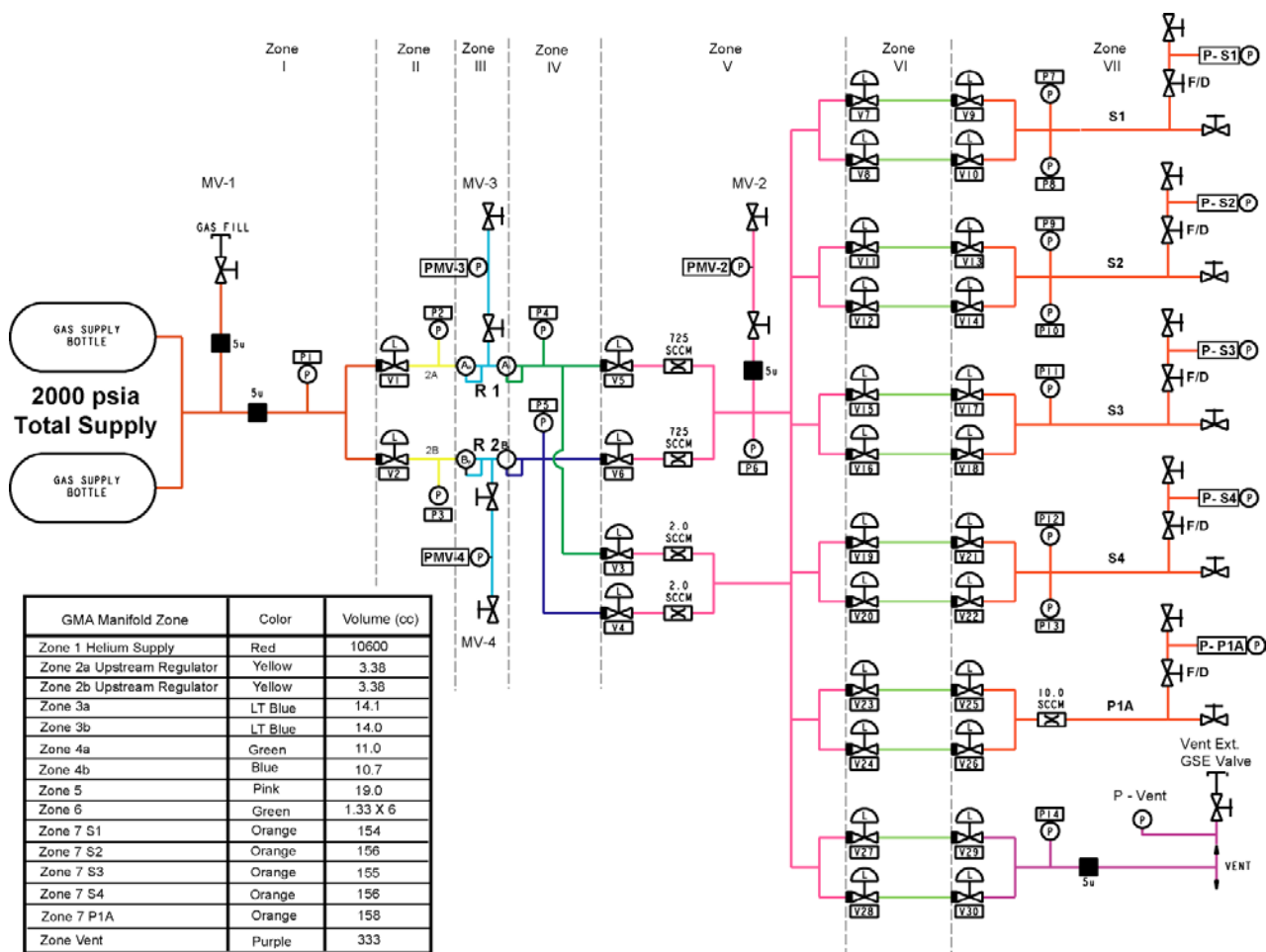


Figure 1

The net leakage rates (net of pressure leaking in and out) for the known zones is displayed below.

Volume ID	leaks from	leaks to	Ground state net rate (sccs)	Launch state net rate (sccs)
Zone I	none	Zones IIA, IIB	n/a*	-5.33E-05
Zone IIA	Zone I	Zone IIIA	n/a*	-3.30E-07
Zone IIB	Zone I	Zone IIIB	n/a*	+1.60E-05
Zone IIIA	Zone IIA	Zone IVA	-1.25E-06	+2.92E-06
Zone IIIB	Zone IIB	Zone IVB	-7.11E-07	+6.39E-06
Zone V	Zones IVA, IVB	Probe, Vent	-7.92E-06	-1.26E-04
Probe	Zone V	none	+6.28E-06	+7.41E-06
Vent	Zone V	none	** -7.92E-06	+2.64E-04

*data has not yet been processed for these calculations

**in ground state, the Vent is open to Zone V and acts as a ballast

C.3.4 Maximum Time Required Between GMA Servicing

1. 20 psia loss of main tank pressure
 - ground state hold time: not available (presumed similar to launch state)
 - launch state hold time: **313 days**
 - what fails: main tank loses 1% of Helium supply
 - mitigation planned: none
 - effect of failure: Helium supply may be inadequate for flight requirements
 - corrective action: determine if supply meets flight needs and refill if required
 - effect of corrective action: restart clock after refill
2. overpressure of GMA (>500 psia in Zone IIIA or IIIB, starting at 300 psia)
 - ground state hold time: not available (presumed similar to launch state)
 - launch state hold time: **345 days**
 - what fails: Zone IIIB >500 psia which implies that Zone IVB might >500 psia
 - mitigation planned: none
 - effect of failure: damage to GMA components may occur
 - corrective action: bleed excess pressure out and repeat regulator lock-up (partial mitigation by scrub launch recovery operation)
 - effect of corrective action: restart clock on Zone IV after scrubbed launch recovery operation, but some estimation is required
3. regulator lock-up (<100 psia in Zone V, starting at 235 psia)
 - ground state hold time: **5120 days**
 - launch state hold time: **22 days**
 - what fails: Zone V <100 psia, which implies that Zone IVA or IVB might <100 psia
 - mitigation planned: restore Zone IV and Zone V to 300 psia via Vent Port GSE after scrubbed launch
 - effect of failure: not safe to launch (regulators could be damaged by shock)
 - corrective action: mitigation plan
 - effect of corrective action: restart clock after scrubbed launch recovery operation
4. cryo-contamination protection (<15 psia in Zone V, starting at 235 psia)
 - ground state hold time: not applicable (the Vent is isolated from atmosphere by GSE)
 - launch state hold time: **35 days**
 - what fails: Zone V no longer at positive pressure with respect to atmosphere
 - mitigation planned: restore Zone IV and Zone V to 300 psia via Vent Port GSE after scrubbed launch
 - effect of failure: Air could leak into Zone V, and ultimately into Probe
 - corrective action: significant servicing of GMA and testing of Probe may be required (this failure should be prevented, recovery would be very difficult)
5. Probe pressure (Main Tank exceeds 1.85 Kelvin or Guard Tank boil-off rate too high)
 - total ground and launch state hold time: **>79 days**

- what fails: sufficient Helium leaks into Probe to effect dewar hold times
- mitigation planned: minimize ground and launch state hold times; monitor probe and dewar temperatures; and increase frequency of dewar servicing if required
- effect of failure: increased thermal exchange leads to increased boil-off rates of liquid Helium supplies resulting in decreased mission duration
- corrective action: determine if current Main Tank temperature is acceptable for launch or service Main and/or Guard tanks
- effect of corrective action: complex – partial restart of clock

Some of the hold times listed above are cumulative – if 20% of the ground state hold time is consumed, then 20% of the launch state hold time may also have been consumed.

C.3.5 Sequence of activity effects

It is necessary to understand that the pre-launch sequence of activities will effect some of the maintained pressures in the following ways:

1. Transition from Ground State to Launch State causes an immediate reduction of Zone V pressure (up to 30.4%) when previously evacuated Zone VI volumes are filled by the Helium in Zone V.
2. Transition from Ground State to Launch State may cause an immediate increase in the total volume of Helium leaked into the probe (in addition to some increased rates of leakage into the probe). This increase depends upon the specific launch configuration chosen (which outlet quads have “swapped pairs”) and the leak rates of the valves in the effected quads.
3. A “scrubbed launch” procedure will restore several volumes. However, it will not directly restore any pressure lost from Zone III or reverse the effects of any pressure leaked into the Probe.

C.3.6 Conclusions

The levels of concern for each failure mode are summarized below.

“Very Low” indicates hold times greater than 300 days *or* extremely low risk of harmful effect

“Low” indicates hold times of 60 days (the maximum predicted ground state hold time) to 300 days *or* low risk of harmful effect

“Moderate” indicates hold times of 5 days (the maximum predicted launch state hold time) to 60 days *and* reasonable risk of harmful effect

“High” indicates hold times less than 5 days *and* reasonable risk of harmful effect

Issue	Mitigation Planned	level of concern with mitigation
GMA Main Tank Helium Supply Loss	none during ground state	very low
	none during launch state	very low
Overpressure of sensitive GMA zones	none during ground state	very low
	none during launch state	very low
Loss of regulator lock-up	maintain vent line @ 300 psia during ground state	very low
Loss of regulator lock-up	minimize launch state hold time (<22 days)	very low
Cryo-contamination	maintain vent line @ 300 psia during ground state	very low
Cryo-contamination	minimize launch state hold time (<35 days)	very low
Probe pressure rise effects Dewar Main Bath Temperature	minimize leakage into probe during ground state (<1E-05) and minimize ground state hold time (<55 days)	low
Probe pressure rise effects Dewar Main Bath Temperature	minimize leakage into probe during launch state (<1E-04) and minimize launch state hold time (<24 days)	low (<1E-05) to moderate (<1E-03)
Probe pressure rise effects Guard Tank Boil Off	minimize leakage into probe and provide more frequent tank servicing after significant cumulative pressure rise	low to moderate (depends upon cumulative effects)

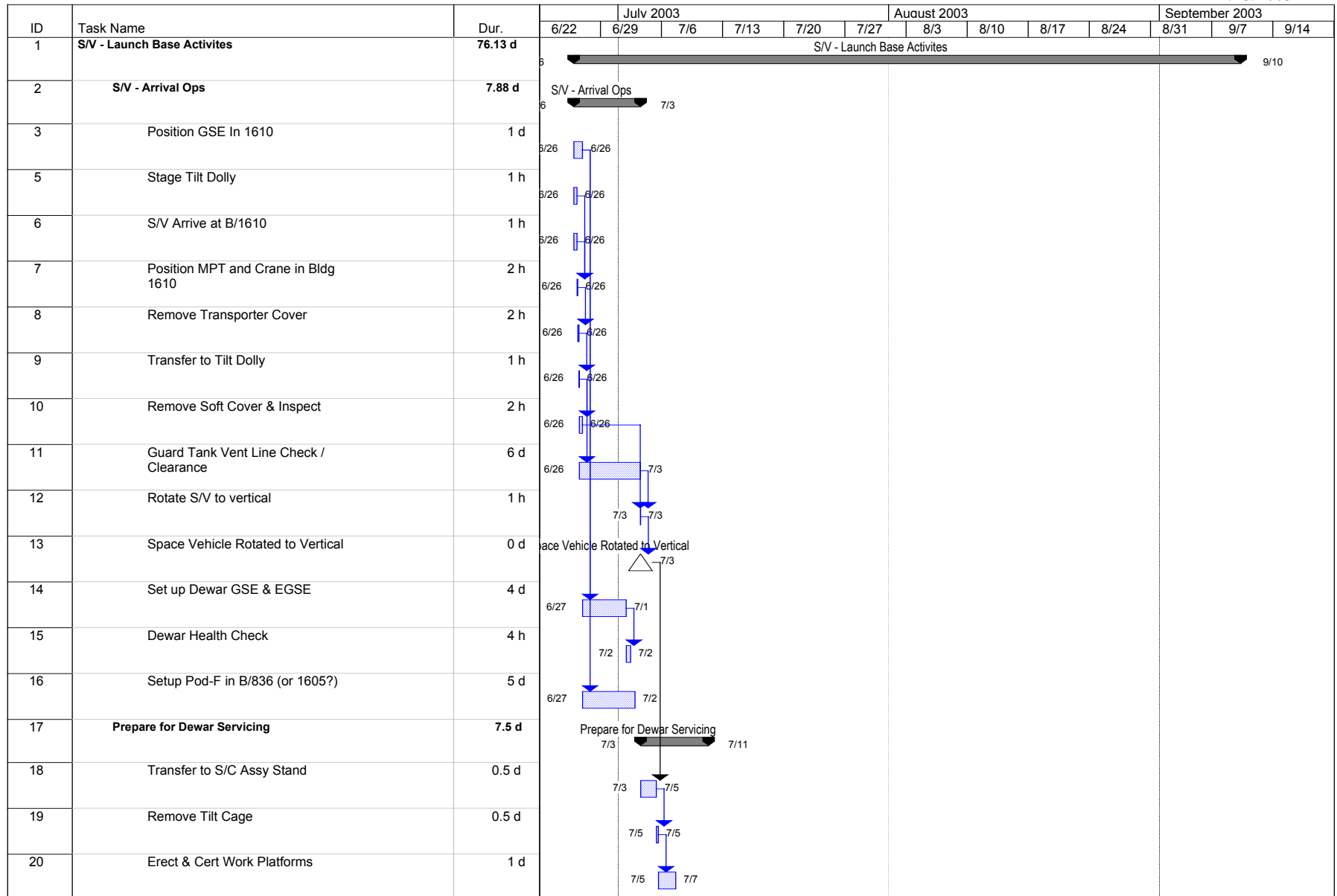
In general, all risks to GP-B mission success caused by GMA leakage issues have been reduced to reasonably low levels. Additionally, significant margin remains for any leakage rate to be somewhat higher (a small order of magnitude) than has been shown to be achievable.

C.4 Time Line

Gas Management Assembly (GMA) Timeline		
Building 1610		
DAYS	GMA Procedures Required at VAFB	GMA Activities at VAFB
67	P0968 Bleed down of the GMA High Pressure at VAFB	Bleed down
67	P0960 GDS Operating Procedure at VAFB	Regulator Lock-up
66	P0974 GMA Rate of Pressure Rise Test Procedure at VAFB	Rate of Rise Evaluation – Launch Configuration
64	P0974 GMA Rate of Pressure Rise Test Procedure at VAFB	Rate of Rise Evaluation – Ground Configuration
62	P0974 GMA Rate of Pressure Rise Test Procedure at VAFB	Rate of Rise Evaluation Complete – Ground Configuration
59	P0960 GDS Operating Procedure at VAFB	GMA Helium Fill "Flight"
42	P0977 Open Gas Inlet Manual Valves (TOP HAT)	Gyro Inlet Manual Valves Opened
26	P0960 GDS Operating Procedure at VAFB	Regulator Lock-up
26	P0973 GMA Vent Extension Service Procedure	Vent Line Service
24	P0973 GMA Vent Extension Service Procedure	Vent Line Service
17	P0973 GMA Vent Extension Service Procedure	Vent Line Service
17	P0973 GMA Vent Extension Service Procedure	Disconnect Vent Line Service
Transportation to Mobile Service Tower (MST)		
16	Procedure not Required	Move Vent Service GSE to MST
Mobile Service Tower (MST)		
12	P0973 GMA Vent Extension Service Procedure	Connect Vent Line Service
12	P0973 GMA Vent Extension Service Procedure	Vent Line Service
8	P0973 GMA Vent Extension Service Procedure	Vent Line Service
7	P0973 GMA Vent Extension Service Procedure	Disconnect Vent Line Service
5	P0973 GMA Vent Extension Service Procedure	Connect Vent Line Service GSE
4	P0973 GMA Vent Extension Service Procedure	Vent Line Service
1	P0973 GMA Vent Extension Service Procedure	Vent Line Service
1	P0973 GMA Vent Extension Service Procedure	Close Vent Quad valves with ECU
1	P0973 GMA Vent Extension Service Procedure	Disconnect Vent Line Service
12 hrs	P0976 GMA Latch Valve Launch Configuration	Configure GMA latch valves for Flight via POD
	Launch Mitigation Complete	Launch Sequence Initiated
SCRUBBED LAUNCH RECOVERY – GMA		
+2	P0976 GMA Latch Valve Launch Configuration	Close all latch valves
1	P0973 GMA Vent Extension Service Procedure	Connect Vent Line Service GSE
1	P0973 GMA Vent Extension Service Procedure	Vent Line Service
1	P0973 GMA Vent Extension Service Procedure	Disconnect Vent Line Service
12 hrs	P0976 GMA Latch Valve Launch Configuration	Configure GMA latch valves for Flight via POD

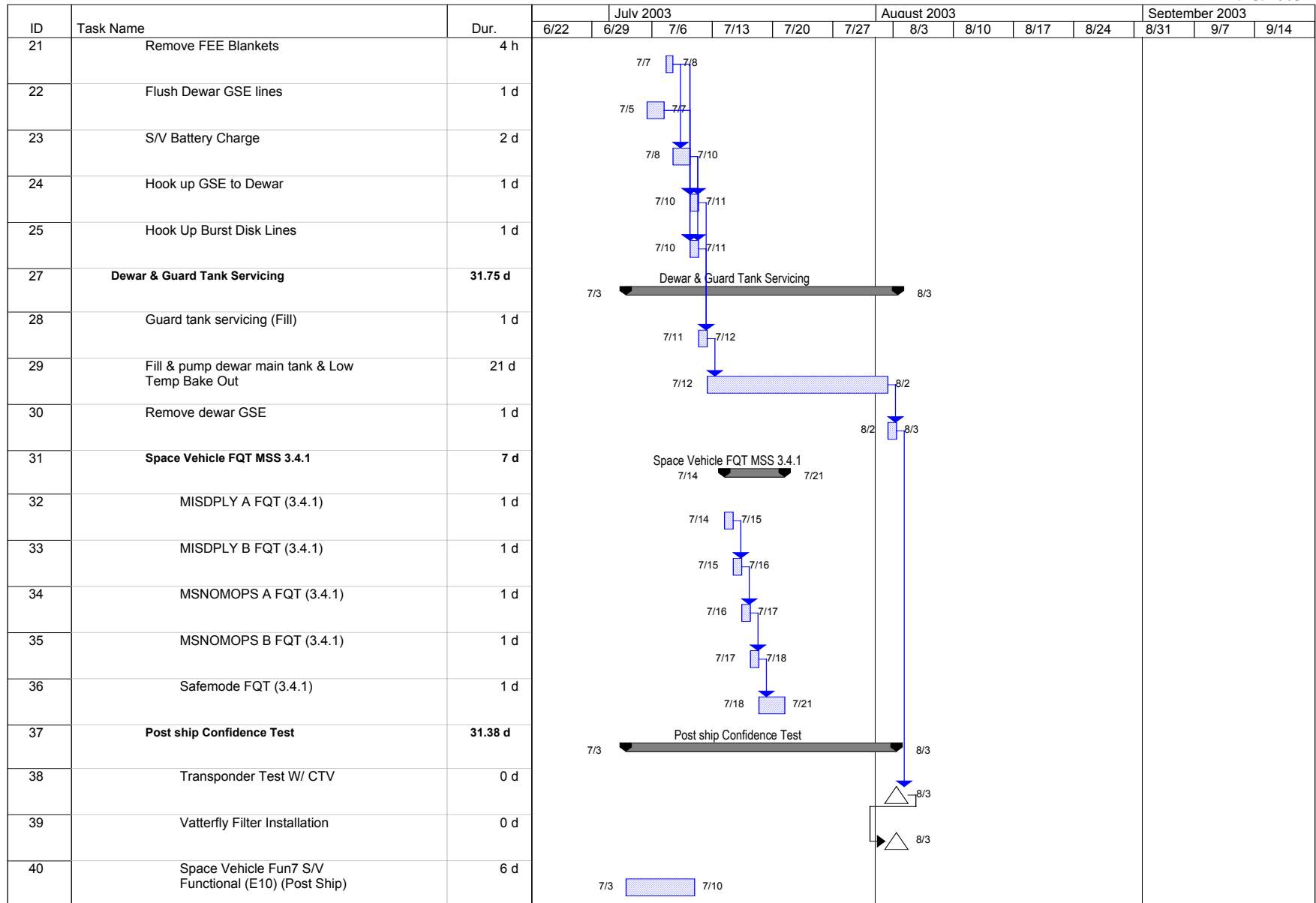
S0701 GMA Valve Leakage Mitigation Plan

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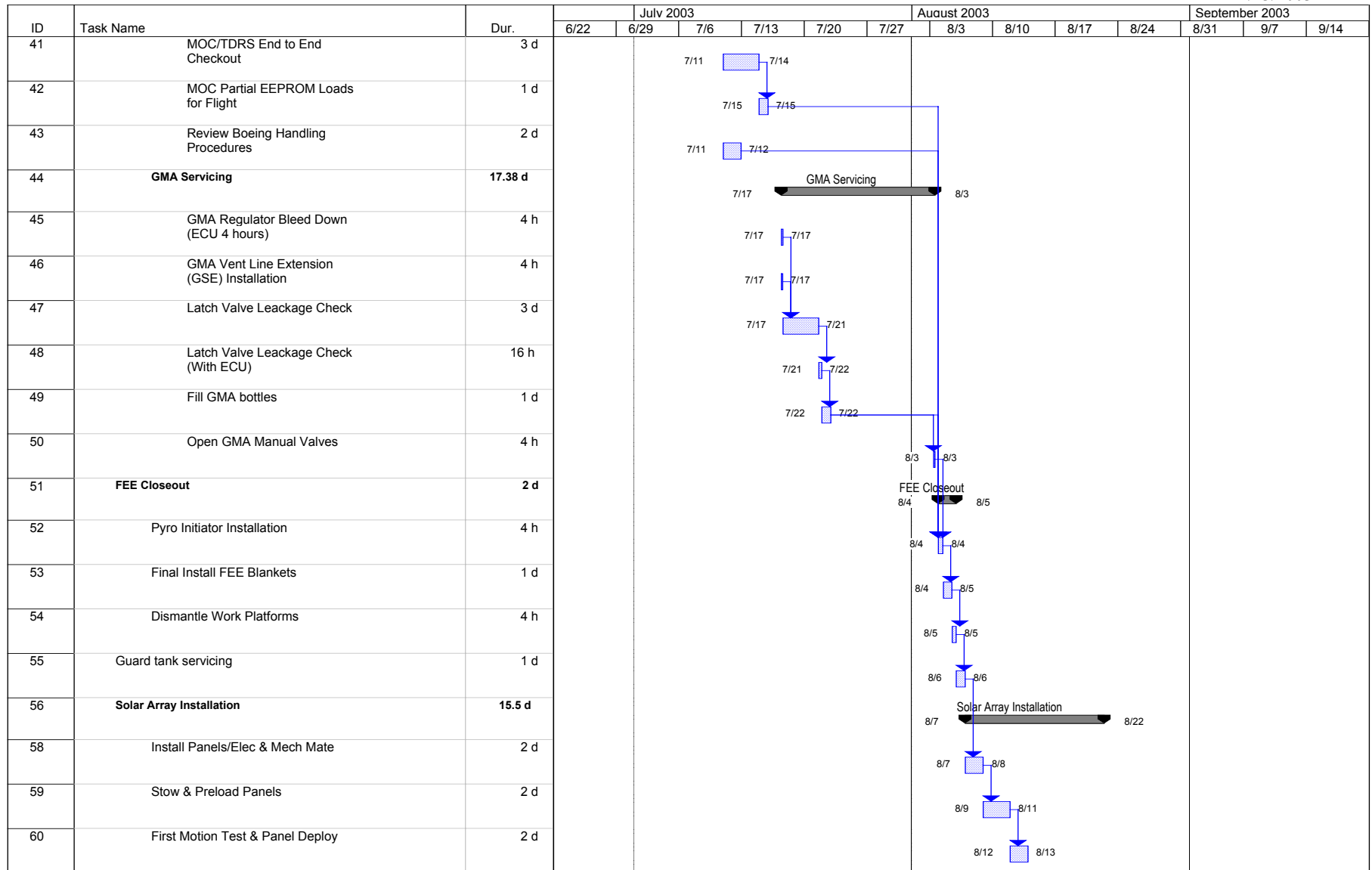
S0701 GMA Valve Leakage Mitigation Plan

2/13/2003



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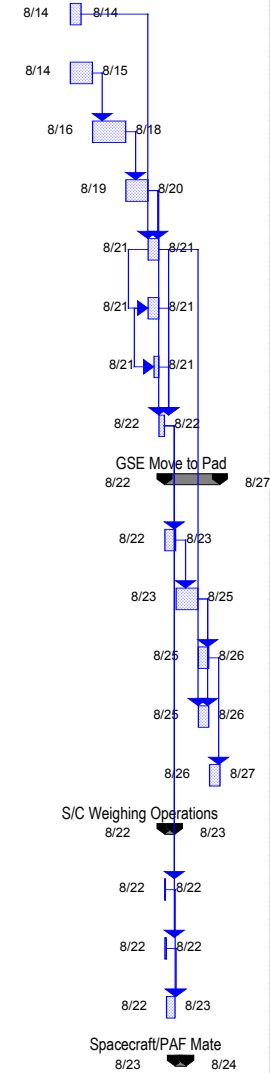
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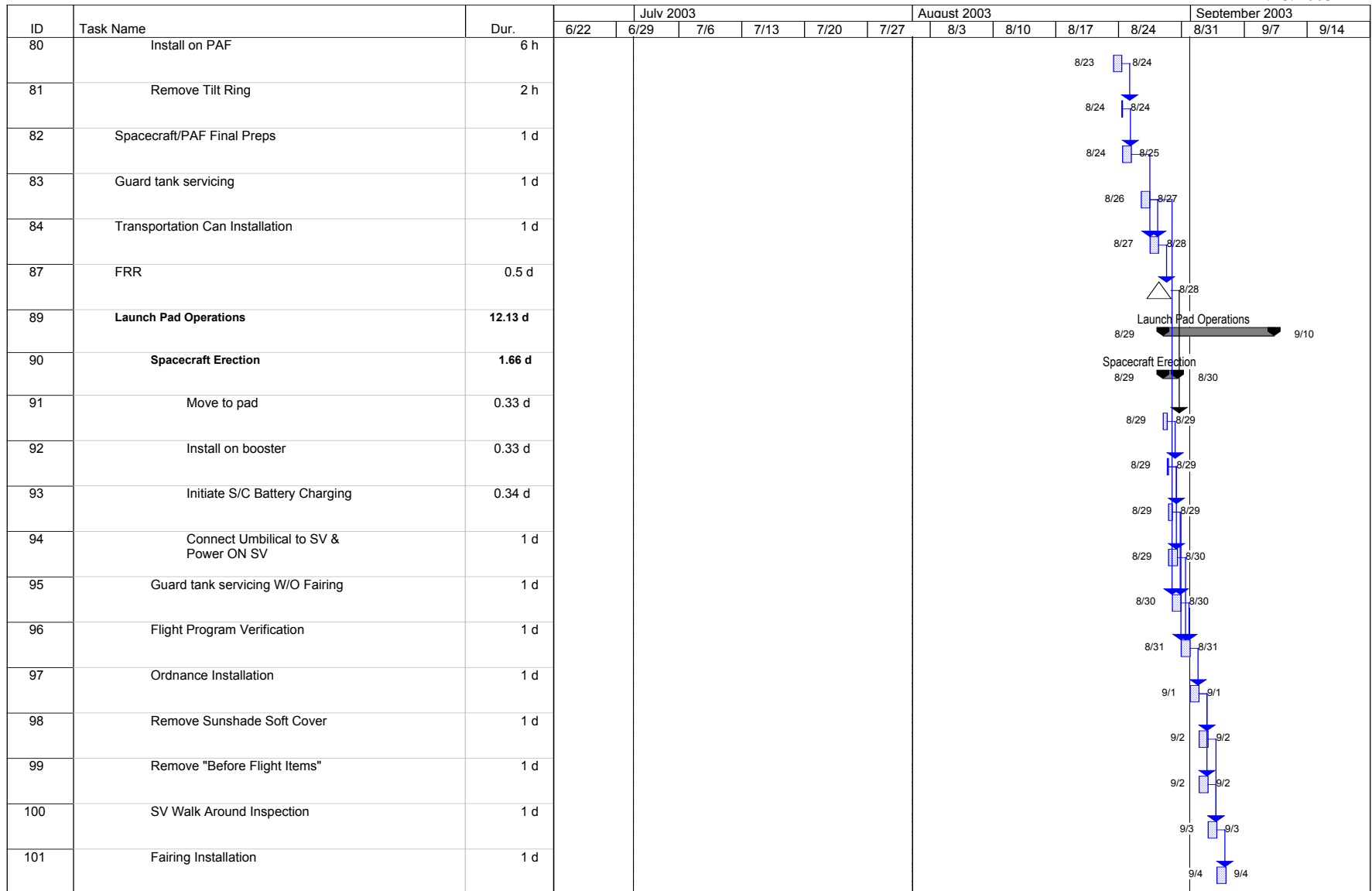
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ID	Task Name	Dur.	July 2003					August 2003					September 2003		
			6/22	6/29	7/6	7/13	7/20	7/27	8/3	8/10	8/17	8/24	8/31	9/7	9/14
61	Guard tank servicing & Dewar Heat Rate Check	1 d													
62	S/A Aliveness Test	2 d													
63	Visually Inspect Solar Cells	2 d													
64	Install Cover, Final Stow & Preload	2 d													
65	Guard tank servicing	1 d													
66	GMA Regulator Lock Up and GSE Removal (ECU 4hours)	1 d													
67	GMA Thermal Blanket Re-Installation	4 h													
68	Install Tilt Ring	4 h													
69	GSE Move to Pad	5 d													
70	Discharge batteries	1 d													
71	Unhook all EGSE	1 d													
72	Move EGSE to pad	1 d													
73	Move guard tank GSE to pad	1 d													
74	Setup/Checkout EGSE	1 d													
75	S/C Weighing Operations	0.88 d													
76	Disconnect Burst Disk Lines	1 h													
77	Remove S/V from S/C Assy Stand	3 h													
78	Weigh S/C	0.5 d													
79	Spacecraft/PAF Mate	1 d													



S0701 GMA Valve Leakage Mitigation Plan

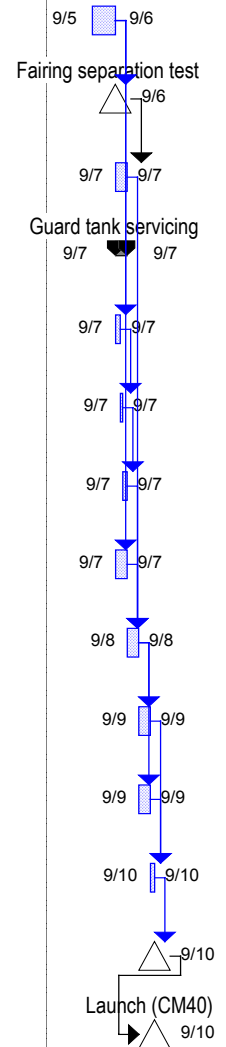
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S0701 GMA Valve Leakage Mitigation Plan

2/13/2003

ID	Task Name	Dur.	July 2003					August 2003					September 2003		
			6/22	6/29	7/6	7/13	7/20	7/27	8/3	8/10	8/17	8/24	8/31	9/7	9/14
102	Fairing Finalling	2 d											9/5	9/6	
103	Fairing Separation Test	0 d												9/6	
104	Final EEPROM Launch Loads from MOC (CCCA-B Checkout)	1 d												9/7	
105	Guard tank servicing	1 d												9/7	
106	Hook up guard tank GSE	0.25 d												9/7	
107	Fill guard tank	0.5 d												9/7	
108	Remove guard tank GSE	0.25 d												9/7	
109	GMA Servicing	1 d												9/7	
110	Second Stage Propellant Loading	1 d												9/8	
111	Beacon, Range Safety & Class A Ord	1 d												9/9	
112	Pre-Launch SV Power Up	1 d												9/9	
113	Delta Countdown	1 h												9/10	
114	NASA Program Managers Schedule Reserve	0 d												9/10	
115	S/V - Launch from VAFB (CM40)	0 d												9/10	



E. Safety

Range Safety Regulations will be followed for all aspects of the mitigation plan. All new hardware that is exposed to pressure will be designed, built and tested to meet required factors of safety in accordance with Boeing's EWR 127-1, Chapter 3. The maximum working pressure for the vent extension will be a low pressure of 300 psia (*with pressure relief*), far less than its MAWP. In addition, Zone V of the GMA meets the same requirements. The 'GMA Vent Extension Service Procedure' (P0973) is considered non-hazardous. Range Safety reviews all procedures during sign-off and has reviewed the drawings for all GSE. GMA servicing will only occur during guard tank servicing to minimize impact on MST activities. The additional flight hardware and GSE required to support the mitigation plan will be included in the Missile System Pre-launch Safety Package (MSPSP) Revision D by Harv Moskowitz.



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GRAVITY PROBE B RELATIVITY MISSION

GMA VALVE LEAKAGE MITIGATION PLAN

S0701 Rev B
(Sections D and Appendix)

D.1 Moog Acceptance Test (Excerpts)

- Regulator Proto-qual Test (including Random Vibe and Shock)

Protoqualification Test Report

for

50E962

High Flow Regulator

Moog Model No.: 50E962

Moog Part No.: C58802-001

Stanford University

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By	K. Lewandowski 20020812	Revisions			
Engr.	J. Barbarits 20020813	Rev.	Description	Date	Approved
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moog

Moog Inc. East Aurora, NY 14052

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MRT16408

Caution: Verify revision of printed copy with MWW prior to use.

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SECTION 1.0

INTRODUCTION

1.1 Scope

This report summarizes the Protoqualification Testing per MRT11231, Rev C of the Moog Model 50E962 Regulator, manufactured by Moog Inc., East Aurora, New York. The Protoqualification campaign successfully demonstrates the regulator's ability to withstand Random Vibration and Shock exposure per customer specification S0569 and fulfill it's function in the GMA feed system, Model No. 50E961.

Moog Model No.
50E962

Moog Part No.
C58802-001

The information contained in this report is segregated by sections as follows:

Section 2.0 of this report lists the reference documents used in the performance of the Protoqualification testing.

Section 3.0 of this report is a summary of the completed Protoqualification testing.
Section 4.0 lists and describes the tests performed and the recorded results.

The appendix of this report is comprised of test data sheets for all tests described herein.

1.2 Test Objective

The Protoqualification Test Program for Moog Inc. Model 50E962 performed to verify by test that the regulator meets and exceeds the regulator Qualification requirements for shock and random vibration testing per S0569, Stanford University specification for the Gas Management System.

1.3 Item Description

The 50E962 Gas Regulator is a two stage redundant regulator, which regulates high pressure gas to a lower pressure under specified flow conditions to a science gyroscope. The regulator is capable of regulating 19.00 psia to 21.00 psia with inlet pressures ranging 100 psia to 2000 psia .

The 50E962 regulator is a device, which has an inlet and outlet filter on each stage. Flow passes through the inlet filter and enters a metal orifice assembly. Flow is metered at the orifice by a plastic seat, which modulates with the orifice. The seat is part of a bellows assembly, which modulates with the downstream pressure level. As bellows and seat modulate, the seat and orifice establish a flow equivalent to the downstream flow demand. The pressure, at which the steady state flow is produced, occurs within the specified regulation band of reference 1.3.1. Should the downstream flow demand become zero, the pressure will increase until the seat is driven by the bellows into the orifice and shuts-off flow.

SECTION 2.0

2.0 REFERENCE DOCUMENTS

2.1 Moog Inc.

2.1.1	C58803	Installation Drawing 50E962
2.1.2	C58802	Assembly Drawing 50E962
2.1.3	MRT1123	High Flow Regulator Random Vibration and Pyro Shock Test Procedure

2.2 Other

2.2.1	S0569	Stanford University Detailed Specification for the Gas Management System
2.2.2	MIL-P-27401	Propellant Pressurizing Agent, Nitrogen
2.2.3	MIL-P-27407	Propellant Pressurizing Agent, Helium
2.2.4	C02E1-067	MGA Test Report

SECTION 3.0

3.1 Summary

Prior to the exposure of random vibration, then shock, Model 50E962, S/N 003 Regulator was baseline tested for performance and external leakage. Performance tests were repeated after random vibration exposure and after shock exposure. An external leakage test was repeated following the completion of random vibration and shock exposures.

3.2 Protoqualification Test Summary

3.2.1 Random Vibration Per MRT11231, Para. 3.3.4

The test article was pressurized to 100 (inlet, outlet and interstage) psia GHe, and subjected to one-minute exposures in each of three axes at an overall Grms of 11.1. Following exposure to random vibration, the regulator showed no change in performance; set points of each stage remained steady in comparison to the pre-vibration baseline performance test. Internal leakage performance also remained steady with respect to baseline performance.

3.2.2 Shock Testing per MRT11231, Para. 3.3.6

The test article was subjected to three shock pulses (2800 G peak) in the axial direction of the regulator. For Pulse 1 the regulator was pressurized to 300 psia (inlet, outlet and interstage) and for Pulse 2 and 3 it was pressurized to 100 psia (inlet, outlet and interstage). The regulator set point and lockup for 1st Stage, 2nd Stage and Two Stage shifted following each shock exposure. Although it shifted, the regulator still met the internal performance specification for regulation and lockup, making it capable of fulfilling its function in the GMA Feed System. The regulator passed the post-vibration/shock external leakage test.

3.2.3. External Leakage Testing per MRT11231, Para. 3.3.7

The test article was subjected to the external leakage conditions as delineated in para 3.3.7 External leakage was measured using a mass spectrometer and found to be $<1 \times 10^{-6}$ scc/sec GHe.

3.2.4 Test Conclusion

Random vibration indicated no effect on the regulator performance as indicated in the before and after data included in Table 1. Shock testing regulator performance data included in Table 2 indicated a regulation band shift within the parameters of MRT11123, Rev. C. Moog Inc. believes that the shifting phenomenon is a function of the bellows (of the aneroid assembly) convolutions slightly readjusting themselves to the energy level of the shock pulse. The adjustment phenomenon is asymptotic with the number of identically applied shock pulses. This bellows readjustment is believed to be a resettling of the bellows plies in the weld joint areas, where non-structural and lower strength diffusion bonds separate, and create a different bellows load at its operating deflection, and hence create different regulator set points. The phenomenon is in no way a structural or functional concern. The regulator is still capable of withstanding proof pressures, and is capable of providing normal regulation function, even though the set point of each stage, and overall two stage operation, has changed. The lockup function is not affected at all. The shifting affect is not believed to be caused by an increased coin in the seat, since the set point would shift higher rather lower.

Based on results of the regulator performance after Protoqualification shock exposure, the allowable regulation band for the GMA feed system, and the assumption that the imposed flight shock spectrum into the pallet will not exceed the levels achieved during Protoqualification shock, Moog believes that a shift from the actual flight shock, if any, will be of the same order of magnitude as experienced from Protoqualification shock. The regulator will still operate within its expected regulation band and therefore provide acceptable helium flowrates to support the GP-B mission.

SECTION 4.0

4.1 Protoqualification Tests

Qualification tests are listed and described in accordance with the sequence and requirements of MRT11231

4.1.1 Physical Examination and Inspection per MRT11231 Para. 3.3.1,

Physical Examination and inspection data for s/n 003 was transcribed from A&TW 50E962, OP220. The test article met or exceeded all dimensional, Identification and workmanship requirements of Moog Inc. drawing C58803-001

4.1.2 External Leakage Test per MRT11231 Para. 3.3.2.

External Leakage testing was not performed due to the unavailability of the necessary test fixturing. The external leakage test was considered to be a low risk test and was performed following the shock and final performance test.

4.1.3 Regulator Performance Test per MRT11231 Para. 3.3.3

Performance data for s/n 003 was transcribed from A&TW 50E962, OP160, Table 3 Dated 4/19/02. Regulation and lockup was in specification as the regulator had been originally set up.

4.1.4 Random Vibration per MRT11231 Para. 3.3.4

The test article was installed into the vibration and shock set up per Figure 3 of MRT11231. The test pressure of 100PSIA was applied to the inlet, interstage and outlet during each axis of the random vibration test. The test article was subjected to a random vibration level of 11.1 Grms in the X, Y and Z axis for a period of one minute per axis. Following the completion of the random vibration requirements the test article was returned to ambient conditions. A visual inspection of the regulator indicated no external configuration damage. The regulator was then removed from the test set up and transported to the Moog Inc. clean room facility for post Random Vibration, pre Shock performance testing.

4.1.5 Performance Testing and Internal Leakage Per MRT11231, Para. 3.3.5.

Performance testing following the completion of the random vibration testing resulted in no abnormalities. Regulation bands for the 1st, 2nd and Two Stage operation are all within the parameters of MRT 11231, Rev. C. The regulator set points indicated no change from those set points established before Random Vibration. Regulation Data before and after Random Vibration testing is compared in Table 1. The lockup or leakage requirements were all achieved within the time required to meet the 0.04 psid for any two readings taken five minutes apart. Prior to and following the completion of the performance test the regulator was placed into a thermovac chamber at 140 degrees F to minimize the negative effects of moisture on the regulator performance insuring that the regulator would be tested under the same condition as prior to Random Vibration.

4.1.6 Pyroshock Testing Per MRT11231 Para. 3.3.6.

Pyroshock testing of the regulator was performed at MGA Research with the test article installed onto the PA001269 shock test fixture and set up per figure 3 of MRT11231 with the direction of the shock pulse being applied in the Z axis. The accelerometer triggering data collection is located on the beam near the fixture. The data accelerometers are located near the regulator mounting on a cube providing three axis accelerometer data in the X, Y and Z axis with the Z axis being the pulse direction accelerometer. Pulse verification was accomplished using a Moog Inc. provided dummy mass. The testing utilizing the dummy provided shock pulse data information that indicated an over test condition at the low, 350 to 500 Hz, and high, 6,500 to 10,000 Hz section of the shock spectrum. The amplitude of the over test was <200g at the low and <2000g at the high frequency sections of the shock spectrum. The dummy mass shock pulse spectrums were viewed by Moog Inc. and Stanford University engineering and deemed acceptable. Three consecutive shock pulses were performed all with similar results. The test article was installed in place of the dummy mass and pressurized to 300 +10/-0 psia at the inlet, interstage and outlet per MRT11231 para 3.3.6 pulse 1 instructions. Regulator performance was not attempted at the MGA Research facility in an effort to maintain a moisture free environment necessary for reliable regulator performance evaluation. The first shock pulse was completed 05/23/02. Following the completion of the first shock pulse the test article pressure was vented to ambient. The test regulator was removed from the test set up. A visual examination of the regulator indicated no external configuration damage resulting from the shock pulse exposure. The regulator was then taken back to Moog Inc. for performance testing per MRT11231, Para. 3.3.8 Rev. C.

Prior to Performance testing a Moog Inc. the regulator was placed into a thermo-vac chamber at 140 degrees F to minimize the negative effects of moisture on the regulator performance and insure conditions identical to prior performance runs.

Performance testing at Moog Inc. 05/28/02, indicated a shift in the regulation band. Regulation band data transcribed from MRT11231 is compared in the Table 2 matrix of this document. Regulation bands for the 1st, 2nd and Two Stage operation were all within the parameters of MRT 11231, RevC. The lockup or leakage requirements were all achieved within the time required meeting the 0.04 psid for any two readings taken five minutes apart.

The Regulator was subjected to two additional pulses each performed with the regulator pressurized to 100 +10/-0 psia per MRT11231 para 3.3.6 Pulse 2 and 3 directions. Each additional pulse was preceded by three dummy mass pulses and performance testing at Moog Inc. per MRT11231, para 3.3.8 rev.C. Performance testing indicated similar regulation band shifts with regulation bands for the 1st, 2nd and Two Stage operation all within the parameters of MRT 11231, RevC. The lockup or leakage requirements were all achieved within the time required meeting the 0.04 psid for any two readings taken five minutes apart. All regulation band data transcribed from MRT11231 is compared in the Table 2 matrix of this document.

Test data per MRA11231 para 3.3.6 copied from MGA Research report No. C02E1-067 showing the shock pulse data overlaid on the shock pulse spectrum parameters for the dummy mass and the Moog Inc. 50E962, S/N 003 regulator are included in appendix 1.

4.1.7 External Leakage Testing Per MRT11231 Para. 3.3.7.

External leakage was performed at Moog Inc. using fixture number PA001289 and a mass spectrometer. The regulator inlet and interstage were pressurized to 2000 psia with an outlet pressure of 50 psia GHe for a period greater than 5 minutes. Using a mass spectrometer with a sensitivity of $>1 \times 10^{-10}$ scc/sec Helium, the measured leakage was 1.1×10^{-9} scc/sec He exceeding the 1×10^{-6} scc/sec maximum specified leakage.

Table 1

Regulator Performance Data for 50-962, S/N 003 High Flow Regulator as recorded before and after Random Vibration testing Per MRT 11231, Rev.C 5/22/02			
	<u>Before Vibration</u>	<u>After Vibration</u>	<u>Delta</u>
1st Stage 100 PSIA			
Flow			
2 SCCM	21.903	21.985	+0.082
725 SCCM	21.679	21.677	-0.002
800 SCCM	21.670	21.668	-0.002
2000 PSIA			
Flow			
2 SCCM	22.193	22.106	-0.087
725 SCCM	21.902	21.836	-0.066
800 SCCM	21.839	21.827	-0.012
2nd Stage 100 PSIA			
Flow			
2 SCCM	21.101	20.966	-.135
725 SCCM	20.748	20.690	-.058
800 SCCM	20.755	20.686	-.069
2000 PSIA			
Flow			
2 SCCM	21.612	21.385	-0.227
725 SCCM	21.327	21.067	-0.305
800 SCCM	21.360	21.070	-0.290
TWO Stage 100 PSIA			
Flow			
2 SCCM	20.815	20.730	-0.085
725 SCCM	20.165	20.135	-0.030
800 SCCM	20.144	20.110	-0.034
2000 PSIA			
Flow			
2 SCCM	20.852	20.809	-0.043
725 SCCM	20.216	20.096	-0.120
800 SCCM	20.182	20.079	-0.103

High Flow Regulator Protoqualification Test Report for 50E962
Revision: Orig.

Table 2

Regulation Data following Shock testing of the 50E962 High Flow Regulator								
Data is transcribed from MRT11231 (6-06-02)								
	Post Vibe	Post Pulse#1	Delta	Post Pulse#2	Delta	Post Pulse#3	Delta	Total Delta
	5/22/02	5/28/02		6/3/02		6/5/06		
	100 PSIA	300 PSIA		100 PSIA		100 PSIA		
1st Stage								
100 PSIA flow								
2 sccm	21.958	21.375	0.583	21.087	0.288	21.043	0.044	0.915
725 sccm	21.677	20.906	0.761	20.798	0.108	20.697	0.101	0.97
800 sccm	21.668	20.933	0.735	20.789	0.144	20.687	0.102	0.981
2000 PSIA flow								
2 sccm	22.106	21.662	0.444	21.041	0.621	21.638	-0.177	0.888
725 sccm	21.836	21.286	0.55	20.721	0.565	20.994	-0.273	0.842
800 sccm	21.827	21.247	0.58	20.713	0.534	20.976	-0.263	0.851
2nd Stage								
100 PSIA flow								
2 sccm	20.966	20.616	0.35	20.411	0.205	20.486	-0.075	0.48
725 sccm	20.69	20.264	0.426	19.938	0.326	19.873	0.065	0.817
800 sccm	20.686	20.248	0.438	19.935	0.313	19.865	0.07	0.821
2000 PSIA flow								
2 sccm	21.358	21.107	0.251	21.041	0.066	21.151	-0.11	0.207
725 sccm	21.067	20.828	0.239	20.721	0.107	21.04	-0.319	0.027
800 sccm	21.07	20.819	0.251	20.713	0.106	21.032	-0.319	0.038
Two Stage								
100 PSIA flow								
2 sccm	20.73	20.324	0.406	20.039	0.285	19.947	0.092	0.783
725 sccm	20.135	19.713	0.422	19.372	0.341	19.247	0.125	0.888
800 sccm	20.11	19.661	0.449	19.341	0.32	19.228	0.113	0.882
2000 PSIA flow								
2 sccm	20.809	20.315	0.494	20.063	0.252	19.996	0.067	0.813
725 sccm	20.096	19.691	0.405	19.416	0.275	19.33	0.086	0.766
800 sccm	20.079	19.668	0.411	19.385	0.283	19.318	0.067	0.761

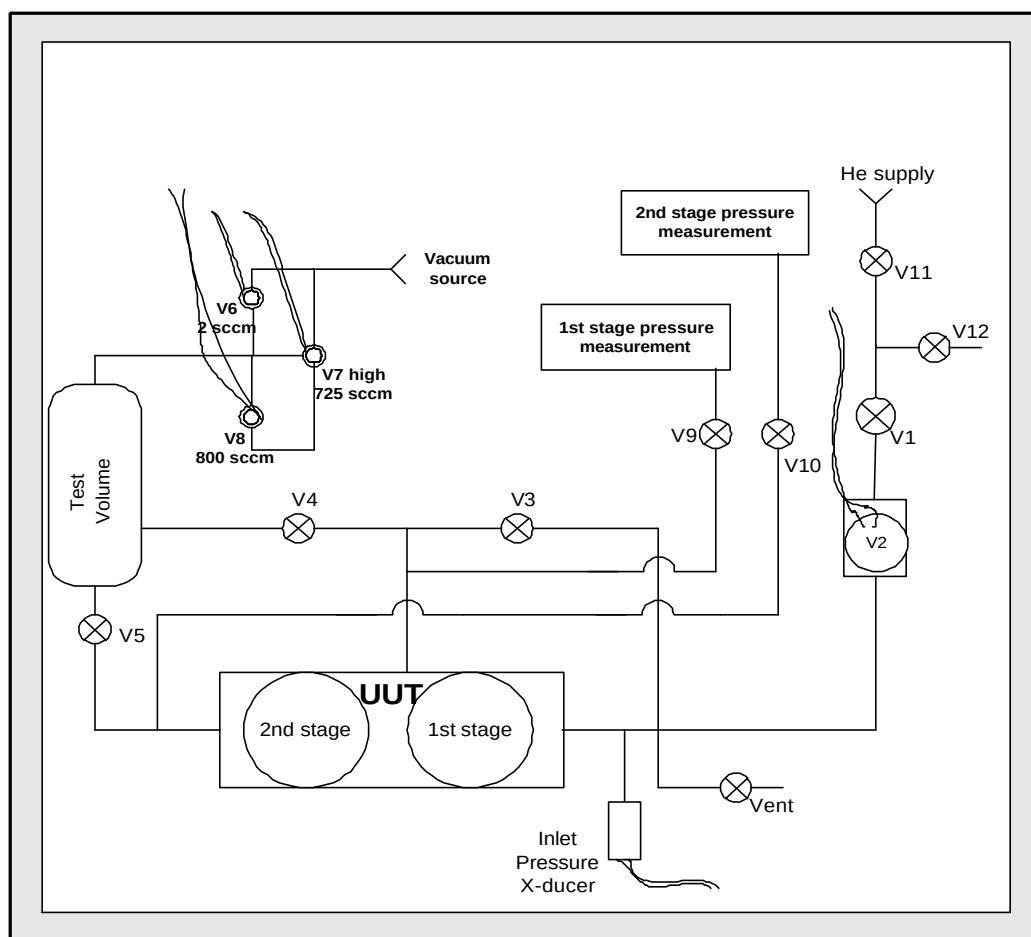
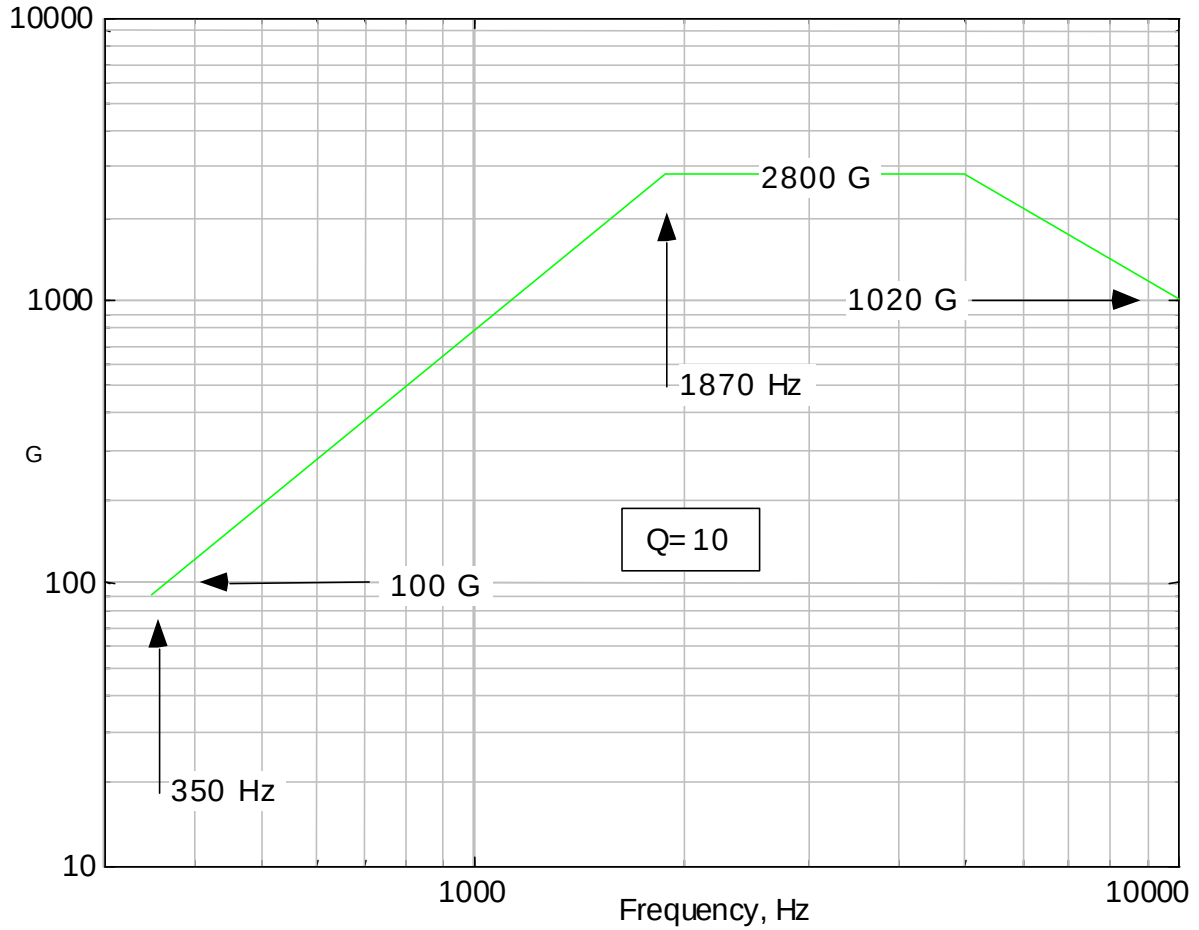


Figure 1



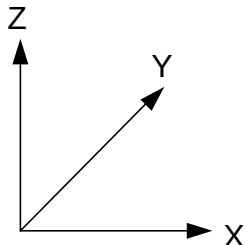
Pyroshock Environment
Shock Response Spectrum

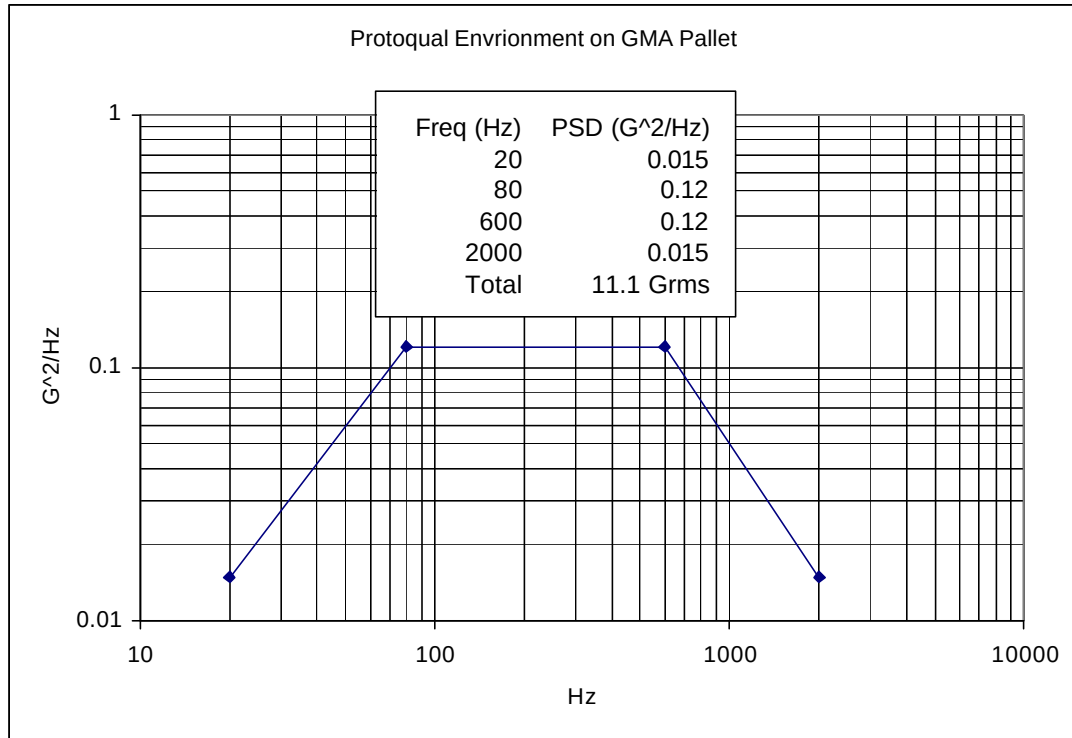
Frequency (Hz)	G's (Q=10)
350	100
1870	2800
5000	2800
10000	1020

Pyroshock Spectrum

Figure 2

Figure 3





GMA Protoqual Random Vibration Environment

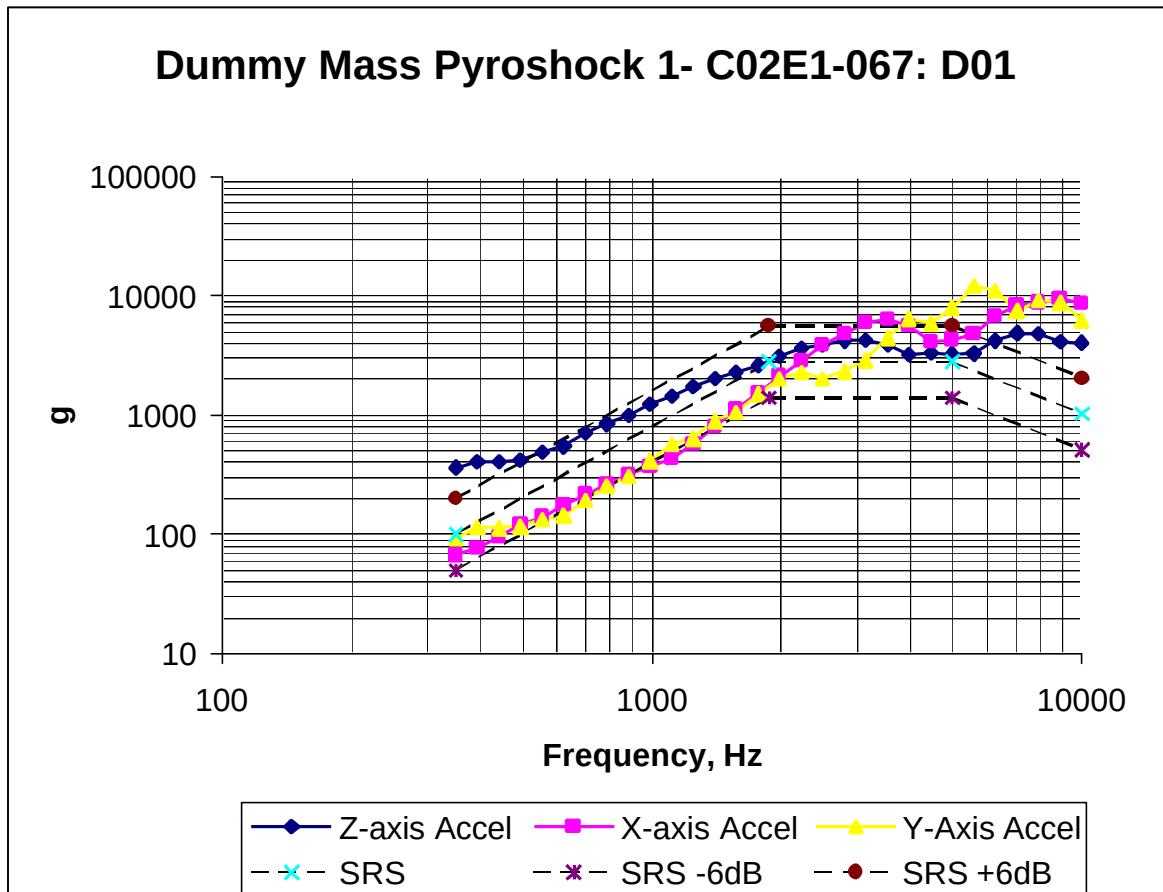
Figure 4

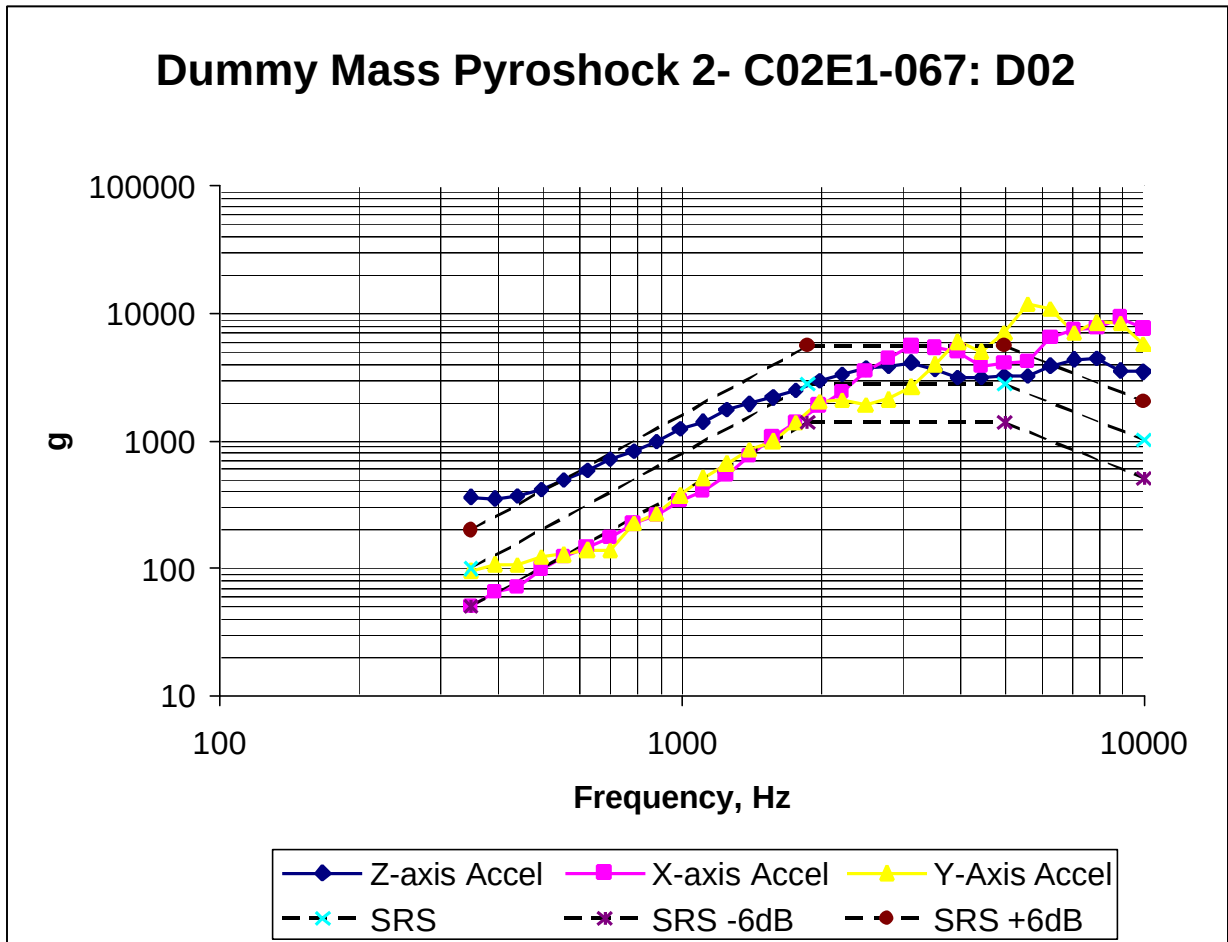
PSD:	20 to 1000 Hz:	+/-1.5dB
	1000 to 2000 Hz:	+/-3dB
RMS:	±10% overall	

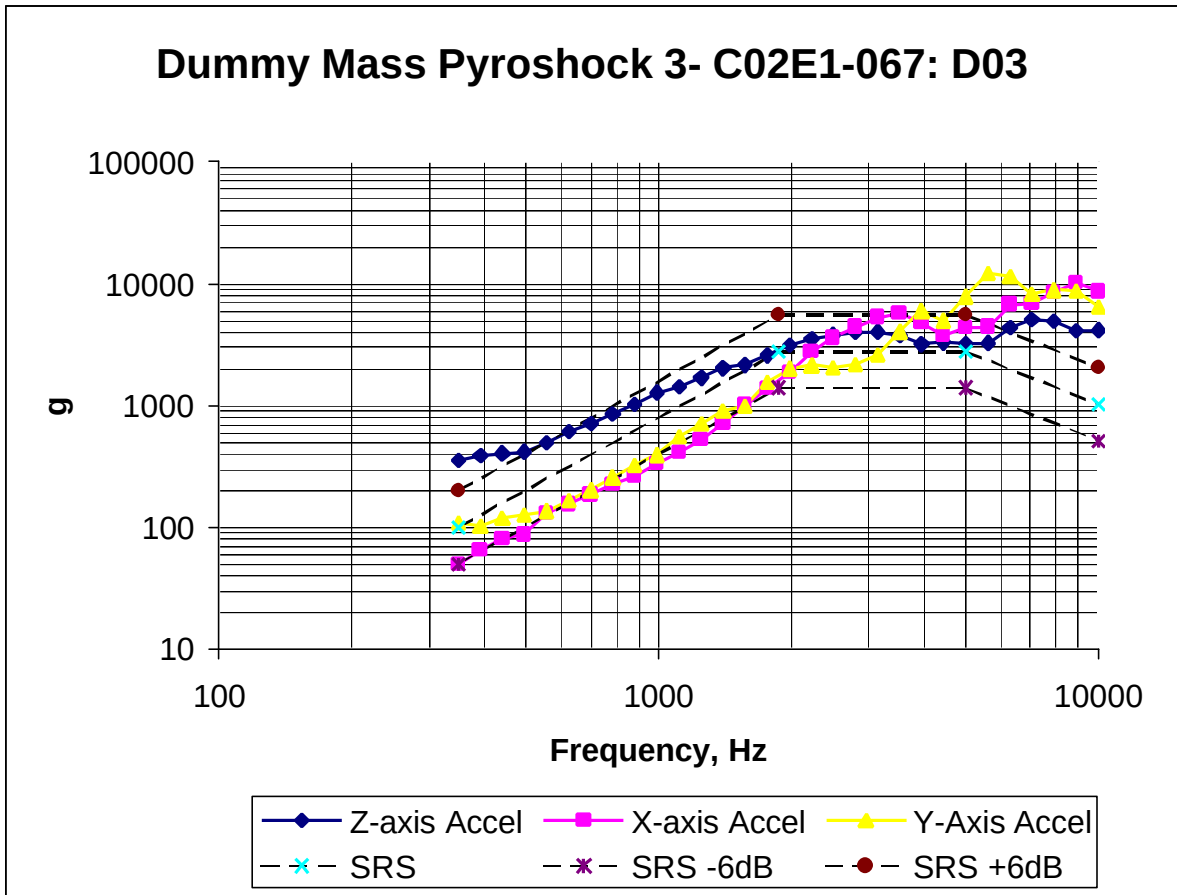
APPENDIX 1

Test Information

Test Data File Name		D01					
Beam Fixture Type		---					
Beam Fixture Configuration		Length	80"	Width	3"	Height	6"
		Span	54"				
Unit Type, Model & S/N		Type	Regulator	Model	n/a	S/N	n/a
Unit Installation Orientation		Z-axis					
Fire Direction	Z		Damper		5/8AL		
Fire Pressure (psi)	203		Trigger Level (V)		.03		
a)	Dummy mass acceptance hit #1						



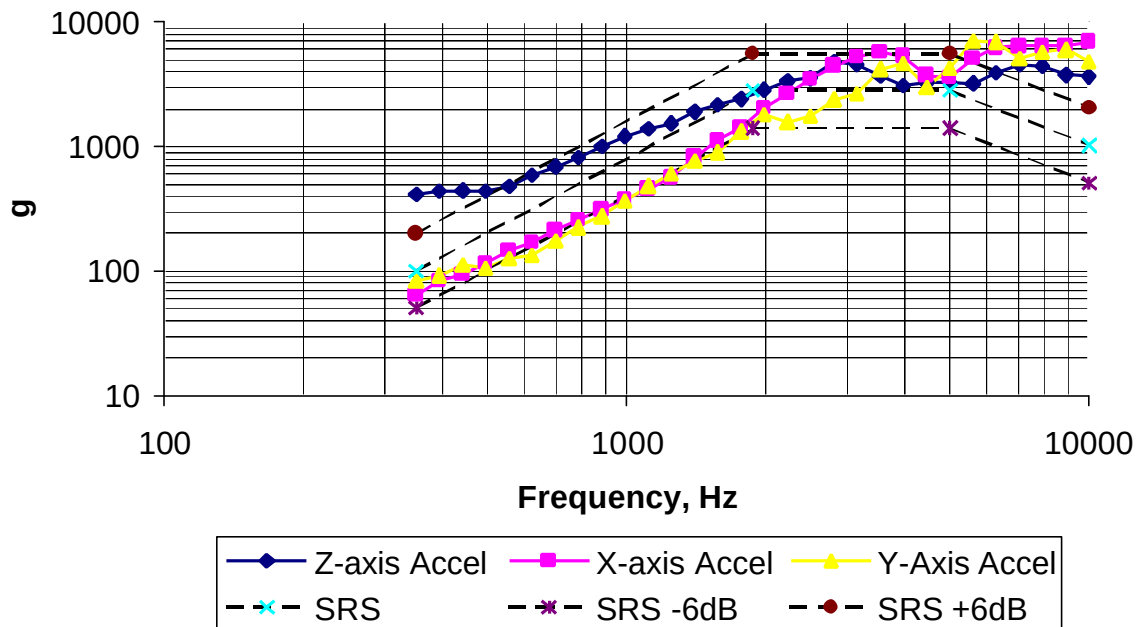


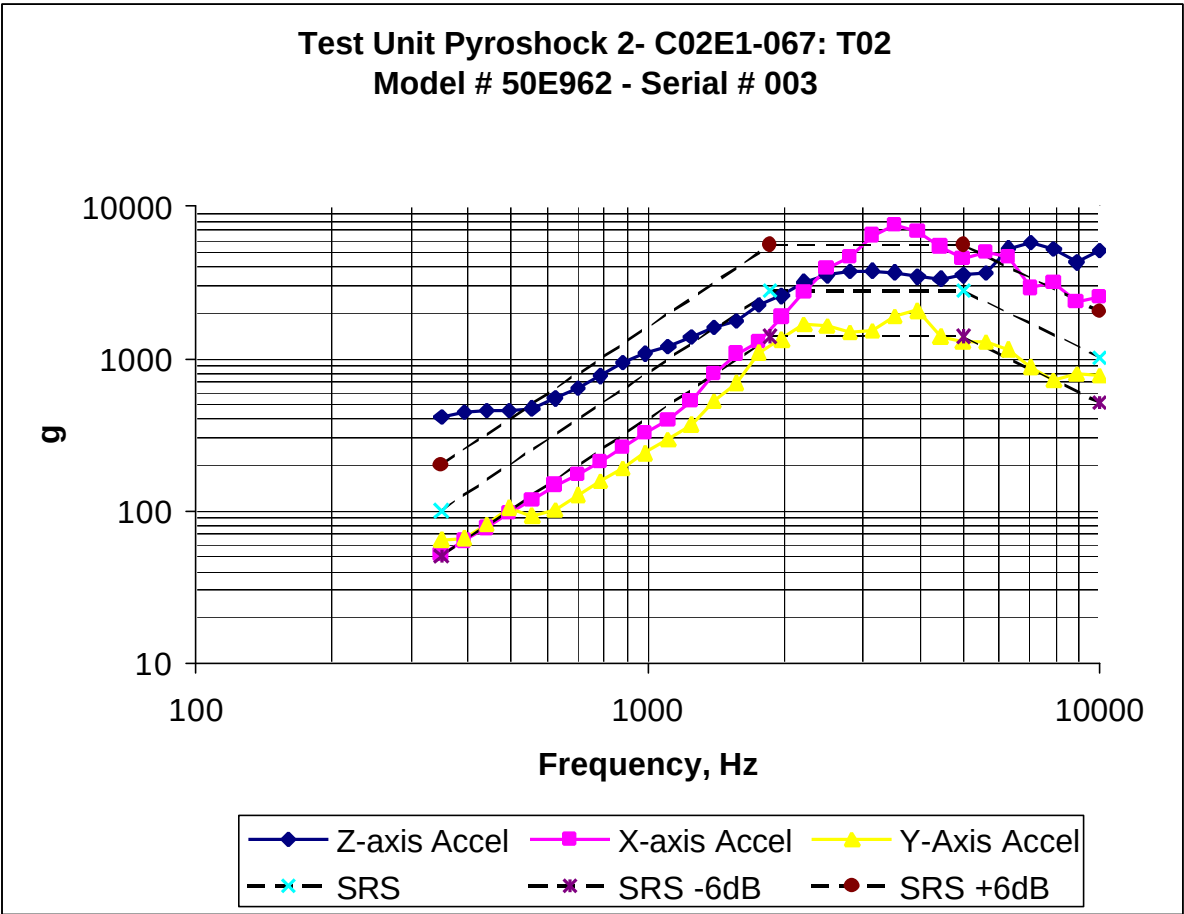


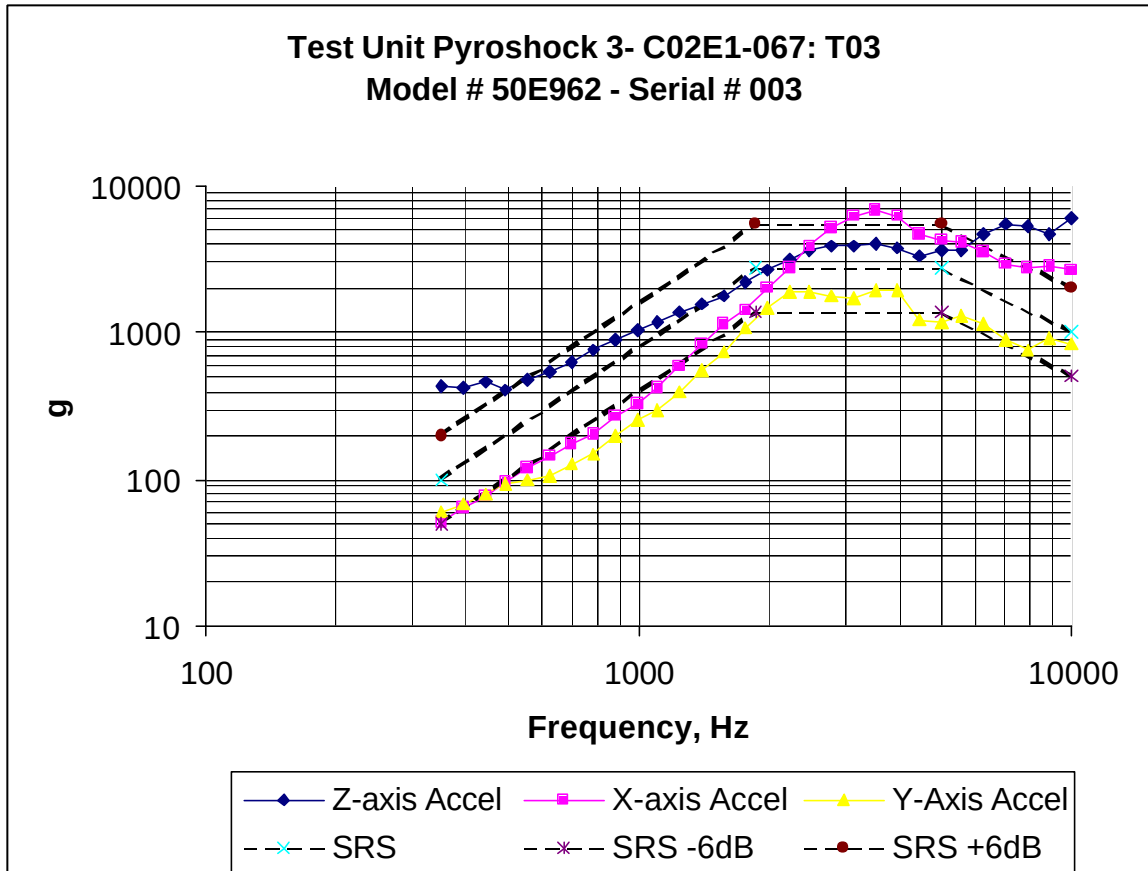
Test Information

Test Data File Name	T01					
Beam Fixture Type	---					
Beam Fixture Configuration	Length	80"	Width	3"	Height	6"
	Span	54"				
Unit Type, Model & S/N	Type	Regulator	Model	50E962	S/N	003
Unit Installation Orientation	Z-axis					
Fire Direction	Z		Damper		5/8AL	
Fire Pressure (psi)	203		Trigger Level (V)		.03	
b)	Regulator s/n 003 hit #1					

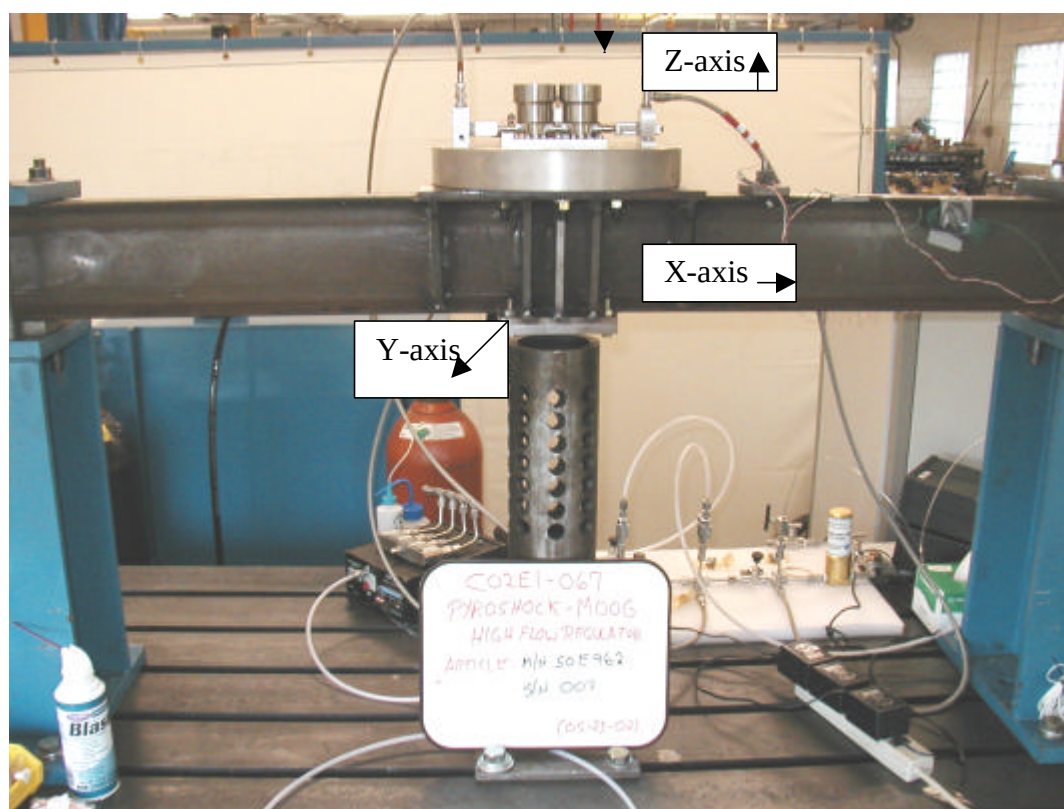
Test Unit Pyroshock 1- C02E1-067: T01 Model # 50E962 - Serial # 003







Mechanical Impulse Pyroshock Simulator Test Set Up At MGA
Research Corporation



D.2 Moog Latch Valve FAR

- Moog FAR
- Leak rate spreadsheet
- Spare valve data
- Fault analysis spreadsheet

 FAILURE ANALYSIS REPORT	<u>Customer:</u> Stanford University	<u>Product Name:</u> Gas Management Assembly (GMA)	Moog Report No. FAR(M)2002- 063 Revision A
			Originator: Paul King
			Quality: John Bonanno
	<u>How Reported:</u> MDR 449854 & 449858 FR(M) 2002-047	<u>Model Number:</u> 50E961 (51E265)	Engineering: Paul King
	<u>Test Document</u> MRA13238 Para. 3.3.4	<u>Serial Number:</u> 001	Customer Rep (If Req'd): N/A
	<u>Moog Part No.:</u> C58800	DCMC (If Req'd): N/A	
<u>Date of Analysis:</u> 6/28/02 – 2/11/02	<u>Cust. Report No.:</u>	<u>Customer Part No:</u> LMSSC 8A02681-101	<u>Issue Date:</u> Original: September 5, 2002 Revision A: February 11, 2003

Report Sequence: (1) History (2) Analysis (3) Conclusions (4) Corrective Action

HISTORY:

Immediately after completing vibration testing per MRA13238 of Moog Model 50E961, Gas Management Assembly (GMA), the internal leakage rates of Moog Latch Valves (Model 51E265) V27 and V29 were measured because of earlier high leakage rates collected during bubble leak testing and post proof internal leak testing. The post-vibration leak rates from both valves exceeded the GMA specification limit of less than 1.0E-04 sccs GHe. These results lead Moog to measure the leakage of all the GMA latch valves. This testing revealed that the V4/V6 valve pair (configuration permits the leakage testing of the valves as a pair only), V11 and V15 exceeded the leakage specification requirement. With concurrence from Stanford University, a series of leakage tests, which required cycling valves, were performed. The V4/V6 valve pair and V15 continued to indicate high leak rates. In order to determine the overall health of the GMA, Moog proceeded with the remainder of the post-vibration testing of the GMA, which included additional internal leakage testing of the latch valves. This testing revealed that valves V21, V27 and V28 also indicated leak rates greater than the specification requirement. At this point GMA testing per MRA13238 was halted. Upon completion of the testing up to this point, the following valves presented suspect/non-conforming performance: V4/V6 pair, V11, V15, V21, V27, V28, V29.

A "Tiger" team was formed consisting of Moog (Paul King, Ron Anderson, John Bonanno), Stanford University (Rob Brumley, Chris Gray, Ken Bower, Ray Pressburg, Bill Wissert), NASA-MSFC (DeWitt Burns, Kent Chojnacki) and Lockheed Martin (Jim Bush). At the direction of the Tiger team, some additional leak testing was performed to investigate the testing method, to characterize the valve leakage behavior versus pressure (see attached plot) and better characterize helium background levels. The Tiger team also concluded that removing the non-conforming valves from the GMA is a worse case exercise warranted by degradation of additional valves and/or additional degradation of internal leakage performance of the valves in question. The basis for this conclusion was the inherent contamination risks to the GMA resulting from cutting valves out of the GMA. However, this course of action does not permit a disassembly/inspect of the questionable valves. The Tiger team also agreed to go forward with testing of the GMA per MRA13238, which included thermal/vacuum testing and several more latch valve internal leakage tests. This testing was completed. An important observation from the all data is that no additional latch valves degraded and the valves were generally consistent in leakage rate from test to test. Some valves also showed some improved performance. Also, the valves in question (V4/V6 pair, V11, V15, V21, V27, V28, V29) did not get any worse. The data from all the additional internal leakage testing and the internal leakage testing per MRA13238 are summarized in the Summary GMA PTP MRA13238 and AVO Internal Leakage Data matrix attached.

Per the direction of the Tiger team, two spare GMA latch valves were subjected to a series of tests including cycle testing and vibration testing. These valves were also subjected to cleanliness sampling to determine the level of particulate in the valve after certain tests. The internal leakage was measured throughout these tests. The valves

MOOG INC. FAILURE ANALYSIS REPORT
(CONTINUATION SHEET)

P/N: C58800	S/N: 001	CUSTOMER: Stanford University	FAR NO. FAR(M)-2002-063 Rev A

were also welded into a mini assembly similar to sub-assemblies used in the GMA. Internal leakage was measured after assembly and the mini assembly (see attached Moog C78437) was subjected to additional vacuum and thermal testing to determine if this type of exposure can degrade sealing characteristics of the Vespel SP-1 (unfilled) poppet material in each valve. Samples of this material were also exposed to these conditions and then tensile tested by an outside lab to determine if the material properties (yield strength, %-elongation) of the Vespel are affected. During this investigation using the spare latch valves and Vespel samples, the GMA was shipped to Stanford University since the GMA test results met the Tiger Team requirements for use-as-is: the performance of the GMA latch valves in question did not degrade further and no additional valves degraded upon completion of protoflight testing.

Spare latch valve SN007 exhibited a general shift in leakage performance from the 1E-07 sccs GHe range to 10E-06 sccs GHe range after integration into the mini assembly. This valve also presented several leakage measurements in the 1E-05 sccs GHe range and one value at 2.0E-04 sccs GHe. Although the performance of this valve was very good, the general shift and outlying data points raised suspicion about the valve. The valve was disassembled and inspected. Spare latch valve SN022, which did not exhibit any shift in internal leakage performance, was also disassembled for comparison.

MOOG INC. FAILURE ANALYSIS REPORT
(CONTINUATION SHEET)

P/N: C58800	S/N: 001	CUSTOMER: Stanford University	FAR NO. FAR(M)-2002-063 Rev A

ANALYSIS:

For reference a functional cross-section of the 51E265 is included at the end of this report as well as a schematic of the GMA and a top view of the GMA indicating valve locations. To facilitate the search for a root cause(s) of these non-conformances, a fault matrix was created, which identifies the subject valves (V4/V6 valve pair, V11, V15, V21, V27, V28 & V29). This matrix is attached. Many of the potential causes are deemed not credible since many of the causes would result in gross leakage or would affect other performance parameters of the valve such as valve response. The Tiger team also used this matrix to determine a pathway for additional investigative testing.

The main focus of the Tiger team effort was to determine why the leakage performance of the valves, in general, degraded from ~1.0E-07 sccs GHe leakage at the component level to >1.0 E-06 sccs GHe at the GMA level and to determine why the valves in question degraded to ~1.0E-04 sccs GHe. The key concerns with regard to excessive latch valve internal leakage are:

1. Loss of lock-up pressure for the GMA regulators prior to launch, which could result in damage to the regulators during the launch shock environment.
2. Helium leakage into the science probe prior to launch, which could degrade the downstream science probe.
3. Leakage of air into the GMA through the vent valve prior to launch, which would degrade the GMA helium purity.
4. General loss of helium that may result in insufficient gas for the mission.

In addition to investigating the causes for excessive leakage of the latch valves, the team also discussed ways to allow the GMA to be used "as-is" provided the internal leakage performance did not get worse after completion of the testing per MRA13238. Stanford would also need to determine ways to mitigate any risks related to the higher leakage rates from the six questionable valves. The mitigation methods discussed at the Tiger team meeting included selecting which valves would be open or closed during launch to minimize leakage into the probe, but maintain ECU redundancy, keep the vent line capped for as long possible, maintain 300 psia helium throughout the low-pressure side of the GMA and keeping all the valves closed as long as possible before launch. The results of this portion of the investigation are available from Stanford University.

As a result of Tiger team discussions, some additional testing was deemed worthwhile to help with resolving the likelihood of specific causes. These tests/investigations include:

- A. Cycle testing of two spare latch valves (51E265, SN007, SN022) to determine if self-generated contamination is a cause: See attached MRA16475 summary matrix. The first 1000 mL effluent IPA sample was collected from each valve and passed through a filter patch. The particles on the patch were then categorized by size and counted under a microscope. After sampling, the valves were certified clean to the GMA requirement before proceeding to the next test. The two latch valves tested did indicate particulate counts greater than the certified clean limits established for the GMA program. The concern for Moog is particle size greater than 100 microns. Some particles of this size were found during this testing and in subsequent cleanliness sample tests performed after the tests described below. Several of these particles were isolated and examined by Moog Material Process Engineering using FTIR and SEM/EDS analysis. These particles were identified as follows: polyurethane polymer (e.g. Spensol L-44, source unknown), nitrocellulose (source: filter patch material), secondary amide (source: human skin), PH stainless steel (source: fixturing, inlet fitting of latch valve). With the exception of the polyurethane polymer, these particles are consistent with contamination from handling and hook-up debris. These materials may have been in the valves or could have been introduced during the sampling procedure. There was no evidence of Vespel, EPR (o-ring), Teflon (bearing rings on armature), CRES 430 or CRES 300 series or braided shielding, all of which are possible materials from the latch valves. The only

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exception was the PH stainless, which could have come from the **filter housing** (15-5 PH) of the latch valve. Note that when a valve is certified clean, IPA is flowed through the valve for two minutes prior to taking a sample. Comparing the first 1000 mL to the certified clean standard is a very conservative approach. The valves did not show any sign of leakage performance degradation. While the spare valves tested were not affected by the presence of these particles, Moog cannot rule out some form of contamination as a root cause for the six valves in question.

- B. Vibration testing of two spare latch valves to determine if the valves are damaged in any way: See attached MRA16475 summary matrix. The two latch valves (SN007 and SN022) were vibration tested in the open condition (see item D below) while mounted in the "stacked" GMA configuration. The GMA level random vibration spectrum was the test input. The valves were cycled and leak tested after each axis. The testing did reveal that the upper valve was subjected to vibration levels of ~40 Grms. The valves did not show any sign of leakage performance degradation or any other valve performance degradation. Since the two spare valves and the majority of the GMA valves continue to perform within specification, Moog does not believe that the vibration testing was a root cause. However, the vibration testing could be coupled with a contamination issue, i.e., vibration freed trapped contamination.

Two Mott flow restrictors were also exposed to vibration testing. The restrictors were then sampled for particles. No metallics were generated from exposure to the vibration environment indicating that the sintered material was not damaged and did not shed. The particle counts were high on one unit, but this is attributed to the sampling technique. The technique was altered on the second unit, which indicated a very "clean" unit. The Motts are not viewed as a source of contamination.

- C. Investigate helium background of GMA and test methodology: See the attached GMA Latch Valve Internal Leakage Fault Analysis matrix. A calibrated leak device (1.5E-05 sccs GHe) was plumbed into the GMA at the GMA vent line. The mass spectrometer was capable of measuring the calibrated leak. The calibrated leak device was subsequently removed from the GMA vent line. Also, the sequence in which valves are leak tested and evacuated to testing was found to have some affect on the leakage measurements when measuring the internal leakage of individual valves. Subsequent testing instructions addressed this issue. However, the magnitude of this adjustment was minor and is not considered a cause for the excessive leak rates.
- D. Review the build paperwork and As-Built-Configuration-Records (ABCRs) from all the valves: All the build data was reviewed to determine if there was any trend in the data to suggest that the valves in question had something in common that would point to a root cause. No trend could be identified with regard to:
- Material/part lots, i.e., material/poppet lots from the valves in question were also used in valves with leakage two orders of magnitude better. This included the poppets, outlet fittings (seats), armatures, poppet springs and cores.
 - Build/performance parameters, e.g., spring preload, valve and poppet stroke, latching force, response, pull-in current.

A trend with regard to weld reworks was noted for valves V27, V28 and V29. All valves except V1 and V2 had the filter body weld reworked. However, V27, V28 and V29 were reworked twice, which exposed these valves to an additional deburring operation. The handling of these valves was consistent with other rework operations. Another trend associated with these particular valves is the fact that they are located in the vent line. The vent line is the primary purging line for GMA testing. This level of gas throughput may offer more opportunity for contamination of the valves. Beyond identifying these trends, no other conclusions were drawn.

The only other trend identified is the valve open/close status and position in the mounting brackets during vibration testing. The V4/V6 pair, V27 and V29 indicated leakage performance problems prior to vibration. However, V11, V15, V27 were open during vibration and located in the upper portion of the mounting bracket. It is important to note that V11 and V15 have a history of intermittent leakage performance, which implies that any

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acceptable leakage data taken prior to vibration was a random occurrence. Additional testing prior to vibration testing may have revealed unacceptable values, as well. V21 was located in the upper portion of the bracket, but was closed during vibration. Also, the valve had acceptable leakage values immediately after vibration testing.

Valve Location	Open/Close Status During Vibration/Launch	Mounting Bracket Location	Non-Conforming Valve
V1	Closed	Lower	
V2	Closed	Lower	
V3	Closed	Upper	
V4	Closed	Upper	X (paired with V6)
V5	Closed	Lower	
V6	Closed	Lower	X (paired with V4)
V7	Open	Upper	
V8	Open	Lower	
V9	Closed	Upper	
V10	Closed	Lower	
V11	Open	Upper	X
V12	Open	Lower	
V13	Closed	Upper	
V14	Closed	Lower	
V15	Open	Upper	X
V16	Open	Lower	
V17	Closed	Upper	
V18	Closed	Lower	
V19	Open	Upper	
V20	Open	Lower	
V21	Closed	Upper	X
V22	Closed	Lower	
V23	Open	Upper	
V24	Open	Lower	
V25	Closed	Upper	
V26	Closed	Lower	
V27	Open	Upper	X
V28	Open	Lower	X
V29	Closed	Upper	X
V30	Closed	Lower	

- E. Investigate the weld assembly process of the GMA latch valve sub-assemblies as a source of contamination: See attached MRA16475 summary matrix. Using valves SN007 and SN022, Moog welded a mini-assembly per C78437 using the same processes and procedures used when welding the GMA latch valve quad and double valve sub-assemblies. This included not protecting the weld process from potential handling contamination from the latch valve lead wire shielding (It was noted during the GMA build that the shielding harbored contaminants. After this was noticed, the shielding was bagged to reduce risk of contamination). Immediately after assembly, the leakage performance of both valves measured ~1.0E-05 sccs GHe. After cycling, the valve leakage performance improved and returned to a level of leakage consistent with the component level leakage performance. However, the internal leakage performance of SN007 did present a general shift from the 1.0E-07 sccs GHe range to the 1.0E-06 sccs GHe range. Valve SN022 did not present this same performance shift. The assembly was also sampled for cleanliness. The particle analysis is detailed in the above discussion.

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While the investigation of the integration process did not lead to a repeat of permanent internal leakage performance degradation on par with the GMA valves, Moog cannot rule this item out as a root cause.

- F. Investigate the potential degradation of the Vespel poppet material as a result of exposure to vacuum and helium at elevated temperatures (104 F to 140 F): During the build of the GMA latch valves, Moog observed that the %-elongation of Vespel might have an affect on the sealing characteristics of the latch valve poppet. The theory with regard to %-elongation is that the lower the % elongation, the more "brittle" or less compliant the Vespel material is for sealing purposes. A concern was raised that the Vespel could be affected by long-term exposure vacuum (via outgassing of Vespel constituents) and/or helium in such that that the %-elongation of poppets in the valves could be affected, or otherwise embrittled, in such a way to degrade leakage performance of SN007. To investigate this concern, the valve mini-assembly was exposed to vacuum and helium. The valves did not show any immediate sign of leakage performance degradation. However, additional cycling (500 cycles total, leakage measured at 100 cycle intervals) of the valves per AVO51E265RA20 showed additional degradation in leakage performance. Several internal leakage measurements were in the 1.0E-05 sccs GHe range and one measurement was 2.0E-04 sccs GHe. In an attempt to improve leakage performance, the mini assembly was flushed with 300-psig helium per "AVO-PTK-100402-Latch Valve GHE Flush at 300 psig" in an effort to remove possible contaminants at the valve seat. No change in performance was noted. Next, SN007 was exposed to 300 psig in the closed position for 48 hours while at 145 F per AVO-PTK-GMA Valve Heating, in an attempt to recoin the seat. No change in performance was noted.

Lockheed Martin (LMSSC) also subjected the poppet material (VESPEL SP-1) to an outgassing test. Below is an e-mail response from Jim Bush from LMSSC regarding the results of this test:

"Jeff Garrett (one of the original designers of the ASTM 1559 test apparatus) runs his own commercial company which runs outgassing tests for a variety of companies. The name of the company is Outgassing Services International in Palo Alto. He has recently tested Vespel SP-1 for a commercial customer. Vespel is seeing some use in GC/MS instruments and high vacuum systems. The test was run at 125 C for a 24-hour period under vacuum conditions of 10⁻⁷ or 10⁻⁸ torr. The results of the test show the following. 1) 99.998% of the outgassing product was water, 2) The VCM for two different runs were 0.001 and 0.002% 3) the outgassing curve was fairly steep with all of the water coming out very rapidly at 125 C and going asymptotic at 24 hours. There was no mass spec data taken to ID the off gassing products but they were at such low levels that the customer did not feel it was important.

Unfortunately since the testing was done for a commercial customer Jeff could not give me a copy of the data since it belongs to that customer. With just the verbal information it was very apparent that with the data that Jeff gave me it would not make sense to run outgassing tests on the material at 40 C or 140 F since the data above was at an even higher temperature and it did not drive off significant outgassing products.

Since outgassing under temperature and vacuum does not seem to be significant the next question is how does helium affect the material and/or does temperature/vacuum cause any changes in physical surface properties, which would affect the shoulder sealing area of the poppet. These questions should be answered in the aging studies you are conducting with the testing at the end."

Moog also performed a Vespel SP-1 aging investigation of vespel samples machined for tensile testing and two poppets. These samples were exposed to vacuum and helium for an extended period of time at temperatures between 104 F and 140 F to "age" the Vespel.

The poppet samples exposed to the vacuum/helium conditions were examined using the Moog Scanning Electron Microscope (SEM). These were compared to two poppets not exposed to vacuum. No difference was noted between the four poppets, e.g., no crazing or other surface disruption. This result agrees with information from Dupont, the manufacturer of Vespel, which states that vacuum/helium exposure would not significantly reduce Vespel properties.

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In the case of the Vespel tensile samples, two different lots (3/8"-OD and 1/4"-OD rod samples) were tested. Two from each lot were exposed to the vacuum/helium environment, while two from each lot were used as control samples. The data from the tensile testing are included in this report. The data indicate a relatively wide spread in tensile strength (UTS= UYS) and %-elongation within a lot of material.

- The 3/8" OD lot of material was certified to a tensile strength of 14,777 psi and %-elongation of 13.3%.
 - The control samples tested: 14296 to 14691 psi and 10.65% to 11.44%.
 - The test samples tested: 12,338 to 14,306 psi and 5.7% to 8.8%.
- The 1/4" OD lot of material was certified to a tensile strength of 14,396 psi and %-elongation of 10.3%.
 - The control samples tested: 10,615 to 14,664 psi and 4.21% to 13.18%.
 - The test samples tested: 13,254 to 14,031 psi and 6.73% to 6.95%.

In both lots tested, the samples exposed to the vacuum/helium environment exhibited much lower %-elongation values than the %-elongation recorded in the vendor material certifications. However, the control samples also exhibited %-elongation values both greater and less than the %-elongation recorded in the vendor material certifications. While some variation is expected, this range of variation is larger than typical according to Dupont, especially for the control samples for the 1/4" OD lot. Dupont believes that the large variation was due to specimen geometry and/or measuring technique. Moog M&PE agreed that the variation is related to the geometry of the sub-sized tensile bars. However, Moog cannot rule out variation in material properties as being a contributing factor in leakage performance. Moog also believes that the test was inconclusive in determining that the vacuum/helium exposure played a role in degraded leakage performance.

G. Disassembly of 51E265, SN007 and SN022: Since SN007 displayed a general trend towards degraded leakage performance; the valve was disassembled per the instructions of Moog AVO-GMA-10-18-02 Latch Valve SN007 Removal. Note however, that the valve leakage performance was typically in the mid 1.0E-06 to mid 1.0E-05 sccs GHe range. Upon completion of the disassembly and inspection of SN007, SN022 was also disassembled for comparison. Valve SN022 did not exhibit any shift in performance. The disassembly of SN022 was performed using the same instructions used for SN007.

The outlet weld was machined in such a way as to reduce the potential of machining debris from entering the valve's wetted area. The condition of the outlet fitting/seat, armature/poppet assembly, core pieces and filter were inspected. The following noteworthy observations were recorded. Unless otherwise noted, inspections were performed using 20-30X magnification. Photos of SN007 are included at the end of this report. Photos of SN022 are also included, but these photos are limited to Moog SEM photos since the piece parts generally looked the same except where noted below. All piece parts are in storage at Moog.

1. Outlet fitting/seat:

SN007: appears normal with no obvious leak scratches that could contribute to leakage. Using the Moog SEM, some surface staining of the seat was observed in the approximate area where the poppet seals on the seat. The stains do not appear to alter the surface and are ~10-microns in size. These stains could also be thin films of Vespel transferred from the poppet. This observation is based on the fact that non-metallics/organics appear as dark spots when viewed with the SEM and the fact that the stains are in a circumferential pattern that would correspond to the poppet sealing surface. Location, size and thickness of these stains make it impossible for Moog's equipment to identify the chemical nature of the stains. The EPR o-ring was also in good shape and did not show evidence of nicks, missing material or trapped contamination.

SN022: appears generally the same as SN007 except no stains were observed. The seat also exhibited a scratch that was located outside of the sealing area. The o-ring as was also in good condition.

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2. Outlet core:

SN007: swage appears normal with no evidence of burrs. The surface of the core that contacts the armature face showed signs of polishing/burnishing from repeated cycles. The shape of the burnish marks also suggests that the armature rotates, either due to cycles or from vibration testing (see below).

SN022: swage appears typical. Also exhibited burnish marks from cycling.

3. Inlet core:

SN007: swage appears normal with no evidence of burrs. The surface of the core that contacts the armature face showed signs of polishing/burnishing from repeated cycles, but to a lesser degree than the outlet core.

SN022: appears typical.

4. Armature assembly:

SN007: armature surfaces show polish/burnish marks corresponding to the marks observed on the inlet/outlet cores. The Teflon bearings appeared normal, i.e., no signs of heavy wear or nicks, missing Teflon or trapped contamination. The poppet retainer, coil spring and shims all appeared in nominal condition. No signs of contamination or damage.

SN022: armature presents similar burnish marks. The Teflon bearings, coil spring, shims and retainer appear typical.

5. Poppet:

SN007: The sealing surface of the poppet showed evidence of coining. The poppet was examined in the Moog SEM and compared to a poppet that was never used. The coining was very apparent, but no signs of chipped Vespel at the sealing edge or cracks were observed at high magnification. The poppet was sent to Lockheed Martin in Sunnyvale (Jim Bush) for additional analysis. Lockheed performed some visual inspections of both the SN007 poppet and the unused poppet at even high magnification using a SEM. Both poppets presented surface defects on the order of 20-microns or less at the sealing surface. These features appear as scratches/crevices/cracks and localized high and low spots. The SN007 poppet also presented some areas that appear as long, narrow burrs. Moog does not know how significant these features are to the sealing capability of the poppet other than they probably do have some adverse effect on the local stresses in the poppet. The similarities between the SN007 poppet and the as-machined, but never installed poppet leads Moog to believe that these features do not play a major role in the out of tolerance leakage performance.

A white residue was observed on the poppet shaft immediately upstream of the sealing surface. Moog's attempts to identify the residue were inconclusive. However, the residue appears to have entrapped some 300 series CRES and aluminum. The residue itself also contains traces of zinc and chlorine. Lockheed identified the residue as aluminum silicate in a hydrated form using micro-FTIR and EDS (Lockheed Lab Report, Evaluation of Foreign Residue and Seal-Surface Irregularities on Poppet (Gravity Probe B Program, Lab Request/Job AJ9029). Forms of aluminum silicate are used in many different products. It is commonly identified as a clay, e.g., kaolinite or china clay, and is used as a filler in paint, rubber and plastics and is widely used in the paper industry to produce glossy paper used in magazines. Moog has attempted to identify sources of aluminum silicate in the build and test process, but has been unsuccessful. While this residue is not found on the sealing surface of the poppet, the residue or the particulate trapped in the residue

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could affect the sealing performance of the valve by periodically breaking free from the poppet and relocating at the poppet/seat interface. This could explain the variation in the leakage performance of this valve. No evidence of the aluminum silicate was found anywhere else in the valve.

SN022: The sealing surface of the poppet shows evidence of coining. The inner side of the coined surface appears less uniform than the SN007 poppet. Also the outer surface exhibits a thin circumferential "feather" burr, probably resulting from the coining process. The poppet was examined with the Moog SEM. The sealing edge did not show signs of any damage at high magnification other than localized high and low spots similar to the features seen on the SN007 and unused poppet. No white residue was evident on the poppet or any other piece parts. The poppet has not been viewed with the Lockheed Martin equipment, which can produce images at higher magnification.

6. Valve Housing:

SN007: The housing appeared normal with no evidence of abnormal wear from armature cycling.

SN022: The housing appeared normal with no evidence of abnormal wear from armature cycling.

7. Filter.

SN007: The filter did not show any signs of contamination on the outer or inner surface. The EPR o-ring did present several white particles less than 50-microns in size. Moog FTIR analysis indicated that the particle was a secondary amide, most likely skin. Otherwise the o-ring was not damaged.

SN022: The filter appeared typical. No signs of contamination were observed. The o-ring was in good condition.

8. Filter Housing & Inlet Fitting:

SN007: A large (~200 micron) white particle was adhered to the inner surface of the inlet fitting immediately upstream of the filter. Moog FTIR analysis indicated that the particle was a secondary amide, most likely skin. This is consistent with the particles found on the filter o-ring. Moog cannot verify if this particle was in the valve since assembly or if it was introduced during the disassembly/inspection process. Both processes require personnel to wear cleanroom gloves while handling the hardware.

SN022: The filter and inlet assembly appeared typical. No evidence of contamination was found.

The results from the disassembly and inspection process support the contamination theory as a root cause. The aluminum silicate with entrapped particulate, the skin particle and the white particles located on the filter o-ring are evidence of contamination in the valve.

H. Armature/Poppet Rotation Experiment: A development valve similar to the 51E265 valve was built, but not welded to determine if the armature and/or poppet does rotate during normal valve cycling. Rotation of the sealing surfaces of the poppet relative to the seat could affect sealing performance. The valve housing, armature and poppet were scribed to provide reference points. All three scribe marks were aligned with each other prior to threading the outlet fitting into the valve. The valve was cycled several times. Upon removing the outlet fitting, it was noted that the scribe lines were still aligned. This was repeated several times with the same result. This result is contrary to the burnish marks noted above in the description of the disassembly and inspection of SN007. Nonetheless, Moog does not believe that poppet rotation is cause in degraded leakage performance based on the fact the experiment does not indicate that the poppet does rotate and the fact that there is no history of leakage problems associated with poppet rotation.

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CONCLUSIONS:

The conclusion of the Tiger team meeting in July was that the status of the GMA would be “use-as-is” provided that the performance of the GMA latch valves in question did not degrade further and that no additional valves degraded. The testing up to shipping the GMA to Stanford has demonstrated that this is the case. Despite a great deal of investigation and testing, no clear root cause(s) has been identified for the out of tolerance leakage values measured for valves V4/V6 pair, V11, V15, V21, V27, V28, V29. All of the testing performed as a result of these investigations up to the date of GMA shipment (cycle testing, vibration testing, review of build paperwork and ABCRs of all the valves, helium background investigation, weld assembly process investigation, vacuum/helium exposure) did not result in a repeat of the high leakage values that we are observing with the six GMA valves. The Summary/Comments section of the Fault Analysis indicates probable causes for the out of tolerance performance of each valve.

Moog believed that the most likely cause is related to some form of contamination. The exceptions to the contamination theory are the suspect poppet in V4 and the mark recorded on the seat of V15. Also, V11 and V15 present intermittent pass/fail data. We cannot be sure that this behavior was or was not present prior to vibration testing.

Having met the requirement set forth by the Tiger team, Moog recommended a use-as-is disposition for the GMA, which was shipped in September 2002. Moog has continued to work with Stanford University to determine the best ways to mitigate the additional risks associated with the out of tolerance leak rates observed in valves V4/V6 pair, V11, V15, V21, V27, V28, V29 or any other valves that later exhibit this behavior.

The post GMA delivery investigation using spare valves SN007 and SN022 did not result in determination of a root cause or result in any new findings that would change Moog’s belief that the most probable root cause is contamination. However, the post delivery investigation did make the following findings:

- The weld assembly process did result in a temporary increase in leakage rate for SN022 and an order of magnitude shift in leakage performance of SN007 from 1E-07 sccs GHe to 1E-06 sccs GHe and also presented higher leak rate ranging from 1E-05 to 1E-04 sccs GHe. This finding supports a root cause of contamination introduced at the time of integration.
- Variations in Vespel properties may be a contributor to leakage performance. Most notable was the variation in %-elongation of Vespel samples tested. However, test sample geometry may have played a factor in this variation.
- A white residue, identified as aluminum silicate, was found on the poppet of SN007 immediately upstream of the poppet sealing surface. As noted above, this valve also exhibited a shift in leakage performance. This aluminum silicate residue also entrapped particles of aluminum and CRES. The source of this contamination is still unknown. This finding supports the root cause of contamination.

At this point, Moog does not have any reason change the past recommendation for “use-as-is” provided Stanford University implements mitigation efforts to prevent or minimize the effects the excessive leakage from the GMA valves has on regulator lock-up, the downstream science probe and gas purity. Moog will continue to support the mitigation efforts.

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CORRECTIVE ACTION:

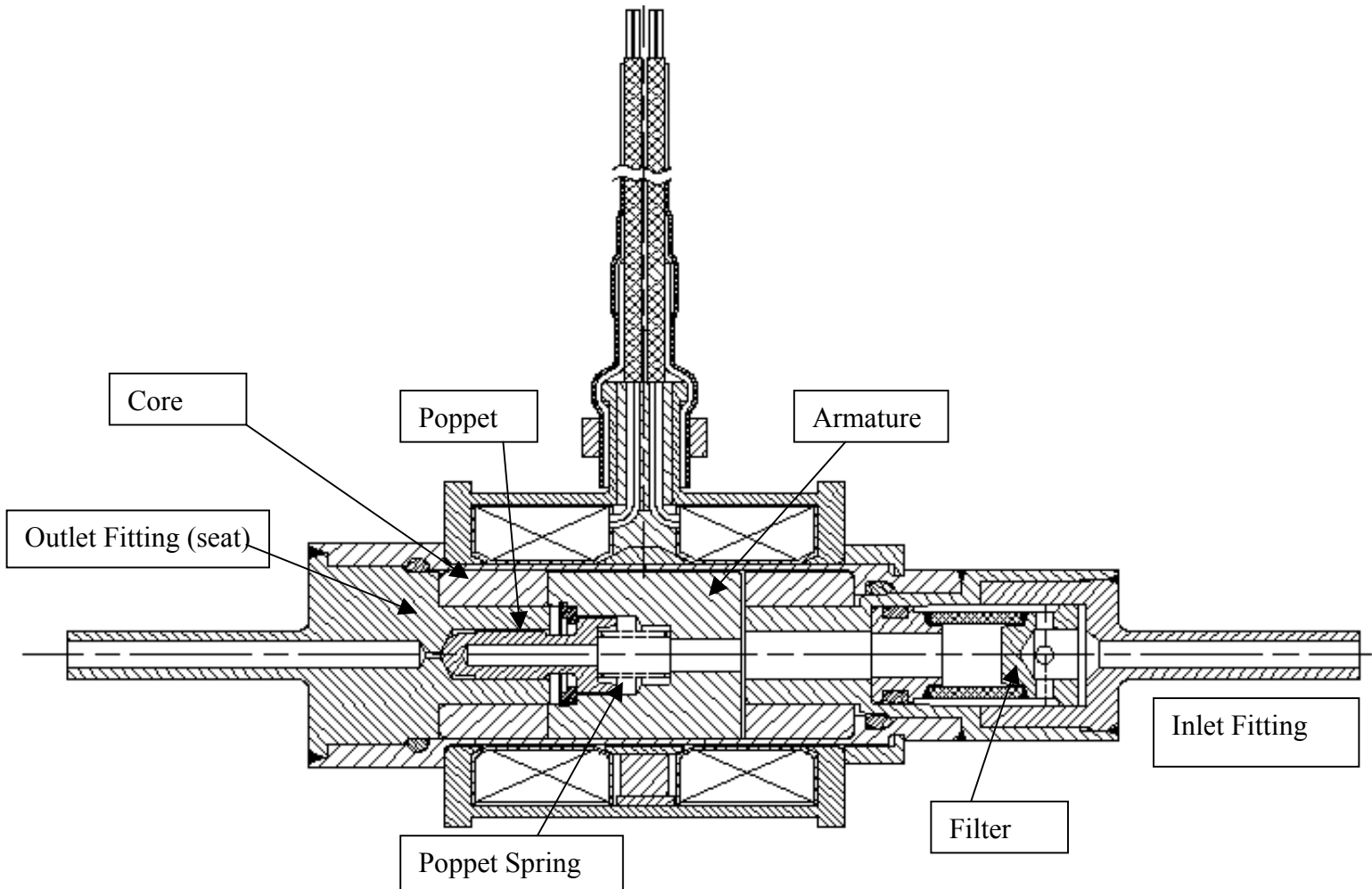
Without a confirmed root cause Moog cannot offer a corrective action for mitigating the latch valve leak rates in excess of 1.0E-04 sccs GHe. The investigations that have been conducted have revealed ways to improve our general processes for building and testing of valves and sub-systems and these will be implemented. These improvements include test methodology and procedure for internal leakage testing of the GMA; proper covering of shielded leads to prevent contamination during assembly and valve cleanliness certification.

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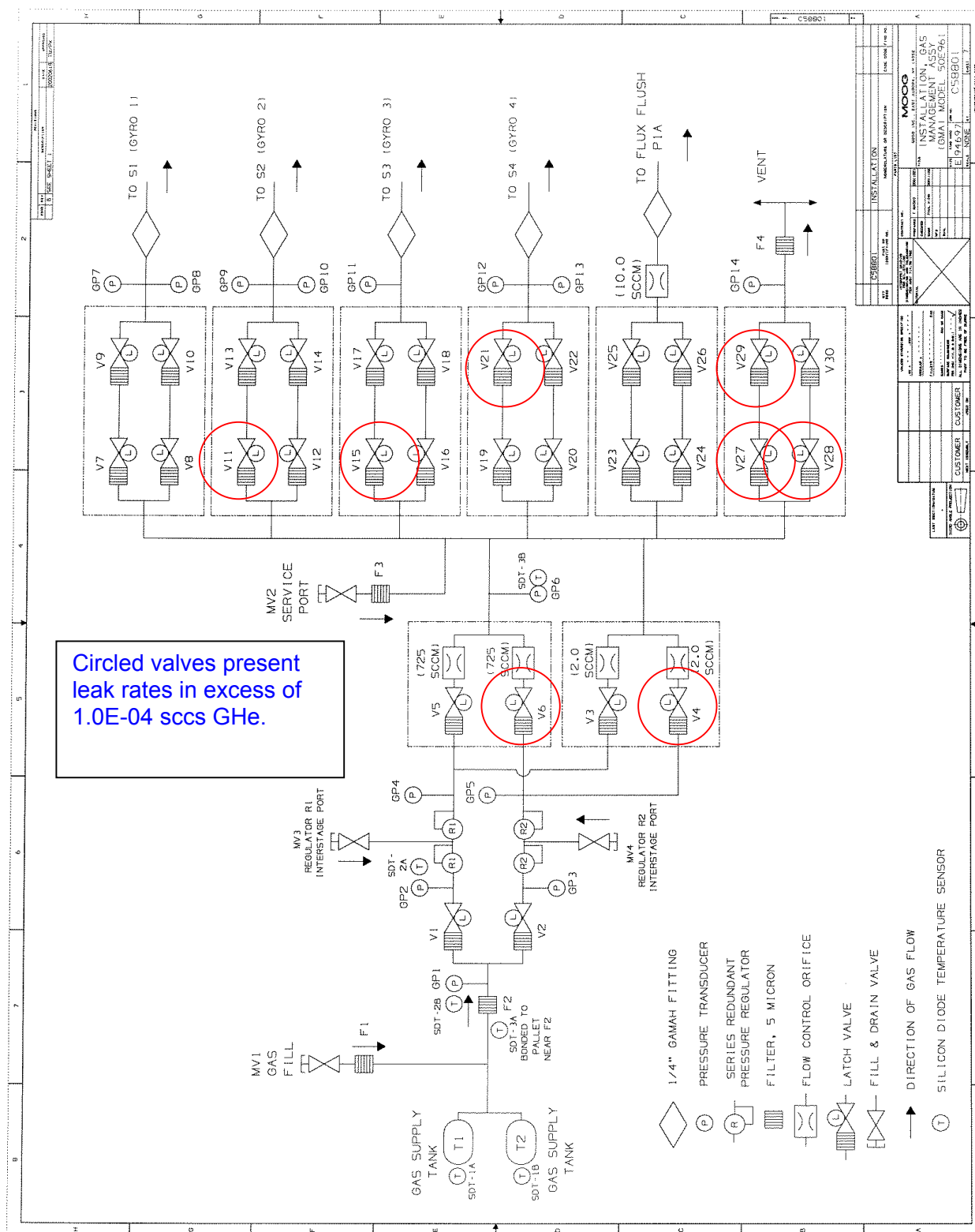
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**GMA: Functional Cross Section of the 51E265
Latch Valve**

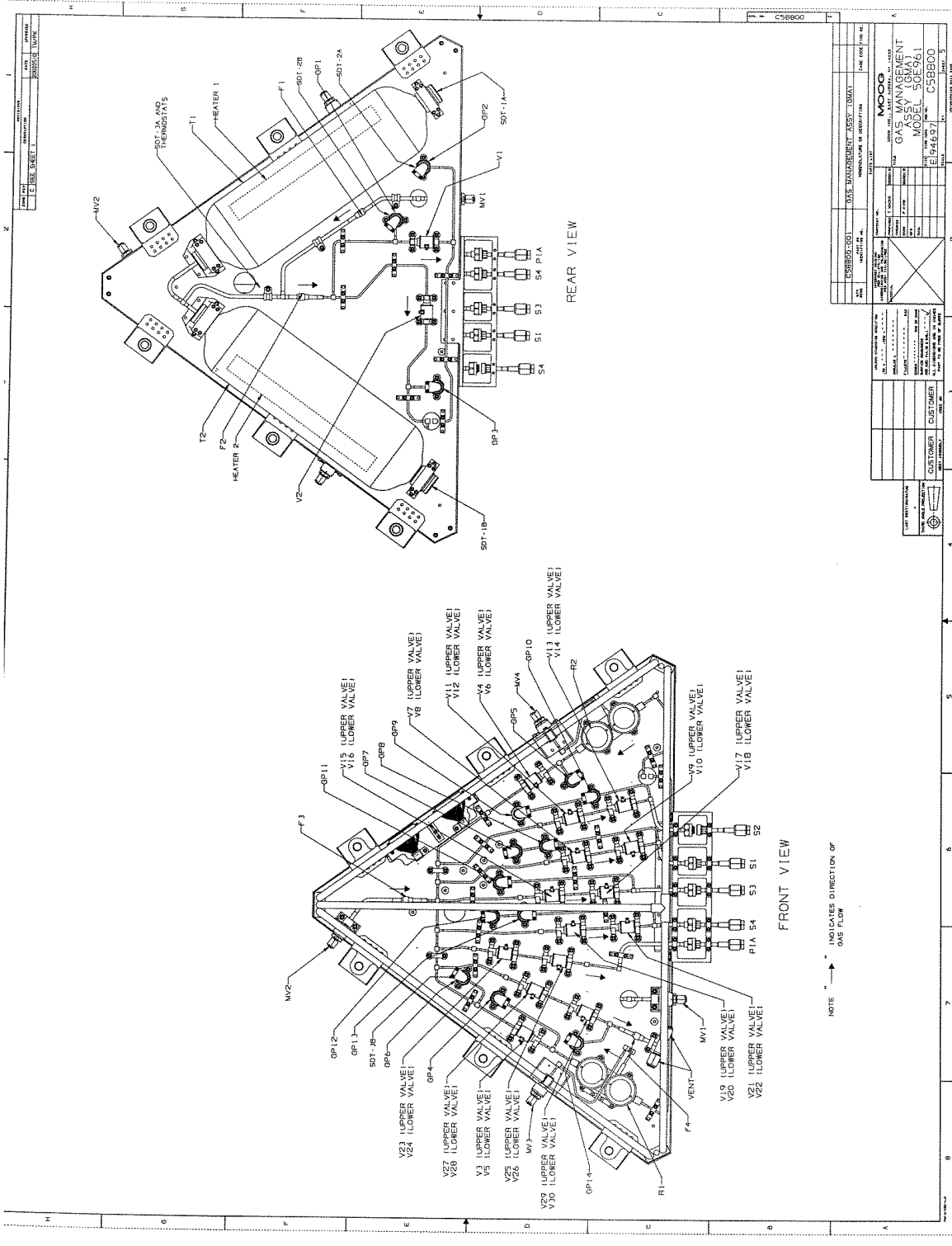
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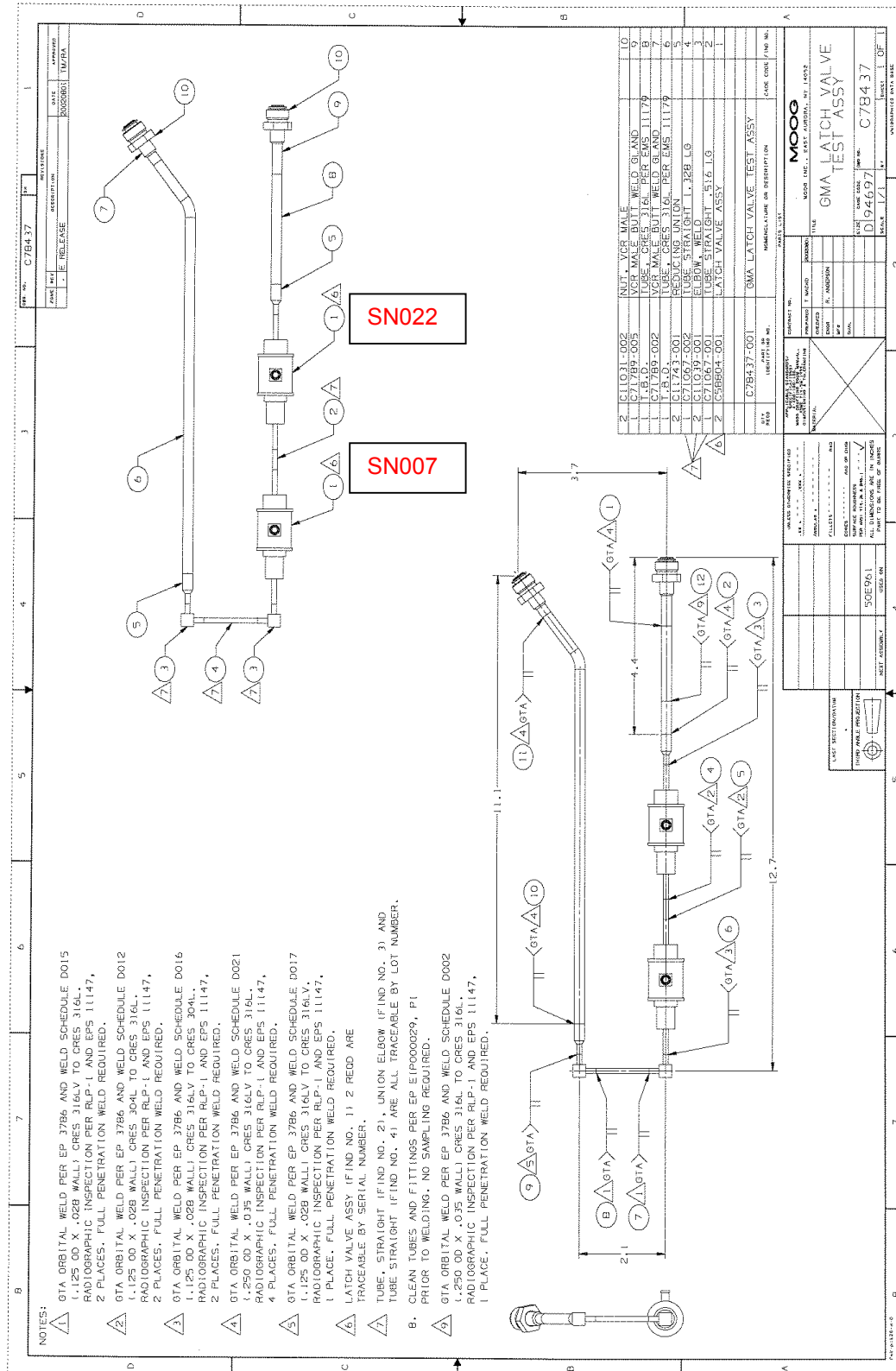
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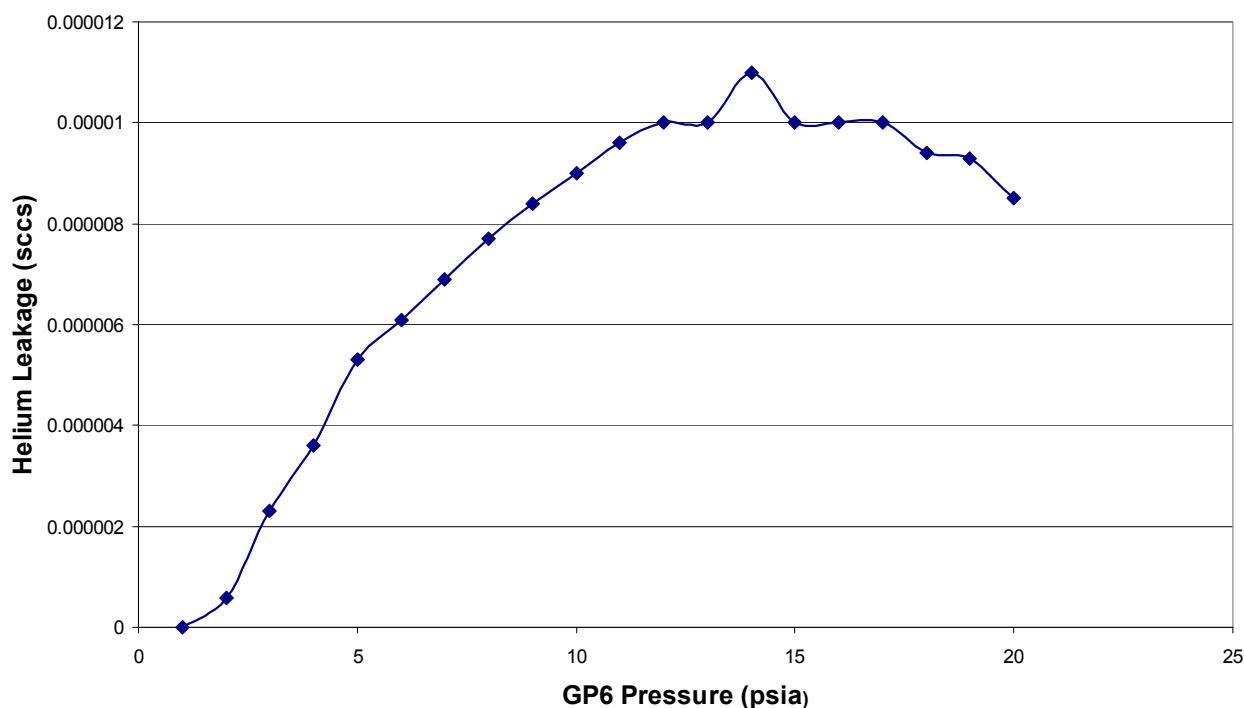


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GMA system internal leakage performance as measured at the outlets of GMA lines S1-S4, P1A and Vent, while the GMA latch valves are configured for launch. The aggregate leak rate of the GMA peaked to a value of 1.1E-05 sccs GHe at 14 psia, which is better than the internal leakage rate required for a single valve.

GMA System Internal Leakage in Flight Configuration
As Tested 7/30/02 at Moog Inc. per AVO50E961RA16



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MATERIAL TESTING LABORATORY
FASTENER TESTING



921-01 & 921-02

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WMT&R Report No. 2-31770

P.O. No. 0208120101

WMT&R Quote No. 292247

Packing Slip No. 277039

CERTIFICATION

September 9, 2002

Moog Aircraft Group

Aircraft Group

East Aurora, NY 14052-0018

Attention: Mr. Tim Mascarella

Subject:

All processes, performed upon the material as received, were conducted at WMT&R, Inc. in accordance with the WMT&R Quality Assurance Manual, Rev. 9, dated 4/1/2000.

The following tests were performed on this order: TENSILE

UTS = UYS => VESPEL DOES NOT EXHIBIT
A TRUE YIELD POINT

TENSILE RESULTS: D638-01

SPEED OF TESTING: 0.2000 in./min.

MATERIAL: Plastic VespeL SP-1

MATERIAL: Plastic										DISPOSITION: Report									
Sample	Test Log	Temp.	UTS	Breaking	UYS	UYS Strain	Modulus	Ult Load	Break	UYL	Orig.	Orig. Area	Machine						
	Number	F	PSI	Str. PSI	PSI	%	KSI	LBS	Load LBS	LBS	Dia. (in.)	(Sq. In.)	Number						
3/8 OD-1	794052	Room	14697.99	14691.76	14697.99	10.650	437.28	707.70	707.70	707.70	0.2476	0.04814943	M9	R					
3/8 OD-2	794053	Room	12338.10	12338.10	12338.10	5.7260	419.31	610.50	610.50	610.50	0.2510	0.04948087	M9	R					
3/8 OD-3	794054	Room	14306.54	14298.43	14302.50	8.8430	448.26	707.90	707.90	707.70	0.2510	0.04948087	M9	R					
3/8 OD-4	794055	Room	14820.49	14814.44	14814.44	11.440	416.30	734.50	734.20	734.20	0.2512	0.04955976	M9	R					
1/4 OD-1	794056	Room	14031.96	14031.96	12891.07	6.7328	425.88	287.80	287.80	264.40	0.1616	0.02061033	M10	R					
1/4 OD-2	794057	Room	10615.65	10615.65	10615.65	4.2109	461.25	218.0	218.0	218.0	0.1617	0.02053572	M10	R					
1/4 OD-3	794058	Room	13254.30	13254.30	13254.30	6.9563	454.76	269.50	269.50	269.50	0.1609	0.02033302	M10	R					
1/4 OD-4	794059	Room	14664.42	14664.42	14664.42	13.1851	411.94	300.40	300.40	300.40	0.1615	0.02049495	M10	R					

C = CONTROL SAMPLE

T = TEST SAMPLE: EXPOSE TO VACUUM AND HELIUM ENVIRONMENTS

① LOT RES25653, BATCH H23004, 3/8" OD
13.3% ELONGATION

② LOT RES26227, BATCH H2861,
1/4" OD, 10.3% ELONGATION

**UNOFFICIAL DATA
NOT APPROVED**

KNOWINGLY OR WILLFULLY FALSIFYING OR CONCEALING A MATERIAL FACT ON THIS FORM OR MAKING FALSE, FICTITIOUS OR FRAUDULENT STATEMENTS OR REPRESENTATIONS HEREIN COULD CONSTITUTE A FELONY PUNISHABLE UNDER FEDERAL STATUTES.
THIS CERTIFICATE OR REPORT SHALL NOT BE REPRODUCED EXCEPT IN FULL, WITHOUT THE WRITTEN APPROVAL OF WMT&R, INC.

[Signature]

Roy E. Stanford A. Stape

9-9-2

September 9, 2002

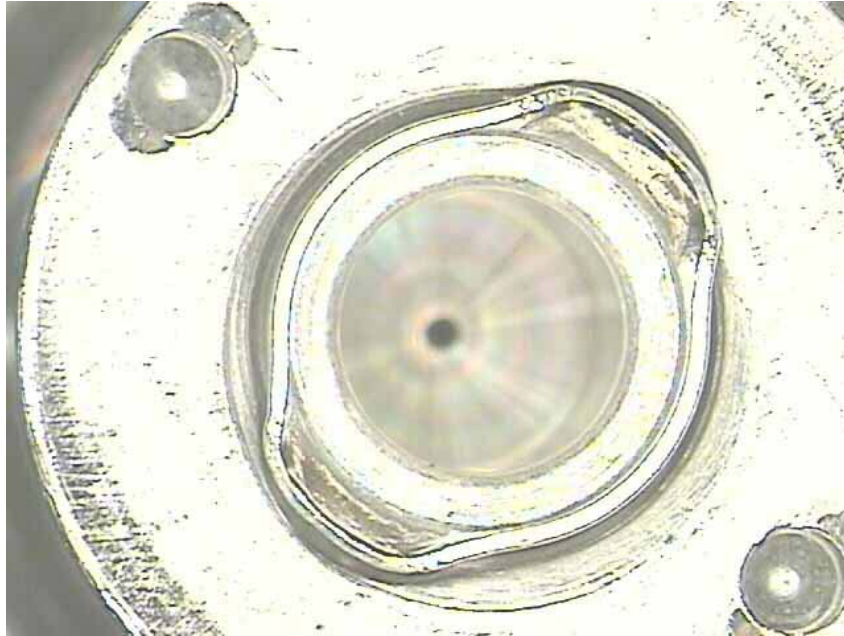
VespeL Tensile Test Data

- 2 lots of material
- 4 tensile samples from each lot
- 2 control & 2 test samples

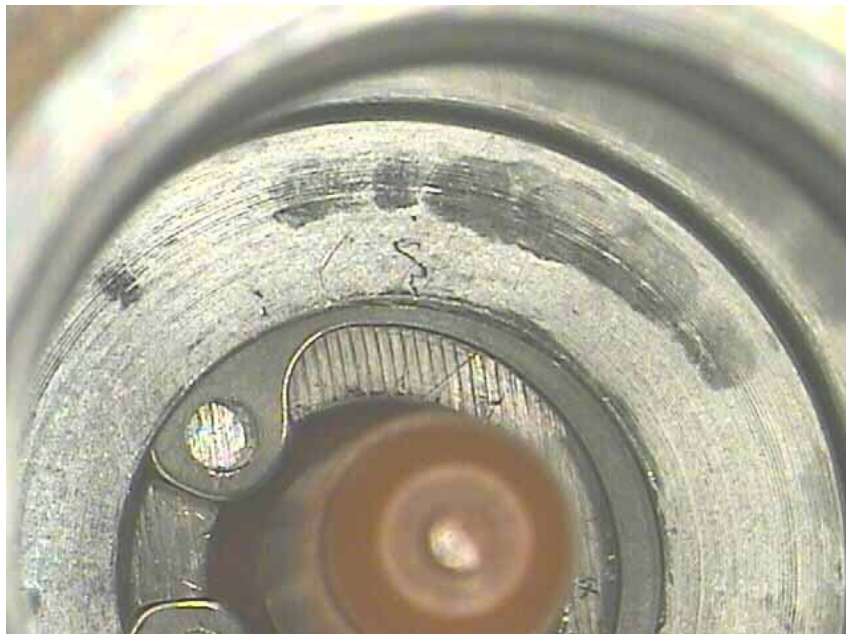
MOOG INC. FAILURE ANALYSIS REPORT
(CONTINUATION SHEET)

P/N: C58800	S/N: 001	CUSTOMER: Stanford University	FAR NO. FAR(M)-2002-063 Rev A

Photos from 51E265 SN007 Disassembly



51E265 SN007 Outlet Core swaged to outlet fitting

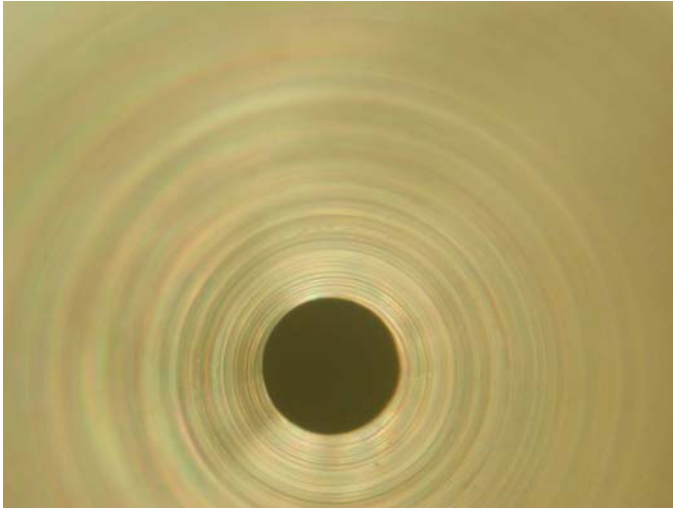


51E265 SN007 Armature Outlet side burnish marks

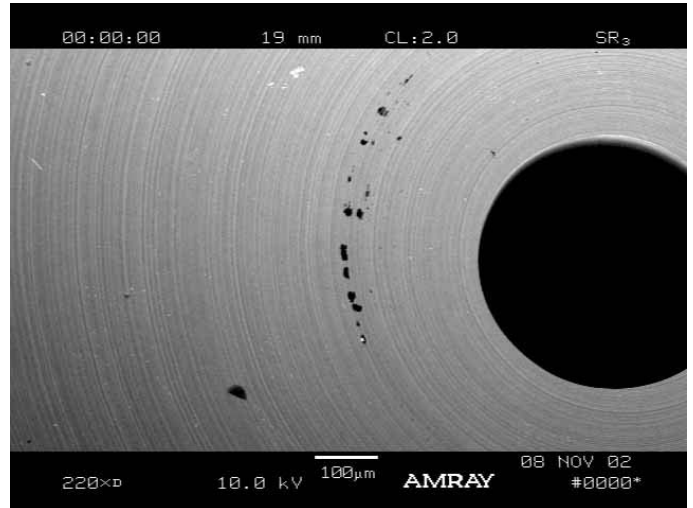
MOOG INC. FAILURE ANALYSIS REPORT
(CONTINUATION SHEET)

P/N: C58800	S/N: 001	CUSTOMER: Stanford University	FAR NO. FAR(M)-2002-063 Rev A

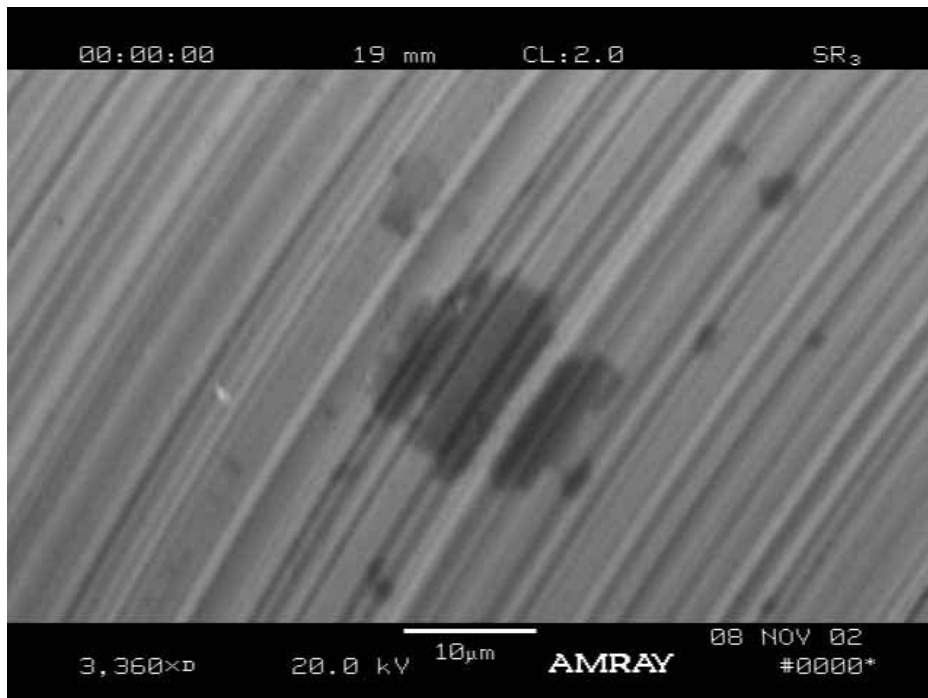
Photos from 51E265 SN007 Disassembly



51E265 SN007 Outlet Fitting Conical Seat with Stains



51E265 SN007 Outlet Fitting Conical Seat Surface Stains viewed with Moog SEM

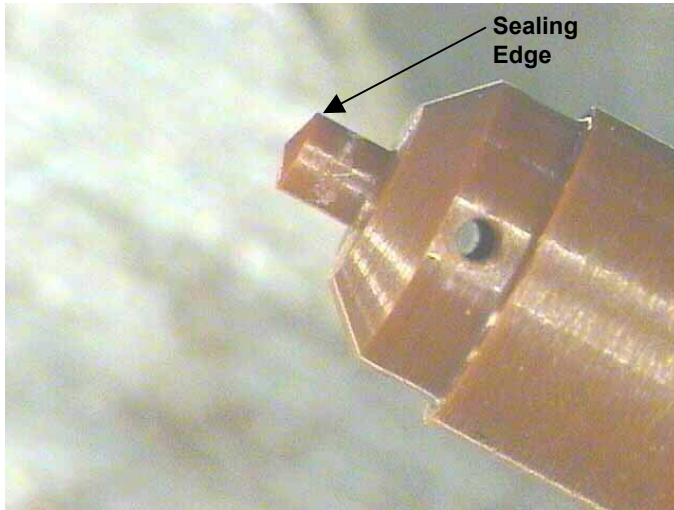


51E265 SN007 Outlet Fitting Conical Seat Surface Stains 2 viewed with Moog SEM

MOOG INC. FAILURE ANALYSIS REPORT
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P/N: C58800	S/N: 001	CUSTOMER: Stanford University	FAR NO. FAR(M)-2002-063 Rev A

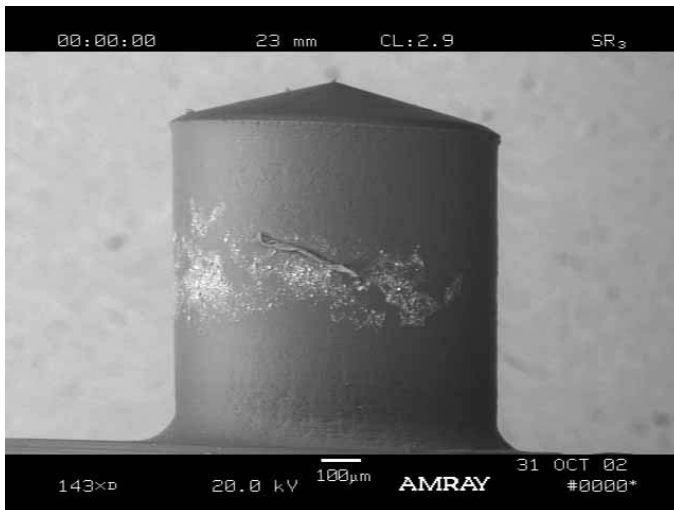
Photos from 51E265 SN007 Disassembly



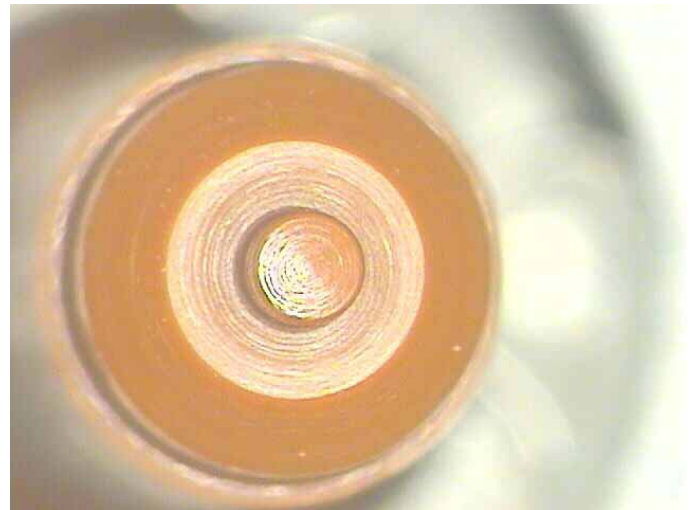
51E265 SN007 Poppet tip showing white residue and flow hole



51E265 SN007 Poppet tip showing white residue (aluminum silicate)



51E265 SN007 Poppet tip viewed with Moog SEM showing white residue and coined sealing edge

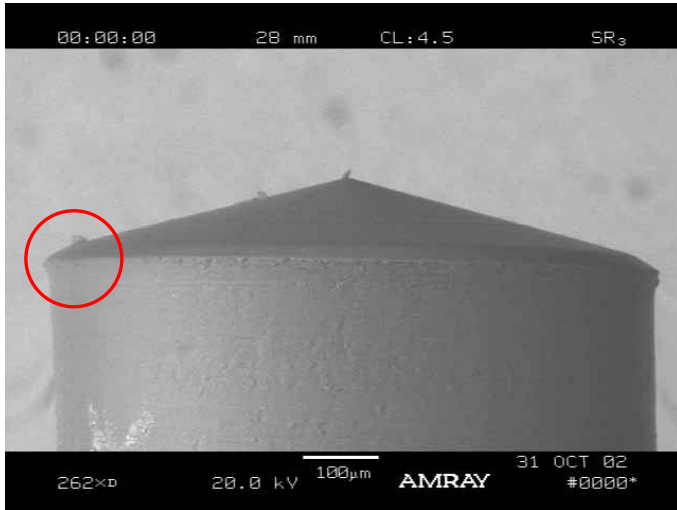


51E265 SN007 Poppet Tip

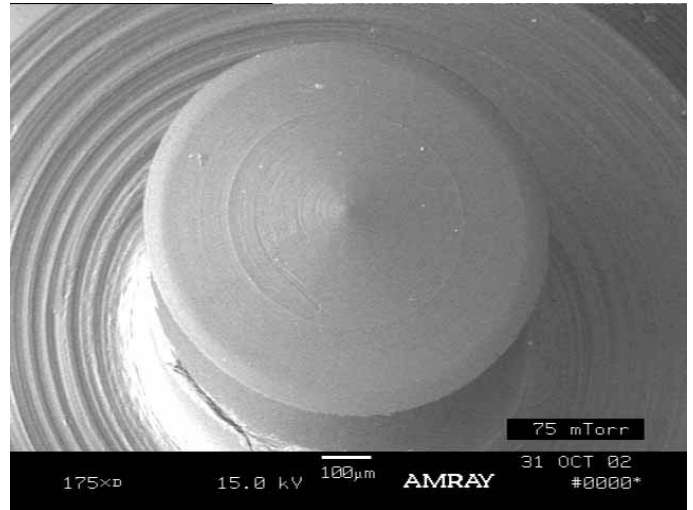
MOOG INC. FAILURE ANALYSIS REPORT
(CONTINUATION SHEET)

P/N: C58800	S/N: 001	CUSTOMER: Stanford University	FAR NO. FAR(M)-2002-063 Rev A

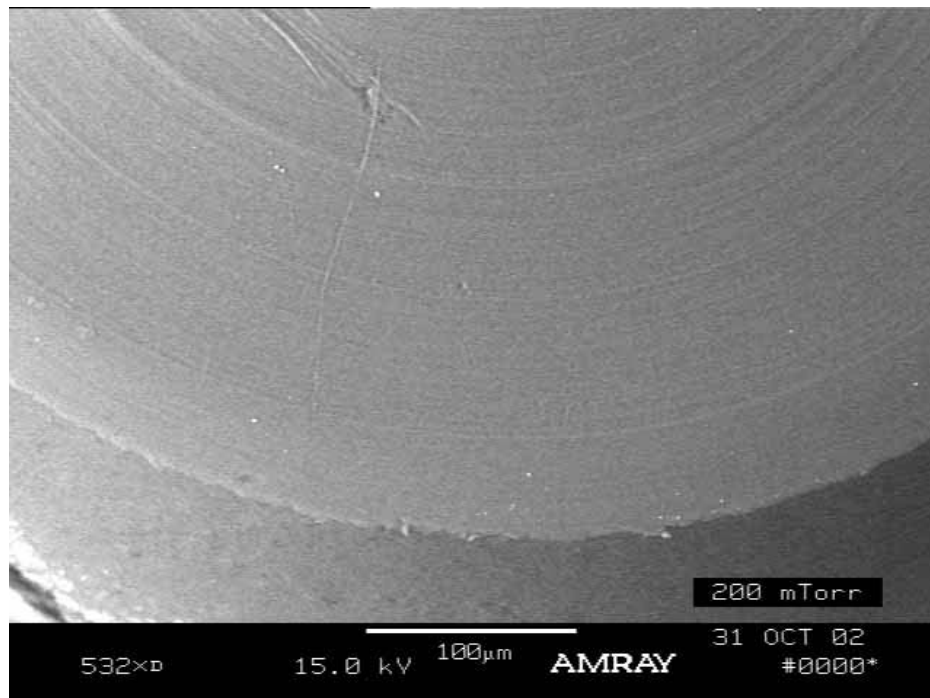
Photos from 51E265 SN007 Disassembly



51E265 SN007 Poppet tip viewed with Moog SEM shows coined edge



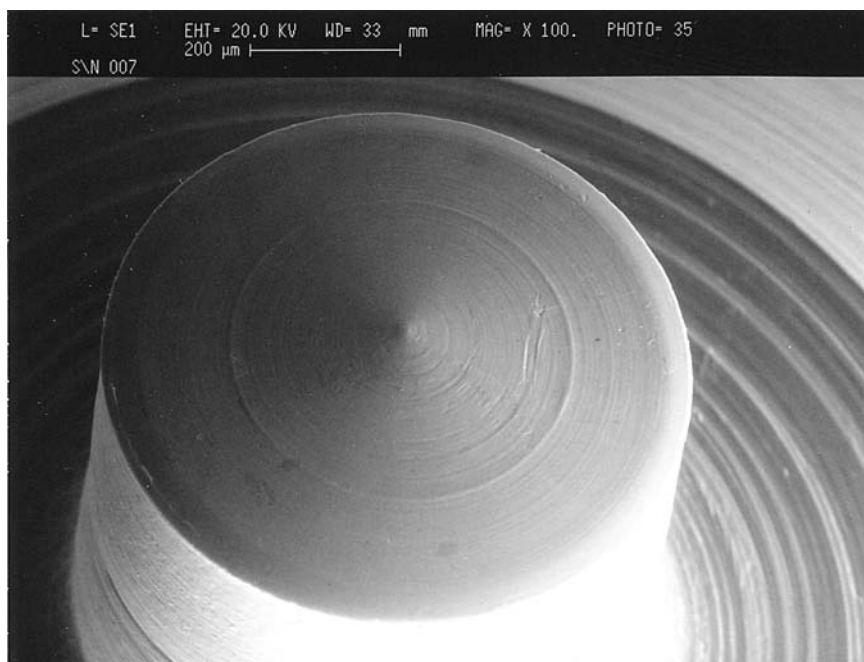
51E265 SN007 Poppet tip viewed with Moog SEM shows coined surface



51E265 SN007 Poppet tip viewed with Moog SEM shows coined edge

MOOG INC. FAILURE ANALYSIS REPORT
(CONTINUATION SHEET)

P/N: C58800	S/N: 001	CUSTOMER: Stanford University	FAR NO. FAR(M)-2002-063 Rev A



51E265 SN007 Poppet tip viewed with Lockheed Martin SEM



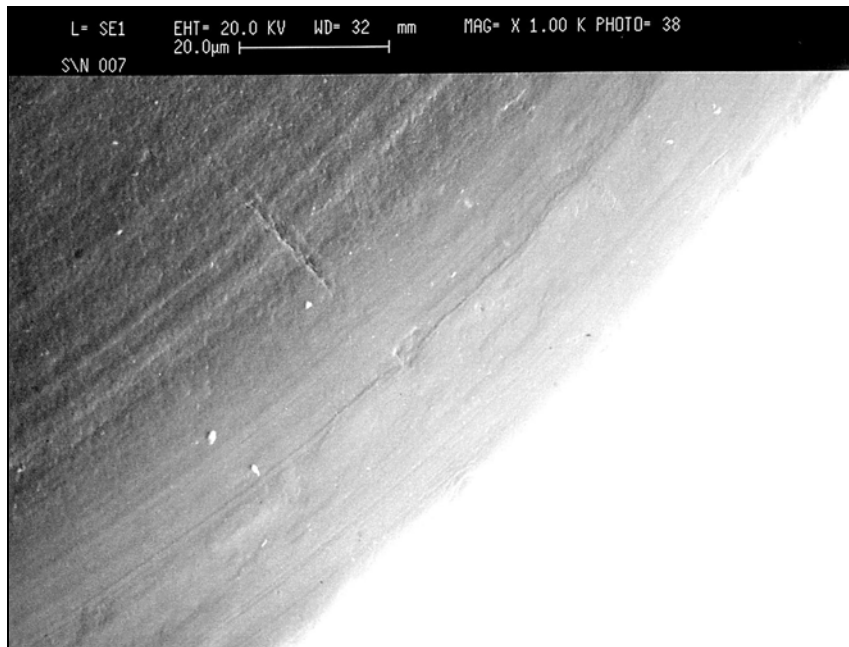
51E265 SN007 Poppet sealing surface viewed with Lockheed Martin SEM. Note scratches.

MOOG INC. FAILURE ANALYSIS REPORT
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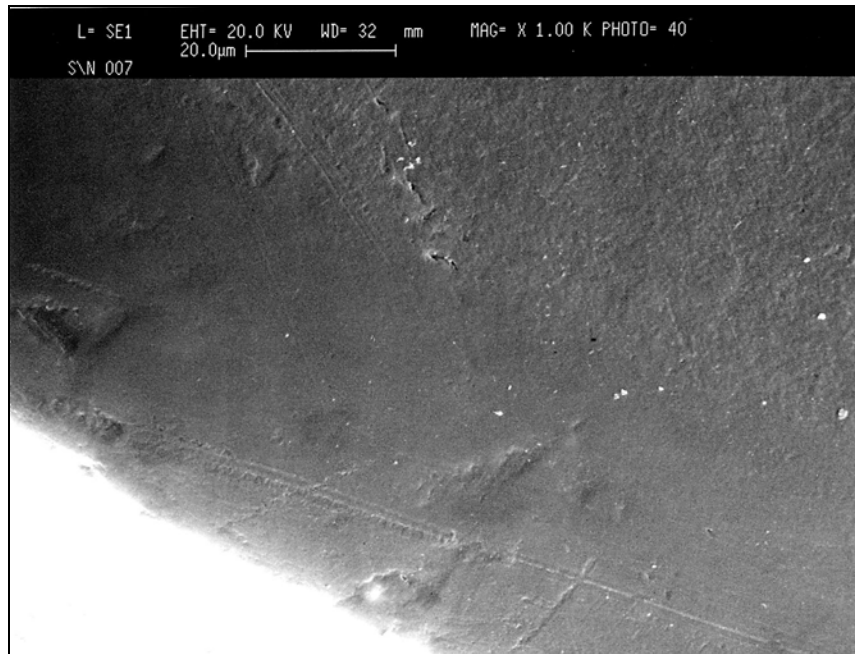
51E265 SN007 Poppet sealing surface viewed with Lockheed Martin SEM. Note burr near sealing edge.



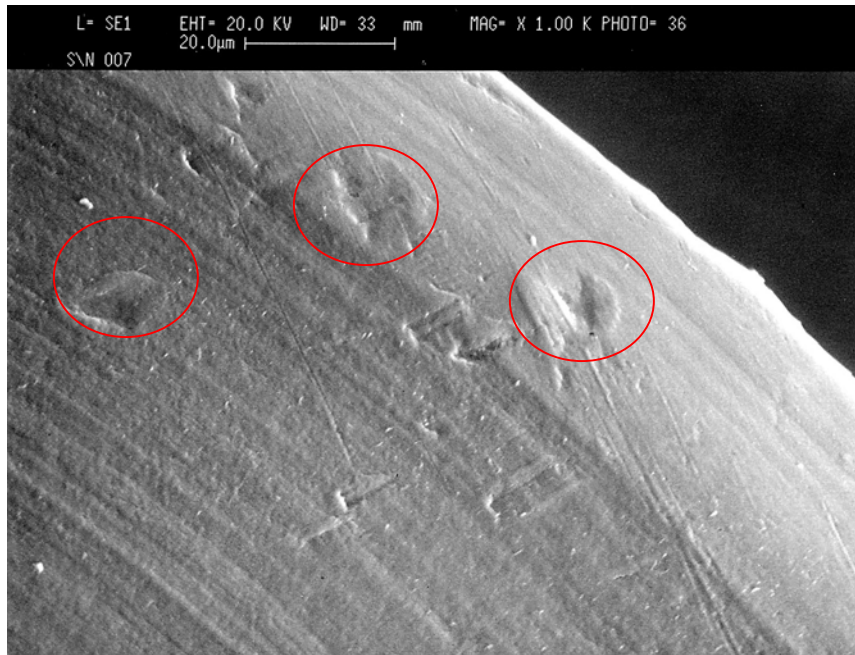
51E265 SN007 Poppet sealing surface viewed with Lockheed Martin SEM. Note localized high and low spots.

MOOG INC. FAILURE ANALYSIS REPORT
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51E265 SN007 Poppet sealing surface viewed with Lockheed Martin SEM. Note localized high and low spots.

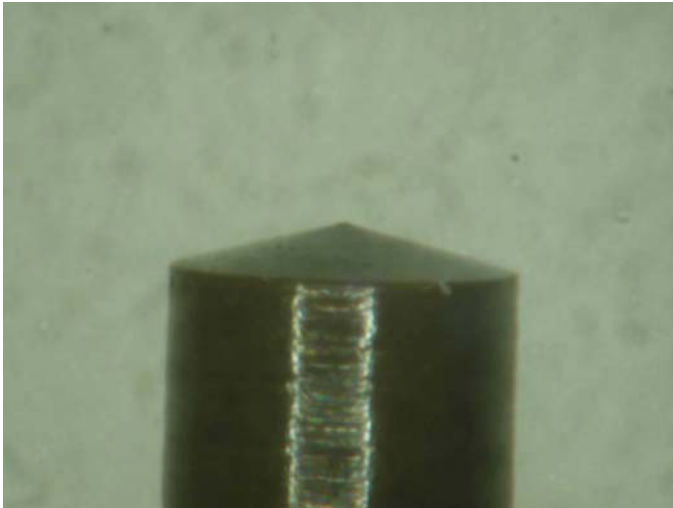


51E265 SN007 Poppet sealing surface viewed with Lockheed Martin SEM. Note localized high and low spots

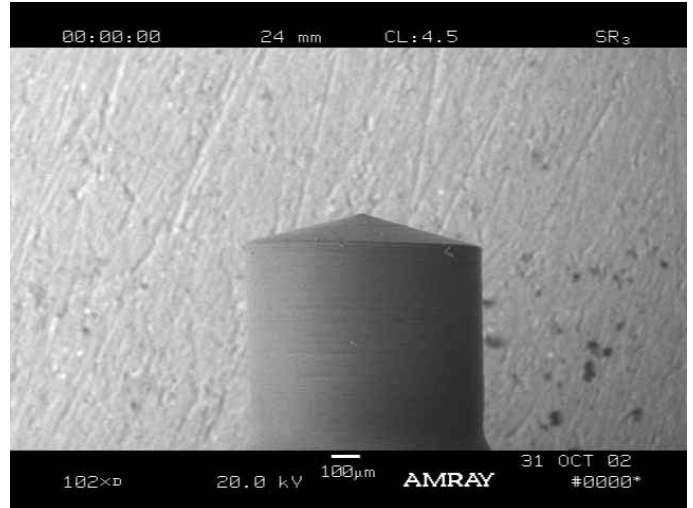
MOOG INC. FAILURE ANALYSIS REPORT
(CONTINUATION SHEET)

P/N: C58800	S/N: 001	CUSTOMER: Stanford University	FAR NO. FAR(M)-2002-063 Rev A

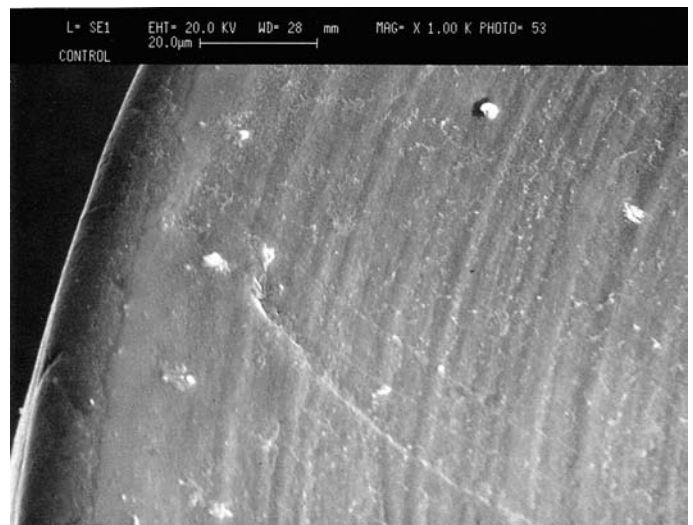
Photos from 51E265 Unused Poppet



51E265 SN007 As Machined Poppet tip – Poppet Never Installed



51E2657 Poppet sealing surface viewed with Lockheed Martin SEM. Poppet never installed.



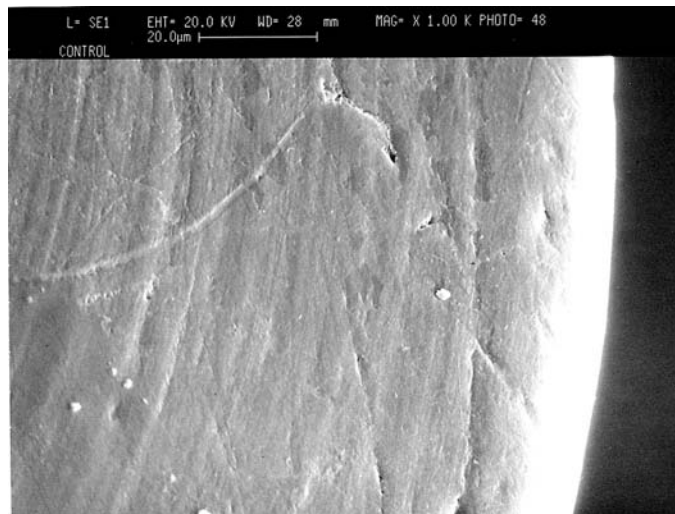
51E265 Poppet sealing surface viewed with Lockheed Martin SEM. Note localized high and low spots and scratches. Poppet never installed.

MOOG INC. FAILURE ANALYSIS REPORT
(CONTINUATION SHEET)

P/N: C58800	S/N: 001	CUSTOMER: Stanford University	FAR NO. FAR(M)-2002-063 Rev A



51E265 Poppet sealing surface viewed with Lockheed Martin SEM. Note localized high and low spots and scratches. Poppet never installed.

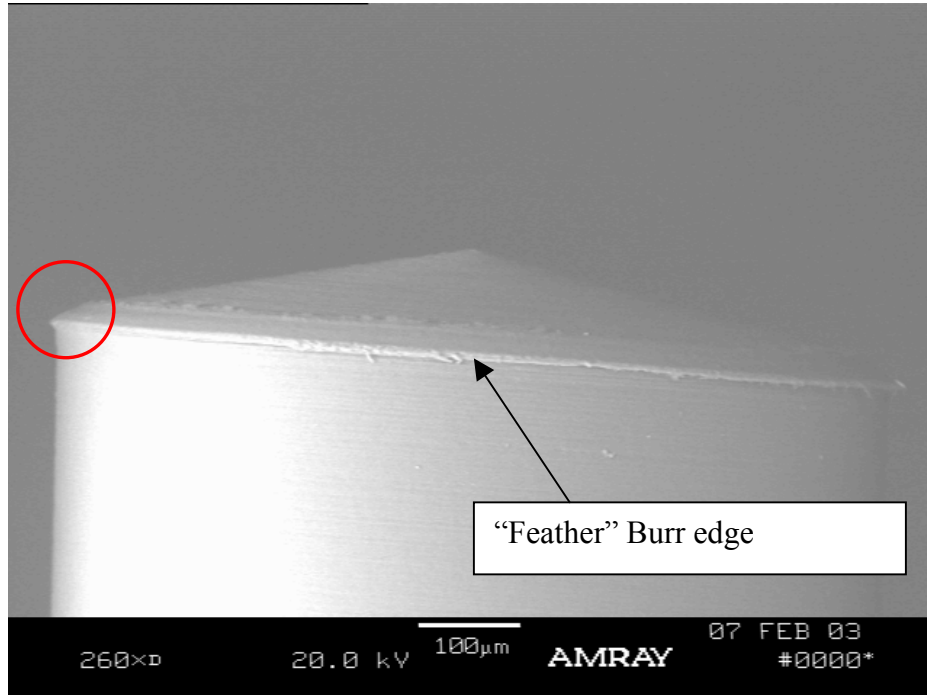


51E265 Poppet sealing surface viewed with Lockheed Martin SEM. Note localized high and low spots and scratches. Poppet never installed.

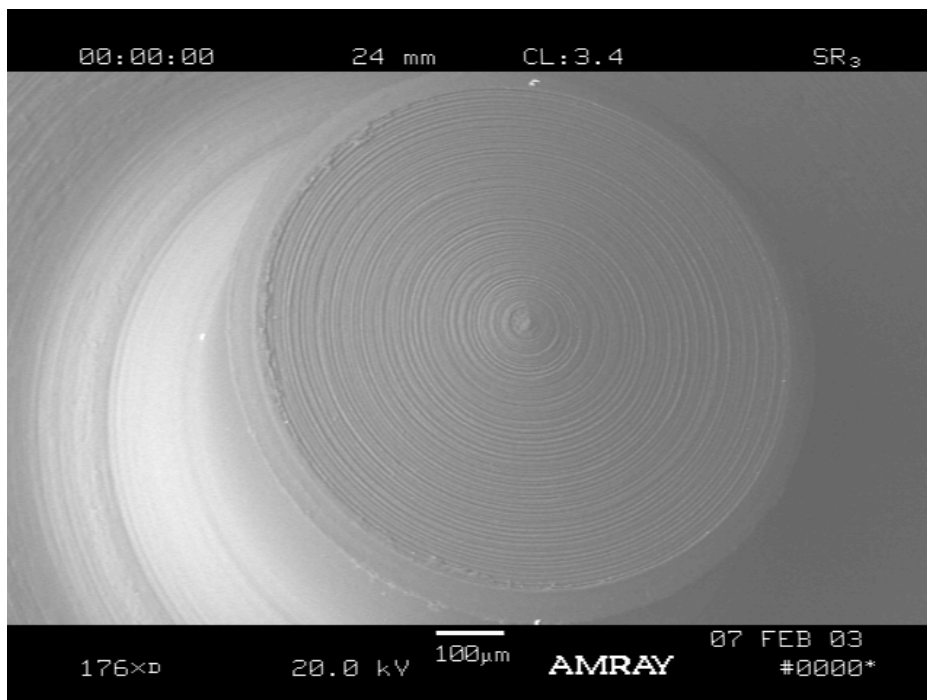
MOOG INC. FAILURE ANALYSIS REPORT
(CONTINUATION SHEET)

P/N: C58800	S/N: 001	CUSTOMER: Stanford University	FAR NO. FAR(M)-2002-063 Rev A

SN022 Poppet



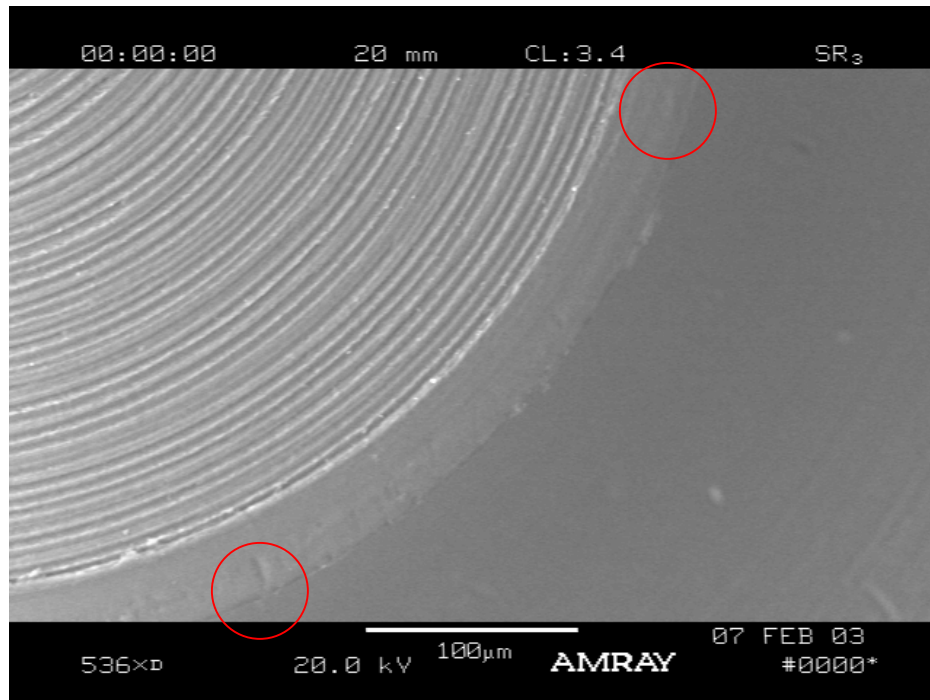
51E265 SN022 Poppet tip viewed with Moog SEM shows coined edge



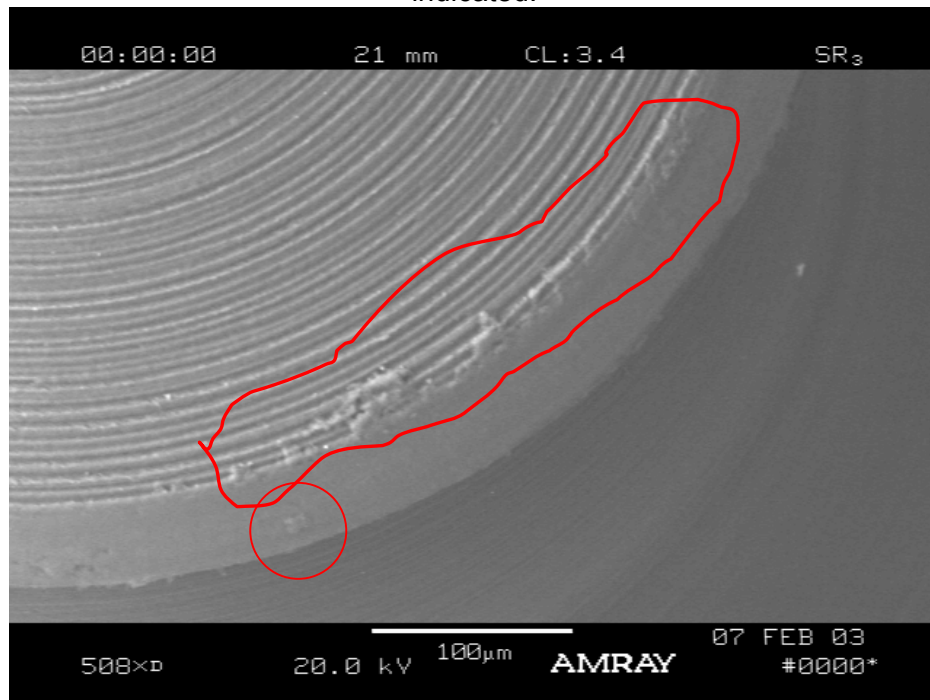
51E265 SN022 Poppet tip viewed with Moog SEM shows coined edge

MOOG INC. FAILURE ANALYSIS REPORT
(CONTINUATION SHEET)

P/N: C58800	S/N: 001	CUSTOMER: Stanford University	FAR NO. FAR(M)-2002-063 Rev A



51E265 SN022 Poppet sealing edge as viewed with Moog SEM. Some surface defects are visible as indicated.



51E265 SN022 Poppet sealing edge as viewed with Moog SEM. Some surface defects are visible. Also inner coining edge is not as uniform as SN007 poppet

	Valve	Post Proof Internal Leakage Check (6-1-02)	Comment	Post Electrical Integration Internal Leakage Check (Bubble/Min, inverted test tube test) 6-21-02	Post Vibration Internal Leak Rate (scsccs GHe) 6-28-02 (AVO50E961RA04)	Post Vibration Internal Leak Test (scsccs GHe) 6-29-02 (AVO50E961RA05)	Post Vibration Internal Leak Test (scsccs GHe) 7-2-02 (AVO-PTK-070102-Repeat Internal Leakage testing of GMA Latch Valves)
	Limit	scsccs GHe (see comment)		< 1 Bubble/Minute	< 1 X 10 ⁻⁴ scsccs GHe	< 1 X 10 ⁻⁴ scsccs GHe	< 1 X 10 ⁻⁴ scsccs GHe
R1	V1	5.60E-05	Measured V1 & V2 at same time. LR < 2 E-4 scsccs GHe Required.	0		2.50E-05	1.40E-05
R2	V2			0		2.60E-05	1.60E-05
R1	V3 & V5	1.30E-04	Measured V3, V4, V5 & V6 at same time. LR < 4 E-4 scsccs GHe Required.	0		1.70E-05	2.20E-05
R2	V4 & V6			0		1.20E-04	8.40E-05
S1	V7	2.30E-05	Measured V7, V8, V11, V12, V15, V16, V19, V20, V23, V24, V27 & V28 at same time. LR < 1.2 E-3 scsccs GHe Required.	0		1.70E-06	3.00E-06
S1	V8			0		1.40E-06	3.00E-06
S1	V9	2.40E-04	Measured V9, V10, V13, V14, V17, V18, V21, V22, V25, V26, V29 & V30 at same time. LR < 1.2 E-3 scsccs GHe Required.	0		1.00E-06	3.00E-06
S1	V10			0		9.80E-07	3.00E-06
S2	V11			0		1.80E-04	3.10E-06
S2	V12			0		1.80E-06	3.10E-06
S2	V13			0		2.10E-06	3.10E-06
S2	V14			0		2.10E-06	3.10E-06
S3	V15			0		1.50E-03	1.60E-05
S3	V16			0		1.50E-06	8.70E-06
S3	V17			0		1.20E-06	2.70E-06
S3	V18			0		1.40E-06	2.00E-06
S4	V19			0		1.40E-06	3.40E-06
S4	V20			0		2.40E-06	4.30E-06
S4	V21			0		1.10E-06	2.30E-06
S4	V22			0		1.00E-06	2.60E-06
S3	V23			0		1.30E-06	2.90E-06
S3	V24			0		2.40E-06	2.90E-06
S3	V25			0		9.90E-07	1.40E-06
S3	V26			0		1.40E-06	1.40E-06
Vent	V27			0	2.60E-04	1.40E-06	1.50E-06
Vent	V28			0.2	2.70E-05	1.30E-06	3.30E-06
Vent	V29			0.8	1.00E-04	2.20E-05	2.30E-05
Vent	V30			0	4.30E-05	3.30E-05	6.90E-06
	System Internal Leakage (V9,V10,V13,V14,V17,V18,V19,V20,V25,V26,V29,V30)						
	System Internal Leakage (V9,V10,V13,V14,V17,V18,V19,V20,V25,V26)						

Moog Comments:

- 1) Latch valve design qualified to 17 Grms random vibration.
- 2) No evidence of post vibration leakage problems with past valves (2 qualification valves, 5 DS-1 valves, 3 PMA valves).
- 3) V11 & V15 were open during vibration. Reduces possibility that poppet was affected by vibration testing.
- 4) In general, valves were cycled 2-10 times between tests.
- 5) For repeated internal leakage testing on 7-1-02, background measured 1.4E-5 scsccs GHe. Background reading was taken with LV 1 and LV2 closed. No GHe in tanks. All other valves open and under vacuum. Note that when tanks were filled with 200 psia GHe, the leakage rate of LV1 was 1.4E-5 scsccs GHe, i.e., no change from background reading. This suggests that the leakage across the valve was really less than 1.4e-5 scsccs GHe.
- 6) GP6 measured approx. 5-6 psia after vibration testing. Was this from air leaking in from the vent line or from GHe leaking from V3-V6?
- 7) All other 15 psia pressure transducers measured at approx. 0 mV (0 psia) after vibration testing.
- 8) All leakage testing performed at approx. 21 psia unless otherwise noted.
- 9) AVO50E961RA12calibrated leak of 1.58E-05 scsccs GHe plumbed at the vent tee was detected as a 1.5E-05 scsccs GHe leak by the mass spectrometer. GDS is not affecting the leak rate measurement.
- 10) V1 & V2 typically tested at 1800-2000 psia
- 11) V3-V30 typically tested at 20-21 psia except V3-V6could be tested at 300 psia per AVO instructions.

Post Vibration Cycle & Internal Leak Test (scs GHe), Cycle 1, 7-2-02 (AVO-PTK 070102-Cycle and Internal Leakage Testing)	Post Vibration Cycle & Internal Leak Test (scs GHe), Cycle 2, 7-2-02 (AVO-PTK 070102-Cycle and Internal Leakage Testing)	Post Vibration Cycle & Internal Leak Test (scs GHe), Cycle 3, 7-2-02 (AVO-PTK 070102-Cycle and Internal Leakage Testing)	Post Vibration Cycle & Internal Leak Test (scs GHe), Cycle 4, 7-2-02 (AVO-PTK 070102-Cycle and Internal Leakage Testing)	Post Vibration Cycle & Internal Leak Test (scs GHe), Cycle 5, 7-2-02 (AVO-PTK 070102-Cycle and Internal Leakage Testing)	Post Vibration Cycle & Internal Leak Test (scs GHe), 300 psia, 7-9-02 (AVO-GMA-PTK-070302-High Pressure Leakage testing of V3-V6)	Post Vibration Cycle & Internal Leak Test (scs GHe), 7-12-02 (AVO50E961RA07)	Post Vibration Internal Leakage Test per PTP (Valve Pairs tested) 7-17-02
< 1 X 10 ⁻⁴ sccs GHe	< 1 X 10 ⁻⁴ sccs GHe	< 1 X 10 ⁻⁴ sccs GHe	< 1 X 10 ⁻⁴ sccs GHe	< 1 X 10 ⁻⁴ sccs GHe	< 1 X 10 ⁻⁴ sccs GHe	< 1 X 10 ⁻⁴ sccs GHe	< 1 X 10 ⁻⁴ sccs GHe
							5.20E-05
					6.90E-05		2.80E-05
					1.10E-04	2.80E-04	1.60E-04
							1.60E-05
							8.50E-06
4.00E-06	2.30E-06	2.20E-06	2.20E-06	2.40E-06			3.00E-05
							1.10E-05
9.00E-05	3.00E-05	6.60E-05	1.20E-05	1.20E-04			1.10E-05
							7.80E-06
2.20E-06	1.70E-06	1.80E-06	1.60E-06	1.80E-06			1.00E-05
							6.50E-04
2.40E-06	1.90E-06	1.90E-06	1.70E-06	1.90E-06			1.00E-05
							8.50E-06
							2.00E-04
							2.60E-04

Post Vibration Internal Leakage Test per PTP (V3-V6 only) all four valves 7-17-02	Post Vibration Internal Leakage Test (sccs GHe) 7-19-02 (AVO50E961RA11)	Post Vibration Internal Leakage Test (sccs GHe) 7-19-02 (AVO) Cycled Valve	Post Vibration Internal Leakage Test (sccs GHe) 7-19-02 (AVO) Cycled Valve	Post Vibration Internal Leakage Test (sccs GHe) 7-27-02 (AVO50E961RA13)	Post Vibration Internal Leakage Test (sccs GHe) 7-29-02 (AVO50E961RA14)	Thermal Cycle -49 C GMA System Internal Leakage per PTP	Thermal Cycle +40 C GMA System Internal Leakage per PTP
< 1 X 10 ⁻⁴ sccs GHe	< 1 X 10 ⁻⁴ sccs GHe	< 1 X 10 ⁻⁴ sccs GHe	< 1 X 10 ⁻⁴ sccs GHe	< 1 X 10 ⁻⁴ sccs GHe	< 1 X 10 ⁻⁴ sccs GHe	< 1.4 X 10 ⁻¹ sccs GHe	< 1.4 X 10 ⁻¹ sccs GHe
	4.30E-05			1.60E-05 3.90E-05	6.70E-07 1.50E-05		
9.20E-05	4.30E-05			3.10E-05			
	2.10E-04	1.20E-04		1.00E-04			
				9.80E-07 9.10E-07			
				2.40E-07 2.90E-07 2.40E-05 1.20E-06 4.20E-06 7.70E-07 2.40E-05 1.40E-06 5.00E-07 9.80E-07 1.20E-06 9.40E-07			
	6.10E-04 2.10E-06	6.30E-04 2.00E-06	5.10E-04	4.40E-04			
				1.10E-06 1.10E-06 1.20E-06 5.00E-07 7.10E-07 3.20E-04 1.20E-05 5.20E-05 1.20E-04			
						9.70E-05	6.00E-05
						5.60E-06	2.40E-06

Thermal Cycle 0 C Internal Leakage Test per PTP (Valve Pairs tested except V3-V6) 8-8-02	Thermal Cycle +40 C Internal Leakage Test per PTP 3.9.4 (Valve Pairs tested except V3-V6) 8-12-02	Thermal Cycle Ambient Internal Leakage Test per PTP 3.11.3 (Valve Pairs tested except V3-V6) 8-14-02	Thermal Cycle Ambient Internal Leakage Test per AVO (Valve Pairs tested except V3-V6) 8-16-02	GMA Line	Valve	Comment
< 1 X 10 ⁻⁴ sccs GHe	< 1 X 10 ⁻⁴ sccs GHe	< 1 X 10 ⁻⁴ sccs GHe	< 1 X 10 ⁻⁴ sccs GHe		Limit	
2.30E-05	6.80E-05	5.20E-05	2.60E-05	R1	V1	Closed during vibration testing
			4.50E-05	R2	V2	Closed during vibration testing
			1.20E-05	R1	V3 & V5	Closed during vibration testing. Leakage rate for two valves
3.90E-05	5.40E-05	2.00E-04	6.60E-05	R2	V4 & V6	Closed during vibration testing. Leakage rate for two valves
5.50E-06	4.90E-06	1.90E-06	1.90E-06	S1	V7	Open during vibration testing
			1.10E-06	S1	V8	Open during vibration testing
4.30E-06	4.70E-06	5.40E-07	7.50E-07	S1	V9	Closed during vibration testing
1.00E-04	2.90E-05	2.50E-05	8.20E-07	S1	V10	Closed during vibration testing
			2.60E-05	S2		V11 Open during vibration testing.
			1.20E-06	S2		V12 Open during vibration testing
6.20E-06	5.50E-06	7.60E-07	2.50E-05	S2	V13	Closed during vibration testing
			1.10E-06	S2	V14	Closed during vibration testing
4.20E-04	5.10E-06	1.80E-06	1.20E-06	S3		V15 Open during vibration testing.
			1.20E-06	S3		V16 Open during vibration testing
4.20E-06	4.60E-06	3.30E-06	6.40E-07	S3	V17	Closed during vibration testing
			9.40E-07	S3	V18	Closed during vibration testing
4.20E-06	4.80E-06	1.30E-06	9.20E-07	S4		V19 Open during vibration testing
			6.90E-07	S4		V20 Open during vibration testing
5.70E-04	4.50E-04	3.70E-04	2.30E-04	S4	V21	Closed during vibration testing
			1.30E-06	S4	V22	Closed during vibration testing
5.20E-06	4.90E-06	1.40E-06	1.00E-06	S3		V23 Open during vibration testing
			8.60E-07	S3		V24 Open during vibration testing
4.50E-06	4.90E-06	9.10E-07	1.80E-06	S3	V25	Closed during vibration testing
			7.50E-07	S3	V26	Closed during vibration testing
3.00E-04	4.60E-04	1.80E-04	8.00E-04	Vent		V27 Open during vibration testing
			8.00E-05	Vent		V28 Open during vibration testing
9.10E-05	1.20E-04	1.80E-04	1.60E-04	Vent	V29	Closed during vibration testing
			6.20E-05	Vent	V30	Closed during vibration testing
					System Internal Leakage (V9,V10,V13,V14,V17,V18,V19,V20,V25,V26,V29,V30)	Valves selected for best internal leakage performance for launch configuration
					System Internal Leakage (V9,V10,V13,V14,V17,V18,V19,V20,V25,V26)	Valves selected for best internal leakage performance for launch configuration, but does not include vent line

Summary of Mott Contamination Counts before and after Vibration Testing

Particle Size (microns)	Limits per 100 mL sample	C58814-001, SN105 From Stock	C58814-001, SN105 Post Vibration	C58814-002, SN110 From Stock	C58814-002, SN110 Post Vibration		
< 5	unlimited (no silting)	OK	OK	OK	OK		
6 to 15	25	21	130	4	6		
16 to 25	7	5	37	2	2		
26 to 50	1	0	5	0	0		
>50	0	0	0	0	0		

Comments:
 1) Vibrated along with latch valves SN007 & SN022.
 2) No metal found on SN105 patch. High counts on SN105 attributed to sampling technique. Nature of contamination was light colored organics. Technician revised sampling technique to avoid splashing. SN110 sampled with improved technique and passed.
 3) C58814-001 = 2 sccm GHe , C58814-002 = 725 sccm GHe
 4) Moog does see contamination from Motts as a credible cause for degrading latch valve leakage performance.

	Legend						
	Likely		Credible, not likely		Not Credible		
Description of Internal Leakage Nonconformance	V4V6 (SN 004 028)	V41 (SN021)	V45 (SN 005)	V21 (SN 020)	V27 (SN 023)	V28 (SN 024)	V29 (SN 003)
	Valve pair measures 2.1E-05 to 1.2E-04 sccs GHe. Valve pair internal leakage was suspect prior to vibration testing.	Valve measured 2.1E-05 to 1.1E-03 sccs GHe. Passing/failing leakage performance was intermittent throughout GMA testing. In general the valve had acceptable internal leakage.	Valve measured 1.1E-05 to 1.5E-03 sccs GHe. Passing/failing leakage performance was intermittent throughout GMA testing.	Immediately after GMA vibration testing, valve leakage measured 1.1E-06 to 2.3E-06 sccs GHe. Leakage degraded after two passing post-vibration leakage tests to 2.4E-04 to 6.5E-04 for remainder of GMA testing.	Valve measured 2.0E-04 sccs GHe leakage immediately after vibration. Subsequent two tests measure 1.4E-06 to 1.4E-04 sccs GHe. Valve eventually degraded to 2.0E-06 to 8.0E-04 sccs GHe.	Valve measured 0.2 bubble/min pre-vibration. Mean spec leakage measured 1.3E-04 to 3.3E-05 sccs GHe	Valve measured 0.1 bubble/min pre-vibration. Mean spec leakage measured 2.2E-06 to 2.3E-05 sccs GHe
Relevant Assembly/Test History	V4: Installed poppet made from bad 120548401 vessel set. Housing was reworked. Mounted in upper bracket position. V6: Housing was reworked. Mounted in lower bracket position. Note that leakage performance improved during/after thermalvac cycling. Valves are closed during launch (random vibration testing)	None. Valve open during launch (random vibration testing)	Build book noted machining mark on seat, unseal poppet covering. Poppet was subsequently replaced. Valve is open during launch (random vibration testing). Valve is mounted in upper position of mounting bracket.	Valve is closed during launch (random vibration testing). Valve is mounted in upper bracket position.	Housing was reworked Housing welds performed three times Valve located on GMA vent line Valve is open during launch (random vibration testing). Valve is mounted in upper bracket position.	Housing was reworked Housing welds performed three times Valve located on GMA vent line Valve is open during launch (random vibration testing). Valve is mounted in upper bracket position.	Housing welds performed three times Valve located on GMA vent line Valve is open during launch (random vibration testing). Valve is mounted in upper bracket position.
Summary/Comments	Probable cause for V4V6 leakage failure is poppet material in V4. All other poppets from this lot were scrapped due to general poor performance from this lot. V4 was already welded together at the time of this discovery and was performing very well. Not reworkable without removal from GMA. Contamination at the seat/poppet interface is also a probable cause. The source of this contamination is most likely from the GMA assembly process. No internal leakage testing was performed on the valves until the GMA was fully assembled. Unable to confirm this cause without disassembly/inspect.	Contamination at the seat/poppet interface is also a probable cause. The source of this contamination is most likely from the GMA assembly process. No internal leakage testing was performed on the valves until the GMA was fully assembled. Unable to confirm this cause without disassembly/inspect. Vibration testing may have also played a role in creating the non-conformance, perhaps by dislodging contamination in the valve. Intermittent nature of leakage rate raises questions about pre-vibration acceptable leak rates.	Contamination at the seat/poppet interface is also a probable cause. The source of this contamination is most likely from the GMA assembly process. No internal leakage testing was performed on the valves until the GMA was fully assembled. Unable to confirm this cause without disassembly/inspect. Vibration testing may have also played a role in creating the non-conformance, perhaps by dislodging contamination in the valve. Intermittent nature of leakage rate raises questions about pre-vibration acceptable leak rates.	Contamination at the seat/poppet interface is also a probable cause. The source of this contamination is most likely from the GMA assembly process. No internal leakage testing was performed on the valves until the GMA was fully assembled. Unable to confirm this cause without disassembly/inspect. Vibration related causes are not suspected since valve had questionable leak rates immediately after vibration.	Contamination at the seat/poppet interface is also a probable cause. The source of this contamination is most likely from the GMA assembly process. No internal leakage testing was performed on the valves until the GMA was fully assembled. Unable to confirm this cause without disassembly/inspect. Vibration related causes are not suspected since valve had questionable leak rates prior to vibration testing.	Contamination at the seat/poppet interface is also a probable cause. The source of this contamination is most likely from the GMA assembly process. No internal leakage testing was performed on the valves until the GMA was fully assembled. Unable to confirm this cause without disassembly/inspect. Vibration testing may have also played a role in creating the non-conformance, perhaps by dislodging contamination in the valve.	Contamination at the seat/poppet interface is also a probable cause. The source of this contamination is most likely from the GMA assembly process. No internal leakage testing was performed on the valves until the GMA was fully assembled. Unable to confirm this cause without disassembly/inspect. Vibration related causes are not suspected since valve had questionable leak rates prior to vibration testing.

Potential Root Cause	Sub-Category	Available Method(s) of Verification and/or Comments	V4V6 (SN 004 028)	V41 (SN021)	V45 (SN 005)	V21 (SN 020)	V27 (SN 023)	V28 (SN 024)	V29 (SN 003)
Category Contamination	At Poppet/Seat Interface, Introduced During Component Assembly	Cycled spare valves while testing to dislodge contamination (this has been done at low pressures without any significant result) Flush valve with high pressure (500 psia) via MV2 to dislodge potential contamination (does not apply to V4V6 because of regulators and Motts). This was not performed due to the risk of contaminating other "good" valves. Particle count could also be performed at GMA outlet, but based on the number of filters and results from Air Products particle counting, this will probably not yield anything. Also, if contaminant damaged poppet sealing surface then removal of contaminant may not have a significant effect. Disassemble and inspect valve (requires removal from GMA). Perform particle counts prior to valve disassembly.	Credible, not likely. Valve certified clean on first flush and passed leakage testing at component level. However, contamination could be trapped at component level. Repeated valve cycling and/or vibration testing may have dislodged contamination (see below).	Credible, not likely. Valve certified clean on first flush and passed leakage testing at component level. However, contamination could be trapped at component level. Repeated valve cycling and/or vibration testing may have dislodged contamination (see below).	Credible, not likely. Valve certified clean on first flush and passed leakage testing at component level. However, contamination could be trapped at component level. Repeated valve cycling and/or vibration testing may have dislodged contamination (see below).	Credible, not likely. Valve certified clean on first flush and passed leakage testing at component level. However, contamination could be trapped at component level. Repeated valve cycling and/or vibration testing may have dislodged contamination (see below).	Credible, not likely. Valve certified clean on first flush and passed leakage testing at component level. However, contamination could be trapped at component level. Repeated valve cycling and/or vibration testing may have dislodged contamination (see below).	Credible, not likely. Valve certified clean on first flush and passed leakage testing at component level. However, contamination could be trapped at component level. Repeated valve cycling and/or vibration testing may have dislodged contamination (see below).	Credible, not likely. Valve certified clean on first flush and passed leakage testing at component level. However, contamination could be trapped at component level. Repeated valve cycling and/or vibration testing may have dislodged contamination (see below).
	At Poppet/Seat Interface, Introduced During GMA Assembly	Same as above Welded two spare units (SN007 and SN022) together using same processes and procedures used to weld GMA. Some particulate found in assembly and initial leak rates were higher than the component level, but valve leakage performance was not affected permanently; after cycling valves the leakage rate returned to levels comparable to the component level. However, later cycle testing revealed that SN007 showed a general shift of one magnitude in leakage performance. The valve also presented leakage data in the 1.0E-05 sccs range. Disassembly of SN027 indicated a residue of aluminum silicate on the poppet immediately upstream of the sealing surface.	Credible, not likely. Valves were not leak tested after component testing until GMA was fully assembled. Handling procedures were taken to protect valves during assembly process, but it is possible that a valve could be contaminated during orbital welding processes. Spare valve SN007 showed a magnitude shift in leakage performance. Later cycle testing indicated intermittent leakage values in the 1.E-05 sccs range.	Credible, not likely. Valves were not leak tested after component testing until GMA was fully assembled. Handling procedures were taken to protect valves during assembly process, but it is possible that a valve could be contaminated during orbital welding processes. Spare valve SN007 showed a magnitude shift in leakage performance. Later cycle testing indicated intermittent leakage values in the 1.E-05 sccs range.	Credible, not likely. Valves were not leak tested after component testing until GMA was fully assembled. Handling procedures were taken to protect valves during assembly process, but it is possible that a valve could be contaminated during orbital welding processes. Spare valve SN007 showed a magnitude shift in leakage performance. Later cycle testing indicated intermittent leakage values in the 1.E-05 sccs range.	Credible, not likely. Valves were not leak tested after component testing until GMA was fully assembled. Handling procedures were taken to protect valves during assembly process, but it is possible that a valve could be contaminated during orbital welding processes. Spare valve SN007 showed a magnitude shift in leakage performance. Later cycle testing indicated intermittent leakage values in the 1.E-05 sccs range.	Credible, not likely. Valves were not leak tested after component testing until GMA was fully assembled. Handling procedures were taken to protect valves during assembly process, but it is possible that a valve could be contaminated during orbital welding processes. Spare valve SN007 showed a magnitude shift in leakage performance. Later cycle testing indicated intermittent leakage values in the 1.E-05 sccs range.	Credible, not likely. Valves were not leak tested after component testing until GMA was fully assembled. Handling procedures were taken to protect valves during assembly process, but it is possible that a valve could be contaminated during orbital welding processes. Spare valve SN007 showed a magnitude shift in leakage performance. Later cycle testing indicated intermittent leakage values in the 1.E-05 sccs range.	Credible, not likely. Valves were not leak tested after component testing until GMA was fully assembled. Handling procedures were taken to protect valves during assembly process, but it is possible that a valve could be contaminated during orbital welding processes. Spare valve SN007 showed a magnitude shift in leakage performance. Later cycle testing indicated intermittent leakage values in the 1.E-05 sccs range.
	At Poppet/Seat Interface, Dislodged During Vibration Testing	Vibration tested two spare valves. Higher particle counts noted. Leakage performance not affected. Disassemble and inspect valve (requires removal from GMA). Perform particle counts prior to valve disassembly.	Not credible; leakage data is consistent before and after vibration. No history of valve cycling being a problem.	Credible, not likely. Valve was open during vibration & located in top position of bracket. Majority of valves that indicate poor leakage performance were open during vibration and located in top position of mounting bracket. Previous valve vibration testing had valve in closed position only. Spare valve testing did not reveal a problem.	Credible, not likely. Valve was open during vibration & located in top position of bracket. Majority of valves that indicate poor leakage performance were open during vibration and located in top position of mounting bracket. Previous valve vibration testing had valve in closed position only. Spare valve testing did not reveal a problem.	Credible, not likely. Valve performed in specification immediately after vibration testing. After additional cycling and testing the valve leakage performance degraded. Spare valve testing did not reveal a problem.	Not credible; valve was identified as a potential problem before vibration.	Credible, not likely. Valve was open during vibration & located in top position of bracket. Majority of valves that indicate poor leakage performance were open during vibration and located in top position of mounting bracket. Previous valve vibration testing had valve in closed position only. Spare valve testing did not reveal a problem.	Not credible; valve was identified as a potential problem before vibration.

		V1V6 (SN 004, 005)	V11 (SN002)	V15 (SN 005)	V21 (SN 020)	V27 (SN 025)	V28 (SN 024)	V29 (SN 003)
At Core/Armature Interface, which prevent proper seating of poppet: Introduced During Component Assembly	Cycled spare valves while flowing to dislodge contamination (this has been done at low pressures without any significant result). Flush valve with high pressure (300 psia) via MV2 to dislodge potential contaminants (does not apply to V4/V6 because of regulators and Minots). This was not performed due to the risk of contaminating other "good" valves. Particle count could also be performed at GMA outlet, but based on the number of filters and results from Air Products particle counting, this will probably not yield anything. Also, if contaminant damaged poppet seating surface then removal of contaminant may not have a significant effect. Disassemble and inspect valve (requires removal from GMA). Perform particle counts prior to valve disassembly.	Not credible. Would also expect gross leakage for this condition.	Not credible. Would also expect gross leakage for this condition.	Not credible. Would also expect gross leakage for this condition.	Not credible. Would also expect gross leakage for this condition.	Not credible. Would also expect gross leakage for this condition.	Not credible. Would also expect gross leakage for this condition.	Not credible. Would also expect gross leakage for this condition.
	Same as above Welded two spare units together using name processes and procedures used to weld GMA. Some particulate found in assembly and initial leak rates were higher than the component level, but valve leakage performance was not affected permanently, after cycling valves the leakage rate returned to levels comparable to the component level. Disassemble and inspect valve (requires removal from GMA). Perform particle counts prior to valve disassembly.	Not credible. Would also expect gross leakage for this condition.	Not credible. Would also expect gross leakage for this condition.	Not credible. Would also expect gross leakage for this condition.	Not credible. Would also expect gross leakage for this condition.	Not credible. Would also expect gross leakage for this condition.	Not credible. Would also expect gross leakage for this condition.	Not credible. Would also expect gross leakage for this condition.
	At Core/Armature Interface, Dislodged During Vibration	Not credible. Would also expect gross leakage for this condition. Valve part was suspect prior to vibration	Not credible. Would also expect gross leakage for this condition.	Not credible. Would also expect gross leakage for this condition.	Not credible. Would also expect gross leakage for this condition.	Not credible. Would also expect gross leakage for this condition. Valve was suspect prior to vibration	Not credible. Would also expect gross leakage for this condition.	Not credible. Would also expect gross leakage for this condition.
	Self-Generated Contamination, e.g. Filter shedding, sliding fits, improperly detuned parts	Same as above. Cycled tested spare valves SN007 & SN022. Particles large enough to affect sealing were disassembled. Analysis of particles indicate these may have come from handling and hook-up. The leakage performance of these valves was not degraded.	Credible, not likely, valve design has no history of self-generated contaminants. Filters go through a very aggressive cleaning prior to assembly into valve. All parts cleaned and inspect during prior to assembly	Credible, not likely, valve design has no history of self-generated contaminants. Filters go through a very aggressive cleaning prior to assembly into valve. All parts cleaned and inspect during prior to assembly	Credible, not likely, valve design has no history of self-generated contaminants. Filters go through a very aggressive cleaning prior to assembly into valve. All parts cleaned and inspect during prior to assembly	Credible, not likely, valve design has no history of self-generated contaminants. Filters go through a very aggressive cleaning prior to assembly into valve. All parts cleaned and inspect during prior to assembly	Credible, not likely, valve design has no history of self-generated contaminants. Filters go through a very aggressive cleaning prior to assembly into valve. All parts cleaned and inspect during prior to assembly	Credible, not likely, valve design has no history of self-generated contaminants. Filters go through a very aggressive cleaning prior to assembly into valve. All parts cleaned and inspect during prior to assembly
	Unusually Large Gas Throughput Through valve	Check gas supply for purity and particulate matter. Disassemble and inspect valve (requires removal from GMA)	Credible, not likely, valves have been used as a primary flow path for GMA purging/servicing. Only filtered, high purity gas used.	Not credible, valve was not used as a primary flow path	Not credible, valve was not used as a primary flow path	Not credible, valve was not used as a primary flow path	Credible, not likely, valves have been used as a primary flow path for GMA purging/servicing. Only filtered, high purity gas used.	Credible, not likely, valves have been used as a primary flow path for GMA purging/servicing. Only filtered, high purity gas used.
Damage to Valve Piece parts due to Vibration		Poppet Surface Damage Cycled valve to recon poppet. Exposed two spare valves (SN007 & SN022) while immersed in the GMA brackets to the GMA system vibration levels with both valves open. Verified leakage between sees. Leakage performance of valves unaffected. Noted high amplification of valve in top bracket (~40 Gms) Disassemble and inspect valve (requires removal from GMA)	Not credible, leak rate was suspect prior to vibration testing. Spare valve testing did not reveal a problem.	Credible, not likely, no history of poppet damage due to vibration. Valve was open during vibration & located in top position of bracket. Majority of valves that indicate poor leakage performance were open during vibration and located in top position of mounting bracket. Spare valve testing did not reveal a problem.	Credible, not likely, no history of poppet damage due to vibration. Valve was open during vibration & located in top position of bracket. Majority of valves that indicate poor leakage performance were open during vibration and located in top position of mounting bracket. Spare valve testing did not reveal a problem.	Credible, not likely, no history of poppet damage due to vibration. Valve was closed during vibration & located in top position of bracket. Majority of valves that indicate poor leakage performance were open during vibration and located in top position of mounting bracket. Spare valve testing did not reveal a problem.	Credible, not likely, no history of poppet damage due to vibration. Valve was closed during vibration & located in top position of bracket. Majority of valves that indicate poor leakage performance were open during vibration and located in top position of mounting bracket. Spare valve testing did not reveal a problem.	Credible, not likely, no history of poppet damage due to vibration. Valve was open during vibration and located in lower position of bracket. Majority of valves that indicate poor leakage performance were open during vibration and located in top position of mounting bracket. Spare valve testing did not reveal a problem.
Yielded/Fatigued Poppet Spring		Checked for gross leakage (indicates failed spring only). Disassemble and inspect valve (requires removal from GMA)	Not credible, spring damage would result in gross leakage leak rate was suspect prior to vibration testing	Not credible, spring damage normally results in gross leakage	Not credible, spring damage normally results in gross leakage	Not credible, spring damage normally results in gross leakage	Not credible, spring damage normally results in gross leakage	Not credible, spring damage normally results in gross leakage
Incorrect Manufacture/Assembly		One or More Piece parts Manufactured From Bad Material Moog & Stanford examined valve As-Built Configuration Record (ABCR) and build folders of all valves. No trend was found with regard to lot numbers or build data.	Likely, VA contains poppet made from bad stainless steel. Data shows the largest changes in sealing performance can occur with this lot.	Not credible, all material lot numbers used in valve conform to specifications	Not credible, all material lot numbers used in valve conform to specifications	Not credible, all material lot numbers used in valve conform to specifications	Not credible, all material lot numbers used in valve conform to specifications	Not credible, all material lot numbers used in valve conform to specifications
Poppet Out of Print		Moog & Stanford examined valve As-Built Configuration Record (ABCR) and build folders of all valves. No trend was found with regard to lot numbers or build data. Disassemble and inspect valve (requires removal from GMA).	Not credible, both valves passed leakage during build	Not credible, valve passed leakage during build	Not credible, valve passed leakage during build	Not credible, valve passed leakage during build & in two tests post vibration.	Not credible, valve passed leakage during build	Not credible, valve passed leakage during build
Core/Armature Out of Print		Moog & Stanford examined valve As-Built Configuration Record (ABCR) and build folders of all valves. No trend was found with regard to lot numbers or build data. Disassemble and inspect valve (requires removal from GMA).	Not credible, both valves passed leakage during build. All cores and armatures measured for valve plugging at time of build	Not credible, both valves passed leakage during build. All cores and armatures measured for valve plugging at time of build	Not credible, both valves passed leakage during build. All cores and armatures measured for valve plugging at time of build	Not credible, both valves passed leakage during build. All cores and armatures measured for valve plugging at time of build	Not credible, both valves passed leakage during build. All cores and armatures measured for valve plugging at time of build	Not credible, both valves passed leakage during build. All cores and armatures measured for valve plugging at time of build
Outlet Fitting (Seal) Out of Print		Moog & Stanford examined valve As-Built Configuration Record (ABCR) and build folders of all valves. No trend was found with regard to lot numbers or build data. Cycled valves to attempt to recon poppet. This was done at ambient and hot. Disassemble and inspect valve (requires removal from GMA)	Not credible, both valves passed leakage during build	Not credible, valve passed leakage during build	Likely, unusual machining mark, noted in valve historical record. All component testing and GMA pre-vibration tests indicated not valve was healthy	Not credible, valve passed leakage during build	Not credible, valve passed leakage during build	Not credible, valve passed leakage during build
Inproper Core Stemming/Preload Adjustment		Moog & Stanford examined valve As-Built Configuration Record (ABCR) and build folders of all valves. No trend was found with regard to lot numbers or build data. Disassemble and inspect valve (requires removal from GMA).	Not credible, Spring preload was measured at time of build, armature and poppet stroke measured at time of build, both valves passed leakage during build	Not credible, Spring preload was measured at time of build, armature and poppet stroke measured at time of build, both valves passed leakage during build	Not credible, Spring preload was measured at time of build, armature and poppet stroke measured at time of build, both valves passed leakage during build	Not credible, Spring preload was measured at time of build, armature and poppet stroke measured at time of build, both valves passed leakage during build	Not credible, Spring preload was measured at time of build, armature and poppet stroke measured at time of build, both valves passed leakage during build	Not credible, Spring preload was measured at time of build, armature and poppet stroke measured at time of build, both valves passed leakage during build

			V16 (SN 004, 005)	V17 (SN021)	V15 (SN 005)	V21 (SN 020)	V27 (SN 023)	V28 (SN 024)	V29 (SN 003)
	Improper Sealing of Core which would permit core to unscrew during after repeated cycling and/or vibration testing. This situation would result in loss of poppet spring preload and may not allow poppet to seat.	Moog & Stanford examined valve As-Built Configuration Record (ABCR) and build folders of all valves. No trend was found with regard to lot numbers or build data. -Disassemble and inspect valve (requires removal from GMA).	Not credible. All swagels are inspected at build. Would also expect gross leakage.	Not credible. All swagels are inspected at build. Would also expect gross leakage. Valve non-conformance is intermittent.	Not credible. All swagels are inspected at build. Would also expect gross leakage.	Not credible. All swagels are inspected at build. Would also expect gross leakage.	Not credible. All swagels are inspected at build. Would also expect gross leakage. Valve non-conformance is intermittent.	Not credible. All swagels are inspected at build. Would also expect gross leakage. Valve non-conformance is intermittent.	Not credible. All swagels are inspected at build. Would also expect gross leakage. Valve non-conformance is intermittent.
	Unusual or Additional Handling	Moog & Stanford examined valve As-Built Configuration Record (ABCR) and build folders of all valves. Trends are noted in matrix. -Disassemble and inspect valve (requires removal from GMA). All valves except V1 & V2 had filter body seal repaired since. Majority of valves are performing within specification.	Credible, not likely, although valves were reworked, the affected parts were cleaned as expected per standard procedure. All valves except V1 & V2 had filter body seal repaired since. Majority of valves are performing within specification.	Not Credible No unusual handling occurred	Not Credible No unusual handling occurred	Not Credible No unusual handling occurred	Credible, not likely, although valves were reworked, the affected parts were cleaned as expected per standard procedure. All valves except V1 & V2 had filter body seal repaired since. Majority of valves are performing within specification.	Credible, not likely, although valves were reworked, the affected parts were cleaned as expected per standard procedure. All valves except V1 & V2 had filter body seal repaired since. Majority of valves are performing within specification.	Credible, not likely, although valves were reworked, the affected parts were cleaned as expected per standard procedure. All valves except V1 & V2 had filter body seal repaired since. Majority of valves are performing within specification.
	Improper seating of poppet retaining ring. Normal cycling and/or vibration testing causes ring to become unusual.	Moog & Stanford examined Valve As-Built Configuration Record (ABCR) and build folders of all valves. No trend was found with regard to lot numbers or build data. -Disassemble and inspect valve (requires removal from GMA).	Not credible. Unusual valve response and gross leakage expected. All valves have in family responses.	Not credible. Unusual valve response and gross leakage expected. All valves have in family responses.	Not credible. Unusual valve response and gross leakage expected. All valves have in family responses.	Not credible. Unusual valve response and gross leakage expected. All valves have in family responses.	Not credible. Unusual valve response and gross leakage expected. All valves have in family responses.	Not credible. Unusual valve response and gross leakage expected. All valves have in family responses.	Not credible. Unusual valve response and gross leakage expected. All valves have in family responses.
Testing/Measurement Error	High Helium Background Levels	Checked background with GMA evacuated and all valves open. -Verified leakage background resolution of mass spectrometer by plumbung a calibrated leak device into GMA at vent line. Mass spectrometer was capable of measuring the calibrated leak of 1.0E-05 sccs GMA.	Not credible. Mixing verified that measuring leakage at MV2 and the outlets yielded the same result.	Credible, not likely, although background leak has caused anomalous reading for one data point (1.0E-03 sccs GMA)	Not credible. Other nearby valves yielded acceptable leakage values	Not credible for any testing performed in the GMA and valves are at the outlet of the GMA	Not credible. Other nearby valves yielded acceptable leakage values	Not credible for any testing performed in the GMA and valves are at the outlet of the GMA	Not credible for any testing performed in the GMA and valves are at the outlet of the GMA
	Incorrect Mass Spectrometer Calibration	Check for consistently out-of-spec measurements on all valves. -Verified leakage background resolution of mass spectrometer by plumbung a calibrated leak device into GMA at vent line. Mass spectrometer was capable of measuring the calibrated leak of 1.0E-05 sccs GMA.	Not credible. Majority of valves measure ~2.0E-06 sccs GMA	Not credible. Majority of valves measure ~2.0E-06 sccs GMA	Not credible. Majority of valves measure ~2.0E-06 sccs GMA	Not credible. Majority of valves measure ~2.0E-06 sccs GMA	Not credible. Majority of valves measure ~2.0E-06 sccs GMA	Not credible. Majority of valves measure ~2.0E-06 sccs GMA	Not credible. Majority of valves measure ~2.0E-06 sccs GMA
	Improper bubbling testing, i.e., test set-up disturbed or set-up improperly	Check leakage using mass spectrometer. This has been performed.	Not credible. Improper set-up would many valves. No reason to believe that test was disturbed.	Not credible. Improper set-up would many valves. No reason to believe that test was disturbed.	Not credible. Improper set-up would many valves. No reason to believe that test was disturbed.	Not credible. Improper set-up would many valves. No reason to believe that test was disturbed.	Not credible. Improper set-up would many valves. No reason to believe that test was disturbed.	Not credible. Improper set-up would many valves. No reason to believe that test was disturbed.	Not credible. Improper set-up would many valves. No reason to believe that test was disturbed.
	Experimental/Statistical Error	Retire via further testing. Additional testing did reveal that the valve sequencing and evacuation procedure does have an effect on the leakage reading, but not enough of an effect to consider this a cause of the non-conforming readings.	Not credible. Multiple leakage measurements show consistent valve performance of good & bad valves.	Not credible. Multiple leakage measurements show consistent valve performance of good & bad valves.	Not credible. Multiple leakage measurements show consistent valve performance of good & bad valves.	Not credible. Multiple leakage measurements show consistent valve performance of good & bad valves.	Not credible. Multiple leakage measurements show consistent valve performance of good & bad valves.	Not credible. Multiple leakage measurements show consistent valve performance of good & bad valves.	Not credible. Multiple leakage measurements show consistent valve performance of good & bad valves.
Normal Performance of valve design	Yes	Review of data from previous programs using the valve design. Perform statistical analysis of past valve performance	Credible, not likely. Review of data from qualification units (2), DS-1 (5), PMA (2) and USERS (3) indicated that the valves typically perform between 5e-05 and 5e-07 sccs. Out of 61 historical data points, 3 data points had (from three different valves) measured ~5e-04 sccs. Higher leakage rate behavior noted occurred 1 time on each valve and did not repeat in future testing. Leakage performance of valves that indicated anomalous behavior returned to leak rate ~5e-05 sccs.	Credible, not likely. Review of data from qualification units (2), DS-1 (5), PMA (2) and USERS (3) indicated that the valves typically perform between 5e-05 and 5e-07 sccs. Out of 61 historical data points, 3 data points had (from three different valves) measured ~5e-04 sccs. Higher leakage rate behavior noted occurred 1 time on each valve and did not repeat in future testing. Leakage performance of valves that indicated anomalous behavior returned to leak rate ~5e-05 sccs.	Credible, not likely. Review of data from qualification units (2), DS-1 (5), PMA (2) and USERS (3) indicated that the valves typically perform between 5e-05 and 5e-07 sccs. Out of 61 historical data points, 3 data points had (from three different valves) measured ~5e-04 sccs. Higher leakage rate behavior noted occurred 1 time on each valve and did not repeat in future testing. Leakage performance of valves that indicated anomalous behavior returned to leak rate ~5e-05 sccs.	Credible, not likely. Review of data from qualification units (2), DS-1 (5), PMA (2) and USERS (3) indicated that the valves typically perform between 5e-05 and 5e-07 sccs. Out of 61 historical data points, 3 data points had (from three different valves) measured ~5e-04 sccs. Higher leakage rate behavior noted occurred 1 time on each valve and did not repeat in future testing. Leakage performance of valves that indicated anomalous behavior returned to leak rate ~5e-05 sccs.	Credible, not likely. Review of data from qualification units (2), DS-1 (5), PMA (2) and USERS (3) indicated that the valves typically perform between 5e-05 and 5e-07 sccs. Out of 61 historical data points, 3 data points had (from three different valves) measured ~5e-04 sccs. Higher leakage rate behavior noted occurred 1 time on each valve and did not repeat in future testing. Leakage performance of valves that indicated anomalous behavior returned to leak rate ~5e-05 sccs.	Credible, not likely. Review of data from qualification units (2), DS-1 (5), PMA (2) and USERS (3) indicated that the valves typically perform between 5e-05 and 5e-07 sccs. Out of 61 historical data points, 3 data points had (from three different valves) measured ~5e-04 sccs. Higher leakage rate behavior noted occurred 1 time on each valve and did not repeat in future testing. Leakage performance of valves that indicated anomalous behavior returned to leak rate ~5e-05 sccs.	Credible, not likely. Review of data from qualification units (2), DS-1 (5), PMA (2) and USERS (3) indicated that the valves typically perform between 5e-05 and 5e-07 sccs. Out of 61 historical data points, 3 data points had (from three different valves) measured ~5e-04 sccs. Higher leakage rate behavior noted occurred 1 time on each valve and did not repeat in future testing. Leakage performance of valves that indicated anomalous behavior returned to leak rate ~5e-05 sccs.
Poppet rotated relative to seat resulting in seat/poppet interface mismatch due to local geometry of parts	Rotation of poppet or preprogrammed sub-assembly due to normal cycling or vibration testing	Disassemble valve to inspect poppet and seat surfaces to normal cycling or vibration testing. Performed experiment on development valve to determine if armature/poppet rotates when the valve is cycled. armature/poppet does not rotate.	Not credible. No history of problem in past and would expect more valves to be affected. Majority of leakage data from all valves is consistent before and after vibration	Not credible. No history of problem in past and would expect more valves to be affected. No data to support cause.	Not credible. No history of problem in past and would expect more valves to be affected. No data to support cause.	Not credible. No history of problem in past and would expect more valves to be affected. No data to support cause.	Not credible. No history of problem in past and would expect more valves to be affected. No data to support cause.	Not credible. No history of problem in past and would expect more valves to be affected. Unit was flagged as a problem prior to vibration	Not credible. No history of problem in past and would expect more valves to be affected. Unit flagged as a problem prior to vibration
Degradation of Poppet Material	Prolonged exposure to vacuum levels ~1.0E-03 torr at temperatures between 104 F and 140 F causes loss of the Vespel material due to outgassing or otherwise degrades sealing interface of poppet	Exposed spare valves to vacuum conditions. SN027 exhibited a general shift in leakage performance from the 1.0E-07 sccs range to 1.0E-06 range. Also presented some values in the 1.0E-05 range and one data point at 2.0E-04 sccs. SN022 performance was unchanged. Performed outgassing testing of Vespel (by MASSCO). Water is the primary outgassing constituent. Not considered a cause. Additional testing using Vespel samples exposed to vacuum and return will be limited tested to determine if properties have been affected by exposure.	Credible, not likely SN007 valve did present some degradation. SN022 was unchanged. Testing of samples indicated a wide variation in tensile strength and % elongation. This result may be due to test specimen geometry. Testing deemed inconclusive.	Credible, not likely SN007 valve did present some degradation. SN022 was unchanged. Testing of samples indicated a wide variation in tensile strength and % elongation. This result may be due to test specimen geometry. Testing deemed inconclusive.	Credible, not likely SN007 valve did present some degradation. SN022 was unchanged. Testing of samples indicated a wide variation in tensile strength and % elongation. This result may be due to test specimen geometry. Testing deemed inconclusive.	Credible, not likely SN007 valve did present some degradation. SN022 was unchanged. Testing of samples indicated a wide variation in tensile strength and % elongation. This result may be due to test specimen geometry. Testing deemed inconclusive.	Credible, not likely SN007 valve did present some degradation. SN022 was unchanged. Testing of samples indicated a wide variation in tensile strength and % elongation. This result may be due to test specimen geometry. Testing deemed inconclusive.	Credible, not likely SN007 valve did present some degradation. SN022 was unchanged. Testing of samples indicated a wide variation in tensile strength and % elongation. This result may be due to test specimen geometry. Testing deemed inconclusive.	Credible, not likely SN007 valve did present some degradation. SN022 was unchanged. Testing of samples indicated a wide variation in tensile strength and % elongation. This result may be due to test specimen geometry. Testing deemed inconclusive.
	Prolonged exposure to helium at 5 to 20 psia at temperatures between 104 F and 140 F degrades sealing interface of poppet	Exposed spare valves to helium conditions. No degradation in leakage performance. Additional testing using Vespel samples exposed to vacuum and return will be limited tested to determine if properties have been affected by exposure Disassemble valve to inspect poppet.	Credible, not likely SN007 valve did present some degradation. SN022 was unchanged. Testing of samples indicated a wide variation in tensile strength and % elongation. This result may be due to test specimen geometry. Testing deemed inconclusive.	Credible, not likely SN007 valve did present some degradation. SN022 was unchanged. Testing of samples indicated a wide variation in tensile strength and % elongation. This result may be due to test specimen geometry. Testing deemed inconclusive.	Credible, not likely SN007 valve did present some degradation. SN022 was unchanged. Testing of samples indicated a wide variation in tensile strength and % elongation. This result may be due to test specimen geometry. Testing deemed inconclusive.	Credible, not likely SN007 valve did present some degradation. SN022 was unchanged. Testing of samples indicated a wide variation in tensile strength and % elongation. This result may be due to test specimen geometry. Testing deemed inconclusive.	Credible, not likely SN007 valve did present some degradation. SN022 was unchanged. Testing of samples indicated a wide variation in tensile strength and % elongation. This result may be due to test specimen geometry. Testing deemed inconclusive.	Credible, not likely SN007 valve did present some degradation. SN022 was unchanged. Testing of samples indicated a wide variation in tensile strength and % elongation. This result may be due to test specimen geometry. Testing deemed inconclusive.	Credible, not likely SN007 valve did present some degradation. SN022 was unchanged. Testing of samples indicated a wide variation in tensile strength and % elongation. This result may be due to test specimen geometry. Testing deemed inconclusive.

D.3 Stanford GMA Acceptance Test

- P0943 “Verification of GMA Outlet Flow Rates”
- P0928 “0 Hz Spin Test/Add Exchange Gas in the GAF Using the GMA”
- P0925 “Gyro Slow Spin Test in the GAF Using the GMA”
- P0935 “Gyro Fast Spin Test in the GAF Using the GMA”



STANFORD UNIVERSITY
W.W. HANSEN EXPERIMENTAL PHYSICS LABORATORY
GRAVITY PROBE B, RELATIVITY GYROSCOPE EXPERIMENT
STANFORD, CALIFORNIA 94305-4085

VERIFICATION OF GMA OUTLET FLOW RATES

GP-B ENGINEERING PROCEDURE

P0943 Rev -

As-run 9/23/02

20 September, 2002

PREPARED *Rick Stephenson*
R. Stephenson, GMA Engineer

9/23/02
Date

APPROVED *Chris Gray*
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9/23/02
Date

APPROVED *Dorrene Ross*
D. Ross, Quality Assurance

9/23/02
Date

APPROVED *R. Brumley*
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9/23/02
Date

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REVISION RECORD

REVISION	ECO	PAGES	DATE

A SCOPE

This procedure connects the Probe Impedance Simulation Manifold (ISM) to the Gyro Acceptance Facility (GAF) in order to measure the helium flow rates of all flow paths in the flight Gas Management Assembly (GMA). This manifold simulates the flow impedance of the flight probe and has flow meters to measure the helium flow.

B SAFETY

The GMA is a gas pressure vessel. Under normal operations, the GMA requires no safety measures or equipment beyond those required for the use of a supply gas cylinder. When any of the systems are pressurized and connected to a vacuum system, be cautious not to vent high pressure through the pumping portions of the system. Note that the GMA is a high value space flight item. Also, the GMA tanks are fracture critical items, so care must be taken not to damage them in any way.

C QUALITY ASSURANCE

C.1 QA Notification

This test will be conducted on a formal basis to approved and released procedures. **The QA program office and ONR representative shall be notified 24 hours prior to the start of this procedure.** A Quality Assurance Representative, designated by D. Ross shall be present during the procedure and shall review any discrepancies noted and approve their disposition. Upon completion of this procedure, the QA Program Engineer, D. Ross or her designate, will certify her concurrence that the effort was performed and accomplished in accordance with the prescribed instructions by signing and dating in the designated place(s) in this document.

C.2 Red-line Authority

Authority to redline (make minor changes during execution) this procedure is given solely to the Test Director or his designate and shall be approved by the QA Representative.

C.3 Discrepancies

Discrepancies will be recorded in a D-log or as a DR per Quality Plan P0108.

D TEST PERSONNEL

The Test Director shall be Chris Gray or an alternate that he shall designate. The Director has overall responsibility for the implementation of this procedure and shall sign off the completed procedure and relevant sections within it.

E REQUIREMENTS

E.1. Electrostatic Discharge Requirements

N/A

E.2. Lifting Operation Requirements

N/A

E.3. Hardware/Software Requirements

Flight Gas Management Assembly (GMA)

ECU Flight Equivalent Unit (FEU)

GMA outlet manifold

Gyro Acceptance Facility

Impedance Simulation Manifold (ISM)

Gas Delivery System (GDS) (optional)

GMA fill manifold (optional)

Vacuum system (Alcatel pump cart or equivalent)

CSTOL script "gma_null.prc"

E.4. Instrument Pretest Requirements

All test equipment used in taking data shall be "in calibration" at time of test.

E.5. Configuration Requirements

GMA must be connected to the GAF per P0923

E.6. Optional Non-flight Configurations

N/A

E.7. Verification/ Success Criteria

Flows for every path through a given flow orifice should be consistent with expected values to within 20%.

E.8. Constraints and Restrictions

none

F REFERENCE DOCUMENTS

F.1. Drawings

GMA Schematic, Dwg. Number 26273

F.2. Supporting documentation

none

F.3. Additional Procedures

P0930 GMA Sleep

P0886 Gas Delivery System Operations (optional)

G OPERATIONS

G.1. Verify Appropriate QA Notification

QA Notified 9/23/02

ONR Notified 9/23/02

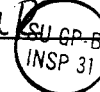
G.2. Verify Configuration Requirements

WARNING

HELIUM USED IN THE GRAVITY PROBE-B PROGRAM REPRESENTS A HAZARDOUS MATERIAL FOR THE PERSONNEL INVOLVED IN TESTING AND CRYOGENIC SYSTEM OPERATIONS. EXTREME CARE SHOULD BE USED WHEN WORKING AROUND OR WITH HELIUM.

- ☒ GMA is connected to the GAF.
- ☒ There is no gyroscope levitated in the GAF, and the GAF is otherwise in a safe mode.
- ☒ Top Hat Spinup Valves are closed (S/U2, S/U3).
- ☒ Manual valve "OMVent-2" is installed per D-log to P0923
- ☒ Sufficient helium must be in the GMA tanks to complete the procedure.
- ☒ GMA zones downstream of the internal pressure regulators are not pressurized to greater than 30 psia (i.e. GMA regulators have not been "locked up").

Quality



G.3 Setup of GMA

Started on: 9/23/02

Note: Mark off each step of procedure as it is completed.

- ☒ 3.1 Start the ECU and run script "load_gma.prc".
- ☒ 3.2 Connect the ISM Gyroscope port to DP1 on the GAF.
- ☒ 3.3 Verify that ISM flow meters have been powered up for at least 15 minutes and set zero point on flow meters.
- ☒ 3.4 Verify that GAF manual valve FF1 is open.
- ☒ 3.5 Verify that ISM manual valves F1, F2, B1, F5, F3, F4, and B2 are firmly closed.
- ☒ 3.6 Connect vacuum pump to ISM valve E2.
- ☒ 3.7 Start vacuum pump.
- ☒ 3.8 Slowly open ISM manual valves E2, E1, M1, and M2.
- ☒ 3.9 Once pressure stabilizes at the vacuum pump, close ISM manual valve E1 and slowly open ISM manual valve B1.
- ☒ 3.10 Once pressure stabilizes at the vacuum pump, slowly open GAF manual valve DP1.
- ☒ 3.11 Once pressure stabilizes at the vacuum pump, slowly open outlet manifold manual valves OMG1, OMG2, OMG3, OMG4, OMP1A, OMPVent, and OMPVent2.

Quality



G.4 Verification of Flow Rates

Started on: 9/23/02

Note: Mark off each step of procedure as it is completed.

- ~~4.1~~ Verify that section G.3 is complete.
- ~~4.2~~ Load CSTOL script "gma_null.prc"
- ~~4.3~~ Use ECU to put GMA solenoid valves into a launch configuration.
- ~~4.4~~ Close ISM manual valve B1 and open ISM manual valve F2.

725 sccm flow path, side A

- ~~4.5~~ Open GMA solenoid valves V1, V5, and V9.
- ~~4.6~~ Wait until a stable flow is reached and record flow rate from FM2 in Table 1 for Gyro1A.
- ~~4.7~~ Close GMA solenoid valve V9 and open V10.
- ~~4.8~~ Wait until a stable flow is reached and record flow rate from FM2 in Table 1 for Gyro1B.
- ~~4.9~~ Close GMA solenoid valve V10 and open V13.
- ~~4.10~~ Wait until a stable flow is reached and record flow rate from FM2 in Table 1 for Gyro2A.
- ~~4.11~~ Close GMA solenoid valve V13 and open V14.
- ~~4.12~~ Wait until a stable flow is reached and record flow rate from FM2 in Table 1 for Gyro2B.
- ~~4.13~~ Close GMA solenoid valve V14 and open V17.
- ~~4.14~~ Wait until a stable flow is reached and record flow rate from FM2 in Table 1 for Gyro3A.
- ~~4.15~~ Close GMA solenoid valve V17 and open V18.
- ~~4.16~~ Wait until a stable flow is reached and record flow rate from FM2 in Table 1 for Gyro3B.
- ~~4.17~~ Close GMA solenoid valve V18 and open V19.
- ~~4.18~~ Wait until a stable flow is reached and record flow rate from FM2 in Table 1 for Gyro4A.
- ~~4.19~~ Close GMA solenoid valve V19 and open V20.
- ~~4.20~~ Wait until a stable flow is reached and record flow rate from FM2 in Table 1 for Gyro4B.
- ~~4.21~~ Close GMA solenoid valve V20 and open V25.
- ~~4.22~~ Wait until a stable flow is reached and record flow rate from FM2 in Table 1 for Flux
Flush A (expected <10 sccm).
- ~~4.23~~ Close GMA solenoid valve V25 and open V26.
- ~~4.24~~ Wait until a stable flow is reached and record flow rate from FM2 in Table 1 for Flux
Flush B (expected <10 sccm).
- ~~4.25~~ Close GMA solenoid valve V26 and open V29.
- ~~4.26~~ Wait until a stable flow is reached and record flow rate from FM2 in Table 1 for VentA.
- ~~4.27~~ Close GMA solenoid valve V29 and open V30.

~~4.28~~ Wait until a stable flow is reached and record flow rate from FM2 in Table 1 for Vent~~B~~.

~~4.29~~ Close V30.

All flow paths nominal.

Test engineer:

Quality:



725 sccm flow path, side B

~~4.30~~ Close GMA solenoid valves V5 and V1.

~~4.31~~ Open GMA solenoid valves V2, V6 and V9.

~~4.32~~ Wait until a stable flow is reached and record flow rate from FM2 in Table 1 for Gyro~~1A~~.

~~4.33~~ Close GMA solenoid valve V9 and open V10.

~~4.34~~ Wait until a stable flow is reached and record flow rate from FM2 in Table 1 for Gyro~~1B~~.

~~4.35~~ Close GMA solenoid valve V10 and open V13.

~~4.36~~ Wait until a stable flow is reached and record flow rate from FM2 in Table 1 for Gyro~~2A~~.

~~4.37~~ Close GMA solenoid valve V13 and open V14.

~~4.38~~ Wait until a stable flow is reached and record flow rate from FM2 in Table 1 for Gyro~~2B~~.

~~4.39~~ Close GMA solenoid valve V14 and open V17.

~~4.40~~ Wait until a stable flow is reached and record flow rate from FM2 in Table 1 for Gyro~~3A~~.

~~4.41~~ Close GMA solenoid valve V17 and open V18.

~~4.42~~ Wait until a stable flow is reached and record flow rate from FM2 in Table 1 for Gyro~~3B~~.

~~4.43~~ Close GMA solenoid valve V18 and open V19.

~~4.44~~ Wait until a stable flow is reached and record flow rate from FM2 in Table 1 for Gyro~~4A~~.

~~4.45~~ Close GMA solenoid valve V19 and open V20.

~~4.46~~ Wait until a stable flow is reached and record flow rate from FM2 in Table 1 for Gyro~~4B~~.

~~4.47~~ Close GMA solenoid valve V20 and open V29.

~~4.48~~ Wait until a stable flow is reached and record flow rate from FM2 in Table 1 for Vent~~A~~.

~~4.49~~ Close GMA solenoid valve V29 and open V30.

~~4.50~~ Wait until a stable flow is reached and record flow rate from FM2 in Table 1 for Vent~~B~~.

~~4.51~~ Close V30.

All flow paths nominal.

Test engineer:

Quality:



2 sccm flow path, side A

- 4.52 Close GMA solenoid valves V6 and V2. ✓
4.53 Close ISM manual valve F2 and open F1. ✓
4.54 Open GMA solenoid valves V1, V3 and V9. ✓
4.55 Wait until a stable flow is reached and record flow rate from FM1 in Table 1 for Gyro1A. *Cycled V5 here.*
4.56 Close GMA solenoid valve V9 and open V10. ✓
4.57 Wait until a stable flow is reached and record flow rate from FM1 in Table 1 for Gyro1B. ✓
4.58 Close GMA solenoid valve V10 and open V13. ✓
4.59 Wait until a stable flow is reached and record flow rate from FM1 in Table 1 for Gyro2A. ✓
4.60 Close GMA solenoid valve V13 and open V14. ✓
4.61 Wait until a stable flow is reached and record flow rate from FM1 in Table 1 for Gyro2B. ✓
4.62 Close GMA solenoid valve V14 and open V17. ✓
4.63 Wait until a stable flow is reached and record flow rate from FM1 in Table 1 for Gyro3A. ✓
4.64 Close GMA solenoid valve V17 and open V18. ✓
4.65 Wait until a stable flow is reached and record flow rate from FM1 in Table 1 for Gyro3B. ✓
4.66 Close GMA solenoid valve V18 and open V19. ✓
4.67 Wait until a stable flow is reached and record flow rate from FM1 in Table 1 for Gyro4A. ✓
4.68 Close GMA solenoid valve V19 and open V20. ✓
4.69 Wait until a stable flow is reached and record flow rate from FM1 in Table 1 for Gyro4B. ✓
4.70 Close GMA solenoid valve V20 and open V25. *Cycled V25 to verify flow rate.*
4.71 Wait until a stable flow is reached and record flow rate from FM1 in Table 1 for Flux
Flush A ✓
4.72 Close GMA solenoid valve V25 and open V26. ✓
4.73 Wait until a stable flow is reached and record flow rate from FM1 in Table 1 for Flux
Flush B. ✓
4.74 Close V26. ✓

All flow paths nominal.

Test engineer: KS

Quality: _____

SU GP-B
INSP 31

2 sccm flow path, side B

- 4.75 Close GMA solenoid valves V3 and V1. ✓
4.76 Open GMA solenoid valves V2, V4, and V9. ✓
4.77 Wait until a stable flow is reached and record flow rate from FM1 in Table 1 for Gyro1A. ✓
4.78 Close GMA solenoid valve V9 and open V10. ✓

- ~~4.79~~ Wait until a stable flow is reached and record flow rate from FM1 in Table 1 for Gyro1~~B~~.
~~4.80~~ Close GMA solenoid valve V10 and open V13.
~~4.81~~ Wait until a stable flow is reached and record flow rate from FM1 in Table 1 for Gyro2~~A~~.
~~4.82~~ Close GMA solenoid valve V13 and open V14.
~~4.83~~ Wait until a stable flow is reached and record flow rate from FM1 in Table 1 for Gyro2~~B~~.
~~4.84~~ Close GMA solenoid valve V14 and open V17.
~~4.85~~ Wait until a stable flow is reached and record flow rate from FM1 in Table 1 for Gyro3~~A~~.
~~4.86~~ Close GMA solenoid valve V17 and open V18.
~~4.87~~ Wait until a stable flow is reached and record flow rate from FM1 in Table 1 for Gyro3~~B~~.
~~4.88~~ Close GMA solenoid valve V18 and open V19.
~~4.89~~ Wait until a stable flow is reached and record flow rate from FM1 in Table 1 for Gyro4~~A~~.
~~4.90~~ Close GMA solenoid valve V19 and open V20.
~~4.91~~ Wait until a stable flow is reached and record flow rate from FM1 in Table 1 for Gyro4~~B~~.
~~4.92~~ Close GMA solenoid valve V20 and open V25.
~~4.93~~ Wait until a stable flow is reached and record flow rate from FM1 in Table 1 for Flux
Flush A
~~4.94~~ Close GMA solenoid valve V25 and open V26.
4.95 Wait until a stable flow is reached and record flow rate from FM1 in Table 1 for Flux
Flush B.
~~4.96~~ Close V26, V4, and V2.

All flow paths nominal.

Test engineer: RL

Quality: SU GP-B

INSP 31

9/23/02

GMA Sleep

- ~~4.97~~ Open ISM manual valve B1.
~~4.98~~ Wait for pressure to stabilize at the vacuum pump.
~~4.99~~ Close outlet manifold manual valves OMG1, OMG2, OMG3, OMG4, OMP1A, OMVent,
and OMVent2.
~~4.100~~ Close DP1. FI 9/23/02 SU GP-B
~~4.101~~ Close ISM manual valves B1 and E2 and shut down vacuum pump. INSP 31 9/23/02
~~4.102~~ Disconnect any unnecessary GSE.
~~4.103~~ Run P0930, "GMA Sleep".

Quality: SU GP-B

INSP 31

9/23/02

G.6 Diagrams

Diagram 1: GMA Schematic

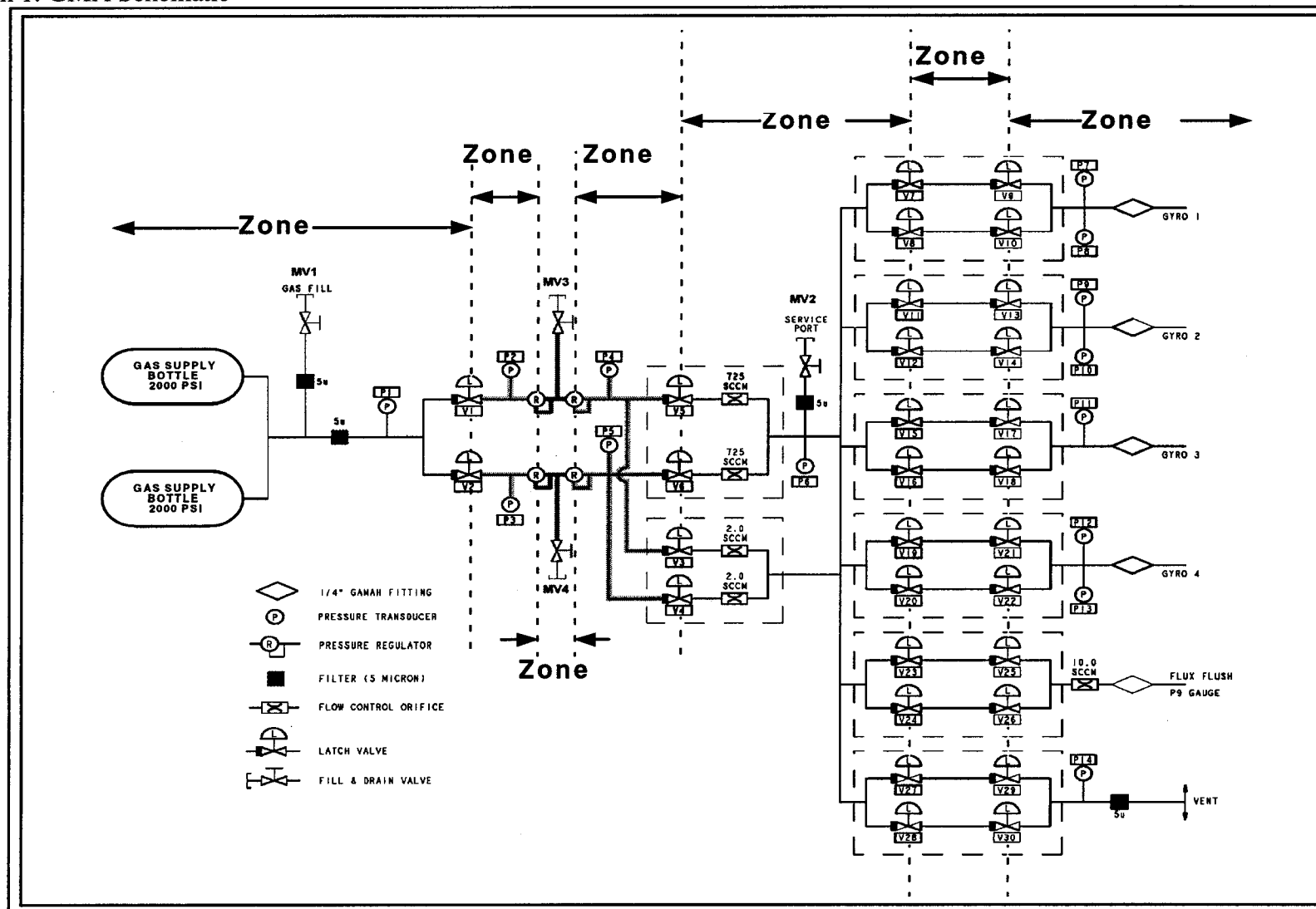
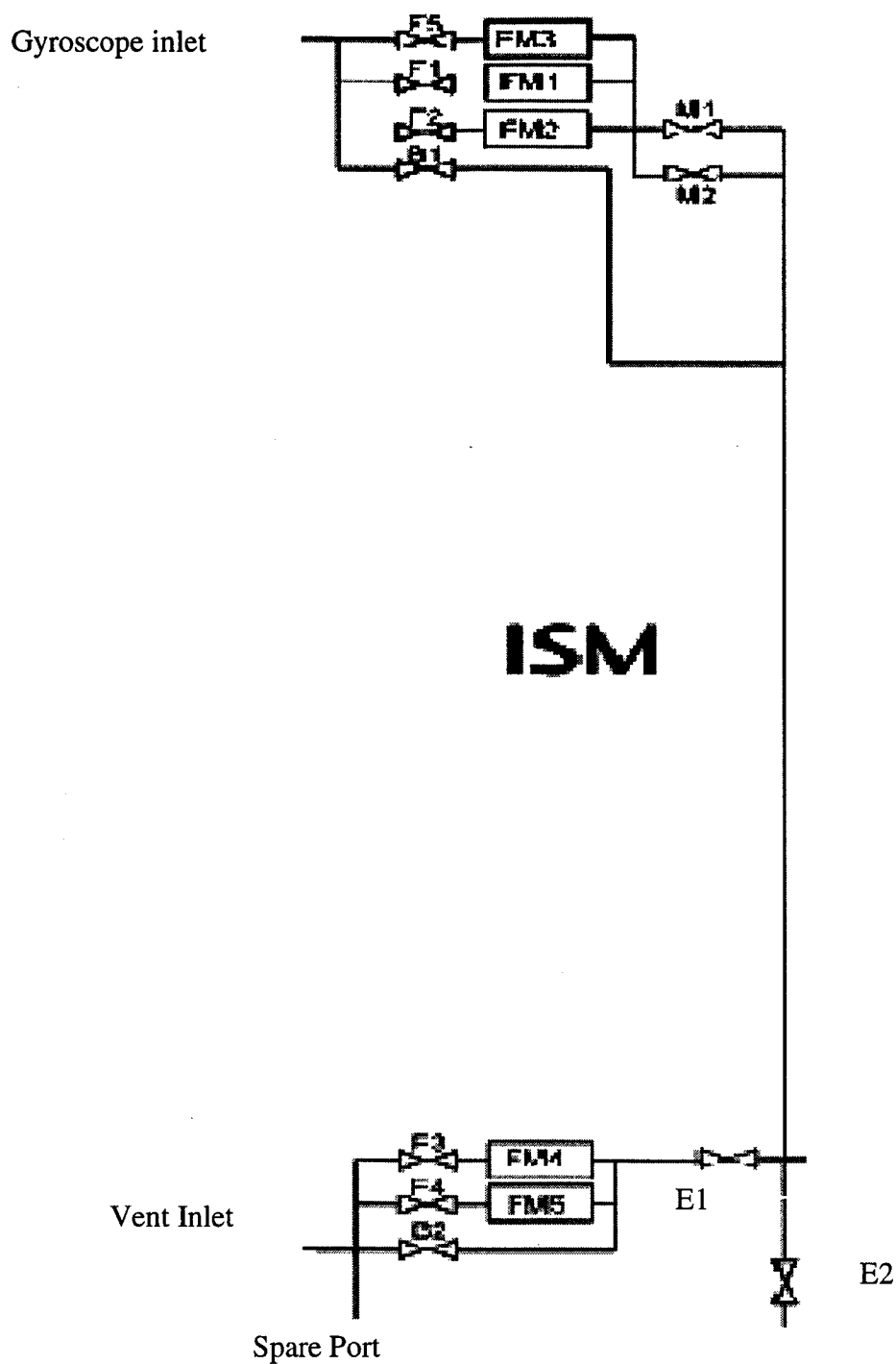


Diagram 2, ISM schematic



GMA Interfaced with Gyro Acceptance Facility

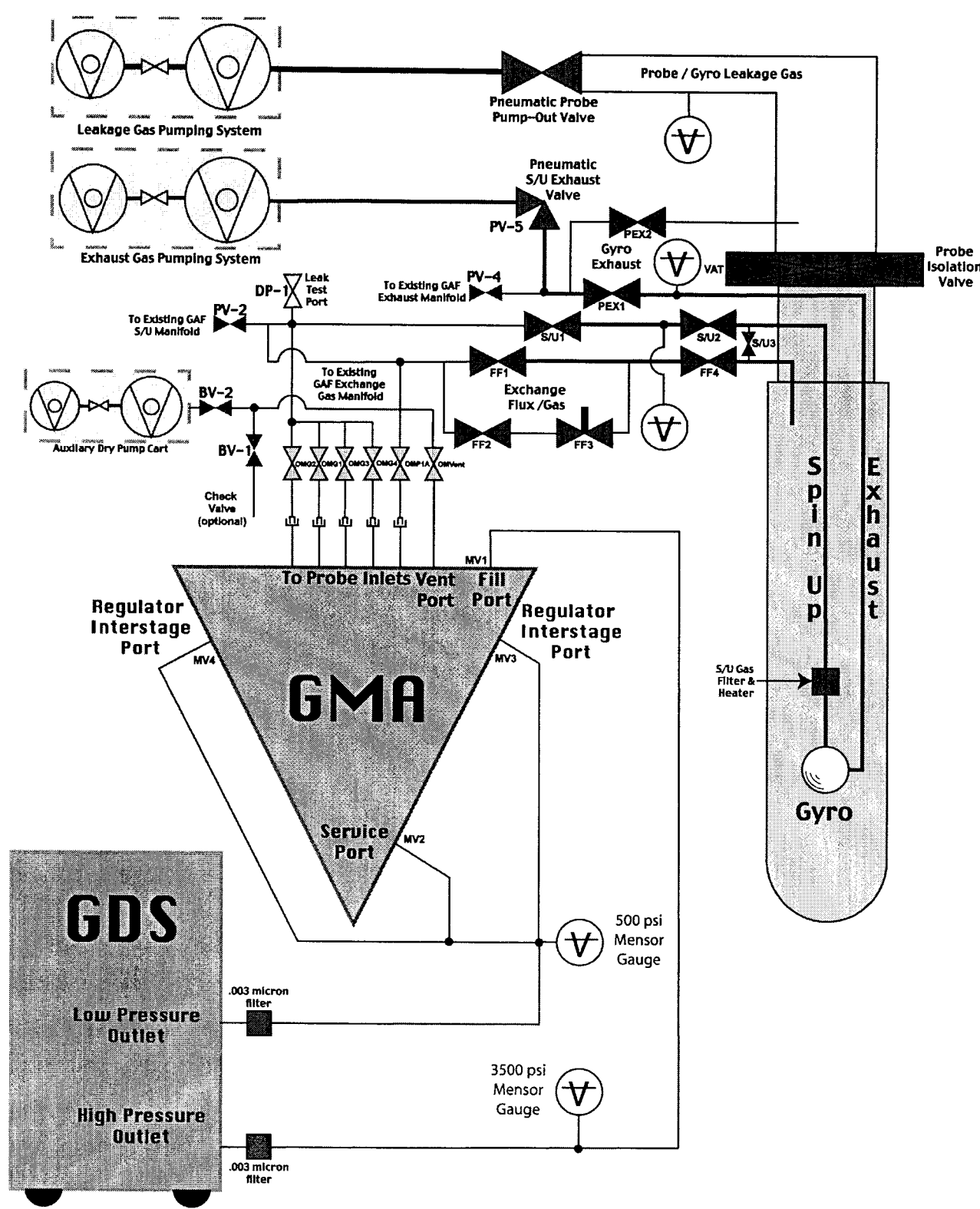


Diagram 3

CSG 7/02

G.8 Tables**Table 1: GMA flow rates**

Gas Path	Regulator Path	Flow Rate SCCM	Test Engineer Initial	QA stamp
725 sccm A	Gyro 1A	630	RL	SU GP-B INSP 31
725 sccm A	Gyro 1B	625	RL	SU GP-B INSP 31
725 sccm A	Gyro 2A	627	RL	SU GP-B INSP 31
725 sccm A	Gyro 2B	630	RL	SU GP-B INSP 31
725 sccm A	Gyro 3A	627	RL	SU GP-B INSP 31
725 sccm A	Gyro 3B	630	RL	SU GP-B INSP 31
725 sccm A	Gyro 4A	631	RL	SU GP-B INSP 31
725 sccm A	Gyro 4B	630	RL	SU GP-B INSP 31
725 sccm A	Flux Flush A	9	RL	SU GP-B INSP 31
725 sccm A	Flux Flush B	9	RL	SU GP-B INSP 31
725 sccm A	Vent A	621	RL	SU GP-B INSP 31
725 sccm A	Vent B	623	RL	SU GP-B INSP 31
725 sccm B	Gyro 1A	647	RL	SU GP-B INSP 31
725 sccm B	Gyro 1B	642	RL	SU GP-B INSP 31
725 sccm B	Gyro 2A	644	RL	SU GP-B INSP 31
725 sccm B	Gyro 2B	647	RL	SU GP-B INSP 31
725 sccm B	Gyro 3A	643	RL	SU GP-B INSP 31
725 sccm B	Gyro 3B	646	RL	SU GP-B INSP 31
725 sccm B	Gyro 4A	648	RL	SU GP-B INSP 31
725 sccm B	Gyro 4B	646	RL	SU GP-B INSP 31
725 sccm B	Vent A	635	RL	SU GP-B INSP 31
725 sccm B	Vent B	638	RL	SU GP-B INSP 31

2 sccm A	Gyro 1A	2.1	RL	SU GP-B INSP 31
2 sccm A	Gyro 1B	2.0	RL	SU GP-B INSP 31
2 sccm A	Gyro 2A	2.0	RL	SU GP-B INSP 31
2 sccm A	Gyro 2B	2.0	RL	SU GP-B INSP 31
2 sccm A	Gyro 3A	2.0	RL	SU GP-B INSP 31
2 sccm A	Gyro 3B	2.0	RL	SU GP-B INSP 31
2 sccm A	Gyro 4A	2.0	RL	SU GP-B INSP 31
2 sccm A	Gyro 4B	2.0	RL	SU GP-B INSP 31
2 sccm A	Flux Flush A	1.6	RL	SU GP-B INSP 31
2 sccm A	Flux Flush B	1.6	RL	SU GP-B INSP 31
2 sccm B	Gyro 1A	2.1	RL	SU GP-B INSP 31
2 sccm B	Gyro 1B	2.1	RL	SU GP-B INSP 31
2 sccm B	Gyro 2A	2.1	RL	SU GP-B INSP 31
2 sccm B	Gyro 2B	2.1	RL	SU GP-B INSP 31
2 sccm B	Gyro 3A	2.1	RL	SU GP-B INSP 31
2 sccm B	Gyro 3B	2.1	RL	SU GP-B INSP 31
2 sccm B	Gyro 4A	2.1	RL	SU GP-B INSP 31
2 sccm B	Gyro 4B	2.1	RL	SU GP-B INSP 31
2 sccm B	Flux Flush A	~~1.4~~ 1.4	RL	SU GP-B INSP 31
2 sccm B	Flux Flush B	1.5	RL	SU GP-B INSP 31

G.8 PRE-TEST CHECKLIST

DATE	PROCEDURE #	CHECKLIST ITEM	COMPLETED	REMARKS
9/23/02	P0943 -	1. VERIFY THE TEST PROCEDURE BEING USED IS THE LATEST REVISION.	✓	
		2. VERIFY ALL CRITICAL ITEMS IN THE TEST ARE IDENTIFIED AND DISCUSSED WITH THE TEST TEAM.	✓	
		3. VERIFY ALL REQUIRED MATERIALS AND TOOLS ARE PRE-STAGED AND AVAILABLE IN THE TEST AREA.	✓	
		4. VERIFY ALL HAZARDOUS MATERIALS INVOLVED IN THE TEST ARE IDENTIFIED TO THE TEST TEAM.	✓	
		5. IF HELIUM IS TO BE USED VERIFY THAT A BLUE "HELIUM" TAG IS AROUND THE NECK OF THE HELIUM CYLINDER.	✓	will tag
		6. VERIFY ALL HAZARDOUS STEPS TO BE PERFORMED ARE IDENTIFIED TO THE TEST TEAM.	✓	
		7. VERIFY EACH TEAM MEMBER KNOWS THEIR INDIVIDUAL RESPONSIBILITIES.	✓	
		8. CONFIRM THAT EACH TEST TEAM MEMBER CLEARLY UNDERSTANDS THAT HE/SHE HAS THE AUTHORITY TO STOP THE TEST IF AN ITEM IN THE PROCEDURE IS NOT CLEAR. NOTE: DURING A HAZARDOUS OPERATION THE TEST WILL ONLY BE STOPPED WHEN IT IS SAFE TO DO SO.	✓	
		9. CONFIRM THAT EACH TEST TEAM MEMBER CLEARLY UNDERSTANDS THAT HE/SHE HAS THE AUTHORITY TO STOP THE TEST IF THERE IS ANY ANOMALY OR SUSPECTED ANOMALY NOTE: DURING A HAZARDOUS OPERATION THE TEST WILL ONLY BE STOPPED WHEN IT IS SAFE TO DO SO	✓	
		10. NOTIFY MANAGEMENT OF ALL DISCREPANCY REPORTS OR D-LOG ITEMS IDENTIFIED DURING THE PROCEDURE. IN THE EVENT AN INCIDENT OCCURS DURING PROCEDURE PERFORMANCE, MANAGEMENT WILL BE NOTIFIED IMMEDIATELY.	✓	
		11. CONFIRM THAT EACH TEST TEAM MEMBER UNDERSTANDS THAT THERE WILL BE A POST-TEST TEAM MEETING.	✓	
		TEAM LEAD SIGNATURE: 		

G.9 POST-TEST CHECKLIST

DATE	PROCEDURE #	CHECKLIST ITEM	COMPLETED	REMARKS
9/23/02	P0943 Rev-	1- VERIFY ALL STEPS IN THE PROCEDURE WERE SUCCESSFULLY COMPLETED.	☒	
		2- VERIFY ALL MINOR/MAJOR DISCREPANCIES DISCOVERED DURING TESTING ARE PROPERLY DOCUMENTED.	☒	
		3- ENSURE MANAGEMENT HAS BEEN NOTIFIED OF ALL MINOR/MAJOR DISCREPANCIES.	☒	
		4- ENSURE THAT ALL STEPS THAT WERE NOT REQUIRED TO BE PERFORMED ARE PROPERLY IDENTIFIED.	☒	
		5- IF APPLICABLE SIGN-OFF TEST COMPLETION.	☒	
		TEAM LEAD SIGNATURE	☒	

H PROCEDURE SIGN OFF

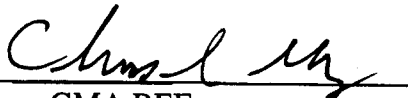
The results obtained in the performance of this procedure are acceptable:


Test Director

date: 9/23/02

Discrepancies if any:

Approved:


C. Gray, GMA REE

date: 9/23/02

Approved:

 
QA Representative

date: 9/23/02

Approved:

 
D. Ross, QA

date: 9/23/02

GRAVITY PROBE B
PROCEDURE FOR
PAYLOAD VERIFICATION
P0928 Rev -

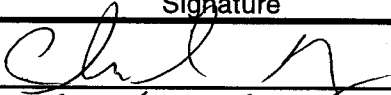
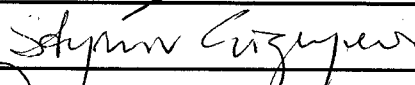
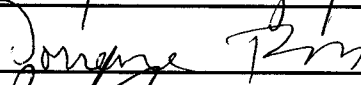
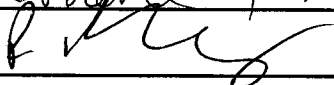
0 HZ SPIN TEST / ADD EXCHANGE
GAS IN THE GAF USING THE GMA

September 18, 2002

As-Run
10/01/02

Prepared by: C. Gray

Approvals:

Program Responsibility	Signature	Date
C. Gray GMA RE		10/1/02
R. Stephenson Engineering		10/01/02
S. Sigurjonsson Software		10/01/02
D. Ross GP-B Quality Assurance		10/01/02
R. Brumley Payload Technical Manager		10/1/02

NOTES:
Level of QA required during performance of this procedure:

Stanford QA Representative

All redlines must be approved by QA

Revision Record:

Revision	Date	ECO #	Summary description
-	9/18/2002	N/A	Original revision.

Acronyms and Abbreviations:

Acronym / Abbreviation	Meaning
ECU	Experiment control unit
FEU	Flight equivalent unit
GAF	Gyro Acceptance Facility
GMA	Flight Gas management assembly
GMOCK	Functionally equivalent GMA

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A Scope

This procedure has two test sections.

The first section runs the 0 Hz Spin software CSTOL script using the Gyro Acceptance Facility (GAF) and either the flight Gas Management Assembly (GMA) or the non-flight functionally equivalent GMA mock-up (G-MOCK). The software script reflects the Flight procedure. It does not flow gas through the Gyro Acceptance Probe, only through the Exhaust Gas Pumping system.

The second section flows ~ 2 sccm He gas from the GMA (or G-MOCK) into the Gyro Acceptance Probe though the P1A port on the GMA to the Probe Exchange Gas Inlet. This section also uses a software CSTOL script.

B Requirements Verification

- B.1 Requirements Cross Reference: none
- B.2 Expected Data for verification per requirement: none

C Configuration Requirements

The gyro commissioning probe is in the low field dewar and being pumped on by the GAF leakage gas pumping system.

The GMA or G-MOCK has been connected to the GAF per P0923 and is configured such that it may be operated using the ECU FEU and associated test set.

D Hardware Required

D.1 Flight hardware required

Description	No. Req'd
GMA (or functionally equivalent non- flight G-MOCK)	1

D.2 Commercial test equipment

Manufacturer	Model	Serial Number	Calibr. Exp. Date
N/A			

D.3 Mechanical/Electrical Special test equipment

Description	Part No.	Rev. no.	Serial No.	Certification Date
Leakage gas management system				
Gyro spinup gas management system				
ECU FEU				

D.4 Tools

Description	No. Req'd
N/A	

D.5 Expendables

Description	Quantity
N/A	

E Software Required

CSTOL scripts: gma_0hz_spinup.prc; gma_add_exc_gas.prc

F Procedures Required

N/A

G Equipment Pretest Requirements

N/A

H Personnel Requirements

The following personnel have received extensive training in operation of the Gyro Acceptance Facility and are qualified to perform this procedure.

- David Hipkins
- Bruce Clarke
- Chris Gray
- Robert Brumley

I Safety Requirements

I.1 General

It is important to be aware at all times of the position of the probe. Be extremely careful not to accidentally bump into the probe or any system connected to the probe. If any connector does not connect smoothly and securely, do not try to force it. Instead, remove the connector and inspect it to find the reason for the difficulty. Great care must be taken at all times during the performance of this procedure.

I.2 Electrostatic Discharge

Grounded wrist straps are to be worn at all times when mating or demating to an electrical connector on flight hardware.

I.3 Personnel Safety

All operations shall take place according to Stanford University safety guidelines. Any person observing a situation that they deem unsafe shall report the fact immediately to the test director. The Quality Assurance representative shall be responsible for monitoring that all activities are performed in a safe manner.

I.4 Electrical mating and demating of flight hardware connectors

I.4.1 Connection and disconnection shall be performed only when the equipment involved is in a powered-down state unless the procedure specifically states otherwise.

I.4.2 Connector savers are to be used unless otherwise specified.

I.4.3 Connectors shall be inspected for contamination and for bent, damaged, or recessed pins prior to mating.

I.4.4 Grounded wrist straps are to be worn prior to removal of connector caps or covers and during mating/demating operations on flight hardware.

I.4.5 ESD-protective caps or covers are to be immediately installed after demating of connectors on flight hardware.

J **General Instructions**

J.1 Quality Assurance

QA Notification

This test will be conducted on a formal basis to approved and released procedures. **The QA program office and ONR representative shall be notified 24 hours prior to the start of this procedure.** A Quality Assurance Representative, designated by D. Ross shall be present during the procedure and shall review any discrepancies noted and approve their disposition. Upon completion of this procedure, the QA Program Engineer, D. Ross or her designate, will certify her concurrence that the effort was performed and accomplished in accordance with the prescribed instructions by signing and dating in the designated place(s) in this document.

J.2 Redline Authority

Redlines can be initiated by any of the qualified operators listed in section H and must be approved by QA.

J.3 Discrepancies

Any nonconformance or test anomaly should be reported by a Discrepancy Report. Refer to the Quality Plan, P0108, for guidance. Do not alter or break test configuration if a test failure occurs; notify quality assurance.

J.4 Test Exit Authority

Only the following persons have the authority to exit/terminate this test or perform a retest:

Rob Brumley, Chris Gray, David Hipkins, Bruce Clarke, Sasha Buchman, William Bencze, and QA personnel.

K References and Applicable Documents

Op. Order No. _____
Date Initiated 10/1/02
Time Initiated 15:30

L OPERATIONS

The following section details how to perform the 0hz. Spin test.

L.1 Pre Test-Checklist

Start Date: 10-1-02

Start Time: 15:30

L.1.1	GMA (or GMOCK) has a Helium pressure > 300 psia	✓
L.1.2	Leakage Gas Pumping System is operating, pumping on the probe (VAT open) and the probe pressure (P_{PB} measured on ion gauge channel A) is < 5×10^{-5} torr	✓
L.1.3	Spinup Exhaust Pumping System is operating and the exhaust gas pressure (EGP) is < 5×10^{-3} torr (this is used to evacuate the spinup manifold)	✓
L.1.4	Verify the probe exhaust (gold manual valve – PEX1) is closed.	✓
L.1.5	Verify the probe exhaust by-pass valve (PEX2) is closed.	✓
L.1.6	Confirm manifold between the GCP spin-up inlet (SU2) and the Gyro Spinup management manifold up to valves PV2 and OMG Valves (with SU1 open and DP1, FF1, FF2, FF3, FF4 closed) is connected and under vacuum.	✓
L.1.7	OMG1, OMG2, OMG3, OMG4, OMP1A, OMVent, and OMVent2 are closed	✓
L.1.8	Pumping cart is connected to the GMA Vent outlet and is pumping up to OMVent. Pressure is < 1×10^{-4} torr.	✓
L.1.9	Software cstol sript gma_0hz_spinup.prc and gma_add_exc_gas.prc is loaded on Oasis	✓

L.2 0 Hz Spin Test

Note: Refer to figures 2 for pumping and gas management system schematic.

✓ L.2.1	Verify a pumping cart is connected to the vent port of the GMA outlet manifold valve OMVent. Pressure should be < 1×10^{-4} torr. Open BV-2 on the pumping cart manifold to evacuate the manifold up to OMVent. After the pressure is 1×10^{-3} torr, open OMVent to the GMA.
✓ L.2.2	Start CSTOL script "gma_0hz_spinup.prc" and run entire script with a 10 minute Hold at the wait command on Oasis. → Run "GMA - CLOSE ALL .PRC" → manually open V27 + V28
L.2.3	After CSTOL is complete and the pumping cart pressure indicates a pressure 1×10^{-4} torr, close OMVent.
L.2.4	0 Hz procedure is complete.

Completed by: Chad
Witnessed by: James P
Date: 10/1/02

→ Gyro's 3 + 4, ~ 5 sec. pause between valve cycles, instead of
close V27 + V28 CSB

SU GP-B
INSP 31

10/1/02

L3 Exchange Gas Test Set-Up

Note: Refer to figures 1 and 2 for pumping and gas management system schematics.

- L.3.1 Check that **SEP-1/SEP-2** pumps are operating and the exhaust gas pressure (EGP on the GAF pumping system) is $< 5 \times 10^{-3}$ torr. The control panel for these pumps is located at the east wall of FIST OPS. If the pumps are not running pressing the momentary switches on the right side of the schematic on the panel can start them. Place the system in Interlock Defeat mode and verify yellow LED is blinking.

EGP = 4.1×10^{-3} mtorr

- ✓ L.3.2 Close (or verify closed) manual valves **FF4, SU2 and SU3**.
- ✓ L.3.3 Open manual valves **FF1, FF2, FF3, SU1 and OMP1A**.
- ✓ L.3.4 Open pneumatic valves **PV2 and PV4**.
- ✓ L.3.5 Wait for the exhaust gas pressure (EGP) to stabilize to the pressure recorded in step L.1.3 +/- 0.1 mtorr.

L4 Purge and Pump Out the Spin-up Manifold Using GAF Bypass Flow

- ✓ L.4.1 Check to ensure the GAF spin-up gas supply bottle contains > 250 psi helium. Open the valve on the gas bottle and on the regulator.
- ✓ L.4.2 The regulator should be set to 20 –25 psig.
- ✓ L.4.3 Open **PV1** (down position- 2000 sccm flow controller).
- ✓ L.4.4 On the 2000 sccm flow controller, rotate the 10-turn pot counter-clockwise on until a flow of 725 sccm is displayed. Continue this purge for 10 minutes. SU GP-B
INSP 31
- ✓ L.4.5 Dial the flow down to zero on the 2000 sccm flow controller and close PV1.
- ✓ L.4.6 Wait for the exhaust gas pressure (EGP) to stabilize to the pressure recorded in step L.2.1 +/- 0.1 mtorr.
- ✓ L.4.7 Open the manual valve **FF4** on the probe and note any exhaust pressure rise (EGP).
- ✓ L.4.8 Close the pneumatic valves **PV2 and PV4**.
- ✓ L.4.9 Verify a pumping cart is connected to the vent port of the GMA outlet manifold valve OMVent. Pressure should be $< 1 \times 10^{-4}$ torr. Open BV-2 on the pumping cart manifold to evacuate the manifold up to OMVent. After the pressure is 1×10^{-3} torr, open OMVent to the GMA.

L.5 Exchange Gas Test

1.7×10^{-7} csg

L.5.1 Record Gyro Acceptance Probe Pressure: ~~3.0×10^{-7}~~

L.5.2 Record Spin-Up and Exhaust Barratron Gauge Pressures

Spin-Up Pressure: $\emptyset$

Exhaust Pressure: $\emptyset$

L.5.3 Execute the CSTOL script "gma_add_exc_gas.prc" which opens V25, V1, and then V3 and hold at the wait for 10 minutes. (open V23 prior to executing gma-add)

L.5.4 After 10 minutes, Record the following pressures:

Gyro Acceptance Probe Pressure: 8.0×10^{-6}

Spin-Up Pressure: $\emptyset$

Exhaust Pressure: $\emptyset$

L.5.5 Continue with the CSTOL script which then closes V25, V1, and then V3. manually close

✓ L.5.6 Open pneumatic valves PV2 and PV4.

✓ L.5.7 Wait for the exhaust gas pressure (EGP) to stabilize to the pressure recorded in step L.1.3 +/- 0.1 mtorr.

✓ L.5.8 Close OMVent, OMP1A, and FF4. then PV2 + PV4. csg

✓ L.5.9 Close (or verify closed) manual valves FF1, FF2, FF3, SU2 and SU3. SU1

✓ L.5.10 Close the valve on the gas bottle and on the regulator for the GAF (Gyro Acceptance Facility).

✓ L.5.11 Close BV-2 and shut off pumping cart unless needed for the next operation.

L.5.11 Exchange gas procedure is complete.

Rem - ~~AB~~ GMA - CLOSE ALL PRK

csg

10/1/02

SU GP-B
INSP 31

Completed by: Cheryl

Witnessed by: Terrence

Date: 10/1/02

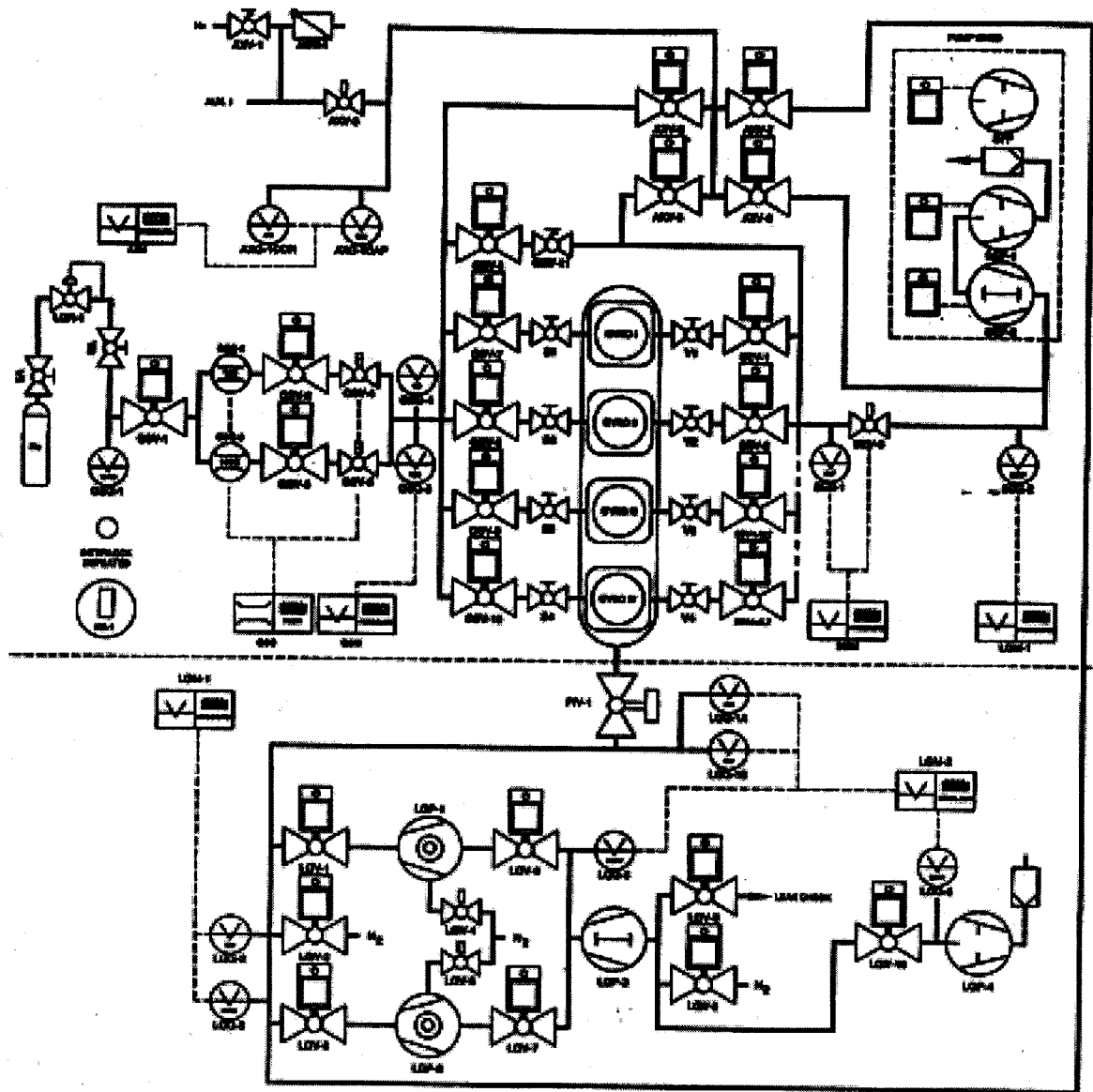
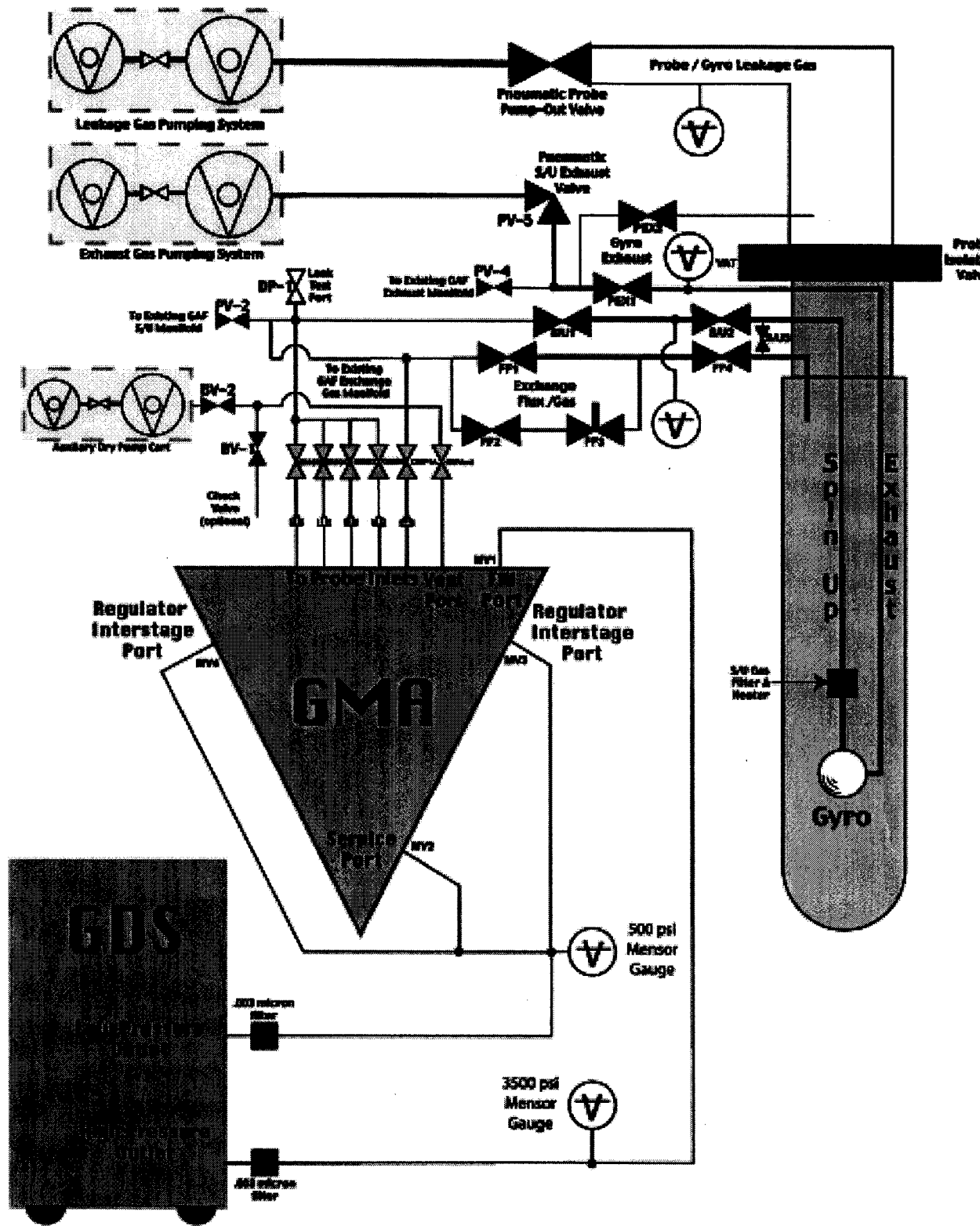


Figure 1: Gyro Gas Management System

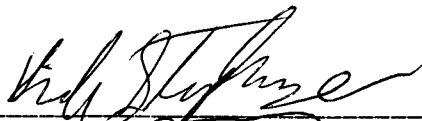
This figure shows the location of the switches for the exhaust pumps SEP-1 and SEP-2. No other valve designations or labels in this figure are used in this procedure. Figure 2 – GMA Interface with the GAF is shown on the next page.

GMA Interfaced with Gyro Acceptance Facility



Procedure Sign Off

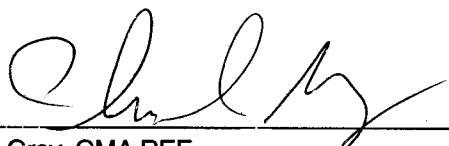
The results obtained in the performance of this procedure are acceptable:



Test Director/GMA Engineer

date: 10/9/02

Discrepancies if any:

Approved: 

C. Gray, GMA REE

date: 10/1/02

Approved: 

QA Representative



date: 10/1/02

Approved: 

D. Ross, QA



date: 10/1/02

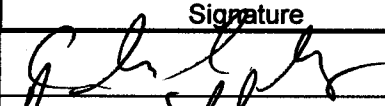
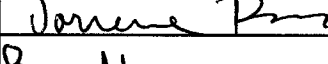
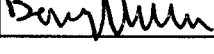
GRAVITY PROBE B
PROCEDURE FOR
PAYLOAD VERIFICATION
P0925 Rev -
GYRO SLOW SPIN TEST
IN THE GAF USING THE GMA

September 17, 2002

As-Run

Prepared by: B. Clarke

Approvals:

Program Responsibility	Signature	Date
C. Gray GMA RE		9/18/02
B. Clarke Gyro Testing RE		9/17/02
D. Ross GP-B Quality Assurance		9/18/02
R. Brumley Payload Technical Manager		9/18/02

NOTES:

Level of QA required during performance of this procedure:
Stanford QA Representative
Government QA Representative

All redlines must be approved by QA

Revision Record:

Revision	Date	ECO #	Summary description
-	9/12/2002	N/A	Original revision.

Acronyms and Abbreviations:

Acronym / Abbreviation	Meaning
ECU	Experiment control unit
FEU	Flight equivalent unit
GAF	Gyro Acceptance Facility
GCP	Gyro Commissioning Probe
GMA	Flight Gas management assembly
GMOCK	Functionally equivalent GMA

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A Scope

This procedure covers the spin-up of a gyroscope at low temperature in the Gyro Acceptance Facility (GAF) using the flight Gas Management Assembly (GMA) or the non-flight functionally equivalent GMA mock-up (G-MOCK). It is only intended for very low speed spins (below 2 Hz).

B Requirements Verification

B.1 Requirements Cross Reference: none

B.2 Expected Data for verification per requirement: none

C Configuration Requirements

The gyro commissioning probe with a gyro installed is in the low field dewar and being pumped on by the GAF leakage gas pumping system. The gyroscope has been levitated continuously for at least one hour and shows no evidence of charging or otherwise unstable suspension as determined by one of the qualified operators listed in section H of this procedure.

The GMA or G-MOCK has been connected to the GAF per P0923B and is configured such that it may be operated using the ECU FEU and associated test set.

D Hardware Required

D.1 Flight hardware required

Description	No. Req'd
GMA (or functionally equivalent non- flight G-MOCK)	1

D.2 Commercial test equipment

Manufacturer	Model	Serial Number	Calibr. Exp. Date
N/A			

D.3 Mechanical/Electrical Special test equipment

Description	Part No.	Rev. no.	Serial No.	Certification Date
Optical readout systems	MOL285DC-12	—	106	—
DDC Suspension system	DDC-3	1.07	DAC-3	—
FFT Data system				
Leakage gas management system	N/A	N/A	N/A	N/A
Gyro spinup gas management system				
ECU FEU	8A01313- GEU-CSE	—	—	2/7/01

D.4 Tools

Description	No. Req'd
N/A	

D.5 Expendables

Description	Quantity
N/A	

E **Software Required**

CSTOL script "gma_low_spinup.prc"

Version 1.2

Date: 9/17/02

F **Procedures Required**

N/A

G **Equipment Pretest Requirements**

N/A

H **Personnel Requirements**

The following personnel have received extensive training in the testing of GP-B gyroscopes and are qualified to perform this procedure.

- David Hipkins
- Bruce Clarke
- Chris Gray
- Robert Brumley
- Dr. Sasha Buchman
- Dr. William Bencze

I **Safety Requirements**

I.1 General

It is important to be aware at all times of the position of the probe. Be extremely careful not to accidentally bump into the probe or any system connected to the probe. If any connector does not connect smoothly and securely, do not try to force it. Instead, remove the connector and inspect it to find the reason for the difficulty. Great care must be taken at all times during the performance of this procedure.

I.2 Electrostatic Discharge

Grounded wrist straps are to be worn at all times when mating or demating to an electrical connector on flight hardware.

I.3 Personnel Safety

All operations shall take place according to Stanford University safety guidelines. Any person observing a situation that they deem unsafe shall report the fact immediately to the test director. The Quality Assurance representative shall be responsible for monitoring that all activities are performed in a safe manner.

I.4 Electrical mating and demating of flight hardware connectors

- I.4.1 Connection and disconnection shall be performed only when the equipment involved is in a powered-down state unless the procedure specifically states otherwise.
- I.4.2 Connector savers are to be used unless otherwise specified.
- I.4.3 Connectors shall be inspected for contamination and for bent, damaged, or recessed pins prior to mating.
- I.4.4 Grounded wrist straps are to be worn prior to removal of connector caps or covers and during mating/demating operations on flight hardware.
- I.4.5 ESD-protective caps or covers are to be immediately installed after demating of connectors on flight hardware.

J General Instructions

J.1 QA Notification

This test will be conducted on a formal basis to approved and released procedures. **The QA program office and ONR representative shall be notified 24 hours prior to the start of this procedure.** A Quality Assurance Representative, designated by D. Ross shall be present during the procedure and shall review any discrepancies noted and approve their disposition. Upon completion of this procedure, the QA Program Engineer, D. Ross or her designate, will certify her concurrence that the effort was performed and accomplished in accordance with the prescribed instructions by signing and dating in the designated place(s) in this document.

J.2 Redline Authority

Redlines can be initiated by any of the qualified operators listed in section H and must be approved by QA.

J.3 Discrepancies

Any nonconformance or test anomaly should be reported by a Discrepancy Report. Refer to the Quality Plan, P0108, for guidance. Do not alter or break test configuration if a test failure occurs; notify quality assurance.

J.4 Test Exit Authority

Only the following persons have the authority to exit/terminate this test or perform a retest:

Rob Brumley, Chris Gray, David Hipkins, Bruce Clarke, Sasha Buchman, William Bencze, and QA personnel.

J.5 Gyroscope Delevitation

A gyro delevitation at any point during this procedure does not in itself imply the GMA or G-MOCK has failed the test. However, if a gyroscope delevitates during the completion of this procedure, all work shall cease and the test configuration shall not be broken. Work may only continue under the guidance of the MRB. A Discrepancy Report shall be immediately opened recording the details of what happened. The immediate concern of the investigation should be to determine whether the GSE was at fault in the delevitation and how this GSE should be re-tested prior to resuming the test.

K References and Applicable Documents

Op. Order No. _____
Date Initiated 9/19/02
Time Initiated 1320

L OPERATIONS

The following sections detail how to spin the gyroscope.

L.1 Pre Spin-Up Checklist

Start Date: 9/19/02

Start Time: 1320

Gyroscope S/N: FQH53/95FH4

L.1.1	Verify the gyroscope is levitated and in the desired position	
	Record Commanded Position [X Y Z]: <u>-100, -100, -100</u>	✓
L.1.2	Verify that the gyroscope is not charged >70 volts	✓
L.1.3	Verify that there is no oscillation in the position greater than 40 micro-inches.	✓
L.1.4	Verify that the gyroscope has been levitated for at least one hour	✓
L.1.5	Leakage Gas Pumping System is operating, pumping on the probe (VAT open) and the probe pressure (P_{PB} measured on ion gauge channel A) is $< 5 \times 10^{-5}$ torr	✓
L.1.6	Spinup Exhaust Pumping System is operating and the exhaust gas pressure (EGP) is $< 5 \times 10^{-3}$ torr (this is used to evacuate the spinup manifold)	✓
L.1.7	Verify the probe exhaust (gold manual valve – PEX1) is open.	✓
L.1.8	Verify the probe exhaust by-pass valve (PEX2) is closed.	✓
L.1.9	Confirm manifold between the GCP spin-up inlet (SU2) and the Gyro Spinup management manifold up to valves PV2 and OMG1 (with SU1 open and DP1, FF1, FF2, FF3, FF4 closed) is connected and under vacuum.	✓
L.1.10	Confirm the helium spinup gas supplies on both the GAF and the GMA (G-MOCK) are Grade 6 He and have Conformance Certification available.	✓
L.1.11	Zero the Baratron gauges. Zero the flowmeters.	✓

L.2 Spin-up Manifold Evacuation

Note: Refer to figures 1 and 2 for pumping and gas management system schematics.

- ~~L.2.1~~ Check that **SEP-1/SEP-2** pumps are operating and the exhaust gas pressure (EGP on the GAF pumping system) is $< 5 \times 10^{-3}$ torr. The control panel for these pumps is located at the east wall of FIST OPS. If the pumps are not running pressing the momentary switches on the right side of the schematic on the panel can start them. Place the system in Interlock Defeat mode and verify yellow LED is blinking.

EGP = 2.6×10^{-3} mtorr

- ~~L.2.2~~ Close (or verify closed) manual valves **FF1, FF2, FF3, FF4, SU2 and SU3**.

- ~~L.2.3~~ Open manual valves **SU1** and **OMG1**.

- ~~L.2.4~~ Open pneumatic valves **PV2** and **PV4**.

- ~~L.2.5~~ Wait for the exhaust gas pressure (EGP) to stabilize to the pressure recorded in step L.2.1 +/- 0.1 mtorr.

L.3 Purge and Pump Out the Spin-up Manifold Using GAF Bypass Flow

- ~~L.3.1~~ Check to ensure the GAF spin-up gas supply bottle contains > 250psi helium. Open the valve on the gas bottle and on the regulator.

- ~~L.3.2~~ The regulator should be set to 20 –25 psig.

- ~~L.3.3~~ Open **PV1** (down position- 2000 sccm flow controller).



- ~~L.3.4~~ On the 2000 sccm flow controller, rotate the 10-turn pot counter-clockwise on until a flow of 725 sccm is displayed. Continue this purge for 10 minutes.

- ~~L.3.5~~ Dial the flow down to zero on the 2000 sccm flow controller and close **PV1**.

- ~~L.3.6~~ Wait for the exhaust gas pressure (EGP) to stabilize to the pressure recorded in step L.2.1 +/- 0.1 mtorr.

- ~~L.3.7~~ Open the manual valve **SU2** on the probe and note any exhaust pressure rise (EGP) @ 1355

- ~~L.3.8~~ Close the pneumatic valves **PV2** and **PV4**.

- ~~L.3.9~~ Open the manual valves **BV2** and **OMVENT** (located on the GMA/G-MOCK OUTLET MANIFOLD).

L.4 Gyroscope Low Speed Spinup Using the GMA /G-MOCK

- ~~L.4.1~~ Start an FFT file on the Sun 386i. Suggested sampling rate 30 Hz, logging interval 300 seconds and estimated spin frequency 0.5 Hz.

Record File name: 8201900.72p ^{CHO}
^{CH1} > OPTICAL

Record any additional useful information concerning the spin speed readout in the lines below (e.g. type of readout used, if the SQUIDs are being used, what range and gain are they on, FFT sampling rate, logging interval, harmonic monitored, etc.).

MONITOR FIRST HARMONIC
SAMPLING RATE 30 HZ
LOGGING INTERVAL 300 SEC.

DDC SNAPSHOT - FQH53036.MAT (pre GMA spin)
INITIAL SPIN SPEED ~.342 HZ BEFORE GMA SPINUP

DDC SNAPSHOT - FQH53037.MAT (post GMA spin)
FINAL SPIN SPEED 0.7376 HZ AFTER GMA SPINUP

L4.2 Start a new NLFF system data file by stopping and re-starting the NLFF3 data acquisition program. Set the logging interval to 20 seconds and write to both the local and network drives.

Record the NLFF filename: 091920.nlf

L4.3 Have the ECU operator to start the low speed spin-up script, "gma_low_spinup.prc". This script will perform the following. **Bold face type must be performed manually using the GAF pneumatic valves.** (LAUNCH CONFIGURATION)

1. Flow 725 sccm through the GMA/G-MOCK vent to the exhaust pump for 60 seconds.
2. Hard wait - enable. **Manually open the GAF pneumatic exhaust valve PV5 prior to sending the enable.**
3. Flow 2 sccm through the GMA/G-MOCK vent to the exhaust pump and through the gyro in parallel for 90 seconds.
4. Flow 2 sccm through the gyro only for 180 seconds.
5. Flow 2 sccm through the GMA/G-MOCK vent to the exhaust pump and through the gyro in parallel for 90 seconds.
6. Close all GMA/G-MOCK valves opened in steps 1-6. **Manually close the GAF pneumatic exhaust valve PV5 after the GMA/G-MOCK valve V9 closes. The ECU**

operator will keep the GAF operator advised of the GMA/G-MOCK valve states as the low speed spin-up script runs.

~~L.4.4~~ Monitor gyro spin speed on the Sun 386i.

L.5 Post-Spinup Procedure for Gyro 1

~~L.5.1~~ Close manual valves **SU1** and **SU2**.

1436

~~L.5.2~~ Close manual valves **BV2**, **OMVENT** and **OMG1**. → GMA to sleep mode.

~~L.5.3~~ Carefully open spin-up bypass valve **SU3** and exhaust bypass valve **PEX2**.

~~L.5.4~~ Adjust the logging interval on the NLFF data acquisition program to 300 seconds and write to both the local and network drives.

L.6 DATA SUMMARY

L.6.1 Monitor the gyro spindown for six hours minimum after performing L.5. A linear fit to the spindown data determines the gyro spindown rate. Record that rate here and attach a copy of the plotted spindown data to this procedure.

$$df/dt = \underline{-0.88 \text{ mHz/hr}}$$

L.6.2 Archived FFT data file name and directory path: HEPL-GYRO/FSTOP/gyros/tgh53/GMA-to-LT-test/GMA/82091900.72 p

L.6.3 Archived NLFF system data file name and directory path: HEPL-GYRO/FSTOP/NLFF/SYSDMA/

L.6.4 Location of data analysis (lab book, Matlab file, EM, etc.):

See attached plot for linear fit.

Test completed.

Date: 9/20/02

Completed by: [Signature] 9/20/02

Witnessed by: [Signature] 9/20/02



7:21 PM 09/18/0209/18/02

GMA Interfaced with Gyro Acceptance Facility

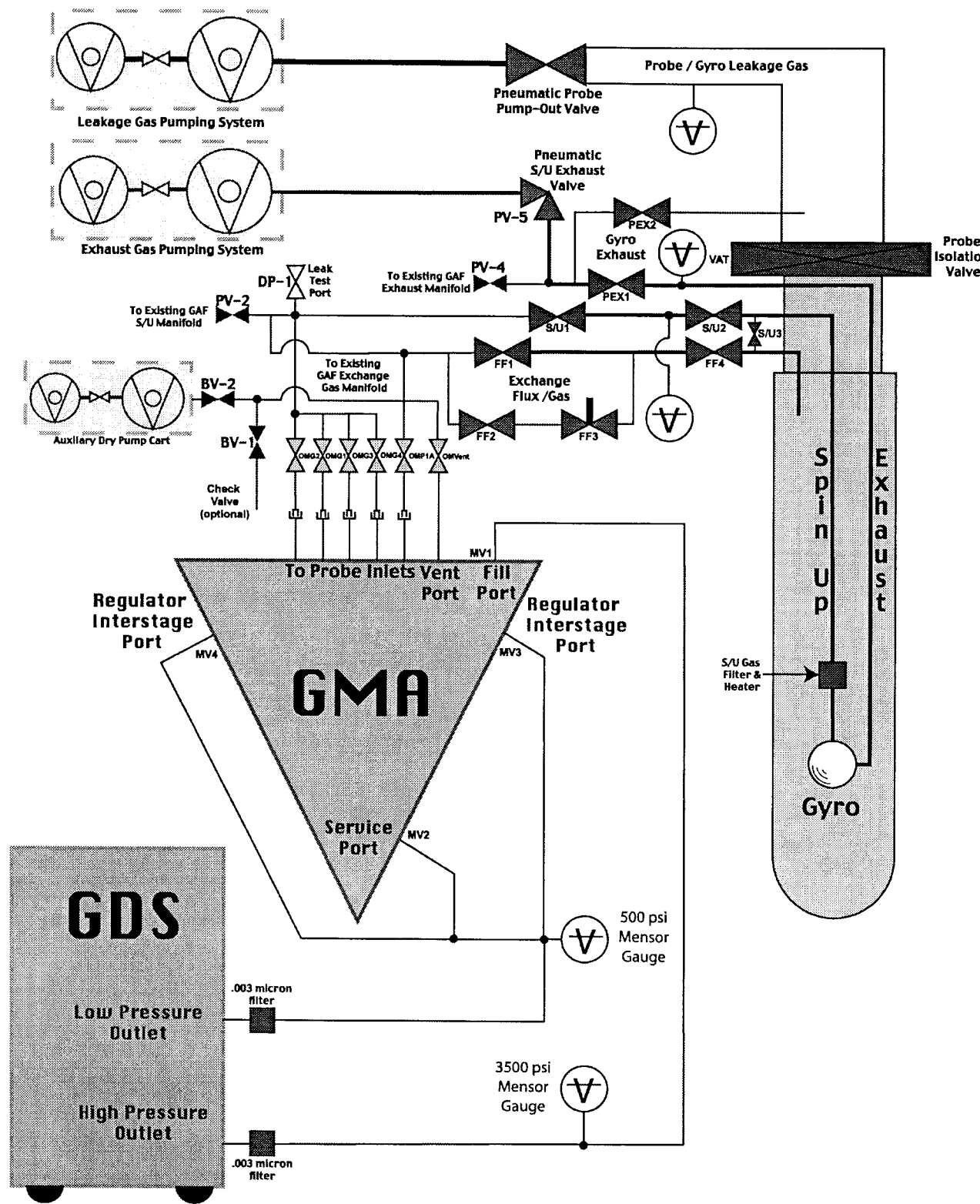
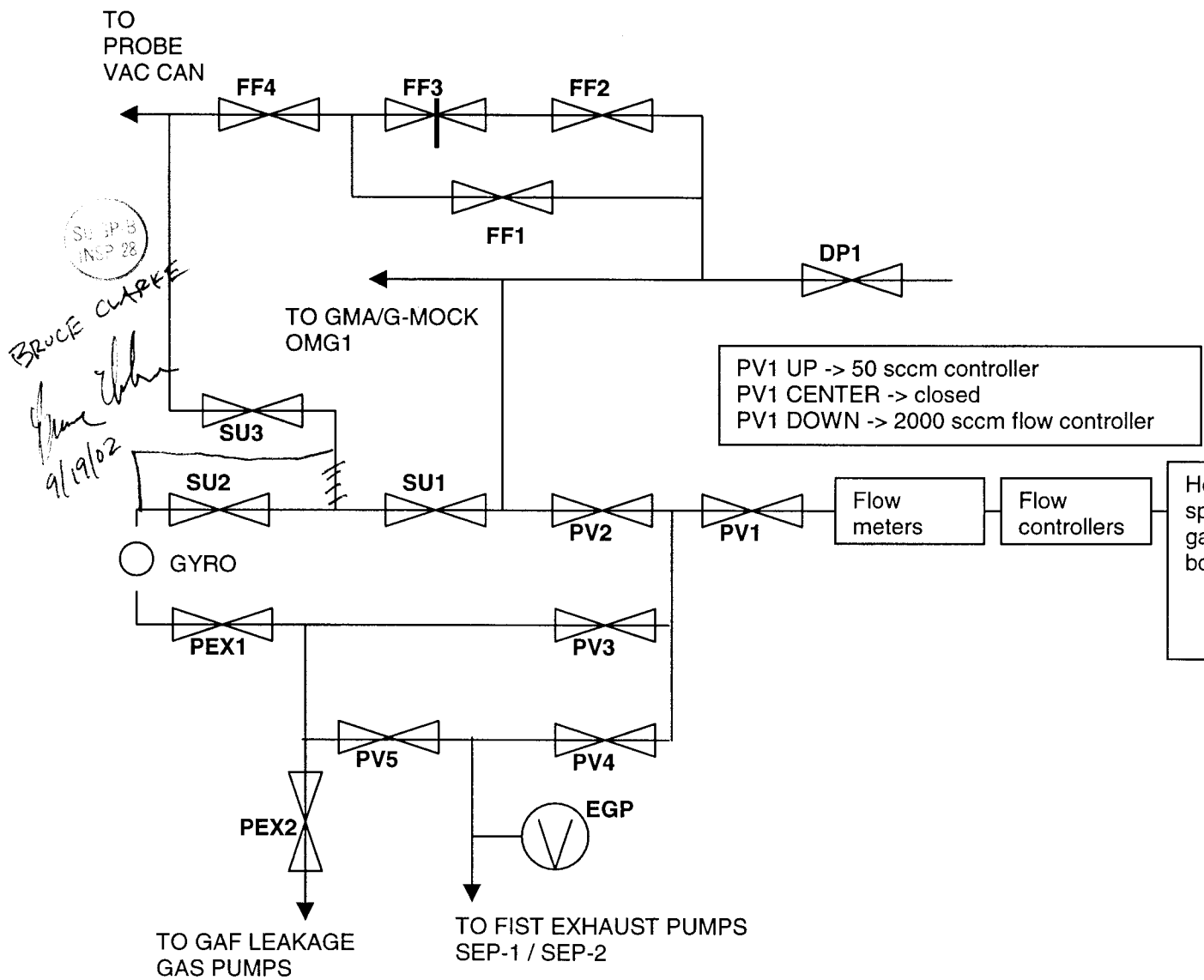
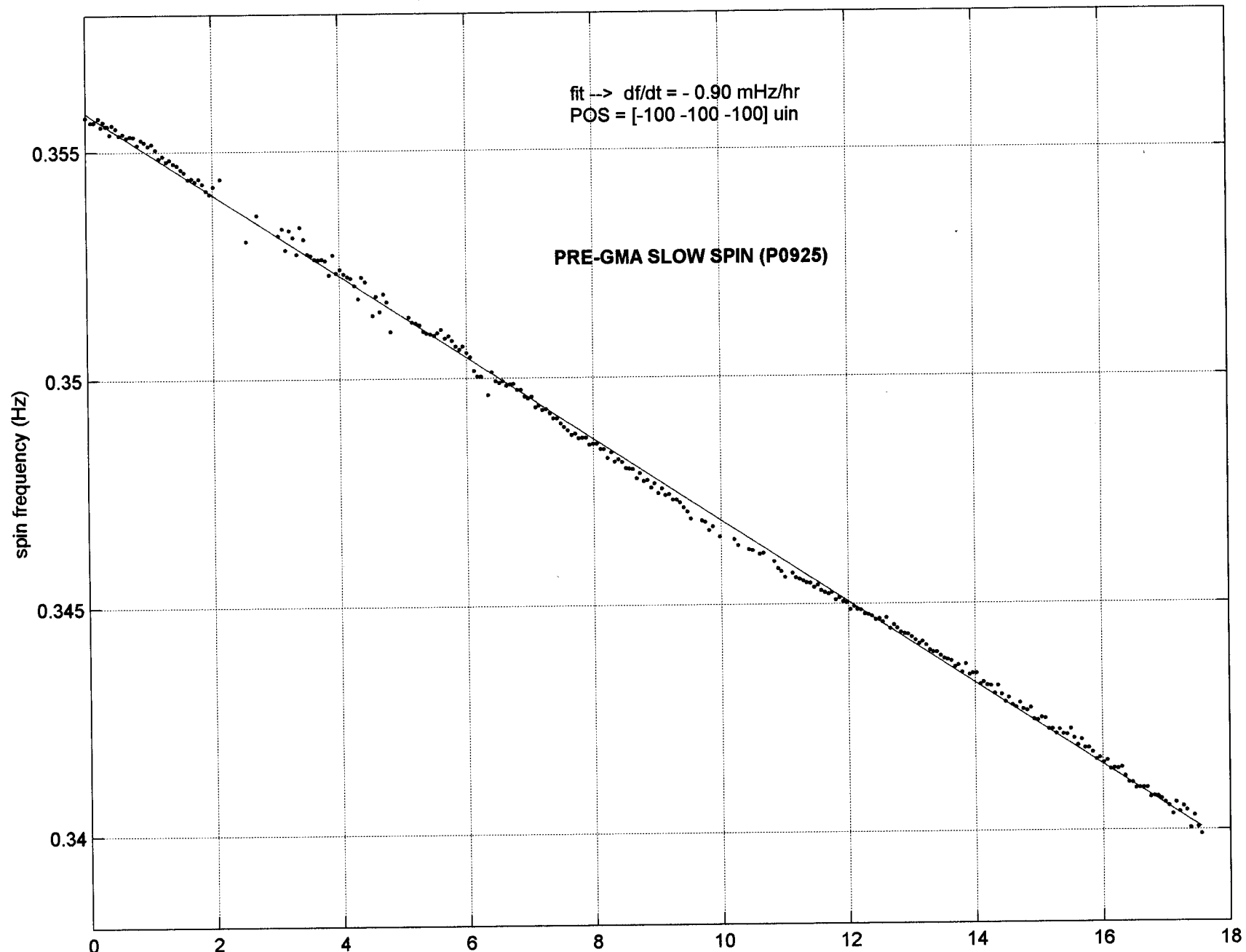
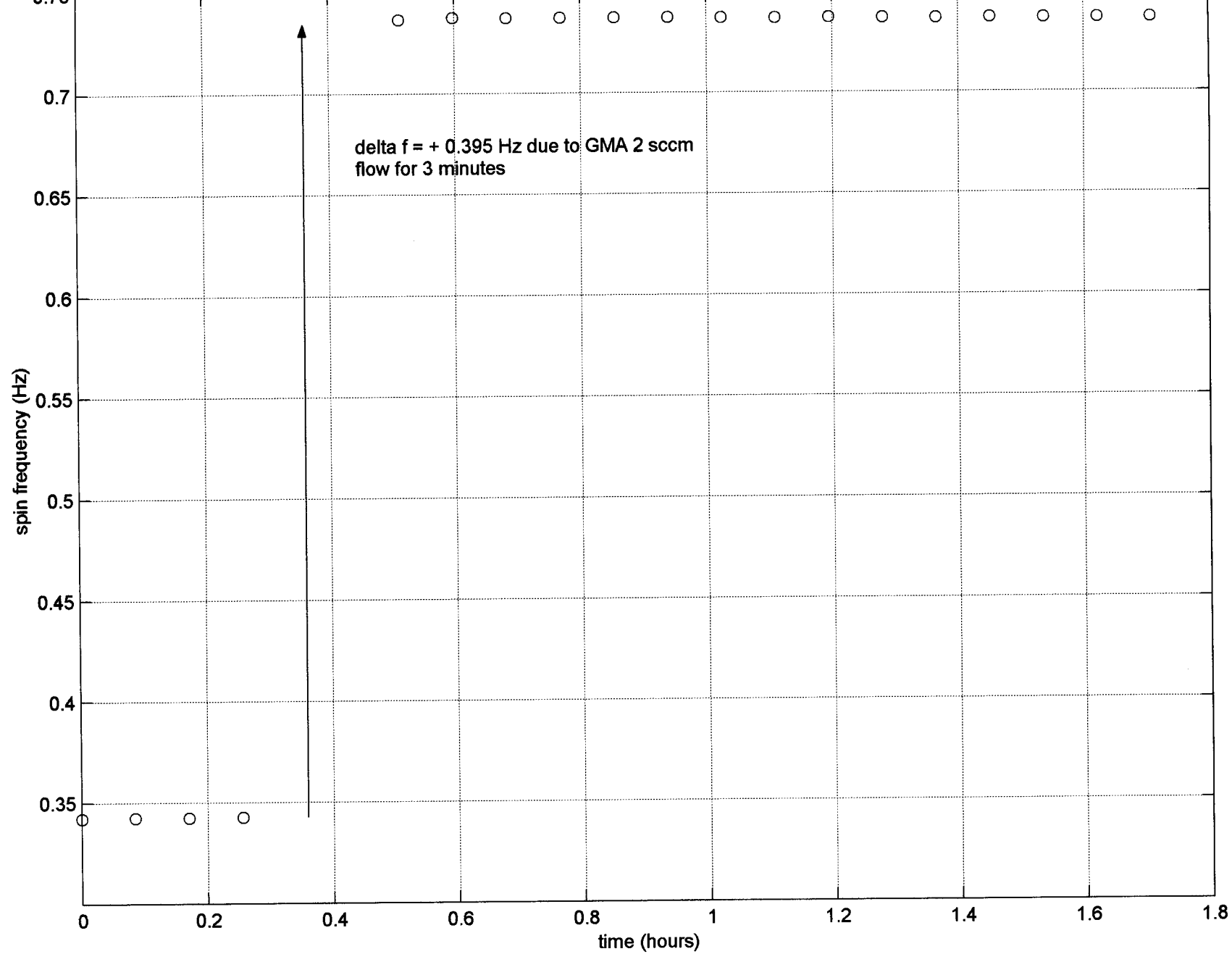


FIGURE 3 – GAF SPIN-UP GAS MANAGEMENT SYSTEM







GRAVITY PROBE B
PROCEDURE FOR
PAYLOAD VERIFICATION

P0935 REV –

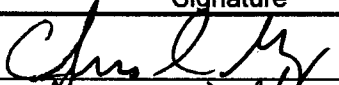
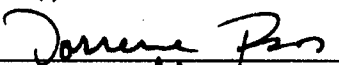
GYRO FAST SPIN TEST
IN THE GAF USING THE GMA

17 September 2002

As - Run

Prepared by: B. Clarke

Approvals:

Program Responsibility	Signature	Date
C. Gray GMA RE		9/18/02
B. Clarke Gyro Testing RE		9/17/02
D. Ross GP-B Quality Assurance		9/18/02
R. Brumley Payload Technical Manager		9/18/02

NOTES:

Level of QA required during performance of this procedure:

____ Stanford QA Representative

____ Government QA Representative

All redlines must be approved by QA

Revision Record:

Revision	Date	ECO #	Summary Description
-	9/12/2002	N/A	Initial Release

Acronyms and Abbreviations:

Acronym / Abbreviation	Meaning
ECU	Experiment control unit
FEU	Flight equivalent unit
GAF	Gyro Acceptance Facility
GCP	Gyro Commissioning Probe
GMA	Flight Gas management assembly
GMOCK	Functionally equivalent GMA

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A. Scope

This procedure covers the spin-up of a gyroscope to high speed (>10 Hz) at low temperature in the Gyro Acceptance Facility (GAF) using the flight Gas Management Assembly (GMA) or the non-flight functionally equivalent GMA mock-up (G-MOCK) and then slowing the gyro to a slow spin speed (<2 Hz).

B. Requirements Verification

- B.1 Requirements Cross-reference: None.
B.2 Expected Data for Verification per Requirement: None.

C. Configuration Requirements

The gyro commissioning probe with a gyro installed is in the low field dewar and being pumped on by the GAF leakage gas pumping system. The gyroscope has been levitated continuously for at least 12 hours in the spin-up position or a more aggressive position (further off center) and shows no evidence of charging or otherwise unstable suspension as determined by one of the qualified operators listed in section H of this procedure.

The GMA or G-MOCK has been connected to the GAF per P0923B and is configured such that it may be operated using the ECU FEU and associated test set.

D. Hardware Required

D.1 Flight hardware required

Description	No. Req'd
GMA (or functionally equivalent non- flight G-MOCK)	1

D.2 Commercial test equipment

Manufacturer	Model	Serial Number	Calibr. Exp. Date
N/A			

D.3 Mechanical/Electrical Special test equipment

Description	Part No.	Rev. no.	Serial No.	Certification Date
Optical readout systems	MDL285DC-C2	—	106 ~~MDL285DC~~	N/A
DDC Suspension system	DDC-3	1.07	DDC-3	N/A
FFT Data system	—	—	—	—

Description	Part No.	Rev. no.	Serial No.	Certification Date
Leakage gas management system	—	—	—	—
Gyro spinup gas management system	—	—	—	—
ECU FEU	8A01313-CEU	—	—	2/7/01

D.4 Tools

Description	No. Req'd
N/A	

D.5 Expendables

Description	Quantity
N/A	

E Software Required

CSTOL script "gma_low_spinup.prc"
CSTOL script "gma_high_spinup.prc"

Version 1.2 Date: 9/17/02
Version 1.2 Date: 9/17 02

F Procedures Required

N/A

G Equipment Pretest Requirements

N/A

H Personnel Requirements

The following personnel have received extensive training in the testing of GP-B gyroscopes and are qualified to perform this procedure.

- David Hipkins
- Bruce Clarke
- Chris Gray
- Robert Brumley
- Dr. Sasha Buchman
- Dr. William Bencze

I Safety Requirements

I.1 General

It is important to be aware at all times of the position of the probe. Be extremely careful not to accidentally bump into the probe or any system connected to the probe. If any connector does not connect smoothly and securely, do not try to force it. Instead, remove the connector and inspect it to

find the reason for the difficulty. Great care must be taken at all times during the performance of this procedure.

I.2 Electrostatic Discharge

Grounded wrist straps are to be worn at all times when mating or demating to an electrical connector on flight hardware.

I.3 Personnel Safety

All operations shall take place according to Stanford University safety guidelines. Any person observing a situation that they deem unsafe shall report the fact immediately to the test director. The Quality Assurance representative shall be responsible for monitoring that all activities are performed in a safe manner.

I.4 Electrical mating and demating of flight hardware connectors

I.4.1 Connection and disconnection shall be performed only when the equipment involved is in a powered-down state unless the procedure specifically states otherwise.

I.4.2 Connector savers are to be used unless otherwise specified.

I.4.3 Connectors shall be inspected for contamination and for bent, damaged, or recessed pins prior to mating.

I.4.4 Grounded wrist straps are to be worn prior to removal of connector caps or covers and during mating/demating operations on flight hardware.

I.4.5 ESD-protective caps or covers are to be immediately installed after demating of connectors on flight hardware.

J **General Instructions**

J.1 QA Notification

This test will be conducted on a formal basis to approved and released procedures. **The QA program office and ONR representative shall be notified 24 hours prior to the start of this procedure.** A Quality Assurance Representative, designated by D. Ross shall be present during the procedure and shall review any discrepancies noted and approve their disposition. Upon completion of this procedure, the QA Program Engineer, D. Ross or her designate, will certify her concurrence that the effort was performed and accomplished in accordance with the prescribed instructions by signing and dating in the designated place(s) in this document.

J.2 Redline Authority

Redlines can be initiated by any of the qualified operators listed in section H and must be approved by QA.

J.3 Discrepancies

Any nonconformance or test anomaly should be reported by a Discrepancy Report. Refer to the Quality Plan, P0108, for guidance. Do not alter or break test configuration if a test failure occurs; notify quality assurance.

J.4 Test Exit Authority

Only the following persons have the authority to exit/terminate this test or perform a retest:

Rob Brumley, Chris Gray, David Hipkins, Bruce Clarke, Sasha Buchman, William Bencze, and QA personnel.

J.5 Gyroscope Delevitation

A gyro delevitation at any point during this procedure does not in itself imply the GMA or G-MOCK has failed the test. However, if a gyroscope delevitates during the completion of this procedure, all work shall cease and the test configuration shall not be broken. Work may only continue under the guidance of the MRB. A Discrepancy Report shall be immediately opened recording the details of what happened. The immediate concern of the investigation should be to determine whether the GSE was at fault in the delevitation and how this GSE should be re-tested prior to resuming the test.

K **References and Applicable Documents**

Op. Order No. _____
Date Initiated 9/20/02
Time Initiated 1040

L OPERATIONS

L1 Pre-Test Checklist

Start Date: 9/20/02

Start Time: 1040

Gyroscope # FQH53 / 95FH4

Orientation of gyro: S HALF UP

Spin-up Position: -325, -325, -325 (To be supplied by the RE).

SNAPSHOT: FQH53042 @ 1044

- L.1.1 Verify that the gyroscope under test has been levitated continuously and spinning in the spin-up position (or in a more aggressive position with regard to rotor freedom of motion, i.e. further off-center) for the last 12 hours. Verify that the spindown rate in this position is acceptable to the RE. Record this spindown rate to two significant figures here and attach a copy of the frequency vs. time plot to the end of this procedure.

df/dt in spinup position = .94 mHz/hr

S/U Position X -325 uin, Y -325 uin, Z -325 uin

- L.1.2 Verify that the rotor has not charged and that the DDC suspension voltages have not shown any anomalous behavior since the rotor was moved into the spinup position.
- L.1.3 Start a new NLFF system data file by stopping and re-starting the NLFF3 data acquisition program. Set the logging interval to 20 seconds and write to both the local and network drives.

Record the NLFF filename: 092020.nlff

- L.1.4 Verify the leakage gas pumping system is operating, pumping on the probe (VAT open) and the probe pressure (P_{PB} measured on GAF ion gauge channel A) is $< 5 \times 10^{-5}$ torr
- L.1.5 Verify the spinup exhaust pumping System is operating and the exhaust gas pressure (measured on the GAF Convectron gauge EGP) is $< 5 \times 10^{-3}$ torr (this is used to evacuate the spinup manifold).
- L.1.6 Verify the probe exhaust (gold manual valve – PEX1) is open.
- L.1.7 Verify the probe exhaust by-pass valve (PEX2) is closed.
- L.1.8 Confirm manifold between the GCP spin-up inlet (SU2) and the Gyro Spinup management manifold up to valves PV2 and OMG1 (with SU1 open and DP1, FF1, FF2, FF3, FF4 closed) is connected and under vacuum.

- L.1.9 Confirm the helium spinup gas supplies on both the GAF and the GMA (G-MOCK) are Grade 6 He and have Conformance Certification available.
- L.1.10 Verify that the optical spin speed readout system and FFT data system is operating and spin speed data is currently being logged.
- L.1.11 Verify that the area around the dewar and probe has been roped off. Only those personnel identified as essential by the RE shall be allowed inside of the roped off area. Those essential personnel working near the probe are to be aware of their motions and avoid causing any mechanical disturbance to the probe.
- L.1.12 Zero the Baratron gauges. Zero the flowmeters.

L.2 Spin-up Manifold Evacuation

Note: Refer to figures 1 - 3 for pumping and gas management system schematics.

- L.2.1 Check that SEP-1/SEP-2 pumps are operating and the exhaust gas pressure (EGP on the GAF pumping system) is $< 5 \times 10^{-3}$ torr. The control panel for these pumps is located at the east wall of FIST OPS. If the pumps are not running pressing the momentary switches on the right side of the panel (see schematic, Figure 1) will start them. Place the system in Interlock Defeat mode and verify yellow LED is blinking.

When the exhaust gas pressure is stable, record the value below.

EGP = 2.6 mtorr

- L.2.2 Close (or verify closed) manual valves FF1, FF2, FF3, FF4, SU2 and SU3.
- L.2.3 Open manual valves SU1 and OMG1.
- L.2.4 Open pneumatic valves PV2 and PV4.
- L.2.5 Wait for the exhaust gas pressure (EGP) to stabilize to the pressure recorded in step L.2.1 +/- 0.1 mtorr.

L.3 Purge and Pump Out the Spin-up Manifold Using GAF Bypass Flow

- L.3.1 Check to ensure the GAF spin-up gas supply bottle contains > 250psi helium. Open the valve on the gas bottle and on the regulator.
- L.3.2 The regulator should be set to 20 -25 psig.
- L.3.3 Open PV1 (down position - 2000 sccm flow controller).
- L.3.4 On the 2000 sccm flow controller, rotate the 10-turn pot counter-clockwise on until a flow of 725 sccm is displayed. Continue this purge for 10 minutes.
- L.3.5 Dial the flow down to zero on the 2000 sccm flow controller and close PV1.
- L.3.6 Wait for the exhaust gas pressure (EGP) to stabilize to the pressure recorded in step L.2.1 +/- 0.1

SU GP-E
INSP 28

mtorr.

- L.3.7 Open the manual valve **SU2** on the probe and note any exhaust pressure rise (EGP).
- L.3.8 Close the pneumatic valves **PV2** and **PV4**.
- L.3.9 Open the manual valves **BV2** and **OMVENT** (located on the GMA/G-MOCK OUTLET MANIFOLD).

L.4 Gyroscope Low Speed Spinup Using the GMA /G-MOCK

- L.4.1 Have the ECU operator to start the low speed spin-up script, "gma_low_spinup.prc". This script will perform the following. **Bold face type must be performed manually using the GAF pneumatic valves.**

STATE TO
CAUSE H
CONF E

1. Flow 725 sccm through the GMA/G-MOCK vent to the exhaust pump for 60 seconds.
2. Hard wait - enable. **Manually open the GAF pneumatic exhaust valve PV5 prior to sending the enable.**
3. Flow 2 sccm through the GMA/G-MOCK vent to the exhaust pump and through the gyro in parallel for 90 seconds.
4. Flow 2 sccm through the gyro only for 180 seconds.
5. Flow 2 sccm through the GMA/G-MOCK vent to the exhaust pump and through the gyro in parallel for 90 seconds.
6. Close all GMA/G-MOCK valves opened in steps 1-6. **Manually close the GAF pneumatic exhaust valve PV5 after the GMA/G-MOCK valve V9 closes. The ECU operator will keep the GAF operator advised of the GMA/G-MOCK valve states as the low speed spin-up script runs.**

- L.4.4 Monitor gyro spin speed on the Sun 386i.

L5 Prepare for Fast Spin

IF AT ANY TIME DURING THE SPIN-UP THE GYRO SUSPENSION BECOMES UNSTABLE OR THE PROBE PRESSURE AS MEASURED ON GAF ION GAUGE A $> 4.2 \times 10^{-3}$ torr,

STOP THE SPIN-UP BY SKIPPING IMMEDIATELY TO SECTION L.7.

- L.5.1 Record the gyro spin speed: 1.486 Hz

- L.5.2 Restart the FFT routine on the SUN 386I using "FFT32". The sampling rate should be set to 500 Hz. The logging interval should be 60 seconds for now (this should be updated to 3s during spinup).

Channel 0 OPTICAL

Channel 1 OPTICAL

Path and Filename 6 GT7 / 82092000.4224p

- L.5.3 Pre-set the HP power supply to 15.25 V but do not connect it to the spin-up heater yet. Turn the power supply off and make the connection to the spin-up heater. Note that the RE may change the gyro target temperature and hence the HP power supply voltage at any time during the spin-up. The target gyro temperature is 6.5 to 7.0 K during spin-up.
- L.5.4 Set the safety radius on the DDC to 1500 uin. This effectively disables the DDC automatic shut down.
- L.5.5 Start the FIST emergency generator if it is not already running.

L.6 Gyroscope High Speed Spinup Using the GMA /G-MOCK

- L.6.1 Have the ECU operator to start the high speed spin-up script, "gma_high_spinup.prc". This script will perform the following. **Bold face type must be performed manually by the GAF operator.**

Launch CONFIG.

1. Hard wait - enable. **The ECU operator will wait for the RE's command to continue the script. Prior to sending the enable, manually open the GAF pneumatic exhaust valve PV5.**
2. Flow 725 sccm through the GMA/G-MOCK vent to the exhaust pump for 60 seconds.
3. Flow 725 sccm through the GMA/G-MOCK vent to the exhaust pump and through the gyro in parallel for 90 seconds.
4. Flow 725 sccm through the gyro only for 180 seconds. **Adjust the FFT logging interval to 3 seconds. Apply the appropriate heater voltage by powering on the HP power supply. Monitor gyro spin-up using the FFT program. Record parameters in Table1 once every two minutes during the spin-up. Monitor the DDC suspension voltages, the FFT tracking of the gyro spin frequency and the probe and gas management system pressures.**
5. Hard wait - enable. **The ECU operator will wait for the RE's command to continue the script. The goal of this part of the test is to record stable gyro s/u, gyro exhaust and vacuum can pressures as well as the gyro and spin-up temperatures. After stability is reached, the RE may continue the spinup in order to collect engineering data on gyro fast spin performance before sending the enable.**
6. Flow 725 sccm through the GMA/G-MOCK vent to the exhaust pump and through the gyro in parallel for 90 seconds. **Turn the spin-up heater off by powering down the HP power supply.**

- ~~7.~~ Flow 725 sccm through the GMA/G-MOCK vent to the exhaust pump for 60 seconds.
- ~~8.~~ Close all GMA/G-MOCK valves opened in steps 1-6. **Manually close the GAF pneumatic exhaust valve PV5 after the GMA/G-MOCK valve V9 closes. This happens at the beginning of step 7 above. The ECU operator will keep the GAF operator advised of the GMA/G-MOCK valve states as the low speed spin-up script runs.**
- L.6.2 Adjust the FFT and NLFF logging interval to 60s. Monitor gyro spin speed on the Sun 386i.
- L.6.3 The RE will determine at what point to move on to section L.7.

L.7 Spin-down

- L.7.1 Carefully close manual valve **SU1**. Close manual valves **BV2**, **OMVENT** and **OMG1**.
- L.7.2 Carefully and slowly move the gyro to 100 uin up in the housing on each axis. Monitor the probe ion gauge during this operation to be sure the housing is not flooded with gas that may be left in the spin-up and exhaust lines. *S-HALF UP → [-100, -100, -100]*
- L.7.3 Open **PV1** (50 sccm flow controller) and **PV4**. Adjust the flow controller to give 2 sccm on the flowmeter.
- L.7.4 Open **PV3** and close **PV4**. Closely monitor the probe pressure and adjust the flow to give a reading of $\sim 5 \times 10^{-4}$ torr on the probe ion gauge. Continue to monitor the pressure during the spin-down and adjust the flow to give an ion gauge reading of no more than 5×10^{-4} torr.
- L.7.5 Adjust the logging interval on the FFT data acquisition to 300 seconds. Continue to update Table 1 every 15 minutes.
- L.7.6 Once the gyro spin speed is below 10 Hz, the FIST emergency standby generator may be turned off (assuming the lab is not currently running on emergency backup power).
- L.7.7 When the spin frequency is no longer decreasing, stop the flow of gas to the gyro exhaust by adjusting the 50-sccm flowmeter to zero. Close **PV3**.
- L.7.8 Pump out the exchange gas manifold by opening **PV4** and manual valve **FF1**. Wait for the exhaust gas pressure (EGP) to return to its base pressure ± 0.1 mtorr (see step L.2.1).
- L.7.9 Using extreme caution not to bump the probe, close probe manual valve **SU2** and open probe manual valve **FF4**. Open **PV2** and close **PV4**.
- L.7.10 Adjust the flow on the 50-sccm flow controller to give a vacuum can pressure reading of $\sim 1 \times 10^{-3}$ torr. Continue to monitor the pressure during the spin-down and adjust the flow to give an ion gauge reading of no more than 1×10^{-3} torr.
- L.7.11 Decrease the DDC safety radius to 250 uin. Continue to monitor the spin-down until the spin frequency is < 0.3 Hz.
- L.7.12 Once the gyro spin speed is below 0.3 Hz, dial the flow down to zero on the 50-sccm flow controller. Close **PV1** and **PV2**.
- L.7.12 The rotor may now be delevitated.

FFT : GT7/82092000.72P
NLFF: 092021.NLF

P0935-.doc

Collect engineering data on
spin down overnight.
Open PEX1 & PEX2.
Close FF4
Open SU3.
& NLFF file.

Start new FFT file

7:21 PM 9/18/2002

SU GP-B
INSP 28

SU GP-B
RDE 14

[Signature]
9/20/02

L7.13 Close manual valves **FF1** and **FF4**. Turn off exhaust pumps **SEP-1** and **SEP-2**.

L7.14 Stop and re-start the NLFF data acquisition program. Set the logging interval to 300s. Archive the NLFF data file from the fast spin.

Server path and filename: //HEPL-GYRO/FISTOP/NLFF/SYSDATA/092020.NLF

L7.15 Stop the FFT program and archive the data files.

Server path and filename: //HEPL-GYRO/BT7/82092000.24P

L7.16 Archive the DDC charge file and any levitation/de-levitation files and/or snapshots.

Server path and filename: //HEPL-GYRO/FISTOP/GYROS/FQHS3/GMA-test-gyro/

LT-test-1/GMA/FQHS3037 through FQHS3048.NAT

Server path and filename: _____

Server path and filename: Same path CH.01657.dat (DDC charge file).

Server path and filename: _____

Server path and filename: _____

Server path and filename: _____

L.8 Data Reduction

L.8.1 From Table 1, enter the stable values of gyro s/u, gyro exhaust and vacuum can pressure as well as the gyro and spin-up (final filter) temperatures. Compare these to the stable values from a similar fast spin performed using the GAF spinup gas management system. If the values agree to within +/- 20 %, the GMA passes the fast spin test.

Parameter	P0935 (this run -- high flow path in GMA/GMOCK)	Previous GAF spin up (725 sccm)	% diff
Probe pressure	2.8 mtorr	3.2 mtorr	+12.5
Gyro spin-up pressure	10.40 torr	12.12 torr	+14.2
Gyro exhaust pressure	0.190 torr	0.200 torr	-5.0
Gyro temperature	7.12 K	7.06 K	+0.8
Spin-up (final filter) temperature	15.5 K	14.7 K	+5.4

L.8.2 Perform a three-parameter exponential fit to the spin-up data collected in section L.6 and attach a printed copy to this procedure. From this fit record the following values:

Asymptotic spin speed: f_a = 86.6 Hz

Spin-up time constant: τ = 22.56 minutes
Initial torque: $df/dt(t=0)$ = 63.96 mHz/s
Fit range = 36 Hz to 55 Hz
Peak-to-peak residue to the fit = 40 mHz

Test completed.

Completed by: [Signature]
Witnessed by: [Signature]
Date: 9/22/02
Time: 2140

SU GP-B
RDE 14

SU GP-B
INSP 28

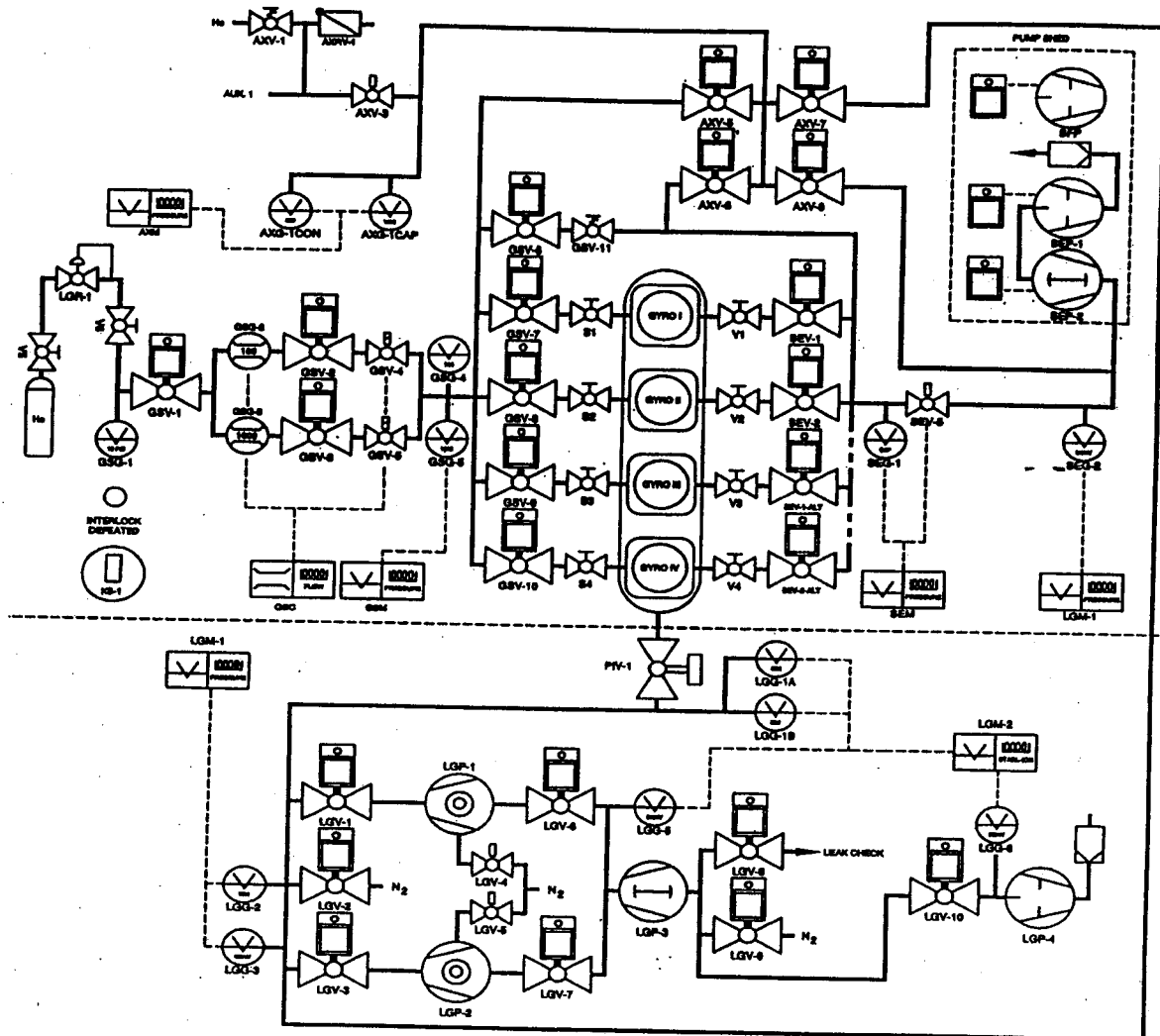


Figure 1: Gyro Gas Management System

This figure shows the location of the switches for the exhaust pumps SEP-1 and SEP-2. No other valve designations or labels in this figure are used in this procedure. Figure 2 – GMA Interface with the GAF is shown on the next page.

The diagram illustrates the GMA (Gas Manifold Assembly) system, which is a central component for gas distribution and regulation. Key components and connections include:

- GMA (Gas Manifold Assembly):** A central triangular manifold with multiple ports:
 - Regulator Interstage Port (MV4):** Connected to the High Pressure Outlet of the GDS.
 - Service Port (MV2):** Connected to the Low Pressure Outlet of the GDS.
 - Fill Port (MV1):** Connected to the 3500 psi Mensor Gauge.
 - To Probe Inlets Vent (MV3):** Connected to the 500 psi Mensor Gauge.
- GDS (Gas Distribution System):** A large rectangular unit with two main outlets:
 - High Pressure Outlet:** Connected to the GMA via MV4.
 - Low Pressure Outlet:** Connected to the GMA via MV2.
- Leakage Gas Pumping System:** Two pumps at the top left, connected to the GMA via a line with a valve.
- Exhaust Gas Pumping System:** Two pumps at the top left, connected to the GMA via a line with a valve.
- Auxiliary Dry Pump Cart:** A pump at the bottom left, connected to the GMA via a line with a valve.
- Valves and Pumps:**
 - PV-1, PV-2, PV-3, PV-4:** Various valves connected to the GMA and other components.
 - DP-1:** A differential pressure sensor connected to the GMA.
 - Check Valve (optional):** Located on the line from the Auxiliary Dry Pump Cart.
 - FF-1, FF-2, FF-3, FF-4:** Flow control valves.
 - PEX-1, PEX-2:** Pressure exchange valves.
 - S/U-1, S/U-2, S/U-3:** Service unit valves.
 - BV-1, BV-2:** Backflow valves.
- Gauges:**
 - 500 psi Mensor Gauge:** Connected to the GMA via MV3.
 - 3500 psi Mensor Gauge:** Connected to the GMA via MV1.
- Probe / Gyro Leakage Gas:** A line at the top right, connected to the GMA via a valve.
- Probe Isolation Valve:** A valve on the line from the Probe / Gyro Leakage Gas.
- Gyro Exhaust:** A line connected to the GMA via a valve.
- Spin Up / Exhaust:** A vertical section on the right, containing a **Gyro** and a **S/U Gas Filter & Heater**.

FIGURE 3 – GAF SPIN-UP GAS MANAGEMENT SYSTEM

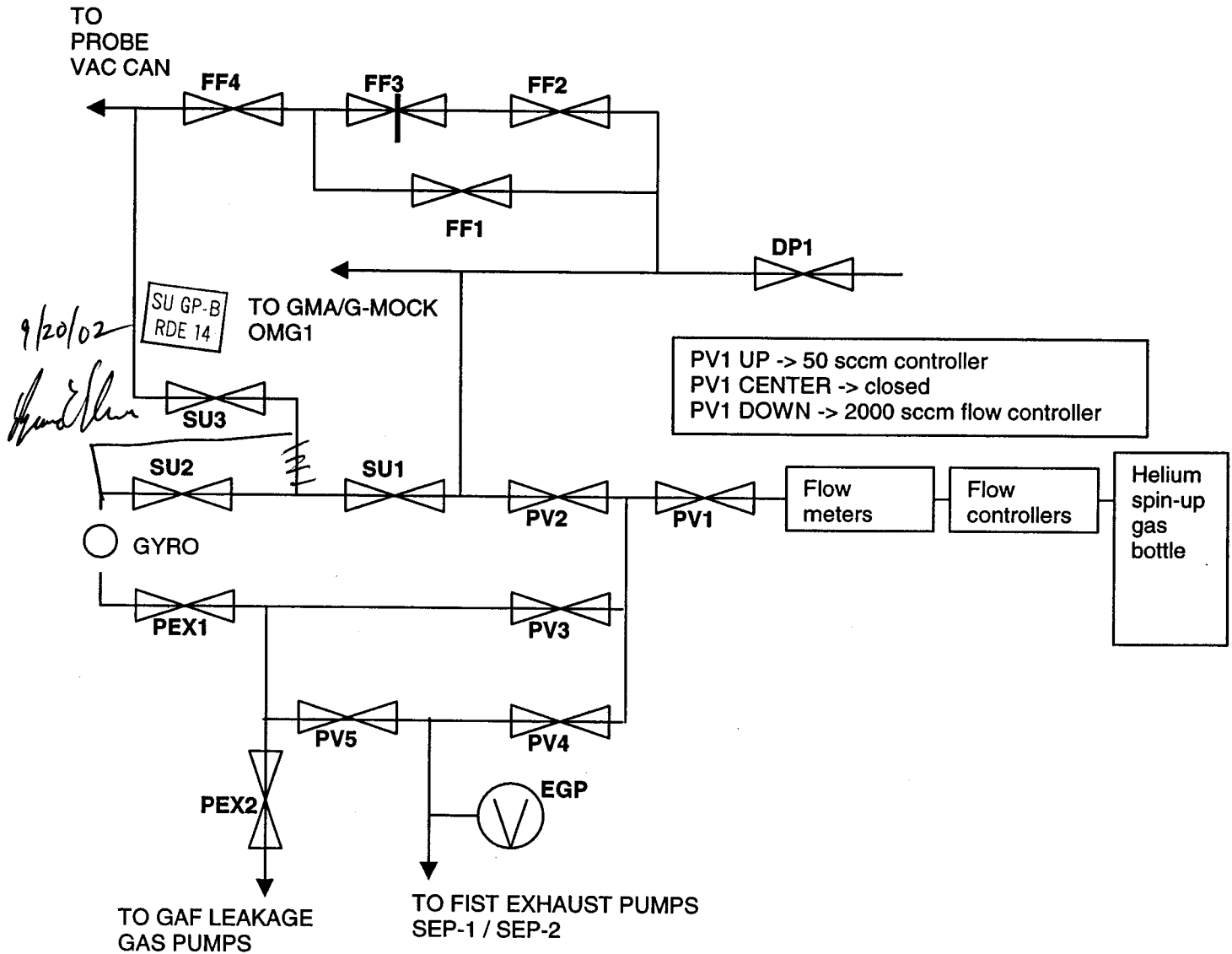


TABLE 1 - FAST SPIN RECORD

Date 9/20/02

Position -325, -325, -325

Page 1 of 3

Gyro FQ1453/95A14

Filename 092020.nff & 82092000.24p

TIME	f (Hz)	flow (sccm)	Pprobe (torr)	~~N~~ Psys (torr)	P s/u (torr)	P ex (torr)	T gyro (Ohms)	T filter (Ohms)	S/U heater (Volts)	Control effort X (g)	Control effort Y (g)	Control effort Z (g)	Net Control Effort (g)
1142	5.18	725	2.6M	~~21~~ X10	8.22	0.19	496	410	15.25	-0.597	-0.565	-0.615	1.026
1145	10.42		2.7M		8.9	0.18	602	64	15.25	-0.601	-0.563	-0.620	1.034
1147	15.63		2.8M		9.9	0.18	555	83	15.25	-0.607	-0.562	-0.625	1.037
1149	21.1		2.8M		10.3	0.18	474	26	15.25	-0.610	-0.565	-0.625	1.038
1151	26.4		2.8M		10.4	0.18	454	41	15.25	-0.612	-0.567	-0.624	1.040
1153	31.3		2.8M		10.4	0.19	461	35	15.25	-0.606	-0.568	-0.625	1.037
1155	36.3		2.7M		10.4	0.19	458	36	15.25	-0.606	-0.562	-0.619	1.037
1157	41.2		2.8M		10.4	0.19	459	54	15.25	-0.608	-0.567	-0.624	1.040
1200	45.4		2.8M		10.4	0.19	471	70	15.25	-0.606	-0.566	-0.622	1.034
1202	49.9		2.8M		10.4	0.19	462	44	15.25	-0.608	-0.567	-0.624	1.039
1204	52.2		2.7M		10.4	0.19	453	62	15.25	-0.604	-0.566	-0.622	1.040
1206	55.5		1.8M		6.08	0.14	489	42	OFF	-0.589	-0.561	-0.604	1.012
1208	57.1		4.9x10 ⁻⁵		0.14	0.01	698	32	OFF	-0.557	-0.564	-0.575	0.981
1210	56.9		1.7x10 ⁻⁶		0.015	0.00	772	47	OFF	-0.557	-0.564	-0.573	0.977
STARTED SPIN DOWN NO PCL 4.7													
1220	55.0	-6	4.0x10 ⁻⁴		0.423	0.683	935	356	—	-0.552	-0.577	-0.599	1.022
1230	42.0	-1.0	7.7x10 ⁻⁴		0.623	0.788	1261	544	—	-0.594	-0.581	-0.599	1.026
1247	28.5	-1.0	7.6x10 ⁻⁴		0.638	0.784	1303	561	—	-0.593	-0.580	-0.597	1.023
13:10	18.74	-1.0	7.7x10 ⁻⁴		0.656	0.784	1302	549	—	-0.594	-0.581	-0.598	1.022
13:20	9.06	-1.0	7.7x10 ⁻⁴		0.669	0.784	1295	530	—	-0.597	-0.581	-0.602	1.027
13:46	4.81	-1.0	7.7x10 ⁻⁴		0.675	0.784	1316	551	—	-0.595	-0.581	-0.600	1.028

OPEN
V29
CLOSE V-9

move to [-100 -100 -100]

TABLE 1 – FAST SPIN RECORD (continued)

Date 9/26/02

Position S/U @ 8-325 -325 -325

Page 2 of 3

Gyro FQH53 / 95FH04

Filename 82092000.24p

TIME	f (Hz)	flow (sccm)	Pprobe (torr)	Psys (torr)	P s/u (torr)	P ex (torr)	T gyro (Ohms)	T filter (Ohms)	S/U heater (Volts)	Control effort X (g)	Control effort Y (g)	Control effort Z (g)	Net Control Effort (g)
1356	2.83	-1.0	7.7/-4	—	0.679	0.783	1298	550	—	-.594	-.582	-.599	1.026
1409	1.69	-1.0	7.7/-4	—	0.679	0.781	1314	558	—	-.599	-.577	-.601	1.025
STARTING TO SPIN UP — STOP FLOW GO TO STEP 1.7.8													
Add exchange gas w/ VHT open. Continuous flow 35 sccm through FF4.													
1430	1.95	FF 35.0	1.0/-3	—	0.00	0.01	1322	553	—	-.582	-.580	-.586	1.010
1437	Flow to 50.0 sccm												
1440	1.89	FF 50	1.2/-3	—	0.015	0.004	1320	550	—	-.579	-.583	-.583	1.007
15:25	1.56	FF 50	1.2/-3	—	0.017	0.003	1321	553	—	-.583	-.577	-.586	1.005
15:45	1.44	FF 50	1.2/-3	—	0.022	0.003	1316	550	—	-.581	-.581	-.586	1.010
16:05	1.32	FF 50	1.2/-3	—	0.025	0.003	1311	563	—	-.582	-.582	-.585	1.006
16:30	1.197	FF 50	1.2/-3	—	0.026	0.003	1309	558	—	-.577	-.579	-.583	1.007
17:18	0.988	FF 50	1.2/-3	—	0.029	0.004	1322	563	—	-.581	-.581	-.586	1.009
Safety radius to 1500 μ m. Start x-far													

TABLE 1 – FAST SPIN RECORD (continued)

Date 9/20/02

Position 90 @ {-325 -325 -325}

Page 3 of 3

Gyro FQHS3/95FH04

Filename 82092000.ZIP

TIME	f (Hz)	flow (sccm)	Pprobe (torr)	Psys (torr)	P s/u (torr)	P ex (torr)	T gyro (Ohms)	T filter (Ohms)	S/U heater (Volts)	Control effort X (g)	Control effort Y (g)	Control effort Z (g)	Net Control Effort (g)
1731	0.938	FF 50	1.3/-3	—	0.026	0.003	1300	561	—	-0.582	-0.583	-0.582	1.010
1750	0.864	FF 50	1.4/-3	—	0.025	0.004	1315	549	—	-0.583	-0.578	-0.584	1.008
1802	0.815	FF 50	1.4/-3	—	0.031	0.004	1320	566	—	-0.579	-0.582	-0.587	1.010
1814	2-fer diam. He = 92% . Safety valves to 300 μ m												
1815	0.765	FF 50	1.3/-3	—	0.035	0.005	1319	549	—	-0.579	-0.582	-0.586	1.009
1827	0.733	FF 50	1.3/-3	—	0.038	0.005	1310	571	—	-0.580	-0.579	-0.583	1.005
1833	SWITCH to 2000 sccm flow controller. 206 sccm $\Rightarrow$ $P_{10} = 2.6/-3$ torr												
1836	0.706	206 FF	2.7/-3	—	0.041	0.006	1327	559	—	-0.580	-0.581	-0.586	1.008
1856	0.573	206 FF	2.9/-3	—	0.043	0.008	1315	559	—	-0.580	-0.580	-0.585	1.006
1912	0.488	206 FF	3.0/-3	—	0.043	0.008	1315	549	—	-0.582	-0.577	-0.584	1.010
1930	0.391	206 FF	3.2/-3	—	0.042	0.009	1321	563	—	-0.580	-0.579	-0.586	1.011
1944	0.330	206 FF	3.2/-3	—	0.042	0.009	1310	562	—	-0.583	-0.580	-0.585	1.008
	GO TO STEP L.7.12												

SU GP-B
INSP 28

9/23/02

TABLE 1 – FAST SPIN RECORD (continued)

Date _____

Position _____

Page ____ of ____

Gyro _____

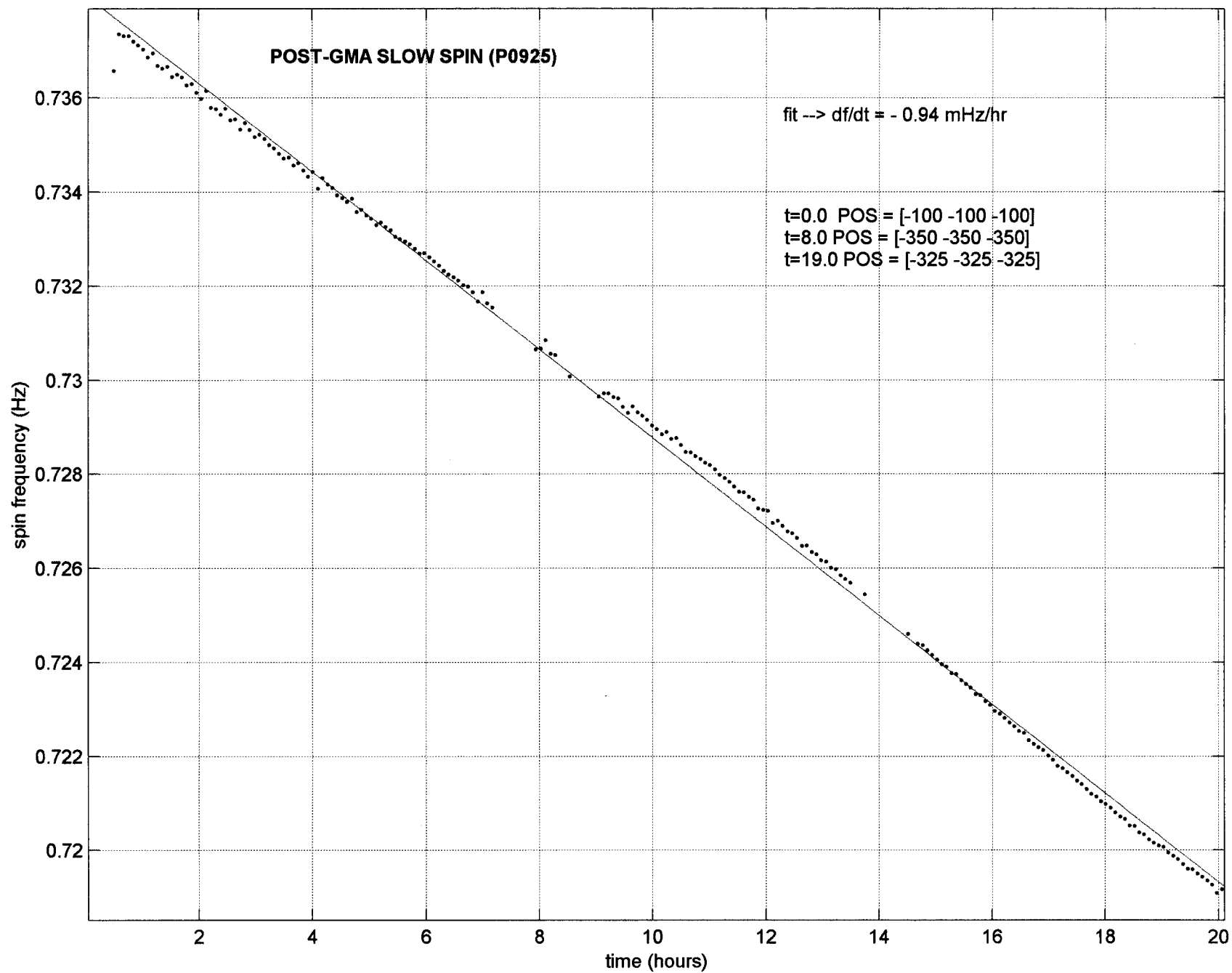
Filename _____

[illegible]

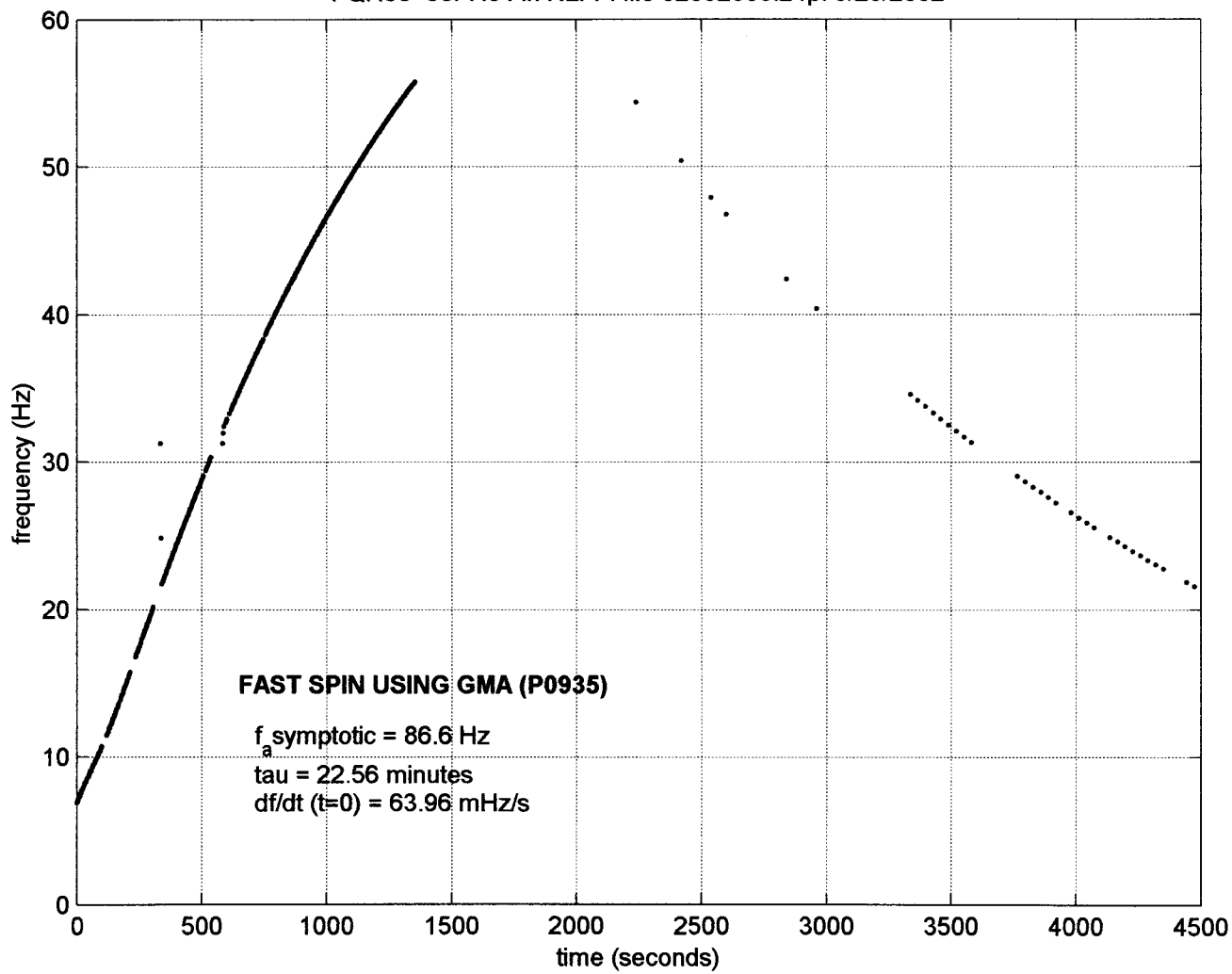
Page ____ of ____

Filename _____

[illegible]

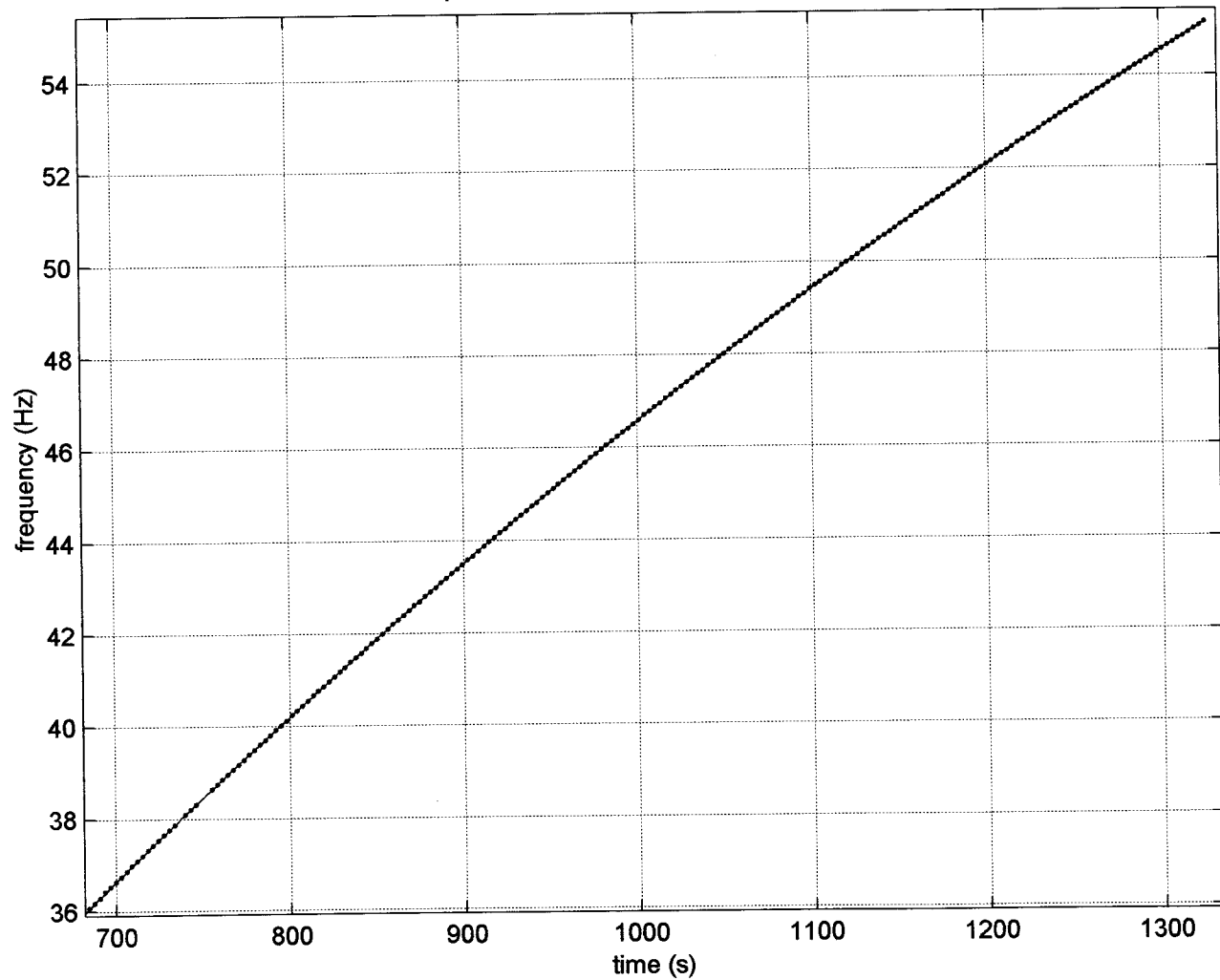


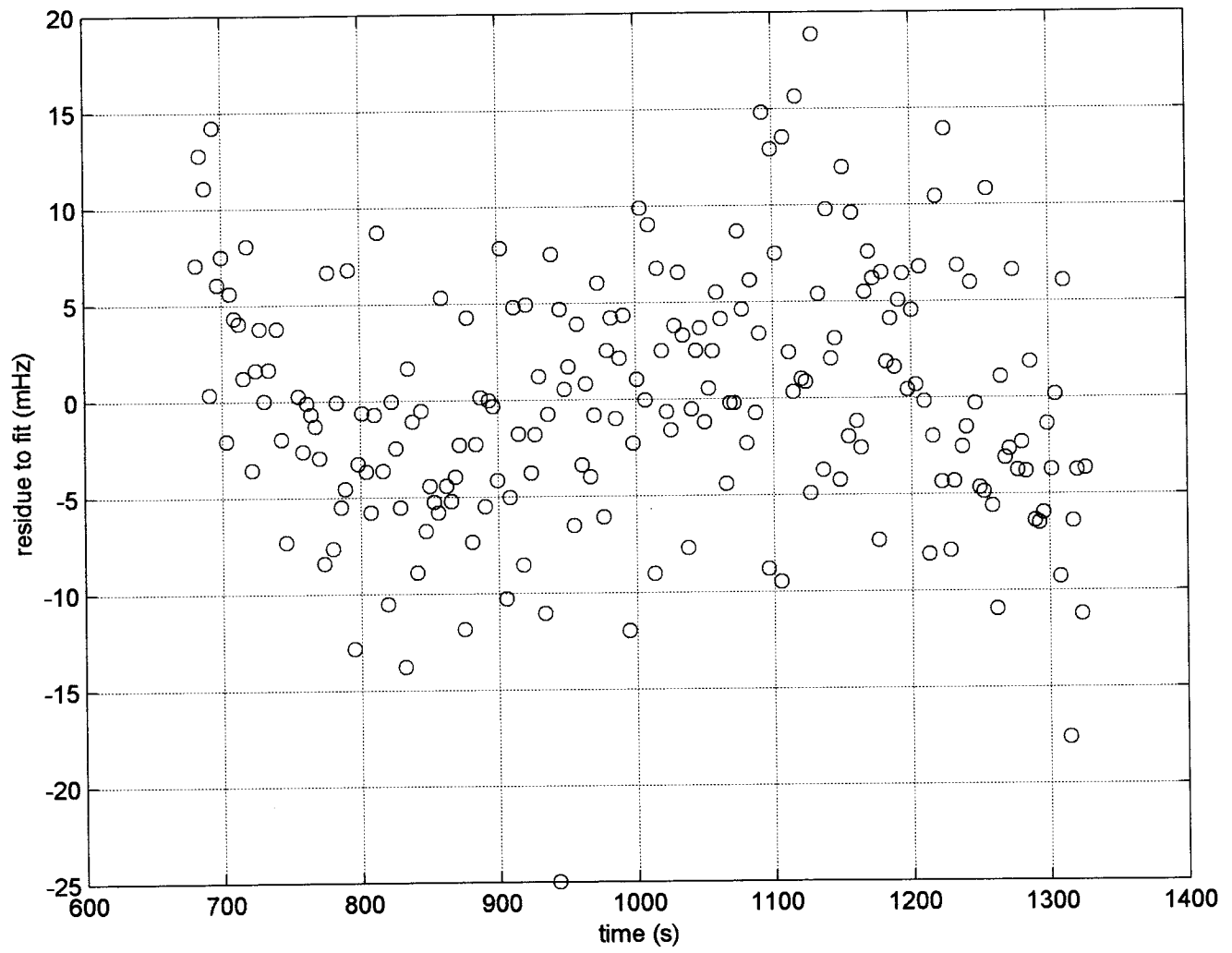
FQH53+95FH04 in NLFF: file 82092000.24p: 9/20/2002

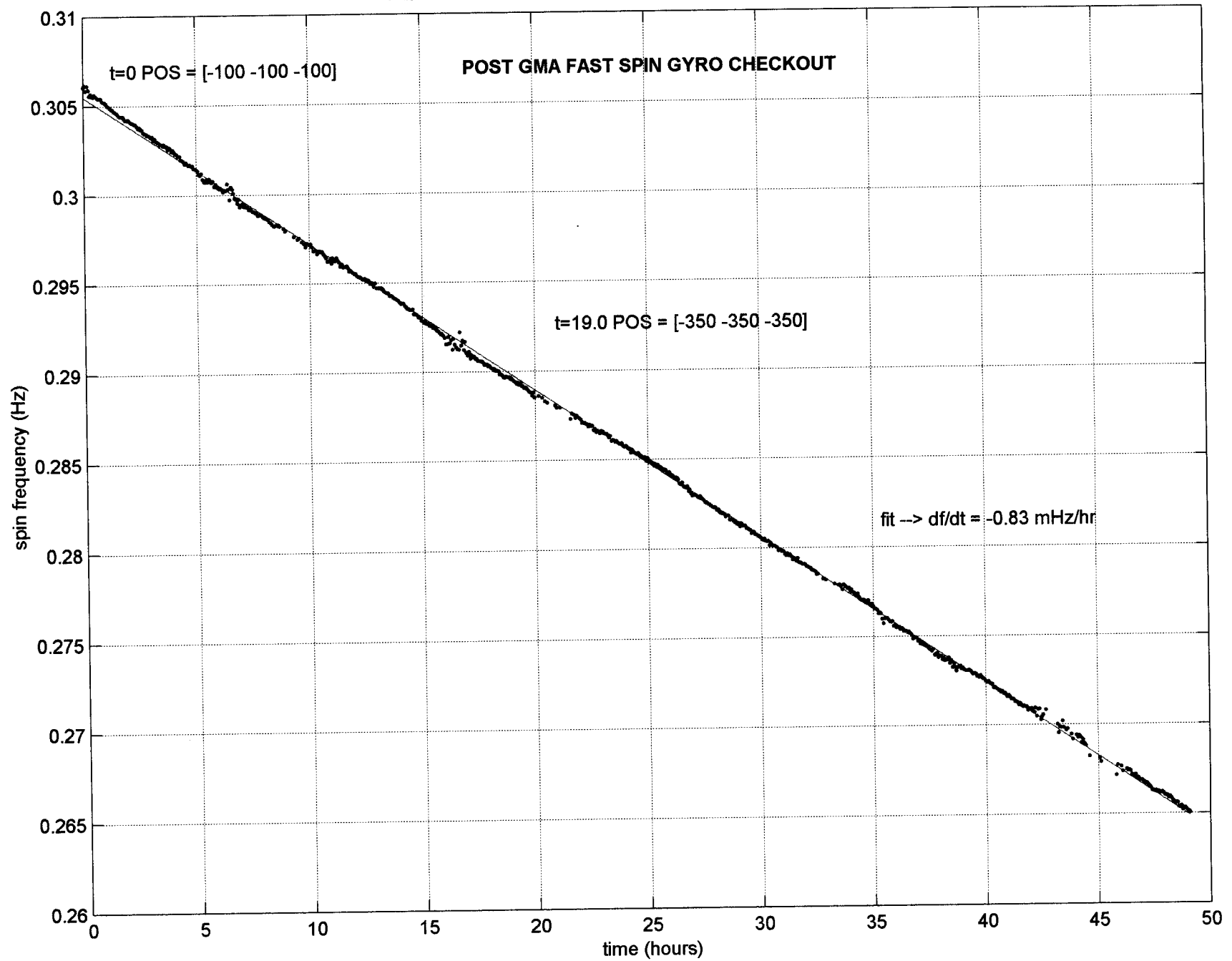


file: 82092000.24p

fa=86.61 Hz, τ =22.57 min, df/dt=63.96 mHz/s







D.4 Thermal Vac Test Summary

GRAVITY PROBE B PROJECT
THERMAL VACUUM GMA OPERATION

15.10.1 GMA FLOW TEST ANALYSIS
(PSVGMAFLOW)

2/10/03

Prepared by: *D. Meriwether*

Scope

This procedure verifies gas flows from the Flight GMA to the payload at each probe inlet (S1, S2, S3, S4, P1A and Vent Line). Both the low and high-flow functionality of the GMA is verified. The ECU is initialized and its internal monitors limit checked. ALL GMA monitors are recorded initially and upon change. All GMA valves are configured into the pre-launch configuration, Each possible Gas flow path is then tested, and finally, all GMA valves are again configured into the pre-launch configuration.

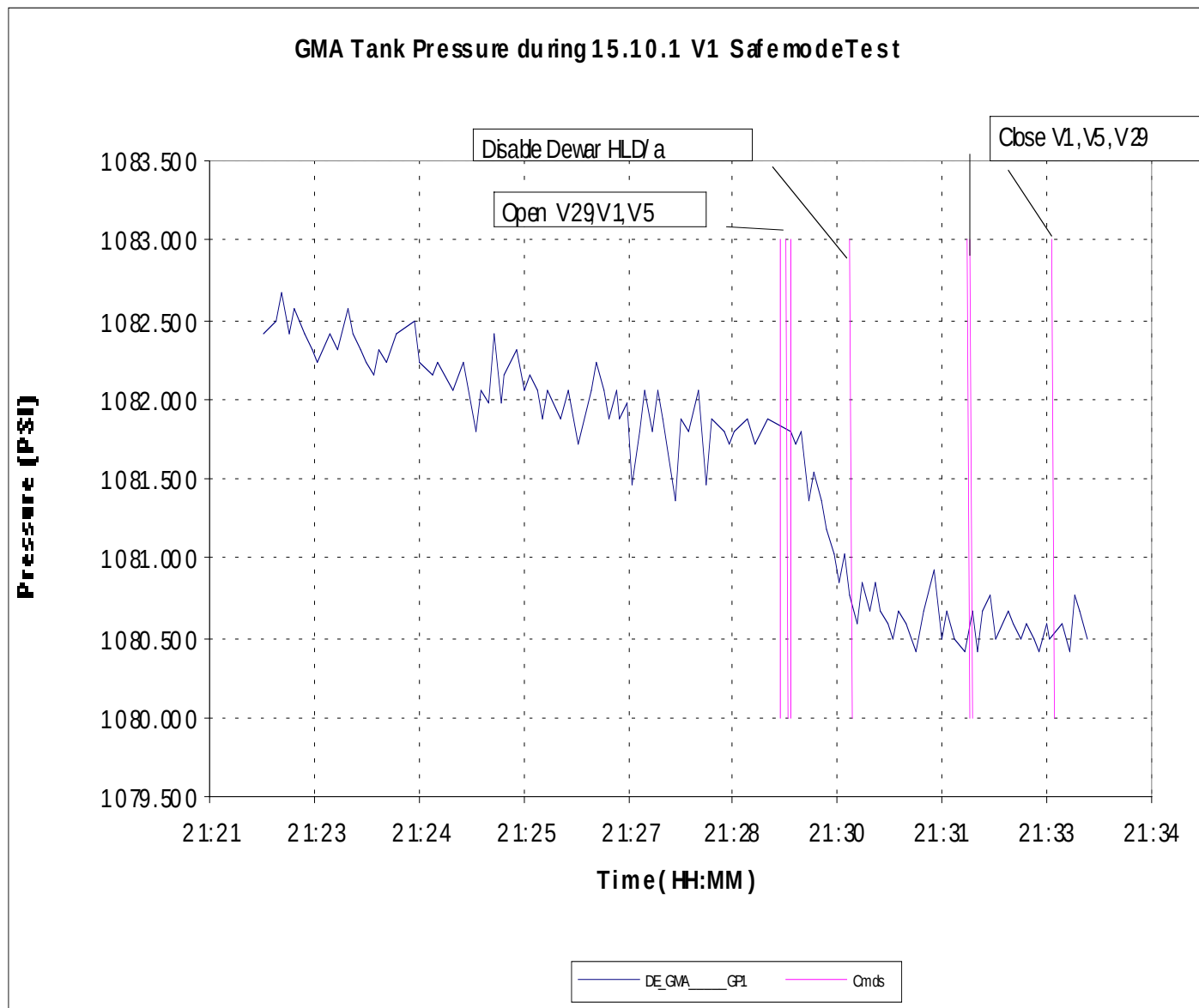
Success Criteria:

This sequence of operations involves instigating flows at 2, 10, and 725 sccm into GSE. For each flow experiment, the success criteria is that the pressure indicated by GSE pressure gauges in the drain vacuum system reads in its nominal range for the given flow (the nominal ranges will be defined in the test procedure). Flows into the gyro spinup lines and P1 line are bypassed into a pumping system at the fill and drain valves, the relevant pressure indicator is the pressure gauge on the line. For flows into the GMA vent path, the relevant pressure indicator is the pressure gauge on the pumping system connected to the vent path. For steps 10 and 11, which test the ability of the valves to respond to the HLD commands, the requirement is that when the dewar HLD is disabled, the flow of gas stops, as indicated by the relevant pressure going to its zero-flow baseline.

11/26/02 Thermal Vac Operation: GMA Flow Path (E28 Test 15.10.1)

1) GMA Valves V1 Safemode:

- a) The valve closest to the Tank (V1) can be closed independent of the state of the ECU under the following conditions:
 - i) The PDU command for the A Side ECU Operated Dewar Heater's High Level Discrete (HLD) has been enabled.
 - ii) The PDU command for the A Side GMA/VATT Valves HLD has been enabled.
- b) Assuming the previous conditions have been met, The GMA Valve V1 will close when the PDU command for the Side A ECU Operated Dewar Heater's High Level Discrete (HLD) is disabled.
- c) Methodology:
 - i) A gas path is opened from the Vent to the Tank (Valves {V29, V27, V5, V1} open)¹
 - ii) GMA Tank Pressure (GP1) is monitored
 - iii) A Side Dewar HLD is disabled
 - iv) Gas path is closed via Safemode

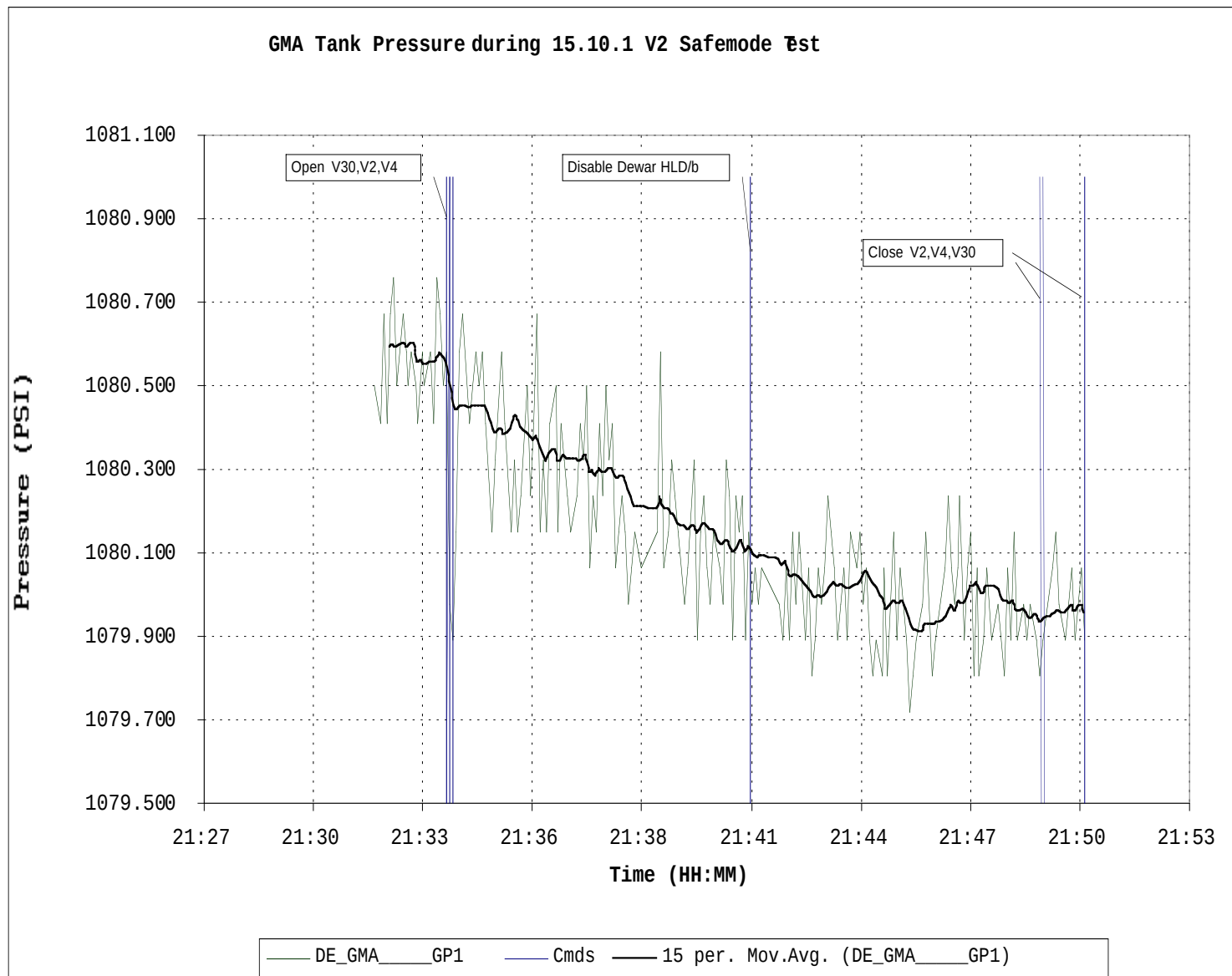


¹ Valve V1 Safemode tested through the fast gas path (725 sccm)

11/26/02 Thermal Vac Operation: GMA Flow Path (E28 Test 15.10.1)

2) GMA Valves V2 Safemode:

- a) The valve closest to the Tank (V2) can be closed independent of the state of the ECU under the following conditions:
 - i) The PDU command for the B Side ECU Operated Dewar Heater's High Level Discrete (HLD) has been enabled.
 - ii) The PDU command for the B Side GMA/VATT Valves HLD has been enabled.
- b) Assuming the previous conditions have been met, The GMA Valve V2 will close when the PDU command for the Side B ECU Operated Dewar Heater's High Level Discrete (HLD) is disabled.
- c) Methodology:
 - i) A gas path is opened from the Vent to the Tank (Valves {V30, V28, V4, V2} open)²
 - ii) GMA Tank Pressure (GP1) is monitored
 - iii) B Side Dewar HLD is disabled
 - iv) Gas path is closed via Safemode
 - v) GMA reset to launch configuration



² Valve V2 Safemode tested through the slow gas path (2 sccm)

11/26/02 Thermal Vac Operation: GMA Flow Path (E28 Test 15.10.1)

3) Gyro 1, Side B, Primary 725 sccm flow path:

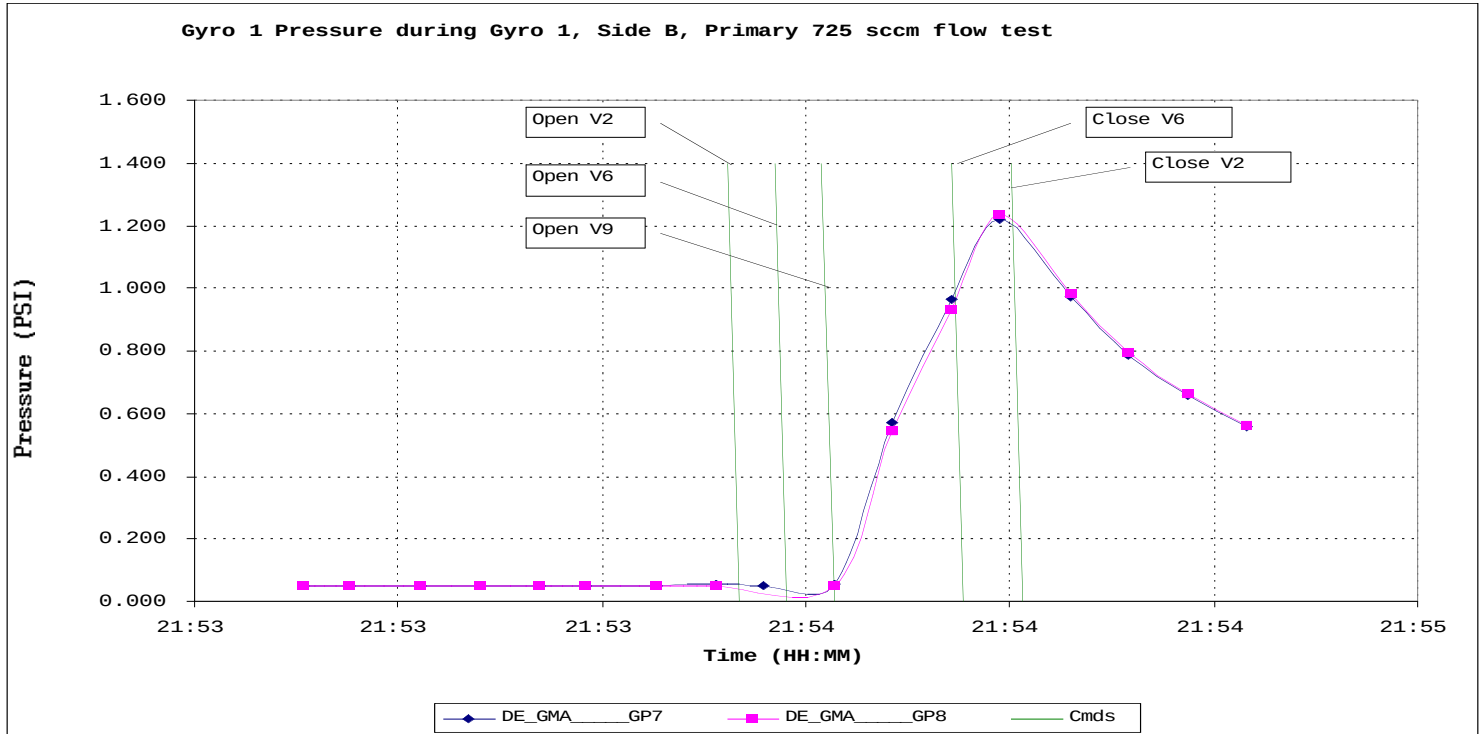
a) Gas lines evacuated through Vent Line.

b) Methodology:

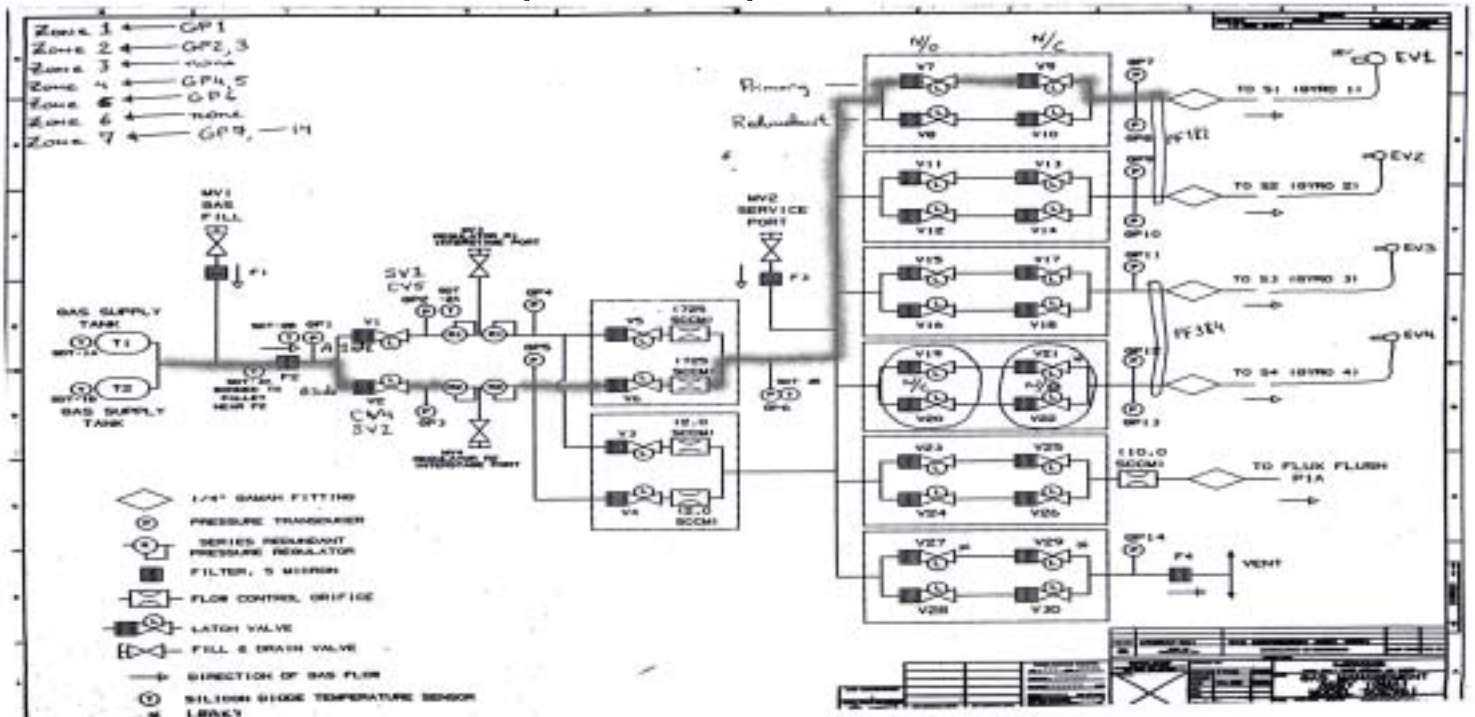
i) Gas path established from GMA Tank to Gyro 1. (Valves {V2, V6, V7, V9} open)

ii) GMA Gyro 1 Inlet Pressure Sensors (GP7 & GP8) and Vent mounted GSE Vacuum System monitored

iii) Gyro 1, Side B, Primary 725 sccm flow path is closed once pressure rise is observed



Gyro 1, Side B, Primary 725 sccm Flow Path



11/26/02 Thermal Vac Operation: GMA Flow Path (E28 Test 15.10.1)

4) Gyro 1, Side A, Primary 725 sccm flow path:

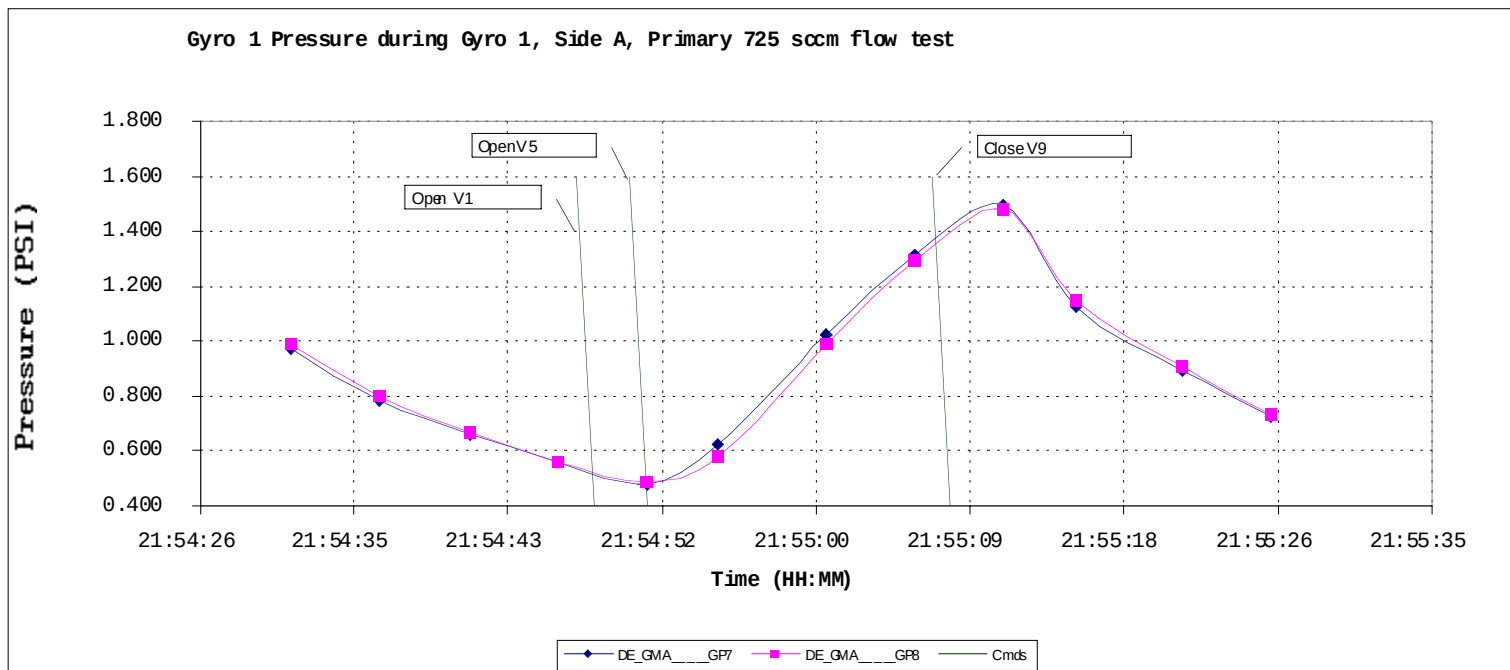
a) Gas lines evacuated through Vent Line.

b) Methodology:

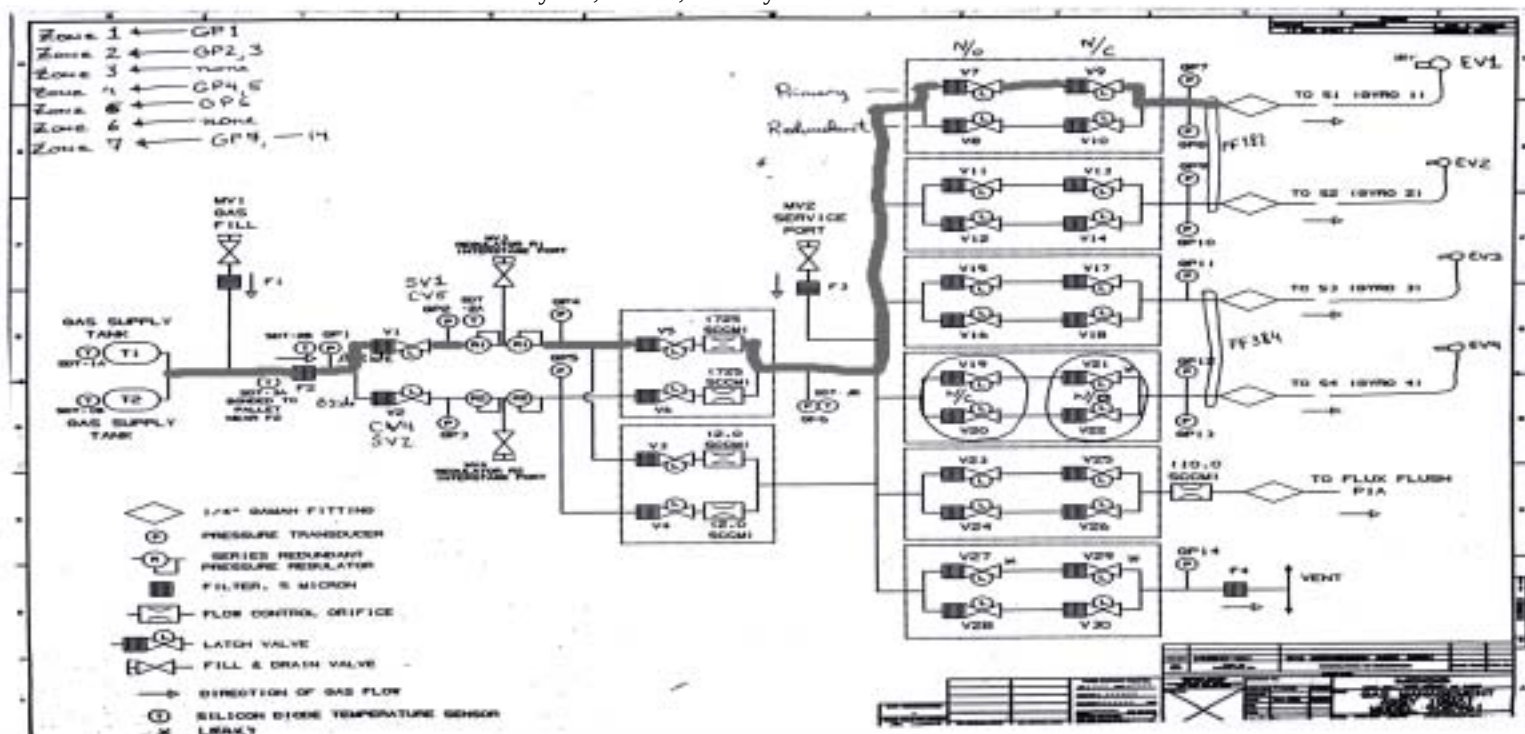
i) Gas path established from GMA Tank to Gyro 1. (Valves {V1, V5, V7, V9} open)

ii) GMA Gyro 1 Inlet Pressure Sensors (GP7 & GP8) and Vent mounted GSE Vacuum System monitored

iii) Gyro 1, Side A, Primary 725 sccm flow path is closed once pressure rise is observed

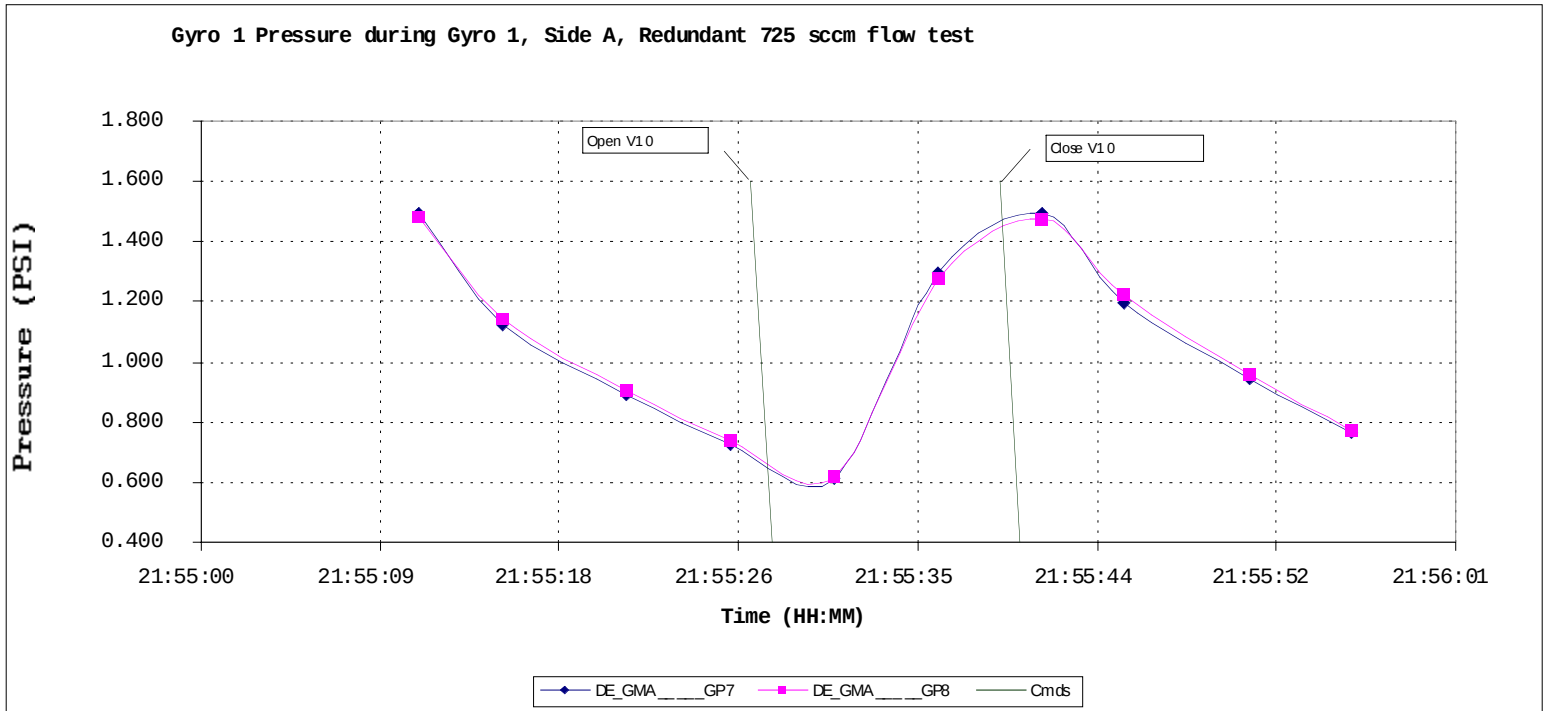


Gyro 1, Side A, Primary 725 sccm Flow Path

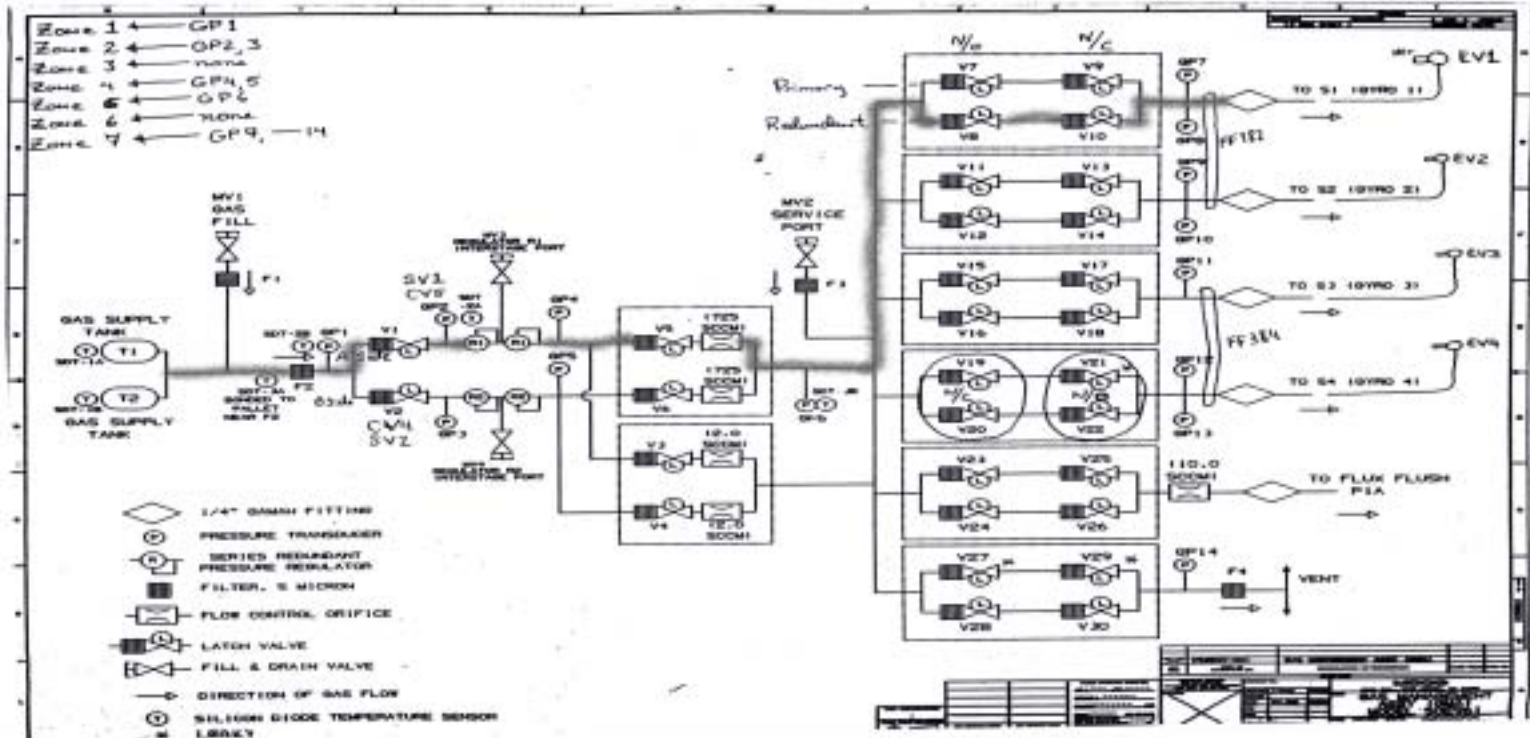


11/26/02 Thermal Vac Operation: GMA Flow Path (E28 Test 15.10.1)

- 5) Gyro 1, Side A, Redundant 725 sccm flow path:
 - a) Gas evacuated through the Vent Line.
 - b) Methodology:
 - i) Gas path established from GMA Tank to Gyro 1. (Valves {V1, V5, V8, V10} open)
 - ii) GMA Gyro 1 Inlet Pressure Sensors (GP7 & GP8) and Vent mounted GSE Vacuum System monitored
 - iii) Gyro 1, Side A, Redundant 725 sccm flow path is closed once pressure rise is observed



Gyro 1, Side A, Redundant 725 sccm Flow Path



11/26/02 Thermal Vac Operation: GMA Flow Path (E28 Test 15.10.1)

6) Gyro 2, Side A, Primary 725 sccm flow path:

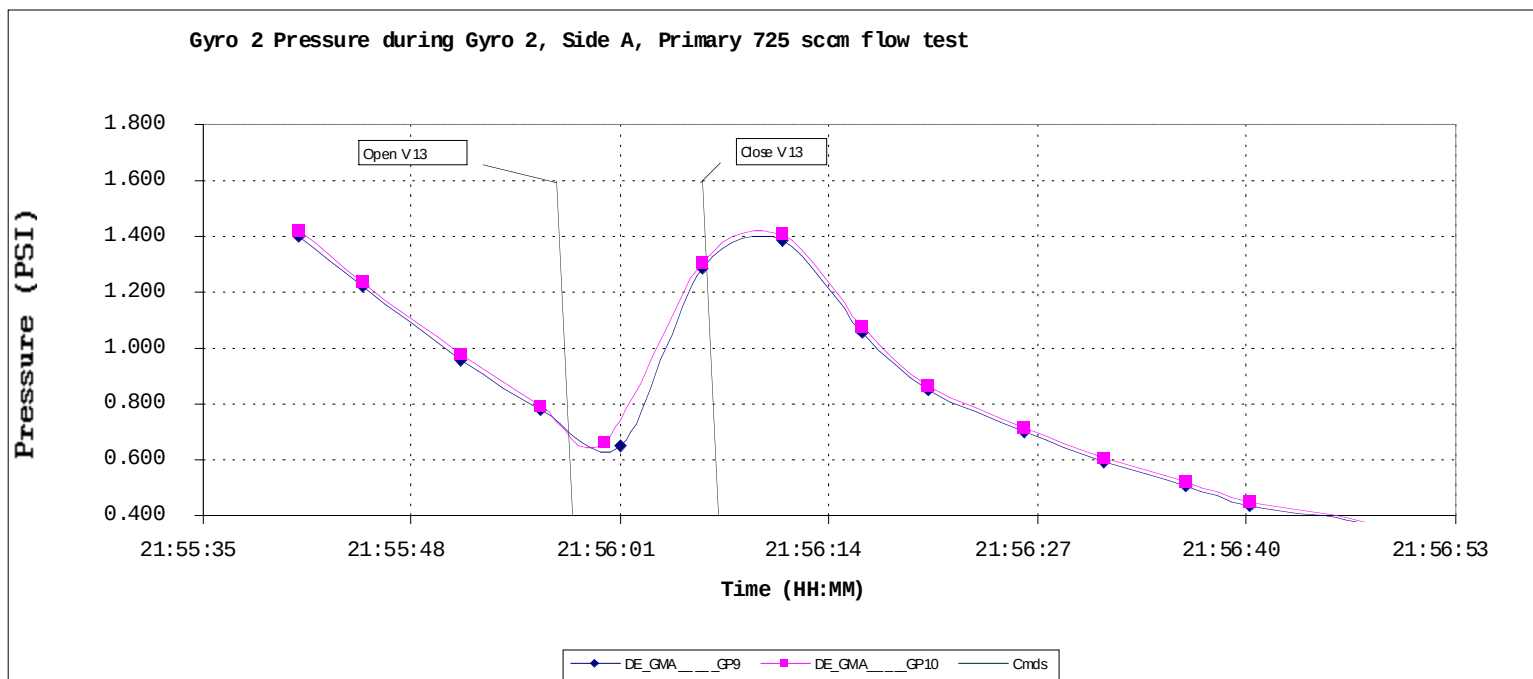
a) Gas evacuated through the Vent Line.

b) Methodology:

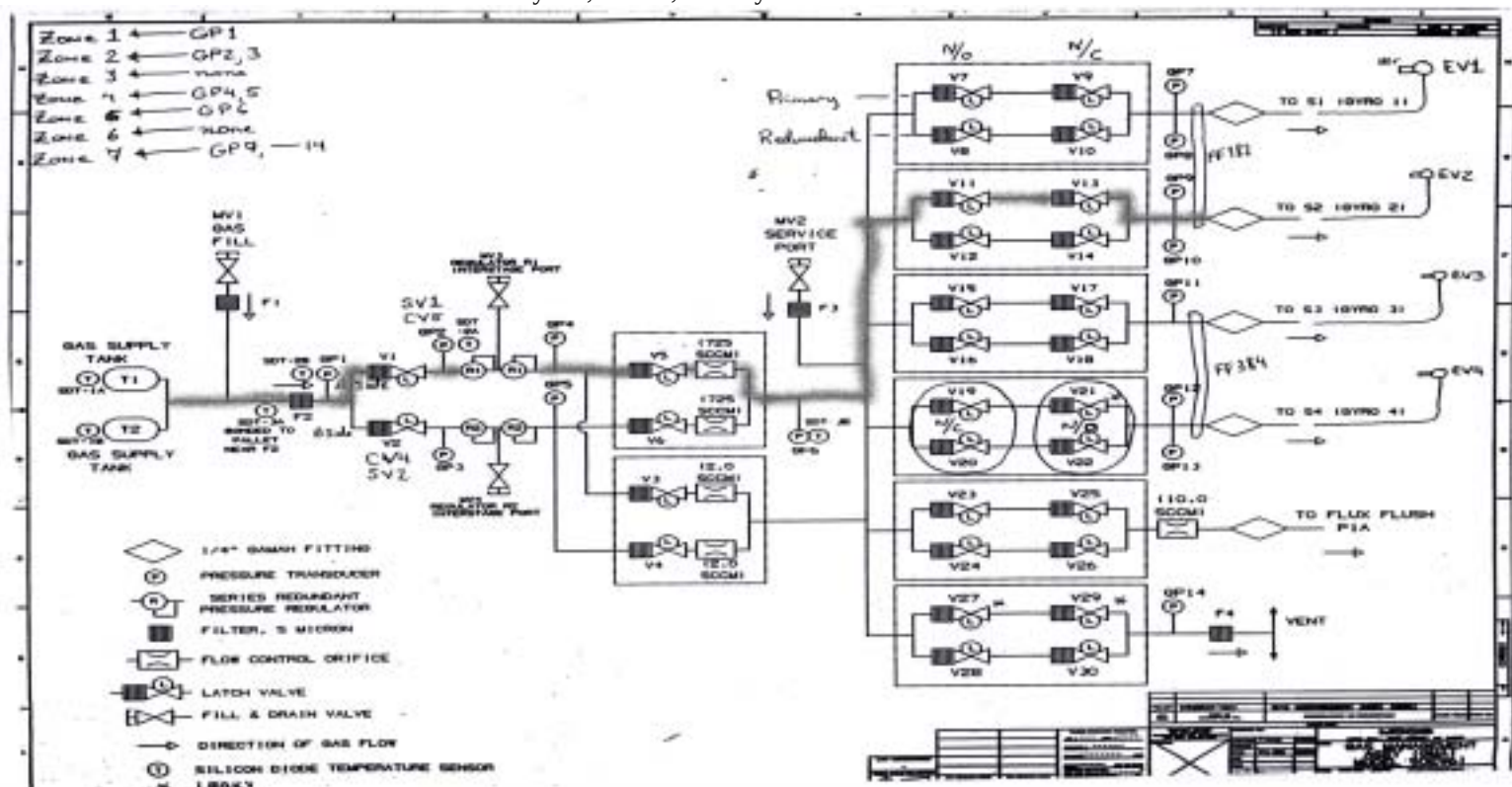
i) Gas path established from GMA Tank to Gyro 2. (Valves {V1, V5, V11, V13} open)

ii) GMA Gyro 2 Inlet Pressure Sensors (GP9 & GP10) and Vent mounted GSE Vacuum System monitored

iii) Gyro 2, Side A, Primary 725 sccm flow path is closed once pressure rise is observed



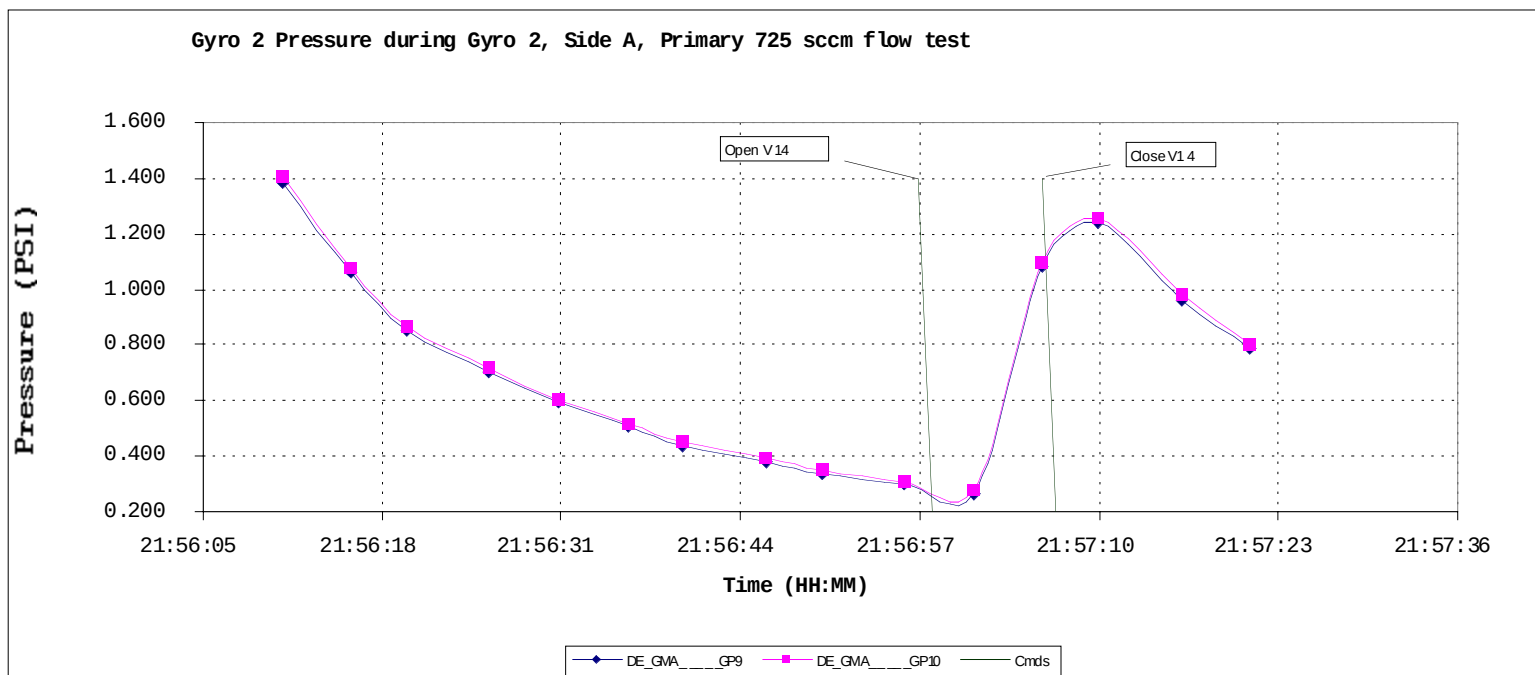
Gyro 2, Side A, Primary 725 sccm Flow Path



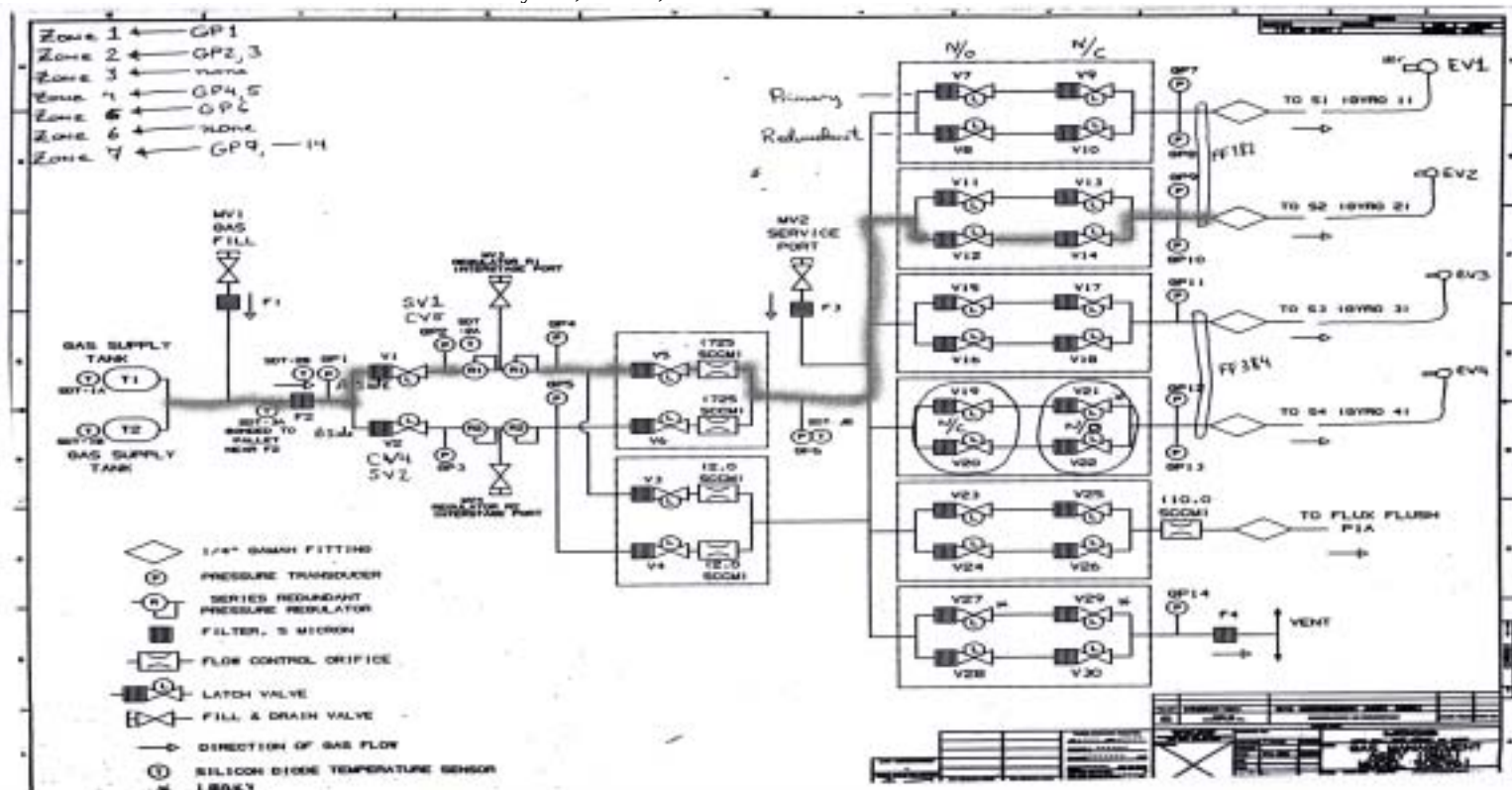
11/26/02 Thermal Vac Operation: GMA Flow Path (E28 Test 15.10.1)

7) Gyro 2, Side A, Redundant 725 sccm flow path:

- Gas evacuated through the Vent Line.
- Methodology:
 - Gas path established from GMA Tank to Gyro 2. (Valves {V1, V5, V12, V14} open)
 - GMA Gyro 2 Inlet Pressure Sensors (GP9 & GP10) and Vent mounted GSE Vacuum System monitored
 - Gyro 2, Side A, Redundant 725 sccm flow path is closed once pressure rise is observed



Gyro 2, Side B, Redundant 725 sccm Flow Path



8) Gyro 3, Side A, Primary 725 sccm flow path:

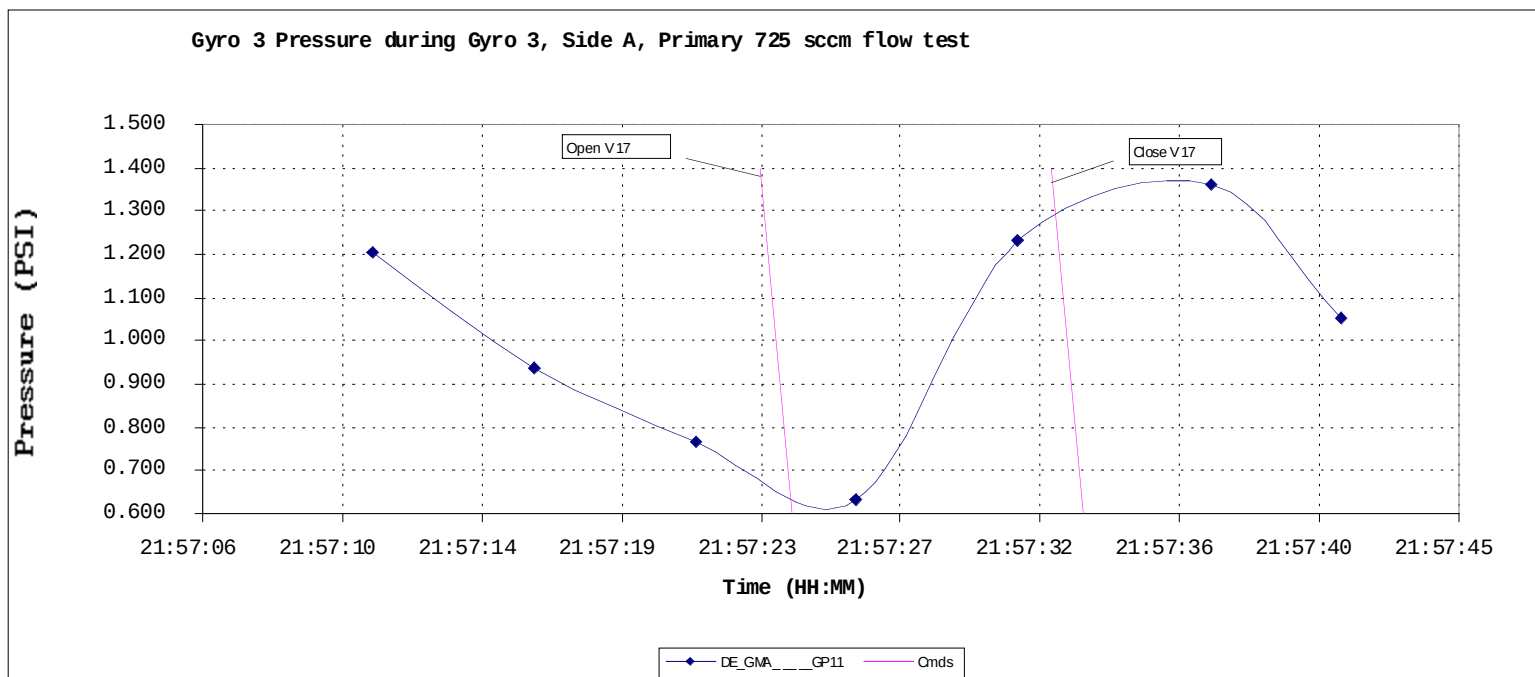
a) Gas evacuated through the Vent Line.

b) Methodology:

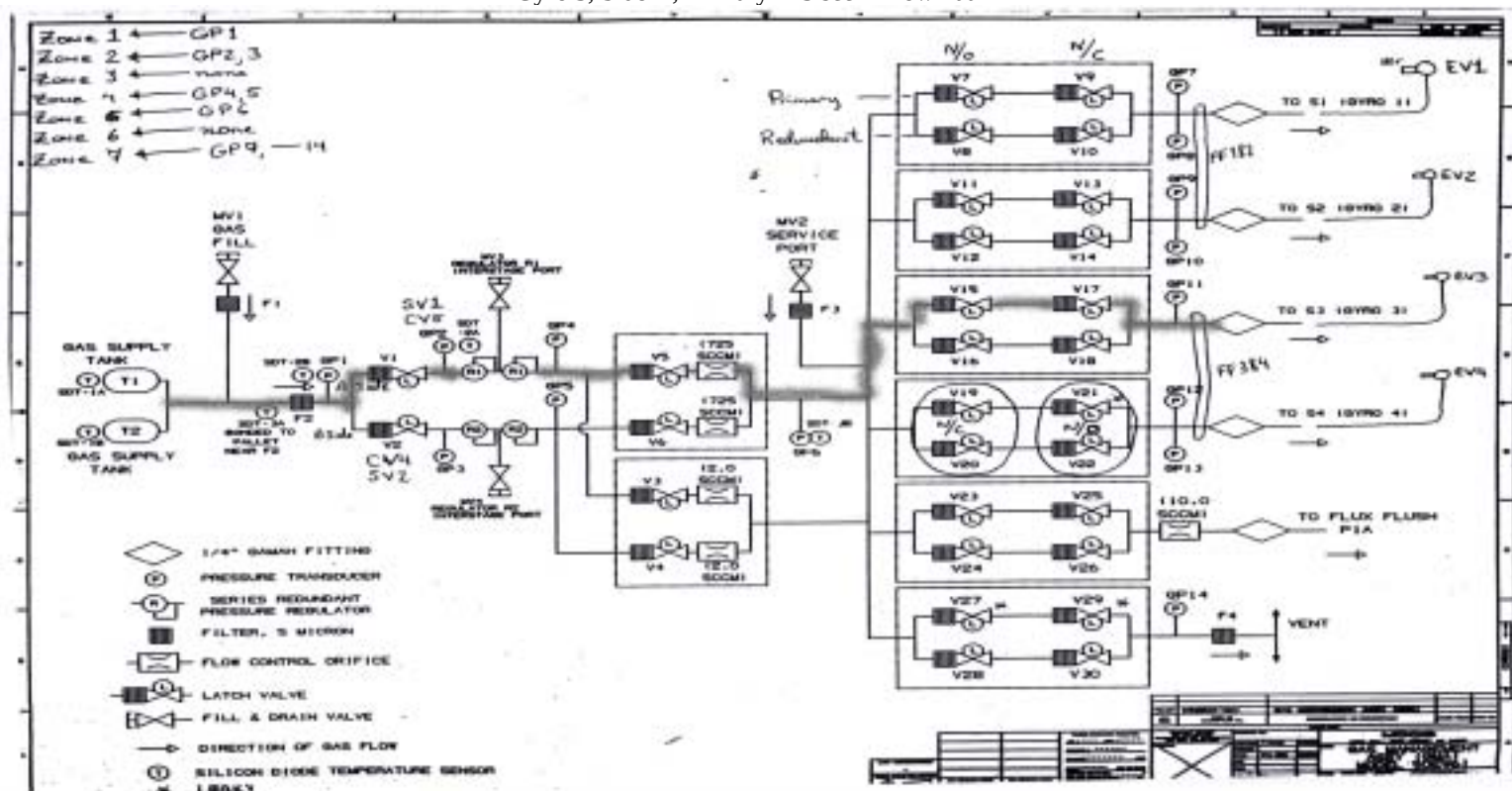
i) Gas path established from GMA Tank to Gyro 3. (Valves {V1, V5, V15, V17} open)

ii) GMA Gyro 3 Inlet Pressure Sensor (GP11) and Vent mounted GSE Vacuum System monitored

iii) Gyro 3, Side A, Primary 725 sccm flow path is closed once pressure rise is observed

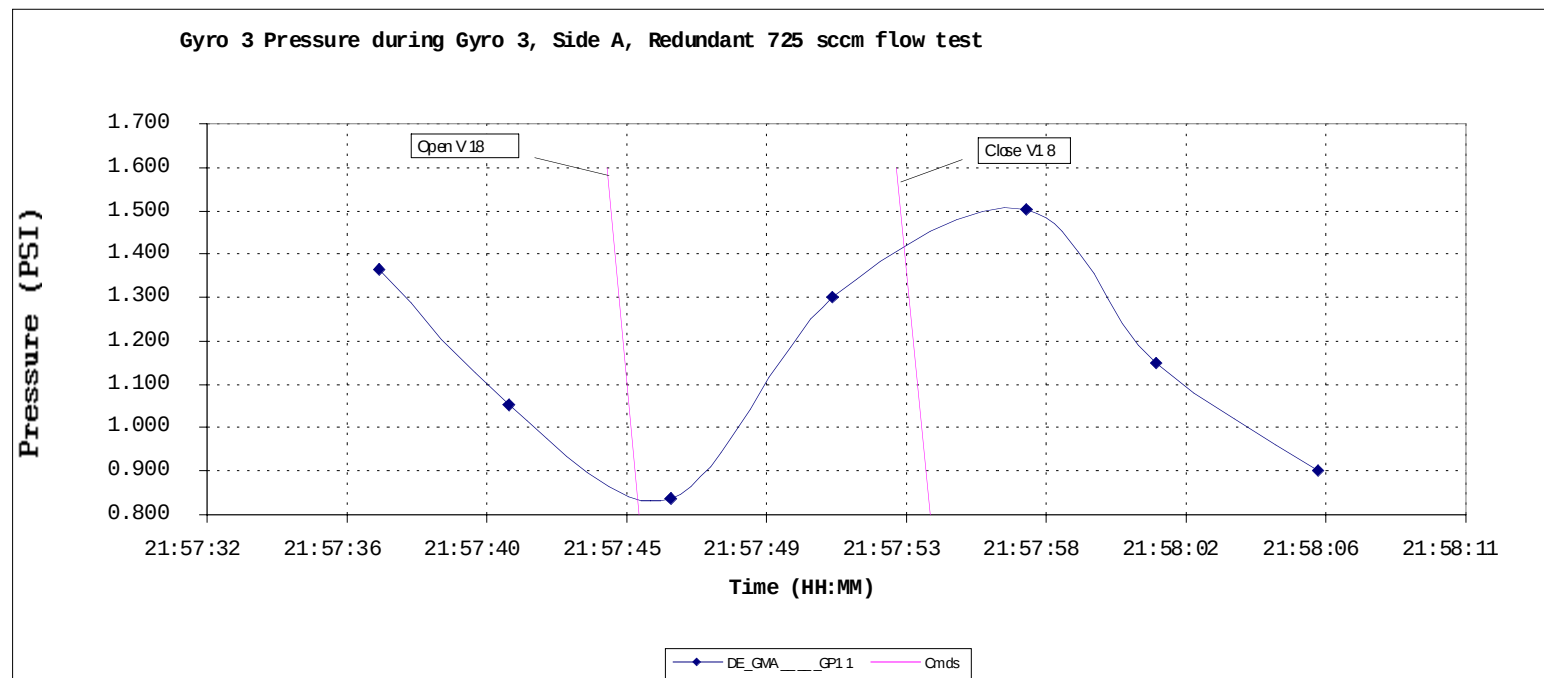


Gyro 3, Side A, Primary 725 sccm Flow Path

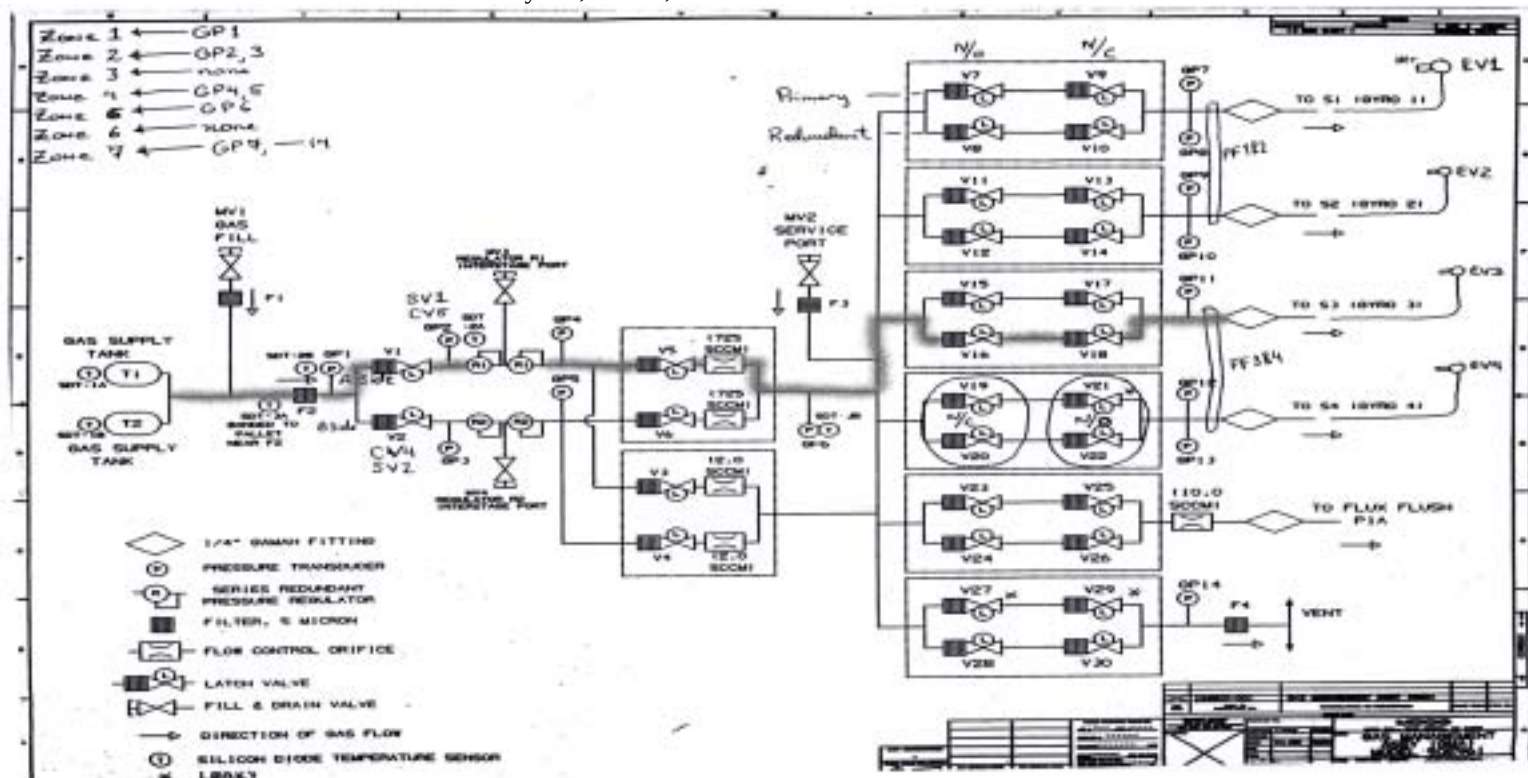


11/26/02 Thermal Vac Operation: GMA Flow Path (E28 Test 15.10.1)

- 9) Gyro 3, Side A, Redundant 725 sccm flow path:
 - a) Gas evacuated through the Vent Line.
 - b) Methodology:
 - i) Gas path established from GMA Tank to Gyro 3. (Valves {V1, V5, V16, V18} open)
 - ii) GMA Gyro 3 Inlet Pressure Sensor (GP11) and Vent mounted GSE Vacuum System monitored
 - iii) Gyro 3, Side A, Redundant 725 sccm flow path is closed once pressure rise is observed



Gyro 3, Side A, Redundant 725 sccm Flow Path



11/26/02 Thermal Vac Operation: GMA Flow Path (E28 Test 15.10.1)

10) Gyro 4, Side A, Primary 725 sccm flow path:

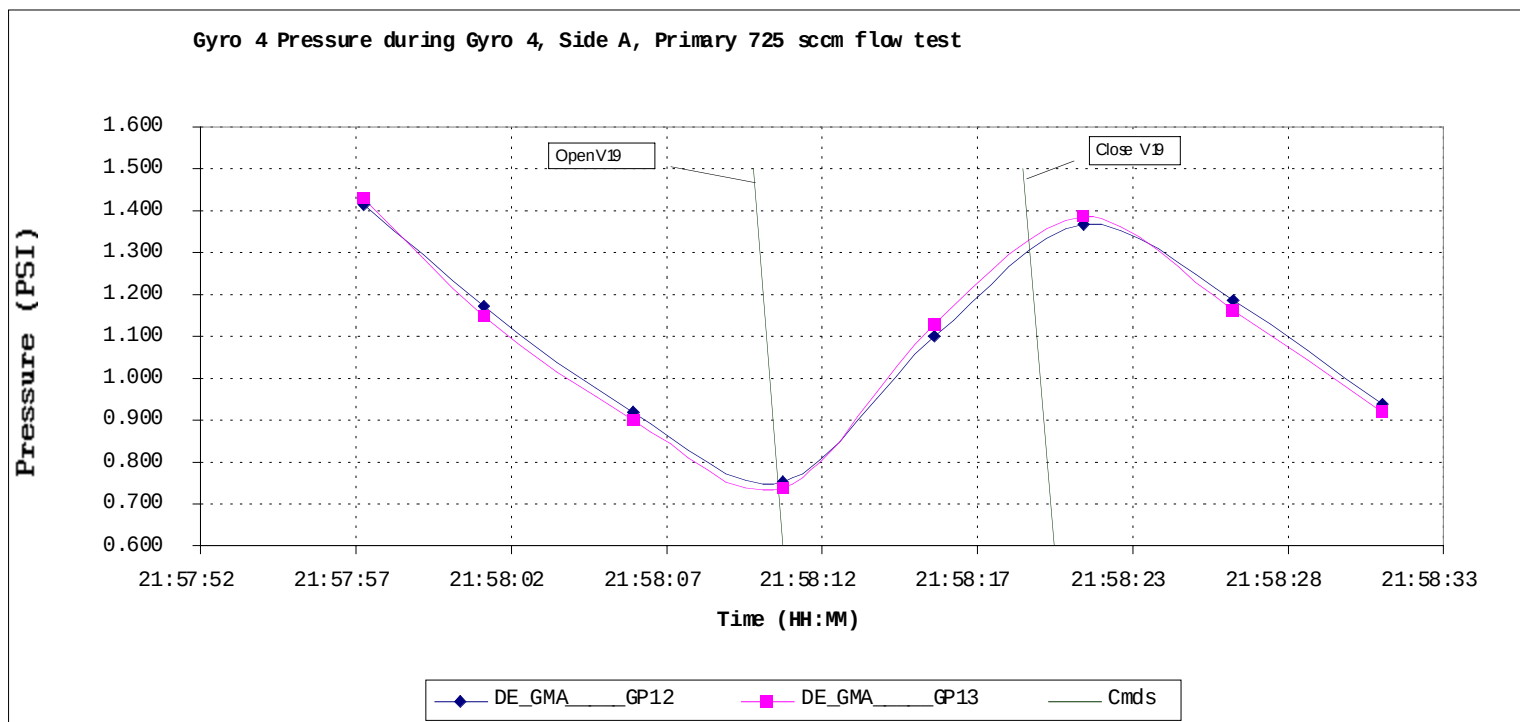
a) Gas evacuated through the Vent Line.

b) Methodology:

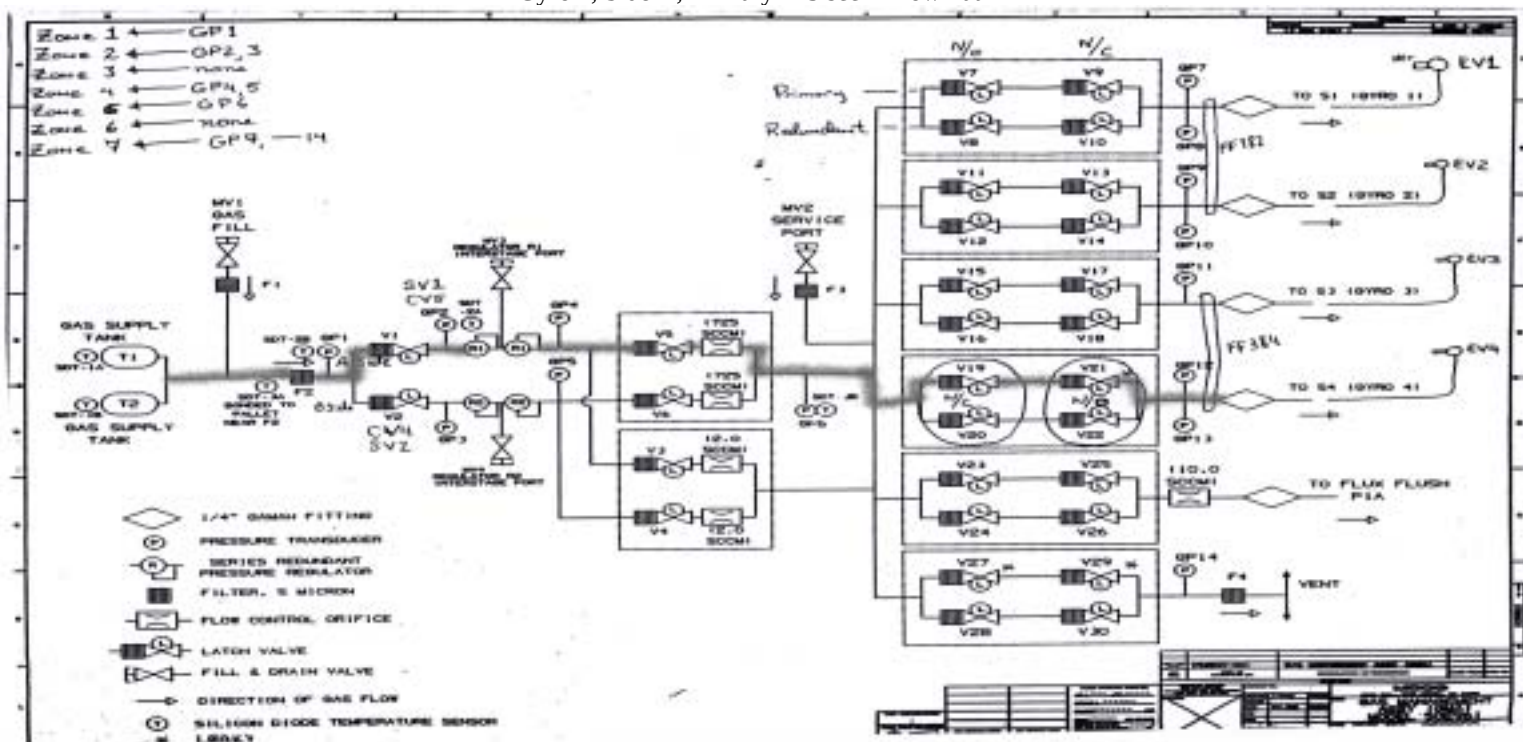
i) Gas path established from GMA Tank to Gyro 4. (Valves {V1, V5, V19, V21} open)

ii) GMA Gyro 4 Inlet Pressure Sensors (GP12 & GP13) and Vent mounted GSE Vacuum System monitored

iii) Gyro 4, Side A, Primary 725 sccm flow path is closed once pressure rise is observed

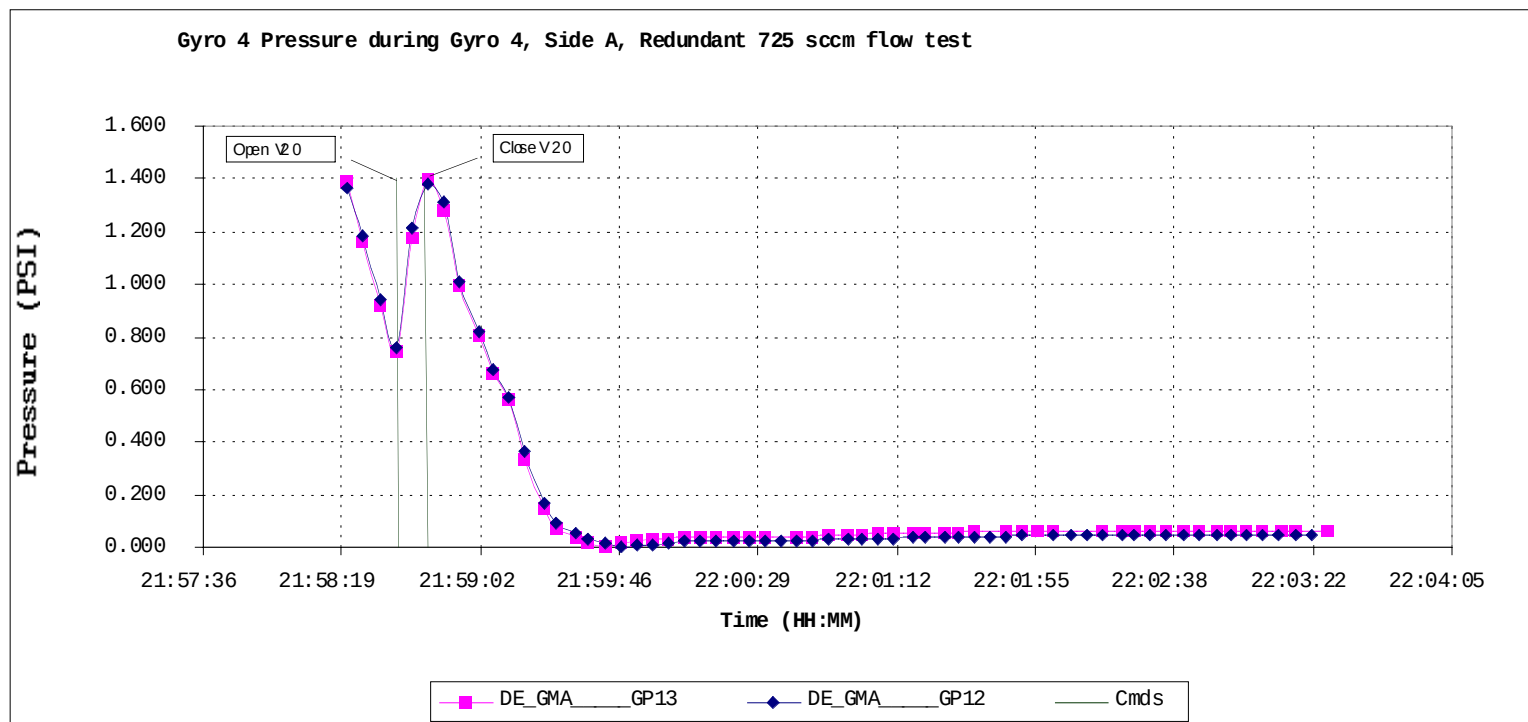


Gyro 4, Side A, Primary 725 sccm Flow Path

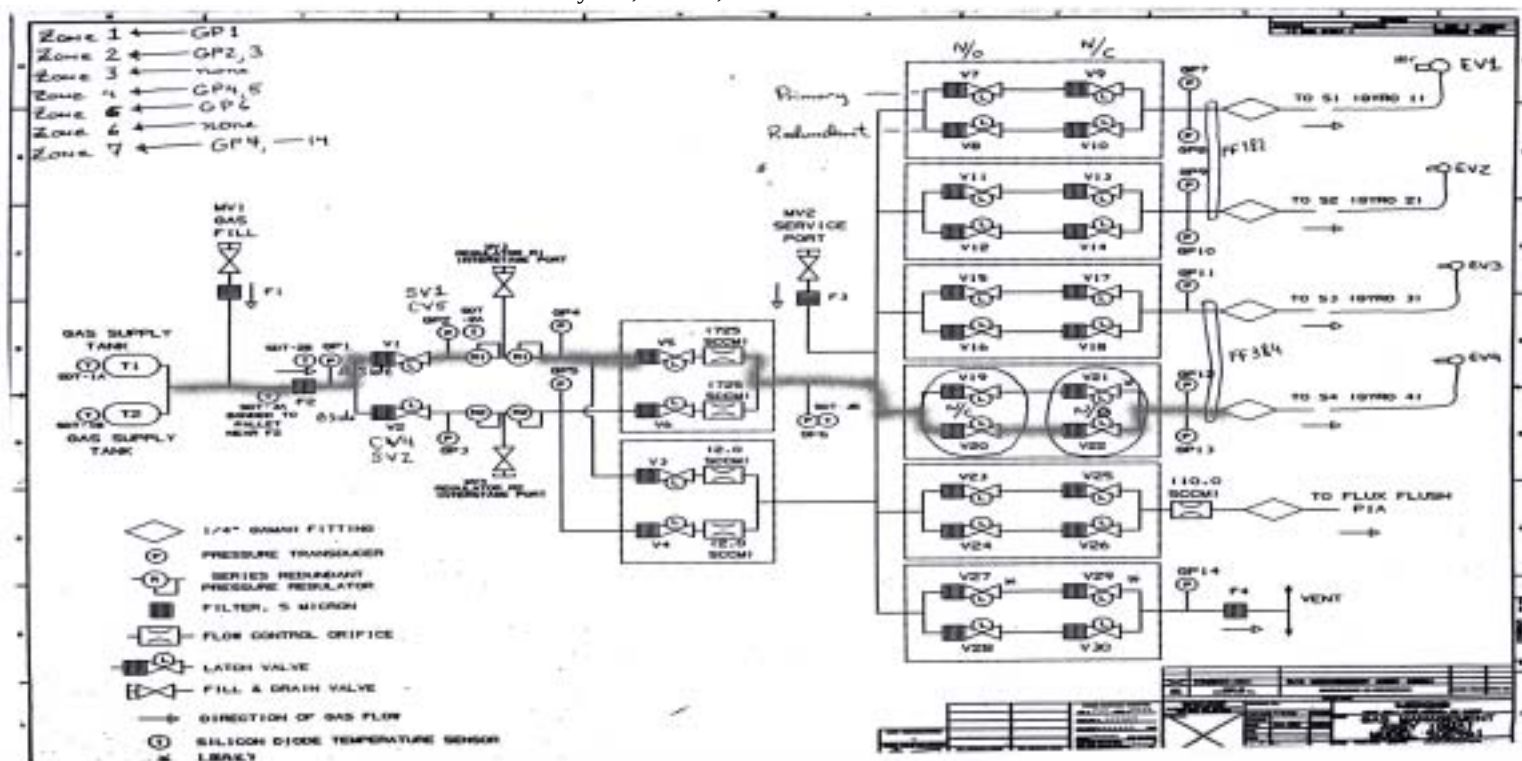


11) Gyro 4, Side A, Redundant flow path:

- a) Gas evacuated through the Vent Line.
- b) Methodology:
 - i) Gas path established from GMA Tank to Gyro 4. (Valves {V1, V5, V20, V22} open)
 - ii) GMA Gyro 4 Inlet Pressure Sensors (GP12 & GP13) and Vent mounted GSE Vacuum System monitored
 - iii) Gyro 4, Side A, Redundant 725 sccm flow path is closed once pressure rise is observed



Gyro 4, Side A, Redundant Flow Path



12) Vent, Side A, Primary flow path:

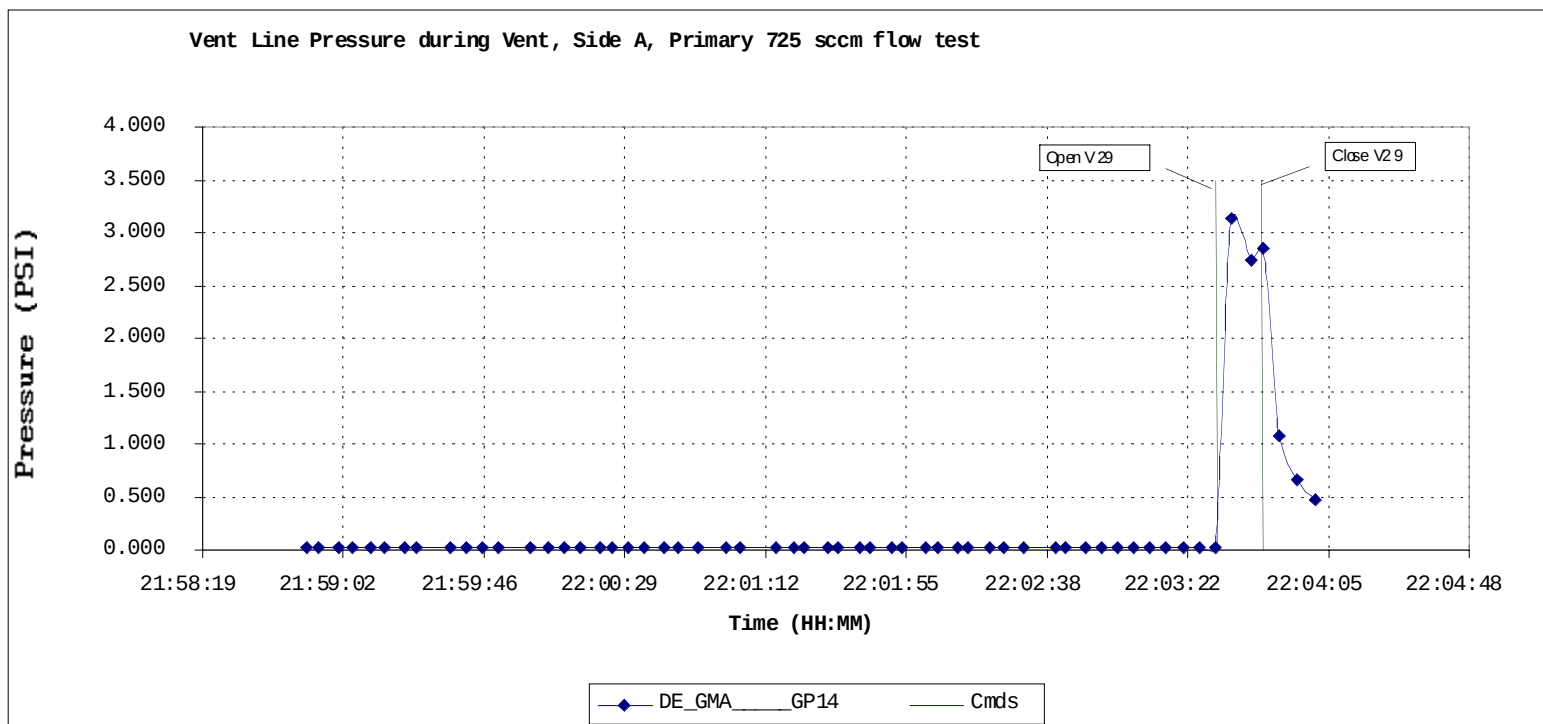
a) Gas evacuated through the Vent Line.

b) Methodology:

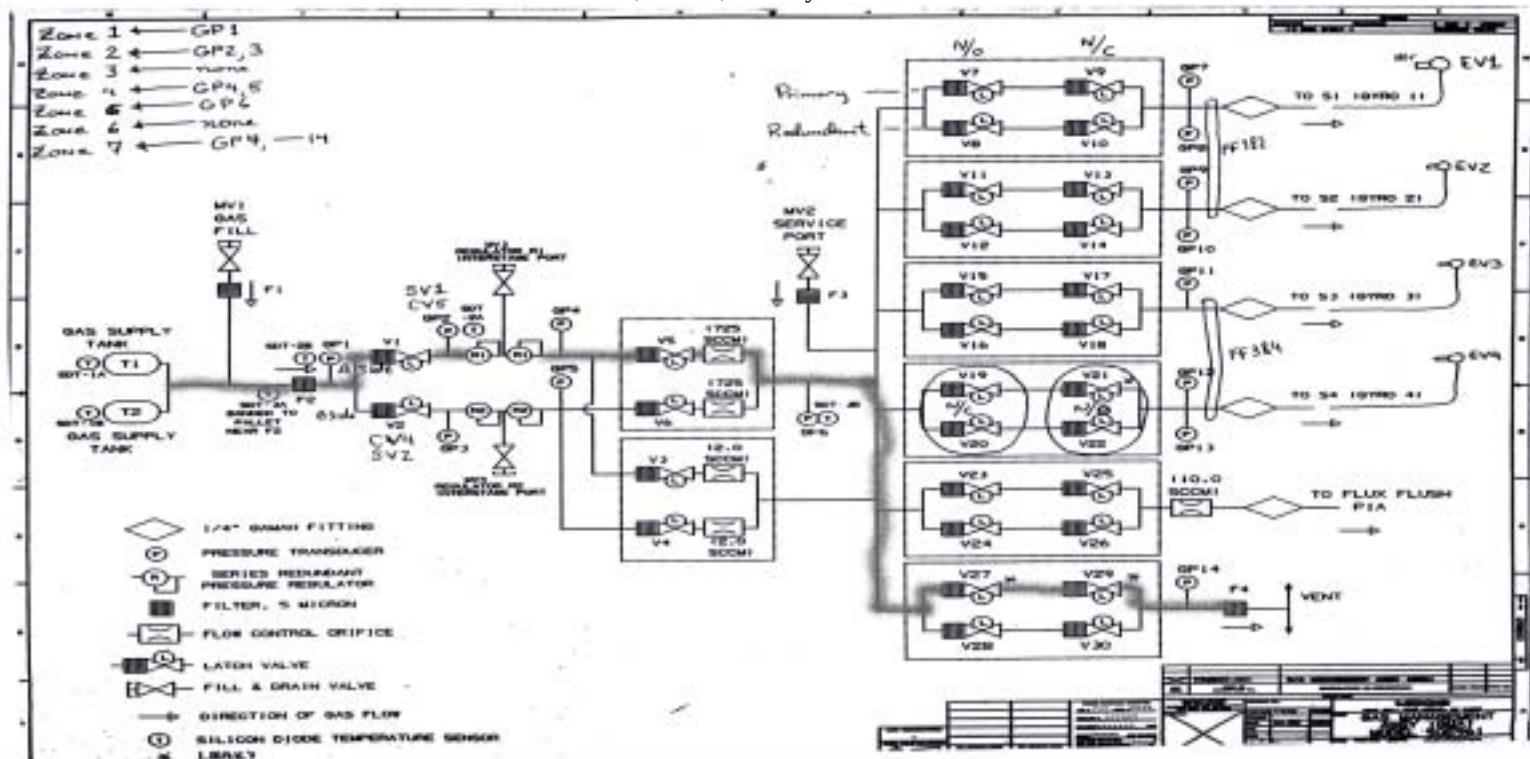
i) Gas path established from GMA Tank to Vent Line. (Valves {V1, V5, V27, V29} open)

ii) GMA Vent Inlet Pressure Sensor (GP14) and Vent mounted GSE Vacuum System monitored

iii) Vent, Side A, Primary 725 sccm flow path is closed once pressure rise is observed

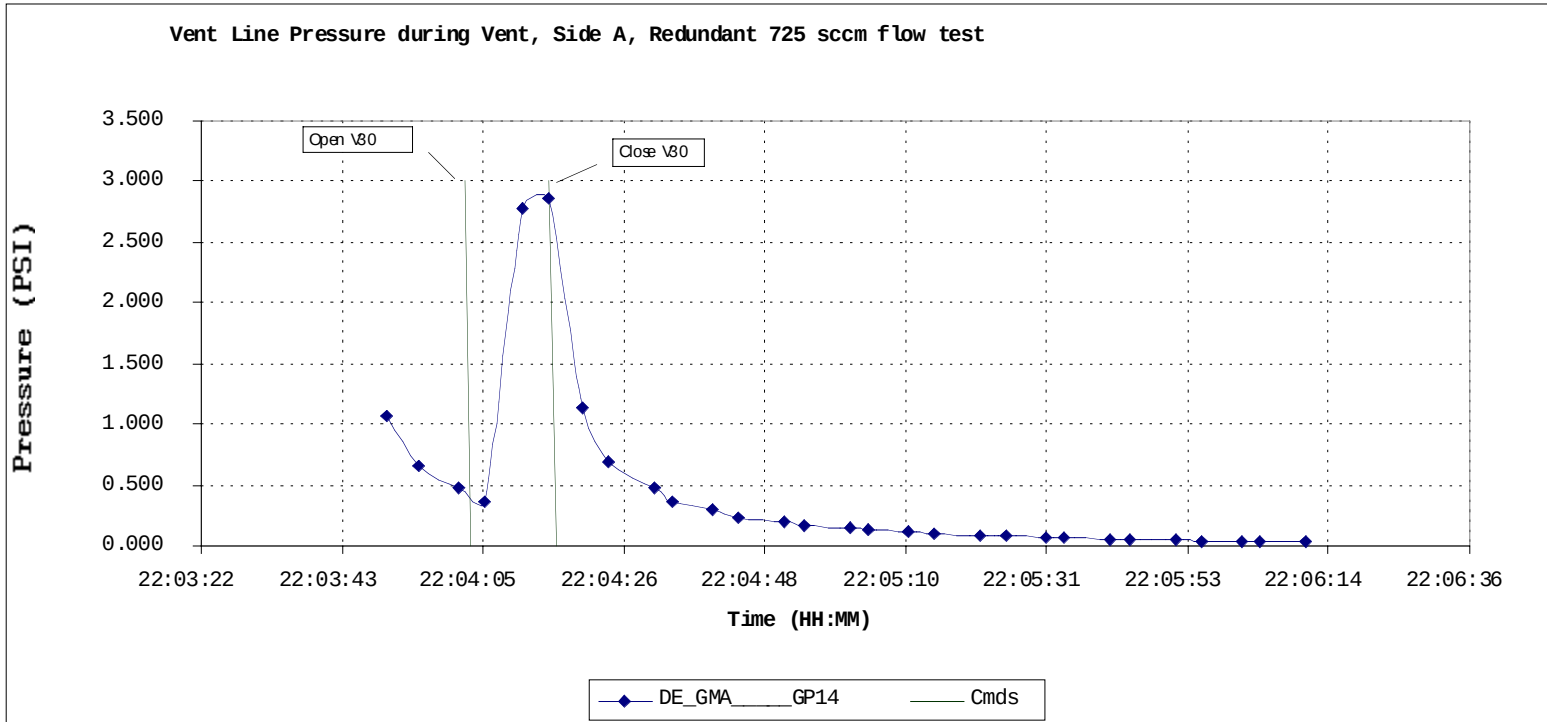


Vent, Side A, Primary Flow Path

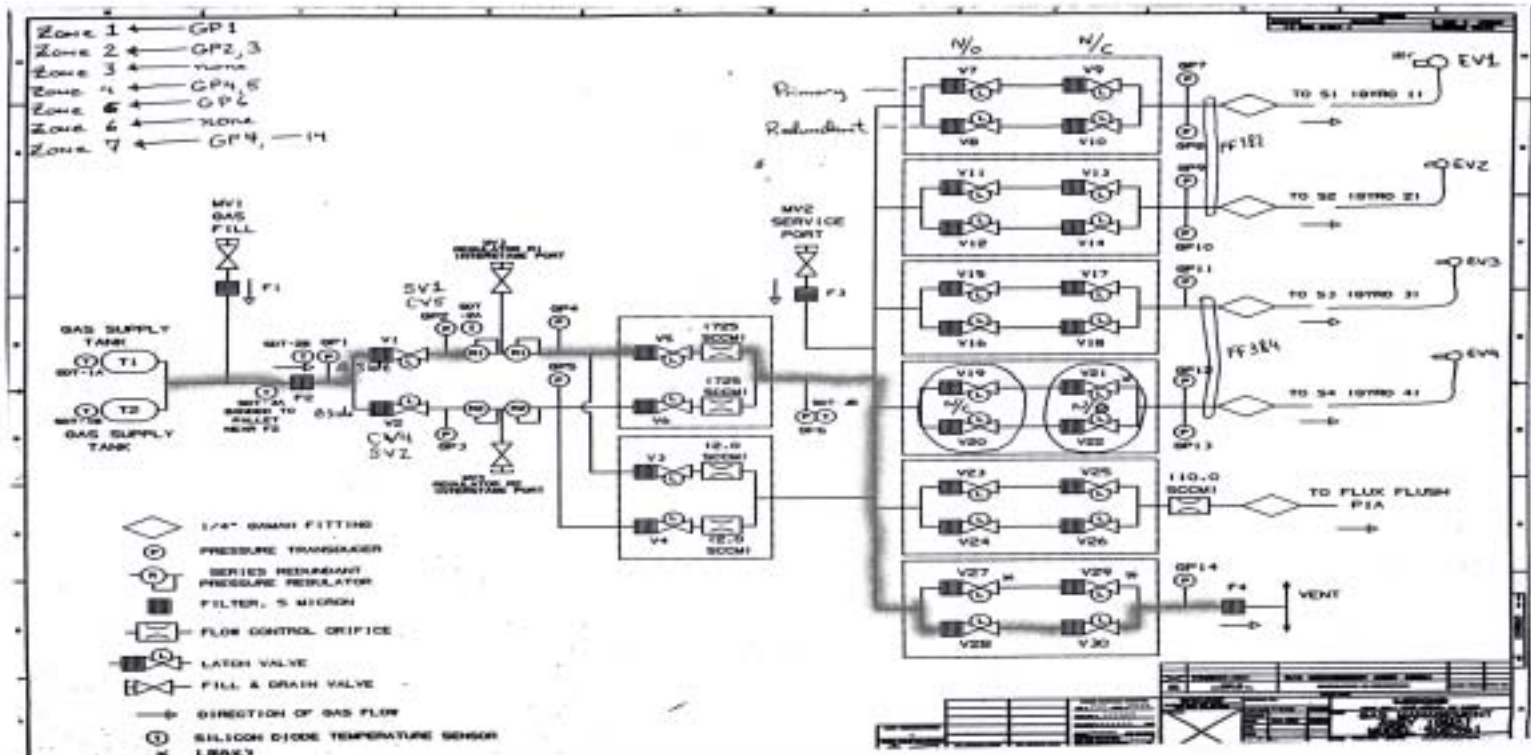


13) Vent, Side A, Redundant flow path:

- a) Gas evacuated through the Vent Line.
- b) Methodology:
 - i) Gas path established from GMA Tank to Vent Line. (Valves {V1, V5, V28, V30} open)
 - ii) GMA Vent Inlet Pressure Sensor (GP14) and Vent mounted GSE Vacuum System monitored
 - iii) Vent, Side A, Redundant 725 sccm flow path is closed once pressure rise is observed

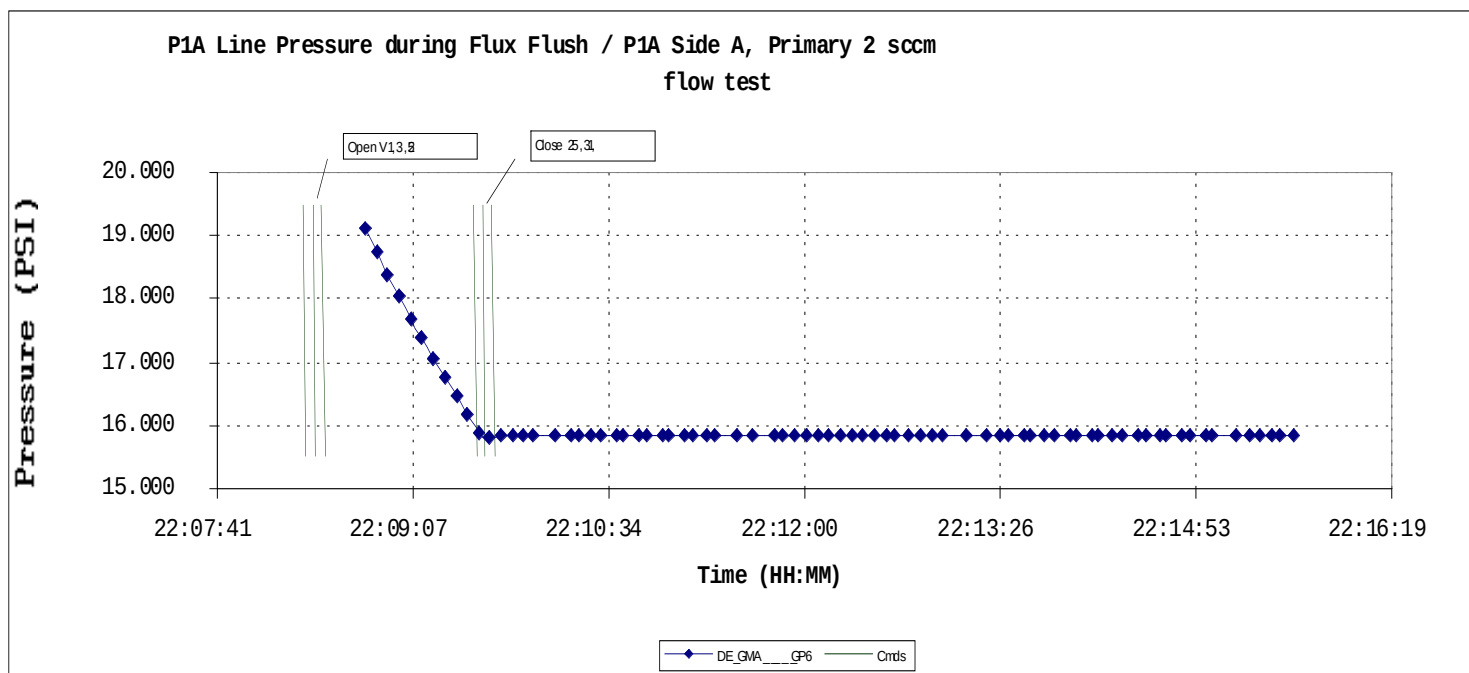


Vent, Side A, Redundant Flow Path

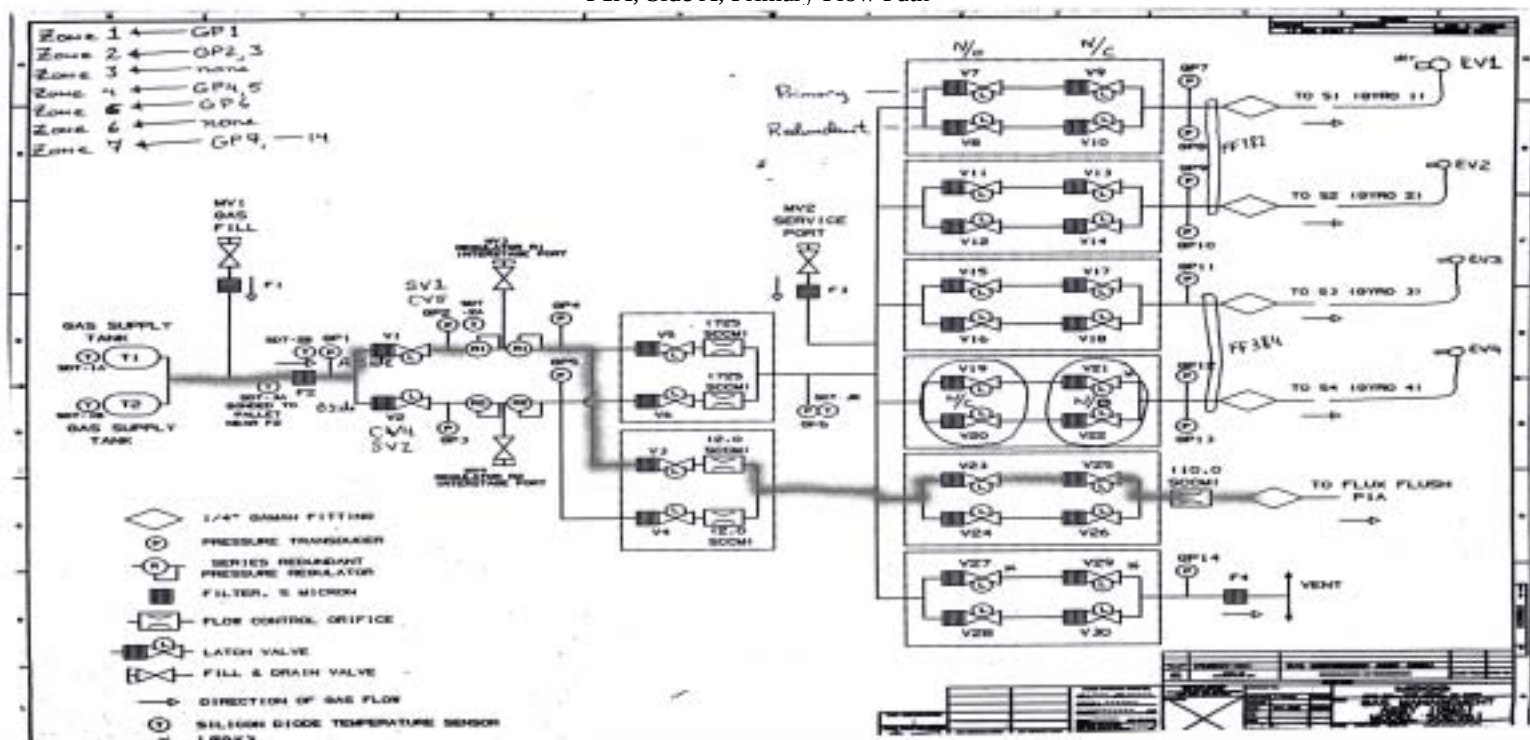


14) P1A, Side A, Primary flow path:

- Gas evacuated through the P1A Line.
- No Pressure sensor at P1A outlet, monitor GP6 in Zone 5
- GP6 maximum calibrated Pressure = 19.125 PSI
- Methodology:
 - Gas path established from GMA Tank to P1A Line. (Valves {V1, V5, V23, V25} open)
 - GMA Post Regulator Orifice (GP6) and Vent mounted GSE Vacuum System monitored
 - P1A, Side A, Primary 2 sccm flow path is closed once pressure rise is observed



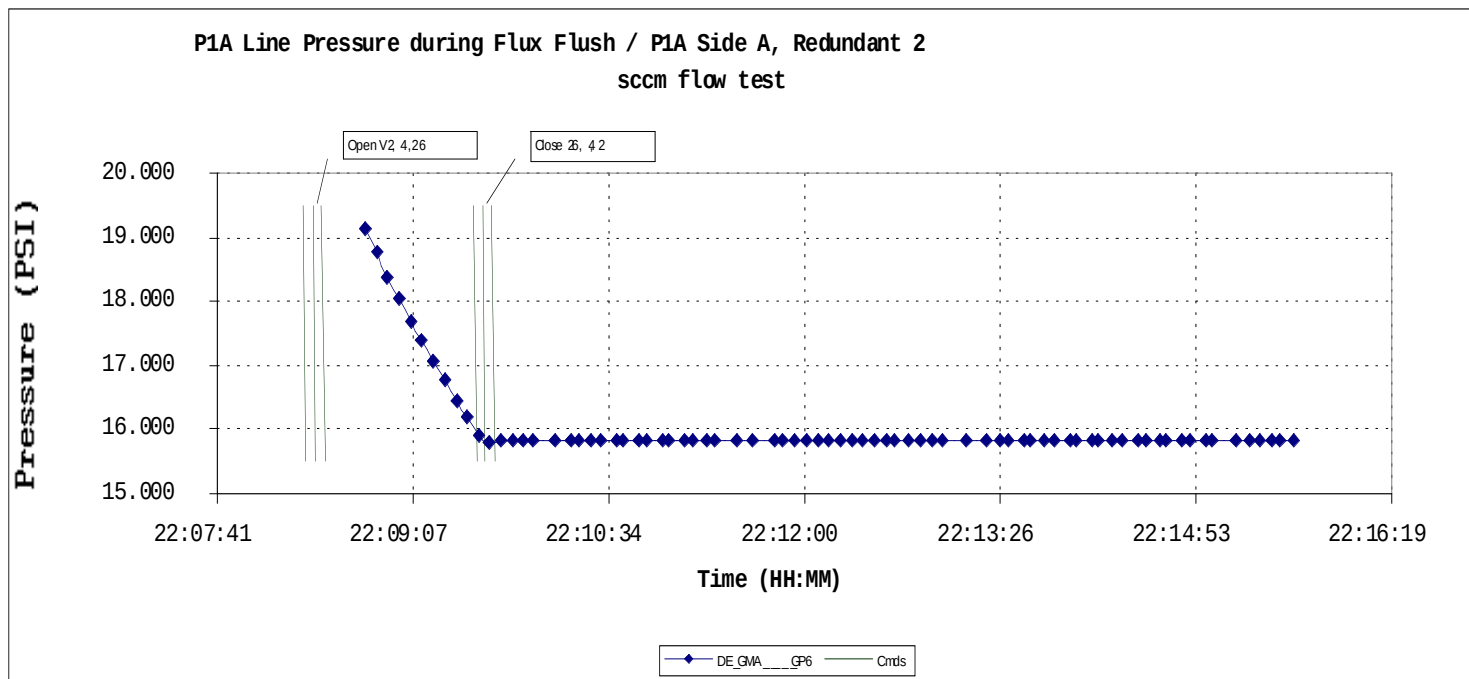
P1A, Side A, Primary Flow Path



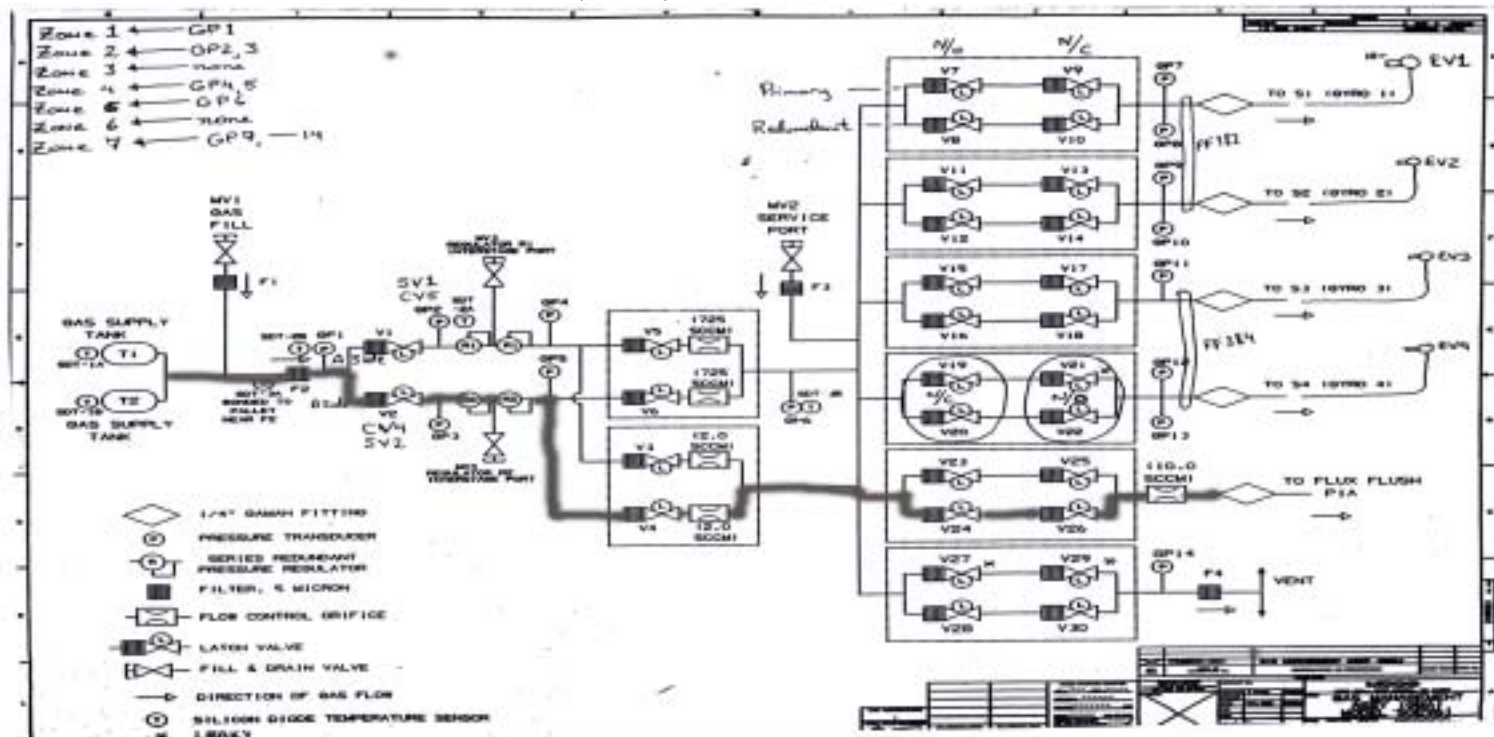
11/26/02 Thermal Vac Operation: GMA Flow Path (E28 Test 15.10.1)

15) P1A, Side B, Redundant 2 sccm flow path:

- Gas evacuated through the P1A.
- No Pressure sensor at P1A outlet, monitor GP6 in Zone 5
- GP6 maximum calibrated Pressure = 19.125 PSI
- Methodology:
 - Gas path established from GMA Tank to P1A Line. (Valves {V1, V5, V24, V26} open)
 - GMA Post Regulator Orifice (GP6) and Vent mounted GSE Vacuum System monitored
- P1A, Side B, Redundant 2 sccm flow path is closed once pressure rise is observed



P1A, Side B, Redundant 2 sccm Flow Path



D.5 E-28 GMA Test 15.10

- Moog FAR
- Leak rate spreadsheet
- Spare valve data
- Fault analysis spreadsheet

Overview

The flight Gas Management Assembly was tested along with the Science Probe as part of S/V test E28, using test 15.10. The requirement for this test was to “Verify [helium] gas flows from GMA to payload at each probe inlet (S1, S2, S3, S4, and P1A)” (LMMS/P479939E, IT01-3B). This requirement was met by connecting vacuum GSE to a Vatterfly valve (LV2) and flowing gas from the GMA through the probe itself. Before the “top hat” valves were opened, a full GMA functional was performed (15.10.1). This test included dewar HLD tests, high volume (725 sccm) flows through the GMA gyroscope and vent outlets directly to GSE, low flow tests (2 sccm) to GSE, and low flow tests through the GMA P1A outlet. After this test was successful, the “top hat” valves were opened to allow helium to flow into the probe. Low helium flows were initiated into the probe through each gyroscope until a pressure rise was detected on the GSE pumping system connected to the Vatterfly Valve. This indicated that all internal probe plumbing was connected and free from obstruction.

Success criteria

The success criteria are that the pressure indicated by relevant pressure gauges reads in its nominal range for the given flow, as set out in the test procedure. Secondly, the flow of gas must stop (as indicated by the relevant pressure sensor going to its “zero flow baseline”) when the dewar HLD is disabled. As is indicated by the following charts, the flows from the GMA can be tracked easily with the pressures. GMA valves V1 and V2 successfully closed, stopping the flow of helium from the GMA when the dewar HLD was disabled.

Description of diagrams:

Note: the heading numbers (e.g. M.37) are off by one between P0921 Rev A and PSvgmaflow.prc Version 1.7 dated 20 December, 2002. The heading numbers in the diagrams follow the numbers from P0921 Rev A.

- Diagrams 1, 2, and 3 are overviews. They show the entire 15.10 test. Diagram 1 contains GP1, GP2, and GP3. These correspond to GMA zones I, IIA, and IIB. Diagram 2 contains GP4, GP5 and GP6, which correspond to GMA zones IVA, VIB, and V.
- Diagram 3 contains GP7 through GP14. These are the pressure transducers at the GMA outlets (S1, S2, S3, S4, and Vent) and correspond to zone VII. There is no GMA transducer on the P1A line. This flow will be measured in flight by the P-9 gauge.
- Diagrams 4, 5, and 6 show the GMA pressures during the dewar HLD tests. In each case, the pressure at the correct sensor (as called out in P0921A) can be seen to rise with the flow and then fall when the HLD is disabled.
- Diagram 7 shows the GMA supply pressure during the 15.10.1 flow tests. Note that there is a small offset between the sensors. This notwithstanding, the pressure in zone II can be seen to rise when the supply valve (V1 or V2) is opened, match the tank pressure during the gas flow, and then fall as the evacuated portion of the GMA is filled from this volume.
- Diagrams 8 and 9 show the GMA low pressure manifold (zones IV and V). The pressure is maintained by the pressure regulators until flow from the GMA starts.

Then the pressure in zone V, and to a lesser extent zone IV, noticeably drops when a 725 sccm flow is initiated (Diagram 8). The pressure recovers again once the GMA outlet valves are closed. Diagram 9 indicates a drop in pressure in zones IV and V due to a low flow through the GMA P1A outlet.

- Diagram 10 shows a rise in pressure for the 725 sccm flow through each gyroscope outlet and the vent. Diagram 11 simply shows the outlets being pumped out in preparation for the probe flows. Because there is no GMA pressure transducer at the P1A outlet, there are no data for that flow here.
- Diagram 12 shows the passage of time between the end of 15.10.1 and the rest of the test. During this time, much work went on with GSE that did not directly involve the GMA. This diagram is included only to maintain temporal continuity between graphs.
- Diagram 13 shows the zone I and II supply pressure during the 2 sccm flows through the probe. The dip at the end shows the running of the procedure “GMA Sleep” which fills the GMA to a known pressure and leaves it in a safe state.
- Diagram 14 shows the low pressure manifold pressure (zones IV and V) during the 2 sccm flows into the probe. The pressure in zones IVA and IVB do not drop much due to the low flow rate. The spikes on GP6 correspond to the pressure rising between flows. The actual flow time corresponds to the top of a spike to the rising edge of the next spike. Again the “GMA Sleep” procedure can be seen near time 23:02.
- Diagram 15 graphically indicates the flows from the GMA outlets. Each spike represents a flow out of the GMA. At the end, every sensor goes out of range (rails) as the outlets are filled to about 20 psia during the procedure “GMA Sleep.”
- Diagram 16 is included to show the temperature stability of the GMA during the 15.10 tests. The temperature measurements come from the silicon diode mounted on the GMA pallet. The vent pressure for the whole test is included on this graph to make it more interesting.

Conclusion

The data shows that all success criteria for this test were met. The flows (as inferred by pressure) were all in the nominal range and all of the GMA components (sensor, latch valves, and flow orifices) functioned well. The pressure rise in the probe also indicates that there was no blockage of the spin-up and exhaust lines.

Diagram 1

GP1, GP2, GP3 (zones I, IIA, IIB);
E28

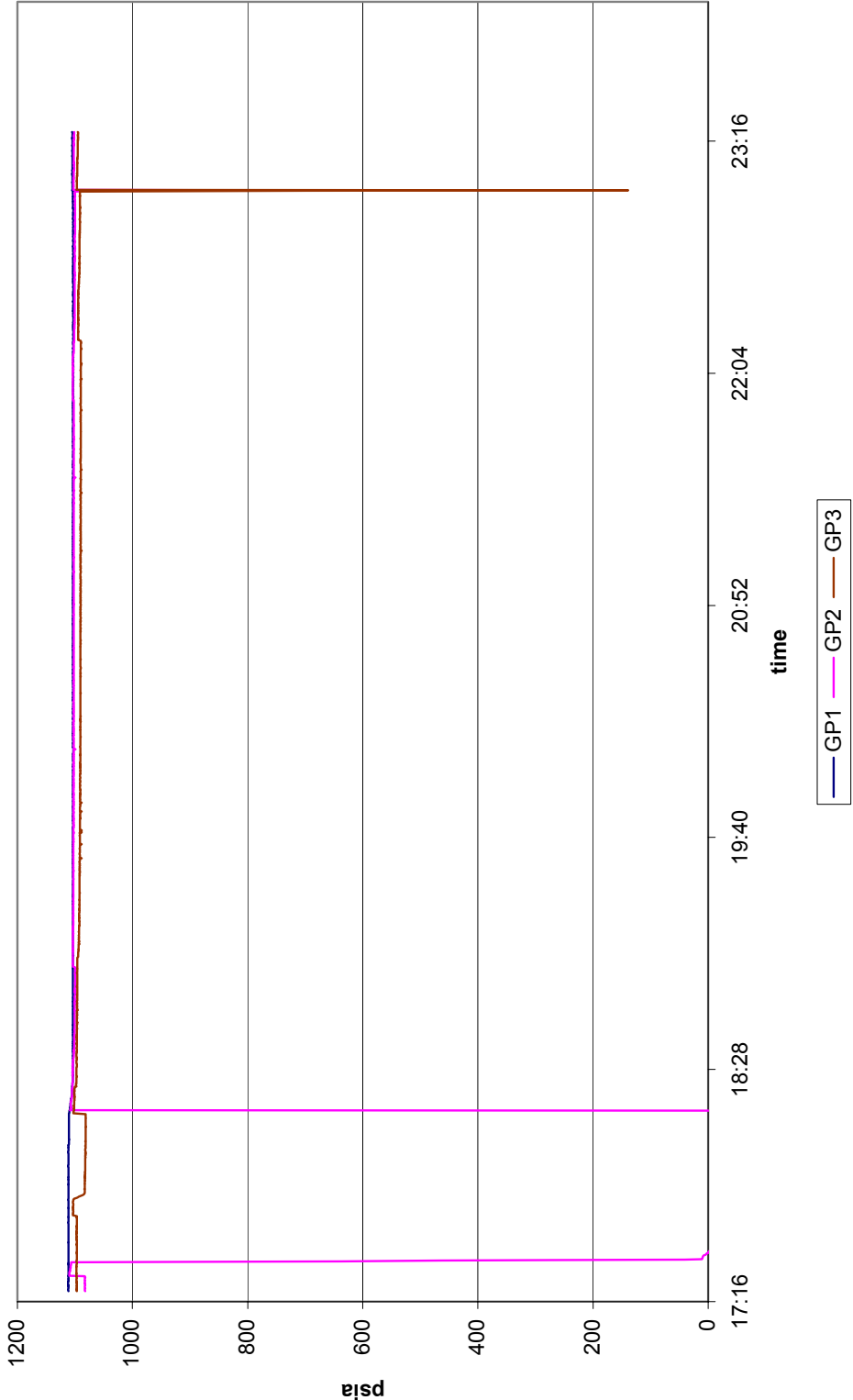


Diagram 2

GP4-GP6 (zones IV, V);
E28

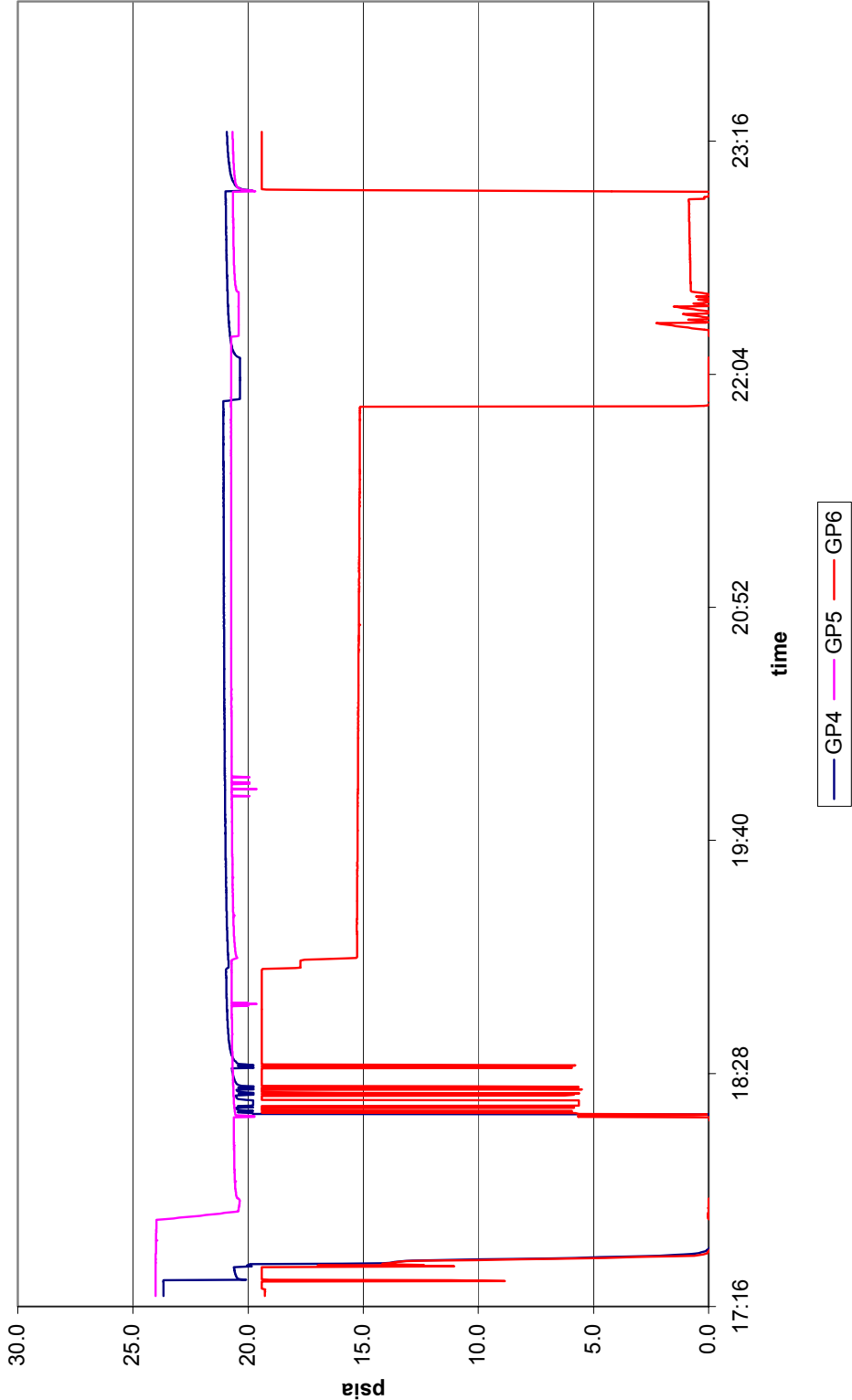


Diagram 3

**GP7-GP14 (zone VII);
E28**

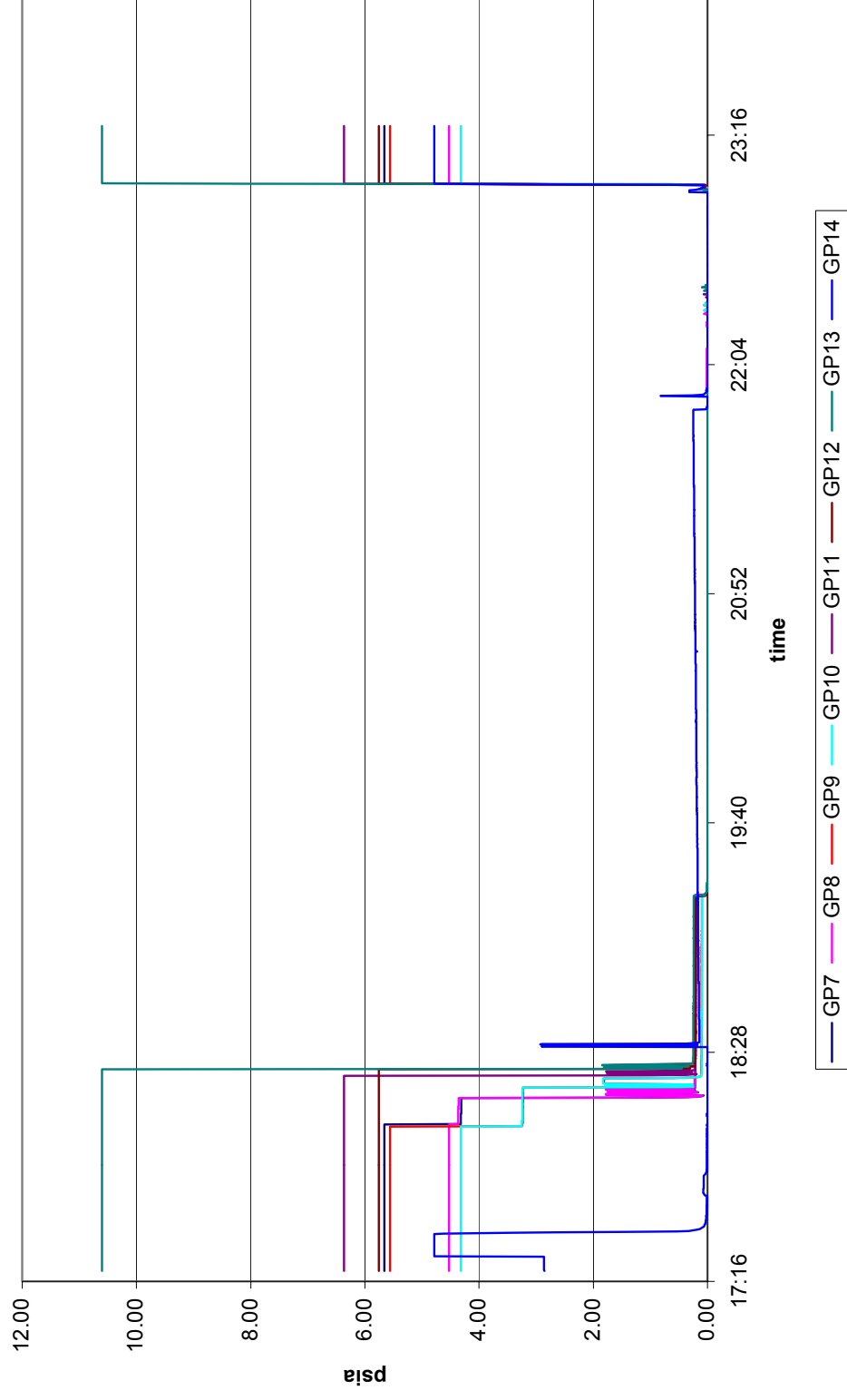


Diagram 4

**GP1, GP2, GP3, (zones I, IIA, IIB);
15.10.1, HLD tests, (M.10)**

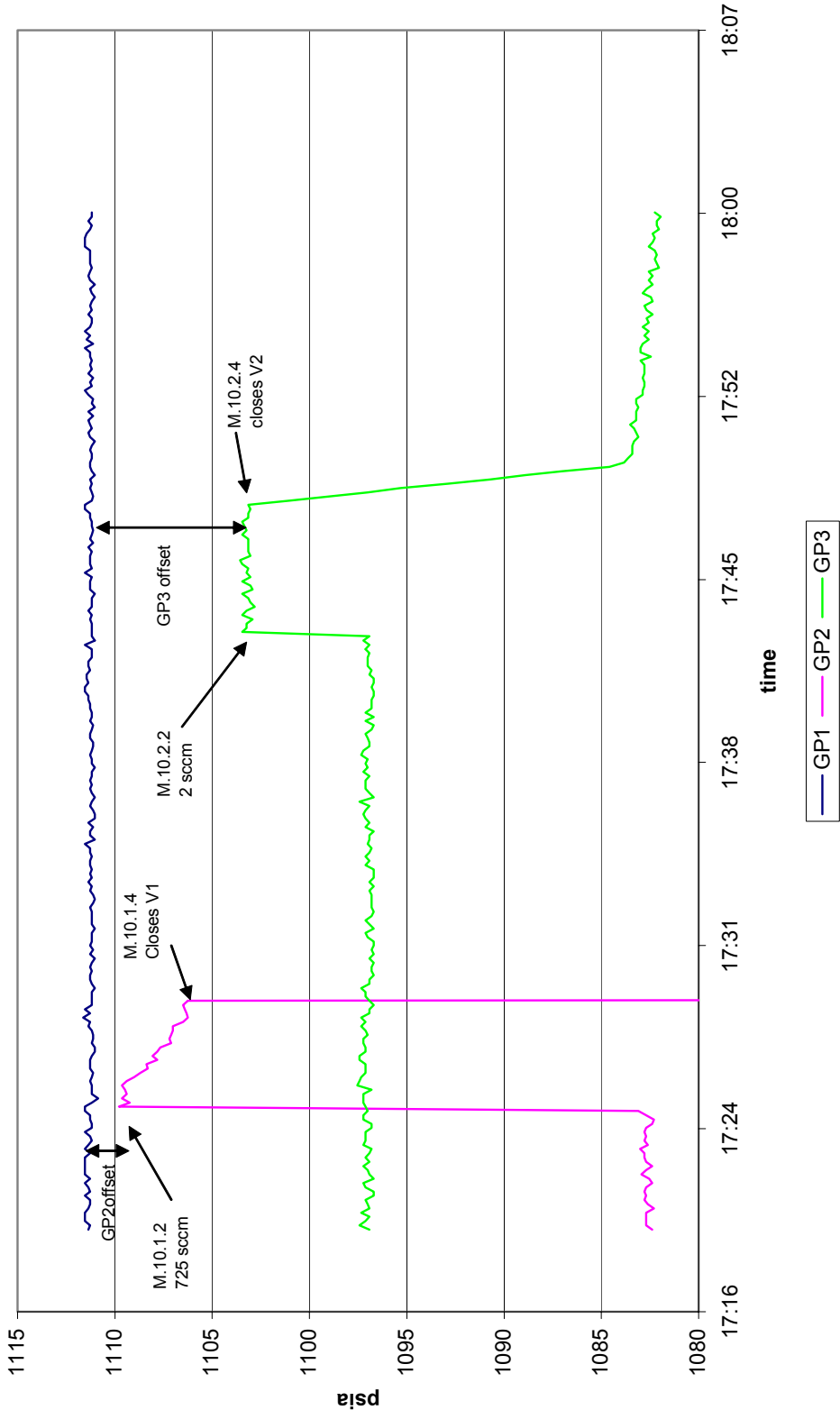


Diagram 5

**GP4, GP5, GP6, (zones IV and V);
15.10.1, HLD tests, (M.10)**

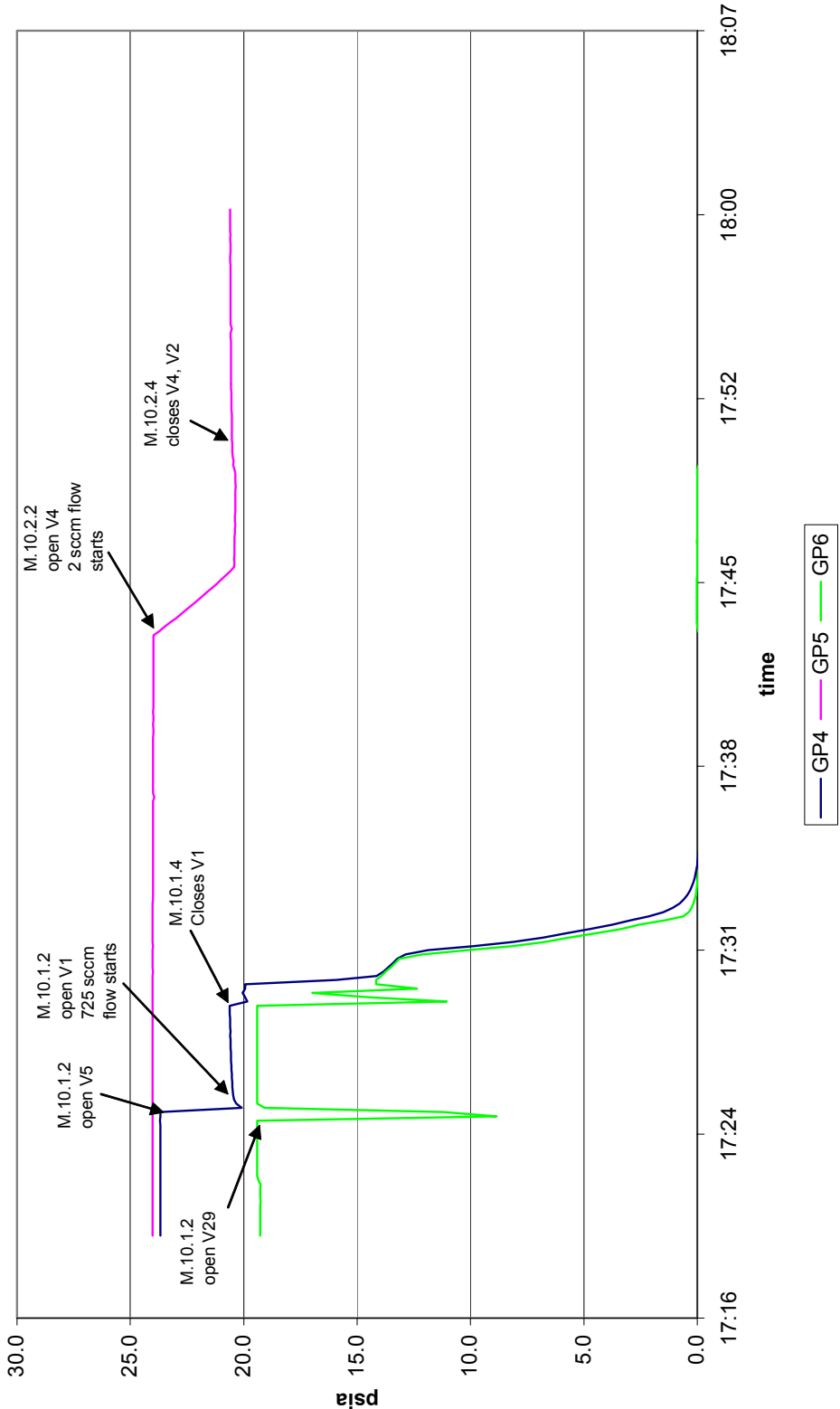


Diagram 6

GP7-GP14 (Zone VII);
15.10.1, HLD tests, (M10)

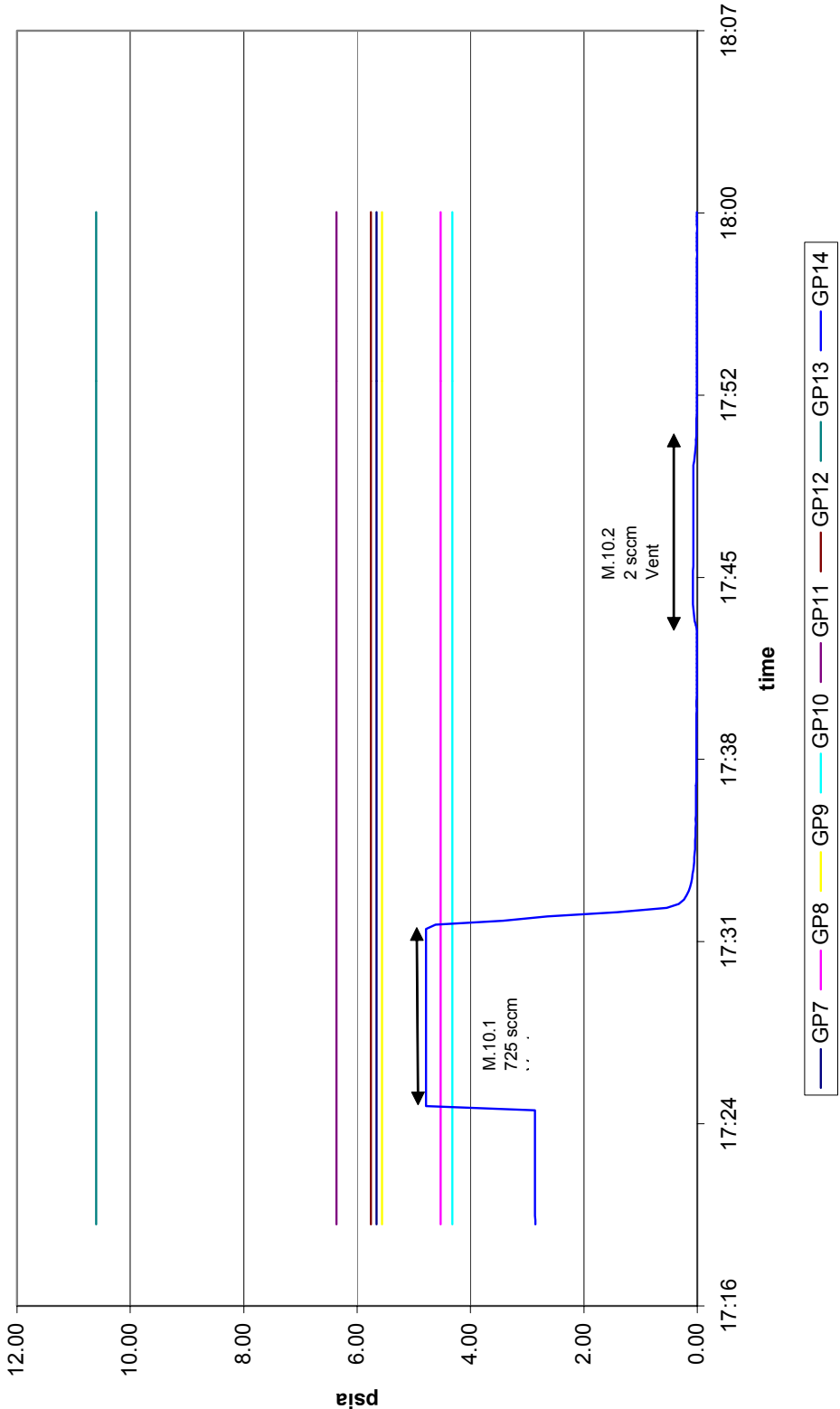


Diagram 7

**GP1, GP2, GP3, (zones I, IIA, IIB);
15.10.1, 725 sccm flows and flux flush, (M.13-M.24)**

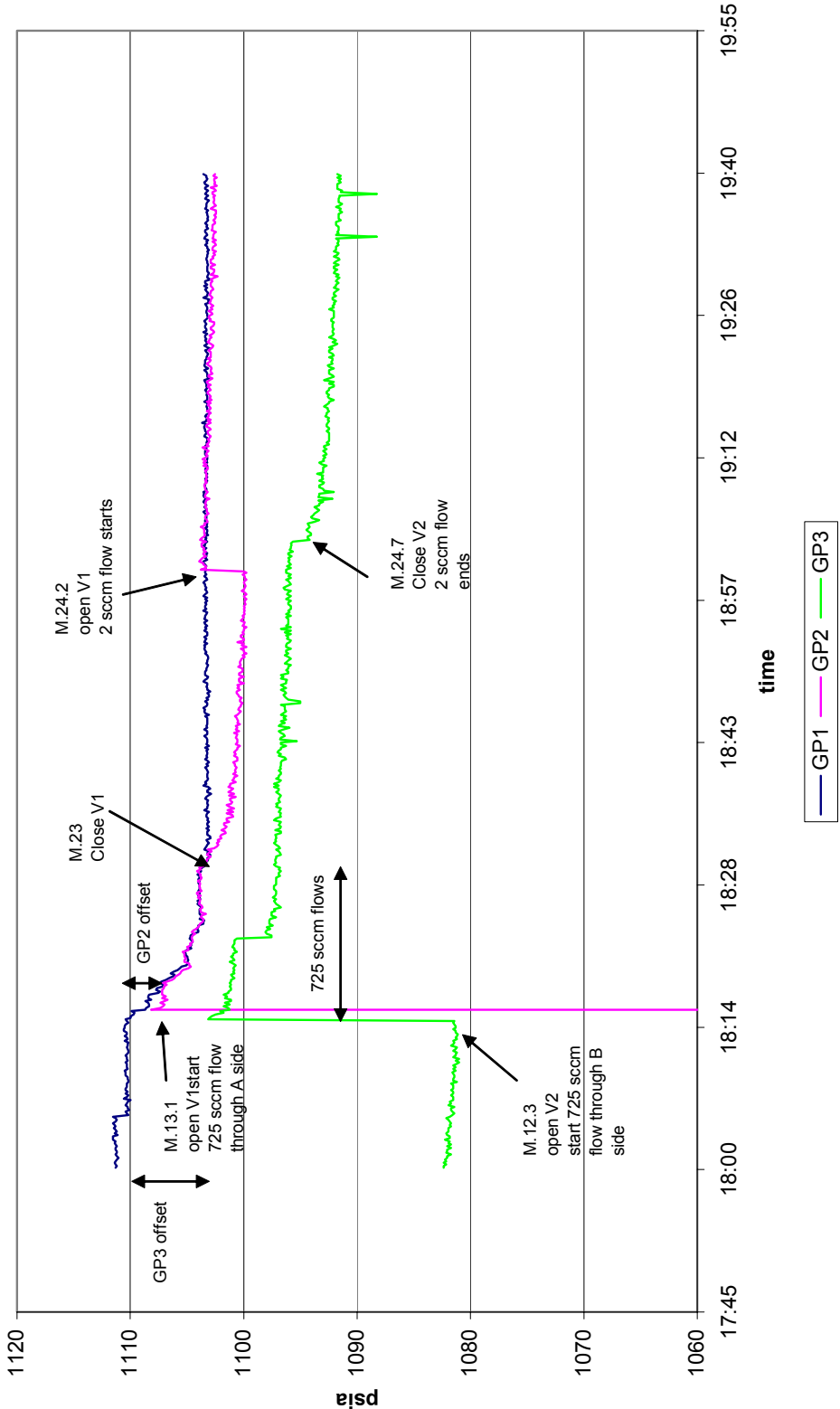


Diagram 8

**GP4, GP5, GP6, (zones IV, V);
15.10.1, 725 sccm flows, (M.13-M.24)**

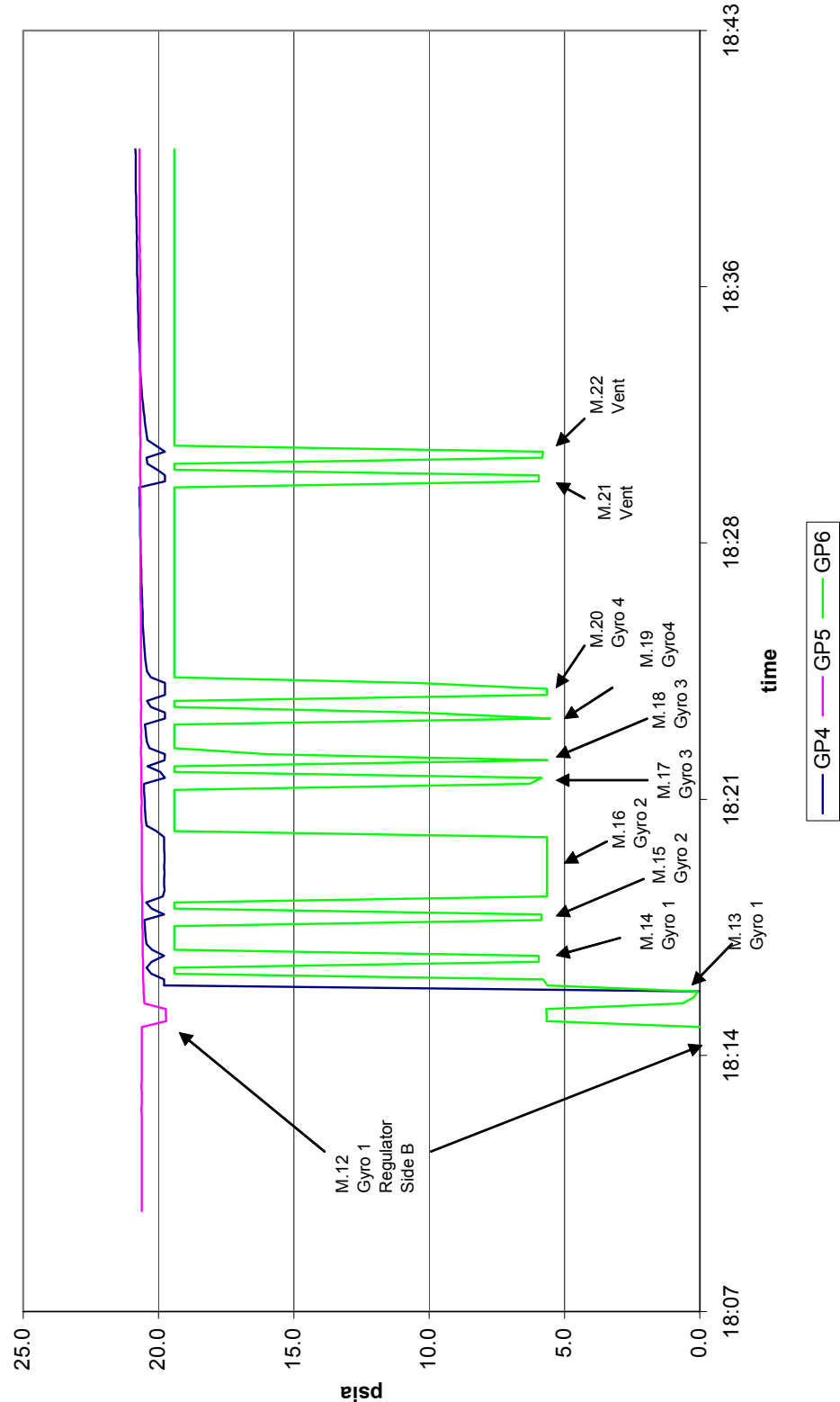


Diagram 9

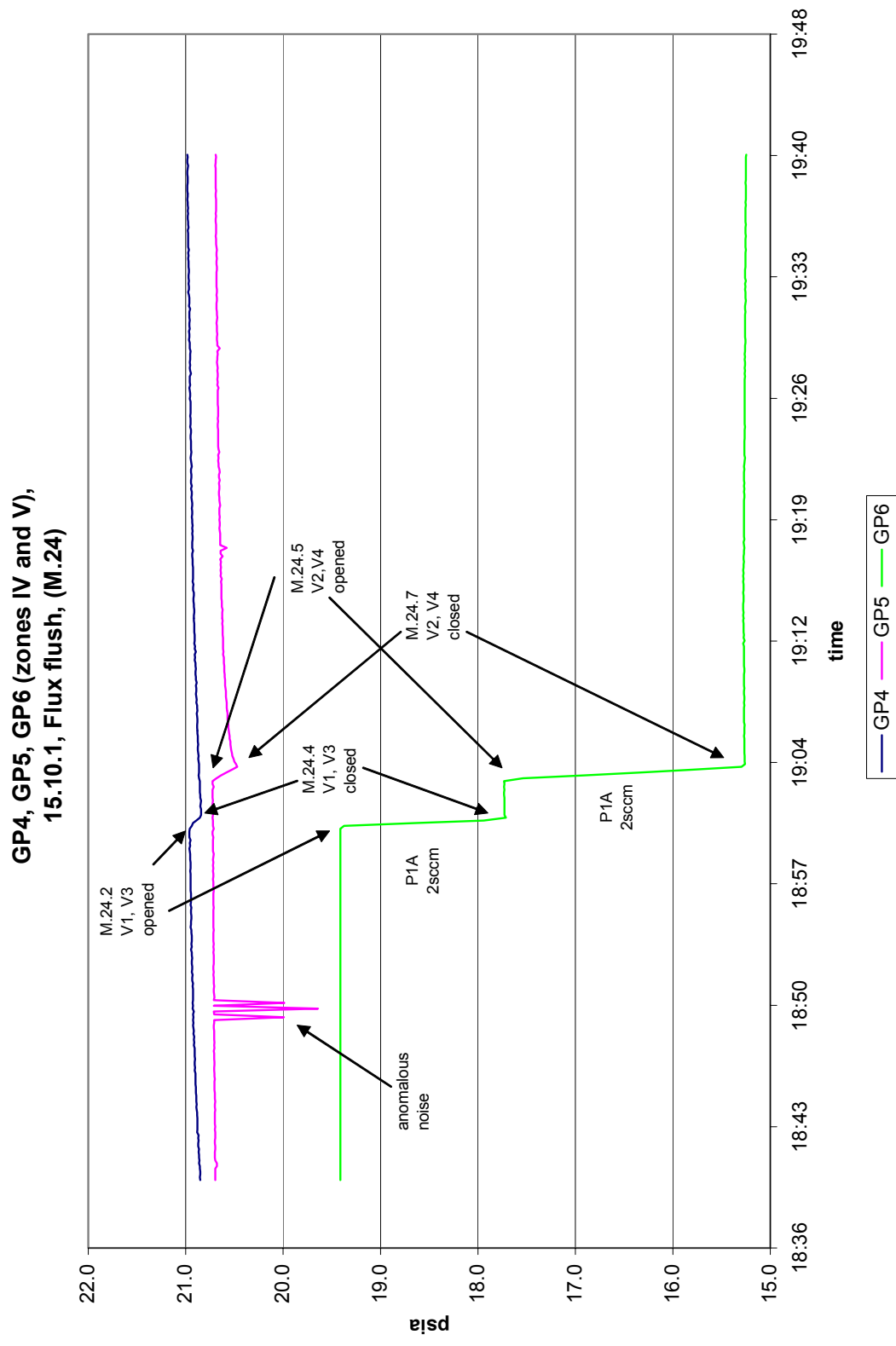


Diagram 10

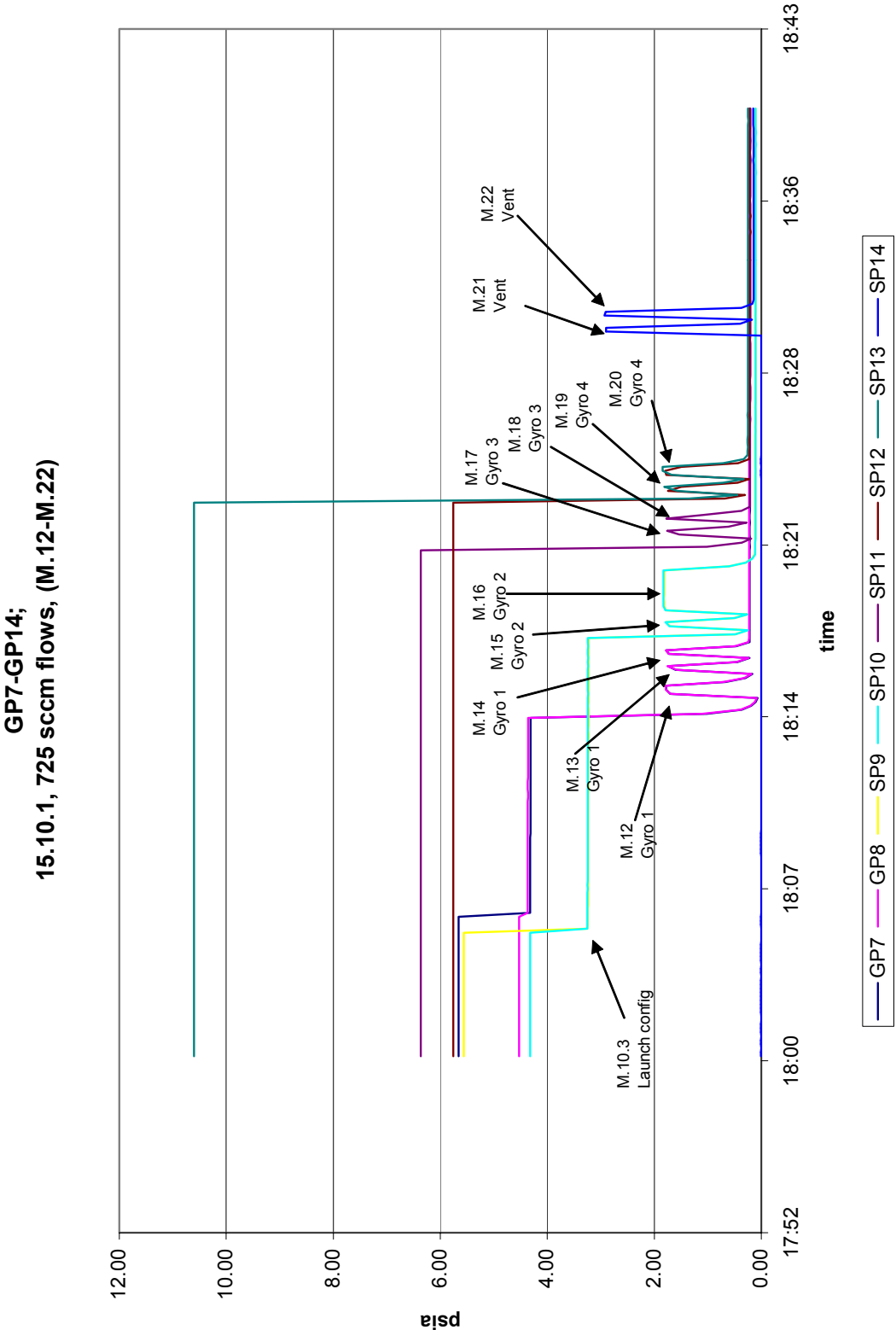


Diagram 11

**GP7-GP14 (zone VII),
15.10.1, flux flush, (M.24)**

(Note: no GP sensor on P1A so no activity on this chart for M.24 "Flux Flush")

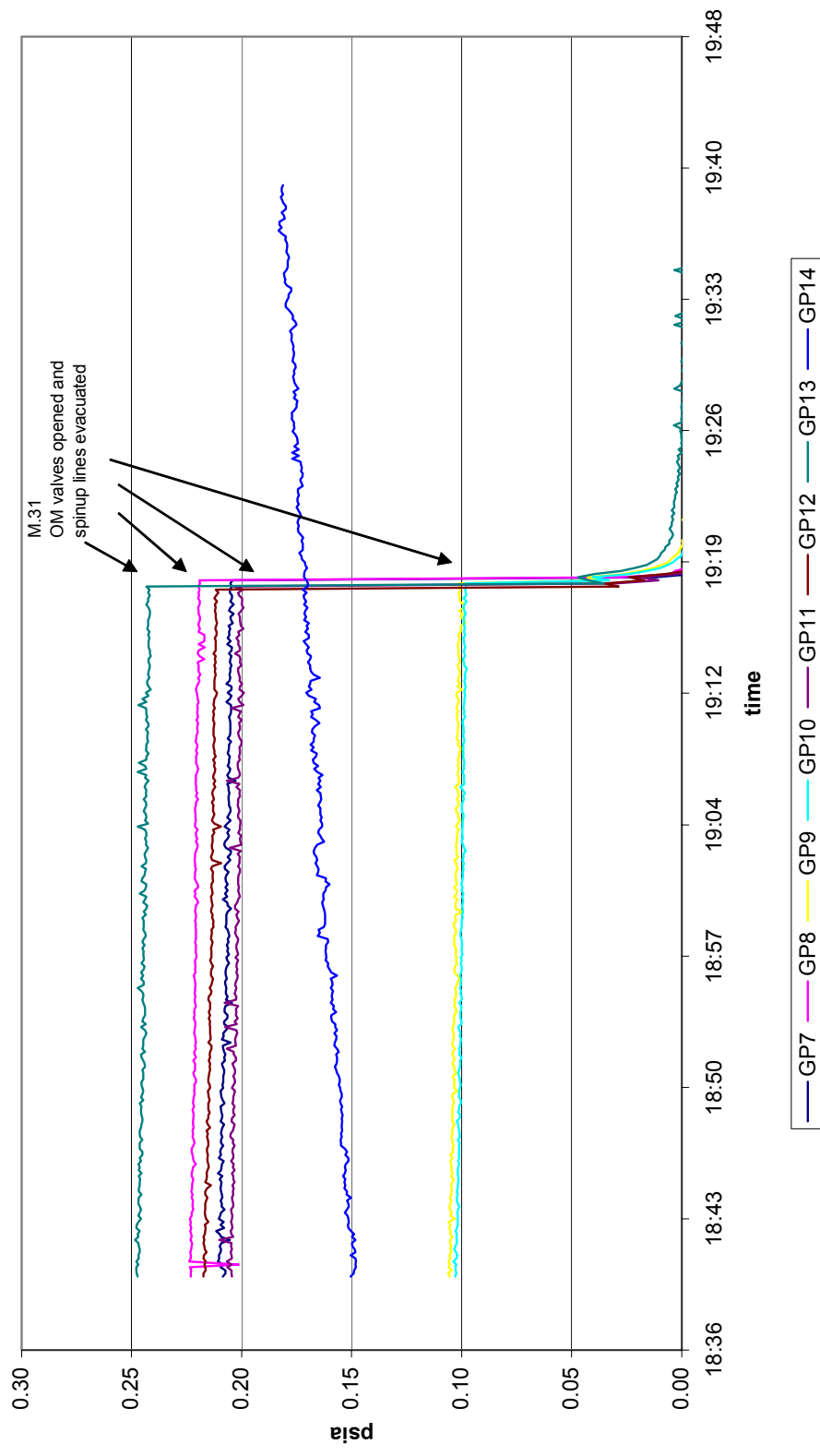


Diagram 12

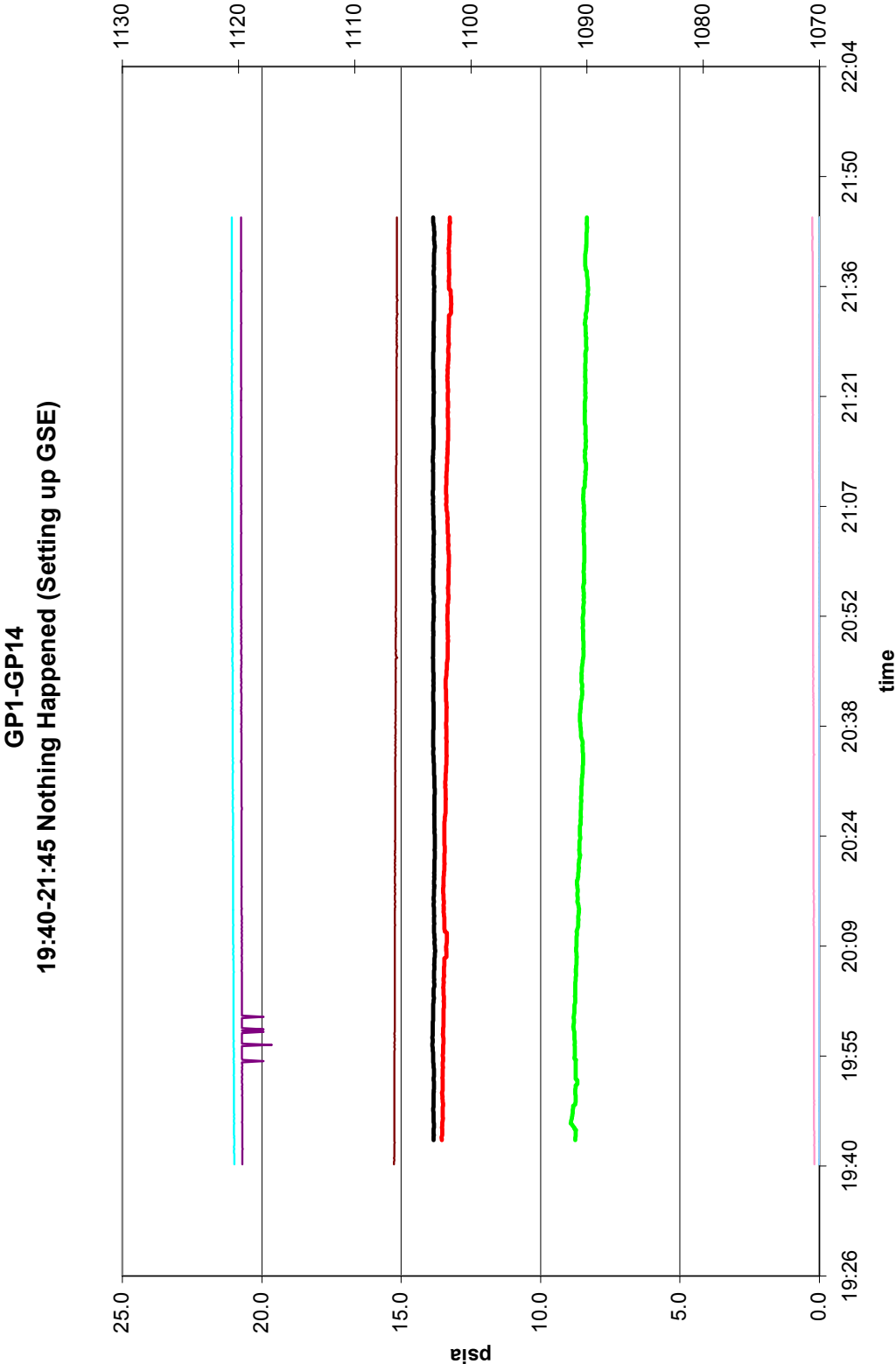


Diagram 13

**GP1, GP2, GP3, (zones I, IIA, IIB);
15.10, (M.35-M.44), 2 sccm flows**

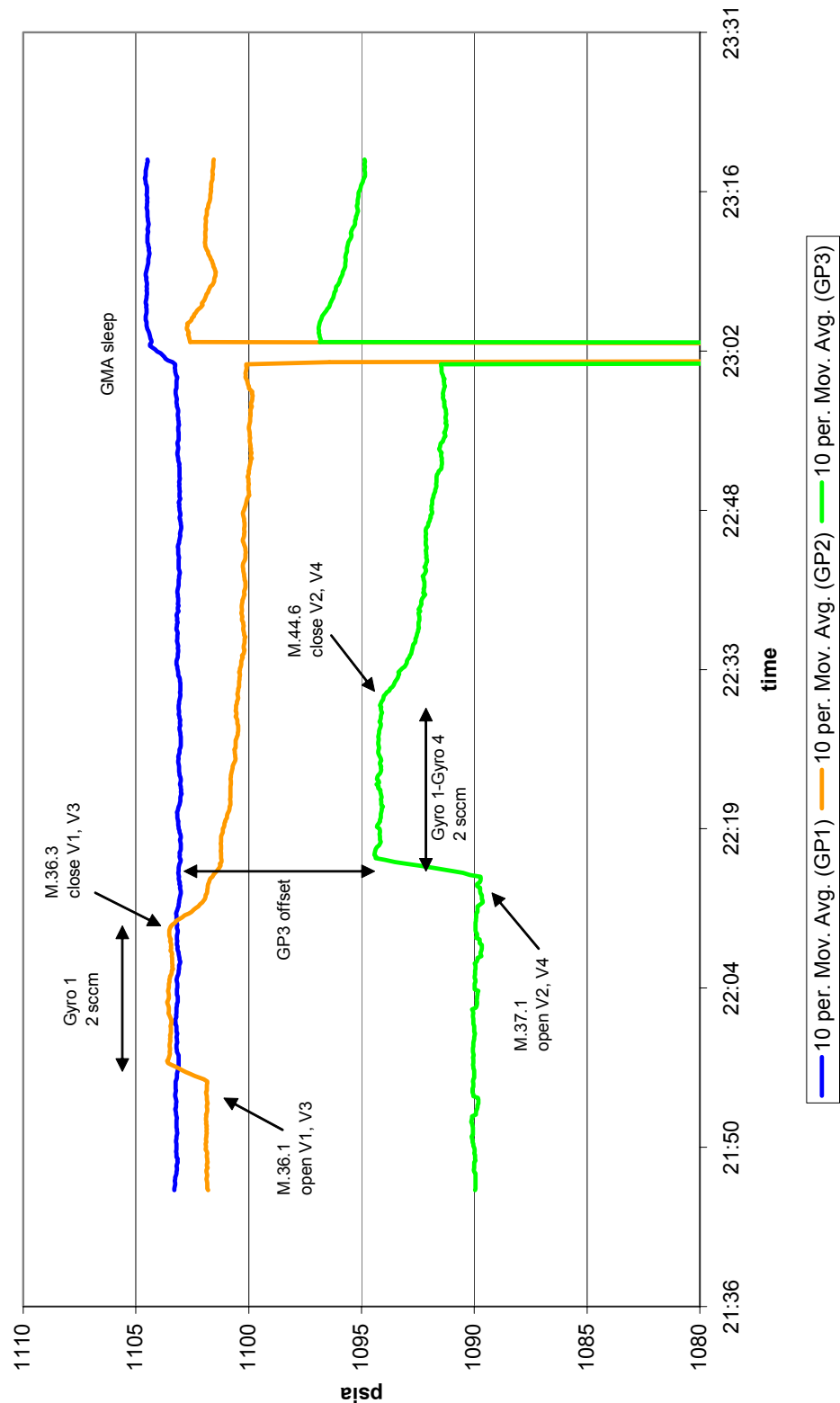


Diagram 14

**GP4, GP5, GP6 (zones IV, V);
15.10 (M.35-M.44), 2 sccm flows**

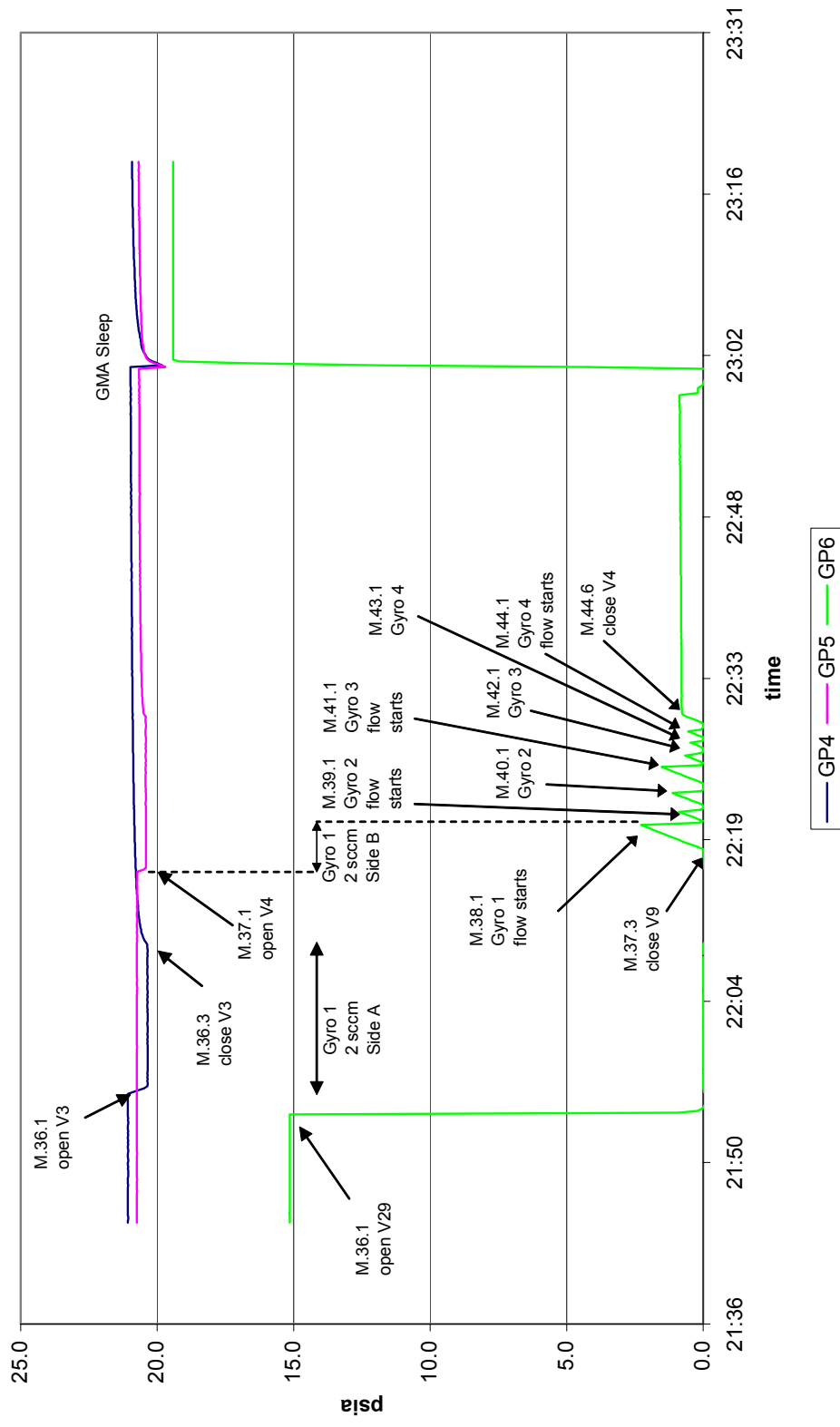


Diagram 15

**GP7-GP14 (zone VII);
15.10, (M35-M44), 2 sccm flows**

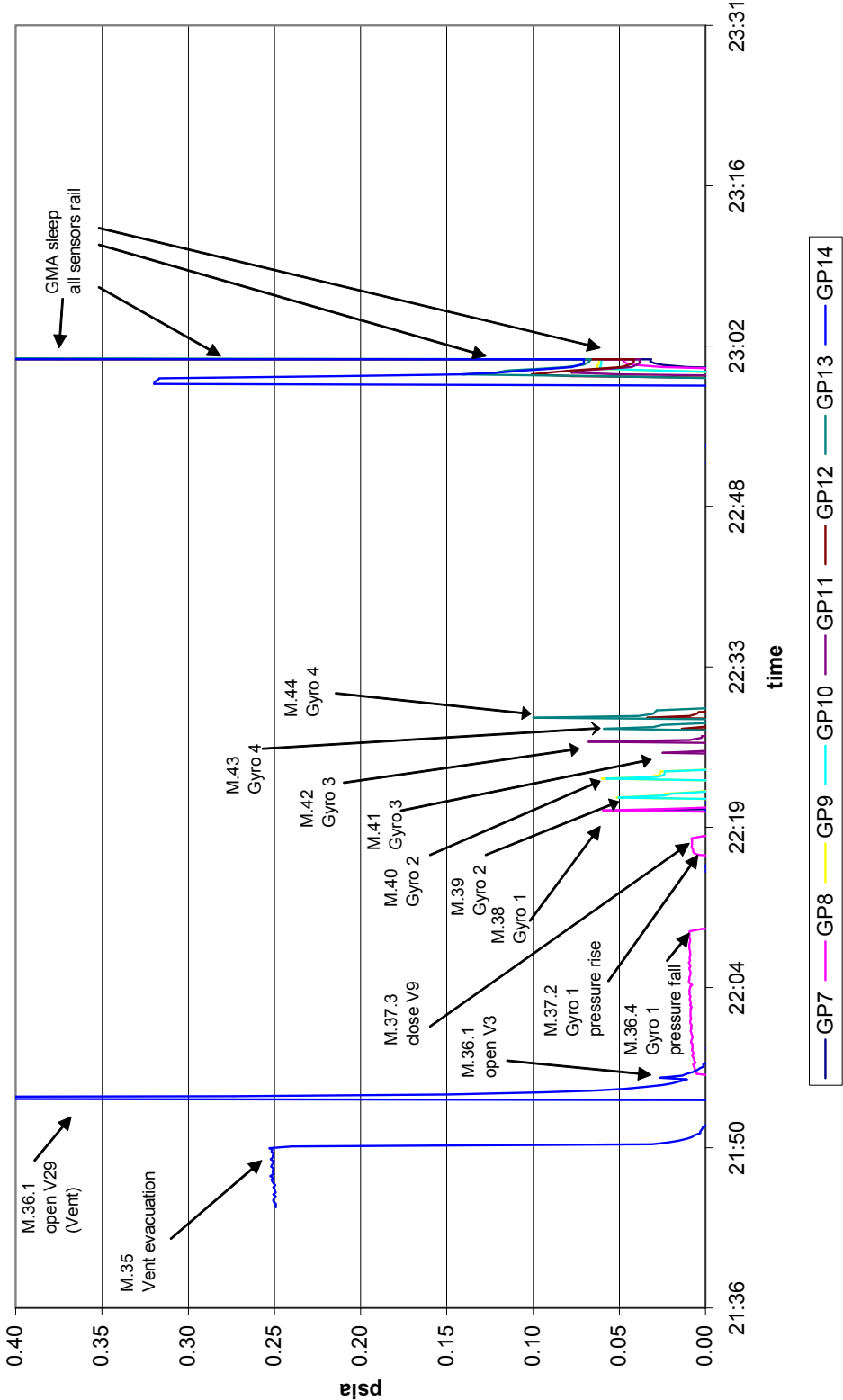
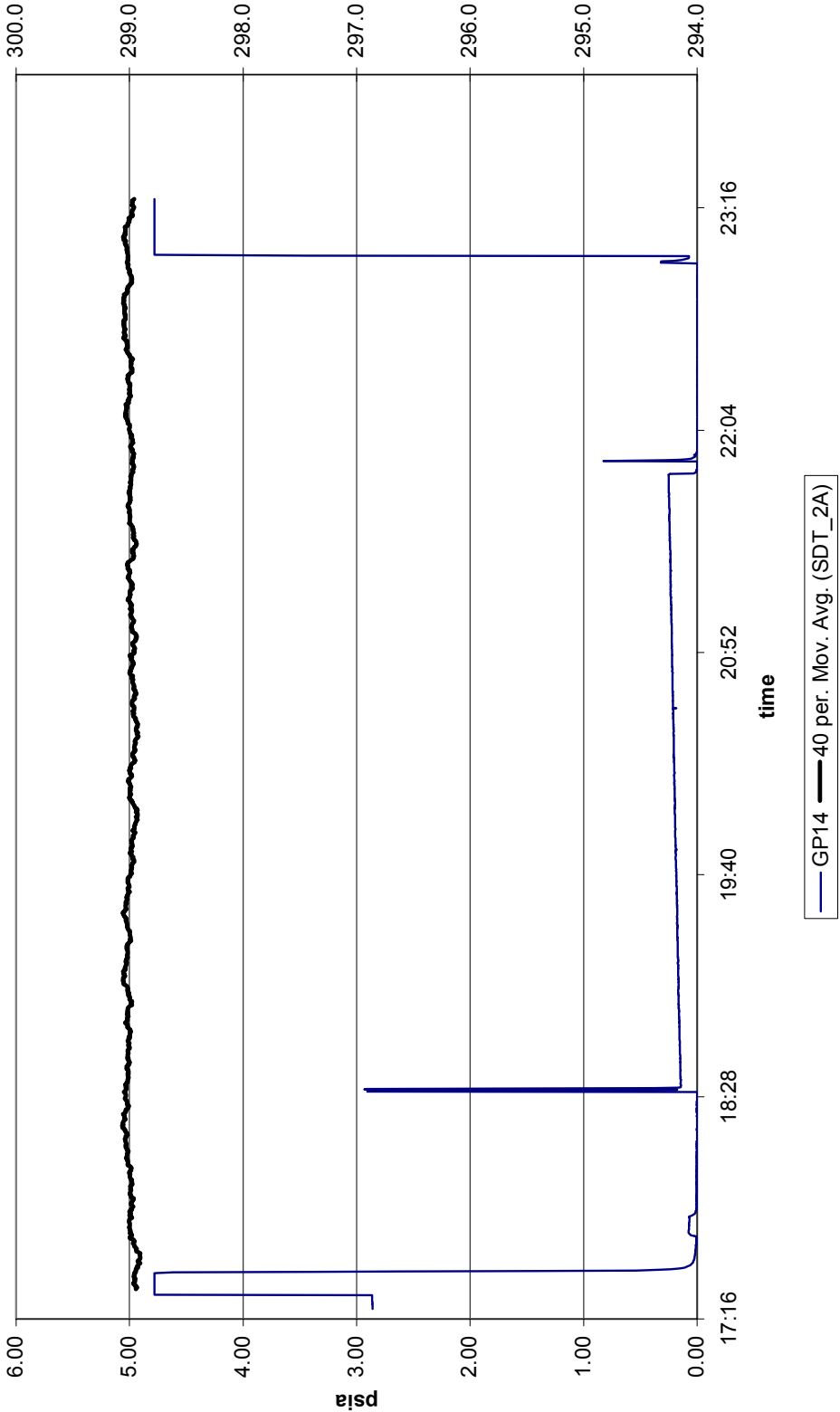


Diagram 16

GP14 (Vent) and SDT2A;
E28 Test



D.6 Dewar main Tank Thermal Analysis

Impact of GMA Leaks on Dewar Main Tank Temperature Rise

This document contains results of an analysis of dewar main bath heating due to helium leaking into the probe via the GMA.

Impact on GMA Mitigation

The following analysis indicates that helium leaking into the probe from the GMA can increase the heat rate into the main tank, and consequently, decrease the time to go from 1.65 K to 1.85 K to less than 90 days. Therefore, as part of this Mitigation Plan, Top Hat Manual Valve opening and Regulator Lock-up operations have been moved to the latest possible times in the program schedule, i.e. just prior to FEE closure and just prior to Solar Panel integration, respectively. With this schedule, if GMA leakage rates remain similar to the Rate of Rise test data, then the time to reach 1.85 K degrades by 9 days to 81 days. While not meeting the 90 day dewar requirement, this would have no impact on launch operations. If the leakage rates increase markedly to the 10^{-3} sccs or 10^{-4} sccs levels considered in the model, there is still schedule margin (considering the time between relevant GMA operations and vehicle move to the MST) to accommodate multiple launch attempts and scrubs before reaching 1.85 K main bath temperature.

Therefore, this Mitigation Plan is robust with regard to main bath temperature rise issues over the range of foreseeable leakage rates.

Dewar Main Tank Temperature Rise Analysis

This analysis models dewar main bath temperature rise due to excess heating caused by helium leaking into the probe via the GMA. Four sources of excess heating are considered: the heat of adsorption of helium on the probe surfaces including the sorption pump; the enthalpy of helium gas as it is cooled from room temperature to probe temperature; the conduction of helium gas in the probe; and the increased thermal radiation due to a change in the temperature profile of probe structures (in particular window 1). The model is based on data that include:

- 1) MT hold test Data 6/14/01
- 2) SMD Flight Payload+SC data file 020410.PCD 4/11/02 – 4/19/02
- 3) ECU Operational Mode Test 4/15/02 – 4/17/02
- 4) Payload parameters, such as:

Main Tank He volume	2200 L
Main Tank initial temp	1.65 K
Sorption Pump area	230 m ²
Probe volume	100-200 L
- 5) Physical parameters, such as:

Helium Latent Heat
Helium Heat Capacity
Adsorption Isotherm
Thermal conductivity

Model Procedure:

The following outlines the model procedure.

- 1) Determine Probe pressure rise as function of time for a given leak rate
 - non linear due to Adsorption
 - use Frankel Halsey Hill Isotherm
 - first layer adsorption energy = 40 K, second layer = 12 K
- 2) Determine extra heat input to Main Bath
 - worst case assuming no Guard Tank mitigation
 - optimistic case assuming Guard Tank mitigation has same relative effect as in the case with no helium gas in probe
 - realistic case based on thermal model of probe with residual gas pressure
- 3) Determine temperature rise of main tank as function of time
 - non linear wrt heat input due to temperature dependent heat capacity, C
 - use measured C data, integrate to determine heat energy as function of temp
 - invert function to determine temp rise vs. heat input

Probe Pressure Rise vs. Leak Rate

The rate of probe pressure increase is a function of the leak rate, probe surface area, volume, temperature, and adsorption energy. An adsorption energy of 40 K/atom for the first free layer of helium and 12 k/atom for the second layer is assumed to determine the (small) heat input due to the heat of adsorption. This is consistent with the Frankel-Halsey-Hill isotherm, shown in figure 1, used to determine the probe pressure as a function of the helium leak rate. The results are not highly dependent on the details of these assumptions. End around check on sensitivity to adsorption model confirms results are not dependent on adsorption details. That is, different plausible adsorption energies and other isotherms all lead an increase in probe pressure at about second layer filling.

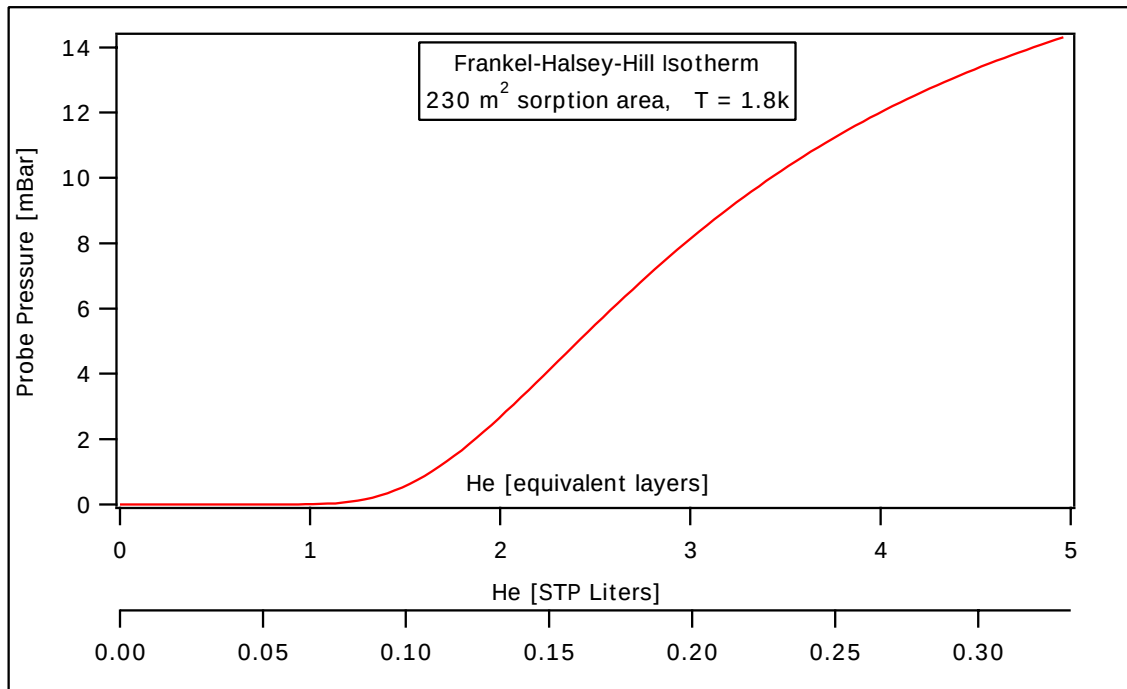


Figure 1. Probe pressure vs. quantity of helium leaked into the probe. The helium quantity in STP liters is found using 230 m² area and assuming adsorbed layer density equal to bulk helium. This particular graph used a 1.8 K sorption pump temperature. Model calculationz were based on a sorption pump temperature of 2.5 K.

Heat Input into Main Bath

Boil-off data taken from 4/11/02 through 4/19/02, shown in figure 2, give the main bath boil off rates with and without residual helium probe pressure. The initial probe pressure, 14 mTorr, is well above the range at which the mean free path is small compared to relevant probe dimensions and therefore the conduction due to the gas should be approximately constant for pressures above this value. From the difference in boil off rates, 6.59 std L/min – 3.62 std L/min, one finds an increased heat load into the main bath of 0.181 J/s. It should be noted that for the heat rate due the probe without residual gas pressure one finds 0.221 J/s. This should be compared to the heat rate value of 0.02 J/s measured with the main tank below the lambda point and with liquid in the guard tank; this gives a 90 day hold time for the main tank temperature to climb from 1.65 K to 1.85 K. Thus, there is a ratio of 0.093 for the heat rate into the main tank (from a probe at vacuum) with liquid in the guard tank. It is uncertain what effect the guard tank will have with residual pressure in the probe. It is plausible that due to thermal accommodation at the windows the probe conduction with gas will behave similar to (but have a higher value) than the evacuated probe and therefore a filled guard tank may cause a similar reduction in the heat flow to the main tank.

We first consider two cases to get an upper and lower bound of heat rate and then extend the thermal model to get the most probable heat rate determination. For the upper bound we take as a worst case no reduction in heat load into the main bath due to the guard tank. For the lower bound case we assume a ratio of heat rate reduction, with and without helium in the guard tank, identical to that with the evacuated probe.

The extended thermal model uses probe window 1 temperature data obtained in the ECU Operational Mode Test 4/15/02 – 4/17/02. These data yield a window 1 temperature of 25.7 K when there was 14 mTorr residual gas in the probe and a temperature of 21 K when no residual gas was present. The model calculates the thermal conduction of the helium gas between window 1 (at the HEX 1 location) and the plane of Station 200, shown in figure 3, and assumes all heat is delivered to the main bath. We use the literature value for the thermal accommodation coefficient of He at 20 K and take worst case values the conductivity of helium gas over the range of 25.7 K to 2.5 K - atmospheric pressure values. This yields an increased heat conduction into the main bath of 5×10^{-2} J/s. Next the model determines the increased thermal radiation from window 1 to be 1×10^{-3} J/s.

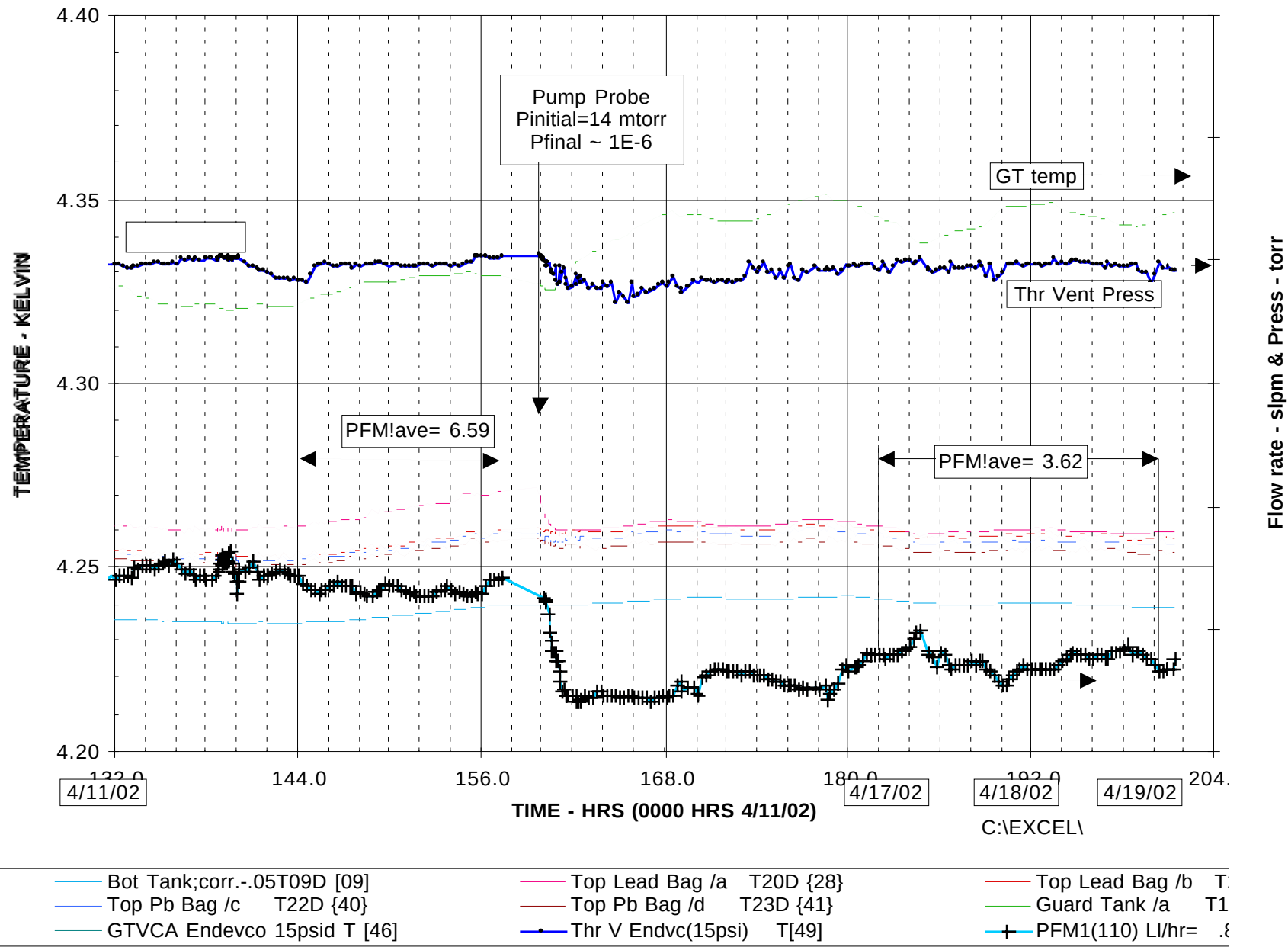


Figure 2. Boil-off data taken from 4/11/02 through 4/19/02.

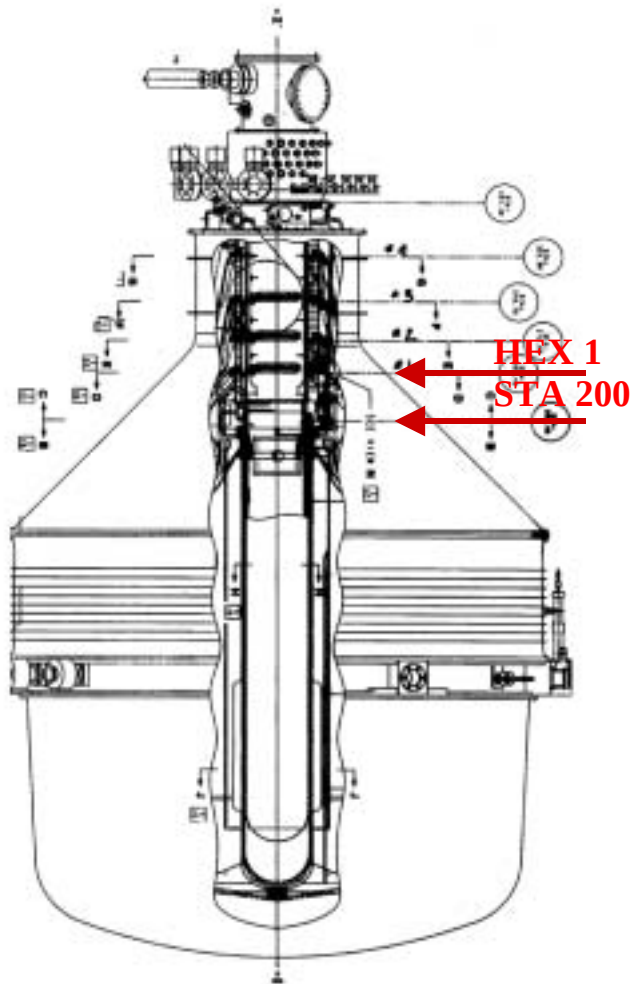


Figure 3 Location of window 1. As a worst case we assume all thermal conduction to the plane of Station 200 is a direct heat load to the main bath.

Temperature Rise Rate of Main Tank

We are interested in the determination of the rate of rise of the main tank temperature from a base of 1.65K. The rate of temperature rise is not linearly proportional to the heat flow to the main bath because the heat capacity of helium varies as shown in figure 4. Heat capacity data were fit over the temperature range of interest to an empirical function that was then integrated to determine the total heat energy absorbed as a function of temperature. This function was then inverted to determine the temperature rise of the helium main tank as a function of heat input.

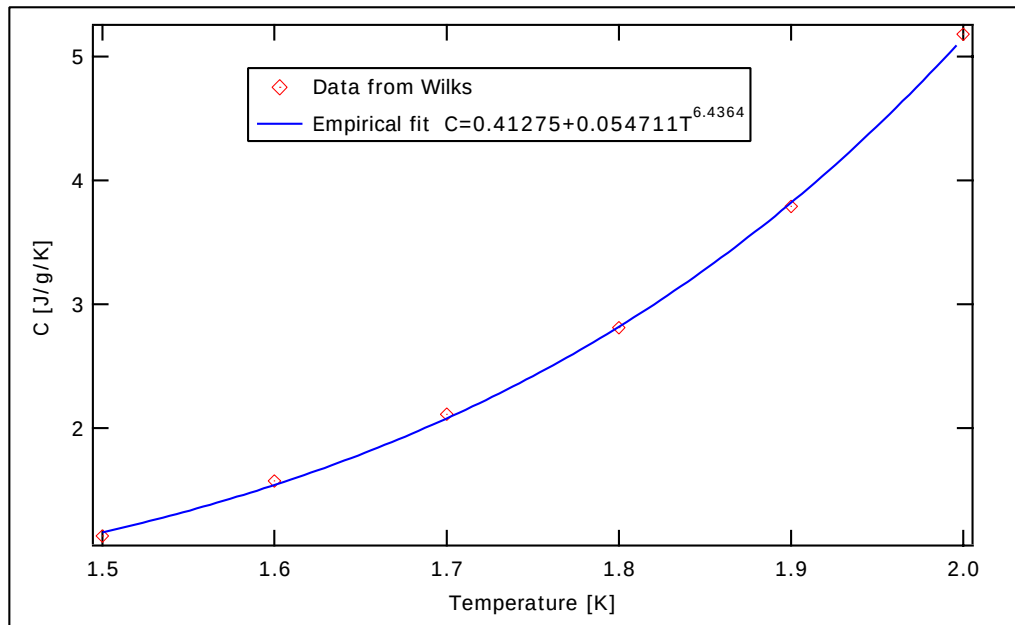


Figure 4 Specific heat of liquid helium at saturated vapor pressure.

Results

Figure 5 shows the main bath temperature as a function of the number of days with exposure to the pressurized GMA. The black curve represents the rise for a probe with no leakage of helium gas and negligible ambient pressure. The dashed blue curve (highest curve) gives the temperature rise for a leak of 10^{-3} mBarL/sec (or sccs) assuming that the guard tank does not intercept any heat from the increased conduction due to the gas in the probe. The abrupt change in slope at about the two day mark is due the sorption pump surface saturating and the corresponding increase in probe pressure. A main bath temperature of 1.85 K is reached at 11 days. The dashed red curve gives the temperature increase for the same leak rate assuming that the mitigating effect of the guard tank has the same relative value as for the case with negligible probe pressure. In this case 1.85 K is reached after 49 days. The dashed purple and orange curves give the respective temperature increases for a leak rate of 10^{-4} mBarL/sec. The main difference here is the longer time needed to saturate the surfaces; once probe gas pressure begins to increase, a similar slope is established. For this leak rate and with no guard tank mitigation it takes 23 days to reach a main bath temperature of 1.85 K vs. 56 days with guard tank mitigation.

The solid red and green curves present the most realistic predictions for leak rates of 10^{-3} mBarL/sec and 10^{-4} mBarL/sec respectively. These are obtained using the extended thermal model. This realistic model predicts:

- 1) a total leak of He into the probe of 10^{-3} STD CC/sec results in a rise of the Main Bath from 1.65 K to 1.85 K in 29 days
- 2) from 1.65 K to 1.95 K in 50 days
- 3) a total leak of He into the probe of 10^{-4} STD CC/sec results in a rise of the Main Bath from 1.65 K to 1.85 K in 38 days
- 4) from 1.65 K to 1.95 K in 59 days

Conclusions Including Rate of Rise Test Data

If GMA leak rates remain similar to the Rate of Rise test data, then the probe pressure will remain negligible to past 55 days after vehicle move to the MST (79 days past regulator lockup). There will be only a slight change in the temperature rise rate as shown in figure 6. For this case the model assumes the Mitigation Plan GMA regulator lock up schedule and uses the Rate of Rise data for the ground configuration mode for the time until vehicle movement to the MST (the first 24 days). Then the launch configuration mode leak rates used thereafter yielding about 79 days total to reach saturation of the sorption pump. Thus, if leak rates remain near rate of rise test levels there will be ample time to accommodate launch. And even in the case of much larger total leak rates, the anticipated launch schedule can be met.

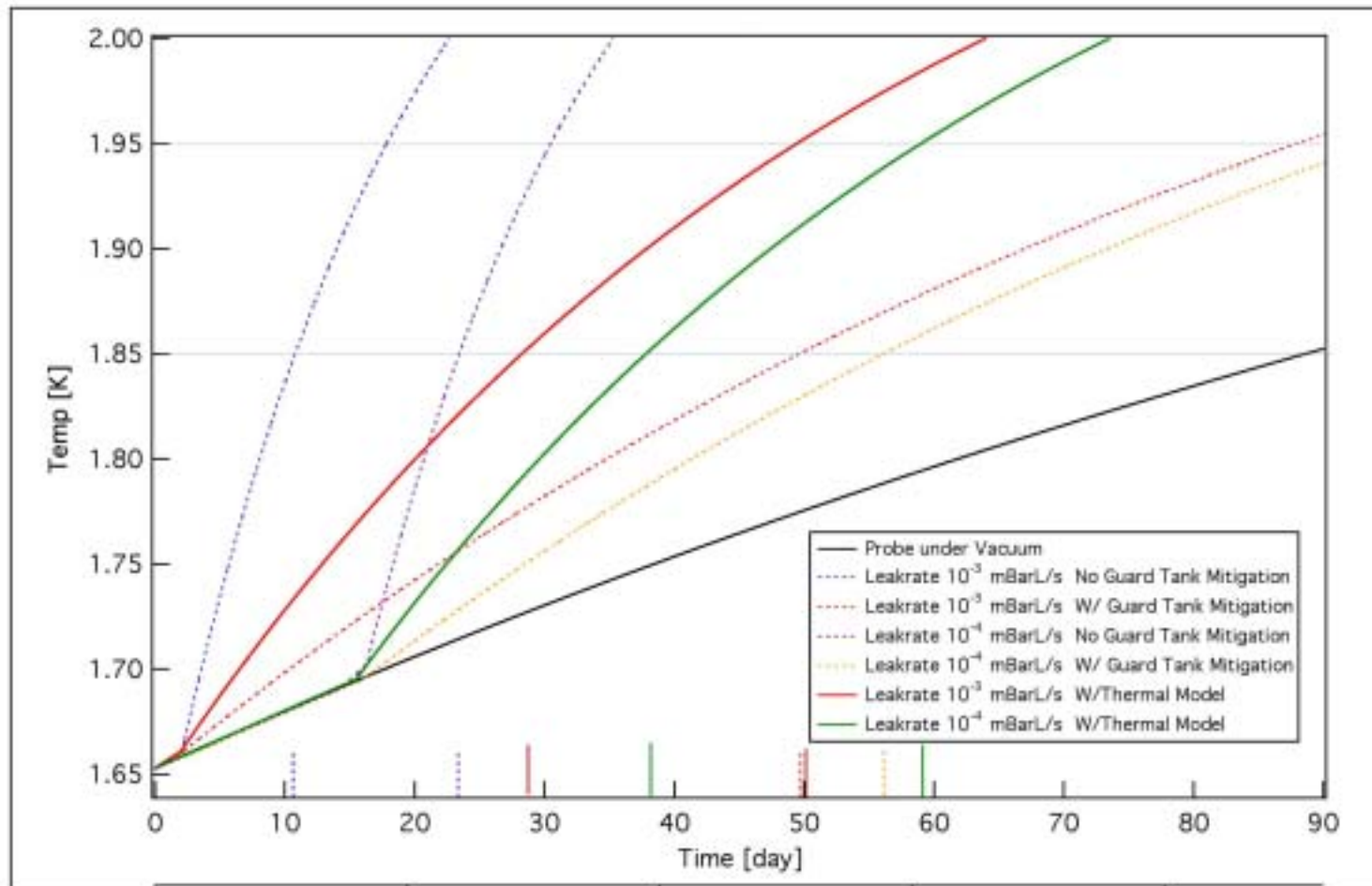


Figure 5. Main bath temperature as a function of the number of days with exposure to the pressurized GMA.

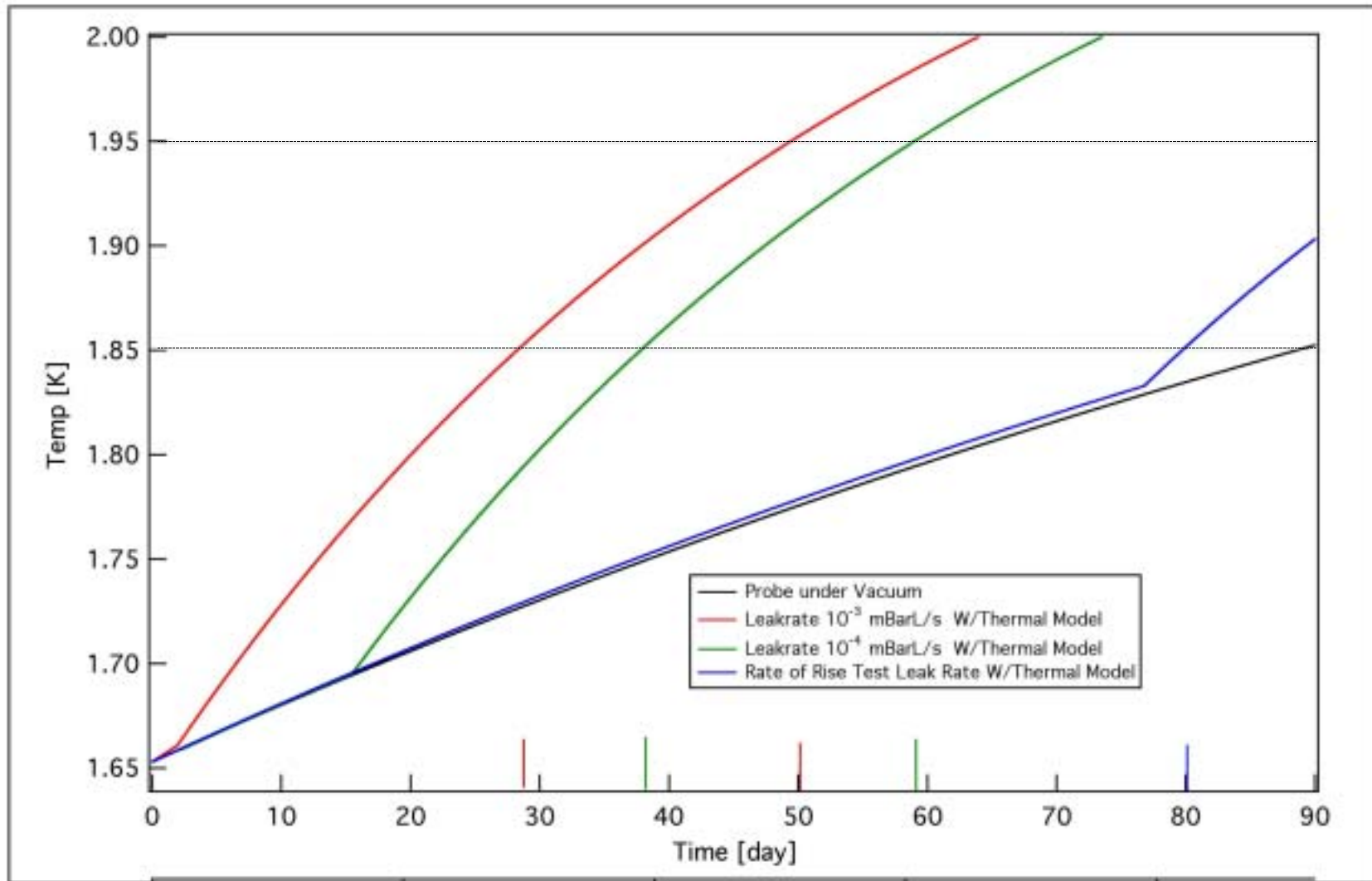


Figure 6 Main Bath temperature rise for leak rates measured by the Rate of Rise Test.

D.7 Guard tank thermal Analysis

Guard Tank Boil Off

The following report, EM TCS 2XX, details an analysis of the impact of probe residual pressure on the Guard Tank boil off rate. The analysis presents a worst case calculation of boil off by fitting the excess heat load of residual helium pressure in the probe based on main tank boil off data. Unfortunately, relevant HEX and probe window temperature data, which could constrain the model, are not available. The result of the fit predicts a helium gas conduction that is higher than published values for helium gas pressure of 0.1 Atmospheres. At the 14 mTorr pressure of the main tank boil off data, one would expect [Dushman, *Scientific Foundations of Vacuum Technique* sec. 1.10] the conductivity of the gas to be markedly lower. Therefore, the following Guard Tank analysis yields a boil off rate that is a sharp upper bound for the likely increase in boil off due to residual probe pressure.

Impact on GMA Mitigation

The analysis indicates that if probe residual pressures become significant, then Guard Tank boil off rates may increase to levels that would require more frequent servicing than the original baseline 5 day interval. As of this document release date, we working with the VAFB and Boeing launch teams to review the impact more frequent servicing if required. No issues have been identified that would prohibit more frequent servicing. Further, scenarios have been identified, such as 2nd shift operations, that would mitigate any possible schedule impacts.

If GMA leak rates remain similar to the Rate of Rise test data (included in this document) probe pressure will remain negligible to past 55 days after vehicle move to the MST (79 days past regulator lockup) and there will be no impact on Guard tank boil off. If leak rates increase markedly such as to the 10^{-3} sccs or 10^{-4} sccs rates considered in section C.4, then the more frequent servicing schedule will mitigate this scenario.

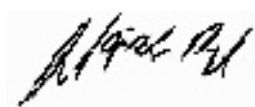
During the time between regulator lock up and vehicle move to the MST, the GMA is in the Ground configuration with all four valves in each spin up and flux flush quad closed. In this configuration it is less likely to have high leak rates into the probe and therefore it is very likely that probe residual pressure will be negligible during the vehicle move to the MST. Quantitatively, total leakage rates into the probe could increase by an order of magnitude and still not saturate the cryopump in the time between regulator lock up and vehicle move to the MST. In the unexpected case that probe pressure and Guard Tank boil off rates do increase in the ground configuration, discussions with VAFB and Boeing launch teams have indicated that the MST move duration should be confined to three days, thus allowing frequent Guard tank servicing.

Therefore, this Mitigation Plan is robust with regard to Guard Tank boil off issues over the range of foreseeable scenarios.



GRAVITY PROBE B SPACECRAFT DEVELOPMENT

ENGINEERING MEMORANDUM

TITLE:		EM NO. TCS 2XX	
Helium Gas Conduction in the Probe during Ground Hold		DATE: 31 Jan 2003	
Prepared By Kevin Burns		REVISED:	
PHONE:	ORGN:	APPROVALS:	
(650) 424-2862	L9-25	 H. J. Dougherty  J. Vanden Beukel	

SUMMARY

The effect of an increase in the helium pressure in the Probe on hold time due to the leakage of helium gas from the Gas Management Assembly (GMA) isolation valves into the Probe is presented and discussed.

The correlated thermal model was compared with test data collected on April 11, 2002. Main tank helium flow rates were recorded with the Probe at a helium gas pressure of 14 milli-torr and 10^{-7} torr. The thermal model predictions matched the observed "pumped-out" vent flow rate (10.7mg/sec observed versus 11.1 mg/sec predicted) with no modifications to the thermal model. For the He-gas-in-Probe case, gas conduction was added to the thermal model using the thermal conductivity of He gas at 0.1 atmospheres. The He gas thermal conductivity was increased by 36% to match the observed vent rate of 6.59 slpm. Temperature data for the interior of the Probe during this testing is not available.

Probe Pressure	Measured		Predicted		Gas Conduction At 0.1 atm
Torr	slpm	gm/sec	slpm	gm/sec	factor
1.0 E-07	3.62	0.0107	3.73	0.0111	1.00
0.014	6.59	0.0195	6.65	0.0199	1.36

Ground hold time was projected using the thermal model and simulated gas conduction within the Probe. He thermal conductivity data for 0.1 atmospheres was

used to simulate gas conduction. The pressure in the Probe was assumed to be similar to the pressure observed for the testing performed on April 11, 2002 (14 milli-torr). The He gas thermal conductivity was increased by 36%.

The predicted ground hold time with NO He gas in the Probe is 7.29 days
Including gas conduction in the Probe, the predicted lifetime is 4.05 days.
These hold time predictions include a margin of 10%.

TECHNICAL DISCUSSION

The thermal model of the Probe was correlated to the data presented in Figure 1. Model output for the 2 cases presented table above are presented in Figures 2 and 3. Prediction of the ground hold time without gas conduction is presented in Figures 4. Predicted hold time with gas conduction in the Probe is presented in Figure 5.

Figure 1

Main bath boil-off rates with and without residual helium probe pressure: No He in Guard Tank

11 Apr 2002 15:11:43 SMD Flight Payload+SC [SV] / Data file: 0204110.PCD / Configuration is: Config4m SMD: Connect w/ SV using only GSE/Umbilical

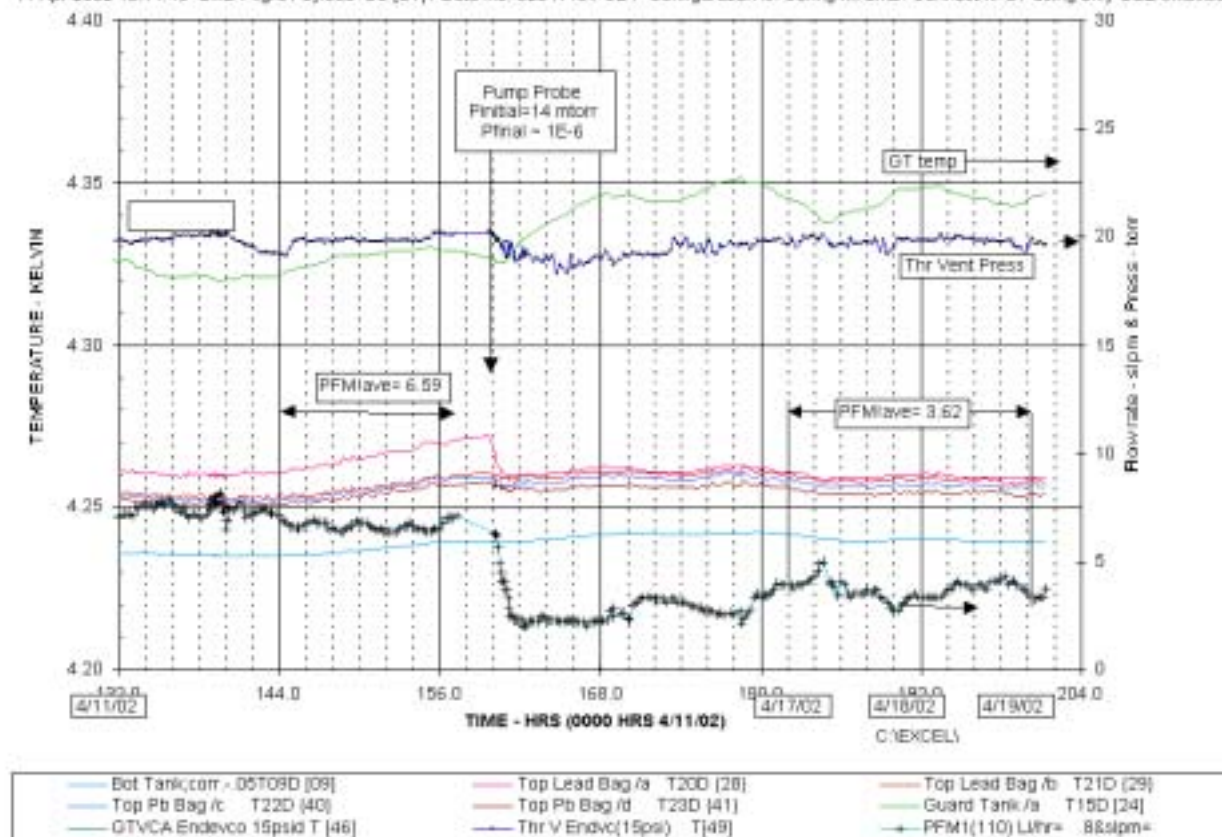


Figure 2

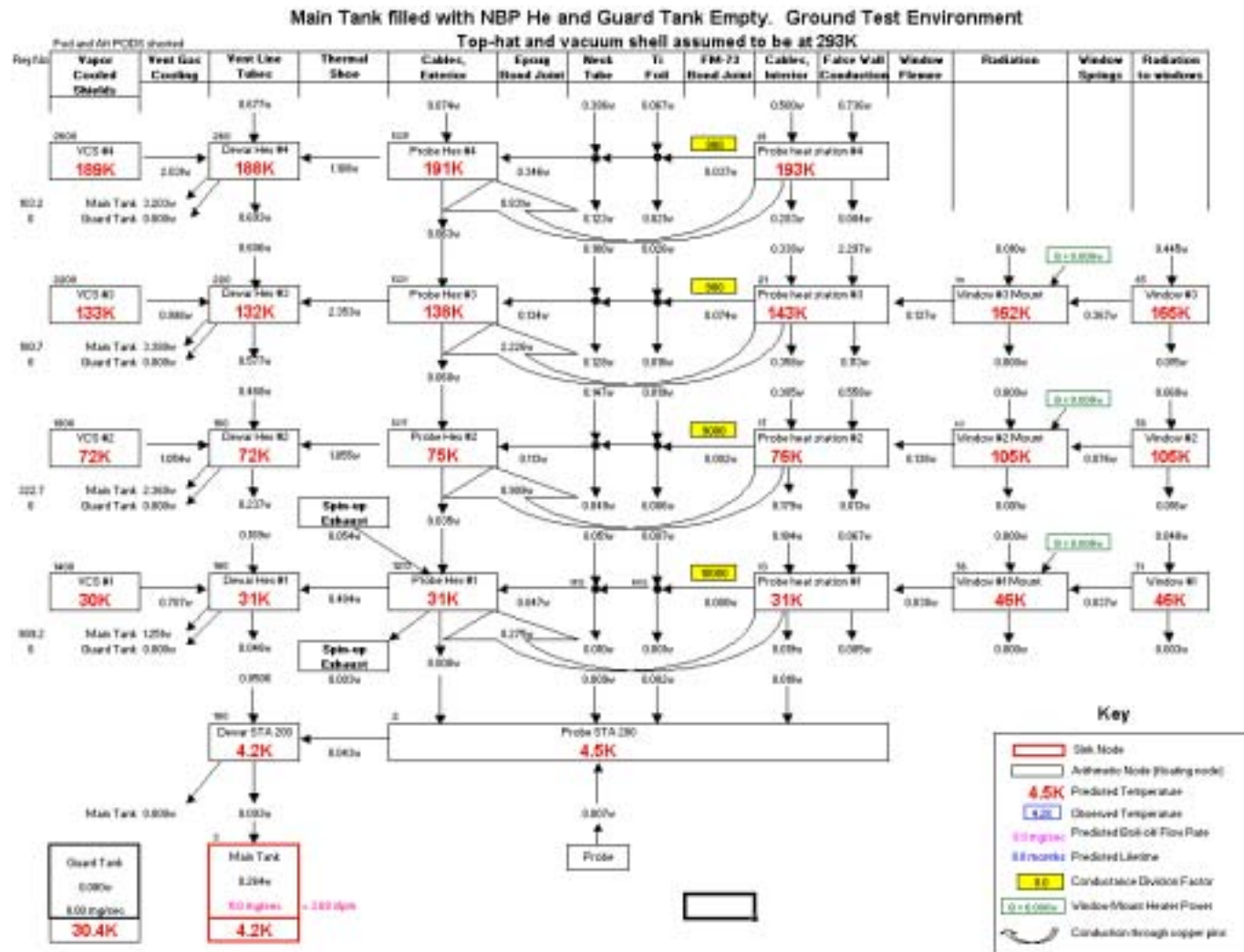


Figure 3

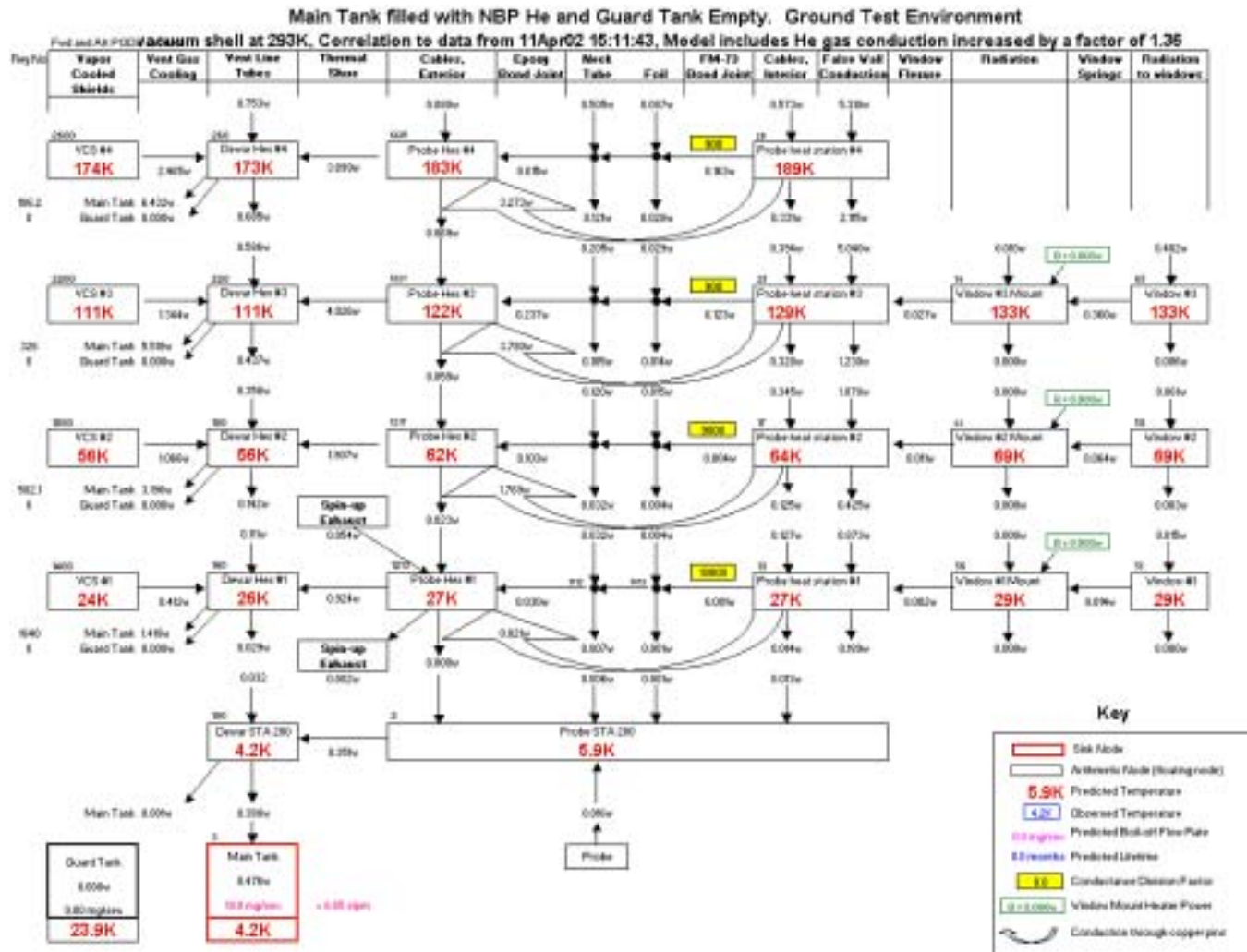


Figure 4

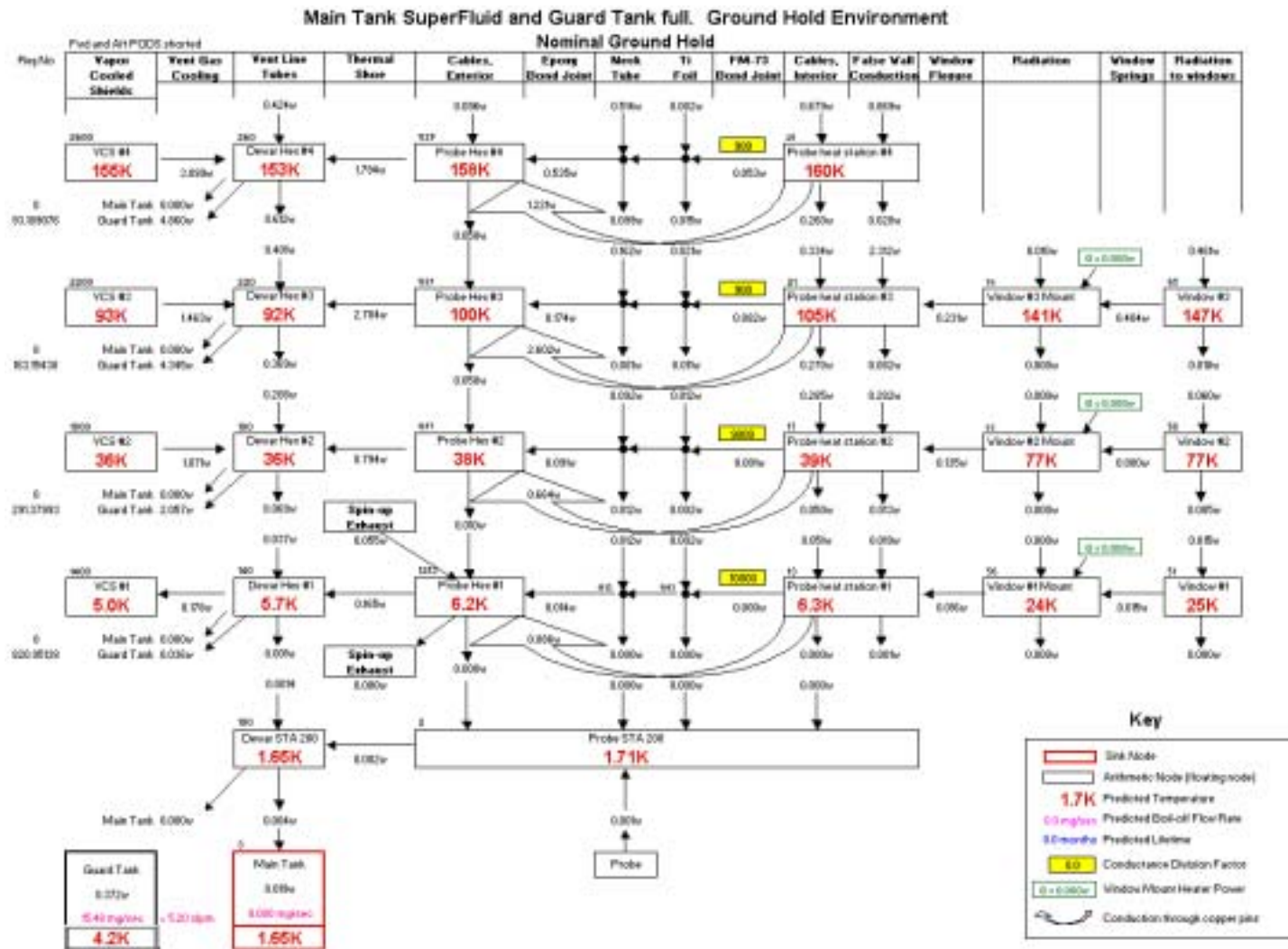
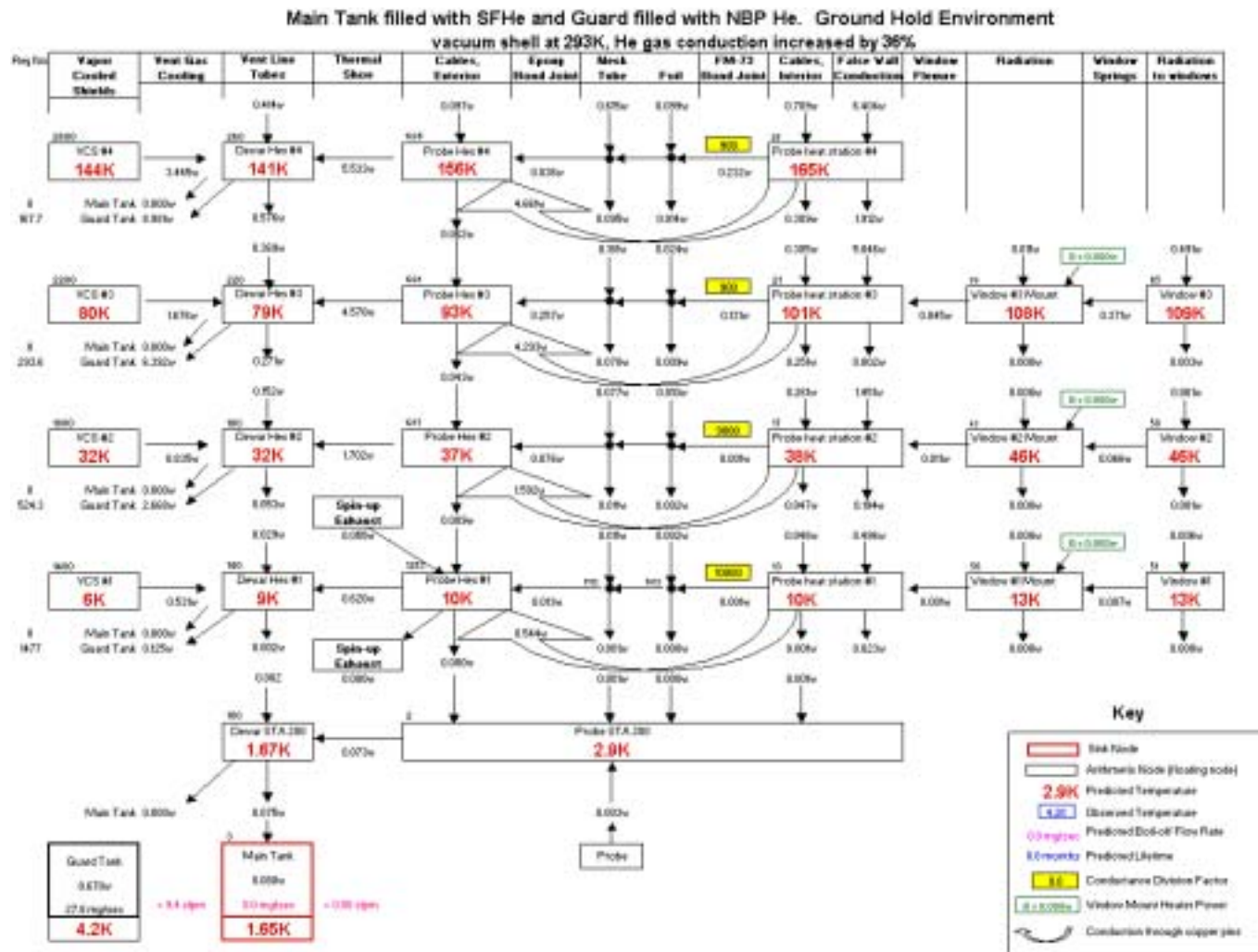


Figure 5



D.8 All latch Valve Leakage Data

D.8 All Latch Valve Leakage Data

GMA PTP MRA13238 Internal Leakage Data				8/9/02					
All test data taken with mass spectrometer unless otherwise stated.									
	Valve	Post Proof Internal Leakage Check (6-1-02)	Comment	Post Electrical Integration Internal Leakage Check (BubbleMin, inverted test tube test) 6-21-02	Post Vibration Internal Leak Rate (scs GHe) 6-28-02 (AVO50E96JRA04)	Post Vibration Internal Leak Test (scs GHe) 6-29-02 (AVO50E96JRA05)	Post Vibration Internal Leak Test (scs GHe) 7-2-02 (AVO-PTK-070102-Repeat Internal Leakage testing of GMA Latch Valves)	Post Vibration Internal Leakage Test per PTP (Valve Pairs tested) 7-17-02	Post Vibration Internal Leakage Test (scs GHe) 7-27-02 (AVO50E96JRA13)
	Limit	scs GHe (see comment)		< 1 Bubble/Minute	< 1 X 10-4 scs GHe	< 1 X 10-4 scs GHe	< 1 X 10-4 scs GHe	< 1 X 10-4 scs GHe	< 1 X 10-4 scs GHe
R1	V1	5.60E-05	Measured V1 & V2 at same time. LR < 2 E-4 scs GHe Required.	0		2.50E-05	1.40E-05	5.20E-05	1.60E-05
R2	V2			0		2.60E-05	1.60E-05		3.90E-05
R1	V3 & V5	1.30E-04	Measured V3, V4, V5 & V6 at same time. LR < 4 E-4 scs GHe Required.	0		1.70E-05	2.20E-05	2.80E-05	3.10E-05
R2	V4 & V6			0		1.20E-04	8.40E-05	1.60E-04	1.00E-04
S1	V7	2.30E-05	Measured V7, V8, V11, V12, V15, V16, V19, V20, V23, V24, V27 & V28 at same time. LR < 1.2 E-3 scs GHe Required.	0		1.70E-06	3.00E-06	1.60E-05	9.80E-07
S1	V8			0		1.40E-06	3.00E-06		9.10E-07
S1	V9	2.40E-04	Measured V9, V10, V13, V14, V17, V18, V21, V22, V25, V26, V29 & V30 at same time. LR < 1.2 E-3 scs GHe Required.	0		1.00E-06	3.00E-06	8.50E-06	2.40E-07
S1	V10			0		9.80E-07	3.00E-06		2.90E-07
S2	V11			0		1.80E-06	3.10E-06	3.00E-05	2.40E-05
S2	V12			0		1.80E-06	3.10E-06		1.20E-06
S2	V13			0		2.10E-06	3.10E-06	1.10E-05	4.20E-06
S2	V14			0		2.10E-06	3.10E-06		7.70E-07
S3	V15			0		1.40E-06	1.60E-05	1.10E-05	2.40E-05
S3	V16			0		1.50E-06	8.70E-06		1.40E-06
S3	V17			0		1.20E-06	2.70E-06	7.80E-06	5.00E-07
S3	V18			0		1.40E-06	2.00E-06		9.80E-07
S4	V19			0		1.40E-06	3.40E-06	1.00E-05	1.20E-06
S4	V20			0		2.40E-06	4.30E-06		9.40E-07
S4	V21			0		1.10E-06	2.30E-06	6.50E-04	4.40E-04
S4	V22			0		1.00E-06	2.60E-06		1.10E-06
S3	V23			0		1.30E-06	2.90E-06	1.00E-05	1.10E-06
S3	V24			0		2.40E-06	2.90E-06		1.20E-06
S3	V25			0		9.90E-07	1.40E-06	8.50E-06	5.00E-07
S3	V26			0		1.40E-06	1.40E-06		7.10E-07
Vent	V27			0	2.60E-04	1.40E-06	1.50E-06	2.00E-04	3.20E-04
Vent	V28			0.2	2.70E-05	1.30E-06	3.30E-06		1.20E-05
Vent	V29			0.8	1.00E-04	2.20E-05	2.30E-05	2.60E-04	5.20E-05
Vent	V30			0	4.30E-05	3.30E-05	6.90E-06		1.20E-04
	System Internal Leakage (V9,V10,V13,V14,V17,V18,V19,V20,V25,V26,V29,V30)								
	System Internal Leakage (V9,V10,V13,V14,V17,V18,V19,V20,V25,V26)								

S0701 GMA Valve Leakage Mitigation Plan

2/13/2003

GMA PTP MRA: All test data taken									
	Valve	Thermal Cycle 0 C Internal Leakage Test per PTP (Valve Pairs tested except V3-V6) 8-8-02	Thermal Cycle +40 C Internal Leakage Test per PTP 3.9.4 (Valve Pairs tested except V3-V6) 8-12-02	Thermal Cycle Ambient Internal Leakage Test per PTP 3.11.3 (Valve Pairs tested except V3-V6) 8-14-02	Thermal Cycle Ambient Internal Leakage Test per AVO (Valve Pairs tested except V3-V6) 8-16-02	Internal Leakage Test at Stanford Immediately after shipment from Moog (individual valves tested except V3-V6) 9-20-02	Internal Leakage Test at Stanford / Post gyro spin-up (individual valves tested except V3-V6) 9-28-02	Internal Leakage Test at LMMS / Post GMA to SIV installation - GMA Outlets Tested thru Off-pallet Fill and Drain Valves and Vent Ports (individual valves tested except V3-V6 pairs) 10-12-02	Leakage data as determined from the "Rate of Rise" test performed at Lockheed B156 1-17-03 thru 1-24-03; All GMA Latch valves are closed
	Limit	< 1 X 10-4 sccs GHe	< 1 X 10-4 sccs GHe	< 1 X 10-4 sccs GHe	< 1 X 10-4 sccs GHe	< 1 X 10-4 sccs GHe	< 1 X 10-4 sccs GHe	< 1 X 10-4 sccs GHe	
R1	V1	2.30E-05	6.80E-05	5.20E-05	2.60E-05	7.00E-06	2.4 E - 06	3.0 E - 04	no data
R2	V2				4.50E-05	2.8 E-05	8.2 E - 04	6.4 E - 04	no data
R1	V3 & V5				1.20E-05	6.5 E - 06	2.2 E - 06	2.4 E - 04	no data
R2	V4 & V6	3.90E-05	5.40E-05	2.00E-04	6.60E-05	1.5 E - 04	5.2 E - 03	2.5 E - 03	
S1	V7	5.50E-06	4.90E-06	1.90E-06	1.90E-06	4.8 E - 08	7.6 E - 08	5.0 E - 08	1.05E-07
S1	V8				1.10E-06	3.5 E - 08	1.2 E - 05	1.7 E - 06	
S1	V9	4.30E-06	4.70E-06	5.40E-07	7.50E-07	8.0 E - 09	1.8 E - 08	3.2 E - 09	
S1	V10				8.20E-07	5.0 E - 06	7.4 E - 08	8.0 E - 09	1.50E-07
S2	V11	1.00E-04	2.90E-05	2.50E-05	2.60E-05	2.5 E - 05	4.6 E - 05	2.6 E - 04	
S2	V12				1.20E-06	2.8 E - 08	8.6 E - 08	1.7 E - 06	
S2	V13	6.20E-06	5.50E-06	7.60E-07	2.50E-05	8.0 E - 09	1.0 E - 07	3.0 E - 05	
S2	V14				1.10E-06	7.0 E - 09	1.6 E - 07	1.0 E - 05	3.01E-07
S3	V15	4.20E-04	5.10E-06	1.80E-06	1.20E-06	4.0 E - 05	2.4 E - 07	6.8 E - 06	
S3	V16				1.20E-06	1.6 E - 08	1.4 E - 07	3.0 E - 07	
S3	V17	4.20E-06	4.60E-06	3.30E-06	6.40E-07	4.0 E - 09	2.0 E - 08	1.0 E - 08	
S3	V18				9.40E-07	1.1 E - 07	5.0 E - 05	2.5 E - 03	3.63E-07
S4	V19	4.20E-06	4.80E-06	1.30E-06	9.20E-07	2.0 E - 08	4.4 E - 08	6.0 E - 08	
S4	V20				6.90E-07	1.5 E - 08	4.2 E - 08	3.5 E - 07	
S4	V21	5.70E-04	4.50E-04	3.70E-04	2.30E-04	3.8 E - 04	7.8 E - 05	2.5 E - 03	
S4	V22				1.30E-06	7.0 E - 08	5.6 E - 08	2.5 E - 03	3.41E-07
S3	V23	5.20E-06	4.90E-06	1.40E-06	1.00E-06	2.8 E - 08	5.4 E - 08	6.0 E - 08	
S3	V24				8.60E-07	2.6 E - 08	4.4 E - 08	4.0 E - 07	
S3	V25	4.50E-06	4.90E-06	9.10E-07	1.80E-06	3.2 E - 09	2.0 E - 08	5.0 E - 09	
S3	V26				7.50E-07	3.4 E - 09	8.2 E - 08	2.5 E - 09	no data
Vent	V27	3.00E-04	4.60E-04	1.80E-04	8.00E-04	1.8 E - 04	1.2 E - 05	3.5 E - 04	
Vent	V28				8.00E-05	5.0 E - 06	1.0 E - 06	5.0 E - 04	
Vent	V29	9.10E-05	1.20E-04	1.80E-04	1.60E-04	1.0 E - 04	6.2 E - 06	4.0 E - 03	
Vent	V30				6.20E-05	9.0 E - 05	3.2 E - 05	4.0 E - 03	
	System Internal Leakage (V9,V10,V13,V14,V17,V18,V19,V20,V25,V26,V29,V30)								
	System Internal Leakage (V9,V10,V13,V14,V17,V18,V19,V20,V25,V26)								

S0701 GMA Valve Leakage Mitigation Plan

2/13/2003

GMA PTP MRA:					
All test data taken					
	Valve	Leakage data as determined from the "Rate of Rise" test performed at Lockhead B156 1-17-03 thru 1-24-03; GMA latch valves are in the launch configuration	Leakage data as determined from the "Rate of Rise" test performed at Lockhead B156 1-17-03 thru 1-24-03; GMA latch valves are in the launch configuration	GMA Line	Valve
	Limit				Limit
R1	V1	3.41E-04	5.33E-05	R1	V1
R2	V2			R2	V2
R1	V3 & V5	2.48E-04	1.78E-04	R1	V3 & V5
R2	V4 & V6			R2	V4 & V6
S1	V7	2.65E-07	no additional data taken	S1	V7
S1	V8			S1	V8
S1	V9	4.02E-07	no additional data taken	S1	V9
S1	V10			S1	V10
S2	V11	4.02E-07	no additional data taken	S2	V11
S2	V12			S2	V12
S2	V13	4.02E-07	no additional data taken	S2	V13
S2	V14			S2	V14
S3	V15	3.49E-04	4.31E-06	S3	V15
S3	V16			S3	V16
S3	V17	3.49E-04	4.31E-06	S3	V17
S3	V18			S3	V18
S4	V19	3.01E-07	no additional data taken	S4	V19
S4	V20			S4	V20
S4	V21	3.01E-07	no additional data taken	S4	V21
S4	V22			S4	V22
S3	V23	2.10E-06	no additional data taken	S3	V23
S3	V24			S3	V24
S3	V25	2.10E-06	no additional data taken	S3	V25
S3	V26			S3	V26
Vent	V27	2.64E-04	no additional data taken	Vent	V27
Vent	V28			Vent	V28
Vent	V29	2.64E-04	no additional data taken	Vent	V29
Vent	V30			Vent	V30
	System Internal Leakage (V9,V10,V13,V14,V17,V18,V19,V20,V25,V26,V29,V30)	2.03E-03			System Internal Leakage (V9,V10,V13,V14,V17,V18,V19,V20,V25,V26,V29,V30)
	System Internal Leakage (V9,V10,V13,V14,V17,V18,V19,V20,V25,V26)	1.77E-03			System Internal Leakage (V9,V10,V13,V14,V17,V18,V19,V20,V25,V26)

D.9 GMA Rate of Rise Report

52 pages of original report follows



STANFORD UNIVERSITY
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GRAVITY PROBE B, RELATIVITY GYROSCOPE EXPERIMENT
STANFORD, CALIFORNIA 94305-4085

GMA

“RATE OF RISE”

TEST

2/12/03

by
Ken Bower

with
Rick Stephenson,
Chris Gray,
Gregg Scott,
and
Dave Meriwether

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A Scope

This report summarizes the data collected during a series of “Rate of Rise” tests conducted on the flight GMA from 1/17/03 to 1/24/03. Additionally, these data will be compared to some comparable data taken during earlier “Leak Rate” tests. These results may become part of the GMA Leakage Mitigation Plan, but that plan is not addressed here.

B Background

The flight GMA is known to have problems with leakage through some latching valves. Sufficient leakage could cause any of the following problems to occur:

1. Atmospheric gases could enter the GMA through the vent port and later contaminate the probe during flight operations.
2. Sufficient volumes of Helium could enter the probe from the GMA prior to flight to cause a significant increase in the boil-off rate of the flight cryogenic supply.
3. Sufficient Helium could leak from internal volumes of the GMA to reduce some pressures below the minimum amount required for safe protection of the GMA pressure regulators during launch.
4. Sufficient Helium could escape from the GMA main tanks to reduce available supply to less than the requirements for flight operations.

Prior to this “Rate of Rise” test, data about leakage rates were collected with a “Leak Rate” approach. The Leak Rate tests indicated seriously high leakage rates which would have a serious impact on flight preparations. However, the recorded results of that testing have been disputed by recent evidence that the tools used to collect those data were not functioning properly for the range of leaks measured.

The observed “flavors” of leakage are of two types (note: no effort is made to determine the cause of the leakage, just to describe the form it takes). Some valves have a consistent leak rate. When that rate is greater than 1×10^{-6} sccs, we generally consider it to be “leaky”. Some valves seem to have variable leak rates, changing from cycle to cycle (call them “intermittent”). The impact of leak rates varies depending upon the valve location and the state of the Space Vehicle and shall be addressed in the GMA Mitigation Plan.

C Method

C.1 Set up

Stanford Procedures P0970 and P0971 were used to conduct these tests. More detailed descriptions of the hardware used can be found in those documents. Figure 1 displays a schematic of the GMA with the related GSE hardware.

The GMA was installed on the GP-B Space Vehicle and fully plumbed to the top hat valves, which were closed (isolating the GMA from the Probe). The GMA was connected to the Engineering Unit ECU for the duration of this test, which provided the controls for the GMA valves and readouts of some GMA transducers. Nine isolated GSE volumes were connected to GMA access points, each with a pressure transducer as follows:

Volume ID	GSE hkup. point	transducer ID*	internal volumes**	nearest thermometer
Zone I	none	GP1	10600 cc	SDT1A, SDT1B
Zone IIA	none	GP2	3.38 cc	SDT3A
Zone IIB	none	GP3	3.38 cc	SDT3A
Zone IIIA	MV3	PMV3	14.1 cc	SDT2A, Fill Manifold
Zone IIIB	MV4	PMV4	14.0 cc	SDT3B, Fill Manifold
Zone IVA	none	(GP4)	11.0 cc	SDT3B
Zone IVB	none	(GP5)	10.7 cc	SDT3B
Zone V	MV2	PMV2, (GP6)	19.0 cc	SDT3B, Fill Manifold
Zone VI	none	none	1.33 cc x6****	SDT3B
Zone VII Vent	Vent	PVent***, (GP14)	333 cc	Outlet Manifold
Zone VII S1	F&DS1	PS1, GP7, GP8	154 cc	Outlet Manifold
Zone VII S2	F&DS2	PS2, GP9, GP10	156 cc	Outlet Manifold
Zone VII S3	F&DS3	PS3, GP11	155 cc	Outlet Manifold
Zone VII S4	F&DS4	PS4, GP12, GP13	156 cc	Outlet Manifold
Zone VII P1A	F&DP1A	PP1A	158 cc	Outlet Manifold

Data is only available for some transducers and thermometers at this time.

*transducers in parenthesis were generally always out of range.

**some volumes are currently estimates – actual volumes should be within 10% of estimates.

***PVent actually has two transducers, a 500 psia and a 50 psia.

****there are six Zone VI's – one each upstream of S1, S2, S3, S4, P1A, and Vent. Total volume is 8.00 cc.

Transducer accuracy data is available. In general, all transducers have a net readout accuracy for pressure changes that is greater than required for this test. Several transducers do have zero-offsets that, when significant, have been corrected in the data presented.

C.2 Test sequences

This series of tests specifically tested two states, “Ground” and “Launch”. During the course of the operations, we decided to add an additional “Alternate Launch” state for a short test run and then repeated “Launch” state (designated run 2).

C.2.1 Ground State

Figure 2 provides a visual description of the test set-up for this state.

The following conditions were established in the GMA to mimic “ground holding state”:

- Zone I (main tanks) was unchanged (~1061 psia)
- Zone II (between tanks and regulators) was filled to 300 psia
- Zone III (between regulators) was filled to 300 psia
- Zone IV (between regulators and flow controllers) was filled to 300 psia
- Zone V (between flow controllers and outlet quads) was filled to 300 psia
- Zone VI (within outlet quads) was evacuated (except for vent quad)
- Zone VII (outlets) was evacuated (except for vent quad)
- Vent quad Zones VI and VII was filled to 300 psia
- All GMA valves were closed

This configuration ran for about 91 hours.

C.2.2 Launch State (run 1)

Figure 3 provides a visual description of the test set-up for this state.

The following conditions were changed from “Ground” state to mimic the transition to “Launch” state expected to occur 36 to 18 hours before launch:

- Vent Zone VII was reduced to 15psia
- GMA valves V7, V8, V11, V12, V15, V16, V21, V22, V23, V24, V27, V28 were opened
- Zone VII was evacuated (except for vent quad)

This configuration ran for about 42 hours.

C.2.3 Alternate Launch State

Figure 4 provides a visual description of the test set-up for this state.

It was observed that S3 pressures were rising very rapidly. The following conditions were changed from “Launch” state to an “Alternate Launch” state to swap the normally open and closed valves in the S3 quad.

- GMA Valves V15 and V16 were closed
- GMA Valves V17 and V18 were opened
- S3 was evacuated

This configuration ran for about 1.5 hours.

C.2.4 Launch State (run 2)

Figure 3 provides a visual description of the test set-up for this state (same as run 1).

Original “Launch” state was restored to learn if V17/V18 was of the “leaky” or “intermittant” variety.

The following conditions were changed from “Alternate Launch” to “Launch” state:

GMA Valves V17 and V18 were closed

GMA Valves V15 and V16 were opened

This configuration ran for about 20 hours.

C.3 Sources of Error

C.3.1 Temperature

The primary source of temperature variation is the ambient room temperature, which is maintained in B156 to within $\sim 1^{\circ}\text{F}$ and monitored within the room. Additionally, a thermocouple device was mounted on the fill manifold and on the outlet manifold and monitored by the same data collection system which monitored the GSE pressure transducers.

Secondary sources of temperature variation are local environmental heating (a person working near the GMA) or cooling (a venting of cooled Helium from the cryogenic tanks). These variations should also be detected by the thermocouples described above.

Potential tertiary sources of temperature variation are the fluctuations inherent with gas flow (minimal with Helium) and brief heating of the valve coils during activation. These effects would probably be undetected by the GSE thermocouples, but might be measured by the flight thermometers.

In general, all thermal variations were slight throughout the test and appeared to have no relevance to the overall results. However, a slight correlation was predicted and measured between the temperature and pressure of the GMA main tanks. Review charts Thermal 1 and Thermal 2 for comparison. This does not, however, have any bearing on the overall results.

C.3.2 Noise

It is apparent that some “noise” effects exist within the data. It is presumed that this noise is primarily due to electrical effects. The net effect of this noise is that longer test periods (hours versus minutes) are required to accurately measure rates over time.

The most significant expression of noise occurs at about 65 hours into the ground state test, but even that seems to have little bearing on the overall results.

D Results

D.1 “Rate of Rise” test data

D.1.1 Overall Timeline

The appended chart (overall timeline) provides a useful view for understanding the entire test run and its various phases (and their lengths). Data collection rate is usually every ten minutes.

- D.1.1.1. Not visible is a very rapid drop at 0 hours from 300 to 295 psia which occurred in less than fifteen minutes.
- D.1.1.2. The “stutter” that occurs at ~65 hours seems to be a test anomaly that is unexplained at present (and presumed to be some kind of electrical effect). This stutter is evident in several data sets.
- D.1.1.3. The significant vertical drop at ~90 hours occurs when the pressure in Zone V expands to fill the vacuums of Zone VI in the S1, S2, S3, and P1A quads.
- D.1.1.4. The rapid drop from ~90 to ~135 hours indicates the losses of pressure through all GMA outlets. These losses are dominated by S3 and the Vent. The brief gap at ~130 hours is due to the recording device being briefly offline to download data.
- D.1.1.5. A fairly imperceptible change in slope occurs at ~138 hours when the S3 closed and open valves were swapped.
- D.1.1.6. The significant vertical drop at ~140 hours occurs when the pressure in Zone V expands to fill the vacuum of Zone VI in the S3 quad.
- D.1.1.7. The final drop from ~140 to ~158 hours again indicates the losses of pressure through all GMA outlets. These losses are dominated by the Vent only.

D.1.2 “Ground” state test data

- D.1.2.1. Zone I (GP1) made no notable changes in pressure. Variations in the reading of Zone I pressure is primarily attributed to temperature variations and electronic noise. Note that no plot is provided – these data are not yet available. This indicates that problem #4 is not a real concern in Ground state.
- D.1.2.2. Zones IIA (GP2) and IIB (GP3) had an initial loss of ~2% in the first several minutes and then had a total variance (positive and negative) of less than 1% over the remaining 90 hours (with a net increase in pressure). Note that no plot is provided – these data are not yet available.
- D.1.2.3. (refer to chart Zones III and V, ground state) Zones IIIA (MV3) and IIIB (MV4) had an initial loss of ~1% in the first several minutes and then had a total loss of about 0.3% over the remaining 90 hours. This indicates that the upper stage of the regulators can be protected (>100psia) in Ground state for >1000 days.
- D.1.2.4. No data could be taken for Zones IVA and IVB during this test. It can be safely assumed that the pressures in Zone IV are between the values for Zones III and V.
- D.1.2.5. (refer to chart Zones III and V, ground state) Zone V (MV2) had an initial loss of ~2% in the first several minutes and then had a total loss of about 0.3% over the remaining 90 hours. This implies that the lower stage of the regulators can be protected (>100psia) in Ground state for >1000 days (with a similar or larger volume Vent configuration).

- D.1.2.6. No data could be taken for Zone VI during this test. There are no requirements for hold time on Zone VI.
- D.1.2.7. (refer to chart Zone VII, ground state) S1, S2, S3, S4, and P1A all had modest measurable rises, generally characterized by sharper increases at the start which taper to a linear rate after several minutes or hours. These leak rates are depicted in the appended charts and summarized in a table. These leak rates should be analyzed with respect to their effect on the probe.
- D.1.2.8. The Vent had drops similar to Zone V. This implies that the vent line acts as a ballast for Zone V in this configuration. (refer to chart Vent, ground state)

D.1.3 “Launch” state test data (run 1)

- D.1.3.1. (refer to chart Zone I, launch state) Zone I (GP1) made no notable changes in pressure. Variations in the reading of Zone I pressure is primarily attributed to temperature variations and electronic noise. This indicates that problem #4 is not a real concern in Launch state.
- D.1.3.2. (refer to chart Zone II, launch state) Zones IIA (GP2) showed essentially no change (perhaps a slight rise). Zone IIB (GP3) showed a ~2% increase in pressure over 44 hours.
- D.1.3.3. (refer to chart Zone III, launch state) Zones IIIA (MV3) and IIIB (MV4) had very small increases over the 44 hours. This indicates that the upper stage of the regulators can be protected (>100psia) in Launch state indefinitely.
- D.1.3.4. No data could be taken for Zones IVA and IVB during this test. It can be safely assumed that the pressures in Zone IV are between the values for Zones III and V.
- D.1.3.5. (refer to chart Zone V, launch state) Zone V (MV2) had an initial loss of ~20% when the Normally Open valves opened and pressure from Zone V filled Zone VI in four quads. It then had a rapid loss (~0.35% per hour). This pressure was leaked out into S1, S2, S3, S4, P1A, and the Vent outlets (dominated by Vent and S3). At this leak rate, Zone V (and potentially Zone IV) would drop below 100 psia in about 7 days, leading to a potential for problem #3 to occur. After about 12 total days, pressure would drop to 15 psia, leading to a potential for problem #1 to occur.
- D.1.3.6. No data could be taken for Zone VI during this test. There are no requirements for hold time on Zone VI.
- D.1.3.7. (refer to chart S1-P1A, launch state – two scales) S1, S2, S4, and P1A all had modest measurable rises, generally characterized by sharper increases at the start which taper to a linear rate after several minutes or hours. S3 had a dramatic increase in pressure. These leak rates are depicted in the appended charts and summarized in a table. These leak rates should be analyzed with respect to their effect on the probe.
- D.1.3.8. (refer to chart Vent, launch state) The Vent ballast had increases in pressure indicating that a significant amount of pressure leaked from Zone V out the Vent.

D.1.4 “Alternate Launch” state test data

- D.1.4.1. (refer to chart Zone I, alternate launch state – two scales) Zone I (GP1) made no notable changes in pressure. Variations in the reading of Zone I pressure is primarily attributed to temperature variations and electronic noise. This indicates that problem #4 is not a real concern in Alternate Launch state.

- D.1.4.2. (refer to chart Zone II, alternate launch state – two scales) Zones IIA (GP2) and IIB (GP3) showed essentially no change (perhaps a slight drop). Note that the short duration of this test makes it difficult to quantify small changes.
- D.1.4.3. (refer to chart Zone III, alternate launch state – two scales) Zones IIIA (MV3) and IIIB (MV4) showed essentially no change (perhaps a slight drop). Note that the short duration of this test makes it difficult to quantify small changes.
- D.1.4.4. No data could be taken for Zones IVA and IVB during this test. It can be safely assumed that the pressures in Zone IV are between the values for Zones III and V.
- D.1.4.5. (refer to chart Zone V, alternate launch state – two scales) Zone V (MV2) had a rapid loss (~0.25% per hour). This pressure was leaked out into S1, S2, S3, S4, P1A, and the Vent outlets (dominated by Vent and S3). At this leak rate, Zone V (and potentially Zone IV) would drop below 100 psia in about 10 days, leading to a potential for problem #3 to occur. After about 16 total days, pressure would drop to 15 psia, leading to a potential for problem #1 to occur. This is a modest improvement (~30%) over the initial Launch state.
- D.1.4.6. No data could be taken for Zone VI during this test. There are no requirements for hold time on Zone VI.
- D.1.4.7. (refer to chart S1-P1A, alternate launch state – two scales) S1, S2, S4, and P1A all had modest measurable rises. S3 had a dramatic increase in pressure. These leak rates are depicted in the appended charts and summarized in a table. These leak rates should be analyzed with respect to their effect on the probe. Note that the short duration of this test makes it difficult to quantify small changes.
- D.1.4.8. (refer to chart Vent, alternate launch state – two scales) The Vent ballast had increases in pressure indicating that a significant amount of pressure leaked from Zone V out the Vent. Note that the short duration of this test makes it difficult to quantify small changes.
- D.1.5 “Launch” state test data (run 2)
 - D.1.5.1. (refer to chart Zone I, launch state 2) similar to run 1.
 - D.1.5.2. (refer to chart Zone II, launch state 2) similar to run 1.
 - D.1.5.3. (refer to chart Zone III, launch state 2) similar to run 1.
 - D.1.5.4. similar to run 1.
 - D.1.5.5. (refer to chart Zone V, launch state 2) Zone V (MV2) had a rapid loss (~0.10% per hour). This pressure was leaked out into S1, S2, S3, S4, P1A, and the Vent outlets (dominated by Vent). At this leak rate, Zone V (and potentially Zone IV) would drop below 100 psia in about 22 days, leading to a remote potential for problem #3 to occur. After about 35 total days, pressure would drop to 15 psia, leading to a potential for problem #1 to occur. This is a consequential improvement (~200%) over the initial Launch state.
 - D.1.5.6. similar to run 1.
 - D.1.5.7. (refer to chart Zone VII, launch state 2 – two scales) S1, S2, S3, S4, and P1A all had modest measurable rises. These leak rates are depicted in the appended charts and summarized in a table. These leak rates should be analyzed with respect to their effect on the probe. This is a dramatic improvement over the initial Launch state. Note that the outlets were not evacuated at the start of this run, so base pressures were higher than the start of other tests.
 - D.1.5.8. (refer to chart Vent, launch state 2) similar to run 1.

E Comparison to prior “Leak Rate” test

E.1 “Leak Rate” test equipment

The last “Leak Rate” test was conducted on 10/12/02, after the GMA was installed on the Space Vehicle and all flight plumbing connection were completed. The measurements were made with an Alcatel model 180t Helium leak detector, using P0931A, a method identical in process to prior tests conducted on the GMA at Stanford and at Moog. Significantly higher leakage rates were measured during this test than in prior tests.

The variance from prior results and severity of leak rates disposed us to further evaluation of the leak detector. The instrument was given field servicing by an Alcatel technician and properly calibrated prior to the test. However, it was theorized that the instrument could have a linearity problem which would only become significant when testing leaks much larger (or much smaller, but smaller leaks are not of a concern to us) than the calibration leaks. Generally, these instruments are used primarily to *detect* leaks and not to *measure* leaks and generally those leaks would be on the order of 10^{-9} to 10^{-6} sccs. We know that we wish to *measure* leaks on the order of 10^{-6} to 10^{-3} sccs.

Unfortunately, further evaluation of the instrument required the acquisition of unusual calibrated leaks, which took many weeks to acquire. Once those leaks were measured by the instrument under similar conditions and calibration values, it was clear that the instrument did indeed have a significant linearity problem. In general, it appears that for every decade of deviation from the calibration point, an additional decade of error is measured (i.e. when calibrated at 10^{-7} , a 10^{-6} leak measures at 10^{-5} and a 10^{-5} measures at 10^{-3}). This deviation also seems to occur for smaller leaks as well (i.e. a 10^{-8} measures at 10^{-9}), but those are not of concern. A simplified display of the most relevant data can be reviewed in chart Alcatel Multi Range Performance.

Further evaluation of the instrument by Alcatel technicians proved that the problem was not field serviceable. The instrument will be sent to the factory for repair.

E.2 “Leak Rate” test conditions

It has always been a significant challenge for GP-B to perform leak checking since most leak detectors are sensitive to the same gas which is used in almost every filled volume in the space vehicle – Helium. This habitually requires that volumes under test require lengthy periods of evacuation to reduce background before accurate leakage measurements can be performed. Depending upon test conditions and GSE set-ups, this time can be from several minutes to several days.

The GMA has been a schedule challenged system from its inception. In order to reduce the time of a single “Leak Rate” test to less than two days (which tests thirty valves and requires several volumes to be pressurized with Helium and then evacuated for test), it was necessary to reduce the standard evacuation time to a nominal ten minutes when possible. This often meant that background (primarily Helium outgassing) could be a significant component of the measured leak rate.

Additionally, it can be observed in several of the plots from the “Rate of Rise” data that initial leakage rates (from the time of valve closure) can be somewhat higher than ultimate leakage rates. These rates typically take several minutes to several hours to stabilize.

The effects described in the preceding three paragraphs all imply that the “Leak Rate” test method (as used) will tend to report higher leakage rates than actually occur over time. This has real consequences, but they are significantly less than the errors introduced by the faulty instrument in the preceding section. This does, however, imply that long term testing is valuable.

F Conclusions

1. Combining the rates of pressure rise with the volumes of the relevant areas allows us to generate simplified long-term leak rates for the volumes tested. This “real application” test is considered to have results which predict average leak rates better than the “Leak Rate” testing method used in prior testing. These simplified leak rates are expressed in Table 1.

2. “Intermittent” valves must be addressed in the GMA Risk Mitigation Plan. Results from this test (and prior “Leak Rate” tests) indicate that “intermittent” valves can seal successfully, but that the leakage must be measured – it can not be predicted.

3. The results from this test should be used in the preparation of the GMA Risk Mitigation Plan. With the preliminary results available at this time, it seems likely that only problem #2 (Helium into the probe) needs significant analysis. The other problems (air contamination, loss of regulator lockup and loss of Helium supply) are easily solved within the current launch operations plan. The methods of this solution will be detailed in the GMA Risk Mitigation Plan. A simplified summary of these effects is expressed in Table 2.

4. Additional testing of this nature would be desirable.

G Figures

G.1 Figure 1 – GMA & GSE Schematic

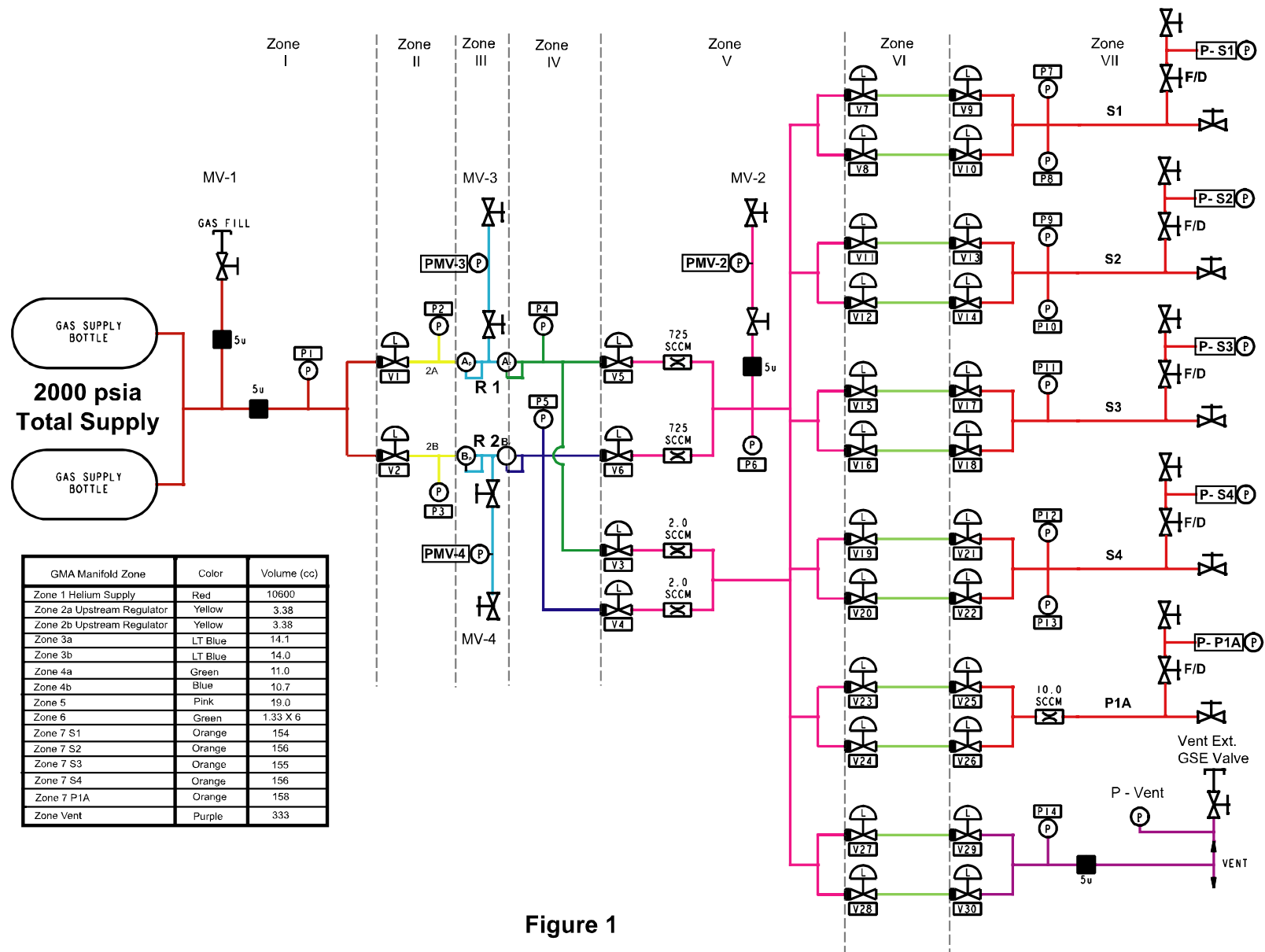
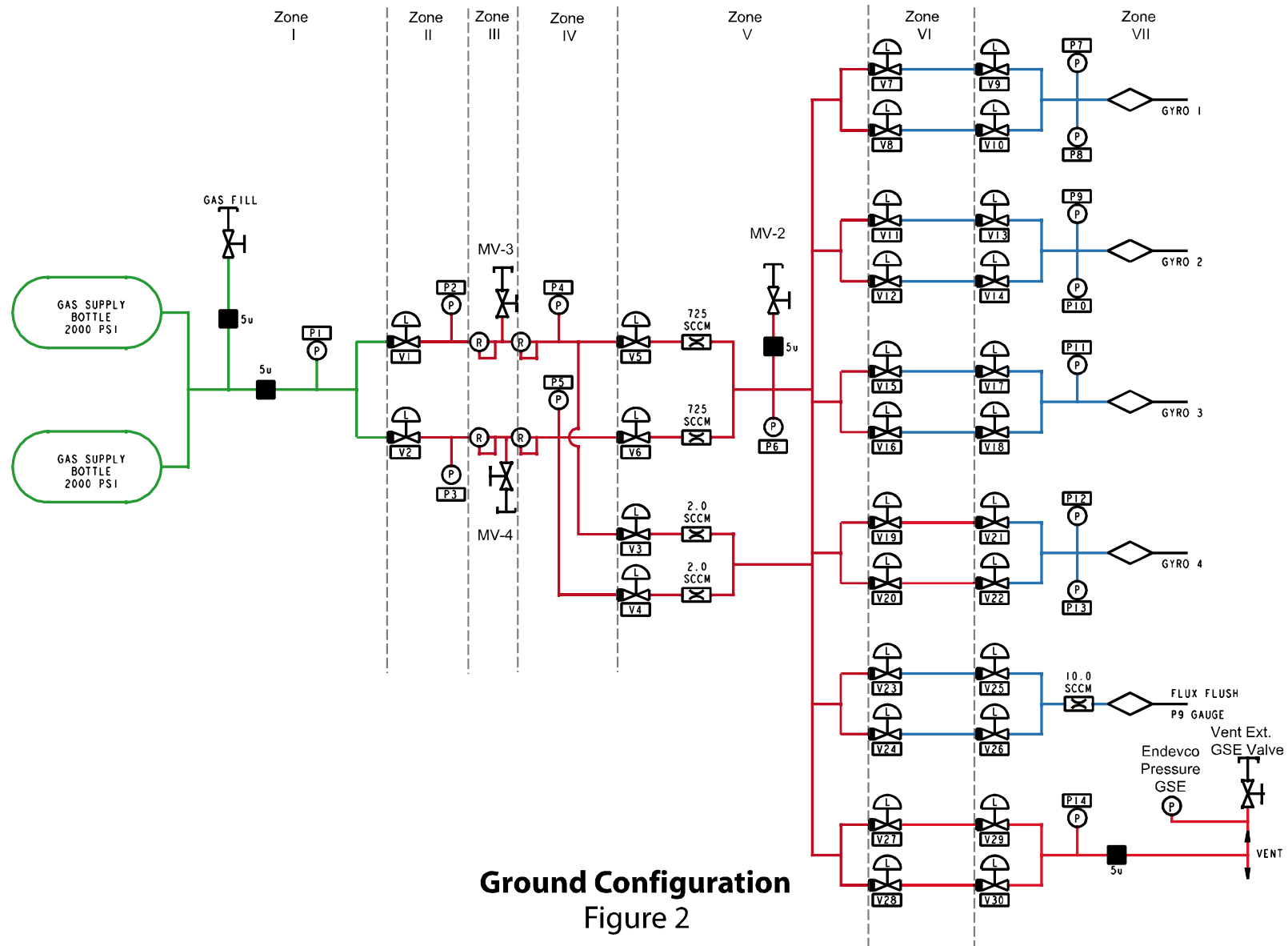
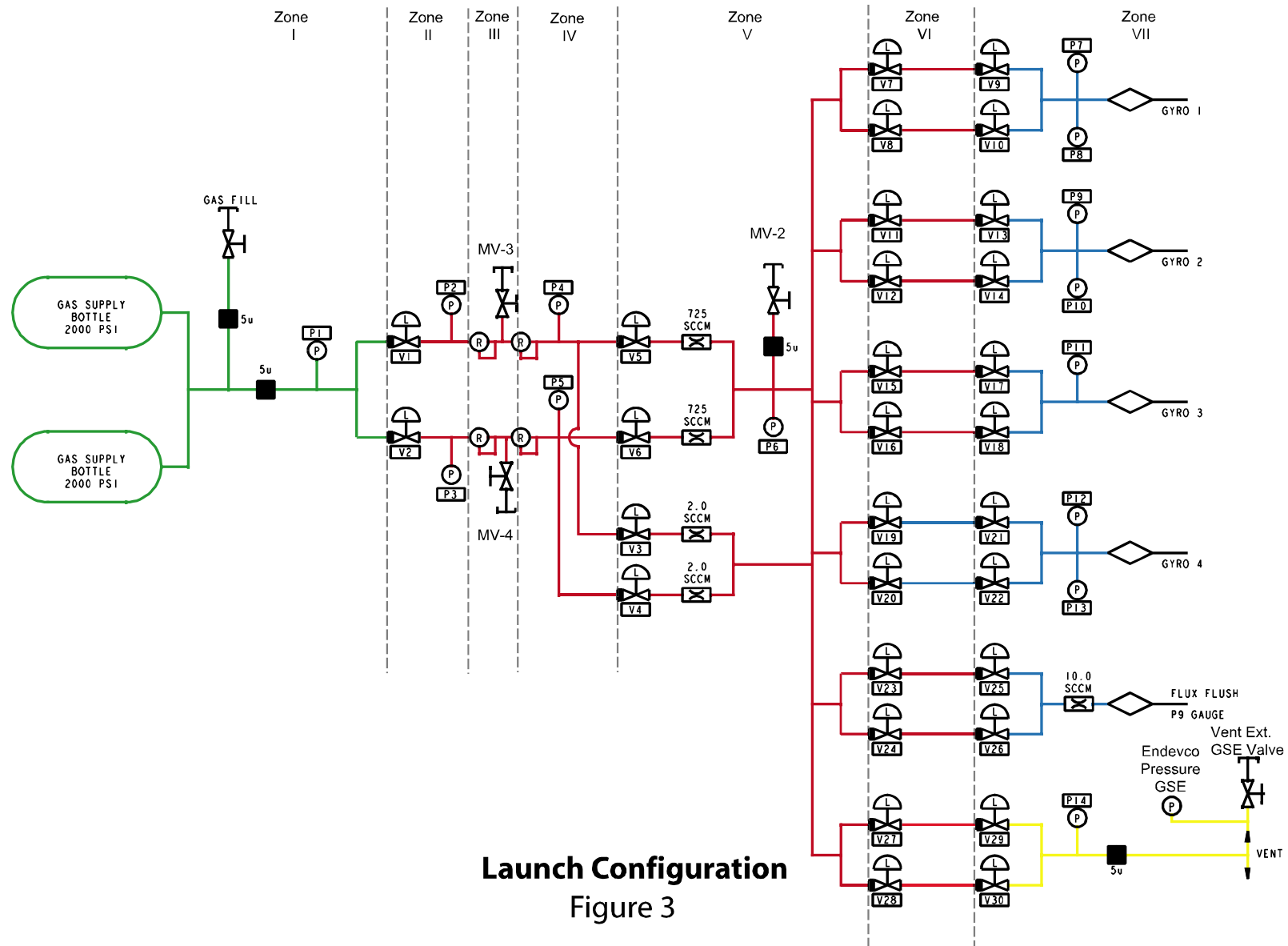


Figure 1

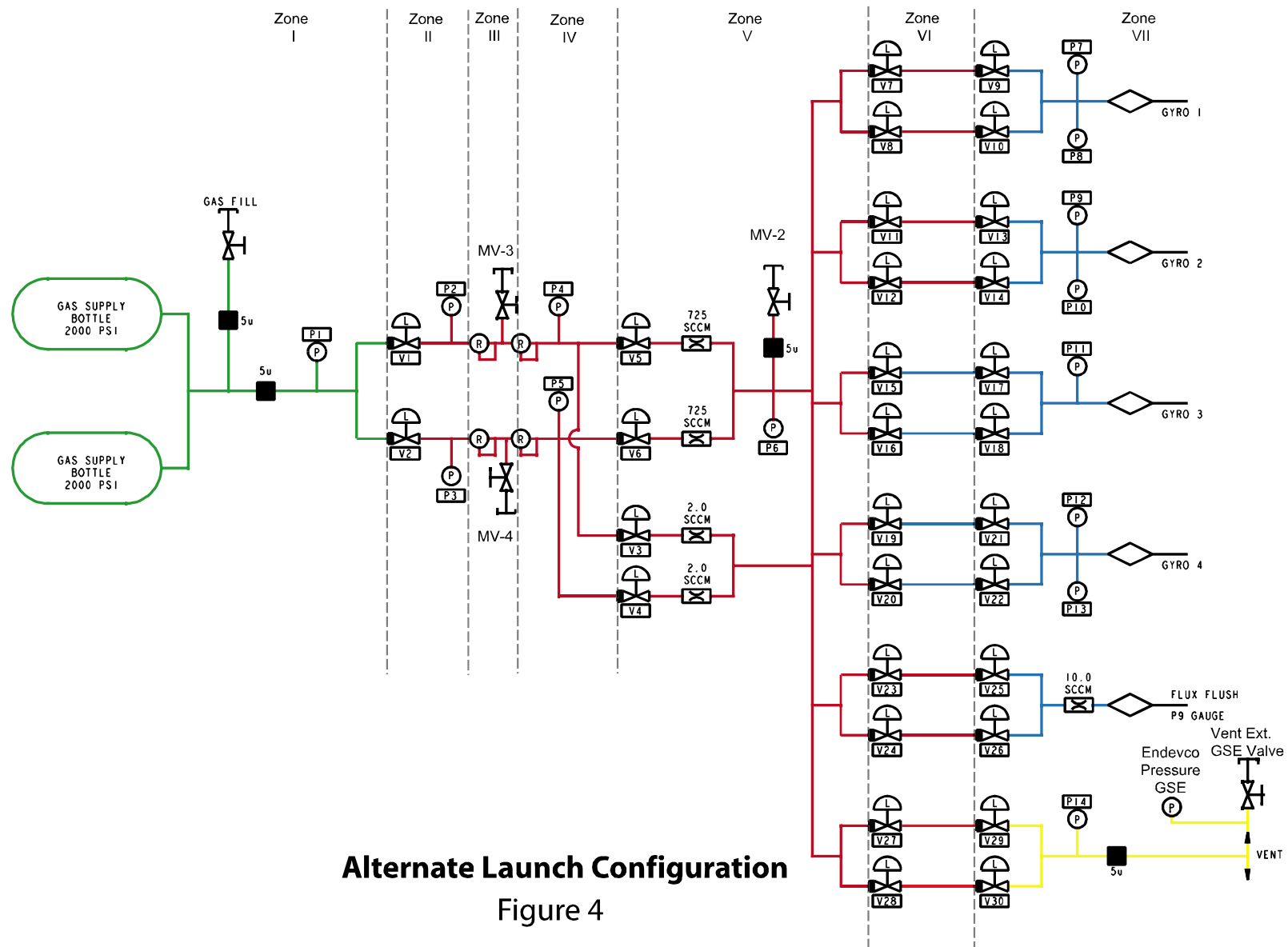
G.2 Figure 2 – Ground State



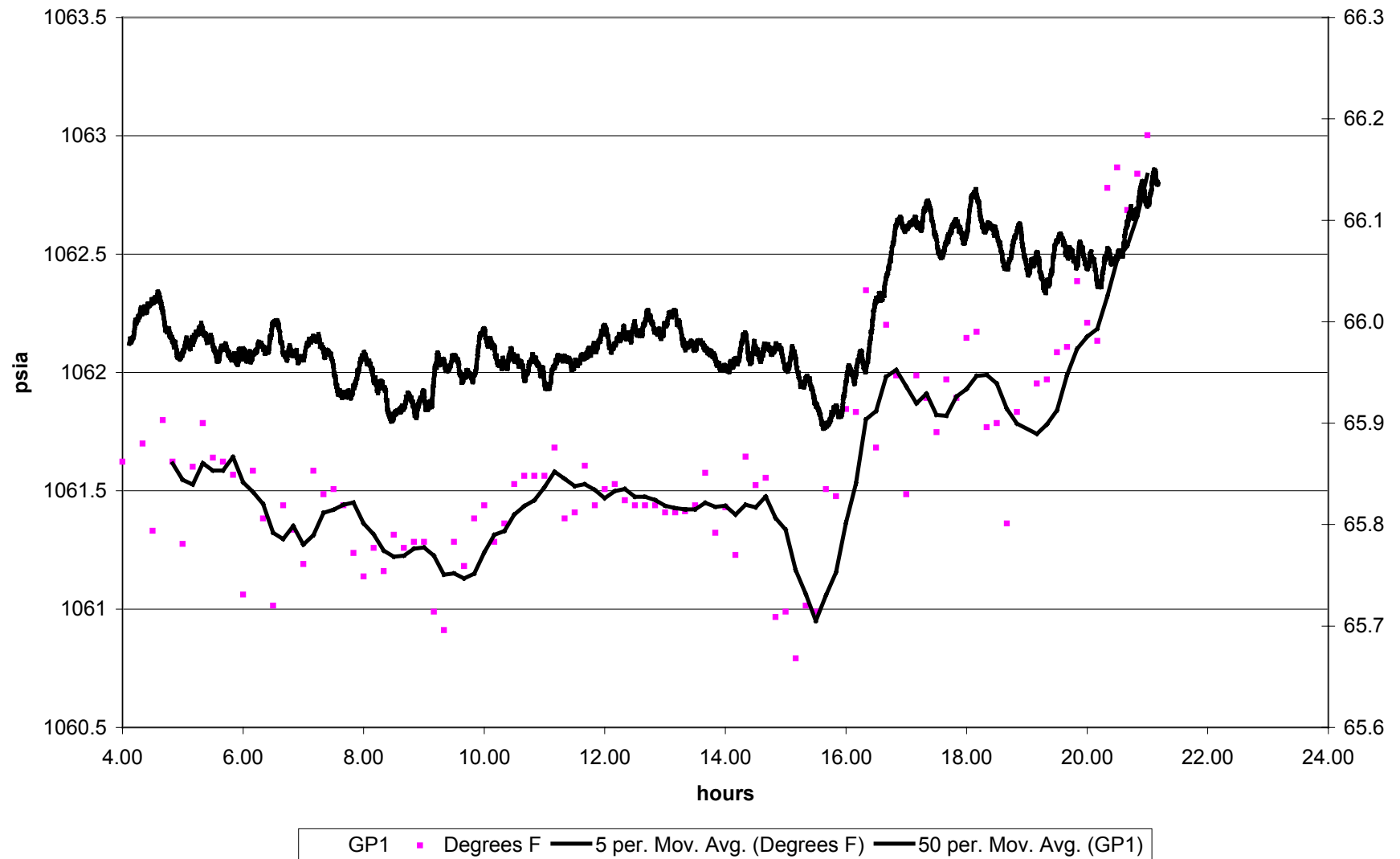
G.3 Figure 3 – Launch State



G.4 Figure 4 – Alternate Launch State



GMA Rate of Rise Test
Ken Bower, et.al.
02/13/03
H Charts

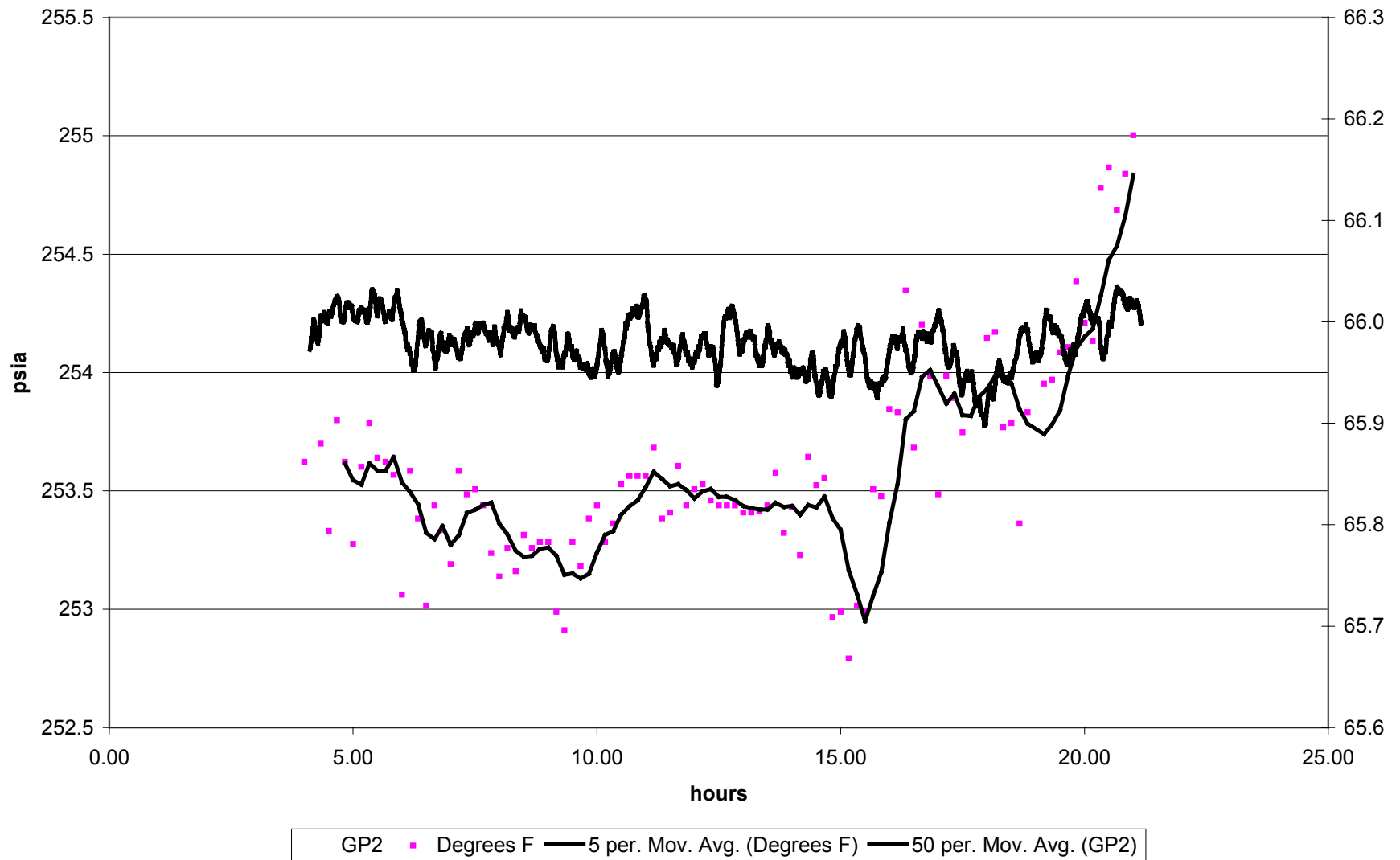


H.1 Chart 1 – Thermal 1

H.2 Chart 2 – Thermal 2

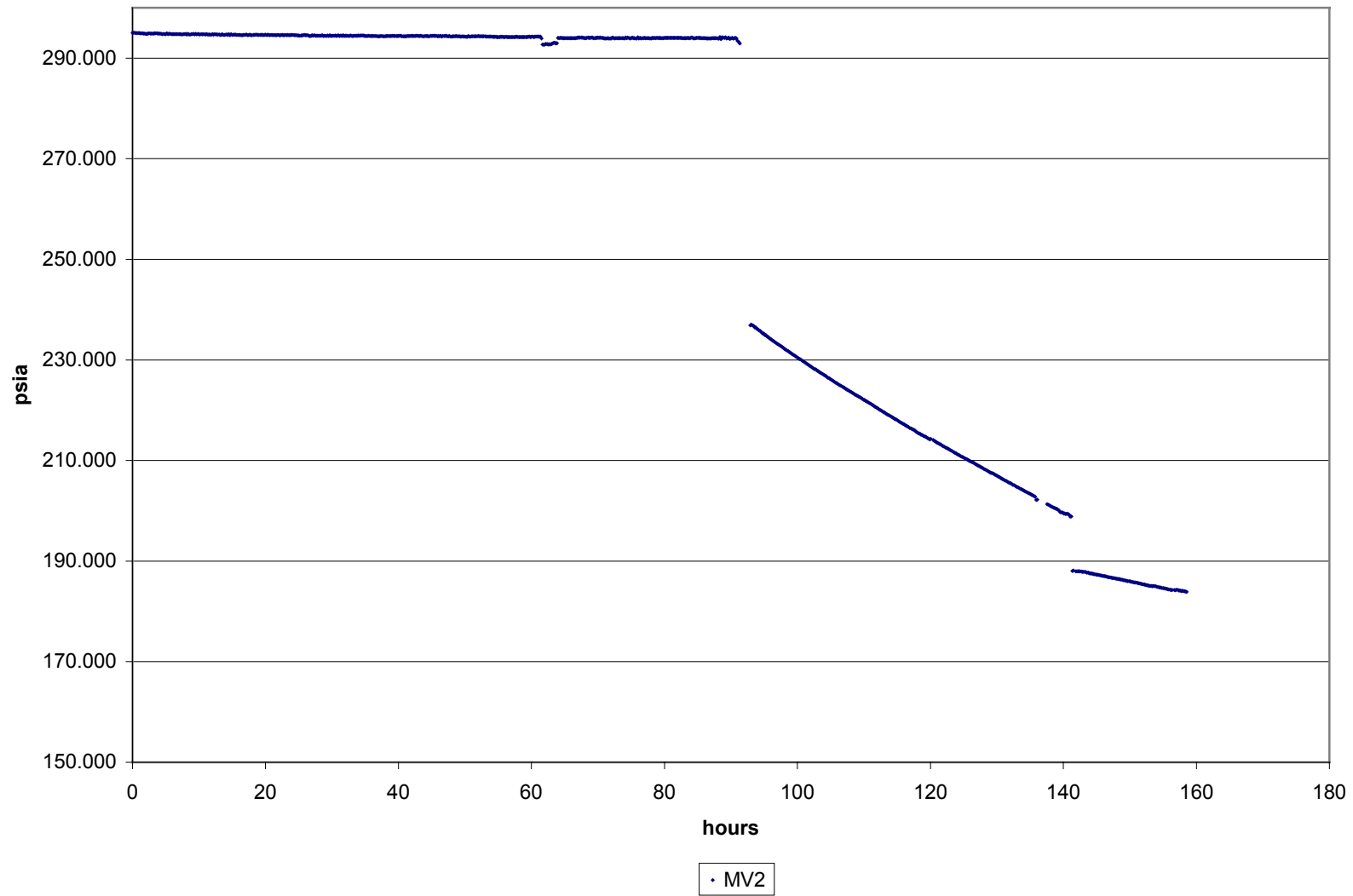
Zone IIA (GP2) vs. Temperature, Launch State, Run 2

C.3.1



Overall Timeline, Zone V (MV2)

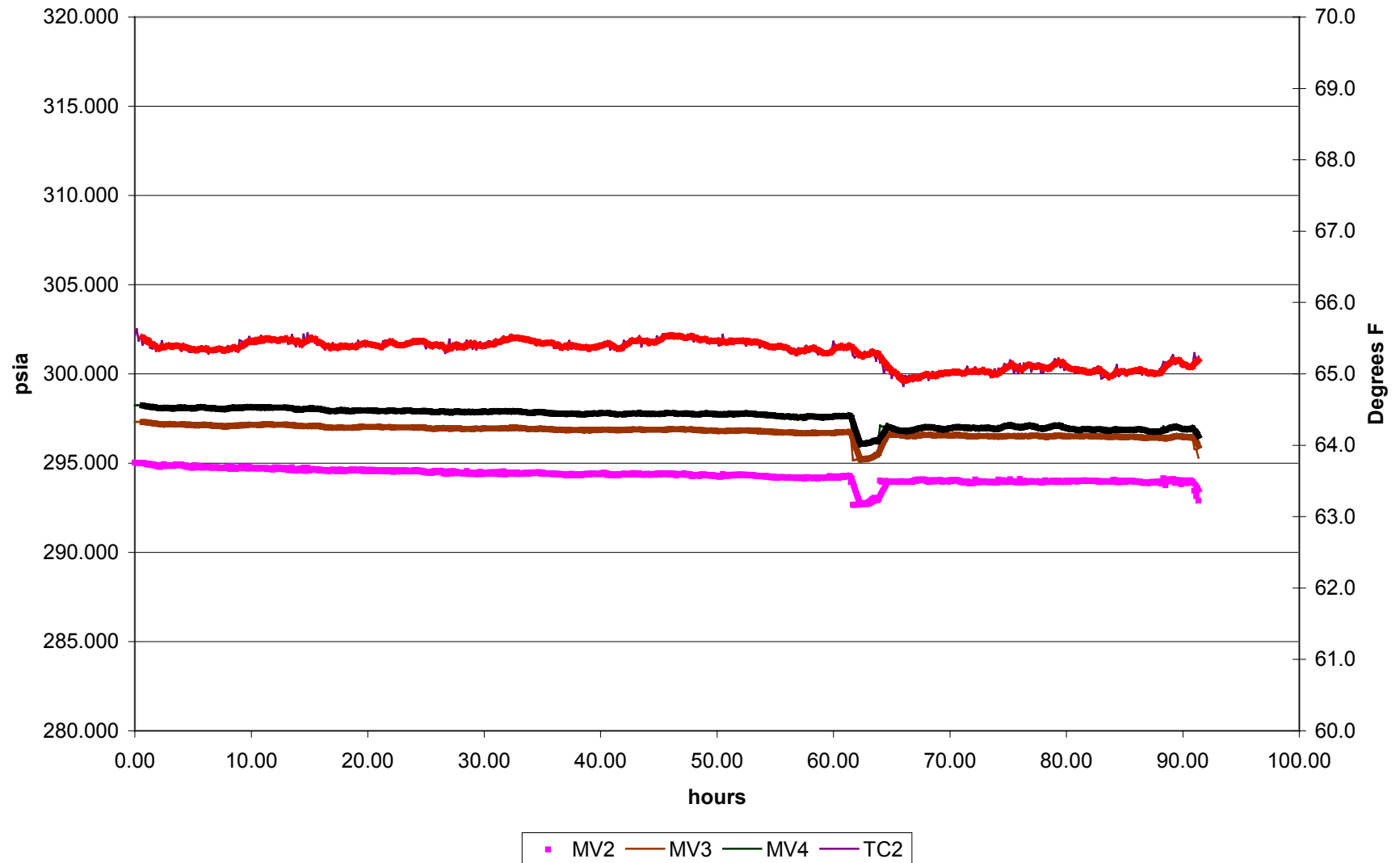
D.1.1



H.3 Chart 3 – Overall Timeline

Zones IIIA, IIIB and V (MV2, MV3, MV4), Ground State

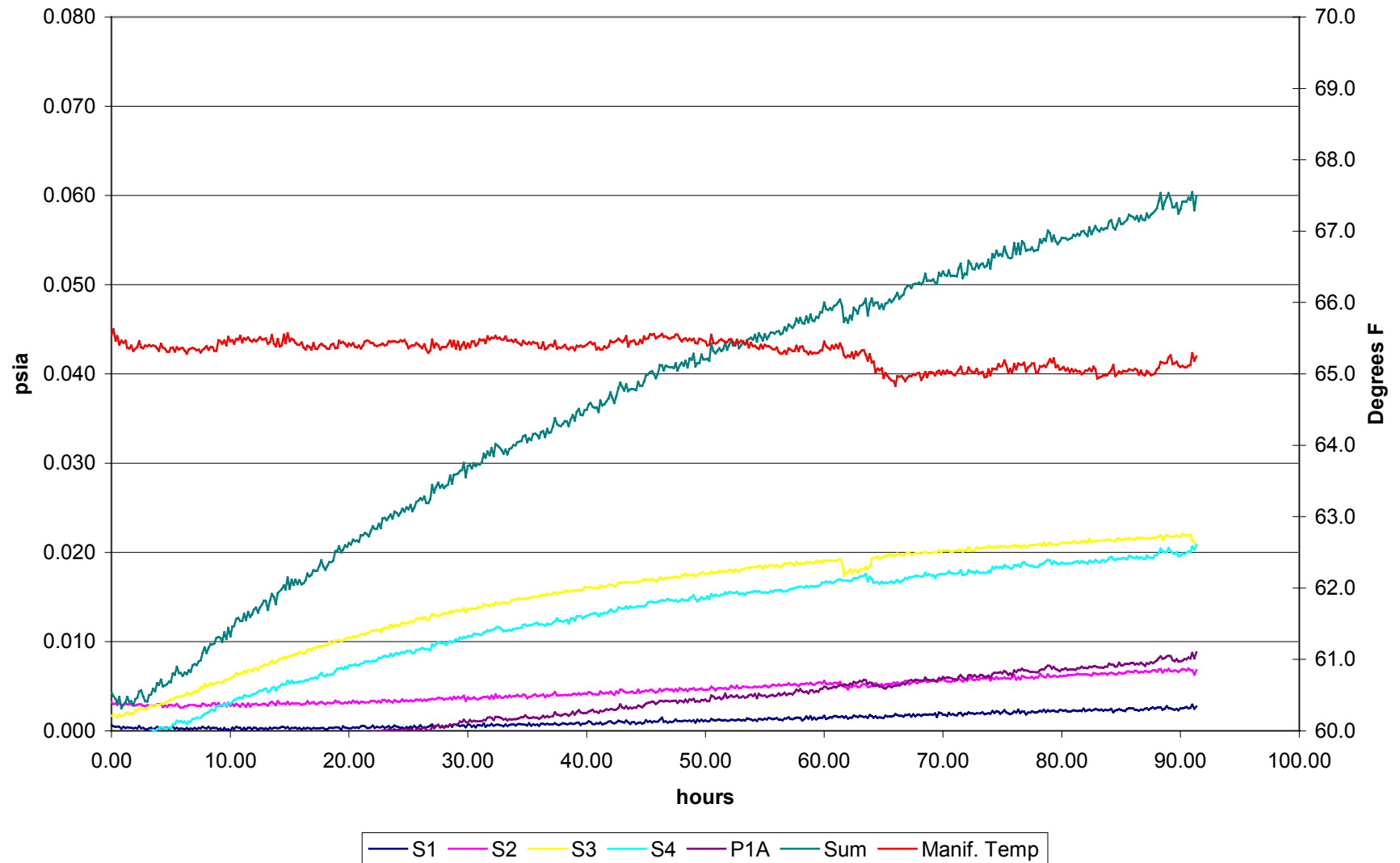
D.1.2.3
D.1.2.5



H.4 Chart 4 – Zone III and V, Ground State

S1, S2, S3, S4, P1A (Zone VII), Ground State

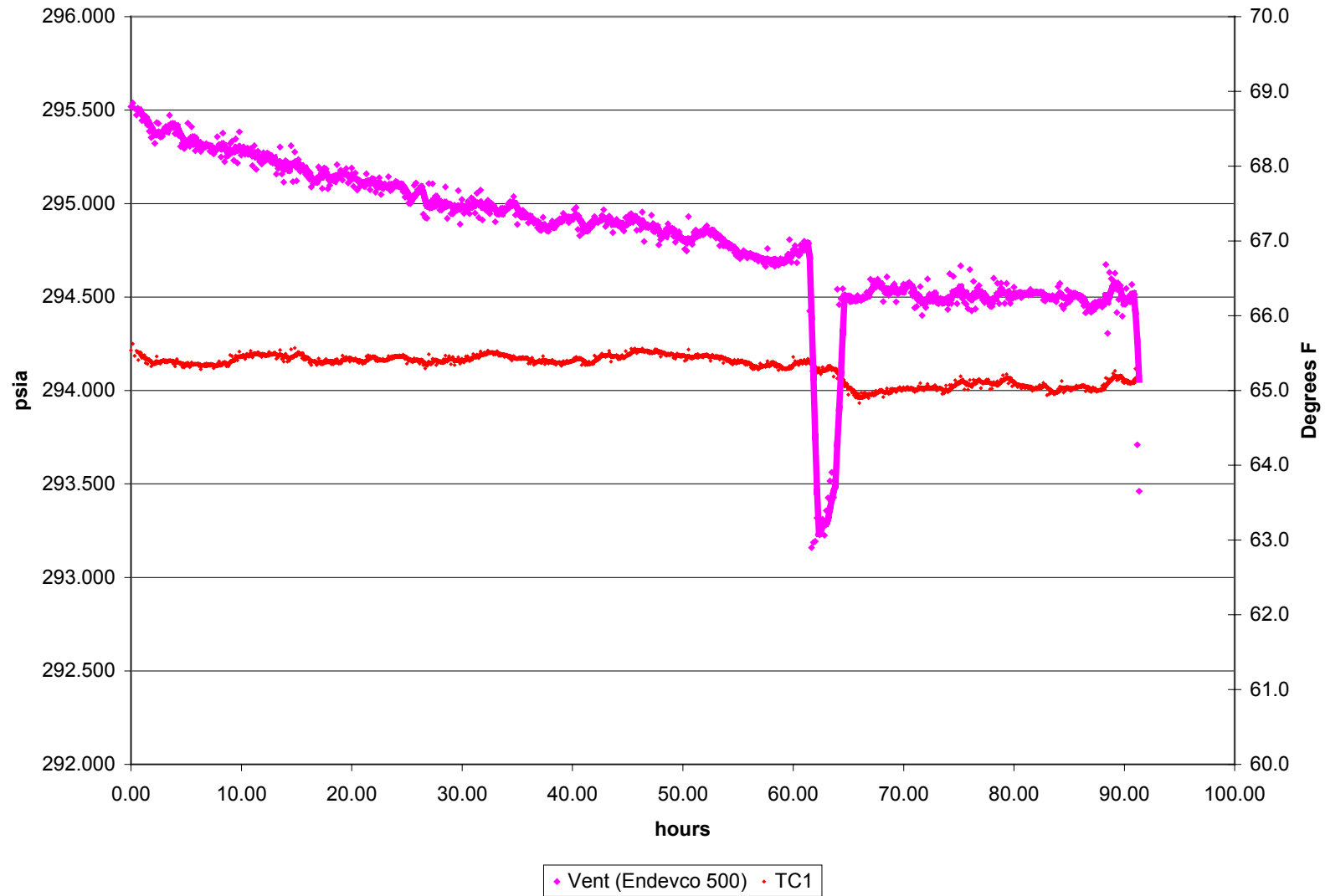
D.1.2.7



H.5 Chart 5 – Zone VII, Ground State

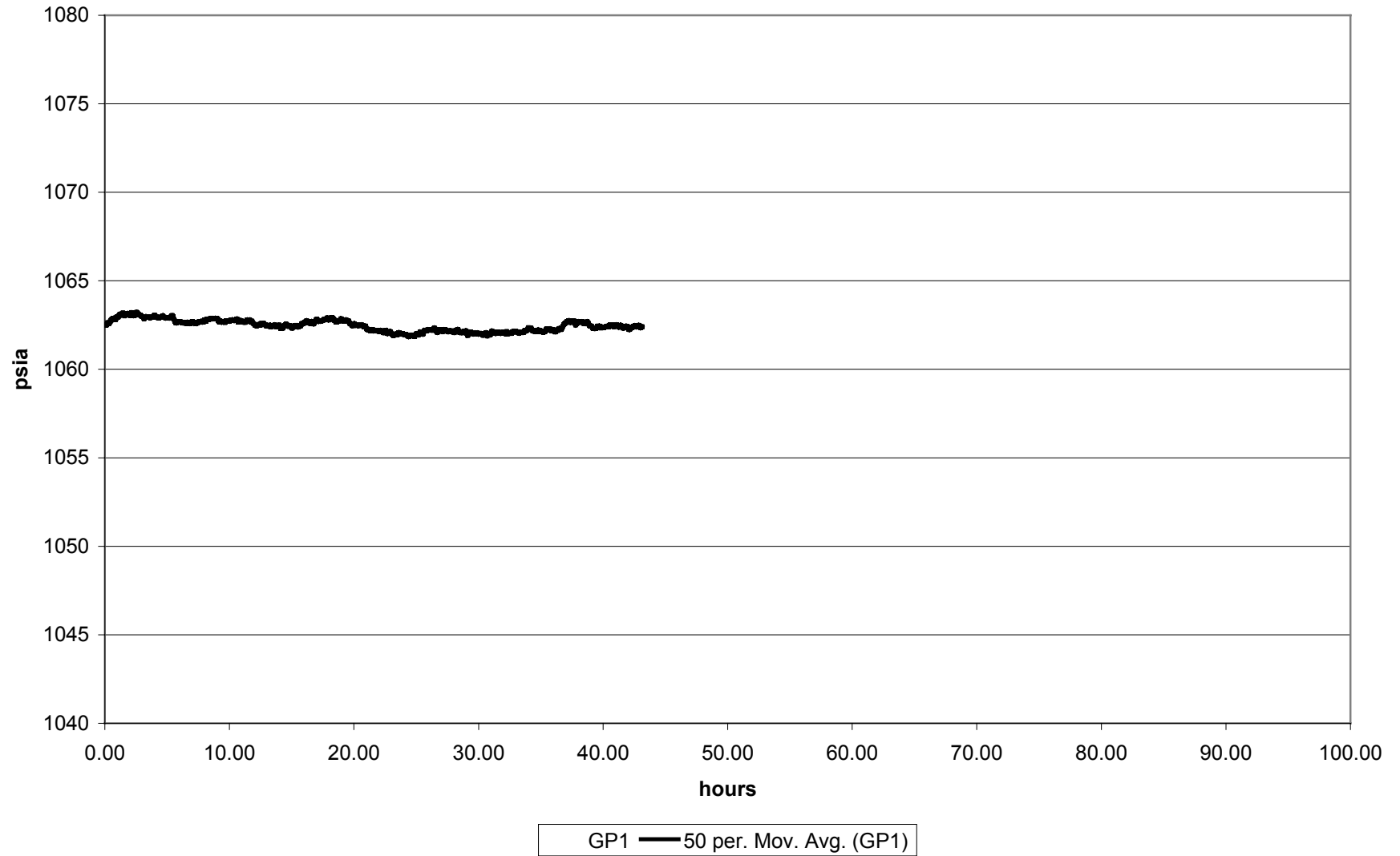
Vent (Zone VII), Ground State, Alternate Scale

D.1.2.8

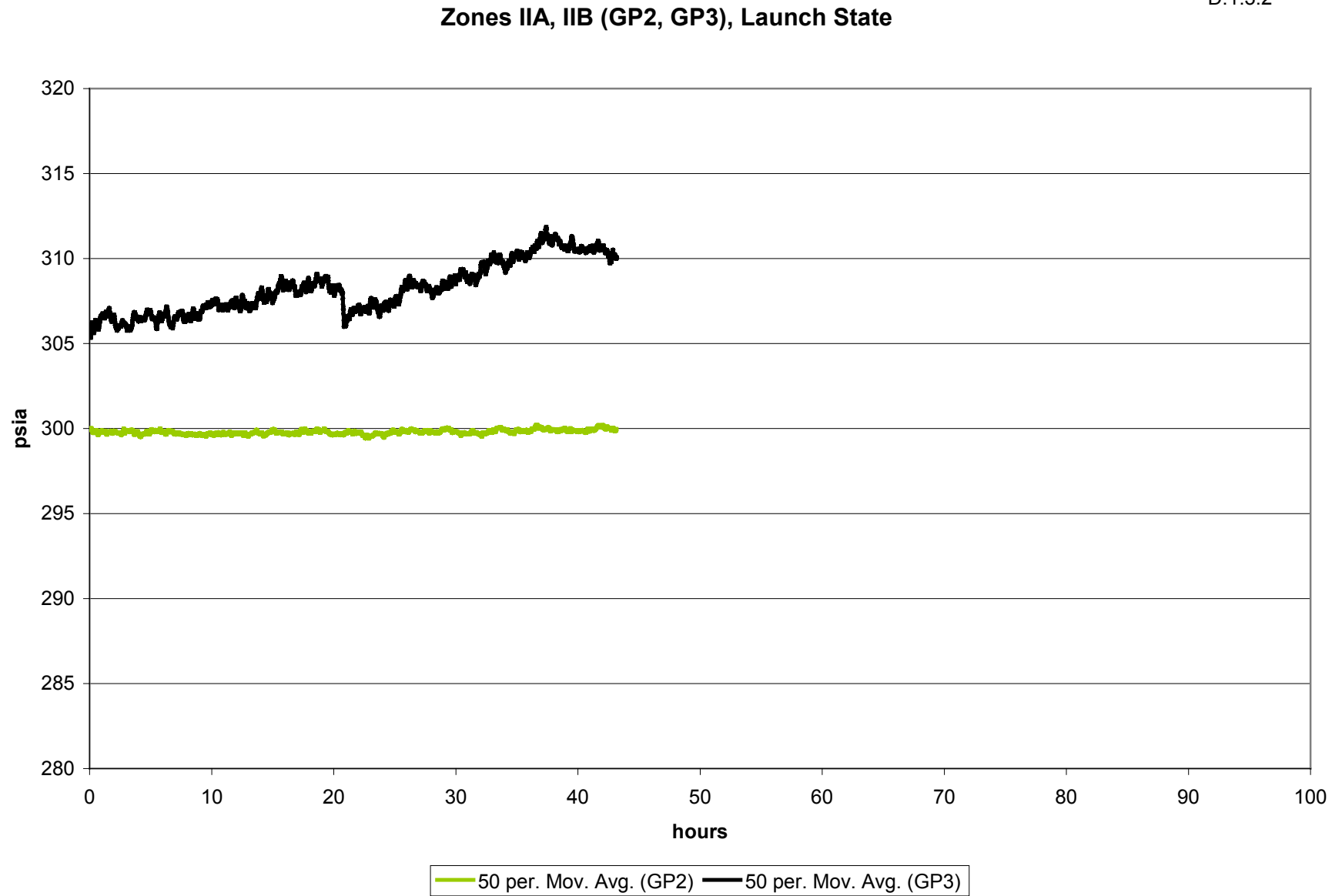


H.6 Chart 6 – Vent, Ground State

Zone I (GP1), Launch State



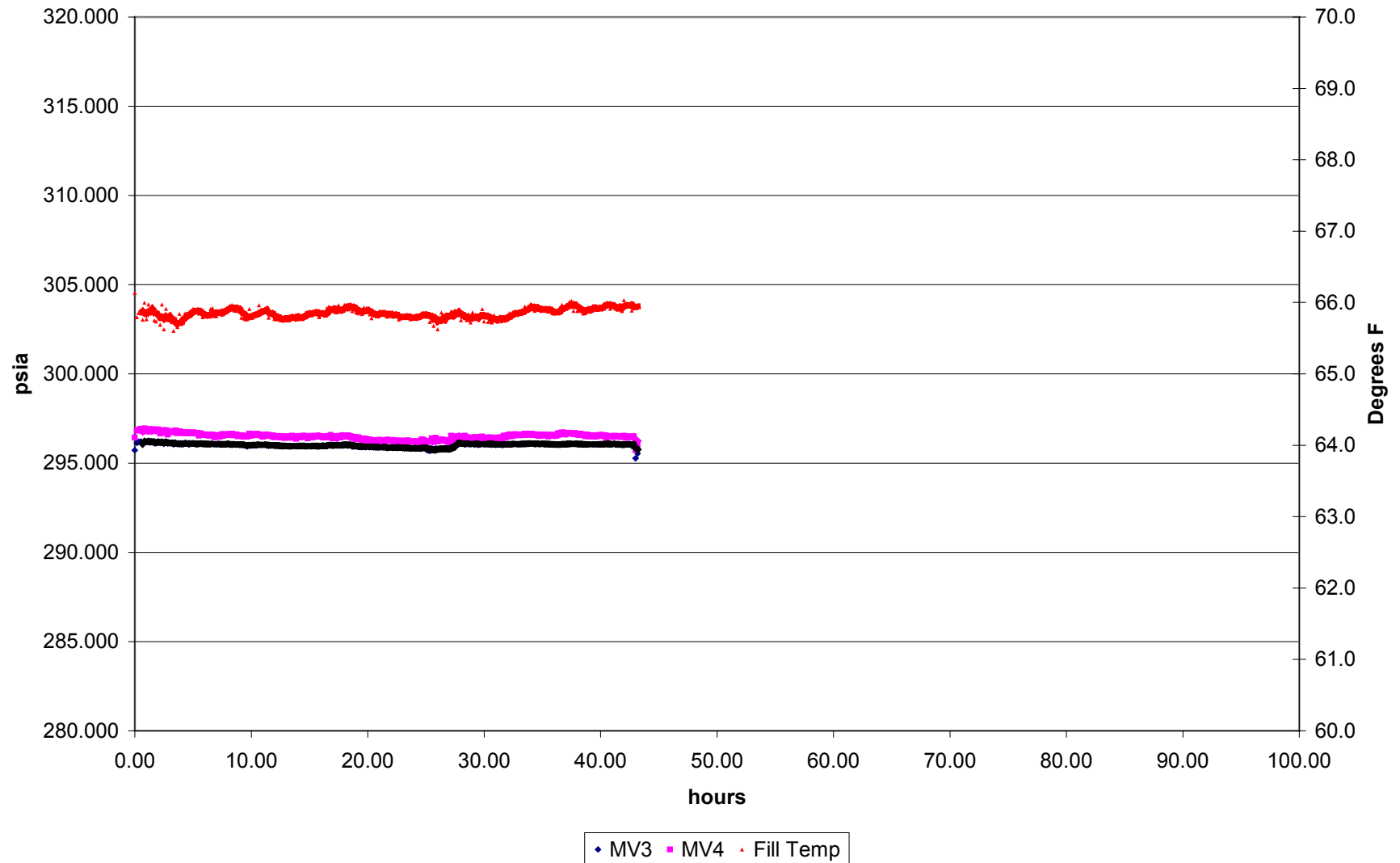
H.7 Chart 7 – Zone I, Launch State



H.8 Chart 8 – Zone II, Launch State

Zones IIIA, IIIB (MV3, MV4); Launch State

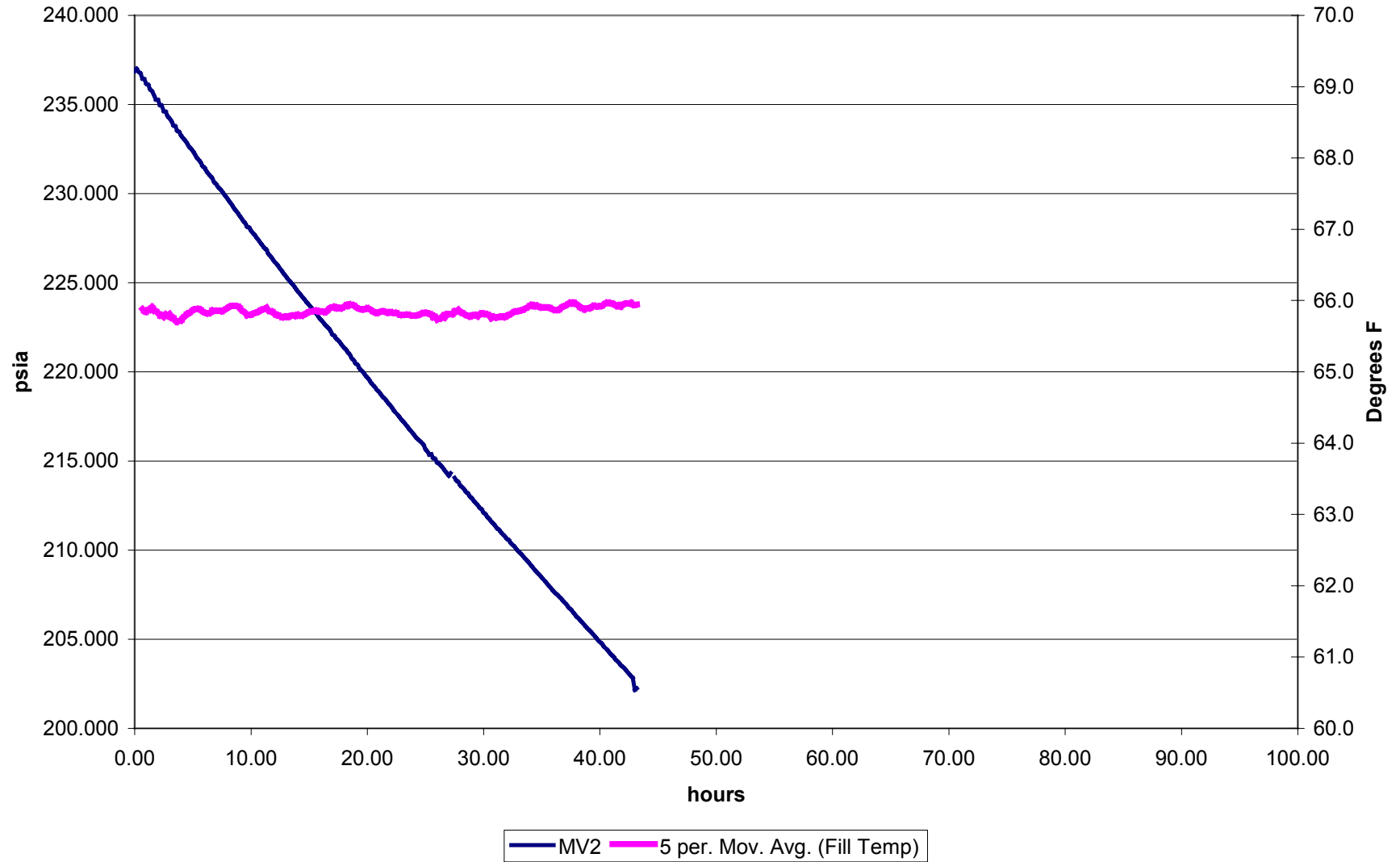
D.1.3.3



H.9 Chart 9 – Zone III, Launch State

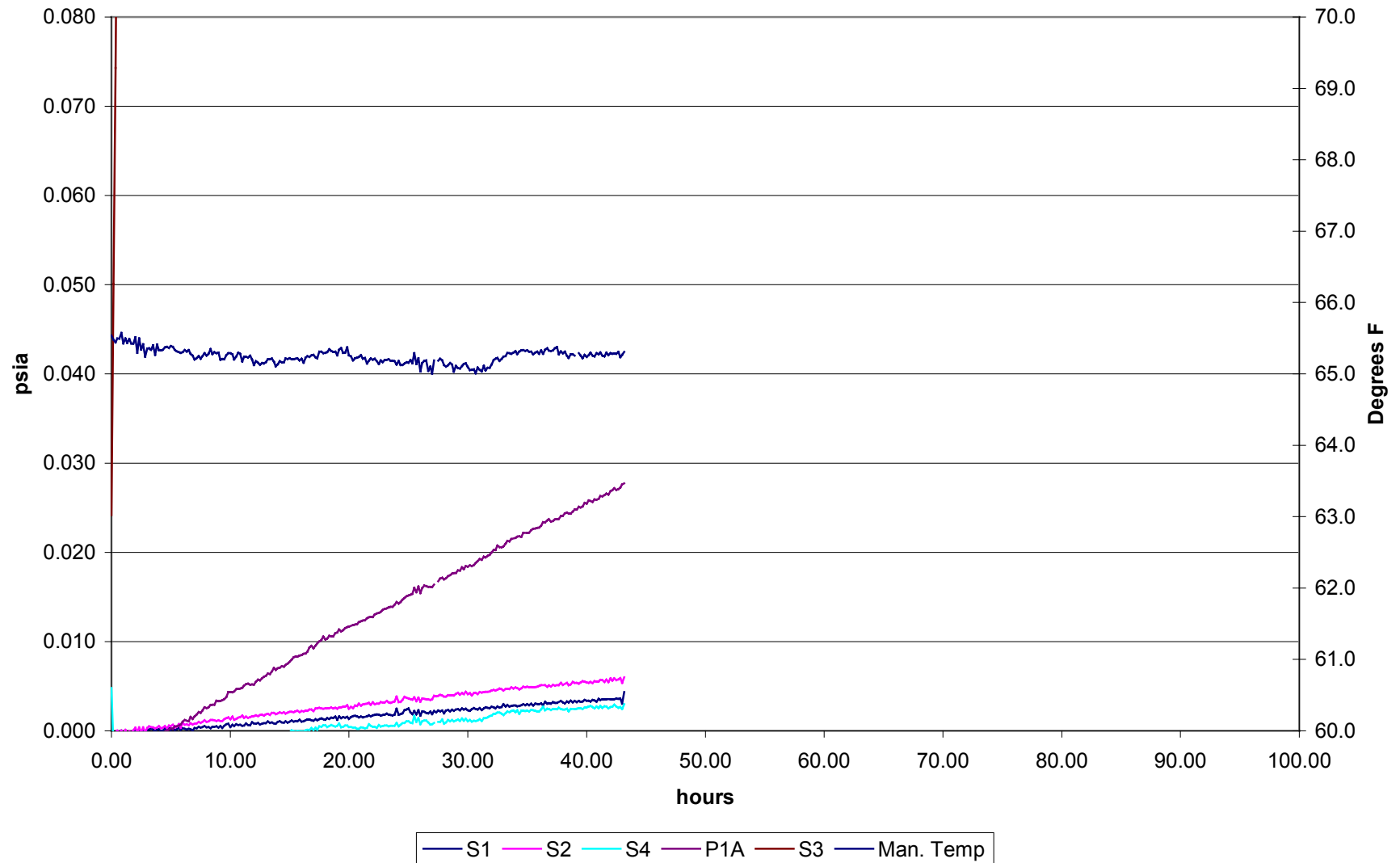
Zone 5 (MV2), Launch State

D.1.3.5



H.10 Chart 10 – Zone V, Launch State

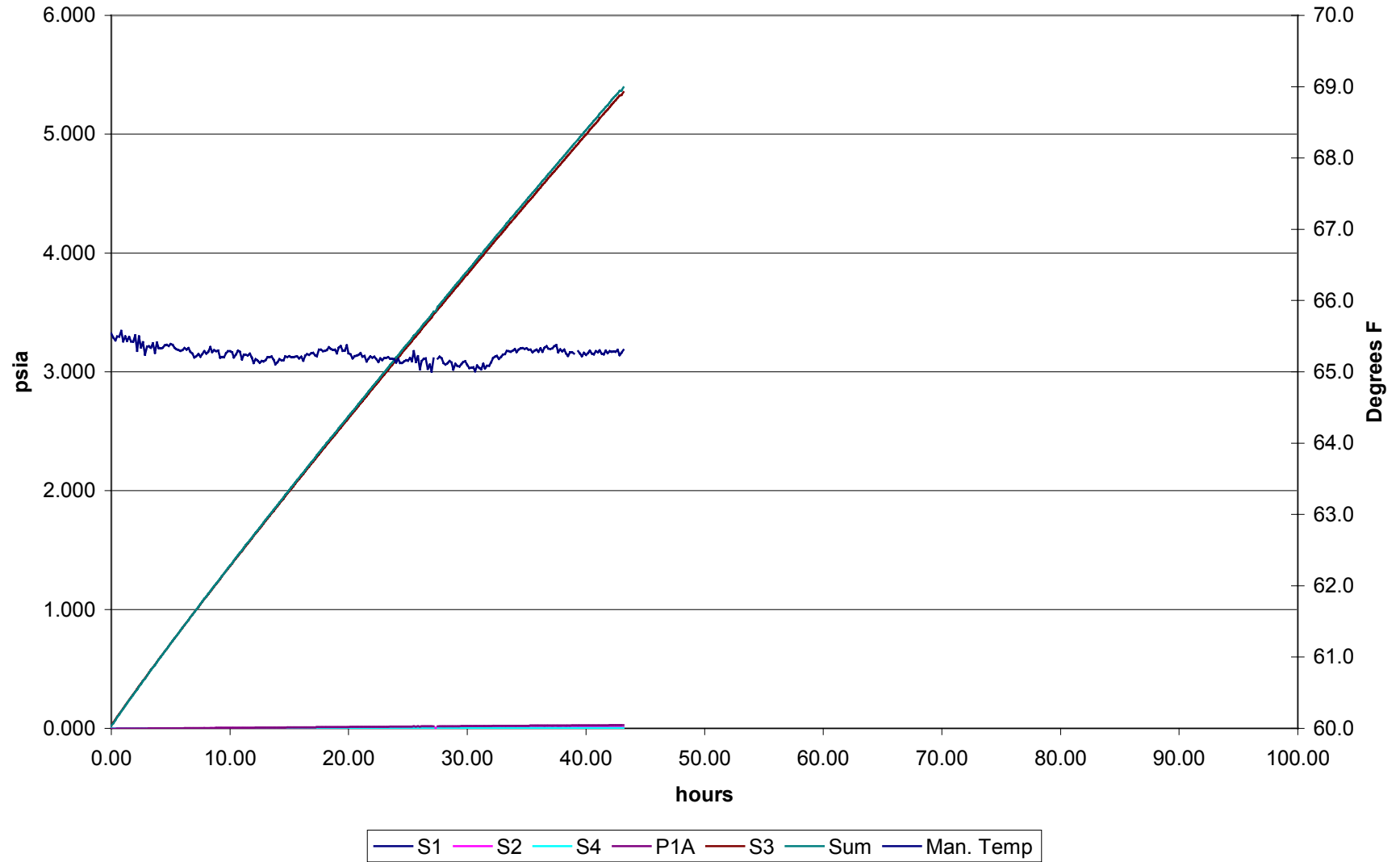
S1, S2, S3, S4, P1A (Zone VII), Launch State



H.11 Chart 11 – S1-P1A, Launch State

S1, S2, S3, S4, P1A (Zone VII), Launch State; Alternate scaling

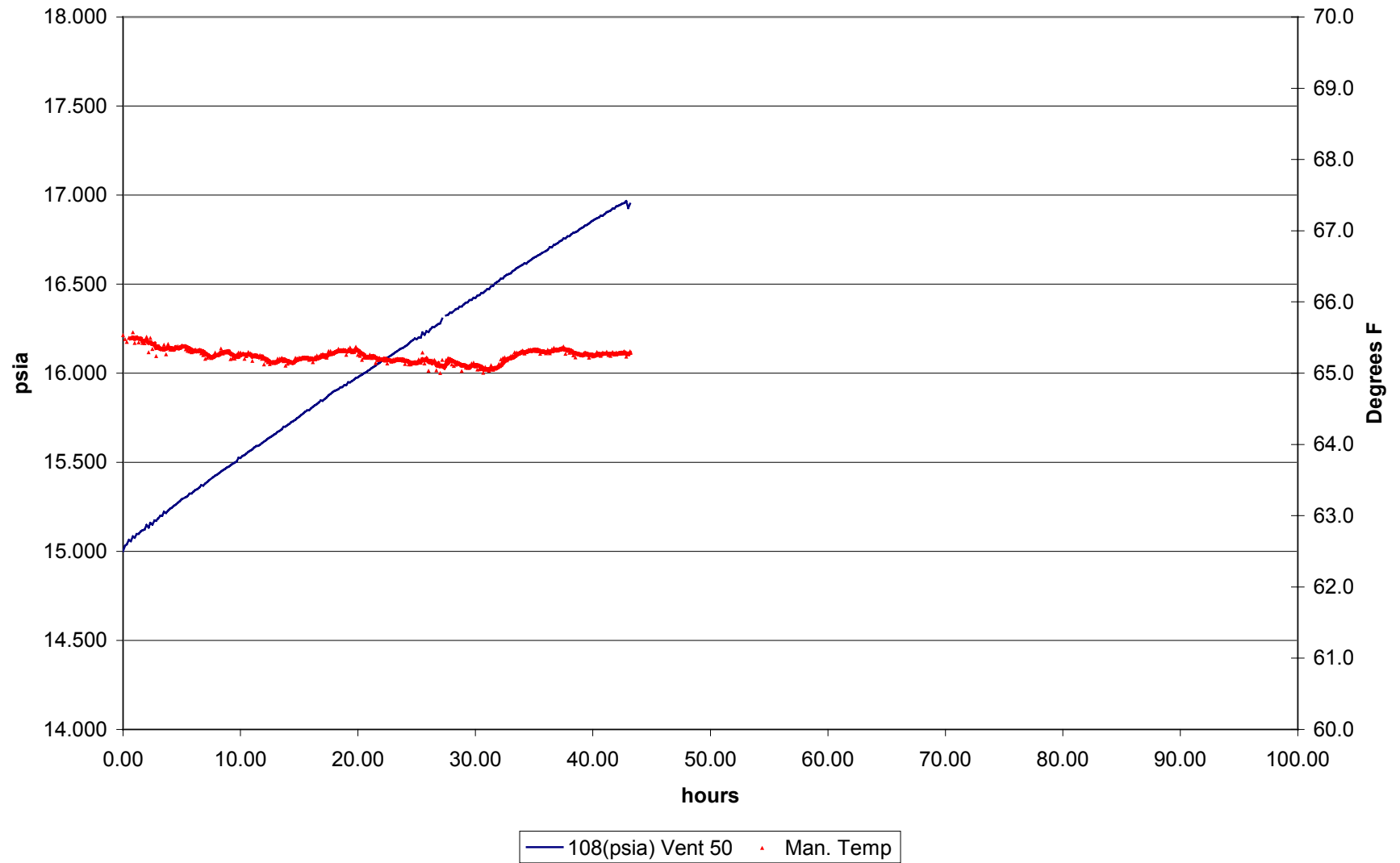
D.1.3.7



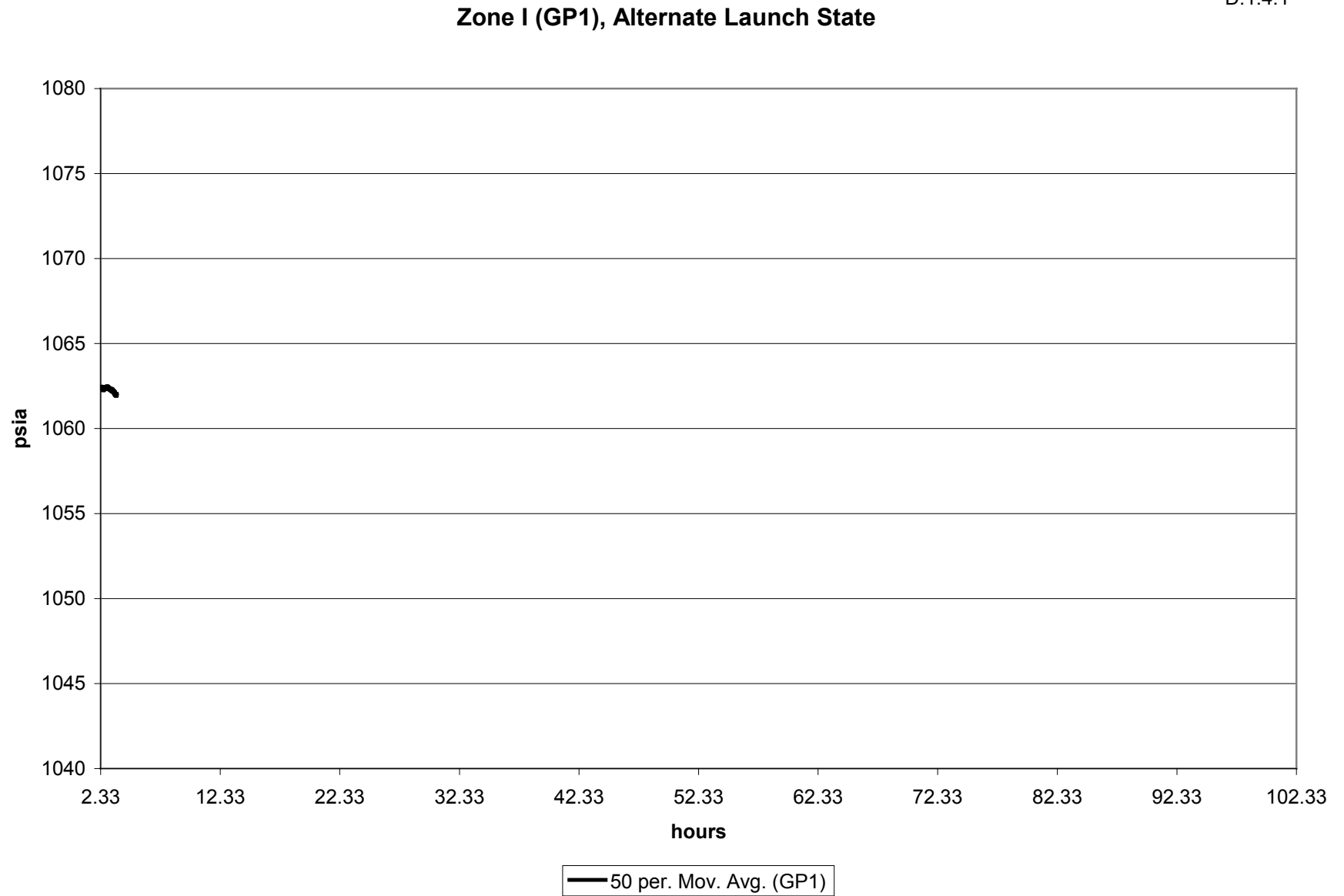
H.12 Chart 12 – S1-P1A, Launch State, alternate scale

Vent (Zone VII), Launch State

D.1.3.8

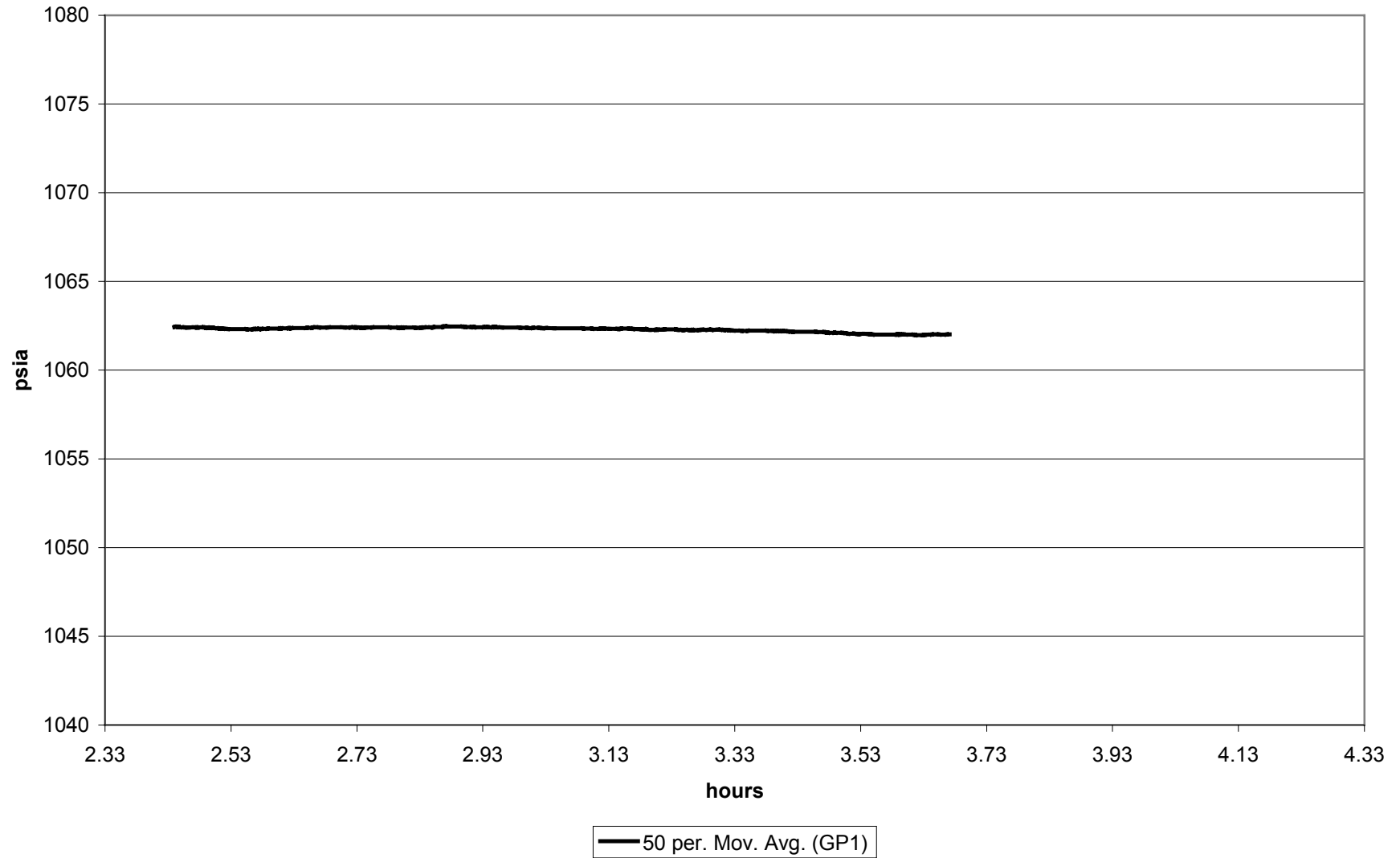


H.13 Chart 13 – Vent, Launch State



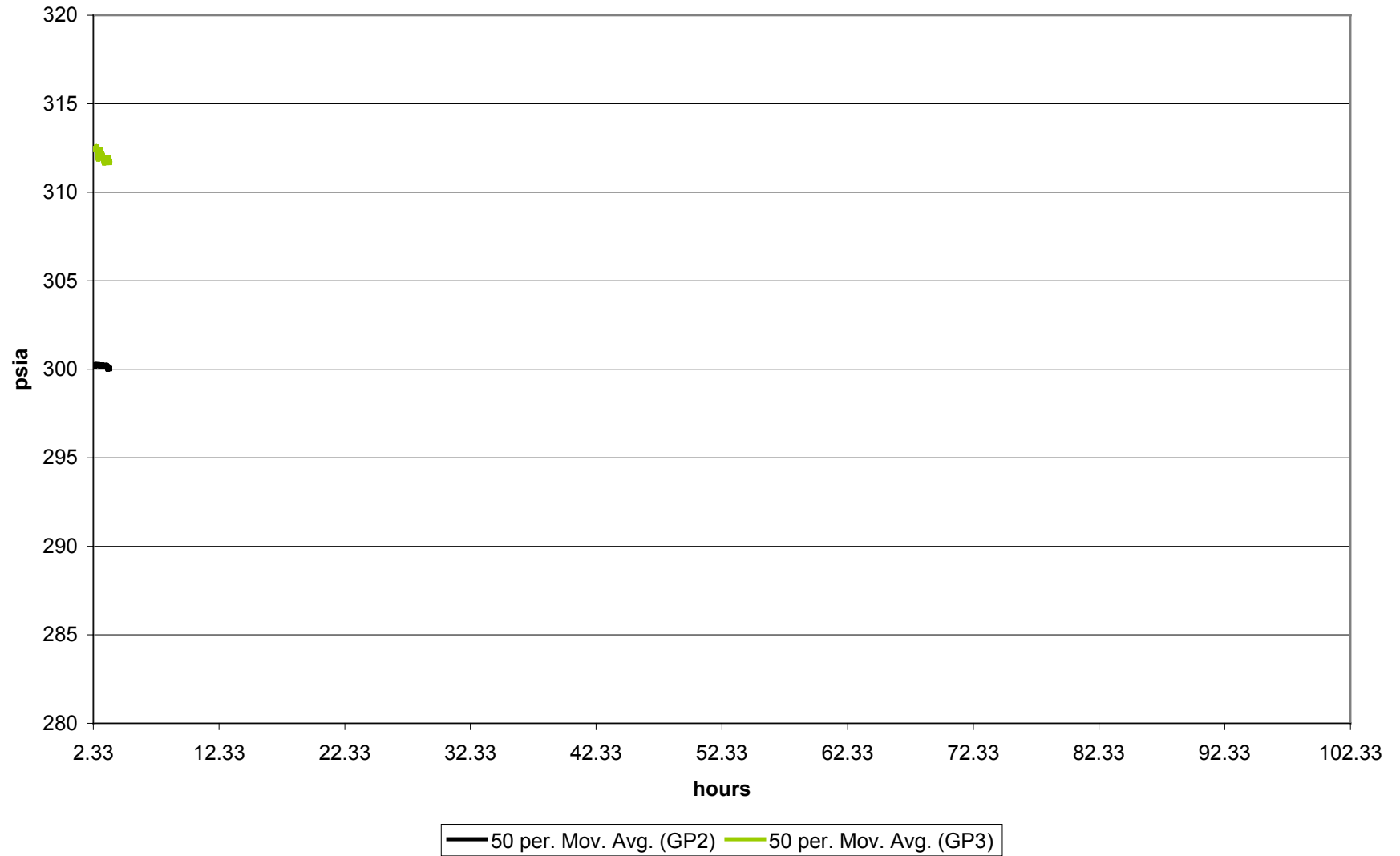
H.14 Chart 14 – Zone I, Alternate Launch State

Zone I (GP1), Alternate Launch State; 1/50 Time Scale



H.15 Chart 15 – Zone I, Alternate Launch State, alternate scale

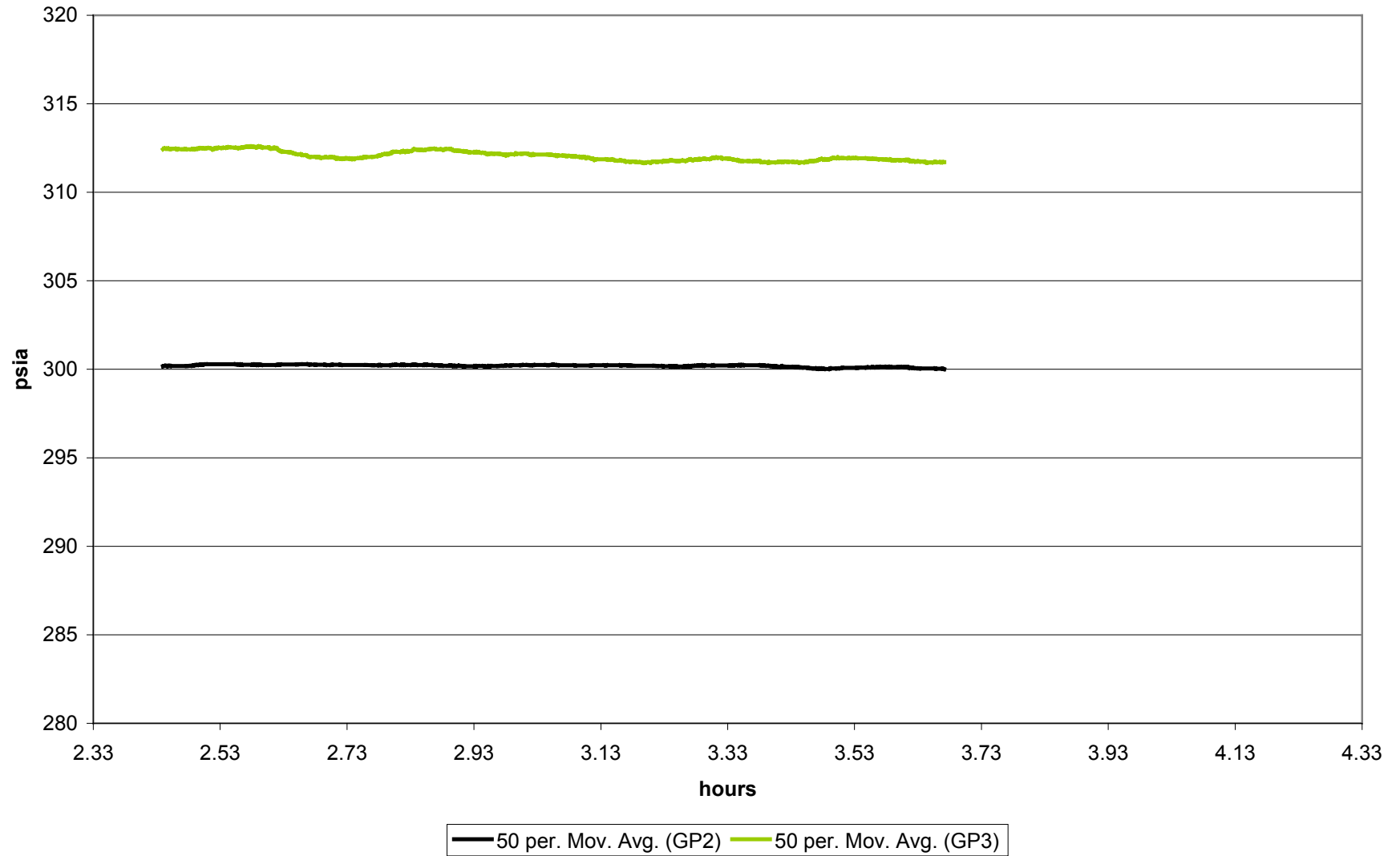
Zones IIA, IIB (GP2, GP3), Alternate Launch State



H.16 Chart 16 – Zone II, Alternate Launch State

Zones IIA, IIB (GP2, GP3), Alternate Launch State; 1/50 time scale

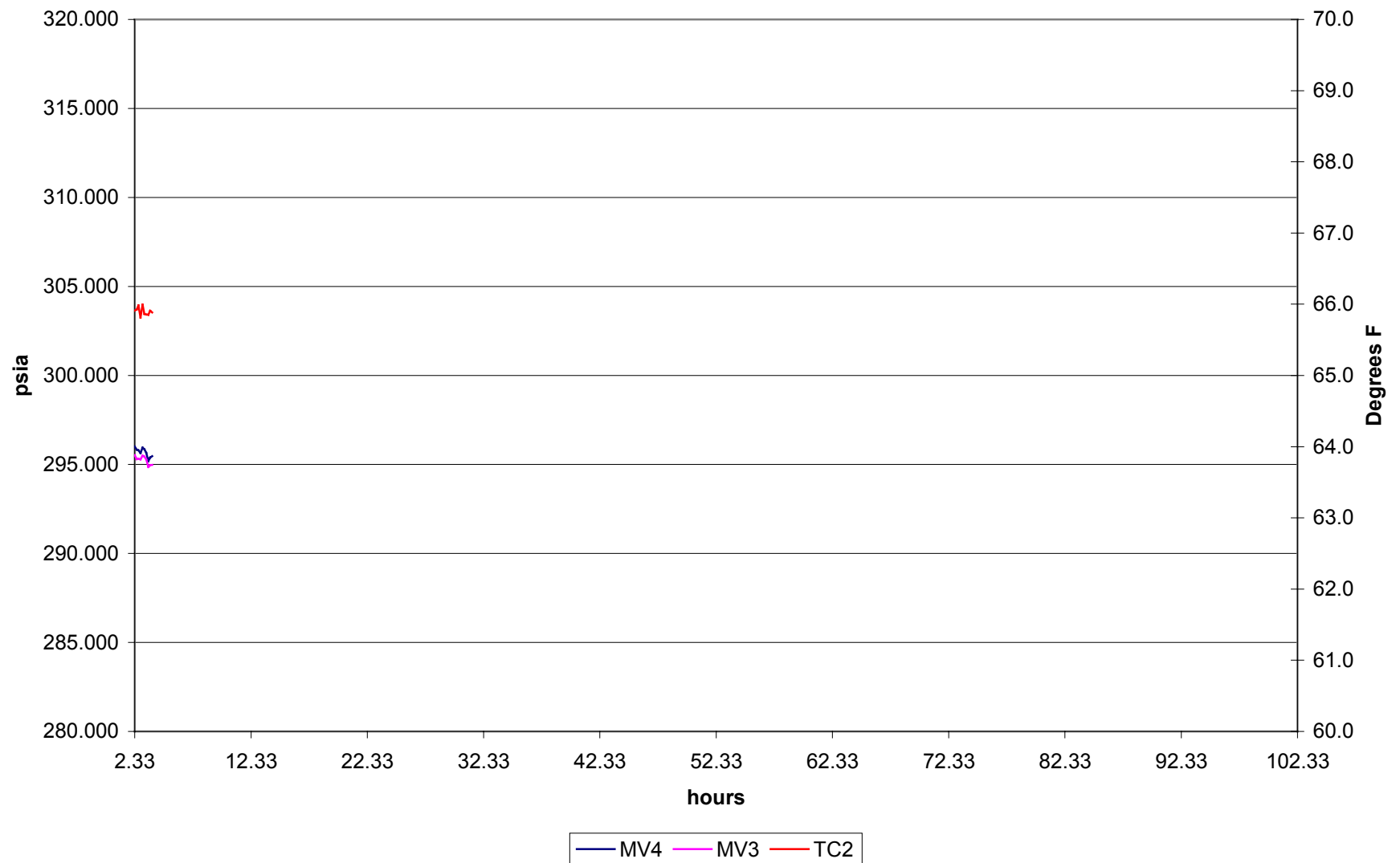
D.1.4.2



H.17 Chart 17 – Zone II, Alternate Launch State, alternate scale

Zones IIIA, IIIB (MV3, MV4), Alternate launch config

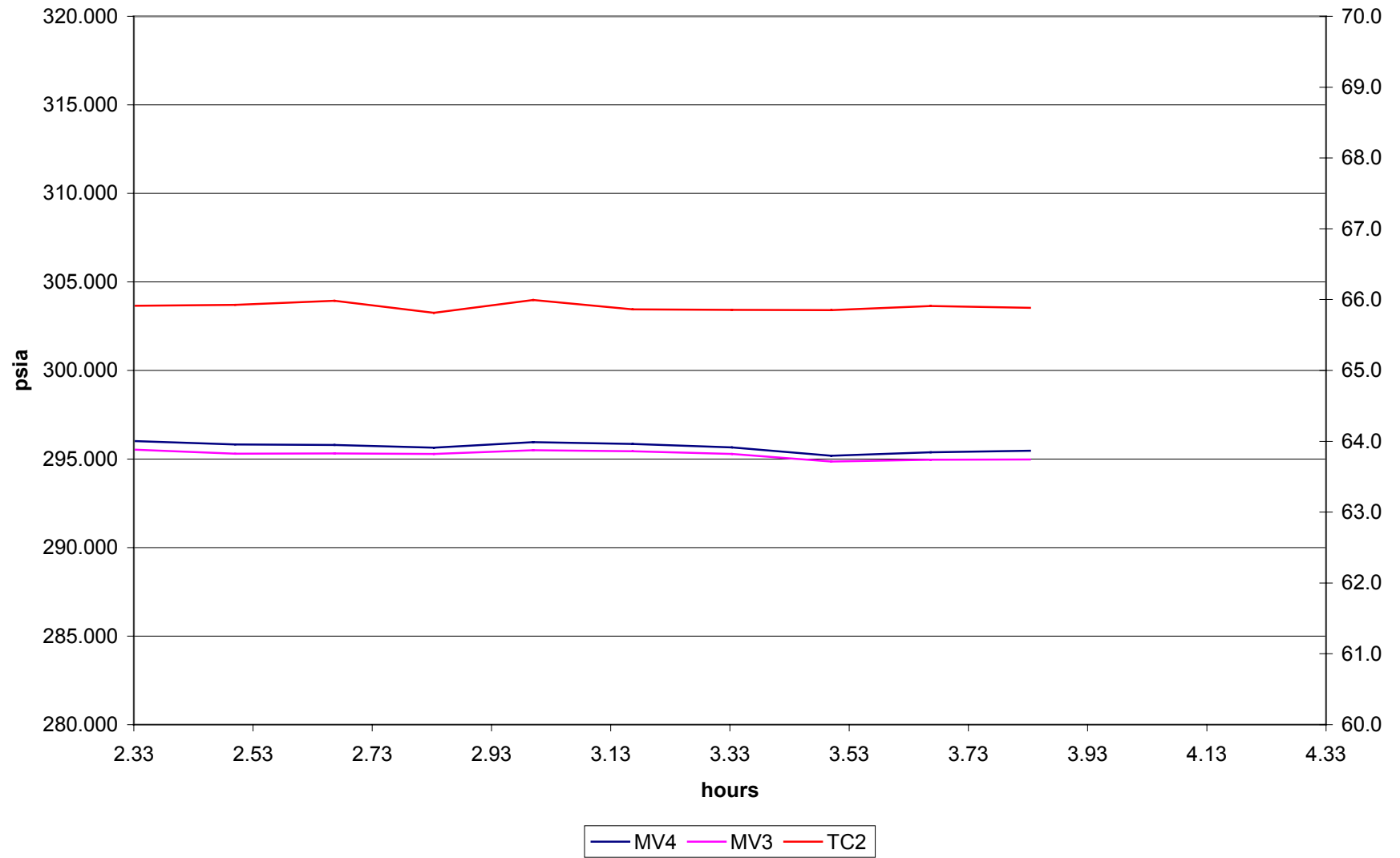
D.1.4.3



H.18 Chart 18 – Zone III, Alternate Launch State

Zones IIIA, IIIB (MV3, MV4), Alternate Launch State; 1/50 time scale

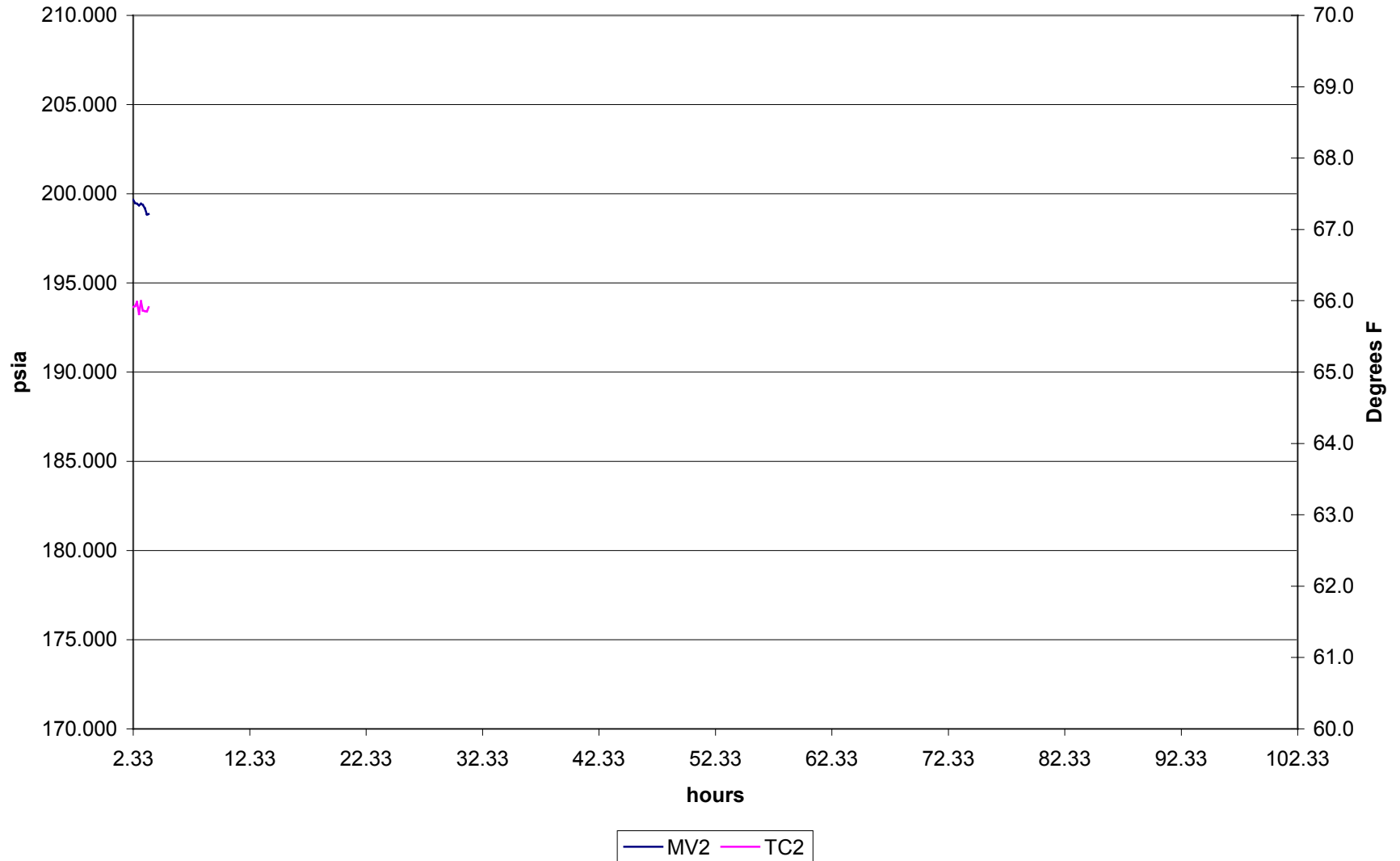
D.1.4.3



H.19 Chart 19 – Zone III, Alternate Launch State, alternate scale

Zone V, (MV2), Alternate Launch State

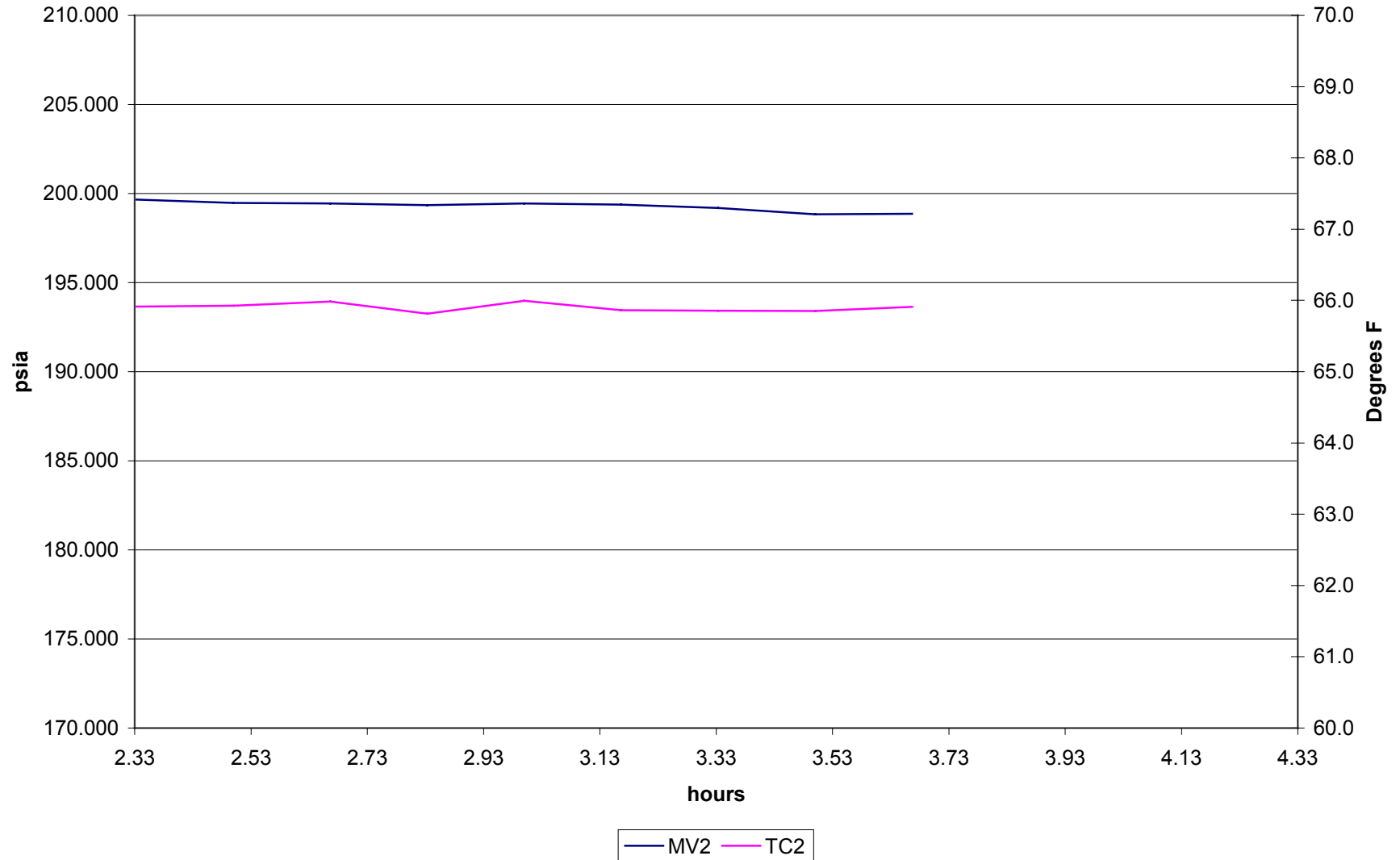
D.1.4.5



H.20 Chart 20 – Zone V, Alternate Launch State

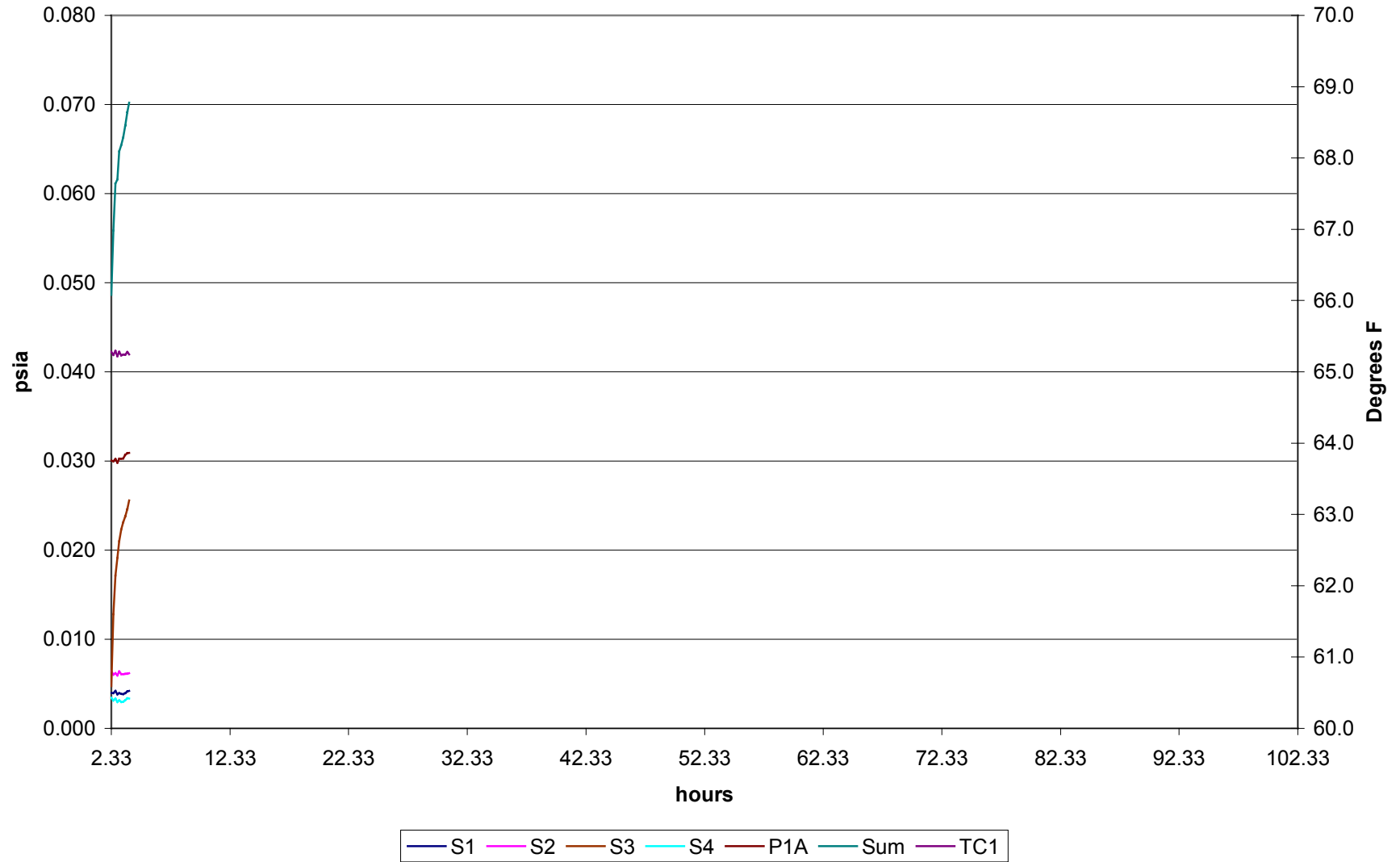
Zone V (MV2), Alternate Launch State; 1/50 time scale

D.1.4.5



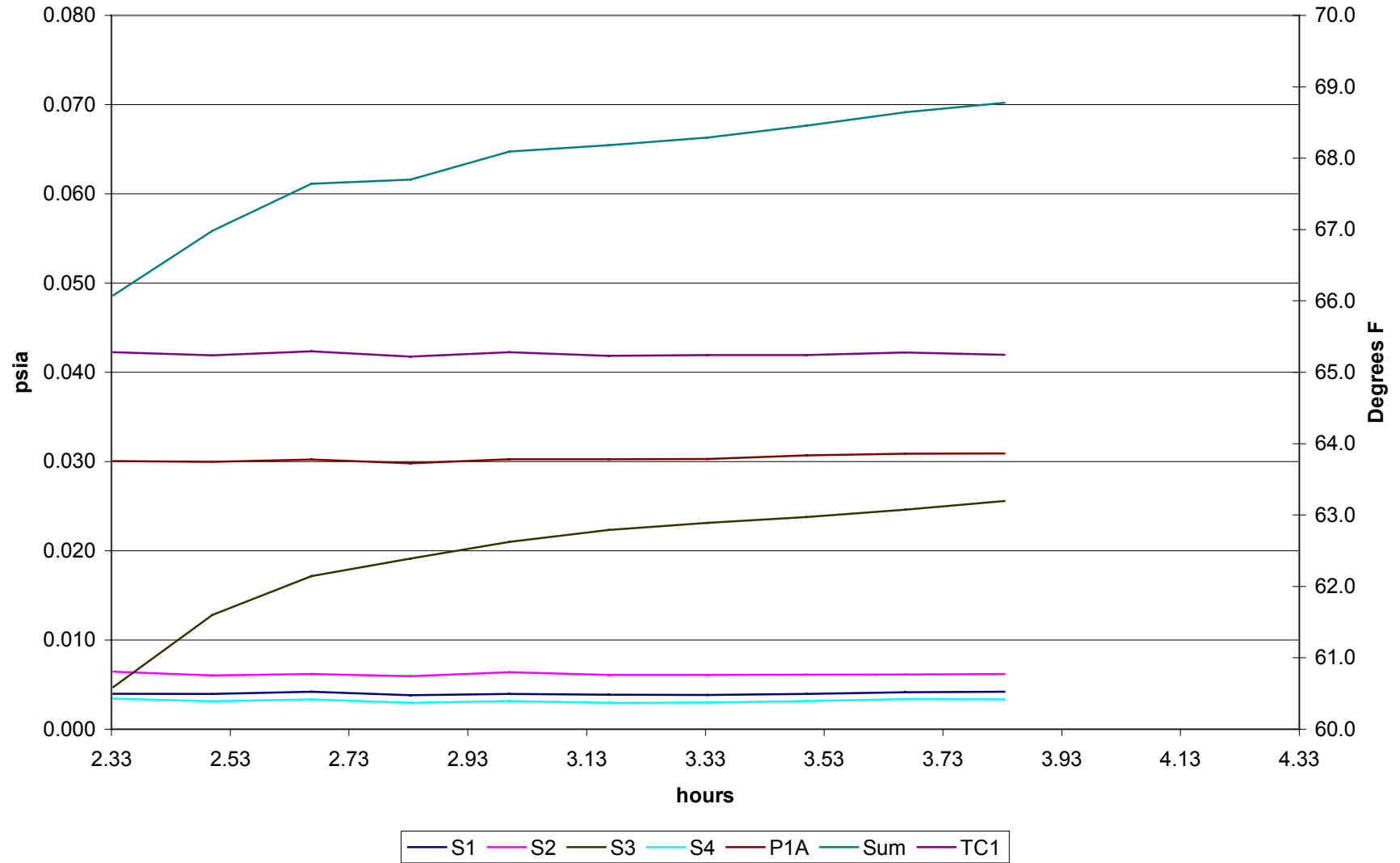
H.21 Chart 21 – Zone V, Alternate Launch State, alternate scale

S1, S2, S3, S4, P1A (Zone VII), Alternate Launch State



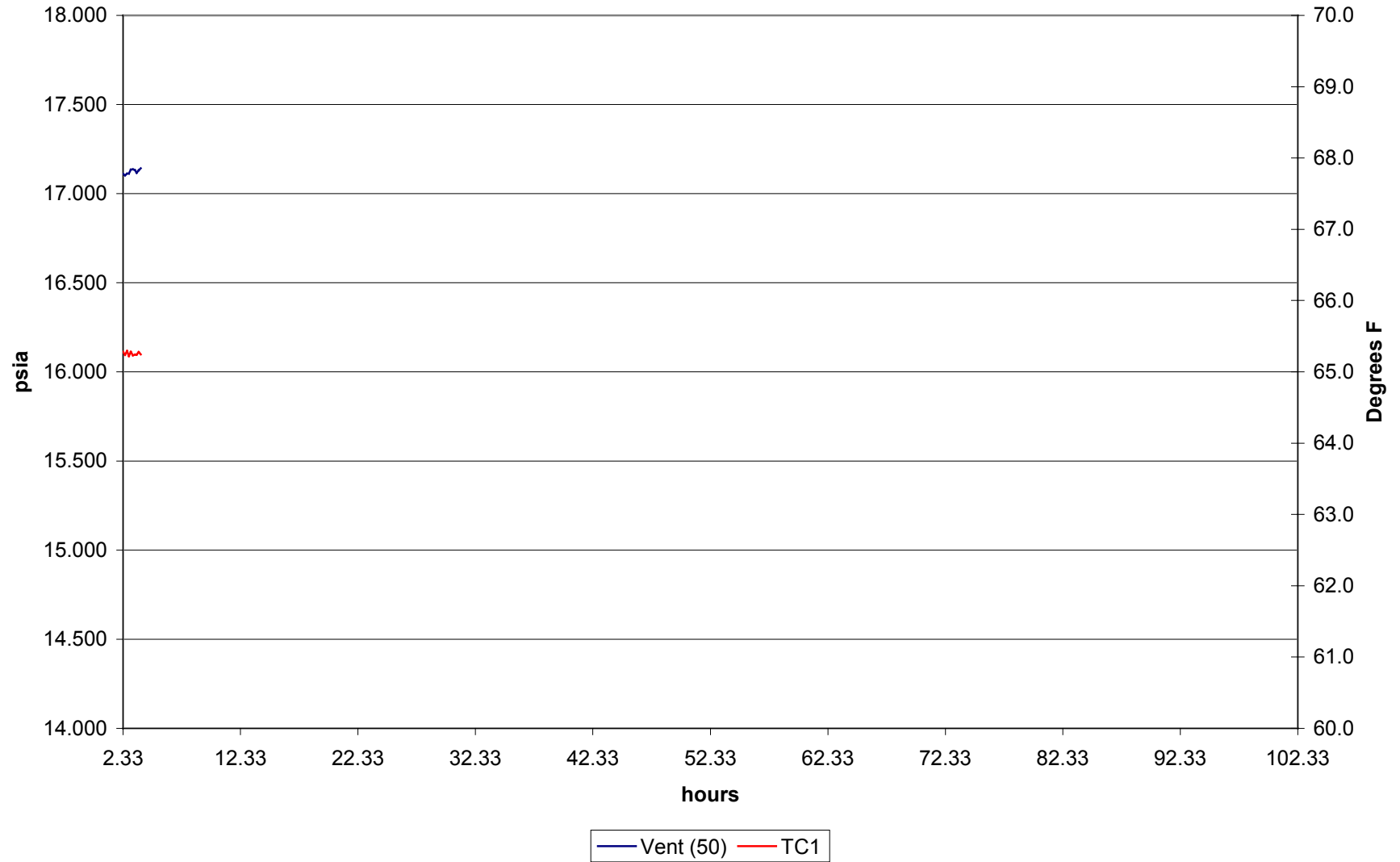
H.22 Chart 22 – S1-P1A, Alternate Launch State

S1, S2, S3, S4, P1A (Zone VII), Alternate Launch State; 1/50 time scale



H.23 Chart 23 – S1-P1A, Alternate Launch State, alternate scale

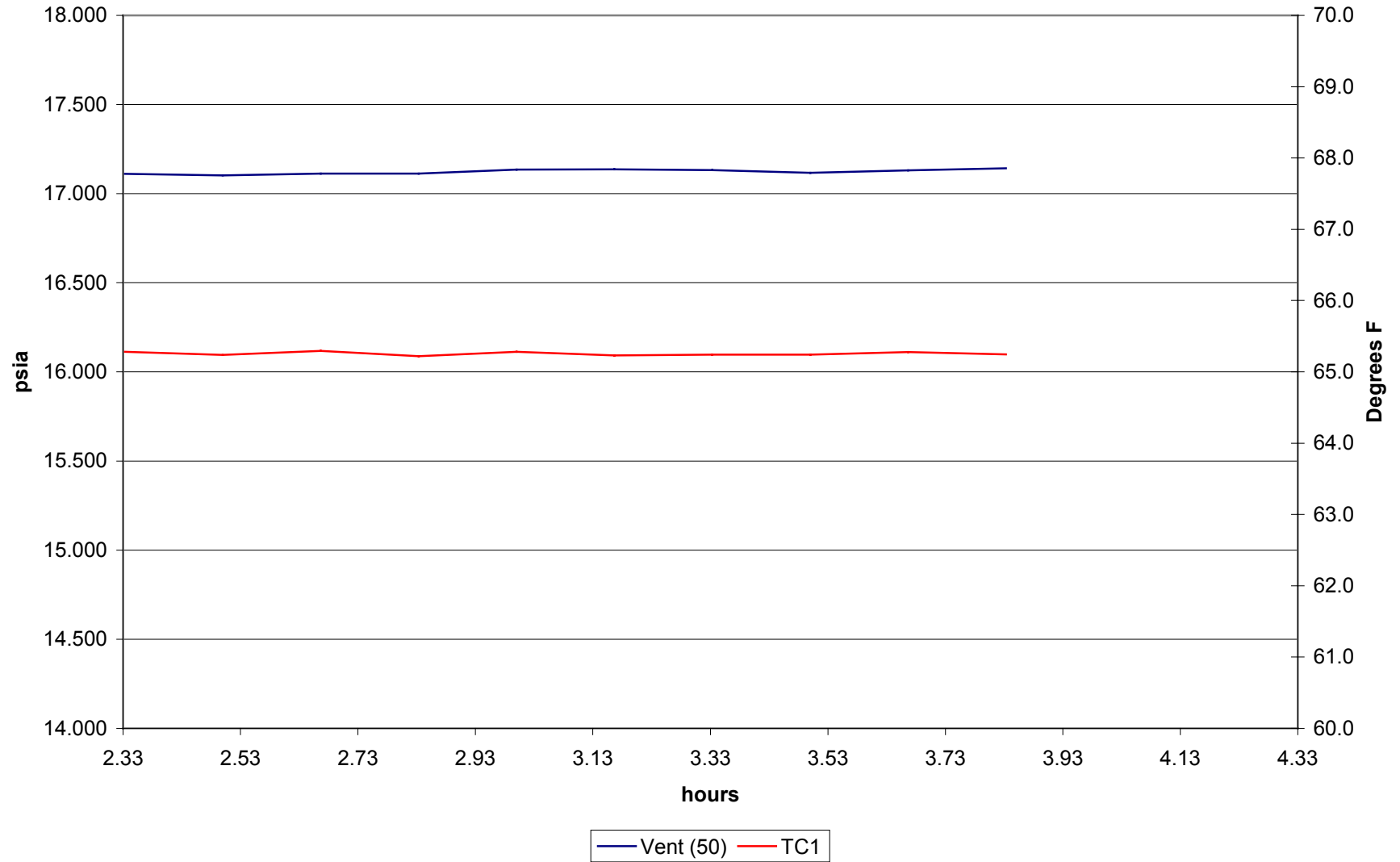
Vent (Zone VII), Alternate Launch State



H.24 Chart 24 – Vent, Alternate Launch State

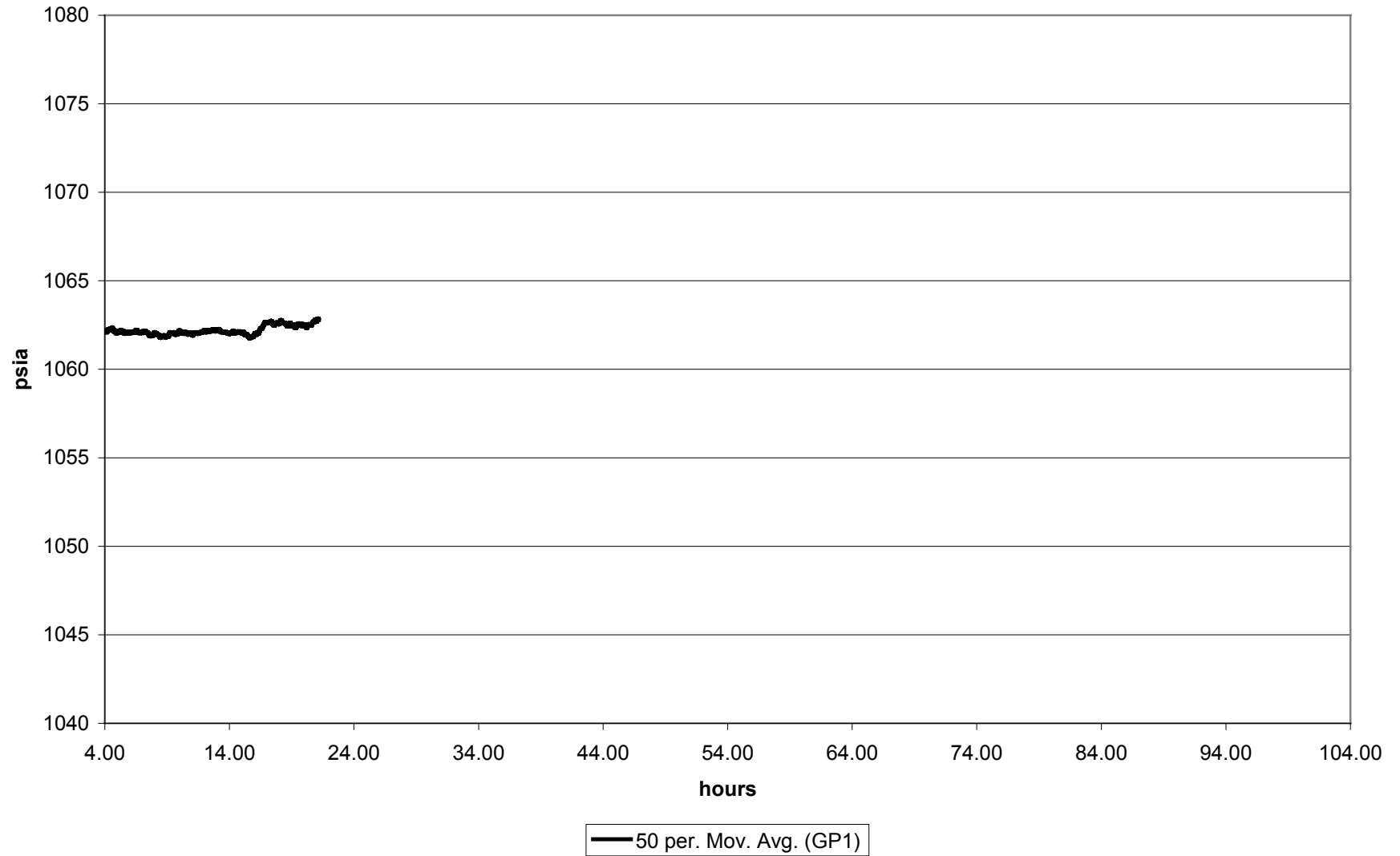
Vent (Zone VII), Alternate Launch State; 1/50 Time Scale

D.1.4.8



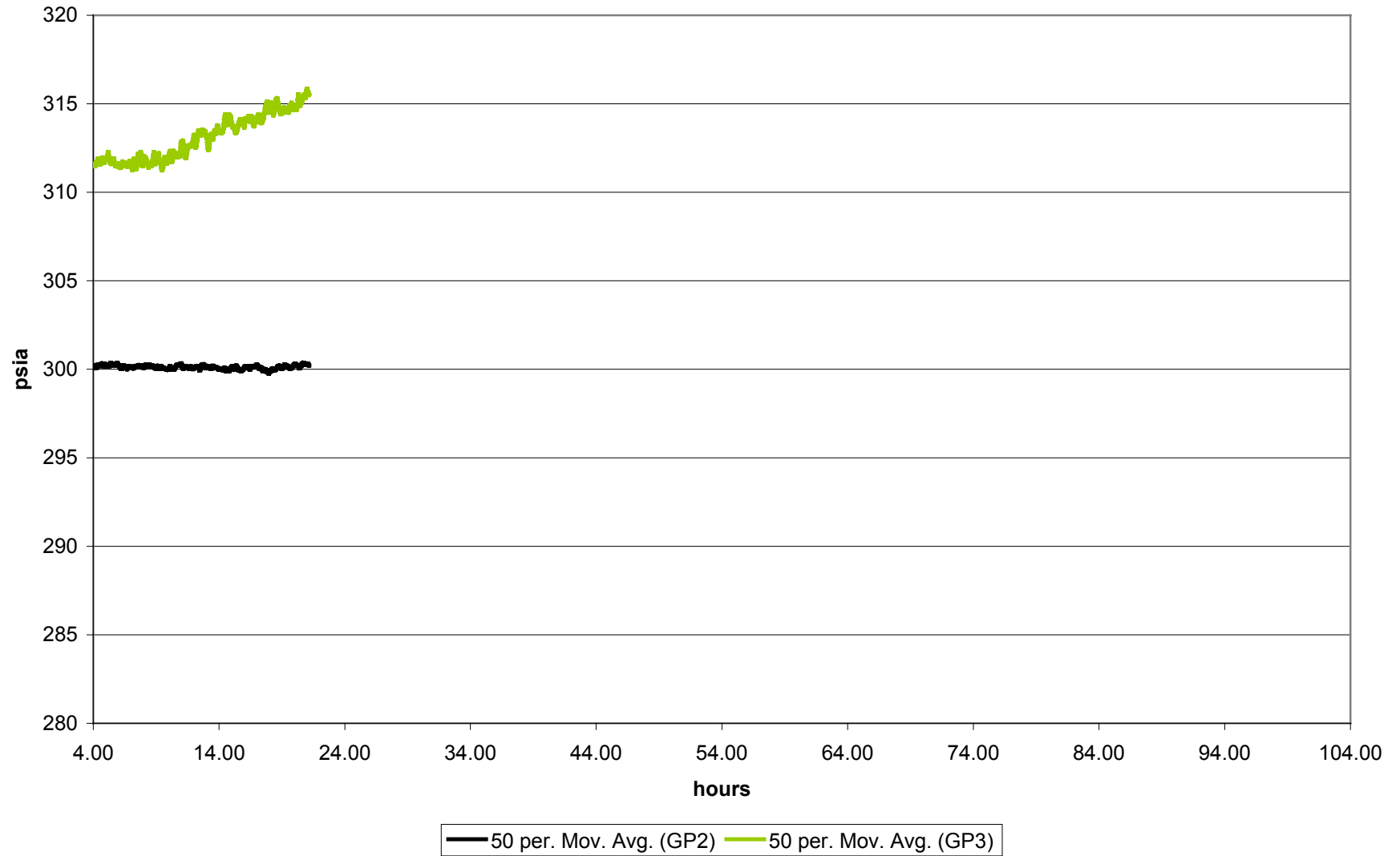
H.25 Chart 25 – Vent, Alternate Launch State, alternate scale

Zone I (GP1), Launch State, Run 2



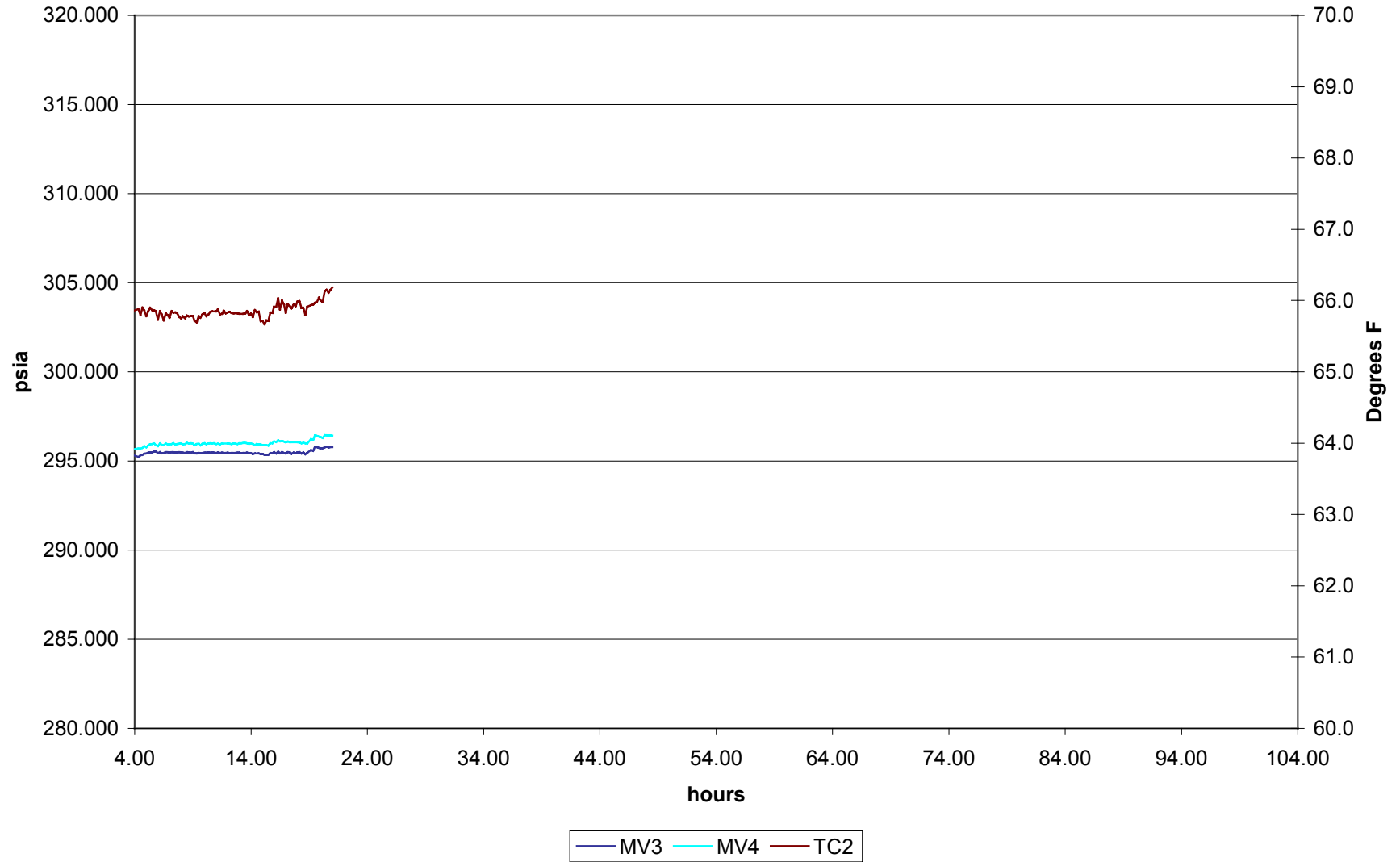
H.26 Chart 26 – Zone I, Launch State (run 2)

Zones IIA, IIB (GP2, GP3), Launch State, Run 2



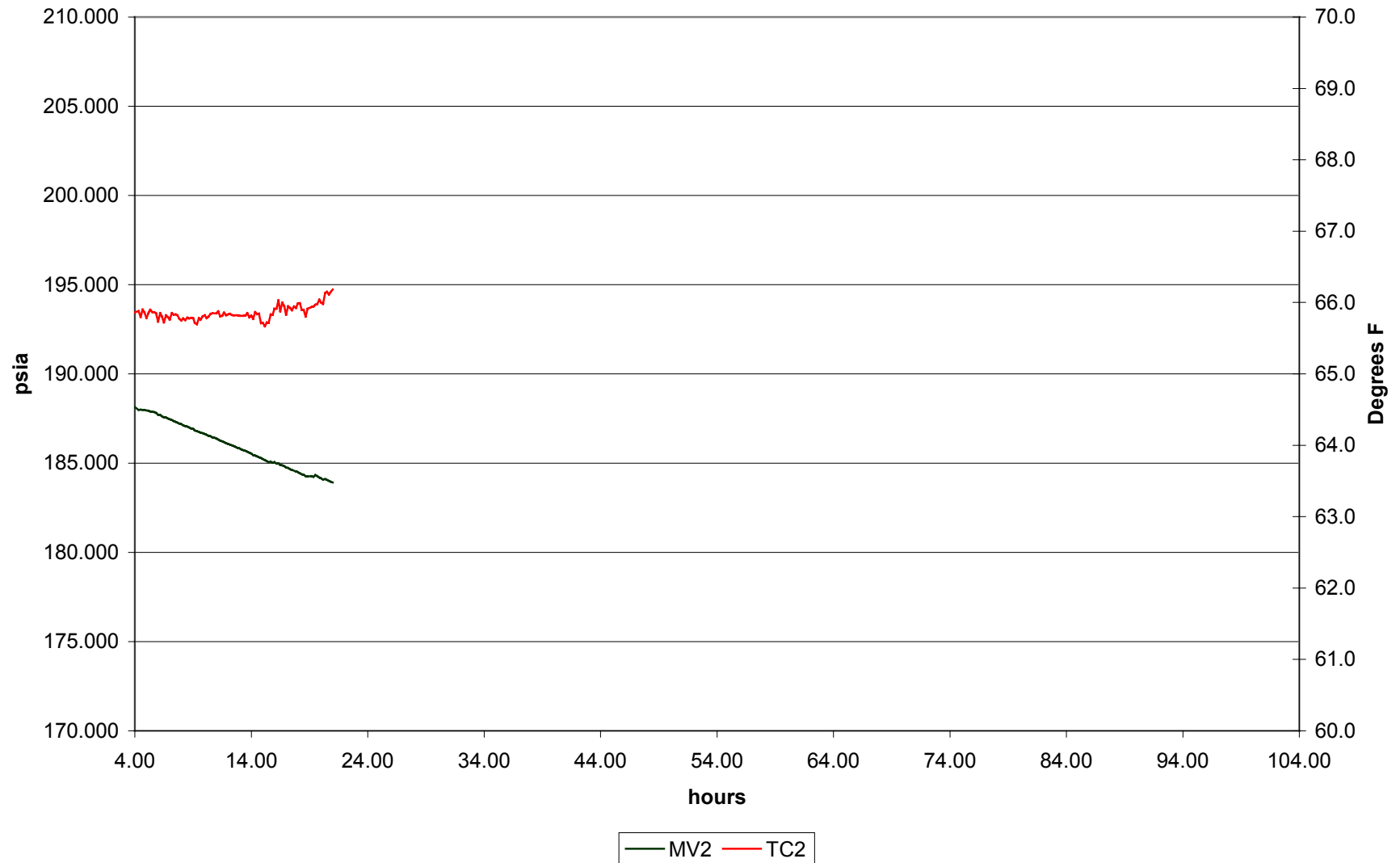
H.27 Chart 27 – Zone II, Launch State (run 2)

Zones IIIA, IIIB (MV3, MV4), Launch State, Run 2



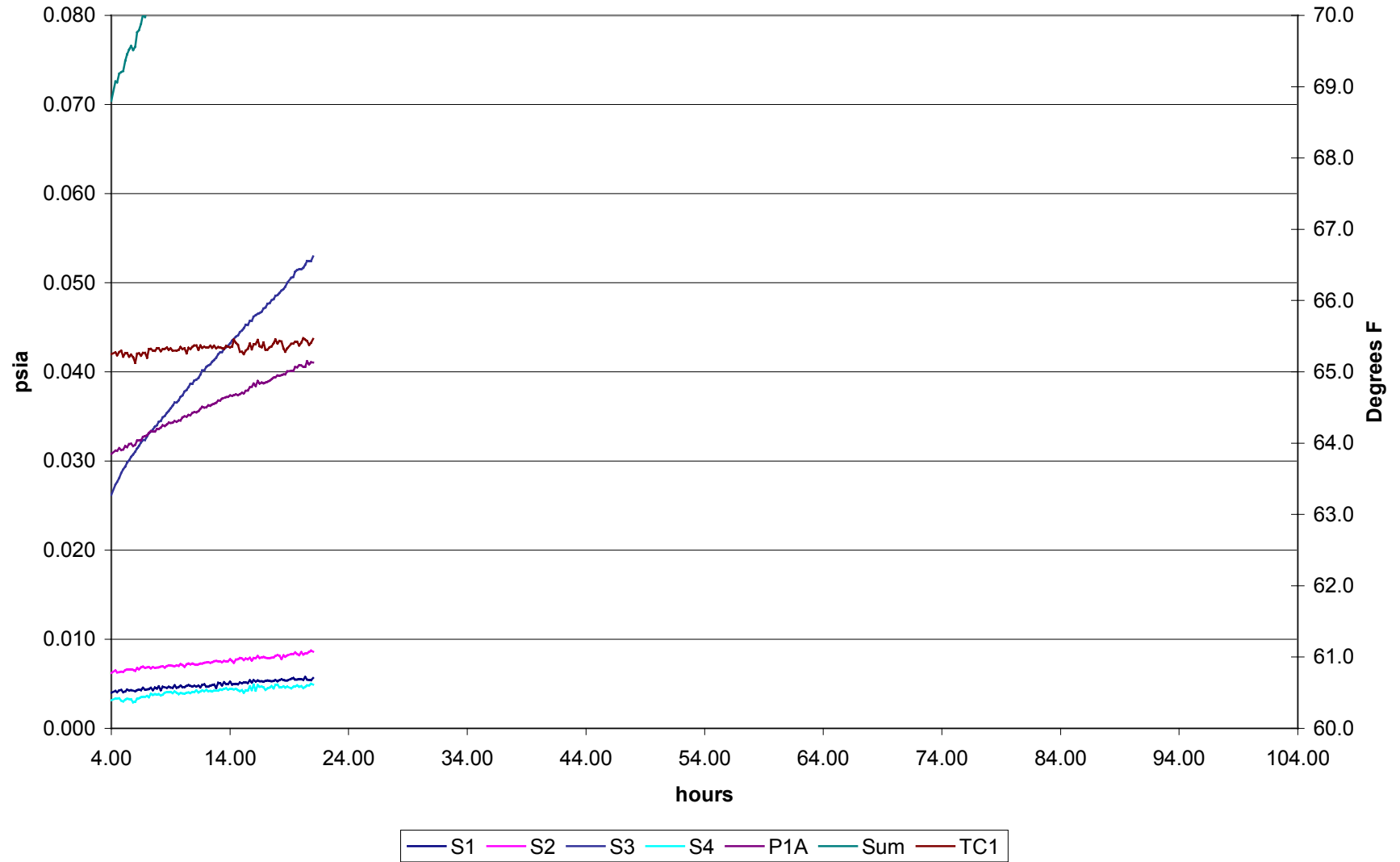
H.28 Chart 28 – Zone III, Launch State (run 2)

Zone V (MV2), Launch State, Run 2



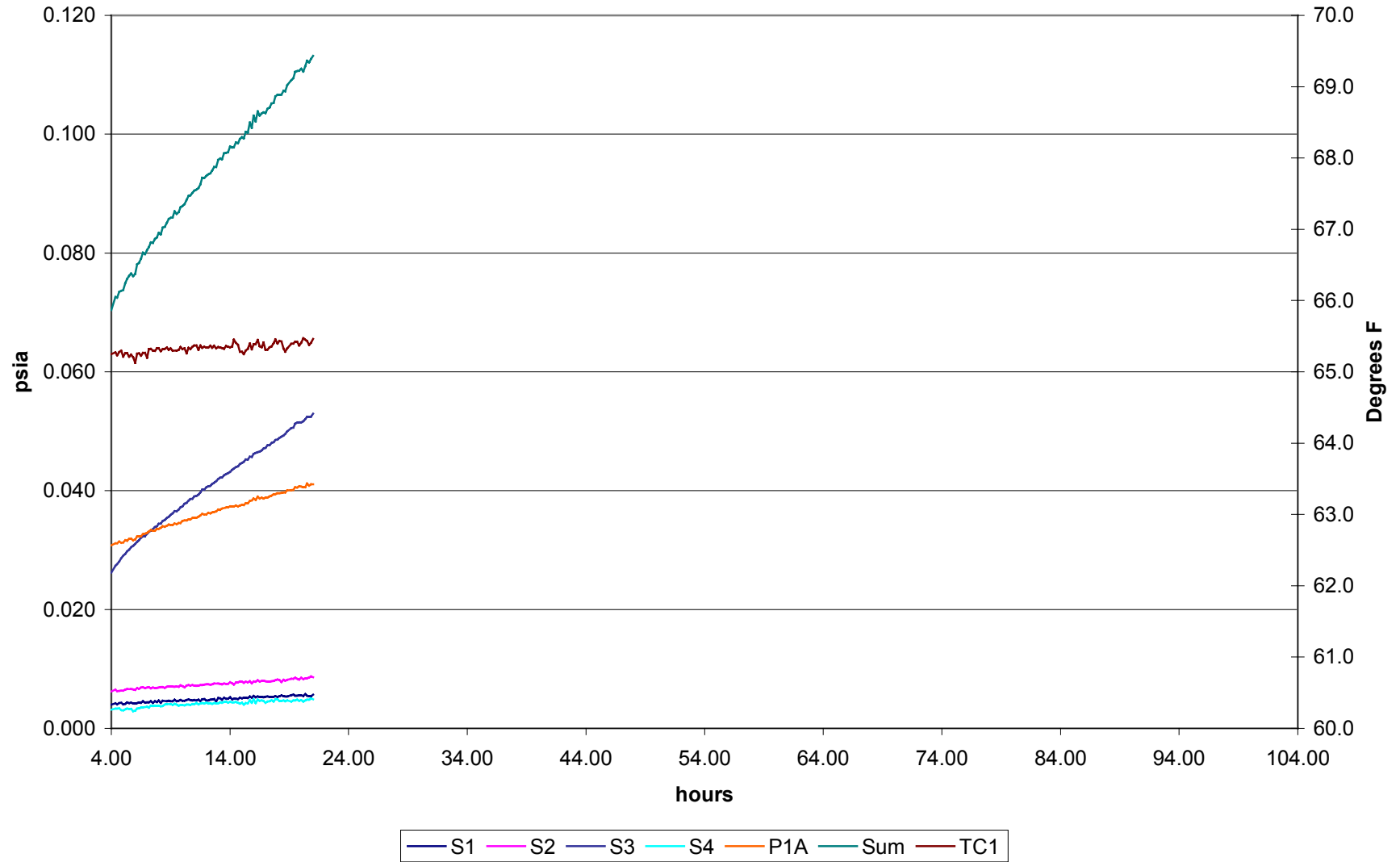
H.29 Chart 29 – Zone V, Launch State (run 2)

S1, S2, S3, S4, P1A (Zone VII), Launch State, Run 2



H.30 Chart 30 – Zone VII, Launch State (run 2)

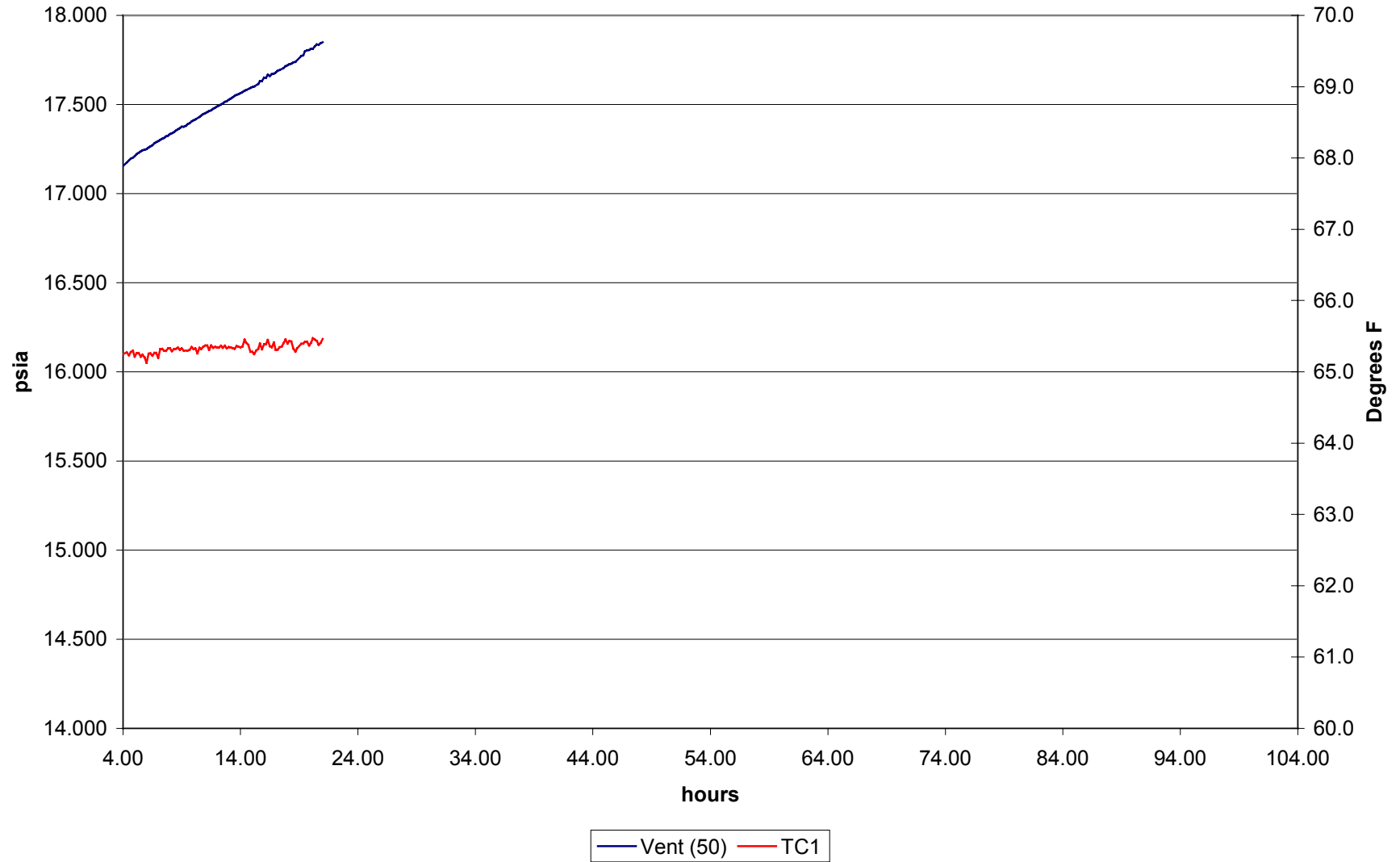
S1, S2, S3, S4, P1A (Zone VII), Launch State, Run 2; Alternate scaling



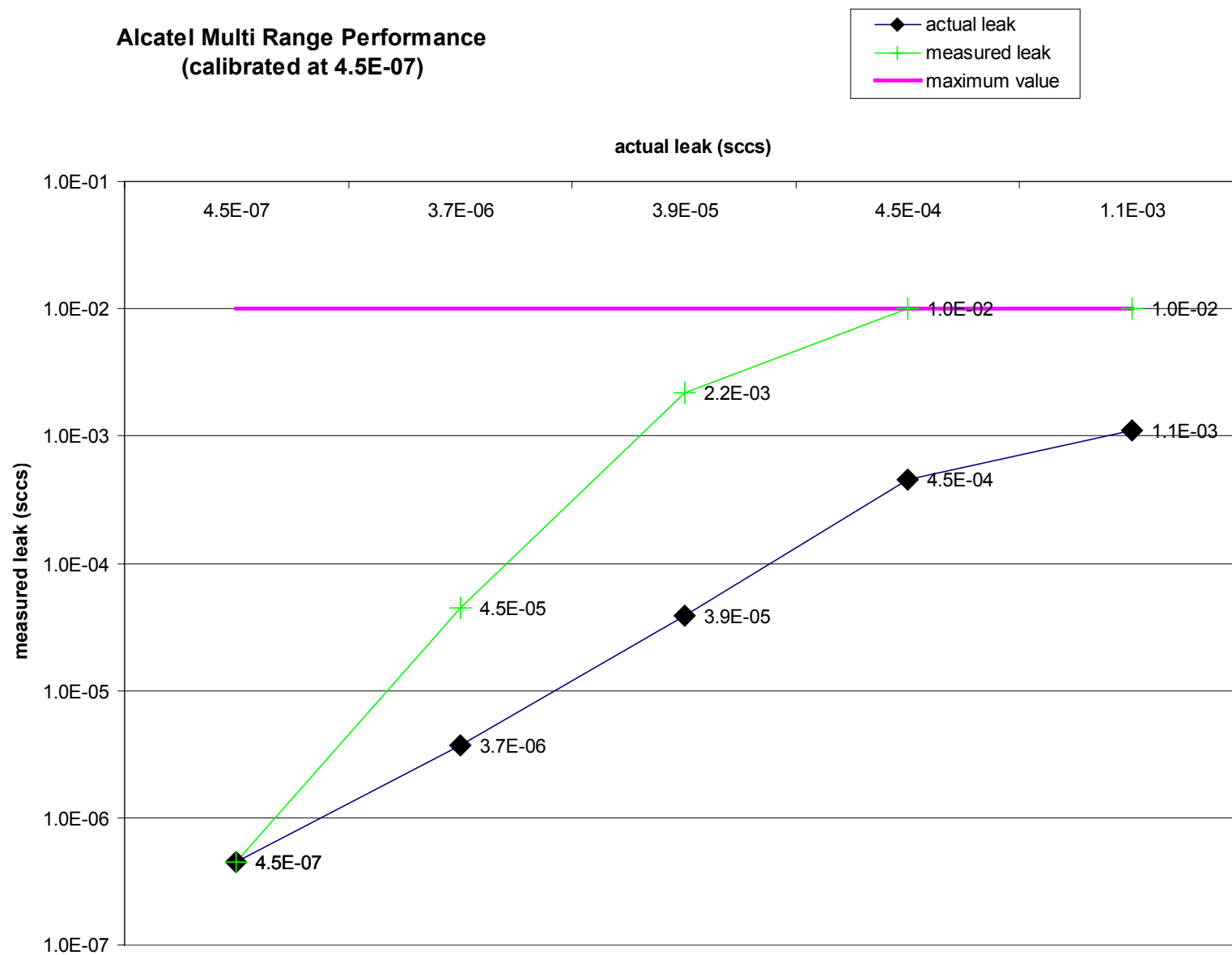
H.31 Chart 32 – Zone VII, Launch State (run 2), alternate scale

Vent (Zone VII), Launch State, Run 2

D.1.5.8



H.32 Chart 32 – Vent, Launch State (run 2)



I Tables**I.1 Table 1 – Leak Rate Summary**

This table lists the leak rates measured during the Rate of Rise evaluations. See section C.2 for test details. The column headings list the GMA zones where the data was taken (see Figure 1). All rates are net (the sum of all leaks into and out of the volume). Positive values indicate increases in pressure.

Leak rates measured during the rate of rise evaluation performed 1/17/03 thru 1/24/03 at Lockheed B156							
all values in sccs	S1 (Zone 7-S1)	S2 (Zone 7-S2)	S3 (Zone 7-S3)	S4 (Zone 7-S4)	P1A (Zone 7-P1A)	Probe Sum (Zone 7 w/o vent)	Vent (Zone 7-vent)
Leak rate, ground state:	1.05E-07	1.50E-07	3.01E-07	3.63E-07	3.41E-07	6.28E-06	-7.92E-06
Leak rate, Launch state (V17,V18 closed):	2.65E-07	4.02E-07	3.49E-04	3.26E-07	2.10E-06	1.77E-03	2.64E-04
Leak rate, Alternate launch state (V15,V16 closed):			2.45E-05				
Leak rate, Launch state (V17,V18 closed) run 2			4.31E-06			7.41E-06	2.64E-04

	MV2 (Zone 5)	MV3 (Zone 3A)	MV4 (Zone 3B)	GP2 (Zone 2A)	GP3 (Zone 2B)	GP1 (Zone 1)
Leak rate, ground state:	-7.92E-06	-1.25E-06	-7.11E-07	no data	no data	no data
Leak rate, Launch state (V17,V18 closed):	-3.68E-04	4.47E-07	3.23E-08	3.17E-07	7.09E-06	-3.41E-04
Leak rate, Alternate launch state (V15,V16 closed):	-2.58E-04	-9.25E-05	-1.18E-04	-9.33E-06	-3.92E-05	-6.37E-03
Leak rate, Launch state (V17,V18 closed) run 2	-1.26E-04	2.92E-06	6.39E-06	-3.30E-07	1.60E-05	-5.33E-05

I.2 Table 2 – Hold Time Summary

This table lists the amount of time the GMA can hold without needing service prior to launch in the different configurations evaluated. See section C.2 for a description of the evaluation. “Net psi/hour” reports the pressure change rate of the given zone (positive values indicate a pressure rise). “Hold time” indicates the hours/days that each zone can remain within in that state without violating launch requirements (high or low). Because it is impossible to measure pressures in zone IV above 30 psia, zones II, III, or V must be used to evaluated zone IV’s status (zone III is the best indicator of zones IV’s maximum value and zone V is the best indicator of zone IV’s minimum value).

		Ground State			Launch State 1		
		net psi/hour	Hold time (hours)	Hold time (days)	net psi/hour	Hold time (hours)	Hold time (days)
time to leak	Zone 2A (GP2)	x	x	x	0.0049303	40566	1690
from 300 psia	Zone 2B (GP3)	x	x	x	0.1102863	1813	76
to <100 psia	Zone 3A (MV3)	-0.0047	42663	1778	0.0017	116954	4873
or >500 psia	Zone 3B (MV4)	-0.0027	74467	3103	0.0001	1606168	66924
Time to leak from							
235 psia to 100 psia:	Zone 5 (MV2)	-0.0010986	122888	5120	-0.7742	174	7
235 psia to 15 psia:	Zone 5 (MV2)	-0.0010986	200262	8344	-0.7742	284	12

		Alternate Launch State			Launch State 2		
		net psi/hour	Hold time (hours)	Hold time (days)	net psi/hour	Hold time (hours)	Hold time (days)
time to leak	Zone 2A (GP2)	-0.1452	1378	57	-0.005132	38974	1624
from 300 psia	Zone 2B (GP3)	-0.6102	328	14	0.249623	801	33
to <100 psia	Zone 3A (MV3)	-0.3473	576	24	0.0110	18242	760
or >500 psia	Zone 3B (MV4)	-0.4476	447	19	0.0242	8275	345
Time to leak from							
235 psia to 100 psia:	Zone 5 (MV2)	-0.5607	241	10	-0.2602	519	22
235 psia to 15 psia:	Zone 5 (MV2)	-0.5607	392	16	-0.2602	845	35

D.10 GMA Pallet Vent Port Access Line Mitigation

SUMMARY & STATUS REPORT

GMA PALLET VENT PORT ACCESS LINE MITIGATION

J. A. KUCK	N/C	FEBRUARY 4, 2003
ORIGINATOR	REVISION	DATE

SECTION	PAGE
I: CONTEXT	2
II: DESIGN CONCEPT REVIEW	2-9
III: DESIGN & COMPONENT CHARACTERISTICS	10
IV: BILL OF MATERIALS / PROCUREMENT STATUS	11-13
V: RELATED DOCUMENTS / STATUS	14

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SECTION I: CONTEXT

PURPOSE

The primary objective of this design is to fulfill a customer generated need, the capability of servicing the Vent Port of the Gas Management Assembly (GMA) while the Space Vehicle is within the Fairing of the Launch Vehicle. The existing design and relative orientation of the Space Vehicle and Fairing only permit access to the Vent Port preceding integration with the Fairing, as the encapsulating Fairing limits access to a few select areas of the Space Vehicle, which does not include the Gas Management Assembly.

FUNCTIONAL REQUIREMENTS

- Allow servicing of the GMA Vent Port while the Space Vehicle is within the Fairing
- Regulate the gaseous flow to and from the GMA Vent Port
- Limit internal and external particle contamination of foreign materials to the GMA Vent Port, 2µm internal particle filtration
- Restrict internal and external leakage to and from the GMA Vent Port, internal 5.0×10^{-8} sccs, external less than 5.0×10^{-9} sccs
- Provide pressure monitoring capabilities of the flow to and from the GMA Vent Port, 0-300 psia
- Accommodate the associated structural load requirements, static, dynamic and thermal

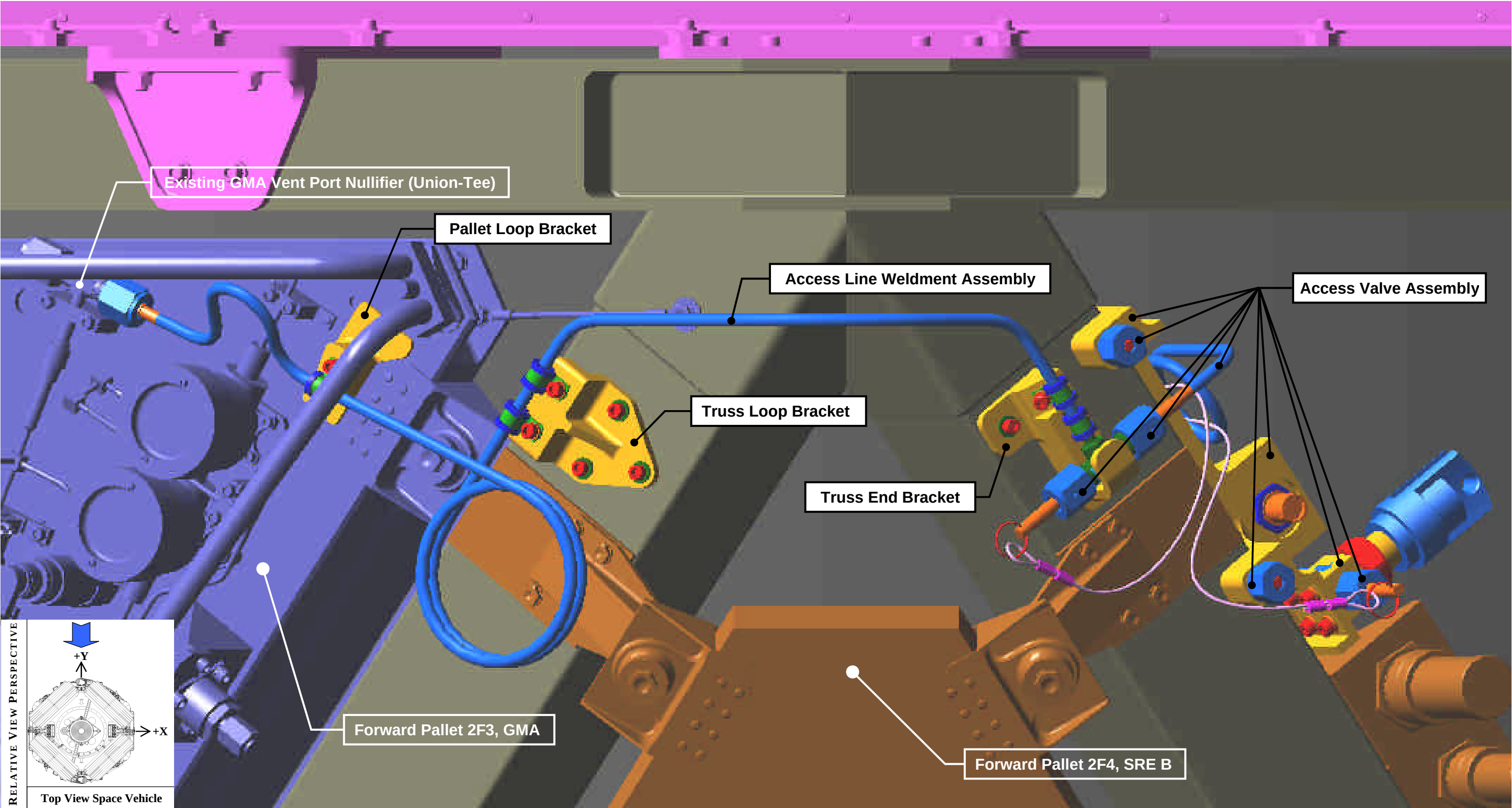
CONSTRAINTS

- Geometric and Physical Properties of Space Vehicle and Fairing
- Limits to modifying the existing Space Vehicle, only minor alterations
- Load environments, static, dynamic and thermal, respective flight and non-flight component qualification
- Schedule, complete integration of design solution by March 31, 2003

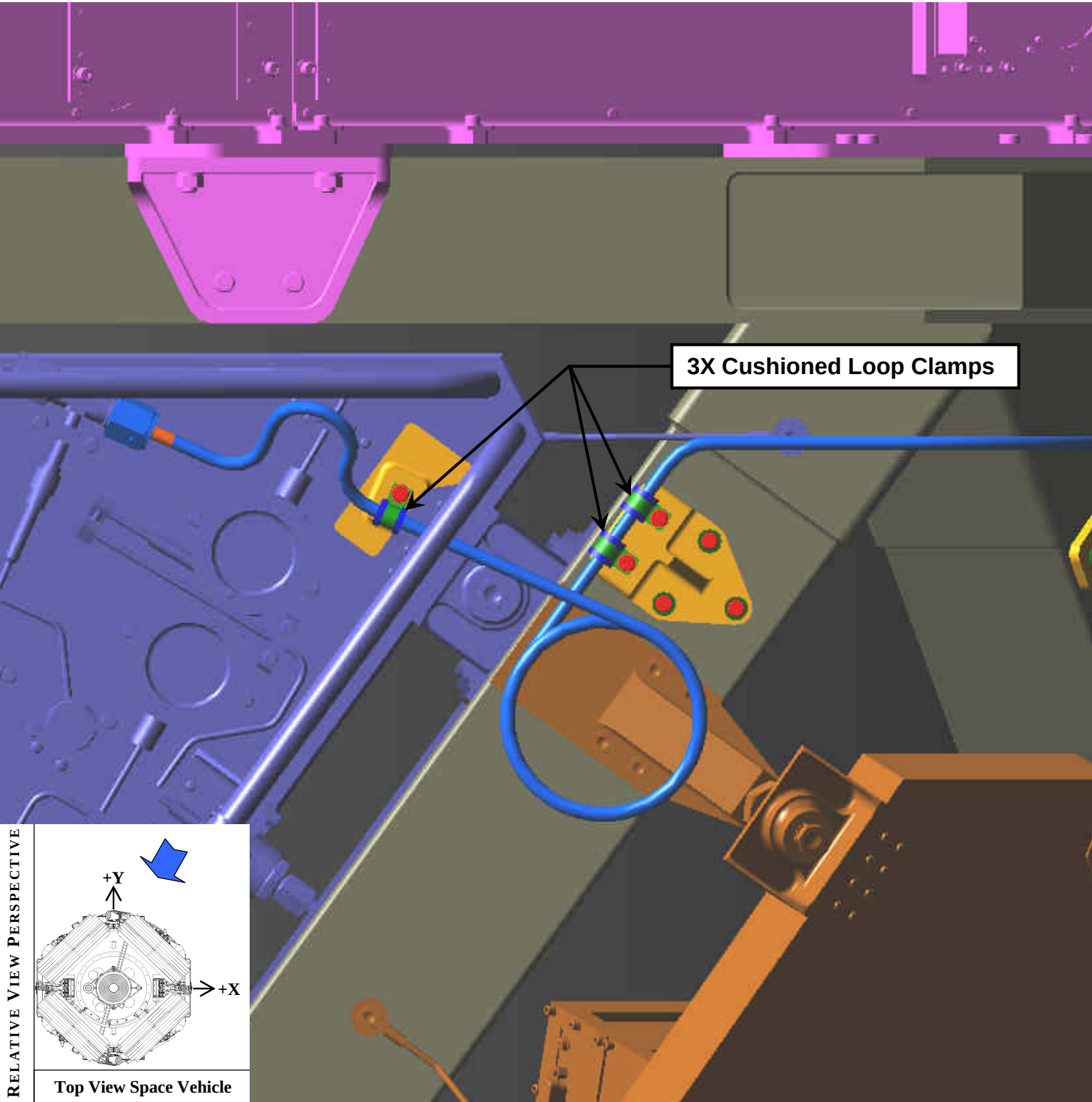
SECTION II: DESIGN CONCEPT REVIEW

The design solution, the GMA Pallet Vent Port Access Line Assembly is comprised of five primary components, four being permanently installed and the remaining item being temporarily installed to the Space Vehicle. The four flight components consist of a plumbing line, the Access Line Weldment Assembly, which extends the GMA Vent Port to the nearest Fairing Access Door and three brackets that support this extension line. The non-flight component, the Access Valve Assembly, attaches to the end of the extension line and contains several subassemblies that provide several servicing capabilities to the GMA Vent Port, including flow regulation, pressure monitoring and in-line filtration.

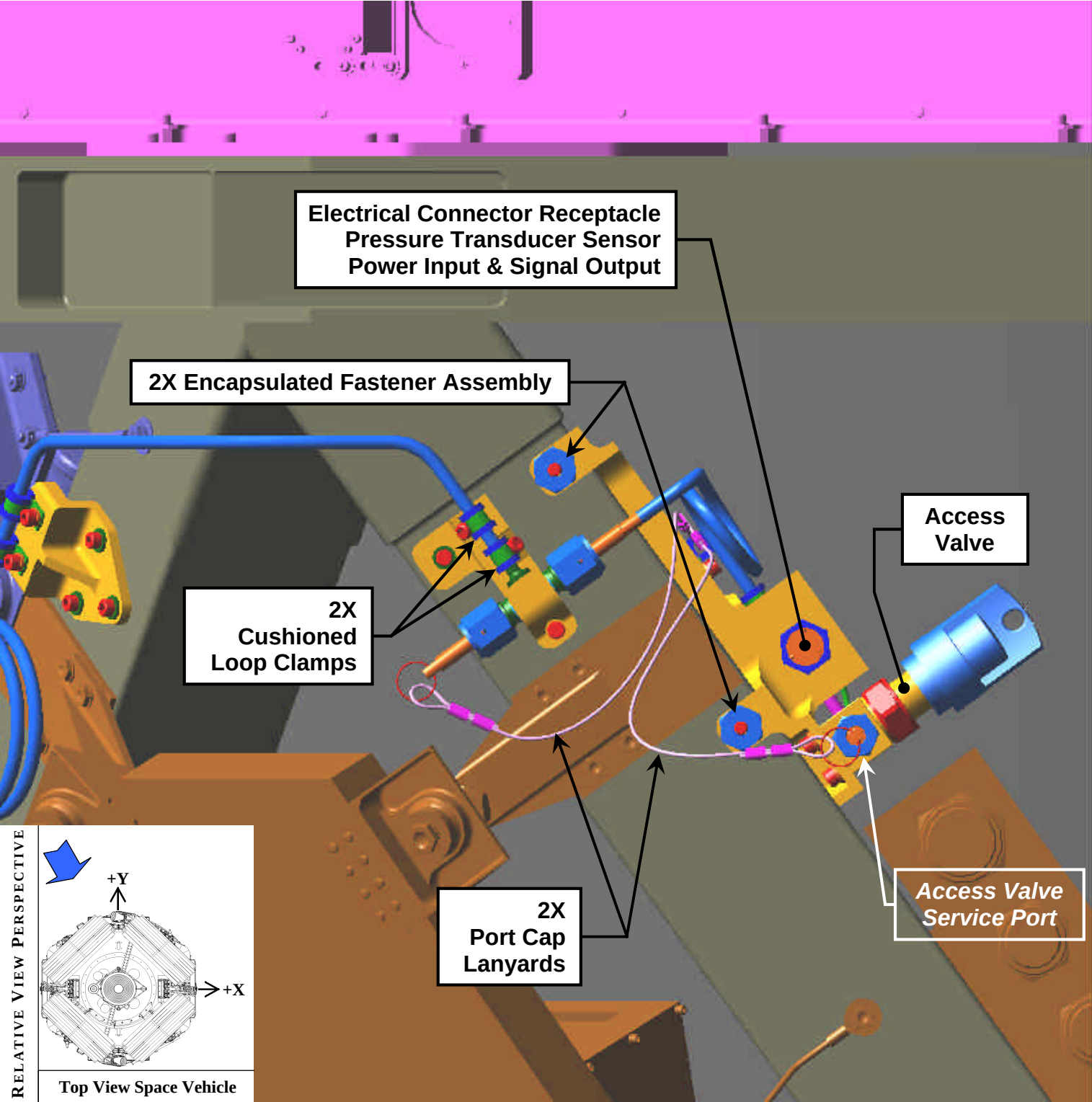
Various views of this design solution can be found on the subsequent pages.



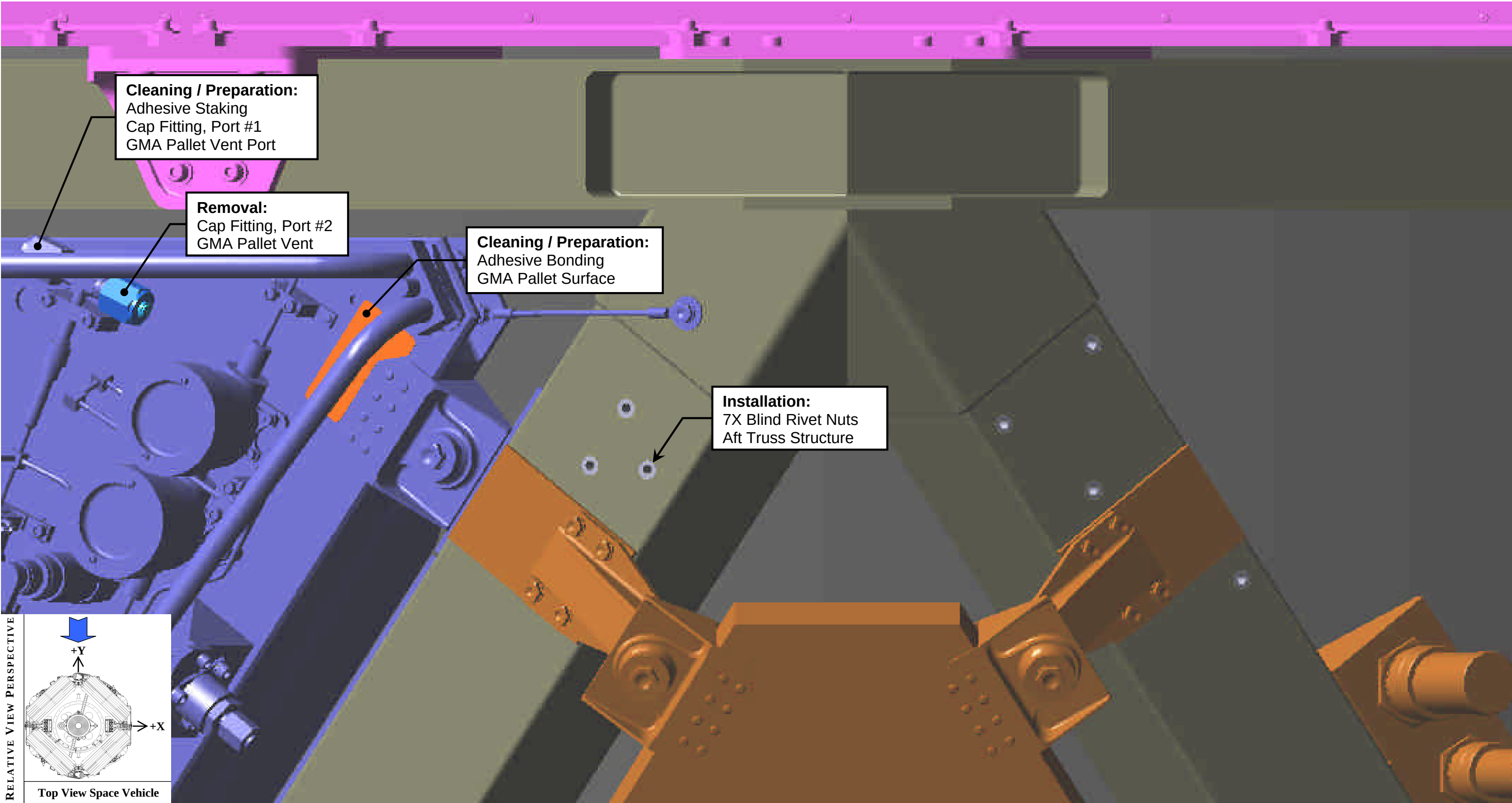
Integrated GMA Pallet Vent Port Access Line Assembly & GSE Access Valve Assembly



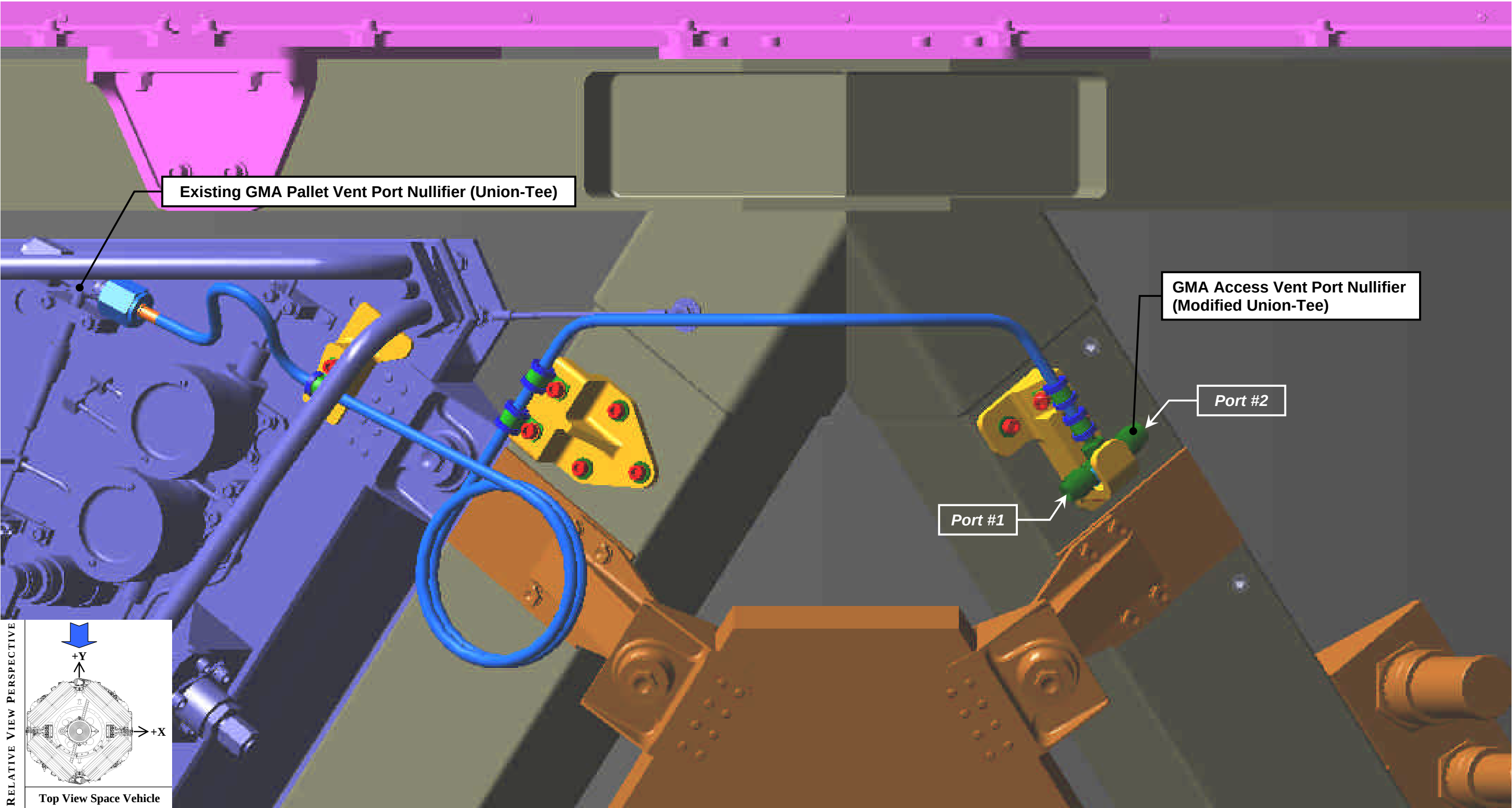
View of the Integrated Assemblies, True View GMA Pallet (30° CW of Space Vehicle +Y Axis)



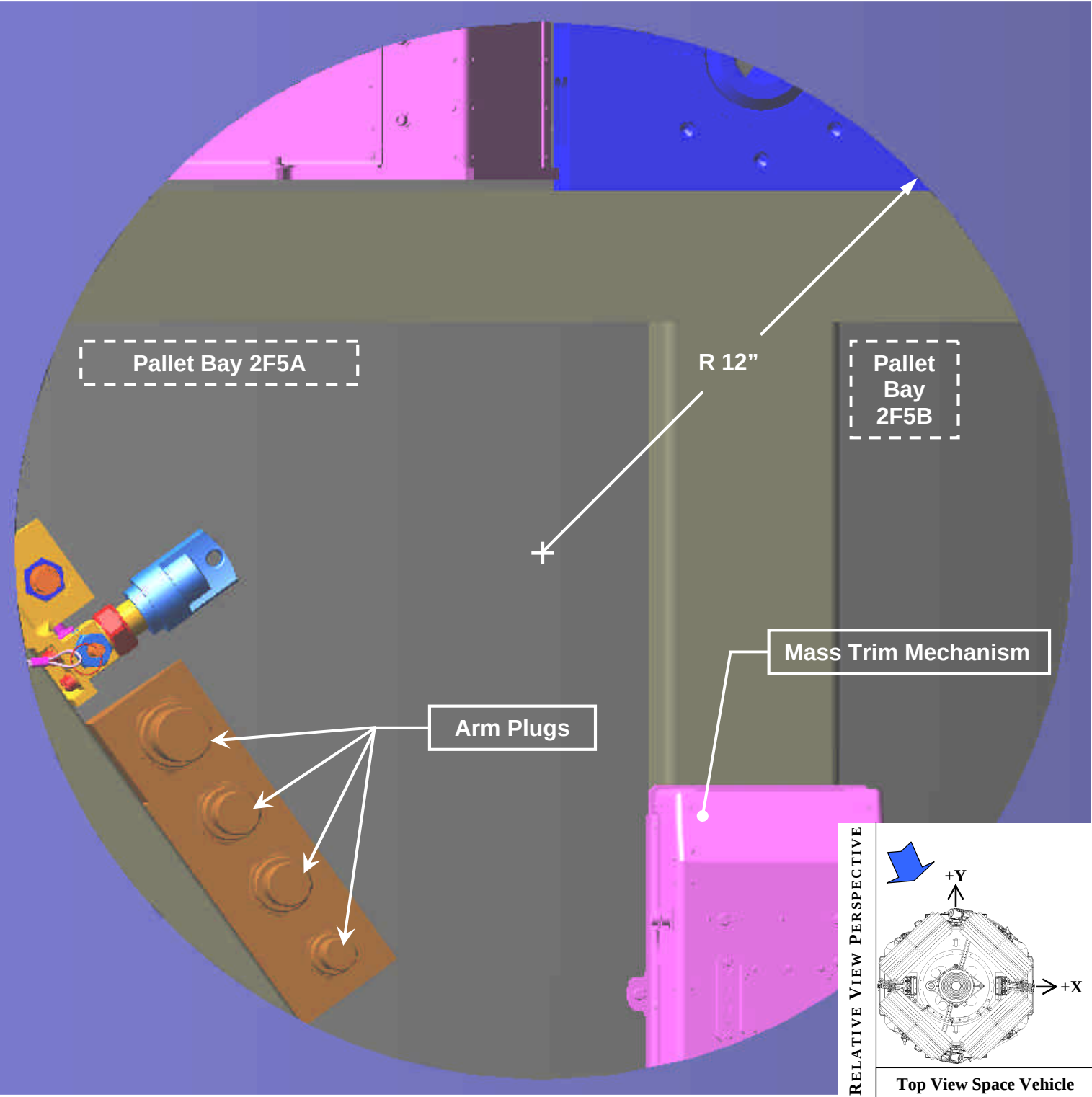
View of the Integrated Assemblies, True View Access Valve Assembly (30° CCW of SV +Y Axis)



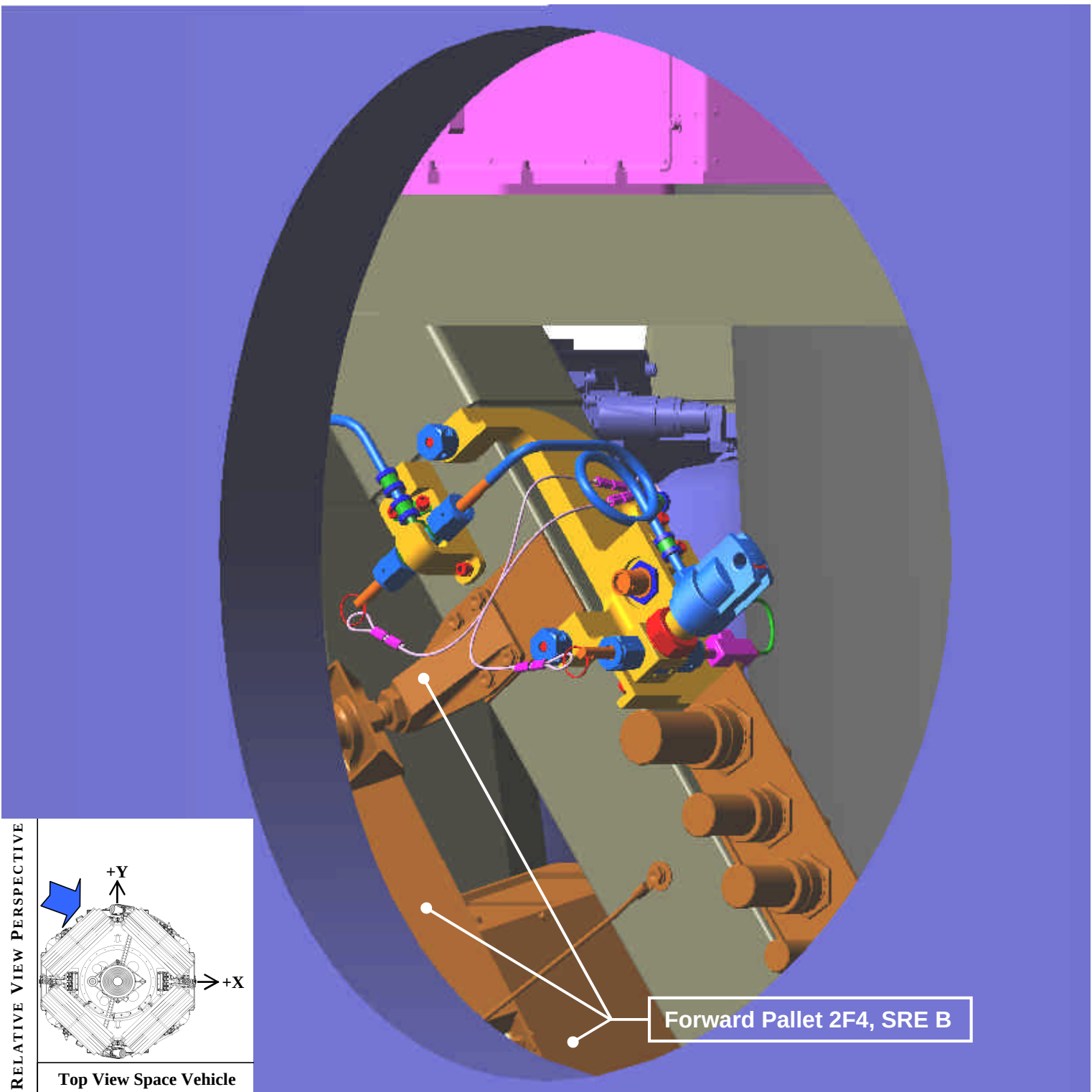
Integration Preparation of the Space Vehicle with Hardware Removal, Installation and Cleaning



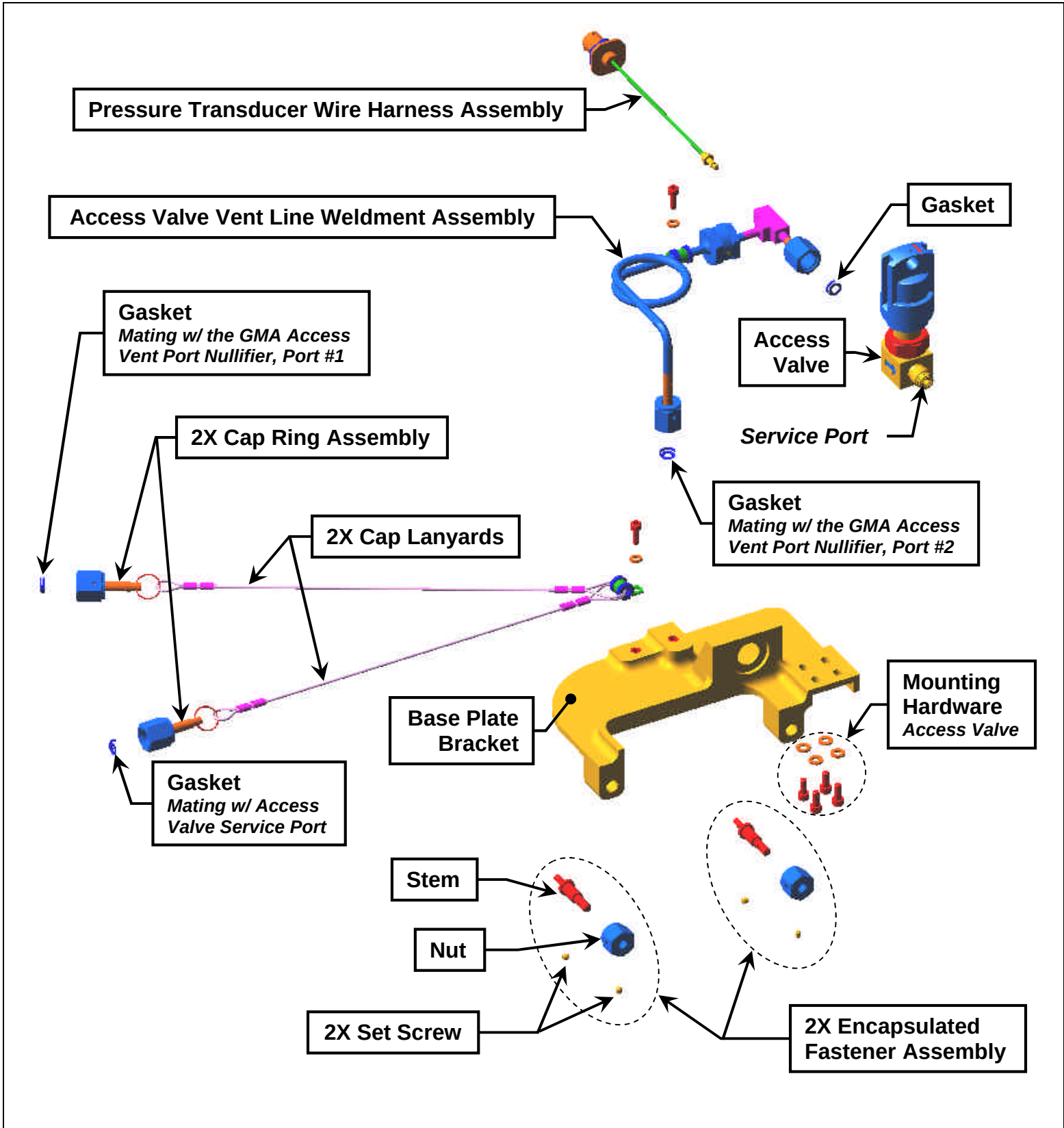
Pre-Flight Configuration of the Integrated GMA Pallet Vent Port Access Line Assembly



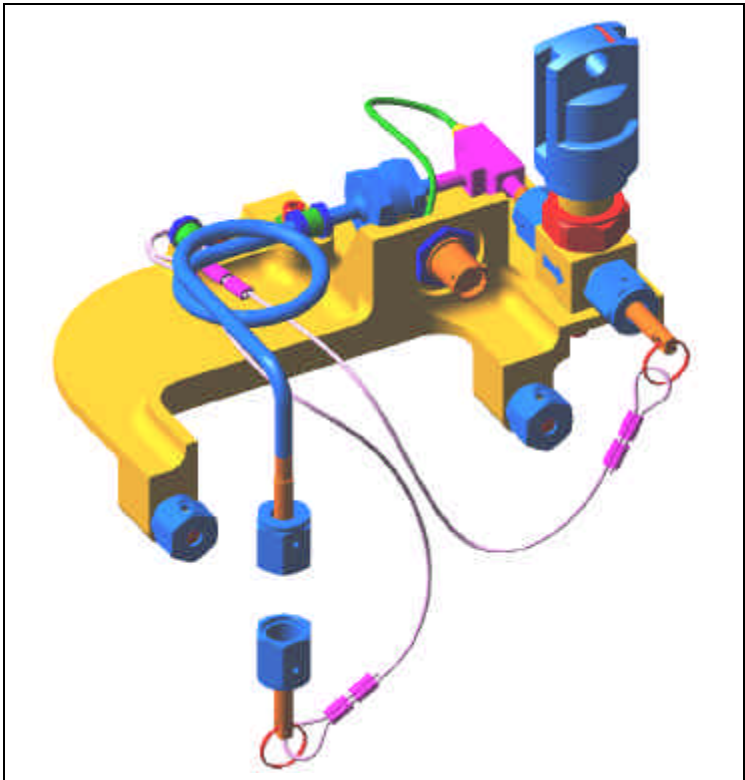
View of the Integrated Assemblies, True View Through Fairing Access Door (24° CCW of SV +Y Axis)



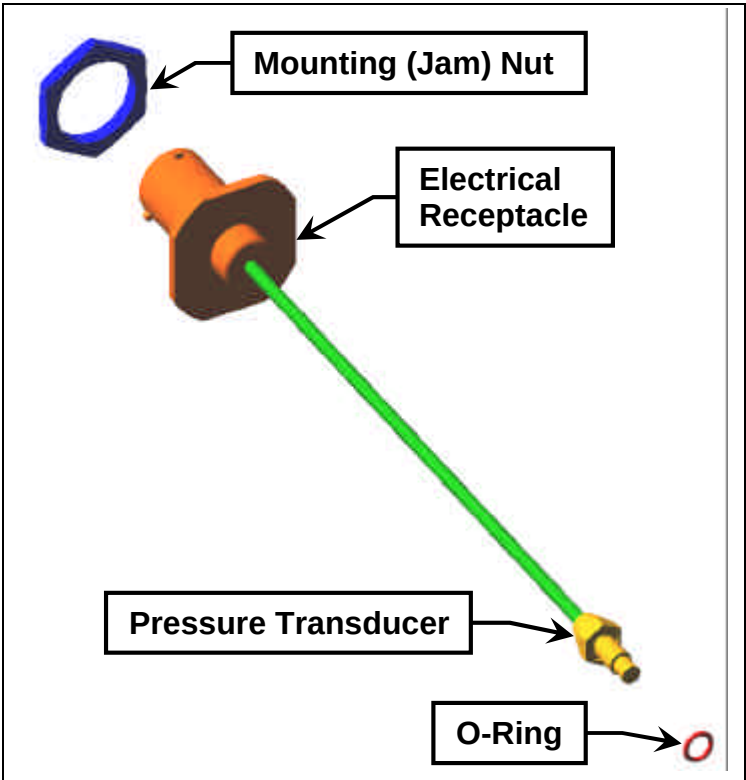
View of the Integrated Assemblies, Operator's View Through Fairing Access Door



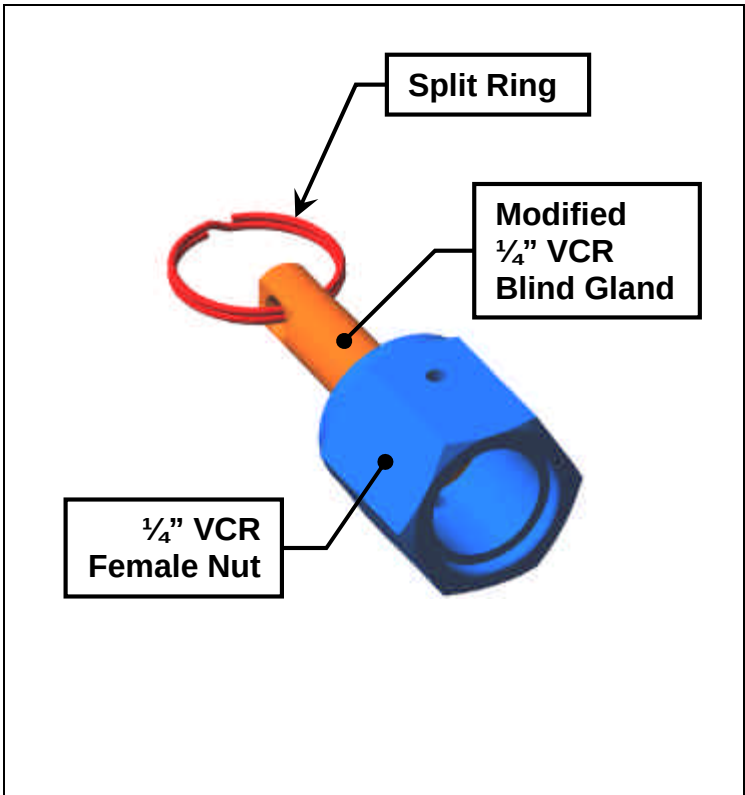
Exploded Access Valve Assembly with Mating Gaskets to Flight Hardware



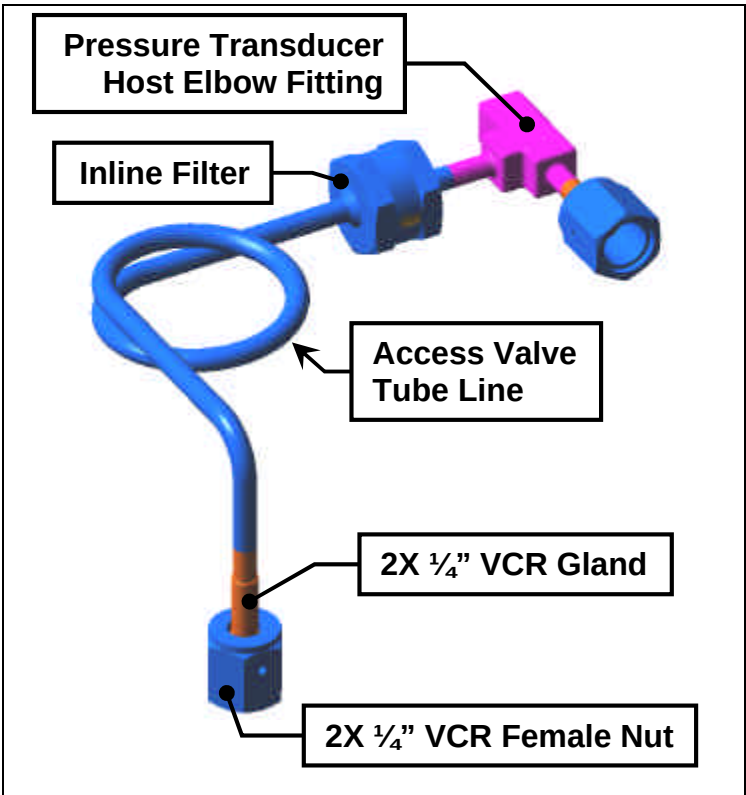
Access Valve Assembly (Installed Configuration)



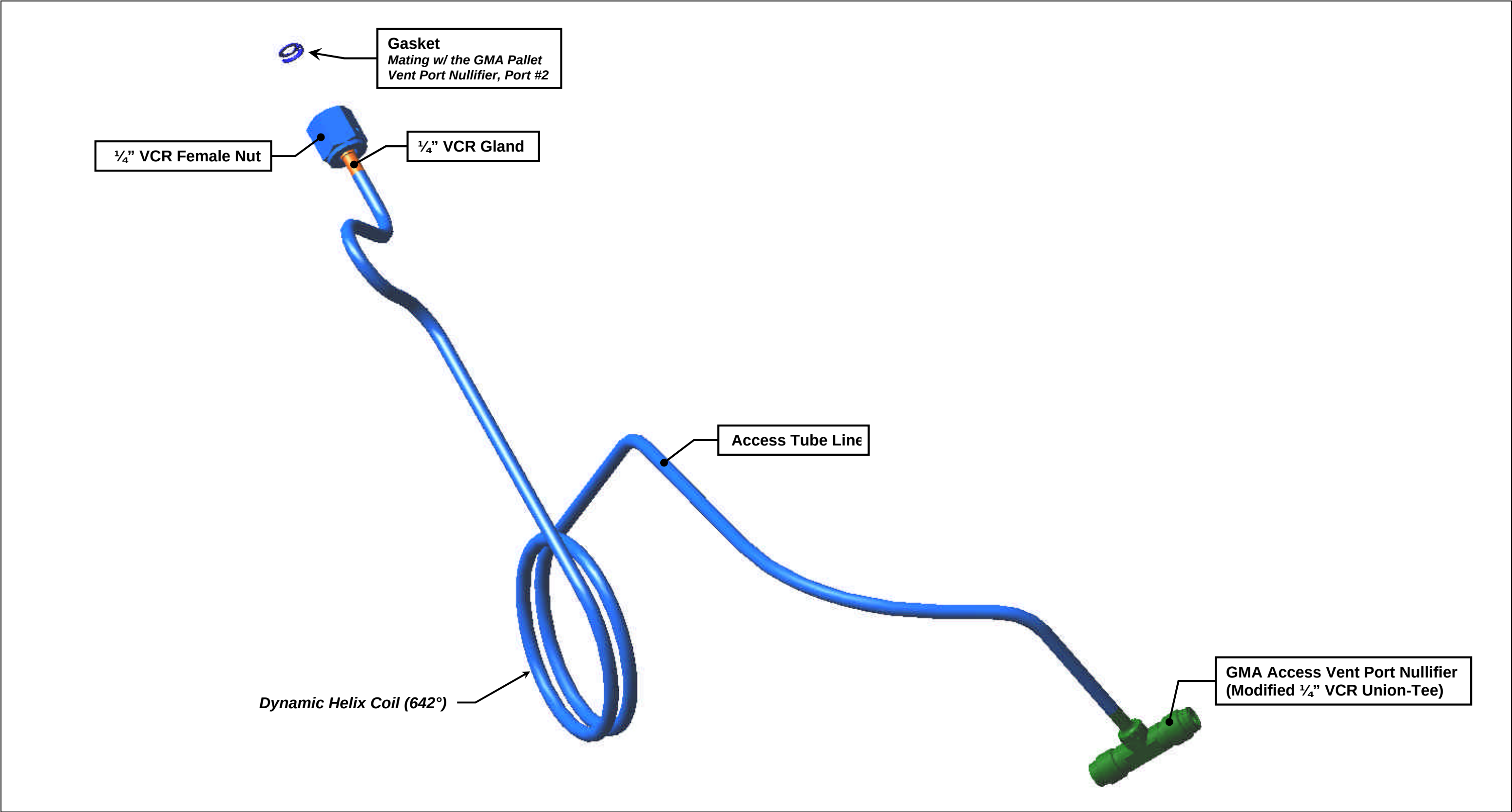
Exploded P. Transducer Wire Harness Assembly



Cap Ring Assembly



Access Valve Line Weldment Assembly



Access Vent Tube Line Weldment Assembly with Mating Gaskets to the GMA Pallet Vent Port

SECTION III: DESIGN & COMPONENT CHARACTERISTICS

INTERNAL FLOW CHARACTERISTICS

Assembly / Assemblies	Centerline Flow Distances	Internal Volumes	
Access Vent Tube Line Weldment	51.0"	1.325 in ³	21.71 cc
Access Valve Vent Line Weldment and Access Valve	21.4"	0.593 in ³	9.72 cc
Total	72.4"	1.918 in ³	31.43 cc

MASS PROSPERITIES CHARACTERISTICS OF FLIGHT HARDWARE

Assembly / Group	Weight	Individual Bracket Assembly	Weight
Access Vent Tube Line Weldment	0.52 lbs	Truss Loop Bracket	0.163 lbs
Brackets	0.44 lbs	Pallet Loop Bracket	0.074 lbs
Mounting Hardware	0.12 lbs	Truss End Bracket	0.203 lbs
Flight Hardware Total	1.08 lbs	Brackets Total	0.440 lbs

SERVICING CHARACTERISTICS, PRESSURE MONITORING

Required Mating Electrical Connector	TBD
Required Supply Voltage	10 Vdc
Required Output Resolution	0.1 mV
Sensitivity (Pressure Transducer S/N: 10872)	0.625 mV / psi

SERVICING CHARACTERISTICS, ACCESS VALVE SERVICE PORT

Required Matting Fitting	Female, Swagelok ¼" VCR Fitting that is able to utilize Side Load Retainer Style Gasket
Required Gasket	Side Load Retainer Style, Nickel, Swagelok ¼" VCR Fitting, P/N: NI-4-VCR-2-ZC-VS

SECTION IV: BILL OF MATERIALS / PROCUREMENT STATUS

FLIGHT HARDWARE

Item	Description	Quantity	Part Number	Fabricator	Delivery Status
1	Access Vent Tube Line Weldment Assembly	1	8A03341-101	AMI	FEB - 21
1.1	Access Tube Line, Formed, 316L Stainless Steel	1	8A03341-102	AMI	-
1.2	Modified Union Tee, 316 Stainless Steel	1	8A03348-101	Sagehill	Completed
1.2.1	Union Tee, 316 Stainless Steel, Swagelok ¼” VCR	1	SS-4-VCR-T	Swagelok	Completed
1.3	Gland Short, 316L VAR Stainless Steel, Swagelok ¼” VCR	1	6LV-4-VCR-3S-4TB3	Swagelok	Completed
1.4	Female Nut, 316 Stainless Steel, w/ Silver Plated Threads, Swagelok ¼” VCR	1	SS-4-VCR-1	Swagelok	Completed
2	Truss Loop Bracket Assembly	1	8A03342-101	Sagehill	Completed
2.1	Truss Loop Bracket, 6061-T6 Aluminum	1	8A03342-102	Sagehill	Completed
2.2	Insert, Light Weight, A286 CRES, ID .1900-32UNF, OD .3125-18UNC	2	NAS1394CA3	-	Completed
3	Pallet Loop Bracket Assembly	1	8A03343-101	Sagehill	Completed
3.1	Pallet Loop Bracket, 6061-T6 Aluminum	1	8A03343-102	Sagehill	Completed
3.2	Insert, Light Weight, A286 CRES, ID .1900-32UNF, OD .3125-18UNC	1	NAS1394CA3	-	Completed
4	Truss End Bracket Assembly	1	8A03344-101	Sagehill	Completed
4.1	Truss End Bracket, 6061-T6 Aluminum	1	8A03344-102	Sagehill	Completed
4.2	Insert, Light Weight, A286 CRES, ID .1900-32UNF, OD .3125-18UNC	2	NAS1394CA3	-	Completed
5	Installation Hardware and Materials (Integration to Space Vehicle)	-	-	-	Completed
5.1	Rivet Nut, Blind, .1900-32UNF, LG .250	7	NAS1330C3-266	-	Completed
5.2	Socket Head Cap Screw, A286 Heat Resistant SS .1900-32UNJF, L 0.750, Locking	5	NAS1351N3LE8	-	Completed
5.2	Socket Head Cap Screw, A286 Heat Resistant SS.1900-32UNJF, L 0.500, Locking	5	NAS1351N3LE12	-	Completed
5.3	Washer Flat, Reduced Size, A286 CRES, ID .195, OD .354, T.063	6	NAS620C10	-	Completed
5.4	Washer Flat, A286 CRES, ID .203, OD .438, T.063	4	NAS1149E0363R	-	Completed
5.5	Loop Tube Clamp, Cushioned, Loop ID .250	5	LS41550-003	-	Completed
5.6	Adhesive, Two Component Epoxy, 3M	A/R	2216 B/A Gray	-	Completed
5.7	Adhesive, Two Component Epoxy, Vantico Epibond	A/R	1210A / 9615-10	-	Completed
5.8	Fiberglass Tape	A/R	24-312-0038100	-	Completed
5.9	Gasket, Side Load Retainer Style, Nickel, Swagelok ¼” VCR Fitting	1	NI-4-VCR-2-ZC-VS	Swagelok	Completed

NON-FLIGHT HARDWARE

Item	Description	Quantity	Part Number	Fabricator	Delivery Status
6	Access Valve Assembly	1	8A03345GSE-101	Stanford	FEB - 21
6.1	Base Bracket Assembly	1	8A03344-102	Sagehill	FEB-12
6.1.1	Base Bracket, Anodized, 6061-T6 Aluminum	1	8A03344-102	Sagehill	-
6.1.2	Insert, Light Weight, A286 CRES, ID .1900-32UNF, OD .3125-18UNC	2	NAS1394CA3	-	Completed
6.2	Diaphragm Valve, Locking Handle, 316L VIM/VAR SS, Swagelok ¼” Male VCR Ends	1	6LVV-DPHLVR4-P	Swagelok	Completed
6.3	Access Valve Vent Line Weldment Assembly	1	8A03359-101	AMI	FEB-21
6.3.1	Access Valve Tube Line, Formed, 316L Stainless Steel	1	8A03359-102	AMI	-
6.3.2	Modified In-Line Filter, 316 Stainless Steel	1	8A03358-101	Sagehill	Completed
6.3.2.1	In-Line Filter, FW Series, Pleated Mesh w/ 2µm Filter, 316SS, Swagelok ¼” VCR	1	SS-4FW--2	Swagelok	Completed
6.3.3	Transducer Host Elbow Weld Fitting, 316 Stainless Steel	1	8A03350-101	Sagehill	Completed
6.3.4	Female Nut, 316 Stainless Steel, w/ Silver Plated Threads, Swagelok ¼” VCR	2	SS-4-VCR-1	Swagelok	Completed
6.3.5	Gland Short, 316 VAR Stainless Steel, Swagelok ¼” VCR	1	6LV-4-VCR-3S-4TB3	Swagelok	Completed
6.3.6	Gland Long, 316 VAR Stainless Steel, Swagelok ¼” VCR	1	6LV-4-VCR-3-4TB3	Swagelok	Completed
6.4	Pressure Transducer Wire Harness Assembly	1	TBD	Lockheed-Martin	FEB-14
6.4.1	Piezoresistive Pressure Transducer, Range 0-500 psia, w/ 30” Integral Cable & O-Ring	1	8530B-500	Endevco	Completed
6.4.2	Electrical Connector Receptacle w/ Mounting Jam Nut	1	LJT07RT-9-3	Amphenol	Completed
6.5	Encapsulated Fastener Kit Assembly	2	8A03366-101	-	FEB-10
6.5.1	Stem, 17-4PH Stainless Steel	1	8A03366-103	Sagehill	FEB-10
6.5.2	Nut, 17-4PH Stainless Steel	1	8A03366-102	Sagehill	FEB-10
6.5.3	Set Screw, Cup Point, Locking, .1640-32UNC, L 3/16	2	90251A189	McMaster-Carr	Completed
6.6	Cap Ring Assembly	2	8A03371GSE-101	Lockheed-Martin	FEB-14
6.6.1	Modified Blind Gland, 316 Stainless Steel	1	8A03349GSE-101	Sagehill	FEB-10
6.6.1.1	Blind Gland, 316 Stainless Steel, Swagelok ¼” VCR	1	SS-4-VCR-3-BL	Swagelok	Completed
6.6.2	Female Nut, 316 Stainless Steel, w/ Silver Plated Threads, Swagelok ¼” VCR	1	SS-4-VCR-1	Swagelok	Completed
6.6.3	Split Ring, 18-8 Stainless Steel, ID .328, OD .430, T.074	1	90990A160	McMaster-Carr	Completed
6.7	Cap Lanyard Assembly	2	8A03369GSE-101	Lockheed-Martin	FEB-07
6.7.1	Coated Wire Rope, OD .070	A/R	-	-	Completed
6.7.2	Oval Sleeve Swage Fitting, Copper	4	-	-	Completed

NON-FLIGHT HARDWARE (CONTINUED)

Item	Description	Quantity	Part Number	Fabricator	Delivery Status
6.8	Installation Hardware and Materials (Integration of Assembly)	-	-	-	FEB-05
6.8.1	Socket Head Cap Screw, A286 CRES, Metric, MJ5 X 0.8, L 12 mm	4	NA0069-050012	-	FEB-05
6.8.2	Washer Flat, Metric, A286 CRES, ID 5.50 mm, OD 10.60 mm, T1.60 mm	4	AS3265-05	-	FEB-05
6.8.3	Socket Head Cap Screw, A286 CRES, .1900-32UNJF, L 0.750, Locking	2	NAS1351N3LE8	-	Completed
6.8.4	Washer Flat, Reduced Size, A286 CRES, ID .195, OD .354, T.063	2	NAS620C10	-	Completed
6.8.5	Loop Tube Clamp, Cushioned, Loop ID .250	2	LS41550-003	-	Completed
6.8.6	Adhesive, Two Component Epoxy, Vantico Epibond	A/R	1210A / 9615-10	-	Completed
6.8.7	Gasket, Side Load Retainer Style, Nickel, Swagelok ¼” VCR Fitting	1	NI-4-VCR-2-ZC-VS	Swagelok	Completed
7	Installation Hardware and Materials (Integration to Space Vehicle)	-	-	-	Completed
7.1	Gasket, Side Load Retainer Style, Nickel, Swagelok ¼” VCR Fitting	2	NI-4-VCR-2-ZC-VS	Swagelok	Completed

SECTION V: RELATED DOCUMENTS / STATUS

DRAWINGS

Item	Description	Drawing Number	Status	Release Date
DWG-01	GMA Pallet Vent Port Access Plumbing Assembly, Integration with Space Vehicle	8A03340	Working	(FEB-07-2003)
DWG-02	Access Vent Tube Line Weldment Assembly	8A03341	Released	DEC-20-2002
DWG-03	Truss Loop Bracket Assembly	8A03342	Released	JAN-10-2003
DWG-04	Pallet Loop Bracket Assembly	8A03343	Released	JAN-10-2003
DWG-05	Truss End Bracket Assembly	8A03344	Released	JAN-10-2003
DWG-06	Access Valve Assembly, Assembly Integration	8A03345GSE	Working	(FEB-07-2003)
DWG-07	Access Valve Support Bracket	8A03347GSE	Released	JAN-29-2003
DWG-08	Modified Union Tee, ¼” VCR Fitting	8A03348	Released	DEC-17-2002
DWG-09	Modified Blind Gland, ¼” VCR Fitting	8A03349GSE	Released	JAN-21-2003
DWG-10	Transducer Host Elbow Weld Fitting	8A03350(GSE)	Released	JAN-08-2003
DWG-11	Modified Filter, Weld Fitting	8A03358(GSE)	Released	JAN-07-2003
DWG-12	Access Valve Vent Line Weldment Assembly	8A03359(GSE)	Released	JAN-07-2003
DWG-13	Encapsulated Fastener Kit Assembly	8A03366(GSE)	Released	JAN-21-2003
DWG-14	Cap Lanyard Assembly	8A03369GSE	Released	JAN-21-2003
DWG-15	Cap Ring Assembly	8A03371GSE	Released	JAN-22-2003
DWG-16	Pressure Transducer Wire Harness Assembly	TBD	Working	(FEB-14-2003)

OPERATIONS / ORDERS

Item	Description	Op/Order Number	Status	Release Date
O/O-1	Fabrication of the Cap Lanyard Assembly	INT-357	Released	JAN-29-2003
O/O-2	Fabrication & Cleaning of the Cap Ring Assembly	INT-358	Released	JAN-29-2003
O/O-3	GMA Pallet Vent Port Access Plumbing Assembly, Integration with Space Vehicle	INT-362	Working	(FEB-07-2003)

D.11 Vent Line Extension GSE Schematic

- Overview
- Parts list
- Drawings

VENT EXTENSION PUMP CART

The GSE for the vent extension line is called the Vent Extension Pump Cart. It is a compact high purity system of six manual shutoff valves, two relief valves, two analog gages, several VCR fittings, a one liter tank, a check valve, a filter, and a regulator. The plumbing layout is shown in the attached schematic. The plumbing is mounted on an aluminum plate (~16.68" X ~18" X ~1/4") which is bolted to four standoffs. The plumbing assembly is connected to an existing Varian T series Turbo Pump Cart. To vent excess GSE pressure, there is a vent line protected by a check valve. The total approximate costs for purchasing the plumbing, machining parts and welding is \$3500. An itemized spreadsheet of the costs is appended. Preliminary isometric and orthogonal drawings are also attached.

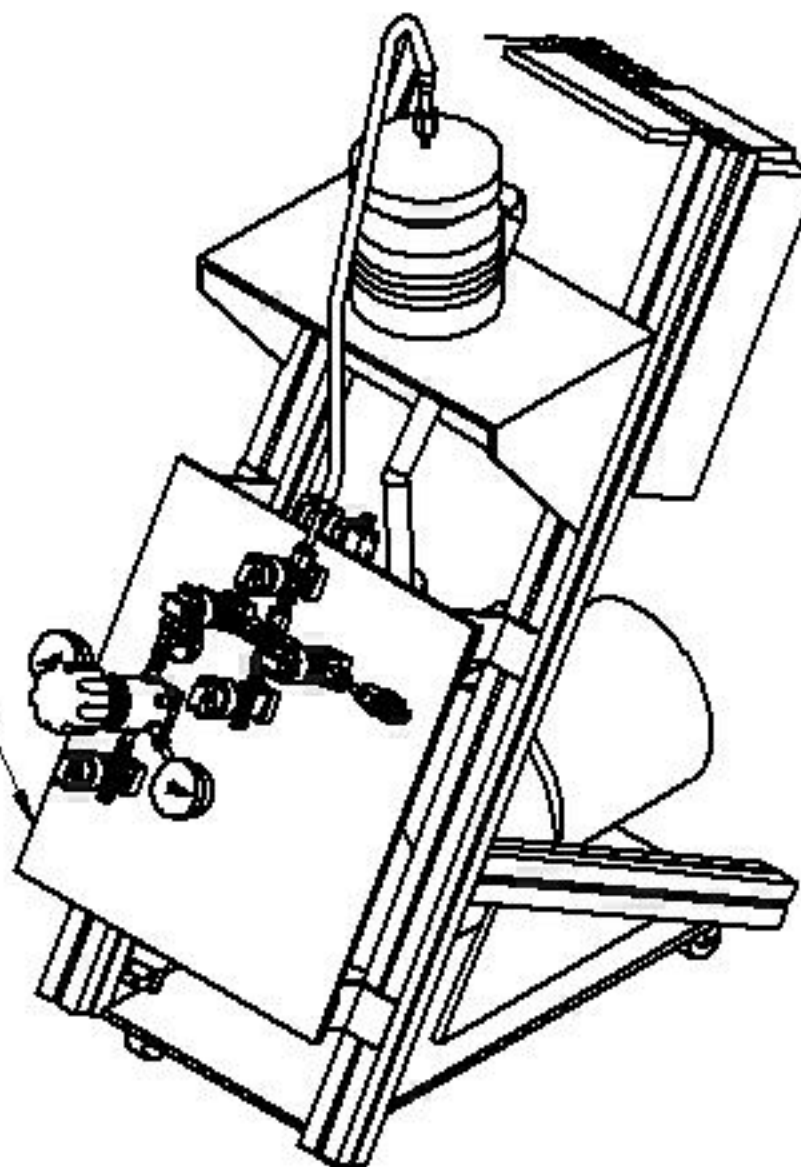
The purpose of the vent extension line GSE is to:

1. Maintain Zone 5 of the GMA at the regulator lock up pressure (approximately 300psig).
2. Provide access for bleeding and evacuating the GMA through the vent.

item	description	supplier	part #	qty	approx unit cost	approx total cost	lead time
1	1L sample cylinder (2X 1/4" NPT)	Swagelok/ SvaleValve	304L-HDF4-1000	1	\$ 229.10	\$ 229.10	3 days
2	high pressure DP valve Male VCR	Swagelok/ SvaleValve	6LVV-DPHLVR4-P	5	\$ 197.20	\$ 986.00	stock
3	high pressure DP valve Female VCR	Swagelok/ SvaleValve	6LVV-DPHLFR4-P	1	\$ 197.20	\$ 197.20	stock
4	ultra high purity inlet P gage-FVCR	Swagelok/ SvaleValve	PGU-50-P3000-L-4FSF	1	\$ 78.65	\$ 78.65	stock
5	ultra high purity outlet P gage-FVCR	Swagelok/ SvaleValve	PGU-50-P600-L-4FSF	1	\$ 78.65	\$ 78.65	stock
6	welded filter	Swagelok/ SvaleValve	SS-4FWS-VCR-.5	1	\$ 77.00	\$ 77.00	3days
7	low P relief valve	Generate	CRVP2-4VS-K-330-UP	1	\$ 320.00	\$ 320.00	3 weeks
8	high P relief valve	Generate	HPRV-250S-V-1620-X	1	\$ 264.00	\$ 264.00	3 weeks
9	pressure regulator	Veriflo/ Valin	QR4005_K5P620FSFFFFF	1	\$ 500.00	\$ 500.00	3 weeks
10	DP valve standoff	Machine Shop	DP_standoff_750	6	\$ 50.00	\$ 300.00	1 week
11	Regulator standoff	Machine Shop	Reg_standoff_375	1	\$ 50.00	\$ 50.00	1 week
12	Mounting plate	Machine Shop	Micro_GDS_mount_palte	1	\$ 100.00	\$ 100.00	1 week
13	Pump cart standoff	Machine Shop	channel_standoff	4	\$ 50.00	\$ 200.00	1 week
14	female VCR cross	AMI welding	FVCR_cross	1	\$ 100.00	\$ 100.00	1 week
15	female to male VCR elbow	AMI welding	elbow_MFVCR	1	na	\$ -	stock
					TOTAL:	\$ 3,480.60	

OFF VEHICLE
GDS FOR VENT
EXTENSION

EXISTING VARIAN
T SERIES PUMP CART



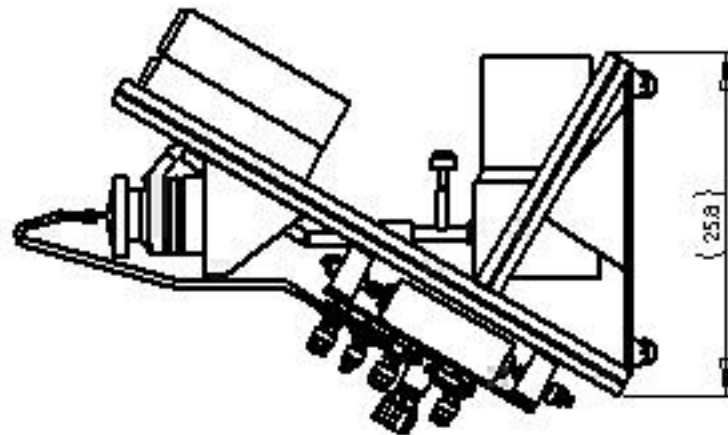
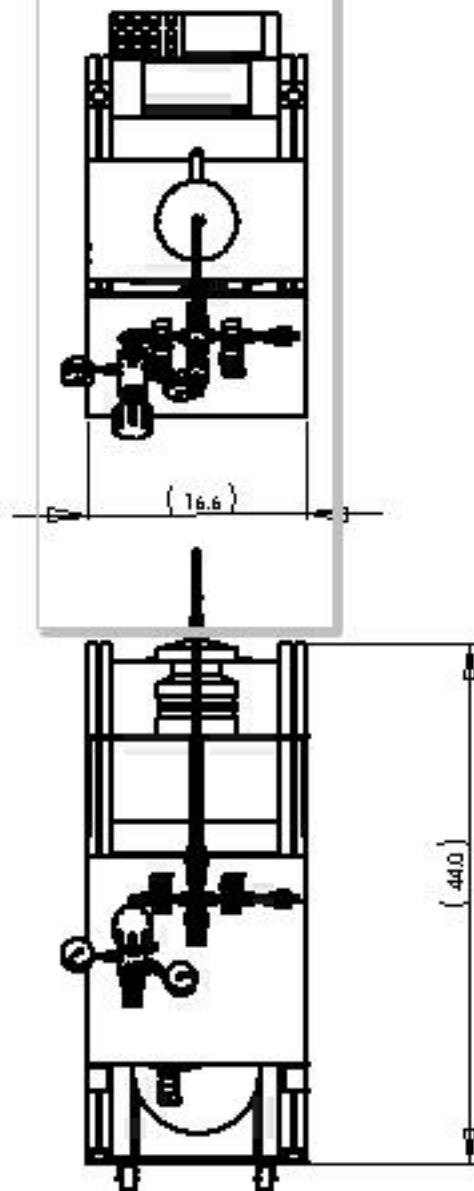
STANFORD UNIVERSITY
CRAMER PROJECT

GDS- GSE
MICRO-GDS ASSEMBLY
VARIAN PUMP CART &
MICRO GDS PLUMBING
PRELIMINARY CONCEPTS

BY: ERIK VORBERG
A micro_gds_vorberg.asm

DATE: 10/03/02

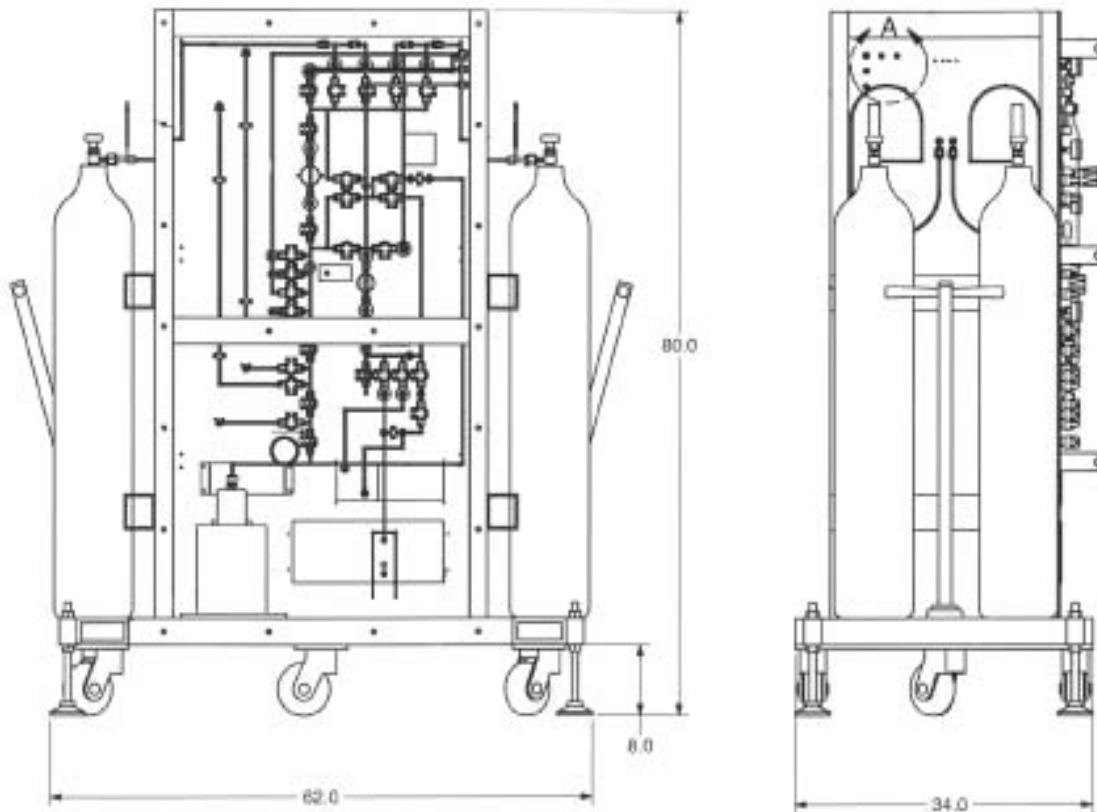
W.



STANFORD UNIVERSITY		
GRAVITY PROBE-B		
GDS-GSE		
MICRO-GDS ASSEMBLY		
VARIAN PUMP CART &		
MICRO GDS PLUMBING		
PRELIMINARY CONCEPTS		
BY: 0016-V0000000	REV:	
A	micro_gds_v001_asm	
DATE: 04/08/00	BY: 0016-V0000000	

D.12 VAFB GSE Support and Configuration

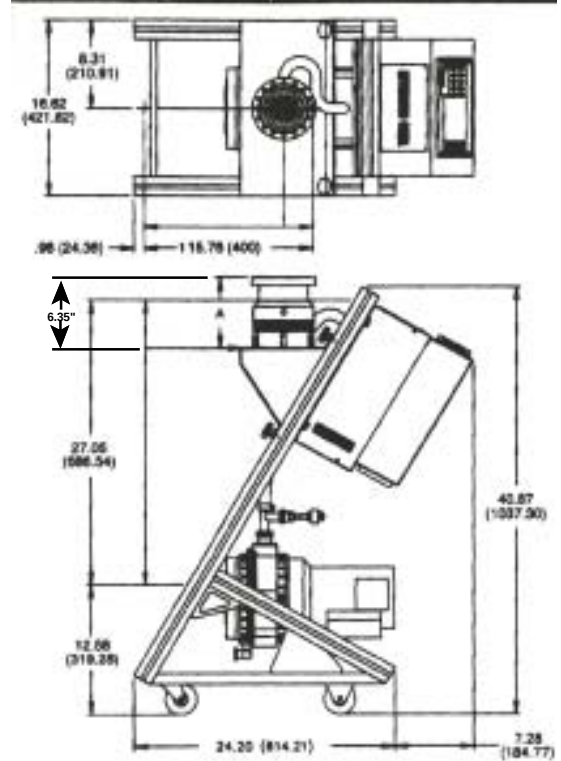
GDS (Gas Delivery System)



Weight = 1495

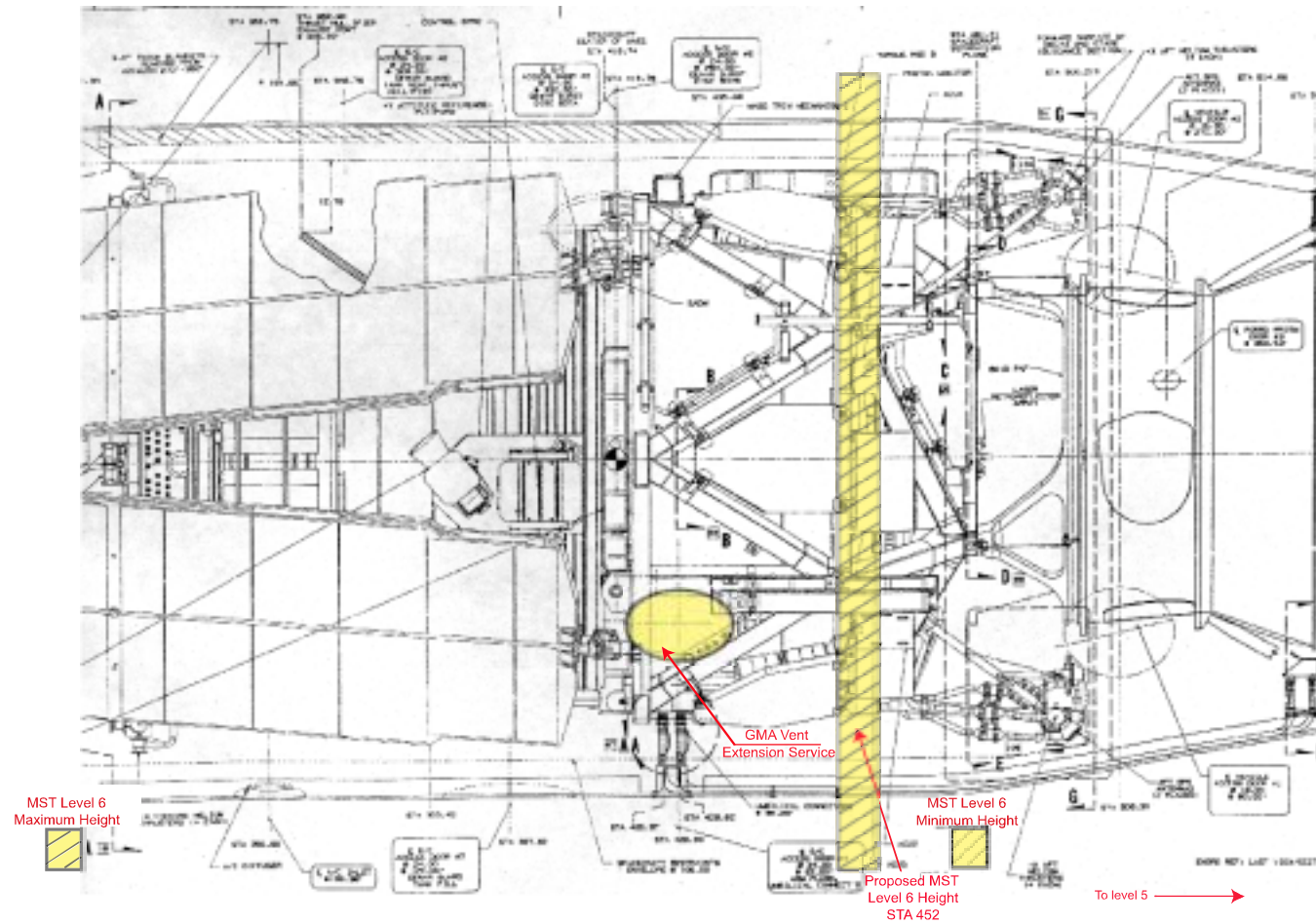
Turbo Pump Cart

Varian T series Turbo Pumping Cart V300HT



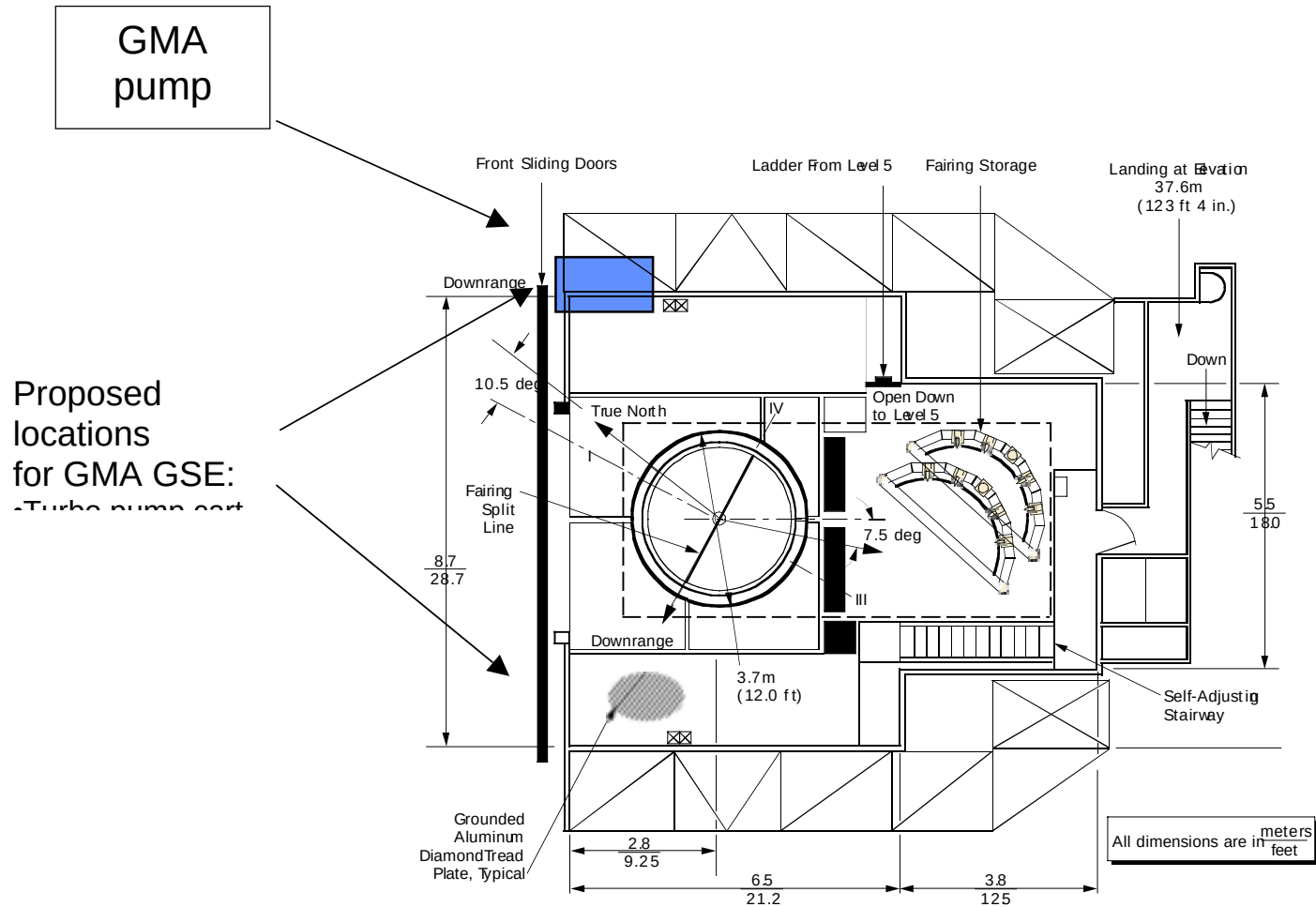
Weight < 125

GMA Service Configuration on the MST



**MST Level 6 Height
Layout**

Level 6 Layout with GMA GSE



MST Level 6 Layout

Appendix

- PCB 570
- DR 439
- DR 439 attachment

PCB number 570
Revision Date 12/09/02
Type I /II to NASA 1
Submittal Date 10/03/02

Program Control Board Change Request

Pg. 1

PCB Name: **Mitigations for Gas Management Assembly (GMA) prior to launch and on orbit**

Screening Committee Disposition: Submit to full PCB for decision () Date of screening _____ Screening Chairman (CSE) _____	Disposition: Rejected () Approved () Date of approval _____ PCB Chairman (Program Mgr) _____	Concurrence (*unless otherwise noted): SU Payload Electronics Manager _____ SU Program Technical Manager _____ SU Spacecraft Manager _____ Chief Systems Engineer _____ Mission Operations Manager _____ LM Program Manager _____ SU Business Manager _____ Chief Scientist _____ SU Quality Manager _____ NASA Resident Manager _____ PI (only for Science Data Changes) _____ NASA Project Manager (Class 1 Only) _____
	Primary Reason for PCB: Spec [X] Cost [X] Schedule [X]	

Additional Signoffs:

Description of Proposed Change:

I. Background:

This was originally a pre-PCB (10.03.02) to provide modifications to the vehicle to mitigate the effects of GMA latch valve leakage.

A. This PCB will now encompass the baseline GMA mitigation plan which is contained in more detail in Stanford's S-doc S0701. This PCB will capture the design and cost of proposed hardware and/or software to be incorporated to the S/V, planned GMA operations and servicing required, new GSE to implement the mitigations, personnel resource estimates, and any potential schedule impact on the baseline schedule.

B. The GMA internal leakage rates for some of the latch valves are out of specification. The potential risks associated with the leakage rate could effect the following areas.

1. Air leaking into the GMA manifold through the Vent Outlet, which adds risk of cryo contamination to the gyro inlets.
2. The GMA regulator lock-up pressure "hold time" from B1610 @ VAFB to launch.
3. Helium gas leaking into the probe, while holding at the MST increases cryogenic thermal boil-off rates.
4. Latch valve launch configuration may require change to the current GMA latch valve launch configuration software.
5. It also may be necessary to open the science probe gas leakage valves (LV-1 or LV-2) as soon possible after launch to pump-out the helium gas within the probe to reduce main tank boil-off.

PCB number 570
Revision Date 12/09/02
Type I /II to NASA 1
Submittal Date 10/03/02

Program Control Board Change Request

Pg. 2

PCB Name: **Mitigations for Gas Management Assembly (GMA) prior to launch and on orbit**

II. Proposed changes:

A. Vent Line Extension:

The risk of greatest concern with internal leakage of latch valves is air leaking into the probe through the GMA vent. This risk can be mitigated by incorporating an extension manifold from the GMA pallet vent outlet to a service door on the fairing which would enable servicing from the MST. This manifold would also incorporate GSE including a manual valve, pressure transducer, and a regulated Helium supply bottle. A preliminary design has been produced and reviewed per the request of the pre-PCB. The design needs to be refined and approved, hardware fabricated and procured, and a placeholder in the schedule approved for installation before spin balance.

Resources required for this task include the following:

Design - LMMS (see attached preliminary design)

Procurement and cleaning preparation of manifold and GSE - Stanford

Installation procedure - LMMS / Stanford

Installation of the hardware on the space vehicle - LMMS / Stanford (see attached LMMS proposed schedule)

Operation of the GSE on the MST (can occur concurrently with guard tank operations)- Stanford

Removal of GSE on the MST - LMMS / Stanford

Reinstallation of GSE and servicing due to a scrubbed launch (contingent)

B. Verifying Latch Valve Leakage Rates:

Latch valves internal leakage rates are tested periodically. Two additional leakage tests are currently scheduled. This test requires approximately three days pumping on the GMA manifold with GSE. Vehicle can be in either a vertical or horizontal orientation. After the GMA's helium background is acceptable, the valve leakage rates are checked using a Helium mass spectrometer and the ECU controlling the valves per Stanford procedure P0931.

This procedure to be revised per GMA mitigation review meeting on 11.19.02.

The ECU time required to collect this data is ~ 16 hours per test. Current schedule has placeholders for these tests at post thermal vacuum and in B1610 @ VAFB.

[Test Set Capability to Support GMA operations during PDU repair including Leakage rate tests: Use existing test set software. One of two leakage tests from above will therefore be removed from the program critical path. BM 12/30/02]

C. Regulator Lock-up:

Regulator lock-up is currently scheduled to occur two more times before launch. The next regulator lock-up will occur prior the S/V shipment to VAFB. The last regulator lock-up will occur just prior to the FEE closure and solar panel installation in B1610. The vehicle can be in any orientation as long as the GMA is accessible. Regulator lock-up is performed per procedure P0960 at VAFB (based upon P0886 released for operations at Stanford). This procedure requires GSE already fabricated plus ECU time of ~ 4 hours. Required GSE is currently available.

PCB number 570
Revision Date 12/09/02
Type I /II to NASA 1
Submittal Date 10/03/02

Program Control Board Change Request

Pg. 3

PCB Name: **Mitigations for Gas Management Assembly (GMA) prior to launch and on orbit**

D. Regulator Lock-up Bleed Down:

When the GMA regulators are locked-up, there is ~300psia Helium in Zones 2,3,4, and 5. This pressure needs to be bled down through the GMA vent quad (V27, V28, V29, and V30). The bleed down requires ECU time (~2hrs.) to operate procedure P0942 using a C-STOL script which is already written and has been used extensively.

E. Launch Configuration Software:

Launch configuration of the GMA latch valves may need to be modified via C-STOL script due to an unacceptable leakage rate from a normally closed latch valve in an output latch valve quad. (If the paired normally open valves leak less, it is a simple matter to "swap states" [N/O for N/C, N/C for N/O] in the paired set.)

F. Probe Leakage Valve Cycling - Flight

It may be necessary to cycle open the probe leakage valve LV-1 or LV-2 as soon as possible after launch to reduce main tank helium boil-off. This would impact software and timeline.

G. GMA Pressure Monitoring:

To fairly establish "hold time," it is necessary to monitor the GMA in multiple locations while the regulators are locked up. This can only partially (limited by location and range of existing transducers) be performed using the ECU and monitoring the pressure sensors. A preferred method Stanford would like to use is to install pressure transducers to the GMA ports MV-2, MV-3, and MV-4. These transducers would be in the proper operating range for lock-up pressure and would not require ECU time to monitor. Stanford has the GSE required for this proposed method. This would only require ECU time to lock-up the regulators (~3 to 4 hrs.)

H. Guard Tank Thermal Analysis:

Lockheed Martin to support a thermal model of the impact to the guard tank with probe gas conduction included.

I. Personnel:

An additional Stanford team member (Steve Buchholz) will be needed to spend 100% time on the GMA mitigation from present to launch. This team member would support the assembly of the mitigation plan, update and write procedures, coordinate operations with LMMS and VAFB, support safety requirements for VAFB, compose a "GMA Operating Manual" for use both at VAFB and the MOC.

III. This is a PCB which authorizes Lockheed to quote the described activities, so that program management can make an assessment as to whether they should be pursued.

PCB number 570
Revision Date 12/09/02
Type I /II to NASA 1
Submittal Date 10/03/02

Program Control Board Change Request

Pg. 4

PCB Name: **Mitigations for Gas Management Assembly (GMA) prior to launch and on orbit**

Reason for the Proposed Change:

See Description of Proposed Change and S0701.

Technical Impact of Proposed Change:

See Description of Proposed Change

Impact if not approved:

Vehicle may not meet the lifetime requirement, depending on the reliability of the GMA valve seals. Increases risk for cryo contamination from the current vent valve configuration.

Cost of Implementing Proposed Change: 843403

See attached cost quote.

Schedule Impact of Implementing Proposed Change:

3 days critical path

5 days non-critical path for vent line extension installation

(see attached cost/schedule quote)

Effect of Implementing Proposed Change on Controlled Budgets and Documents:

Weight:

1.1 lbs

Electrical Power:

None

PCB number 570
Revision Date 12/09/02
Type I /II to NASA 1
Submittal Date 10/03/02

Program Control Board Change Request

Pg. 5

PCB Name: **Mitigations for Gas Management Assembly (GMA) prior to launch and on orbit**

Lifetime:

These modifications are being proposed to ensure the vehicle will meet its lifetime requirements even with significant GMA valve leakage.

Documents & Drawings Affected:

Space vehicle and GMA ICD's

Recommendation to PCB:

Approve this change request.

PCB Disposition (to be completed at the PCB meeting):

Reviewed with the following Stanford screening committees (list the individual) and individuals:

Contamination & vacuum Committee () _____

EMI Committee () _____

Magnetics Committee () _____

Originator C Gray

Date of submittal 10/03/02

DISCREPANCY REPORT No.439 09/05/02

Nomenclature: **GMA MANIFOLD**

Part No. **8A02681-101** Rev. Serial No. **001**

Date of Event: **09/05/02** Reported By: **R Pressburg** Disposition:

Severity: **Major** Status: **Draft**

Discrepancy:

Reference MOOG MDR 449858. MOOG Latch valves model 51E265 presented internal leakage rates greater than GMA specification of $1.0E-4$ SCCS GHe. Out of tolerance leakage rates range from $1.5E-03$ to $1.0E-04$ SCCS GHe. Valves affected are V4/V6 pair, V11, V15, V21, V27, V28, V29. S/N 032/036 Pair, 021, 005, 028, 023, 024, 001.

10/4/02

As of the GMA ship to Lockheed date of 10/4/02, there are two valves that fail to meet the $1e-4$ specification, V2 and the V4/V6 pair. However, GMA valve leakage performance has been intermittent across its testing history.

2/13/03

PCB #570 and Mitigation Plan S0710 being released to demonstrate the plan to mitigate the GMA leakage. With the acceptance of this plan, this DR can be closed.

Cause:

Cause is unknown, however the tiger team review of this discrepancy narrowed the cause to suspected contamination at Poppet Seal interface. See attached FAR (M 2002-063) for details.

10/4/02

This root cause investigation is still on-going at Moog. However, based on the Tiger team investigation report (see Valve Leakage and Root Causes.doc), the root cause has been narrowed to one of two categories:

(1) Contamination entered the GMA during integration, and is interfering with the poppet seal (most probable cause)

DISCREPANCY REPORT No.439 09/05/02

Nomenclature: **GMA MANIFOLD**

Part No. **8A02681-101** Rev. Serial No. **001**

Date of Event: **09/05/02** Reported By: **R Pressburg** Disposition:

Severity: **Major** Status: **Draft**

(2) Valve poppet deterioration due to materials properties (in the process of closeout -- see Moog FAR__Latch_Valve.doc).

Effect on Service:

See GMA LEAKAGE AND PERFORMANCE DURING TESTING.doc. With the current performance, the GMA will meet all ground and on-orbit objectives without modification to the GMA or the space vehicle.

However, if valve performance were to degrade significantly, it could endanger the ability of GP-B to meet the 90-day ground hold requirement (no effect on post-launch performance). Therefore PCB #570 has been sent to Lockheed to investigate the option of making the required vehicle modifications so that the GMA can be fully serviced on the launch pad.

Recommended Corrective Action:

See PCB #570.

Repair Procedure:

None. However, see PCB #570 for potential vehicle modifications.

NASA Notification:

Technical Investigation:

The technical investigation is documented in the attached documents:

MDR449858 (Moog Latch Valve Discrepancy Report)

Valve Leakage and Root Causes.doc (Moog Tests and Fault Tree)

FAR__Latch_Valve.doc (Moog Failure Analysis Report)

GMA LEAKAGE PERFORMANCE DURING TESTING.doc (Results from the Stanford Testing)

As of the GMA ship to Lockheed date of 10/4/02, there are two valves that fail to meet the 1e-4 specification, V2 and the V4/V6 pair. See further details in GMA LEAKAGE PERFORMANCE DURING TESTING.doc

DISCREPANCY REPORT No.439 09/05/02

Nomenclature: **GMA MANIFOLD**

Part No. **8A02681-101** Rev. Serial No. **001**

Date of Event: **09/05/02** Reported By: **R Pressburg** Disposition:

Severity: **Major** Status: **Draft**

Leak rate data from the Rate of Pressure Rise evaluation added. See GMA LEAKAGE PERFORMANCE DURING TESTING.doc.

Status Notes:

9/06/02 (RAP) Initial information on this DR (discrepancy and cause) was taken from MOOG Material Discrepancy Report MDR 449858.

Marshall and Stanford agree that there is little risk in performance GMA integration and space vehicle thermal vac testing with the GMA. We see no perceived risk to the GMA or space vehicle in proceeding with system test with the GMA as is. The root cause is thought to be well understood (contamination in the poppet seat), although the final closeout of all tests is still pending. The current GMA meets all program needs, and there is a plan in place (addressed in PCB 570) for ensuring that the vehicle will meet all requirements even should the GMA valve leakage degrade.

Signoffs:

R Brumley	_____	_____
R Geveden	_____	_____
C Gray	_____	_____
G Green	_____	_____
E Ingraham	_____	_____
D Ross	_____	_____
R Whelan	_____	_____

Since the Stanford DR database only allows one attachment, a number of files have been compiled into one attachment (DR439Attach.pdf)

file: **Valve Leakage and Root Causes.doc** starts on next page

(Moog Tests and Fault Tree)

Moog Latch Valve Tiger Team Report

July 30, 2002

This documents the current state of the technical investigation which is on going (10/6/02) to isolate the root cause of the failure.
arise.

WORKING FAULT TREE

(Shaded = Closed)

Item	Assessment	Assigned to Test	Result of Test	Status
Contamination				
CONTAMINATION DURING WELD SET-UP (BRAIDED SHIELD)	C/P	6,12		
WELD/ASSEMBLY DEBRIS	C/NL	6,12		
SELF GENERATED	C/P *	1		Status 7/30/02: Observed particulates in 1 of 2 latch valves after vibration means this is still open. Note that the observed particles could have been due to GSE. Needs more work to close.
OTHER COMPONENTS (TANKS, TRANSDUCERS, FLOW ORIFICE)	C/P	4		
FILTER SHEDDING	NC (Cert.)	N/A	CLOSED	N/A (Not Credible failure mode)
FLOW OUTPUT LEADS TO POPPET EROSION	NC	N/A	CLOSED	N/A (Not Credible failure mode)
Valve Design / Process (D = Design, P = Process)				
VIBRATION (D) Qual program was with valves closed, most failed valves were open for vibration)	C/P	1	CLOSED BY TEST Passed test. We consider that the design is qualified to fly.	CLOSED 7/29/02
POPPET MATERIAL (D) (V4 has poppet material that has known problems, but other valves have been retrofitted with appropriate material)	C/L for V4 C/P all others	13,14		Status 7/30/02: Renewed investigation into this issue has resulted in the group establishing that this is a possible issue for all poppets. Tests 13 and 14 were developed for establish whether this is cause of the anomaly.

Item	Assessment	Assigned to Test	Result of Test	Status
INSUFFICIENT LATCH FORCE (D/P) - magnet orientation - loose magnet - insufficient poppet preload	NC	N/A	CLOSED	N/A (Not Credible failure mode)
DIMENSIONAL (P)	C/P	8	Completed audit of build paperwork. No correlation found. Note: standard variations in process or dimensions may contribute to variations in leakage rate.	CLOSED
LOT VARIATION (P)	C/P	8	Completed audit of build paperwork. No correlation found. Note: standard variations in process or dimensions may contribute to variations in leakage rate	CLOSED
ASSEMBLY VARIATION (P) - swage operations - damaged parts -- outlet fittings	C/P	8	Completed audit of build paperwork. No correlation found. Note: standard variations in process or dimensions may still contribute to variations in leakage rate	CLOSED
IMPROPER SWAGE OF CORE (P)	NC	N/A	CLOSED	N/A (Not Credible failure mode)
MECHANICAL DEFORMATION OF OUTLET FITTING DUE TO GMA ASSEMBLY OPERATIONS (added 7/29/02)	NC	N/A	CLOSED	N/A (Not Credible failure mode)

Item	Assessment	Assigned to Test	Result of Test	Status
STATIC CHARGED POPPET ATTRACTING EXISTING CONTAMINATION (added 7/29/02)	P,NL	N/A	CLOSED	CLOSED. This is really just a subset of other contamination items. It is merely a mechanism whereby contamination, if it exists, is more likely to migrate to the poppet seat. It is not, however, the source of the contamination
WELD REPAIR	C/L	N/A	CLOSED	CLOSED. Detail review of this process indicates that there is very little opportunity for additional particles because of this operation. Although it it may have introduced additional opportunities for contamination, it is closed to the more general contamination due to welding node in this tree.
VALVE DESIGN PERFORMANCE IS NOT 1E-6 * New 7/29/02	C/P	15	There are definitely indications that valve performance after system integration can be 1e-4. One previous program (w/ aprox. 20% the number of valves as the GMA) had a similar percentage of valves in the 1e-4 range after system vibration (in spec for that program). Valves went on to perform nominally.	OPEN.
KEY CHARACTERISTICS VS. SERIAL NUMBER – preload – latching force – stroke (arm-poppet)	C/P	8	CLOSED	CLOSED. For all parameters investigated (see Test #8), no correlation was found to the failed valves.

Item	Assessment	Assigned to Test	Result of Test	Status
Testing Procedure				
TRAPPED GAS *	C/P	2,10	CLOSED BY TEST	N/A
GDS	C/P	2,10	CLOSED BY TEST	N/A
VALVE SEQUENCE *	C/P	2,10	CLOSED BY TEST	N/A
IMPLEMENTATION	C/P	2,10	CLOSED BY TEST	N/A
LOW VOLTAGE ACTUATION	C/P			
MASS SPECTROMETER USAGE *	C/P	2,10	CLOSED BY TEST	N/A
MASS SPECTROMETER CALIBRATION *	C/P	2,10	CLOSED BY TEST	N/A
EXTERNAL TO INTERNAL LEAK *	C/P	2,10	CLOSED BY TEST	N/A
FLOW METER LEAKAGE RESIDUAL	C/P	2	CLOSED BY TEST	N/A
TURBO PUMP *	C/P	2,10	CLOSED BY TEST	N/A
VIBRATION LEVEL ON VALVES	C/P	1		Status 7/30/02 Need further analysis of vibration data obtained during latch valve vibration.
TRAPPED GAS, MOTT SPECIFIC *	C/P		CLOSED BY TEST	N/A
VIBRATION SETS POPPET OFF CENTER	C/NL	1	CLOSED BY TEST	N/A
WELD TECH. VS. CONFIGURATION	C/NL			Status 7/30/02 Still under investigation.
TEST ORDER: 2000 – 20 PSIA, THEN 20 PSIA (do you need 2000 psi to seat it properly?)	C/P	9,1	CLOSED BY TEST	Status 7/30/02 Combination of Tests 9 and 1 exposed valves to suspect operations, and valve sealing performance remained nominal.
HIGH BACKGROUND *	C/P	2,10	ITEM CLOSED	N/A

Assessment Categories:
Credible (C) or Not Credible (NC) /
Likely (L), Possible (P), Not Likely (NL)
* = Test operator dependent

TEST MATRIX

(Shaded = closed)

Test	Expected Results	Test Hardware	Schedule	Results (if complete)
1. Vibration of two spare flight valves in double deck configuration to GMA protoqual level of 11.1 grms (GMA has fixtures which stack two valves on top of each other, but valves were qualified in single configuration).	- Instrument for accel - Effect on leak - Leak -> Vib -> Leak -> Cleanliness Check - Leak @ 20 psi - 1 data point before - 5 data points after each vibration (Possibly vib two more of the flight spares pending the results)	SN7 + 22 Vib table Vib fixture Need valves certified clean prior to start	Morning plus one shift (Sat a.m.)	Status 7/27/02 The vibration test was completed on 7/27/02. The two valves used for the 500 cycle test (S/N 7 and S/N 22) were shook to 11.1 grms (input) for 1 minute each axis. After each shake, the valves were cycled 5 times with the leakage rate measured at each cycle. Results: The valves consistently performed in the low 10^{-7} to high 10^{-8} sccs range. No degradation in leakage rate has been observed as a result in the 500 cycles/random vibration combined test. However, note that the “top” valve in the pair saw a very high acceleration (~41 grms) due to a resonance in the structure near 1 kHz. For the flight GMA, this would have been mitigated by the presence of the rigid plumbing between the valves. However, it may have been exacerbated by the fact that some of the output valves are connected to the output bracket, which experienced a known very high g-load in random vib. However, the general consensus of the group is that the test performed on the spare valves today should be a “worst-case” test, and no degradation was seen. Status 7/30/02: First flush on lower valve (S/N 7) was discrepant (300 100 micron particles). On second flush it passed. Second one passed on first go around. ONGOING. The high g-loads of the top valve need to be further investigated
2. Cal leak with GDS attached 2.5e-6	- Does GDS add to known leak rate - All GMA valves closed - Pull from GMA outlet through GDS	Cal Leak GDS Mass spectrometer GMA	Sat a.m.	Status 7/27/02 This test was performed as part of the ATP review and run through on Saturday. The results were as expected, and indicated that the GDS was not contributing to an error in the measurement of GMA leakage rates. COMPLETE

Test	Expected Results	Test Hardware	Schedule	Results (if complete)
3. Bubble test V21	- Feel good to verify mass spectrometer data Would need to break into system N2 or He?	GMA Bubble test apparatus	TABLED	Status 7/27/02 The days activities have resulted in increased confidence by the group that the results being measured are real. This makes the “bubble test” much less valuable, and there is no plan to perform it soon.
4. Contamination from Moots flow orifice in Vib?	Does vibration release contamination from moots? Cleanliness Verification -> Vibration -> Cleanliness Verification Perform as part of Latch Valve vibration	Motts Vib fixture Vib table	Sat Morning	Status 7/27/02 Random vibration test was performed. Cleanliness verification will be witnessed by DeWitt Burns and will be complete Monday 7/29/02. ONGOING. Expect closure Tuesday 7/30/02 with completion of cleanliness verification.
4a. Contamination from Pressure Transducer	- Shake spare pressure transducer and examine cleanliness of container	Vibration hardware, spare pressure transducer	TBD	Status 7/30/02 Start effort to prepare for this, but it is unlikely results we come in this week. This test is a lower priority than 6, 12, 13, and 14.
5. Valve contamination (intentional) w/ weld debris	Is weld susceptible to debris generated by weld? -> Sacrificial valve	Requires a non-flight valve	TABLED	This requires sacrificing a flight backup or flight-like valve. These are in very limited supply, and the group feels right now they should be saved for other applications. COMPLETE (TABLED).
6. Weld sample (preps for potential valve replacement) - cut existing tube assembly w/ tube cutter, debur edge, reweld - Demonstrates valve removal & reweld - Allows cleanliness check of weld process - Test Hardware: tube assembly, tubing cutter, TIG welder	Data to contribute to certification of valve replacement process (should this be necessary)	Misc. spare hardware	TBD	IN PROCESS Status 7/30/02: Preparations for this work are still in process.

Test	Expected Results	Test Hardware	Schedule	Results (if complete)
7. Interview Kevin Neff about valve lead braided shield handling during weld - Covers orbital tube welds (used for GMA integration)	- Get an idea of whether the welding process is likely to have introduced contamination into the valves.	None	Monday July 29	Status 7/27/02: Interview with Kevin Neff scheduled Monday 7/29 a.m. Status 7/30/02: Establish bagging order and welding order. Note that vent quad was the first welded, increasing the probability that the leads were still bagged. At this point, we know there was a change in the weld process at some point to correct for the exposed particulating shield, but we don't know exactly when that happened. There is a high probability that the vent quad (which has the highest anomaly rate) was welded before the fix in the process was implemented. COMPLETE
8. Build Paperwork Review	Latching Force (OP 150) Preload Poppet (OP 180) Pull-in Voltage open/close (OP 460) Cleanliness Verif (Op 480) Armature stroke (Op 210) Poppet Stroke (OP 220) Vs. Serial #	None	By Monday	Status 7/27/02 The review has been completed by Dan Balon ahead of schedule. He presented the results in matrix form to the group. No significant issues were seen in the build paperwork that differentiates the valves with high leakage rates from others. One of the failing valves did have particle counts a factor of 2 higher than the others, but they were still in spec, and the size of the particles was less than could interfere with the sealing process. Finally, some of the discrepant valves had very low particle counts, so that no correlation could be found. Note that Dan Balon will enter the results into a table on his computer on Monday for distribution to interested parties. COMPLETE. However, review of build paperwork is expected to remain an on-going process through the investigation as required.

Test	Expected Results	Test Hardware	Schedule	Results (if complete)
9. 500 cycle test Cycle two of the spare flight valves 500 times each, with periodic leakage checks to see if valves have a tendency to degrade with cycles.	- Measure variation in leakage as a function of # of cycles. - Measure contamination as a result of cycles		Complete 7/24/02	Status 7/27/02: <u>SN#7</u> Cycled with leak check at 0, 10, 15, 25, 100, 150, 200, 250 300, 350, 400, 450, 500. At cycle 0 cleanliness failed, checked with new process. Failed with new process at 25-50 micron range. <u>SN#22</u> New cleanliness process -> passed 500 cycles passed leakage failed cleanliness after cycling -- hookup debris -- self generating -- packing material (found some debris visually clearly looks like packing material) Status: COMPLETE

Test	Expected Results	Test Hardware	Schedule	Results (if complete)
10. ATP Review / Walkthrough of valve leakage rate measuring process	“Are we measuring what we think we are?” - Trapped gas - valve sequence - Procedure implementation - mass spec usage - mass spec calibration - high background - inadequate vacuum - residual leakage in flow meter, turbo pump, etc. - steady state vs. transient	GMA, GDS, and all other standard GMA test equipment.	Sat Morning 7/27/02	Status: 7/27/02 The group has not found anything in the test sequence for the valves which could yield significantly elevated leakage rates. However, Moog did identify a mechanism in the current procedure which could result in slightly elevated leakage rates. A modification to the test procedure was incorporated into the Saturday test to keep this from occurring. The test resulted in some improvement for the valves that were “in-spec”, i.e. many of the valves tested in the 10^{-7} sccs range. Several valves that had previously tested bad (e.g. V11 and V15) were in spec. Some others (e.g. V4/V6 and V21) still performed in the 10^{-7} range. Finally, one valve on the GMA vent to space (V30) which had never previously shown a problem now tests out of spec. This means that all 4 valves in the GMA vent quad have at some point displayed high leakage. Note that this quad is not mission critical, and in principle it can be capped on the pad so as to avoid air incursion into the GMA. If this choice were taken, then conceivably other valves in the GMA could be double strapped to ECU valve drivers so as that the same valve could be operated off of the A or B-side ECU. This could be used, for example, to regain some system redundancy if we decide to fly the GMA with all valves closed. Note that the results as indicated at this time are preliminary, and a complete data review needs to be performed. They will be confirmed in the 7/29 status report. STATUS: Complete. Data Review has been completed.

Test	Expected Results	Test Hardware	Schedule	Results (if complete)
11. Verification of V1/V2 leakage rates by pumping through MV3 and MV4 (plumbed to the interstitial space between the regulators). (New 7/27/02)	Background: The V1/V2 valves have never yet measured out of specification. Currently, this leakage rate is performed by pumping through the rest of the GMA to the leak detector. The Helium background for the test as it has been performed is expected to be quite high. These valves have been measured in the mid 10^{-5} range, but it is suspected that the valves might actually be performing much better than this, and we are simply observing background. This new test will connect the leak detector to a location much closer to V1/V2, decreasing the background and allowing for a more sensitive measurement of the V1/V2 leakage rates. Rationale: If V1/V2 measure in the 10^{-6} or 10^{-7} range, <i>and</i> we can find a way to fly the regulator locked open and evacuated (rather than locked shut and pressurized to 300 psia as in the current configuration), then all He gas would be buffered by those two valves, and the ground hold requirement could be met utilizing only V1/V2. In this scenario, the leakage rate of all other valves would not contribute (to first order) to the ground hold requirement. At this point, flying the GMA in this configuration probably requires some way to shock mount the entire GMA assembly plus some delta qual tests on the regulator (which might fail). Finally, note that V1/V2 are not mounted as part of the stacked pair assembly, so if there is any issue resulting from high g-loads on those pairs, then presumably the V1/V2 pair is unharmed.	GDS must be plumbed to the MV3 and MV4 ports of the GMA.	Monday 7/29/02	COMPLETE 7/29/02. Previous leakage data from one of the two valves was found to be dominated by He background in the measurement. However, one of the two valves is still performing in the 1e-5 range. This experiment was performed to give data as to the potential efficacy of several mitigations, and does not directly address the issue of root cause of the anomaly.

Test	Expected Results	Test Hardware	Schedule	Results (if complete)
12. Weld two spare latch valves together and measure performance.	Measure valve leakage rates before and after the weld. Assess whether the welding process affects valve sealing.	Two backup flight valves, weld components, procedures	Approx 8 days to perform the weld	Status 7/30/02 The decision has been made to perform this test. Note that this supplements Test #6 which examines the cleanliness of the weld process from purely a contamination point of view. This test is a more general repeat of the steps which were performed on the flight valves in order to find any way the process harmed the valve leakage rates.
13. Valve lifetime test under vacuum at 140 degrees F	Examine whether the	Welded flight spares from Test #12, oven, paperwork, misc. manifold H/W.	2-3 weeks after the completion of 12.	Status 7/30/02 This test was determined to be important in order to confirm that the poppet Vespel is not degrading over time. It will be performed after Test #12, primarily because we need to accomplish 12 (or something that is roughly the schedule equivalent) in order to perform the test. Also, the combination of (12) and (13) most closely represents the actual path the flight valves went through.
14. Measure change in Vespel mechanical properties in heat and vacuum	Details defined by Jim Bush. This is a measurement on the change in mechanical properties of the Vespel used on the valve poppet when exposed to heat and vacuum. Changes in certain key parameters known to be important for the valves to function properly will be measured as part of the lifetime test.	Vespel from the same lot that was used to manufacture the latch valves, misc. test equipment.	TBD	Status 7/30/02 This test will be performed as detailed by Jim Bush. There is some question who should perform the actual analyses. Moog will look at the test definition which Jim Bush developed and assess whether it should be performed in house. This data will likely be available before Test #13.

Test	Expected Results	Test Hardware	Schedule	Results (if complete)
15. Review of latch valve history in other Moog programs	Establish what the expected baseline for valve performance should be.	None	First stage completed, second stage in approx 1 week.	Status 7/30/02 Review of the data from one previous program indicated that approximately the same percentage of latch valves on that system had leakage rates in the 1e-4 range after vibration as we are seeing in the flight GMA. Note that in that case the leakage rates improved during the system thermal vacuum test. Moog has agreed to provide a spreadsheet summary for other valves. However, it was stated verbally during the meeting that of the approx. 25 valves delivered prior to the GMA, a total of 3 had leakage rates in excess of 1e-4 at some point in the test program. However, most of these were delivered as components and Moog did not integrate them into a system. ONGOING. Will close when receive spreadsheet details from other valves.

(shaded items are considered complete)

file: **FAR__Latch_Valve.doc** starts on next page

(Moog Failure Analysis Report)

 FAILURE ANALYSIS REPORT	<u>Customer:</u> Stanford University	<u>Product Name:</u> Gas Management Assembly (GMA)	Moog Report No. FAR(M)2002- 063
			Originator: Paul King
			Quality: John Bonanno
	<u>How Reported:</u> MDR 449854 FR(M) 2002-047	<u>Model Number:</u> 50E961 (51E265)	Engineering: Paul King
	<u>Test Document</u> MRA13238 Para. 3.3.4	<u>Serial Number:</u> 001	Customer Rep (If Req'd): N/A
		<u>Moog Part No.:</u> C58800	DCMC (If Req'd): N/A
<u>Date of Analysis:</u> 6/28/02 – 9/6/02	<u>Cust. Report No.:</u>	<u>Customer Part No:</u> LMSSC 8A02681-101	<u>Issue Date:</u> September 3, 2002

Report Sequence: (1) History (2) Analysis (3) Conclusions (4) Corrective Action

HISTORY:

Immediately after completing vibration testing per MRA13238 of Moog Model 50E961, Gas Management Assembly (GMA), the internal leakage rates of Moog Latch Valves (Model 51E265) V27 and V29 were measured because of earlier high leakage rates collected during bubble leak testing and post proof internal leak testing. The post-vibration leak rates from both valves exceeded the GMA specification limit of less than 1.0E-04 sccs GHe. These results lead Moog to measure the leakage of all the GMA latch valves. This testing revealed that the V4/V6 valve pair (configuration permits the leakage testing of the valves as a pair only), V11 and V15 exceeded the leakage specification requirement. With concurrence from Stanford University, a series of leakage tests, which required cycling valves, were performed. The V4/V6 valve pair and V15 continued to indicate high leak rates. In order to determine the overall health of the GMA, Moog proceeded with the remainder of the post-vibration testing of the GMA, which included additional internal leakage testing of the latch valves. This testing revealed that valves V21, V27 and V28 also indicated leak rates greater than the specification requirement. At this point GMA testing per MRA13238 was halted. Upon completion of the testing up to this point, the following valves presented suspect/non-conforming performance: V4/V6 pair, V11, V15, V21, V27, V28, V29.

A "Tiger" team was formed consisting of Moog, Stanford University, NASA-MSFC and Lockheed Martin. At the direction of the Tiger team, some additional leak testing was performed to investigate the testing method, to characterize the valve leakage behavior versus pressure (see attached plot) and better characterize helium background levels. The Tiger team also concluded that removing the non-conforming valves from the GMA is a worse case exercise warranted by degradation of additional valves and/or additional degradation of internal leakage performance of the valves in question. The basis for this conclusion was the inherent contamination risks to the GMA resulting from cutting valves out of the GMA. However, this course of action does not permit a disassembly/inspect of the questionable valves. The Tiger team also agreed to go forward with testing of the GMA per MRA13238, which included thermal/vacuum testing and several more latch valve internal leakage tests. This testing was completed. An important observation from the all data is that no additional latch valves degraded and the valves were generally consistent in leakage rate from test to test. Some valves also showed some improved performance. Also, the valves in question (V4/V6 pair, V11, V15, V21, V27, V28, V29) did not get any worse. The data from all the additional internal leakage testing and the internal leakage testing per MRA13238 are summarized in the Summary GMA PTP MRA13238 and AVO Internal Leakage Data matrix attached.

Per the direction of the Tiger team, two spare GMA latch valves were subjected to a series of tests including cycle testing and vibration testing. These valves were also subjected to cleanliness sampling to determine the level of particulate in the valve after certain tests. The internal leakage was measured throughout these tests. The valves were also welded into a mini assembly similar to sub-assemblies used in the GMA. Internal leakage was measured after

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assembly and the mini assembly (see attached Moog C78437) was subjected to additional vacuum and thermal testing to determine if this type of exposure can degrade sealing characteristics of the Vespel SP-1 poppet material in each valve. Samples of this material were also exposed to these conditions and then tensile tested by an outside lab to determine if the material properties (yield strength, %-elongation) of the Vespel are affected.

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ANALYSIS:

For reference a functional cross-section of the 51E265 is included at the end of this report as well as a schematic of the GMA and a top view of the GMA indicating valve locations. To facilitate the search for a root cause(s) of these non-conformances, a fault matrix was created, which identifies the subject valves (V4/V6 valve pair, V11, V15, V21, V27, V28 & V29). This matrix is attached. Many of the potential causes are deemed not credible since many of the causes would result in gross leakage or would affect other performance parameters of the valve such as valve response. The Tiger team also used this matrix to determine a pathway for additional investigative testing.

The main focus of the Tiger team effort was to determine why the leakage performance of the valves, in general, degraded from ~1.0E-07 sccs GHe leakage at the component level to >1.0 E-06 sccs GHe at the GMA level and to determine why the valves in question degraded to ~1.0E-04 sccs GHe. The key concerns with regard to excessive latch valve internal leakage are:

1. Loss of lock-up pressure for the GMA regulators prior to launch, which could result in damage to the regulators during the launch shock environment.
2. Helium leakage into the science probe prior to launch, which could degrade the science probe.
3. Leakage of air into the GMA through the vent valve prior to launch, which would degrade the GMA helium purity.

In addition to investigating the causes for excessive leakage of the latch valves, the team also discussed ways to allow the GMA to be used "as-is" provided the internal leakage performance did not get worse after completion of the testing per MRA13238. Stanford would also need to determine ways to mitigate any risks related to the higher leakage rates from the six questionable valves. The mitigation methods discussed at the Tiger team meeting included selecting which valves would be open or closed during launch to minimize leakage into the probe, but maintain ECU redundancy, keep the vent line capped for as long as possible, maintain 300 psia helium throughout the low-pressure side of the GMA and keeping all the valves closed as long as possible before launch. The results of this portion of the investigation are available from Stanford University.

As a result of Tiger team discussions, some additional testing was deemed worthwhile to help with resolving the likelihood of specific causes. These tests/investigations include:

- A. Cycle testing of two spare latch valves (51E265, SN007, SN022) to determine if self-generated contamination is a cause: See attached MRA16475 summary matrix. The first 1000 mL effluent IPA sample was collected from each valve and passed through a filter patch. The particles on the patch were then categorized by size and counted under a microscope. After sampling, the valves were certified clean to the GMA requirement before proceeding to the next test. The two latch valves tested did indicate particulate counts greater than the certified clean limits established for the GMA program. The concern for Moog is particle size greater than 100 microns. Some particles of this size were found during this testing and in subsequent cleanliness sample tests performed after the tests described below. Several of these particles were isolated and examined by Moog Material Process Engineering using FTIR and SEM/EDS analysis. These particles were identified as follows: polyurethane polymer (e.g. Spensol L-44, source unknown), nitrocellulose (source: filter patch material), secondary amide (source: human skin), PH stainless steel (source: fixturing, inlet fitting of latch valve). With the exception of the polyurethane polymer, these particles are consistent with contamination from handling and hook-up debris. These materials may have been in the valves or could have been introduced during the sampling procedure. There was no evidence of Vespel, EPR (o-ring), Teflon (bearing rings on armature), CRES 430 or CRES 300 series or braided shielding, all of which are possible materials from the latch valves. The only exception was the PH stainless, which could have come from the

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inlet of the latch valve. However, the inlet fitting is upstream of the 5-micron filter and the particles in question are greater than 100-microns in size. Note that when a valve is certified clean, IPA is flowed through the valve for two minutes prior to taking a sample. Comparing the first 1000 mL to the certified clean standard is a very conservative approach. The valves did not show any sign of leakage performance degradation. While the spare valves tested were not affected by the presence of these particles, Moog cannot rule out some form of contamination as a root cause for the six valves in question.

- B. Vibration testing of two spare latch valves to determine if the valves are damaged in any way: See attached MRA16475 summary matrix. The two latch valves (SN007 and SN022) were vibration tested in the open condition (see item D below) while mounted in the "stacked" GMA configuration. The GMA level random vibration spectrum was the test input. The valves were cycled and leak tested after each axis. The testing did reveal that the upper valve was subjected to vibration levels of ~40 Grms. The valves did not show any sign of leakage performance degradation or any other valve performance degradation. Since the two spare valves and the majority of the GMA valves continue to perform within specification, Moog does not believe that the vibration testing was a root cause. However, the vibration testing could be coupled with a contamination issue, i.e., vibration freed trapped contamination.

Two Mott flow restrictors were also exposed to vibration testing. The restrictors were then sampled for particles. No metallics were generated from exposure to the vibration environment indicating that the sintered material was not damaged and did not shed. The particle counts were high on one unit, but this is attributed to the sampling technique. The technique was altered on the second unit, which indicated a very "clean" unit. The Motts are not viewed as a source of contamination.

- C. Investigate helium background of GMA and test methodology: See the attached GMA Latch Valve Internal Leakage Fault Analysis matrix. A calibrated leak device (1.5E-05 sccs GHe) was plumbed into the GMA at the GMA vent line. The mass spectrometer was capable of measuring the calibrated leak. The calibrated leak device was subsequently removed from the GMA vent line. Also, the sequence in which valves are leak tested and evacuated to testing was found to have some affect on the leakage measurements when measuring the internal leakage of individual valves. Subsequent testing instructions addressed this issue. However, the magnitude of this adjustment was minor and is not considered a cause for the excessive leak rates.
- D. Review the build paperwork and As-Built-Configuration-Records (ABCRs) from all the valves: All the build data was reviewed to determine if there was any trend in the data to suggest that the valves in question had something in common that would point to a root cause. No trend could be identified with regard to:
- Material/part lots, i.e., material/poppet lots from the valves in question were also used in valves with leakage two orders of magnitude better. This included the poppets, outlet fittings (seats), armatures, poppet springs and cores.
 - Build/performance parameters, e.g., spring preload, valve and poppet stroke, latching force, response, pull-in current.

A trend with regard to weld reworks was noted for valves V27, V28 and V29. All valves except V1 and V2 had the filter body weld reworked. However, V27, V28 and V29 were reworked twice, which exposed these valves to an additional deburring operation. The handling of these valves was consistent with other rework operations. Another trend associated with these particular valves is the fact that they are located in the vent line. The vent line is the primary purging line for GMA testing. This level of gas throughput may offer more opportunity for contamination of the valves. Beyond identifying these trends, no other conclusion can be drawn.

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The only other trend identified is the valve open/close status and position in the mounting brackets during vibration testing. The V4/V6 pair, V27 and V29 indicated leakage performance problems prior to vibration. However, V11, V15, V27 were open during vibration and located in the upper portion of the mounting bracket. It is important to note that V11 and V15 have a history of intermittent leakage performance, which implies that any acceptable leakage data taken prior to vibration was a random occurrence. Additional testing prior to vibration testing may have revealed unacceptable values, as well. V21 was located in the upper portion of the bracket, but was closed during vibration. Also, the valve had acceptable leakage values immediately after vibration testing.

E. Investigate the weld assembly process of the GMA latch valve sub-assemblies as a source of contamination: See attached MRA16475 summary matrix. Using valves SN007 and SN022, Moog welded a mini-assembly per C78437 using the same processes and procedures used when welding the GMA latch valve quad and double valve sub-assemblies. This included not protecting the weld process from potential handling contamination from the latch valve lead wire shielding (It was noted during the GMA build that the shielding harbored contaminants. After this was noticed, the shielding was bagged to reduce risk of contamination). Immediately after assembly, the leakage performance of both valves measured $\sim 1.0E-05$ sccs GHe. After cycling, the valve leakage performance improved and returned to a level of leakage consistent with the component level leakage performance. The valve was also sampled for cleanliness. The particle analysis is detailed in the above discussion. While the investigation did not lead to a repeat of permanent internal leakage performance, Moog cannot rule this item out as a root cause.

F. Investigate the potential degradation of the Vespel poppet material as a result of exposure to vacuum and helium at elevated temperatures (104 F to 140 F): During the build of the GMA latch valves, Moog determined that the %-elongation of Vespel appears to have an affect on the sealing characteristics of the latch valve poppet. The theory with regard to %-elongation is that the lower the % elongation, the more "brittle" or less compliant the Vespel material is for sealing purposes. A concern was raised that the Vespel could be affected by long-term exposure vacuum (via outgassing of Vespel constituents) and/or helium in such a way that the %-elongation of poppets in the valves could be affected, or otherwise embrittled, in such a way to degrade leakage performance. To investigate this concern, the valve mini-assembly was exposed to vacuum and helium. The valves did not show any sign of leakage performance degradation. Lockheed Martin (LMSSC) also subjected the poppet material (VESPEL SP-1) to an outgassing test. Below is an e-mail response from Jim Bush from LMSSC regarding the results of this test:

"Jeff Garrett (one of the original designers of the ASTM 1559 test apparatus) runs his own commercial company which runs outgassing tests for a variety of companies. The name of the company is Outgassing Services International in Palo Alto. He has recently tested Vespel SP-1 for a commercial customer. Vespel is seeing some use in GC/MS instruments and high vacuum systems. The test was run at 125 C for a 24-hour period under vacuum conditions of 10⁻⁷ or 10⁻⁸ torr. The results of the test show the following. 1) 99.998% of the outgassing product was water, 2) The VCM for two different runs were 0.001 and 0.002% 3) the outgassing curve was fairly steep with all of the water coming out very rapidly at 125 C and going asymptotic at 24 hours. There was no mass spec data taken to ID the off gassing products but they were at such low levels that the customer did not feel it was important.

Unfortunately since the testing was done for a commercial customer Jeff could not give me a copy of the data since it belongs to that customer. With just the verbal information it was very apparent that with the data that Jeff gave me it would not make sense to run outgassing tests on the material at 40 C or 140 F since the data above was at an even higher temperature and it did not drive off significant outgassing products.

Since outgassing under temperature and vacuum does not seem to be significant the next question is how does helium affect the material and/or does temperature/vacuum cause any changes in physical surface properties which would affect the shoulder sealing area of the poppet. These questions should be answered in the aging studies you are conducting with the testing at the end."

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Exposure to vacuum and helium did not have any affect on the valve internal leakage performance. Moog also performed a Vespel SP-1 aging investigation of vespel samples. These samples were exposed to vacuum and helium for an extended period of time at temperatures between 104 F and 140 F to "age" the Vespel. These samples are to be tensile tested to determine if the properties of the vespel (yield strength, %-elongation) are affected by this exposure. The results from this testing will be available after the GMA Acceptance Data review.

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CONCLUSIONS:

The conclusion of the Tiger team meeting in July was that the status of the GMA would be “use-as-is” provided that the performance of the GMA latch valves in question did not degrade further and that no additional valves degraded. The testing to date has demonstrated that this is the case. Despite a great deal of investigation and testing, no clear root cause(s) has been identified for the out of tolerance leakage values measured for valves V4/V6 pair, V11, V15, V21, V27, V28, V29. All of the testing performed as a result of these investigations (cycle testing, vibration testing, review of build paperwork and ABCRs of all the valves, helium background investigation, weld assembly process investigation, vacuum/helium exposure) did not result in a repeat of the high leakage values that we are observing with the six GMA valves. The Summary/Comments section of the Fault Analysis indicated probable causes for the out of tolerance performance of these valves. Moog believes that the most likely cause is related to some form of contamination, but Moog cannot be determined what the source or nature of this contamination may be without removing the valves from the GMA and performing a disassembly and inspection. The exceptions to the contamination theory are the suspect poppet in V4 and the mark recorded on the seat of V15. Also, V11 and V15 present intermittent pass/fail data. We cannot be sure that this behavior was or was not present prior to vibration testing.

Having met the requirement set forth by the Tiger team, Moog recommends a use-as-is disposition for the GMA. Moog will work with Stanford University to determine the best ways to mitigate the additional risks associated with the out of tolerance leak rates observed in valves V4/V6 pair, V11, V15, V21, V27, V28, V29 and any further risks associated with latch valves which are out of tolerance due to internal leak rates.

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CORRECTIVE ACTION:

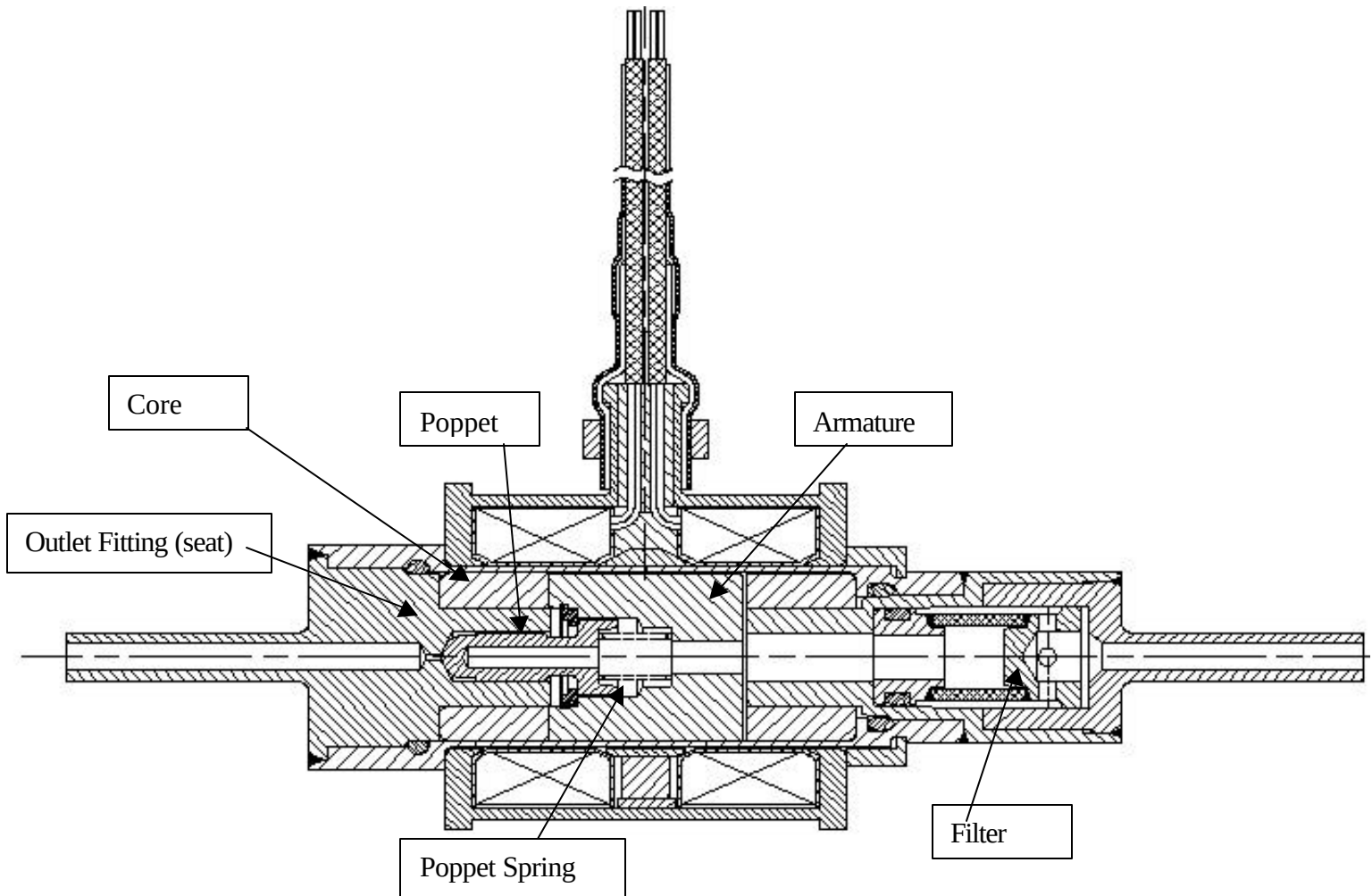
Without a confirmed root cause Moog cannot offer a corrective action for mitigating the latch valve leak rates in excess of 1.0E-04 sccs GHe. The investigations that have been conducted have revealed ways to improve our general processes for building and testing of valves and sub-systems and these will be implemented. These improvements include test methodology and procedure for internal leakage testing of the GMA, proper covering of shielded leads to prevent contamination during assembly and valve cleanliness certification.

DISTRIBUTION:

J. Bowen
J. Bonanno
D. Bushway
D. Finucane
P. King
D. Marten (2)
J. Nayda
K. Neff
B. Vogt
L. Wisher

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(CONTINUATION SHEET)

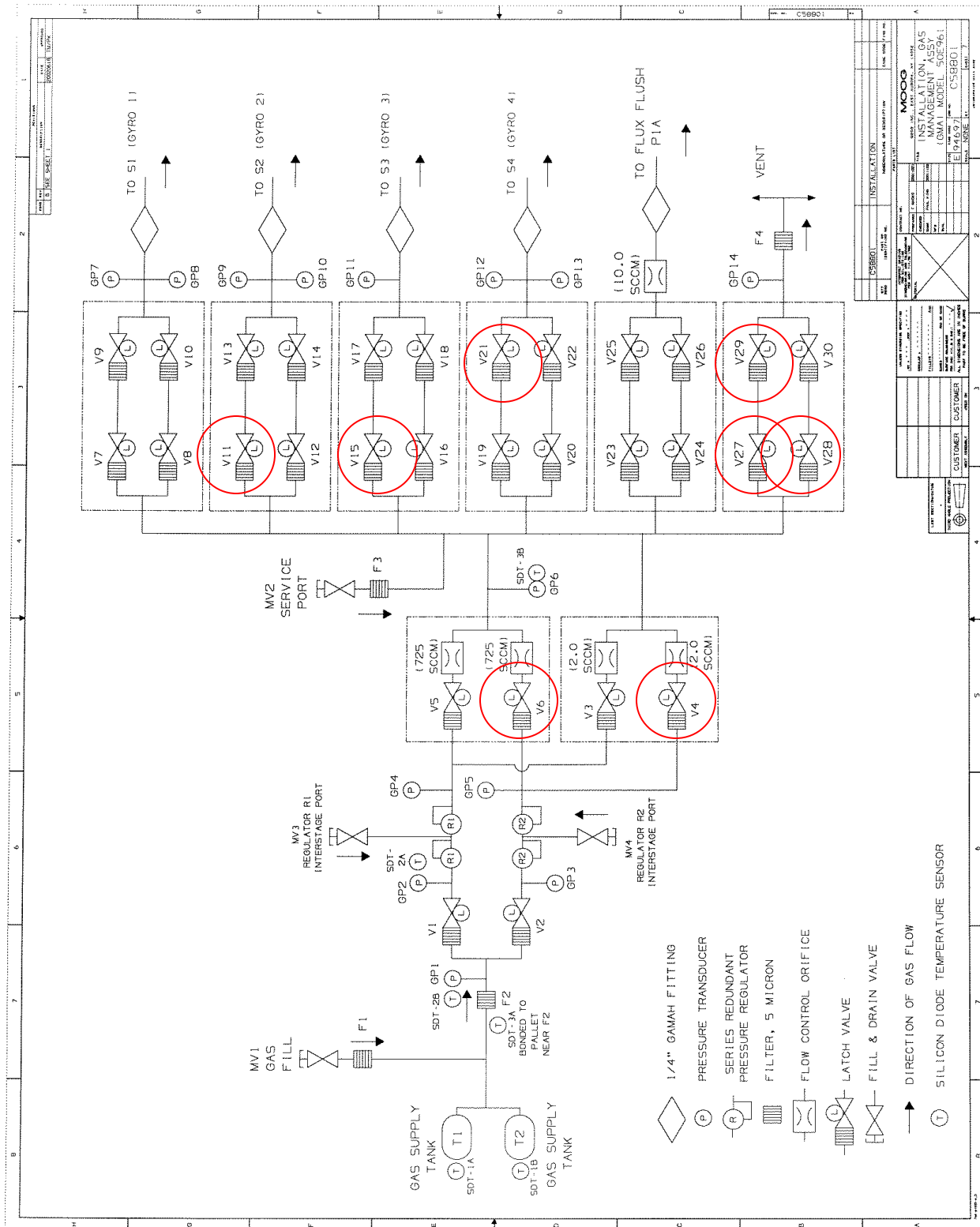
P/N: C58800	S/N: 001	CUSTOMER: Stanford University	FAR NO. FAR(M)-2002-063



**GMA: Functional Cross Section of the 51E265
Latch Valve**

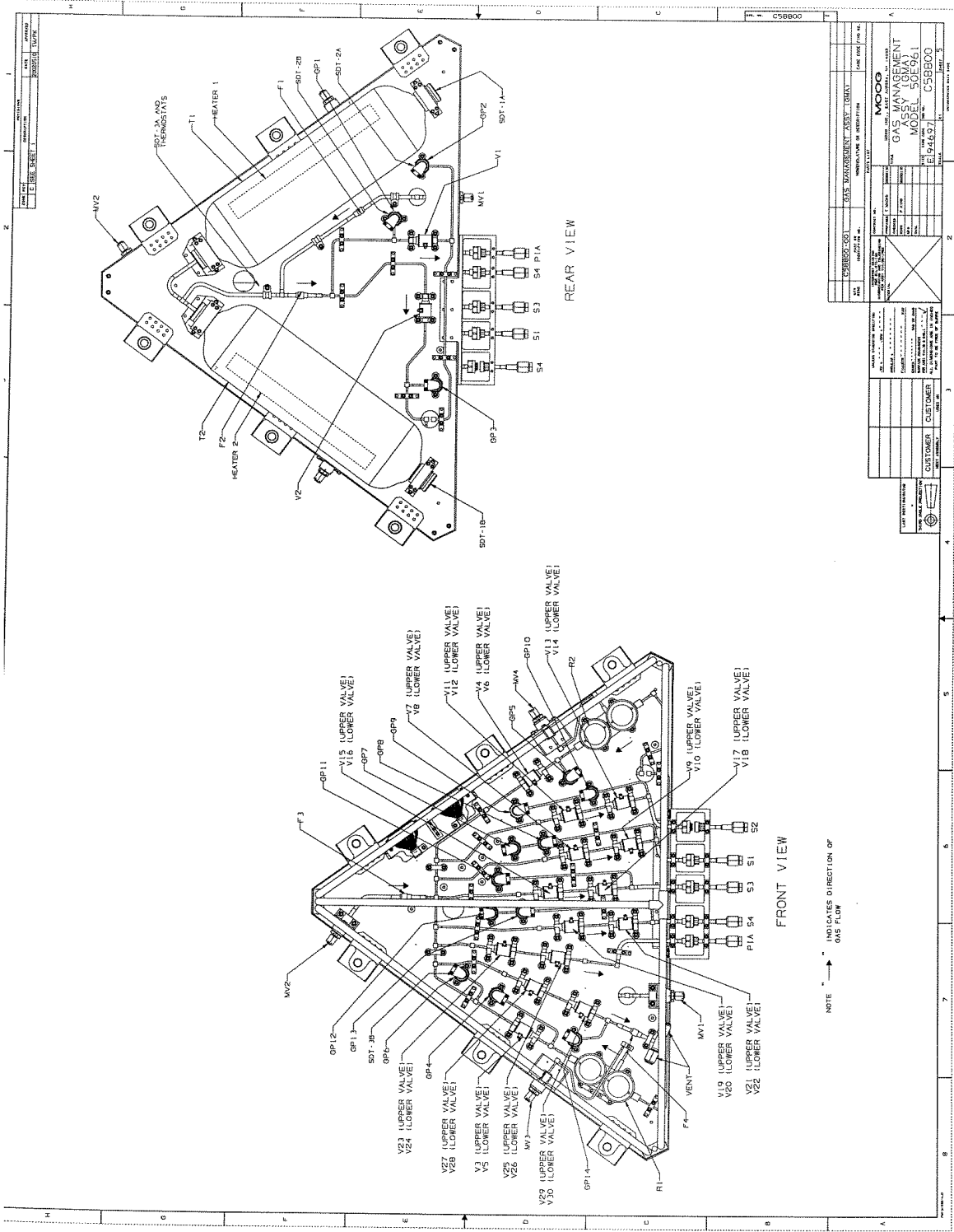
MOOG INC. FAILURE ANALYSIS REPORT (CONTINUATION SHEET)

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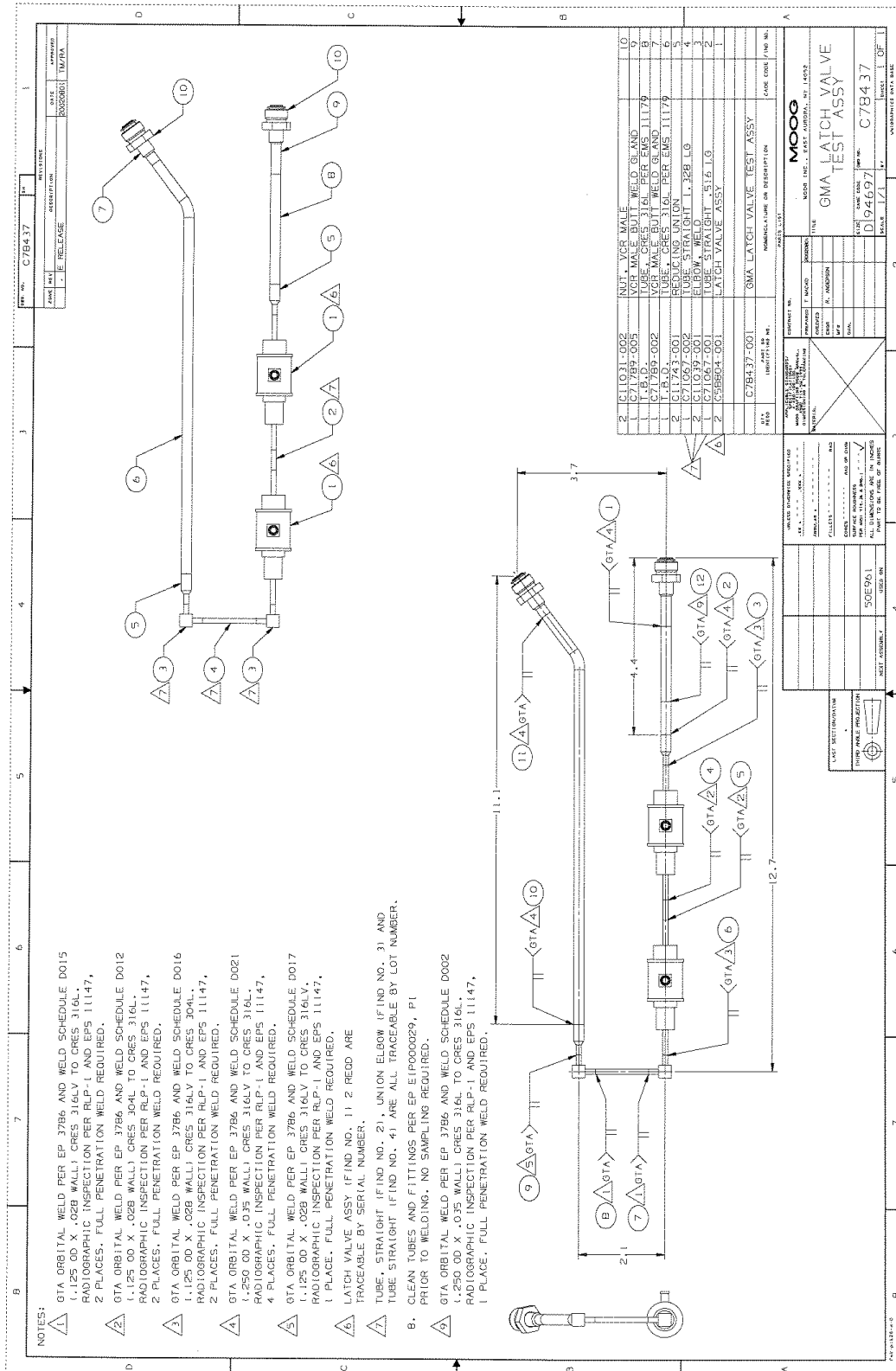
MOOG INC. FAILURE ANALYSIS REPORT (CONTINUATION SHEET)

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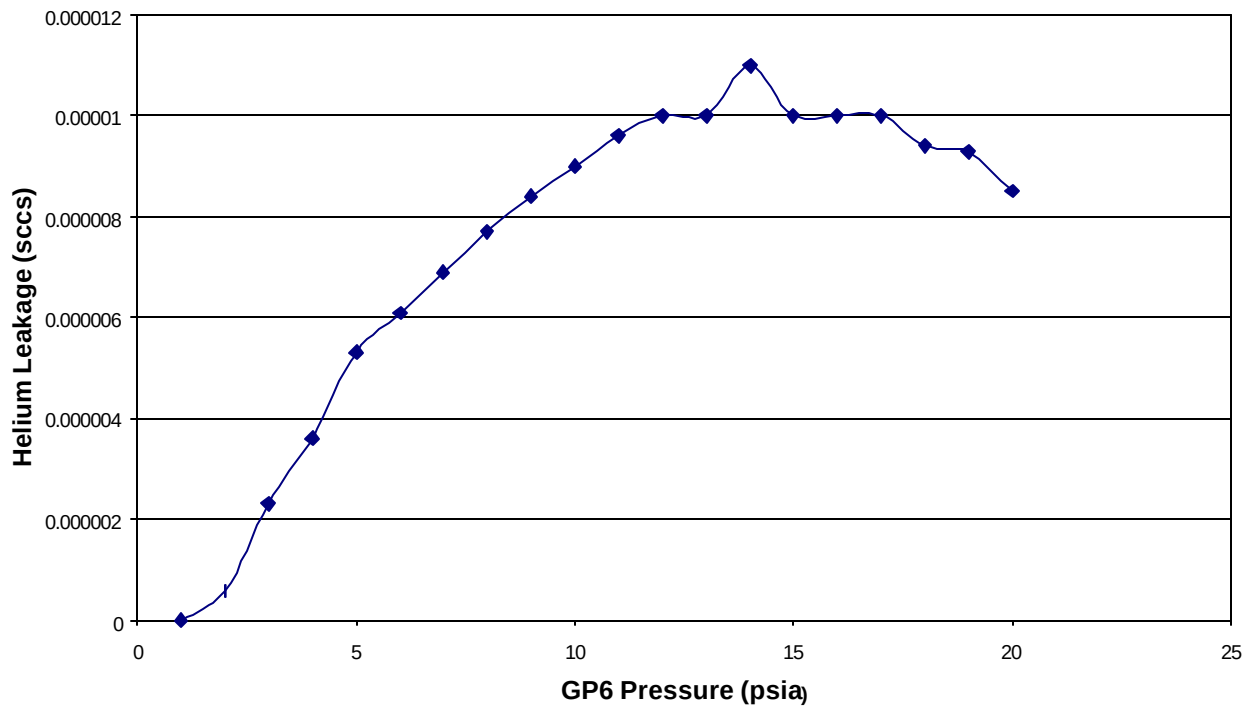
MOOG INC. FAILURE ANALYSIS REPORT
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GMA system internal leakage performance as measured at the outlets of GMA lines S1-S4, P1A and Vent, while the GMA latch valves are configured for launch. The aggregate leak rate of the GMA peaked to a value of 1.1E-05 sccs GHe at 14 psia

GMA System Internal Leakage in Flight Configuration

As Tested 7/30/02 at Moog Inc. per AVO50E961RA16



file: **GMA LEAKAGE PERFORMANCE DURING
TESTING.doc** starts on next page

(Results from the Stanford Testing)

GMA LEAKAGE PERFORMANCE DURING TESTING AT STANFORD UNIVERSITY

1. Observed Leakage Rates

The GMA valve leakage rates were measured during GMA testing at Stanford University on 9/29 – 9/30/2002 using Stanford procedure P0931 Rev A. The results are indicated in the table below.

Valve	Leakage		Valve	Leakage
V1	2.4×10^{-6}		V17	2.0×10^{-8}
V2	8.2×10^{-4}		V18	5.0×10^{-5}
V3 + V5	2.2×10^{-8}		V19	4.4×10^{-8}
V4 + V6	5.2×10^{-3}		V20	4.2×10^{-8}
V7	7.6×10^{-8}		V21	7.8×10^{-5}
V8	1.2×10^{-5}		V22	5.6×10^{-8}
V9	1.8×10^{-8}		V23	5.4×10^{-8}
V10	7.4×10^{-8}		V24	4.4×10^{-8}
V11	4.6×10^{-5}		V25	2.0×10^{-8}
V12	8.6×10^{-8}		V26	8.2×10^{-8}
V13	1.0×10^{-7}		V27	1.2×10^{-5}
V14	1.6×10^{-7}		V28	1.0×10^{-6}
V15	2.4×10^{-7}		V29	6.2×10^{-5}
V16	1.4×10^{-7}		V30	3.2×10^{-5}

Although the V4/V6 pair and V2 show a degradation from the results reported at Moog, the overall system performance has improved. This is summarized in the next few sections.

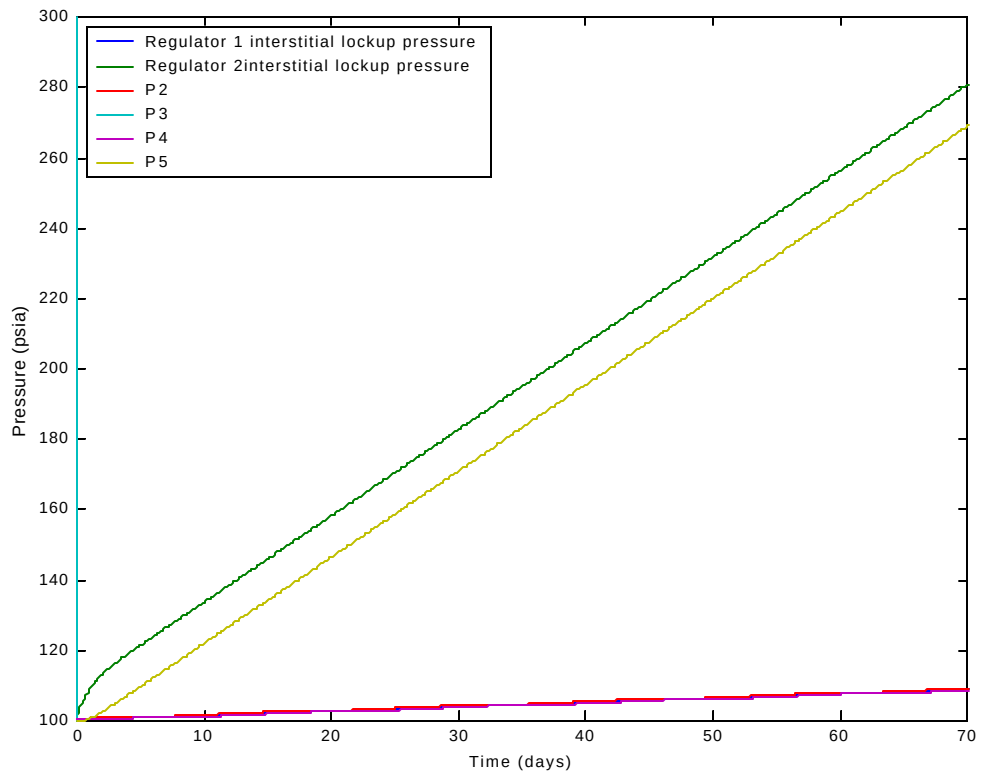
2. The GMA Simulation

A simulation was developed to calculate the evolution of various pressures and gas volumes during a GMA hold period with leaky valves. The simulation was developed in Simulink. Appendix A shows a high-level diagram of the simulation, Appendix B is the specific parameter file for the plots that will be shown in this report, and Appendix C is the actual command file that generates the simulation pictured in Appendix A.

3. Regulator Lockup

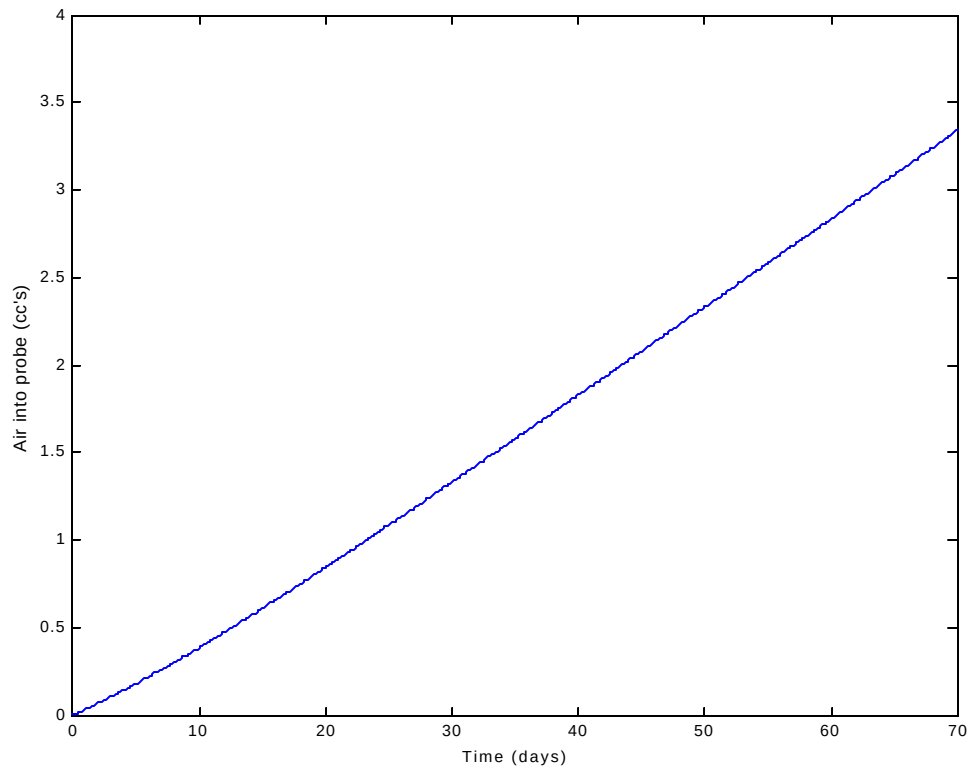
There is a requirement that the regulator lockup pressure be maintained between 100 and 300 psi during launch. The requirement for the dewar hold time is 90 days, but since the GMA can be serviced 20 days after the final dewar servicing, the equivalent hold time requirement on the GMA is 70 days.

The following graph shows all pressures pertaining to GMA lockup. Note that they remain within specification for the required time.



4. Gas Leakage into Probe

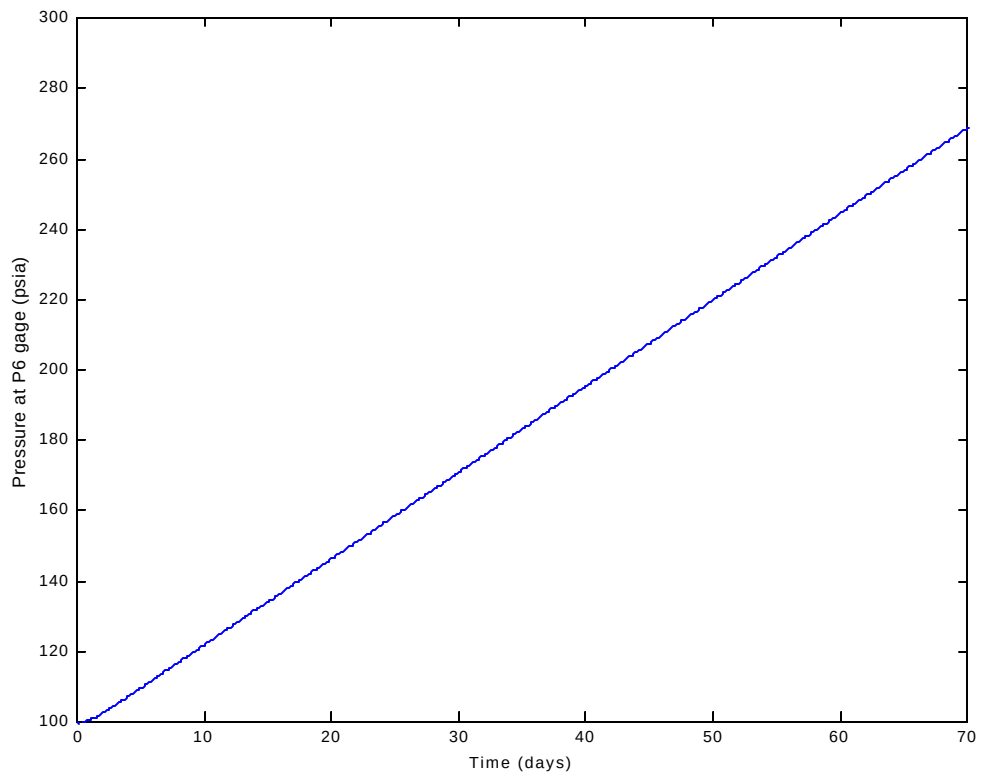
The GMA can not leak more than 100 cc's of Helium into the probe over the 70 day period. This is to avoid providing a thermal "short" that would result in an increased heat load into the dewar that would threaten its launch pad hold time. The following plot shows the air incursion over the 70 day period.



The air that would leak into the probe is less than 4% of the total allowed value. Note that the Helium background level for the Stanford leak tests was lower than was achieved at Moog, meaning that the leakage rates of many of the valves (those that measured in spec at Moog) are substantially better than was measured at that time.

5. **Air in the GMA**

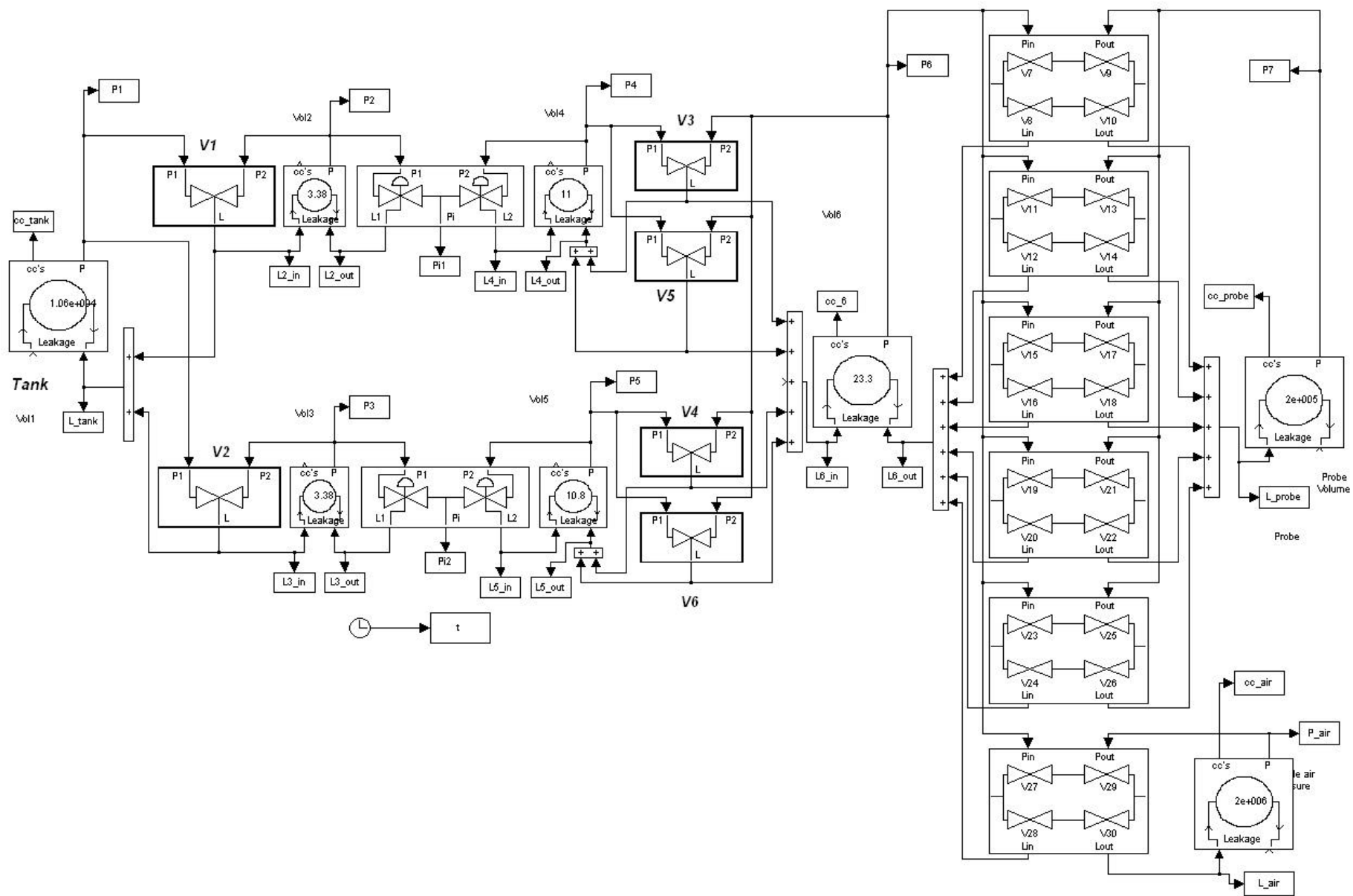
The third main requirement area which must be examined when determining the impact of valve leakage on system performance is air incursion into the probe. The following plot shows the pressure in the region of the GMA measured by the P6 pressure gage. If this pressure remains greater than 14.7 psia, then Helium will tend to leak out of the GMA, as opposed to air leaking in. From the plot it is clear that air incursion into the GMA is not a concern.



Overall, approximately 90 cc's of air leaks out of the GMA during the 70 day hold period, so there is no concern about overall depletion of the gas supply in the tanks.

6. Conclusion

GMA performance as measured at Stanford meets all system level requirements for ground hold operation. The system also meets all on-orbit requirements for valve leakage (which are much less stringent than the ground hold requirements). Therefore current GMA performance meets all program objectives. However, this conclusion could change dramatically if the leakage rate in several valves were to worsen significantly. Therefore system-level mitigations should be investigated that would allow for the space vehicle to meet the ground hold requirement in this eventuality.



GMA LEAKAGE PERFORMANCE DURING TESTING AT LOCKHEED

Observed leakage rates:

The GMA valve leakage rates were measured after Space Vehicle integration at Lockheed Martin Building 159 on 10/12/02 per Stanford procedure P0931 Rev A. The results are in the table below.

Valve	Leak rate (sccs)		Valve	Leak rate (sccs)
V1	3.0e-4		V17	1.0e-8
V2	6.5e-4		V18	2.5e-3
V3 + V5	2.4e-4		V19	6.0e-8
V4 + V6	2.5e-3		V20	3.5e-7
V7	5.0e-8		V21	2.5e-3
V8	1.7e-6		V22	2.5e-3
V9	3.2e-9		V23	6.0e-8
V10	8.0e-9		V24	4.0e-7
V11	2.6e-4		V25	5.0e-9
V12	1.7e-6		V26	2.5e-9
V13	3.0e-5		V27	3.5e4
V14	1.0e-5		V28	5.0e-4
V15	6.8e-6		V29	4.0e-3
V16	3.0e-7		V30	4.0e-3

GMA Pressure Rate of Rise Evaluation

This table represents the GMA internal leak rates as calculated from the GMA Rate of Rise evaluation. This test was performed from 1/17/03 to 1/24/03 at Lockheed Martin Building 156 after the Thermal Vacuum Test. These data show leak rates that are considerably lower than those measured in previous leak tests performed with a Helium leak detector. See the GMA mitigation plan for a full report of the testing.

Leak rates measured during the rate of rise evaluation performed 1/17/03 thru 1/24/03 at Lockheed B156							
	into	into	into	into	into	into	into
all values in sccs	S1	S2	S3	S4	P1A	Probe Sum	Vent
Leak rate, ground state:	1.05E-07	1.50E-07	3.01E-07	3.63E-07	3.41E-07	6.28E-06	-7.92E-06
Leak rate, Launch state (V17,V18 closed):	2.65E-07	4.02E-07	3.49E-04	3.26E-07	2.10E-06	1.77E-03	2.64E-04
Leak rate, Alternate launch state (V15,V16 closed):			2.45E-05			2.76E-05	2.64E-04
Leak rate, Launch state (V17,V18 closed) run 2			4.31E-06			7.41E-06	2.64E-04
	out of	out of	out of	out of	out of	out of	
	Zone 5	Zone 3A	Zone 3B	Zone 2A	Zone 2B	Zone 1	
	MV2	MV3	MV4	GP2	GP3	GP1	
Leak rate, ground state:	7.92E-06	1.25E-06	7.11E-07	no data	no data	no data	
Leak rate, Launch state (V17,V18 closed):	3.68E-04	-4.47E-07	-3.23E-08	-3.17E-07	-7.09E-06	3.41E-04	
Leak rate, Alternate launch state (V15,V16 closed):	2.58E-04	9.25E-05	1.18E-04	9.33E-06	3.92E-05	6.37E-03	
Leak rate, Launch state (V17,V18 closed) run 2	1.26E-04	-2.92E-06	-6.39E-06	3.30E-07	-1.60E-05	5.33E-05	

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(and supporting attachments)

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(Moog Failure Analysis Report, received February 2003)

 FAILURE ANALYSIS REPORT	<u>Customer:</u> Stanford University	<u>Product Name:</u> Gas Management Assembly (GMA)	Moog Report No. FAR(M)2002- 063 Revision A
			Originator: Paul King
			Quality: John Bonanno
	<u>How Reported:</u> MDR 449854 & 449858 FR(M) 2002-047	<u>Model Number:</u> 50E961 (51E265)	Engineering: Paul King
	<u>Test Document</u> MRA13238 Para. 3.3.4	<u>Serial Number:</u> 001	Customer Rep (If Req'd): N/A
		<u>Moog Part No.:</u> C58800	DCMC (If Req'd): N/A
<u>Date of Analysis:</u> 6/28/02 – 2/11/02	<u>Cust. Report No.:</u>	<u>Customer Part No:</u> LMSSC 8A02681-101	<u>Issue Date:</u> Original: September 5, 2002 Revision A: February 11, 2003

Report Sequence: (1) History (2) Analysis (3) Conclusions (4) Corrective Action

HISTORY:

Immediately after completing vibration testing per MRA13238 of Moog Model 50E961, Gas Management Assembly (GMA), the internal leakage rates of Moog Latch Valves (Model 51E265) V27 and V29 were measured because of earlier high leakage rates collected during bubble leak testing and post proof internal leak testing. The post-vibration leak rates from both valves exceeded the GMA specification limit of less than 1.0E-04 sccs GHe. These results lead Moog to measure the leakage of all the GMA latch valves. This testing revealed that the V4/V6 valve pair (configuration permits the leakage testing of the valves as a pair only), V11 and V15 exceeded the leakage specification requirement. With concurrence from Stanford University, a series of leakage tests, which required cycling valves, were performed. The V4/V6 valve pair and V15 continued to indicate high leak rates. In order to determine the overall health of the GMA, Moog proceeded with the remainder of the post-vibration testing of the GMA, which included additional internal leakage testing of the latch valves. This testing revealed that valves V21, V27 and V28 also indicated leak rates greater than the specification requirement. At this point GMA testing per MRA13238 was halted. Upon completion of the testing up to this point, the following valves presented suspect/non-conforming performance: V4/V6 pair, V11, V15, V21, V27, V28, V29.

A "Tiger" team was formed consisting of Moog (Paul King, Ron Anderson, John Bonanno), Stanford University (Rob Brumley, Chris Gray, Ken Bower, Ray Pressburg, Bill Wissert), NASA-MSFC (DeWitt Burns, Kent Chojnacki) and Lockheed Martin (Jim Bush). At the direction of the Tiger team, some additional leak testing was performed to investigate the testing method, to characterize the valve leakage behavior versus pressure (see attached plot) and better characterize helium background levels. The Tiger team also concluded that removing the non-conforming valves from the GMA is a worse case exercise warranted by degradation of additional valves and/or additional degradation of internal leakage performance of the valves in question. The basis for this conclusion was the inherent contamination risks to the GMA resulting from cutting valves out of the GMA. However, this course of action does not permit a disassembly/inspect of the questionable valves. The Tiger team also agreed to go forward with testing of the GMA per MRA13238, which included thermal/vacuum testing and several more latch valve internal leakage tests. This testing was completed. An important observation from the all data is that no additional latch valves degraded and the valves were generally consistent in leakage rate from test to test. Some valves also showed some improved performance. Also, the valves in question (V4/V6 pair, V11, V15, V21, V27, V28, V29) did not get any worse. The data from all the additional internal leakage testing and the internal leakage testing per MRA13238 are summarized in the Summary GMA PTP MRA13238 and AVO Internal Leakage Data matrix attached.

Per the direction of the Tiger team, two spare GMA latch valves were subjected to a series of tests including cycle testing and vibration testing. These valves were also subjected to cleanliness sampling to determine the level of particulate in the valve after certain tests. The internal leakage was measured throughout these tests. The valves

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were also welded into a mini assembly similar to sub-assemblies used in the GMA. Internal leakage was measured after assembly and the mini assembly (see attached Moog C78437) was subjected to additional vacuum and thermal testing to determine if this type of exposure can degrade sealing characteristics of the Vespel SP-1 (unfilled) poppet material in each valve. Samples of this material were also exposed to these conditions and then tensile tested by an outside lab to determine if the material properties (yield strength, %-elongation) of the Vespel are affected. During this investigation using the spare latch valves and Vespel samples, the GMA was shipped to Stanford University since the GMA test results met the Tiger Team requirements for use-as-is: the performance of the GMA latch valves in question did not degrade further and no additional valves degraded upon completion of protoflight testing.

Spare latch valve SN007 exhibited a general shift in leakage performance from the 1E-07 sccs GHe range to 10E-06 sccs GHe range after integration into the mini assembly. This valve also presented several leakage measurements in the 1E-05 sccs GHe range and one value at 2.0E-04 sccs GHe. Although the performance of this valve was very good, the general shift and outlying data points raised suspicion about the valve. The valve was disassembled and inspected. Spare latch valve SN022, which did not exhibit any shift in internal leakage performance, was also disassembled for comparison.

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ANALYSIS:

For reference a functional cross-section of the 51E265 is included at the end of this report as well as a schematic of the GMA and a top view of the GMA indicating valve locations. To facilitate the search for a root cause(s) of these non-conformances, a fault matrix was created, which identifies the subject valves (V4/V6 valve pair, V11, V15, V21, V27, V28 & V29). This matrix is attached. Many of the potential causes are deemed not credible since many of the causes would result in gross leakage or would affect other performance parameters of the valve such as valve response. The Tiger team also used this matrix to determine a pathway for additional investigative testing.

The main focus of the Tiger team effort was to determine why the leakage performance of the valves, in general, degraded from $\sim 1.0\text{E-}07$ sccs GHe leakage at the component level to $>1.0\text{E-}06$ sccs GHe at the GMA level and to determine why the valves in question degraded to $\sim 1.0\text{E-}04$ sccs GHe. The key concerns with regard to excessive latch valve internal leakage are:

1. Loss of lock-up pressure for the GMA regulators prior to launch, which could result in damage to the regulators during the launch shock environment.
2. Helium leakage into the science probe prior to launch, which could degrade the downstream science probe.
3. Leakage of air into the GMA through the vent valve prior to launch, which would degrade the GMA helium purity.
4. General loss of helium that may result in insufficient gas for the mission.

In addition to investigating the causes for excessive leakage of the latch valves, the team also discussed ways to allow the GMA to be used "as-is" provided the internal leakage performance did not get worse after completion of the testing per MRA13238. Stanford would also need to determine ways to mitigate any risks related to the higher leakage rates from the six questionable valves. The mitigation methods discussed at the Tiger team meeting included selecting which valves would be open or closed during launch to minimize leakage into the probe, but maintain ECU redundancy, keep the vent line capped for as long possible, maintain 300 psia helium throughout the low-pressure side of the GMA and keeping all the valves closed as long as possible before launch. The results of this portion of the investigation are available from Stanford University.

As a result of Tiger team discussions, some additional testing was deemed worthwhile to help with resolving the likelihood of specific causes. These tests/investigations include:

- A. Cycle testing of two spare latch valves (51E265, SN007, SN022) to determine if self-generated contamination is a cause: See attached MRA16475 summary matrix. The first 1000 mL effluent IPA sample was collected from each valve and passed through a filter patch. The particles on the patch were then categorized by size and counted under a microscope. After sampling, the valves were certified clean to the GMA requirement before proceeding to the next test. The two latch valves tested did indicate particulate counts greater than the certified clean limits established for the GMA program. The concern for Moog is particle size greater than 100 microns. Some particles of this size were found during this testing and in subsequent cleanliness sample tests performed after the tests described below. Several of these particles were isolated and examined by Moog Material Process Engineering using FTIR and SEM/EDS analysis. These particles were identified as follows: polyurethane polymer (e.g. Spensol L-44, source unknown), nitrocellulose (source: filter patch material), secondary amide (source: human skin), PH stainless steel (source: fixturing, inlet fitting of latch valve). With the exception of the polyurethane polymer, these particles are consistent with contamination from handling and hook-up debris. These materials may have been in the valves or could have been introduced during the sampling procedure. There was no evidence of Vespel, EPR (o-ring), Teflon (bearing rings on armature), CRES 430 or CRES 300 series or braided shielding, all of which are possible materials from the latch valves. The only

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exception was the PH stainless, which could have come from the **filter housing** (15-5 PH) of the latch valve. Note that when a valve is certified clean, IPA is flowed through the valve for two minutes prior to taking a sample. Comparing the first 1000 mL to the certified clean standard is a very conservative approach. The valves did not show any sign of leakage performance degradation. While the spare valves tested were not affected by the presence of these particles, Moog cannot rule out some form of contamination as a root cause for the six valves in question.

- B. Vibration testing of two spare latch valves to determine if the valves are damaged in any way: See attached MRA16475 summary matrix. The two latch valves (SN007 and SN022) were vibration tested in the open condition (see item D below) while mounted in the "stacked" GMA configuration. The GMA level random vibration spectrum was the test input. The valves were cycled and leak tested after each axis. The testing did reveal that the upper valve was subjected to vibration levels of ~40 Grms. The valves did not show any sign of leakage performance degradation or any other valve performance degradation. Since the two spare valves and the majority of the GMA valves continue to perform within specification, Moog does not believe that the vibration testing was a root cause. However, the vibration testing could be coupled with a contamination issue, i.e., vibration freed trapped contamination.

Two Mott flow restrictors were also exposed to vibration testing. The restrictors were then sampled for particles. No metallics were generated from exposure to the vibration environment indicating that the sintered material was not damaged and did not shed. The particle counts were high on one unit, but this is attributed to the sampling technique. The technique was altered on the second unit, which indicated a very "clean" unit. The Motts are not viewed as a source of contamination.

- C. Investigate helium background of GMA and test methodology: See the attached GMA Latch Valve Internal Leakage Fault Analysis matrix. A calibrated leak device (1.5E-05 sccs GHe) was plumbed into the GMA at the GMA vent line. The mass spectrometer was capable of measuring the calibrated leak. The calibrated leak device was subsequently removed from the GMA vent line. Also, the sequence in which valves are leak tested and evacuated to testing was found to have some affect on the leakage measurements when measuring the internal leakage of individual valves. Subsequent testing instructions addressed this issue. However, the magnitude of this adjustment was minor and is not considered a cause for the excessive leak rates.
- D. Review the build paperwork and As-Built-Configuration-Records (ABCRs) from all the valves: All the build data was reviewed to determine if there was any trend in the data to suggest that the valves in question had something in common that would point to a root cause. No trend could be identified with regard to:
- Material/part lots, i.e., material/poppet lots from the valves in question were also used in valves with leakage two orders of magnitude better. This included the poppets, outlet fittings (seats), armatures, poppet springs and cores.
 - Build/performance parameters, e.g., spring preload, valve and poppet stroke, latching force, response, pull-in current.

A trend with regard to weld reworks was noted for valves V27, V28 and V29. All valves except V1 and V2 had the filter body weld reworked. However, V27, V28 and V29 were reworked twice, which exposed these valves to an additional deburring operation. The handling of these valves was consistent with other rework operations. Another trend associated with these particular valves is the fact that they are located in the vent line. The vent line is the primary purging line for GMA testing. This level of gas throughput may offer more opportunity for contamination of the valves. Beyond identifying these trends, no other conclusions were drawn.

The only other trend identified is the valve open/close status and position in the mounting brackets during vibration testing. The V4/V6 pair, V27 and V29 indicated leakage performance problems prior to vibration. However, V11, V15, V27 were open during vibration and located in the upper portion of the mounting bracket. It is important to note that V11 and V15 have a history of intermittent leakage performance, which implies that any

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acceptable leakage data taken prior to vibration was a random occurrence. Additional testing prior to vibration testing may have revealed unacceptable values, as well. V21 was located in the upper portion of the bracket, but was closed during vibration. Also, the valve had acceptable leakage values immediately after vibration testing.

Valve Location	Open/Close Status During Vibration/Launch	Mounting Bracket Location	Non-Conforming Valve
V1	Closed	Lower	
V2	Closed	Lower	
V3	Closed	Upper	
V4	Closed	Upper	X (paired with V6)
V5	Closed	Lower	
V6	Closed	Lower	X (paired with V4)
V7	Open	Upper	
V8	Open	Lower	
V9	Closed	Upper	
V10	Closed	Lower	
V11	Open	Upper	X
V12	Open	Lower	
V13	Closed	Upper	
V14	Closed	Lower	
V15	Open	Upper	X
V16	Open	Lower	
V17	Closed	Upper	
V18	Closed	Lower	
V19	Open	Upper	
V20	Open	Lower	
V21	Closed	Upper	X
V22	Closed	Lower	
V23	Open	Upper	
V24	Open	Lower	
V25	Closed	Upper	
V26	Closed	Lower	
V27	Open	Upper	X
V28	Open	Lower	X
V29	Closed	Upper	X
V30	Closed	Lower	

- E. Investigate the weld assembly process of the GMA latch valve sub-assemblies as a source of contamination: See attached MRA16475 summary matrix. Using valves SN007 and SN022, Moog welded a mini-assembly per C78437 using the same processes and procedures used when welding the GMA latch valve quad and double valve sub-assemblies. This included not protecting the weld process from potential handling contamination from the latch valve lead wire shielding (It was noted during the GMA build that the shielding harbored contaminants. After this was noticed, the shielding was bagged to reduce risk of contamination). Immediately after assembly, the leakage performance of both valves measured ~1.0E-05 sccs GHe. After cycling, the valve leakage performance improved and returned to a level of leakage consistent with the component level leakage performance. However, the internal leakage performance of SN007 did present a general shift from the 1.0E-07 sccs GHe range to the 1.0E-06 sccs GHe range. Valve SN022 did not present this same performance shift. The assembly was also sampled for cleanliness. The particle analysis is detailed in the above discussion.

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While the investigation of the integration process did not lead to a repeat of permanent internal leakage performance degradation on par with the GMA valves, Moog cannot rule this item out as a root cause.

- F. Investigate the potential degradation of the Vespel poppet material as a result of exposure to vacuum and helium at elevated temperatures (104 F to 140 F): During the build of the GMA latch valves, Moog observed that the %-elongation of Vespel might have an affect on the sealing characteristics of the latch valve poppet. The theory with regard to %-elongation is that the lower the % elongation, the more "brittle" or less compliant the Vespel material is for sealing purposes. A concern was raised that the Vespel could be affected by long-term exposure vacuum (via outgassing of Vespel constituents) and/or helium in such that that the %-elongation of poppets in the valves could be affected, or otherwise embrittled, in such a way to degrade leakage performance of SN007. To investigate this concern, the valve mini-assembly was exposed to vacuum and helium. The valves did not show any immediate sign of leakage performance degradation. However, additional cycling (500 cycles total, leakage measured at 100 cycle intervals) of the valves per AVO51E265RA20 showed additional degradation in leakage performance. Several internal leakage measurements were in the 1.0E-05 sccs GHe range and one measurement was 2.0E-04 sccs GHe. In an attempt to improve leakage performance, the mini assembly was flushed with 300-psig helium per "AVO-PTK-100402-Latch Valve GHE Flush at 300 psig" in an effort to remove possible contaminants at the valve seat. No change in performance was noted. Next, SN007 was exposed to 300 psig in the closed position for 48 hours while at 145 F per AVO-PTK-GMA Valve Heating, in an attempt to recoin the seat. No change in performance was noted.

Lockheed Martin (LMSSC) also subjected the poppet material (VESPEL SP-1) to an outgassing test. Below is an e-mail response from Jim Bush from LMSSC regarding the results of this test:

"Jeff Garrett (one of the original designers of the ASTM 1559 test apparatus) runs his own commercial company which runs outgassing tests for a variety of companies. The name of the company is Outgassing Services International in Palo Alto. He has recently tested Vespel SP-1 for a commercial customer. Vespel is seeing some use in GC/MS instruments and high vacuum systems. The test was run at 125 C for a 24-hour period under vacuum conditions of 10⁻⁷ or 10⁻⁸ torr. The results of the test show the following. 1) 99.998% of the outgassing product was water, 2) The VCM for two different runs were 0.001 and 0.002% 3) the outgassing curve was fairly steep with all of the water coming out very rapidly at 125 C and going asymptotic at 24 hours. There was no mass spec data taken to ID the off gassing products but they were at such low levels that the customer did not feel it was important.

Unfortunately since the testing was done for a commercial customer Jeff could not give me a copy of the data since it belongs to that customer. With just the verbal information it was very apparent that with the data that Jeff gave me it would not make sense to run outgassing tests on the material at 40 C or 140 F since the data above was at an even higher temperature and it did not drive off significant outgassing products.

Since outgassing under temperature and vacuum does not seem to be significant the next question is how does helium affect the material and/or does temperature/vacuum cause any changes in physical surface properties, which would affect the shoulder sealing area of the poppet. These questions should be answered in the aging studies you are conducting with the testing at the end."

Moog also performed a Vespel SP-1 aging investigation of vespel samples machined for tensile testing and two poppets. These samples were exposed to vacuum and helium for an extended period of time at temperatures between 104 F and 140 F to "age" the Vespel.

The poppet samples exposed to the vacuum/helium conditions were examined using the Moog Scanning Electron Microscope (SEM). These were compared to two poppets not exposed to vacuum. No difference was noted between the four poppets, e.g., no crazing or other surface disruption. This result agrees with information from Dupont, the manufacturer of Vespel, which states that vacuum/helium exposure would not significantly reduce Vespel properties.

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In the case of the Vespel tensile samples, two different lots (3/8"-OD and 1/4"-OD rod samples) were tested. Two from each lot were exposed to the vacuum/helium environment, while two from each lot were used as control samples. The data from the tensile testing are included in this report. The data indicate a relatively wide spread in tensile strength (UTS= UYS) and %-elongation within a lot of material.

- The 3/8" OD lot of material was certified to a tensile strength of 14,777 psi and %-elongation of 13.3%.
 - The control samples tested: 14296 to 14691 psi and 10.65% to 11.44%.
 - The test samples tested: 12,338 to 14,306 psi and 5.7% to 8.8%.
- The 1/4" OD lot of material was certified to a tensile strength of 14,396 psi and %-elongation of 10.3%.
 - The control samples tested: 10,615 to 14,664 psi and 4.21% to 13.18%.
 - The test samples tested: 13,254 to 14,031 psi and 6.73% to 6.95%.

In both lots tested, the samples exposed to the vacuum/helium environment exhibited much lower %-elongation values than the %-elongation recorded in the vendor material certifications. However, the control samples also exhibited %-elongation values both greater and less than the %-elongation recorded in the vendor material certifications. While some variation is expected, this range of variation is larger than typical according to Dupont, especially for the control samples for the 1/4" OD lot. Dupont believes that the large variation was due to specimen geometry and/or measuring technique. Moog M&PE agreed that the variation is related to the geometry of the sub-sized tensile bars. However, Moog cannot rule out variation in material properties as being a contributing factor in leakage performance. Moog also believes that the test was inconclusive in determining that the vacuum/helium exposure played a role in degraded leakage performance.

G. Disassembly of 51E265, SN007 and SN022: Since SN007 displayed a general trend towards degraded leakage performance; the valve was disassembled per the instructions of Moog AVO-GMA-10-18-02 Latch Valve SN007 Removal. Note however, that the valve leakage performance was typically in the mid 1.0E-06 to mid 1.0E-05 sccs GHe range. Upon completion of the disassembly and inspection of SN007, SN022 was also disassembled for comparison. Valve SN022 did not exhibit any shift in performance. The disassembly of SN022 was performed using the same instructions used for SN007.

The outlet weld was machined in such a way as to reduce the potential of machining debris from entering the valve's wetted area. The condition of the outlet fitting/seat, armature/poppet assembly, core pieces and filter were inspected. The following noteworthy observations were recorded. Unless otherwise noted, inspections were performed using 20-30X magnification. Photos of SN007 are included at the end of this report. Photos of SN022 are also included, but these photos are limited to Moog SEM photos since the piece parts generally looked the same except where noted below. All piece parts are in storage at Moog.

1. Outlet fitting/seat:

SN007: appears normal with no obvious leak scratches that could contribute to leakage. Using the Moog SEM, some surface staining of the seat was observed in the approximate area where the poppet seals on the seat. The stains do not appear to alter the surface and are ~10-microns in size. These stains could also be thin films of Vespel transferred from the poppet. This observation is based on the fact that non-metallics/organics appear as dark spots when viewed with the SEM and the fact that the stains are in a circumferential pattern that would correspond to the poppet sealing surface. Location, size and thickness of these stains make it impossible for Moog's equipment to identify the chemical nature of the stains. The EPR o-ring was also in good shape and did not show evidence of nicks, missing material or trapped contamination.

SN022: appears generally the same as SN007 except no stains were observed. The seat also exhibited a scratch that was located outside of the sealing area. The o-ring as was also in good condition.

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2. Outlet core:

SN007: swage appears normal with no evidence of burrs. The surface of the core that contacts the armature face showed signs of polishing/burnishing from repeated cycles. The shape of the burnish marks also suggests that the armature rotates, either due to cycles or from vibration testing (see below).

SN022: swage appears typical. Also exhibited burnish marks from cycling.

3. Inlet core:

SN007: swage appears normal with no evidence of burrs. The surface of the core that contacts the armature face showed signs of polishing/burnishing from repeated cycles, but to a lesser degree than the outlet core.

SN022: appears typical.

4. Armature assembly:

SN007: armature surfaces show polish/burnish marks corresponding to the marks observed on the inlet/outlet cores. The Teflon bearings appeared normal, i.e., no signs of heavy wear or nicks, missing Teflon or trapped contamination. The poppet retainer, coil spring and shims all appeared in nominal condition. No signs of contamination or damage.

SN022: armature presents similar burnish marks. The Teflon bearings, coil spring, shims and retainer appear typical.

5. Poppet:

SN007: The sealing surface of the poppet showed evidence of coining. The poppet was examined in the Moog SEM and compared to a poppet that was never used. The coining was very apparent, but no signs of chipped Vespel at the sealing edge or cracks were observed at high magnification. The poppet was sent to Lockheed Martin in Sunnyvale (Jim Bush) for additional analysis. Lockheed performed some visual inspections of both the SN007 poppet and the unused poppet at even high magnification using a SEM. Both poppets presented surface defects on the order of 20-microns or less at the sealing surface. These features appear as scratches/crevices/cracks and localized high and low spots. The SN007 poppet also presented some areas that appear as long, narrow burrs. Moog does not know how significant these features are to the sealing capability of the poppet other than they probably do have some adverse effect on the local stresses in the poppet. The similarities between the SN007 poppet and the as-machined, but never installed poppet leads Moog to believe that these features do not play a major role in the out of tolerance leakage performance.

A white residue was observed on the poppet shaft immediately upstream of the sealing surface. Moog's attempts to identify the residue were inconclusive. However, the residue appears to have entrapped some 300 series CRES and aluminum. The residue itself also contains traces of zinc and chlorine. Lockheed identified the residue as aluminum silicate in a hydrated form using micro-FTIR and EDS (Lockheed Lab Report, Evaluation of Foreign Residue and Seal-Surface Irregularities on Poppet (Gravity Probe B Program, Lab Request/Job AJ9029). Forms of aluminum silicate are used in many different products. It is commonly identified as a clay, e.g., kaolinite or china clay, and is used as a filler in paint, rubber and plastics and is widely used in the paper industry to produce glossy paper used in magazines. Moog has attempted to identify sources of aluminum silicate in the build and test process, but has been unsuccessful. While this residue is not found on the sealing surface of the poppet, the residue or the particulate trapped in the residue

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could affect the sealing performance of the valve by periodically breaking free from the poppet and relocating at the poppet/seat interface. This could explain the variation in the leakage performance of this valve. No evidence of the aluminum silicate was found anywhere else in the valve.

SN022: The sealing surface of the poppet shows evidence of coining. The inner side of the coined surface appears less uniform than the SN007 poppet. Also the outer surface exhibits a thin circumferential "feather" burr, probably resulting from the coining process. The poppet was examined with the Moog SEM. The sealing edge did not show signs of any damage at high magnification other than localized high and low spots similar to the features seen on the SN007 and unused poppet. No white residue was evident on the poppet or any other piece parts. The poppet has not been viewed with the Lockheed Martin equipment, which can produce images at higher magnification.

6. Valve Housing:

SN007: The housing appeared normal with no evidence of abnormal wear from armature cycling.

SN022: The housing appeared normal with no evidence of abnormal wear from armature cycling.

7. Filter.

SN007: The filter did not show any signs of contamination on the outer or inner surface. The EPR o-ring did present several white particles less than 50-microns in size. Moog FTIR analysis indicated that the particle was a secondary amide, most likely skin. Otherwise the o-ring was not damaged.

SN022: The filter appeared typical. No signs of contamination were observed. The o-ring was in good condition.

8. Filter Housing & Inlet Fitting:

SN007: A large (~200 micron) white particle was adhered to the inner surface of the inlet fitting immediately upstream of the filter. Moog FTIR analysis indicated that the particle was a secondary amide, most likely skin. This is consistent with the particles found on the filter o-ring. Moog cannot verify if this particle was in the valve since assembly or if it was introduced during the disassembly/inspection process. Both processes require personnel to wear cleanroom gloves while handling the hardware.

SN022: The filter and inlet assembly appeared typical. No evidence of contamination was found.

The results from the disassembly and inspection process support the contamination theory as a root cause. The aluminum silicate with entrapped particulate, the skin particle and the white particles located on the filter o-ring are evidence of contamination in the valve.

H. Armature/Poppet Rotation Experiment: A development valve similar to the 51E265 valve was built, but not welded to determine if the armature and/or poppet does rotate during normal valve cycling. Rotation of the sealing surfaces of the poppet relative to the seat could affect sealing performance. The valve housing, armature and poppet were scribed to provide reference points. All three scribe marks were aligned with each other prior to threading the outlet fitting into the valve. The valve was cycled several times. Upon removing the outlet fitting, it was noted that the scribe lines were still aligned. This was repeated several times with the same result. This result is contrary to the burnish marks noted above in the description of the disassembly and inspection of SN007. Nonetheless, Moog does not believe that poppet rotation is cause in degraded leakage performance based on the fact the experiment does not indicate that the poppet does rotate and the fact that there is no history of leakage problems associated with poppet rotation.

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CONCLUSIONS:

The conclusion of the Tiger team meeting in July was that the status of the GMA would be “use-as-is” provided that the performance of the GMA latch valves in question did not degrade further and that no additional valves degraded. The testing up to shipping the GMA to Stanford has demonstrated that this is the case. Despite a great deal of investigation and testing, no clear root cause(s) has been identified for the out of tolerance leakage values measured for valves V4/V6 pair, V11, V15, V21, V27, V28, V29. All of the testing performed as a result of these investigations up to the date of GMA shipment (cycle testing, vibration testing, review of build paperwork and ABCRs of all the valves, helium background investigation, weld assembly process investigation, vacuum/helium exposure) did not result in a repeat of the high leakage values that we are observing with the six GMA valves. The Summary/Comments section of the Fault Analysis indicates probable causes for the out of tolerance performance of each valve.

Moog believed that the most likely cause is related to some form of contamination. The exceptions to the contamination theory are the suspect poppet in V4 and the mark recorded on the seat of V15. Also, V11 and V15 present intermittent pass/fail data. We cannot be sure that this behavior was or was not present prior to vibration testing.

Having met the requirement set forth by the Tiger team, Moog recommended a use-as-is disposition for the GMA, which was shipped in September 2002. Moog has continued to work with Stanford University to determine the best ways to mitigate the additional risks associated with the out of tolerance leak rates observed in valves V4/V6 pair, V11, V15, V21, V27, V28, V29 or any other valves that later exhibit this behavior.

The post GMA delivery investigation using spare valves SN007 and SN022 did not result in determination of a root cause or result in any new findings that would change Moog’s belief that the most probable root cause is contamination. However, the post delivery investigation did make the following findings:

- The weld assembly process did result in a temporary increase in leakage rate for SN022 and an order of magnitude shift in leakage performance of SN007 from 1E-07 sccs GHe to 1E-06 sccs GHe and also presented higher leak rate ranging from 1E-05 to 1E-04 sccs GHe. This finding supports a root cause of contamination introduced at the time of integration.
- Variations in Vespel properties may be a contributor to leakage performance. Most notable was the variation in %-elongation of Vespel samples tested. However, test sample geometry may have played a factor in this variation.
- A white residue, identified as aluminum silicate, was found on the poppet of SN007 immediately upstream of the poppet sealing surface. As noted above, this valve also exhibited a shift in leakage performance. This aluminum silicate residue also entrapped particles of aluminum and CRES. The source of this contamination is still unknown. This finding supports the root cause of contamination.

At this point, Moog does not have any reason change the past recommendation for “use-as-is” provided Stanford University implements mitigation efforts to prevent or minimize the effects the excessive leakage from the GMA valves has on regulator lock-up, the downstream science probe and gas purity. Moog will continue to support the mitigation efforts.

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CORRECTIVE ACTION:

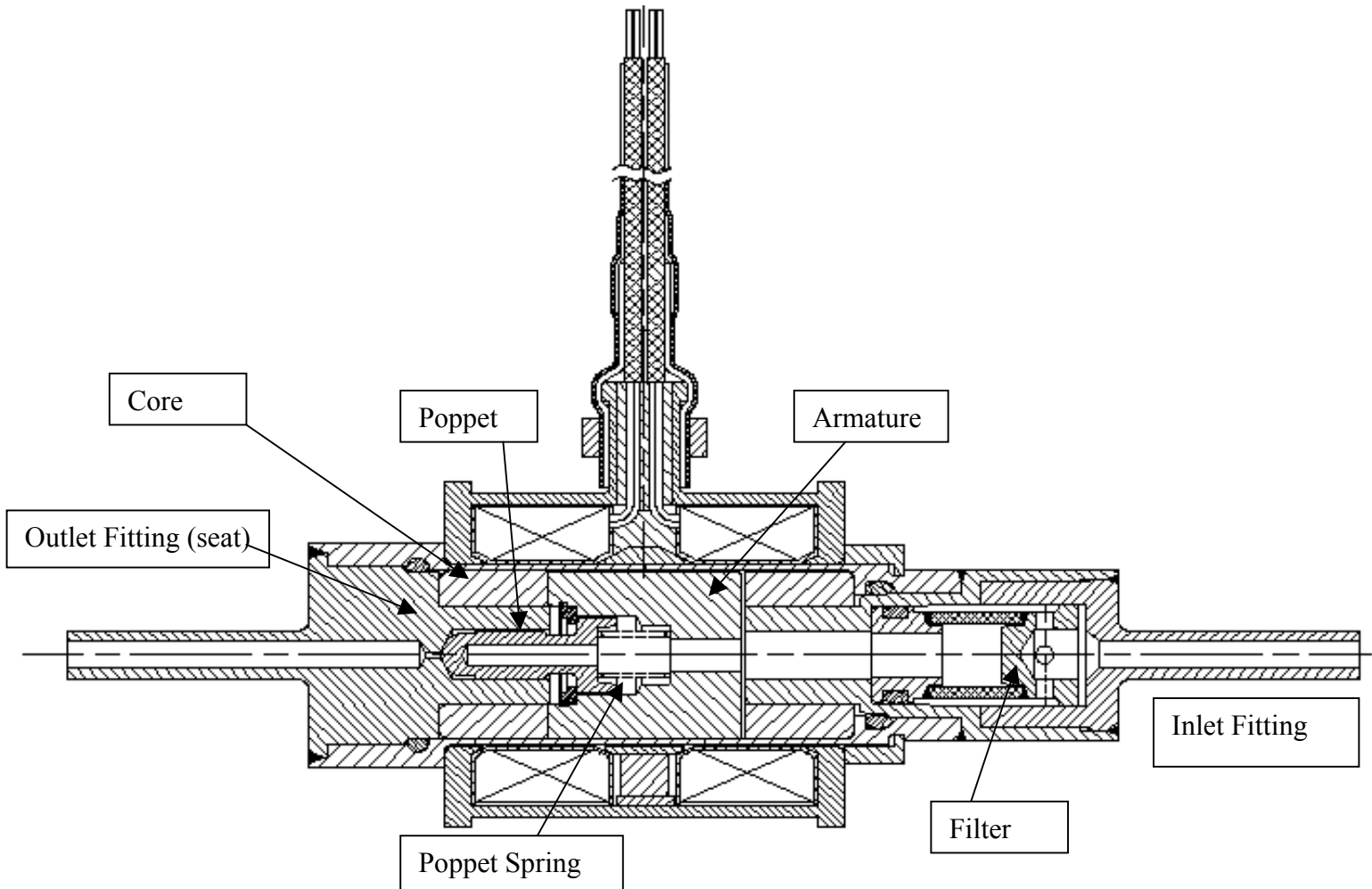
Without a confirmed root cause Moog cannot offer a corrective action for mitigating the latch valve leak rates in excess of 1.0E-04 sccs GHe. The investigations that have been conducted have revealed ways to improve our general processes for building and testing of valves and sub-systems and these will be implemented. These improvements include test methodology and procedure for internal leakage testing of the GMA; proper covering of shielded leads to prevent contamination during assembly and valve cleanliness certification.

DISTRIBUTION:

J. Bowen
J. Bonanno
D. Bushway
D. Finucane
P. King
D. Marten (2)
J. Nayda
K. Neff
B. Vogt
L. Wisher

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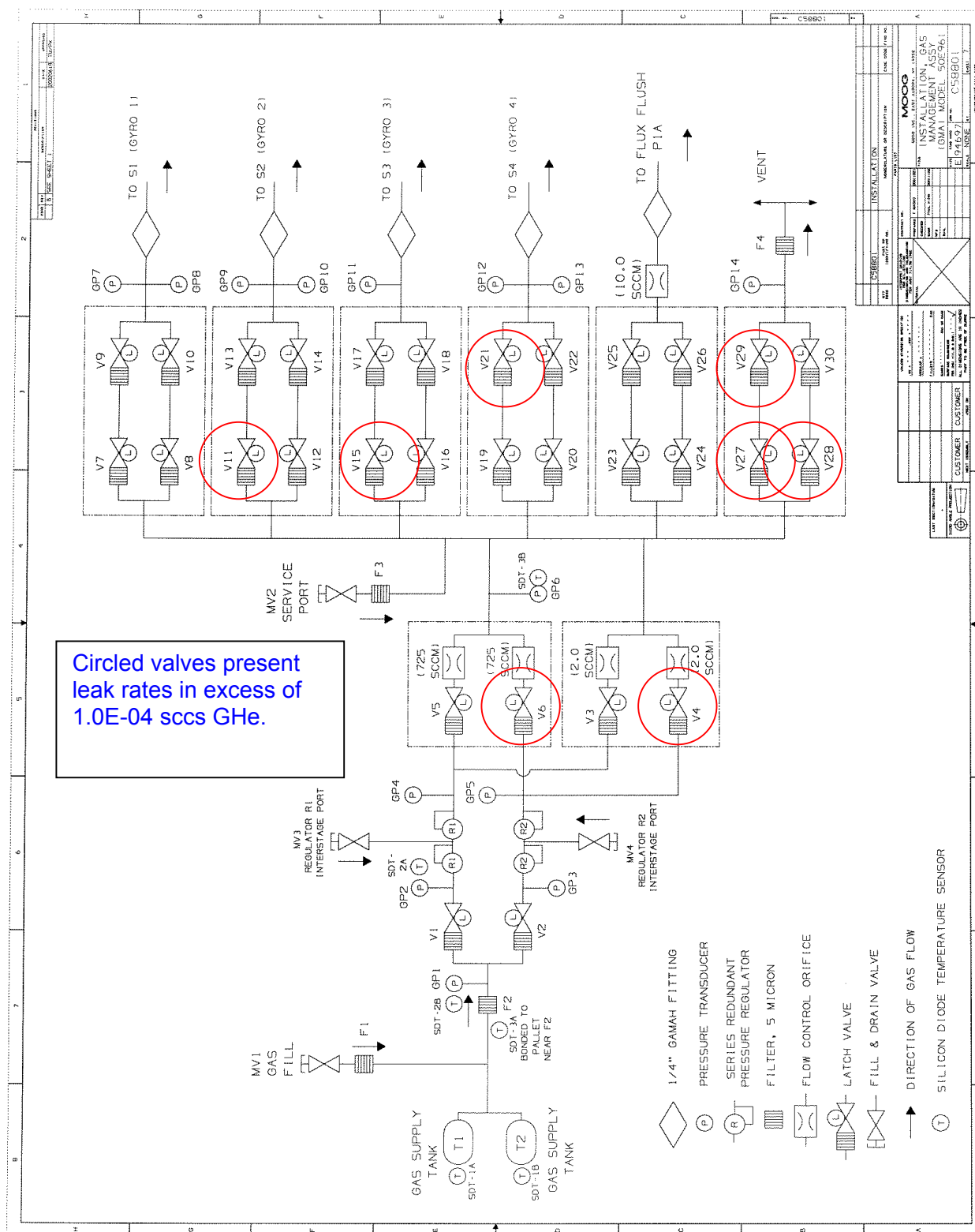
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**GMA: Functional Cross Section of the 51E265
Latch Valve**

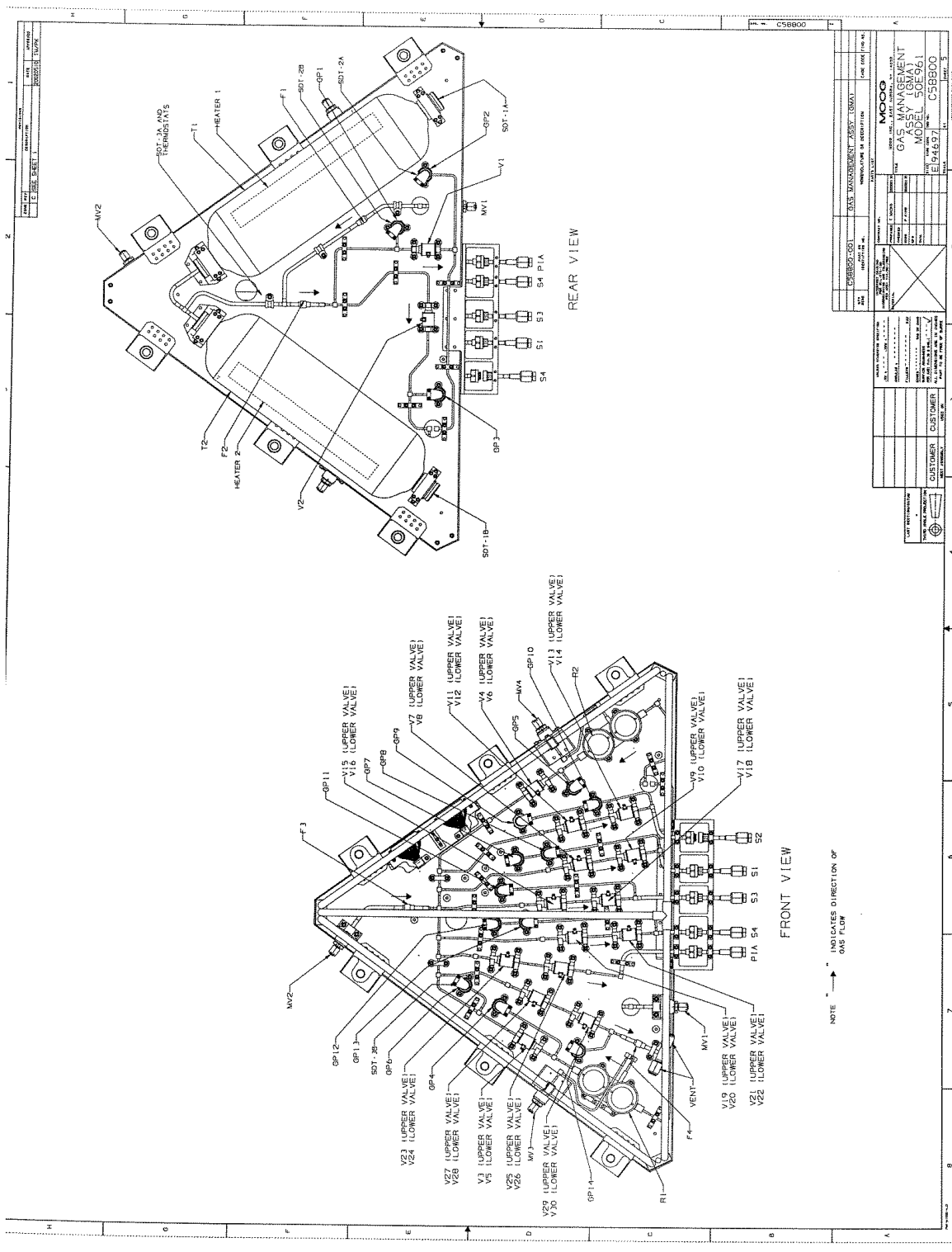
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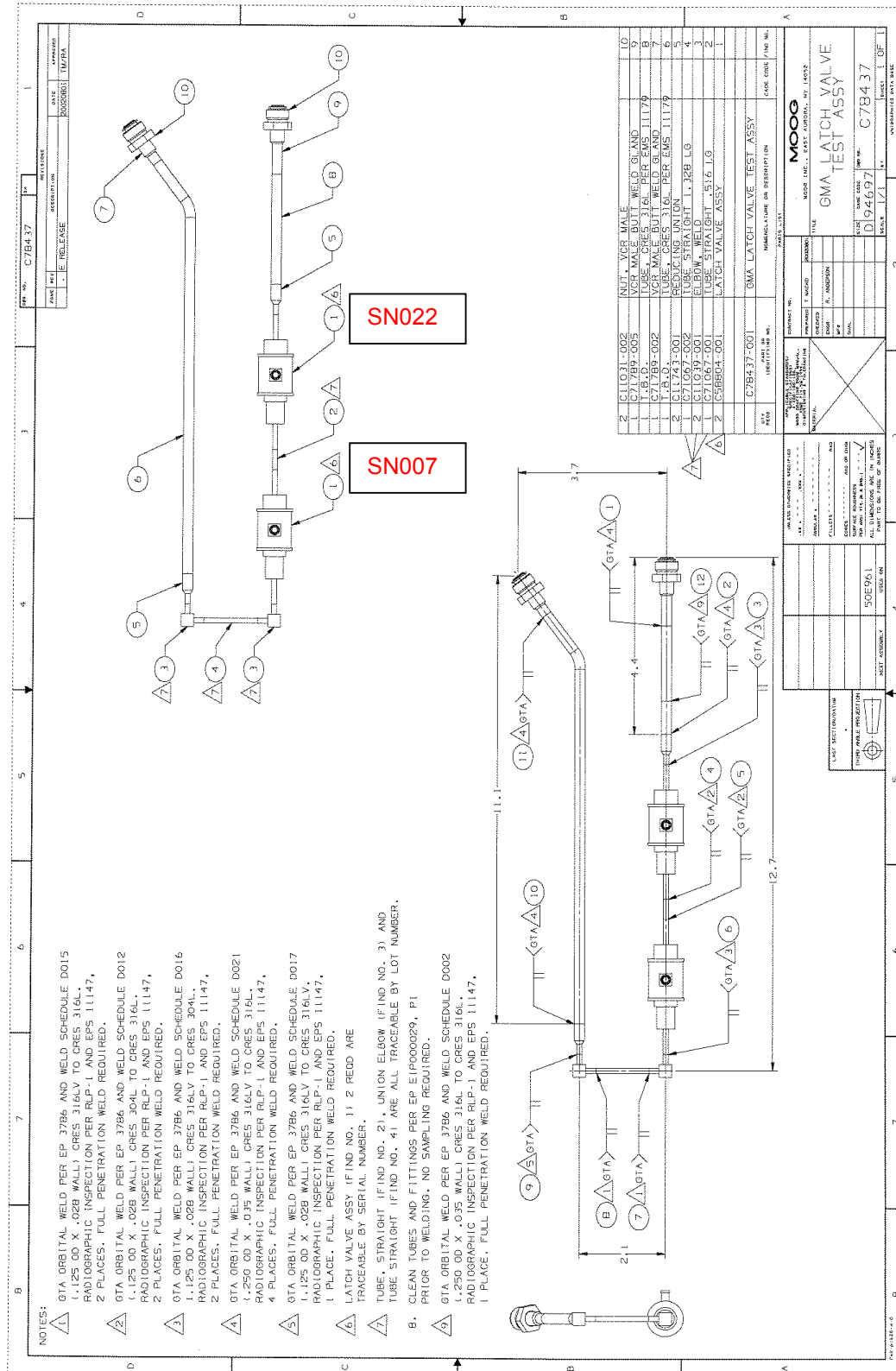
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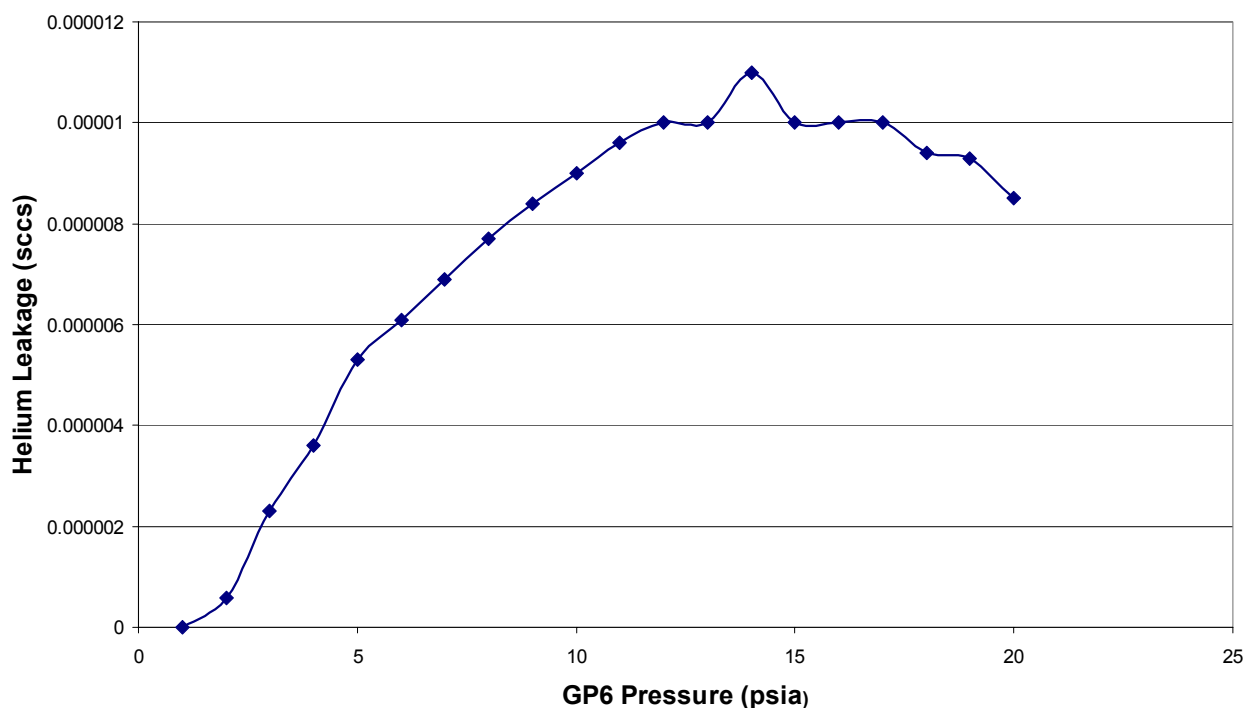


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GMA system internal leakage performance as measured at the outlets of GMA lines S1-S4, P1A and Vent, while the GMA latch valves are configured for launch. The aggregate leak rate of the GMA peaked to a value of 1.1E-05 sccs GHe at 14 psia, which is better than the internal leakage rate required for a single valve.

GMA System Internal Leakage in Flight Configuration
As Tested 7/30/02 at Moog Inc. per AVO50E961RA16



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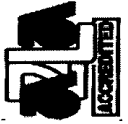
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TENSILE OFFICE

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MATERIAL TESTING LABORATORY
FASTENER TESTING



921-01 & 921-02

CERTIFICATION

Section 1 of 1

WMT&R Report No. 2-31770

P.O. No. 0208120101

WMT&R Quote No. 292247

Packing Slip No. 277039

September 9, 2002

Moog Aircraft Group

Aircraft Group

East Aurora, NY 14052-0018

Attention: Mr. Tim Mascarella

Subject: All processes, performed upon the material as received, were conducted at WMT&R, Inc. in accordance with the WMT&R Quality Assurance Manual, Rev. 9, dated 4/1/2000.
The following tests were performed on this order: TENSILE

UTS = UYS => VESPEL DOES NOT EXHIBIT
A TRUE YIELD POINT

TENSILE RESULTS: D638-01

SPEED OF TESTING: 0.2000 in./min.

MATERIAL: Plastic VespeL SP-1

Sample	Test Log	Temp.	UTS	Breaking	UYS	UYS Strain	Modulus	Util Load	Break Load	UYS	Orig. Dia.	Orig. Area	Machine	Machine	Machine
	Number	F	PSI	Str. PSI	PSI	%	KSI	LBS	LBS	LBS	(in.)	(Sq. In.)	Number	Number	Number
3/8 OD-1	794052	Room	14697.99	14691.76	14697.99	10.650	437.28	707.70	707.40	707.70	0.2476	0.04814943	M9	R	R
3/8 OD-2	794053	Room	12338.10	12338.10	12338.10	5.7260	419.31	610.50	610.50	610.50	0.2510	0.04948087	M9	R	R
3/8 OD-3	794054	Room	14306.54	14298.43	14302.50	8.8430	448.26	707.90	707.40	707.70	0.2510	0.04948087	M9	R	R
3/8 OD-4	794055	Room	14820.49	14814.44	14814.44	11.440	418.30	734.50	734.20	734.20	0.2512	0.04955976	M9	R	R
1/4 OD-1	794056	Room	14031.96	14031.96	12891.07	6.7328	425.88	287.80	287.80	287.80	0.1616	0.02051033	M10	R	R
1/4 OD-2	794057	Room	10615.65	10615.65	10615.65	4.2109	461.25	218.0	218.0	218.0	0.1617	0.02053572	M10	R	R
1/4 OD-3	794058	Room	13254.30	13254.30	13254.30	6.9563	454.76	269.50	269.50	269.50	0.1609	0.02033302	M10	R	R
1/4 OD-4	794059	Room	14664.42	14664.42	14664.42	13.1851	411.94	300.40	300.40	300.40	0.1615	0.02049495	M10	R	R

DISPOSITION: Report

UTS = UYS => VESPEL DOES NOT EXHIBIT
A TRUE YIELD POINT

UTS = UYS => VESPEL DOES NOT EXHIBIT
A TRUE YIELD POINT

① LOT RES25653, BATCH H23004, 3/8" OD
13.3% ELONGATION

② LOT RES26227, BATCH H2861,
1/4" OD, 10.3% ELONGATION

**UNOFFICIAL DATA
NOT APPROVED**

KNOWINGLY OR WILLFULLY FALSIFYING OR CONCEALING A MATERIAL FACT ON THIS FORM
OR MAKING FALSE, FICTITIOUS OR FRAUDULENT STATEMENTS OR REPRESENTATIONS
HEREIN COULD CONSTITUTE A FELONY PUNISHABLE UNDER FEDERAL STATUTES.
THIS CERTIFICATE OR REPORT SHALL NOT BE REPRODUCED EXCEPT IN FULL,
WITHOUT THE WRITTEN APPROVAL OF WMT&R, INC.

[Signature]

Roy E. Stanford A. Stape

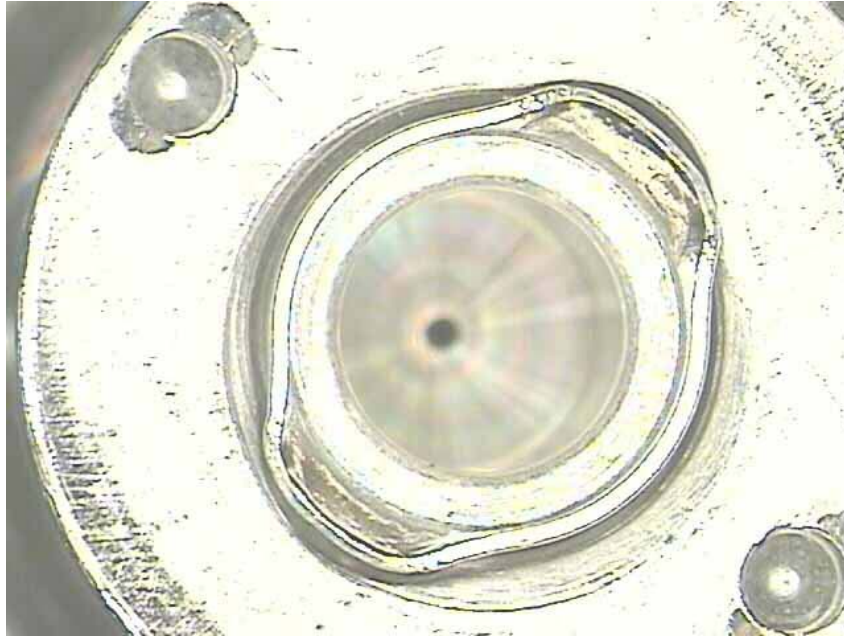
9-9-2

September 9, 2002

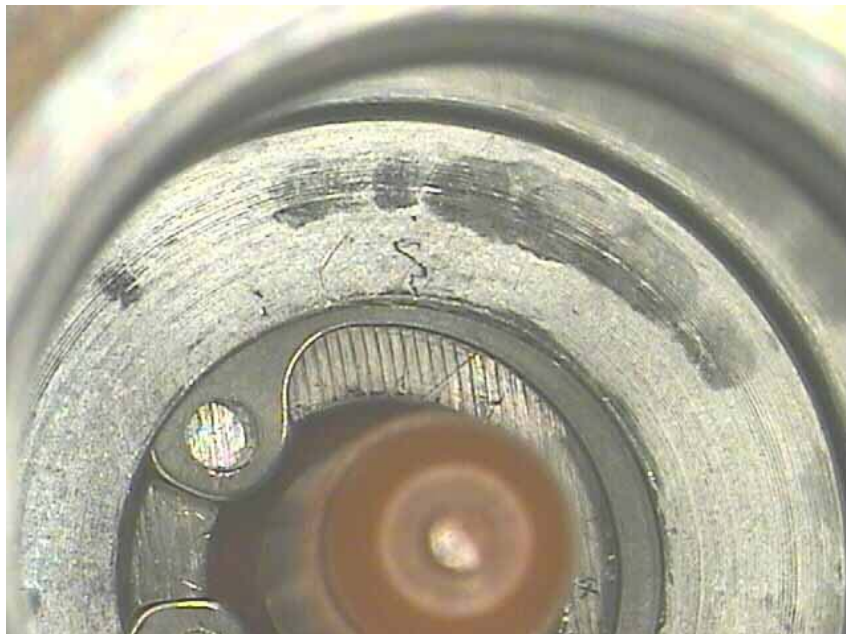
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Photos from 51E265 SN007 Disassembly



51E265 SN007 Outlet Core swaged to outlet fitting

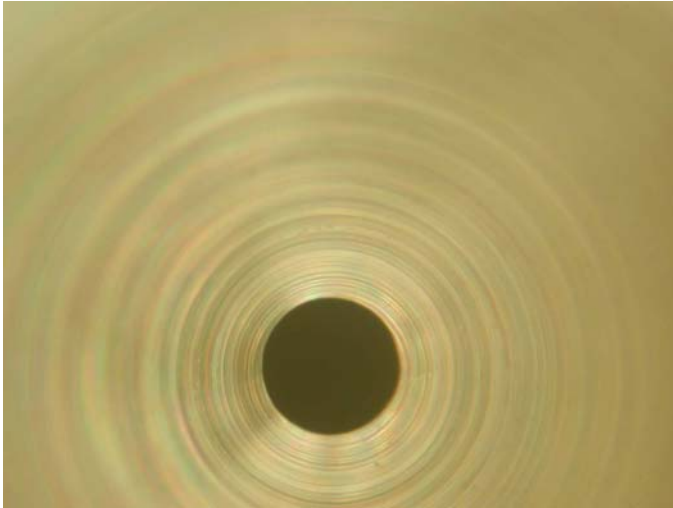


51E265 SN007 Armature Outlet side burnish marks

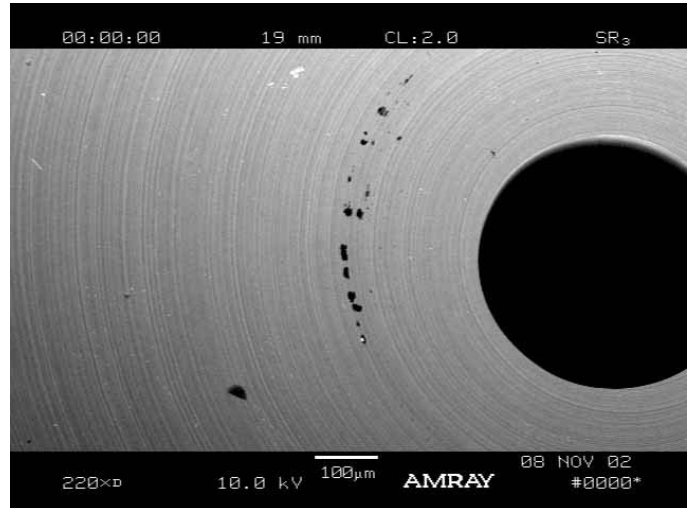
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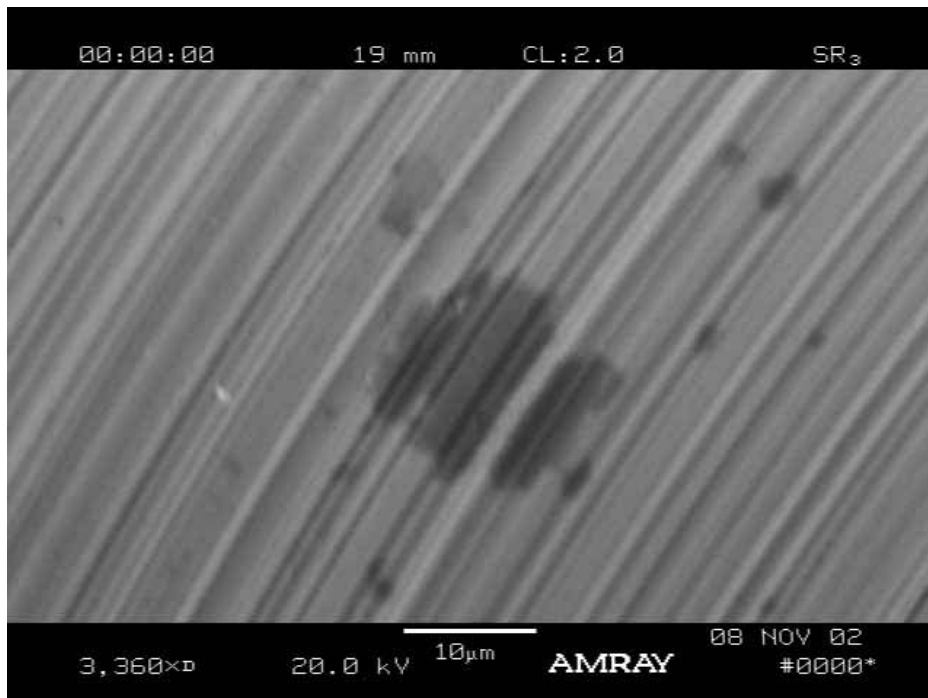
Photos from 51E265 SN007 Disassembly



51E265 SN007 Outlet Fitting Conical Seat with Stains



51E265 SN007 Outlet Fitting Conical Seat Surface Stains viewed with Moog SEM

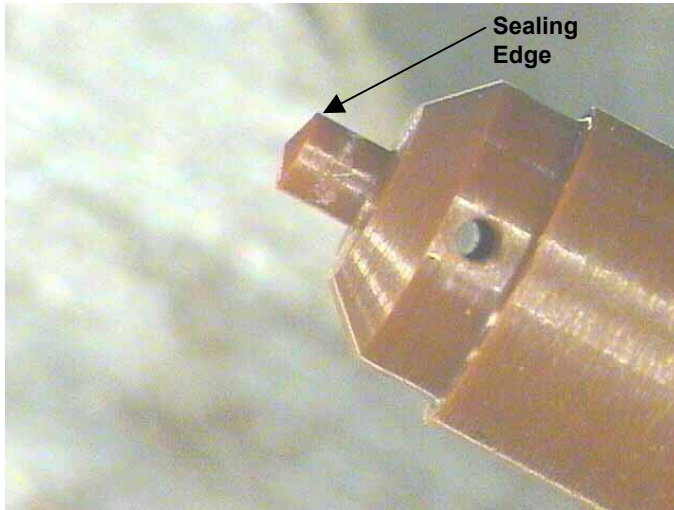


51E265 SN007 Outlet Fitting Conical Seat Surface Stains 2 viewed with Moog SEM

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(CONTINUATION SHEET)

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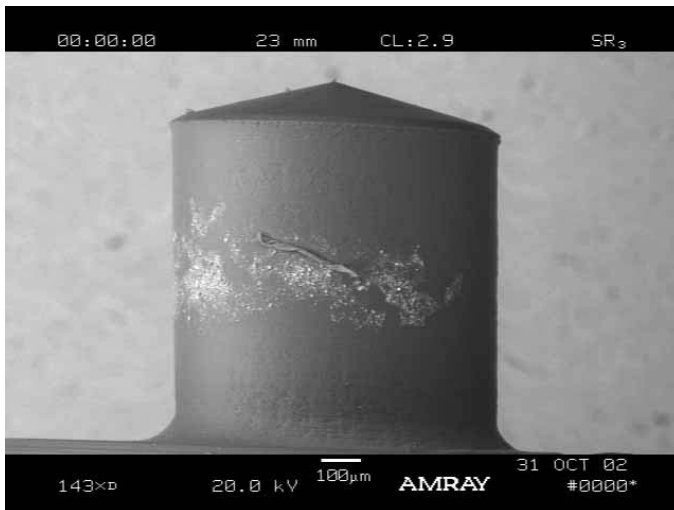
Photos from 51E265 SN007 Disassembly



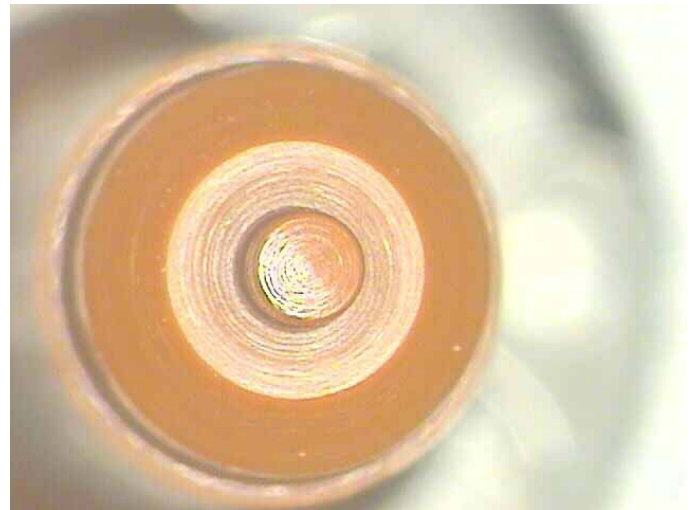
51E265 SN007 Poppet tip showing white residue and flow hole



51E265 SN007 Poppet tip showing white residue (aluminum silicate)



51E265 SN007 Poppet tip viewed with Moog SEM showing white residue and coined sealing edge

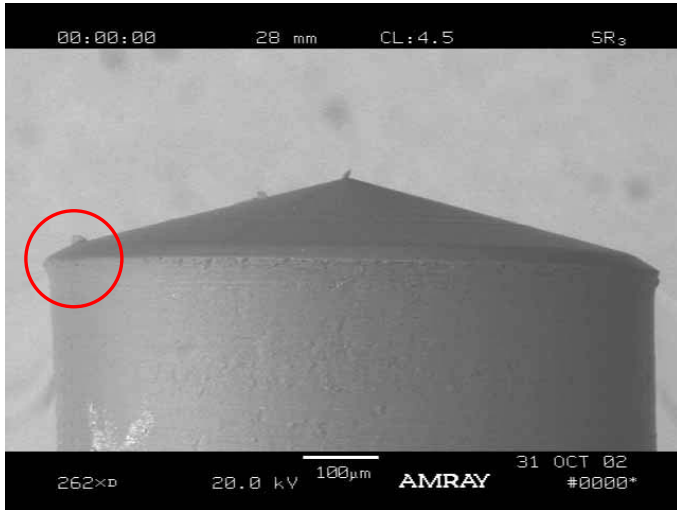


51E265 SN007 Poppet Tip

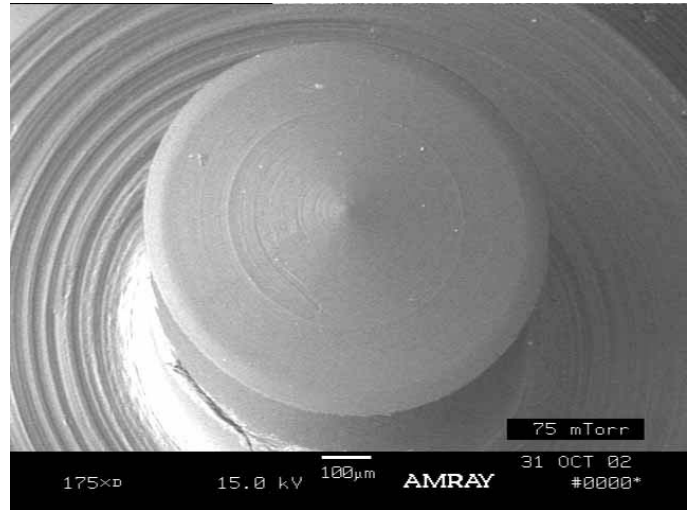
MOOG INC. FAILURE ANALYSIS REPORT
(CONTINUATION SHEET)

P/N: C58800	S/N: 001	CUSTOMER: Stanford University	FAR NO. FAR(M)-2002-063 Rev A

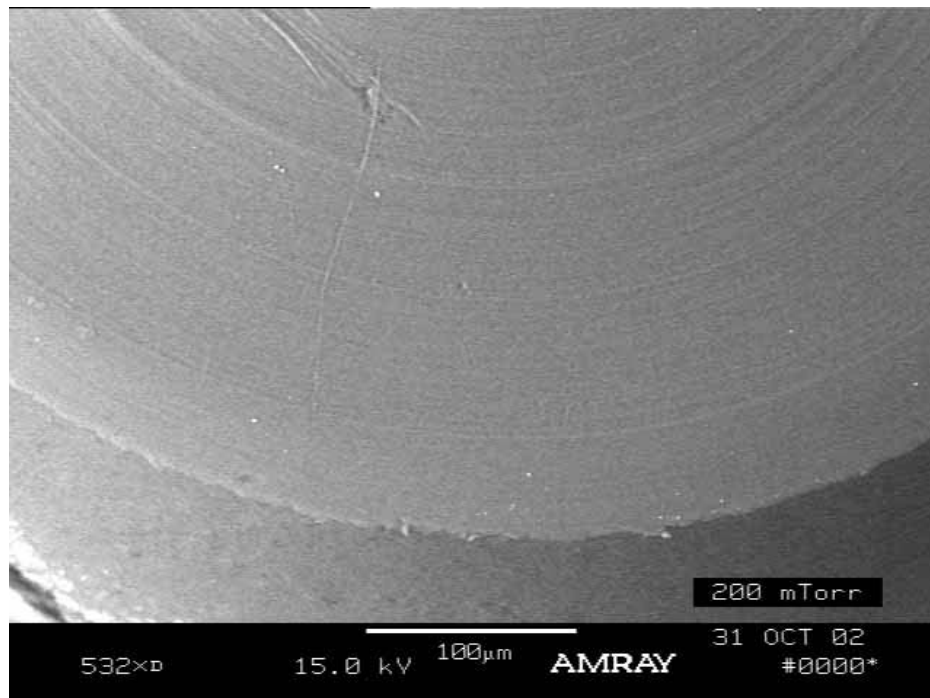
Photos from 51E265 SN007 Disassembly



51E265 SN007 Poppet tip viewed with Moog SEM shows coined edge



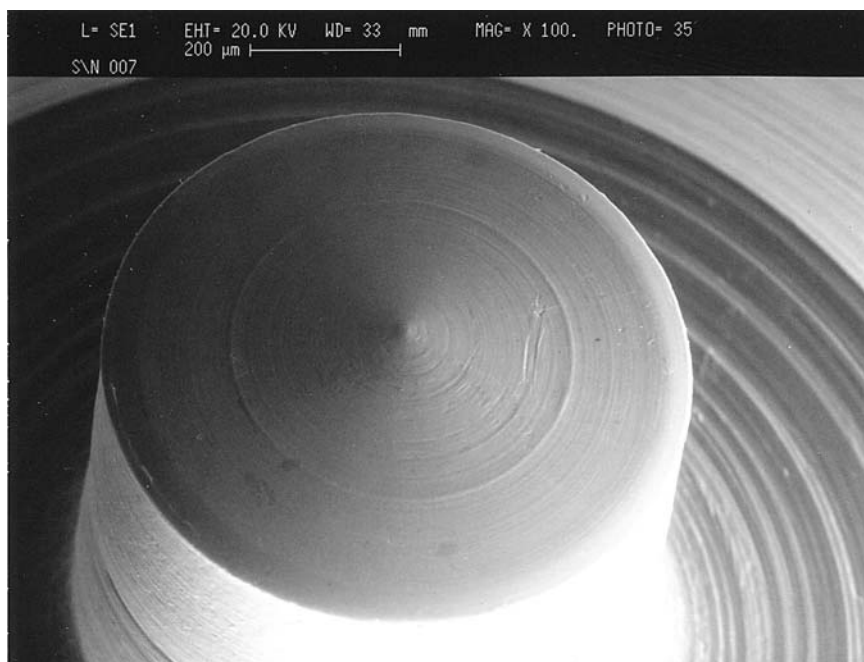
51E265 SN007 Poppet tip viewed with Moog SEM shows coined surface



51E265 SN007 Poppet tip viewed with Moog SEM shows coined edge

MOOG INC. FAILURE ANALYSIS REPORT
(CONTINUATION SHEET)

P/N: C58800	S/N: 001	CUSTOMER: Stanford University	FAR NO. FAR(M)-2002-063 Rev A



51E265 SN007 Poppet tip viewed with Lockheed Martin SEM



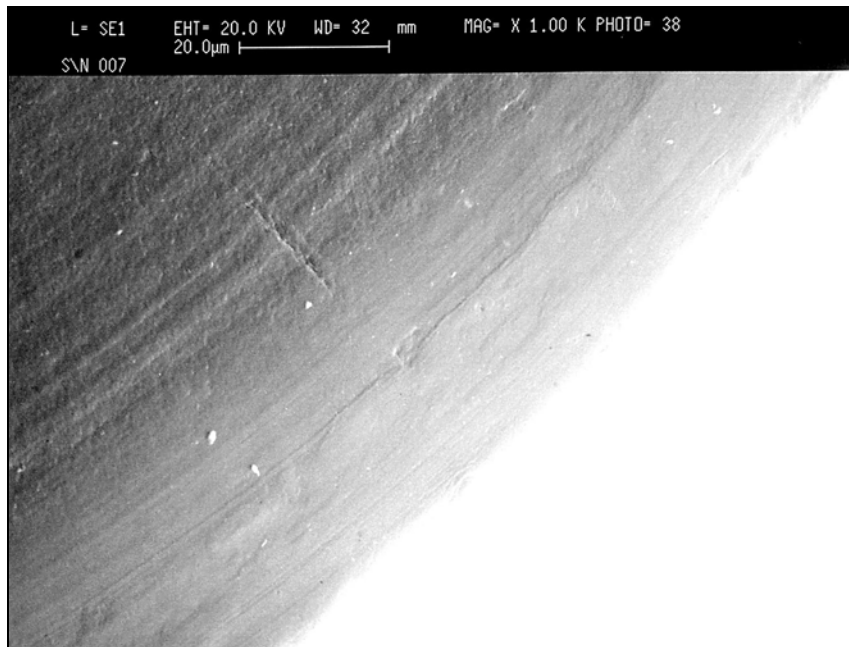
51E265 SN007 Poppet sealing surface viewed with Lockheed Martin SEM. Note scratches.

MOOG INC. FAILURE ANALYSIS REPORT
(CONTINUATION SHEET)

P/N: C58800	S/N: 001	CUSTOMER: Stanford University	FAR NO. FAR(M)-2002-063 Rev A



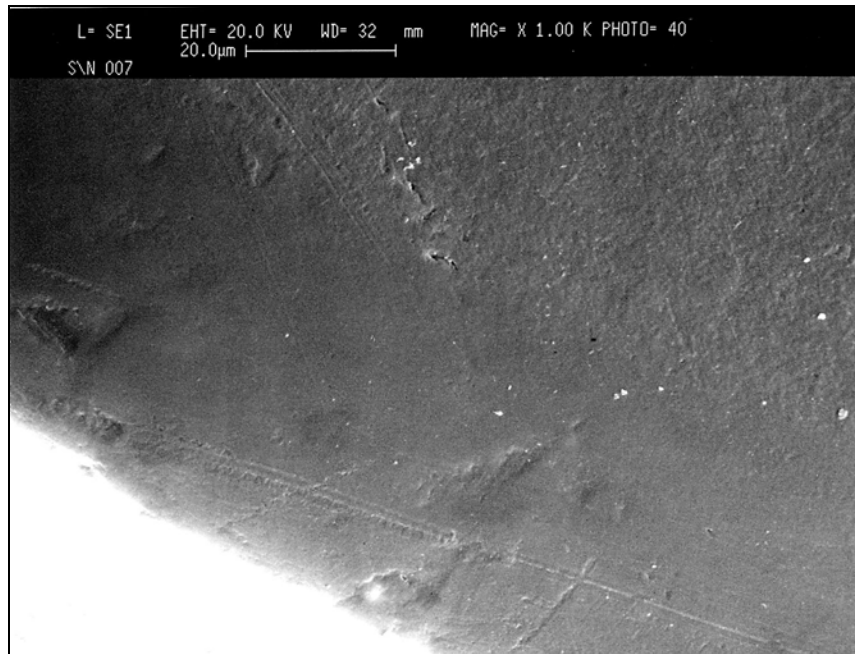
51E265 SN007 Poppet sealing surface viewed with Lockheed Martin SEM. Note burr near sealing edge.



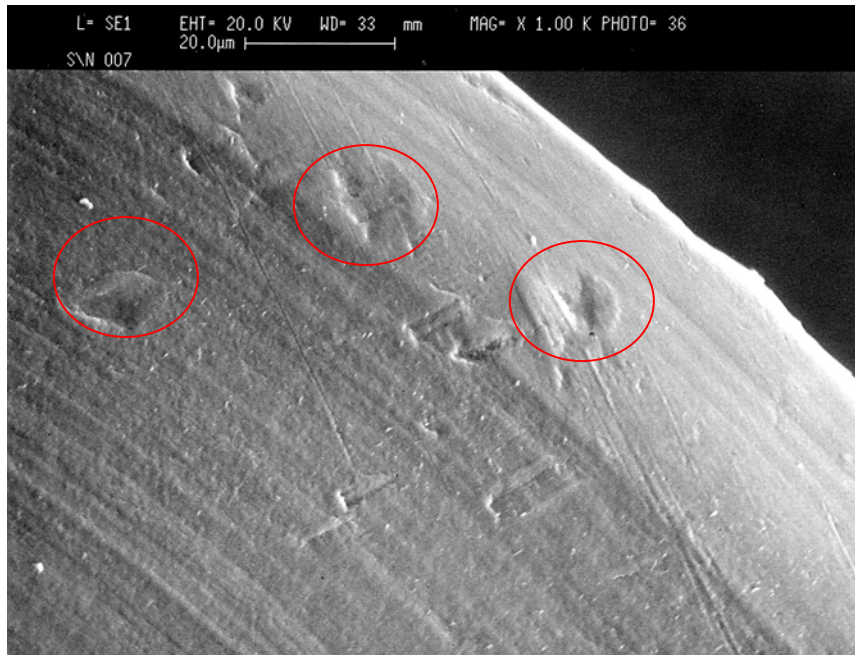
51E265 SN007 Poppet sealing surface viewed with Lockheed Martin SEM. Note localized high and low spots.

MOOG INC. FAILURE ANALYSIS REPORT
(CONTINUATION SHEET)

P/N: C58800	S/N: 001	CUSTOMER: Stanford University	FAR NO. FAR(M)-2002-063 Rev A



51E265 SN007 Poppet sealing surface viewed with Lockheed Martin SEM. Note localized high and low spots.

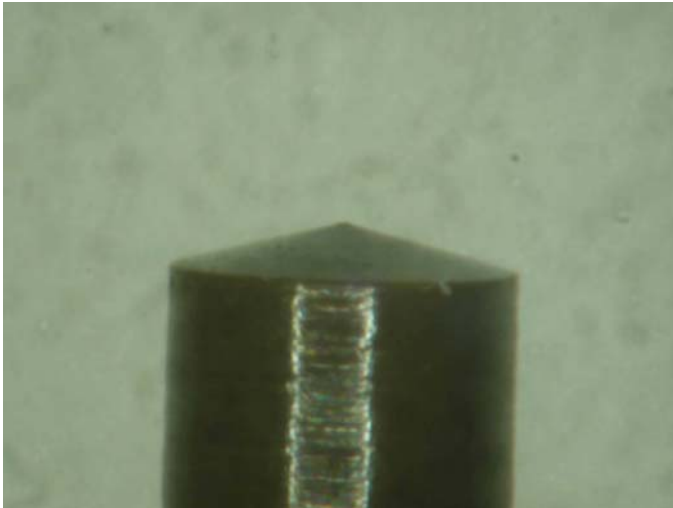


51E265 SN007 Poppet sealing surface viewed with Lockheed Martin SEM. Note localized high and low spots

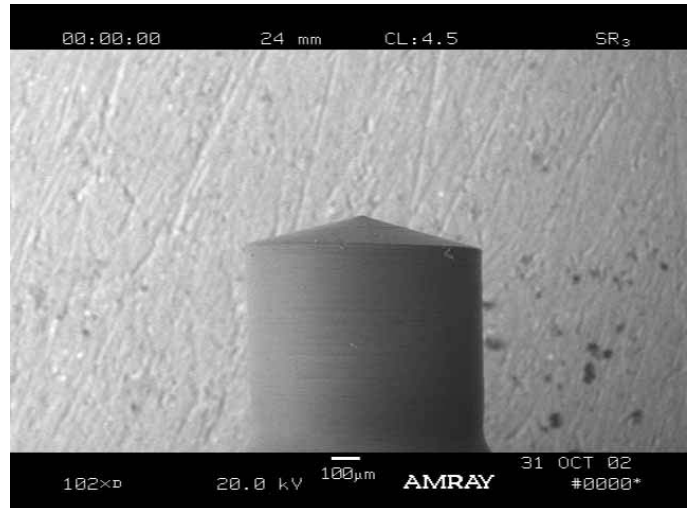
MOOG INC. FAILURE ANALYSIS REPORT
(CONTINUATION SHEET)

P/N: C58800	S/N: 001	CUSTOMER: Stanford University	FAR NO. FAR(M)-2002-063 Rev A

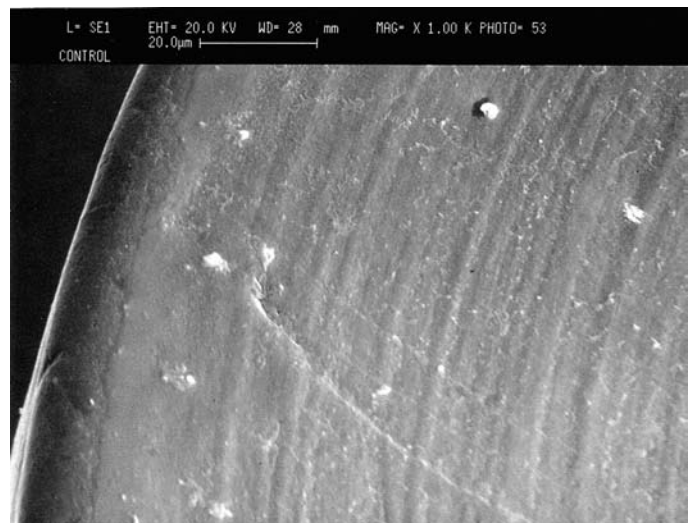
Photos from 51E265 Unused Poppet



51E265 SN007 As Machined Poppet tip – Poppet Never Installed



51E2657 Poppet sealing surface viewed with Lockheed Martin SEM. Poppet never installed.



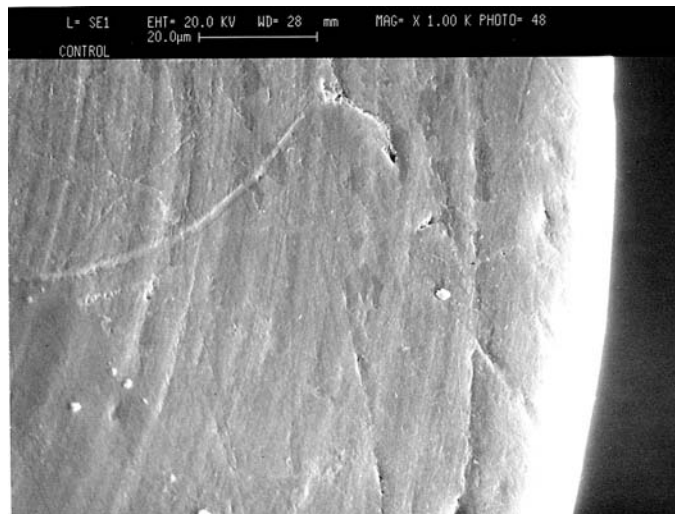
51E265 Poppet sealing surface viewed with Lockheed Martin SEM. Note localized high and low spots and scratches. Poppet never installed.

MOOG INC. FAILURE ANALYSIS REPORT
(CONTINUATION SHEET)

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51E265 Poppet sealing surface viewed with Lockheed Martin SEM. Note localized high and low spots and scratches. Poppet never installed.

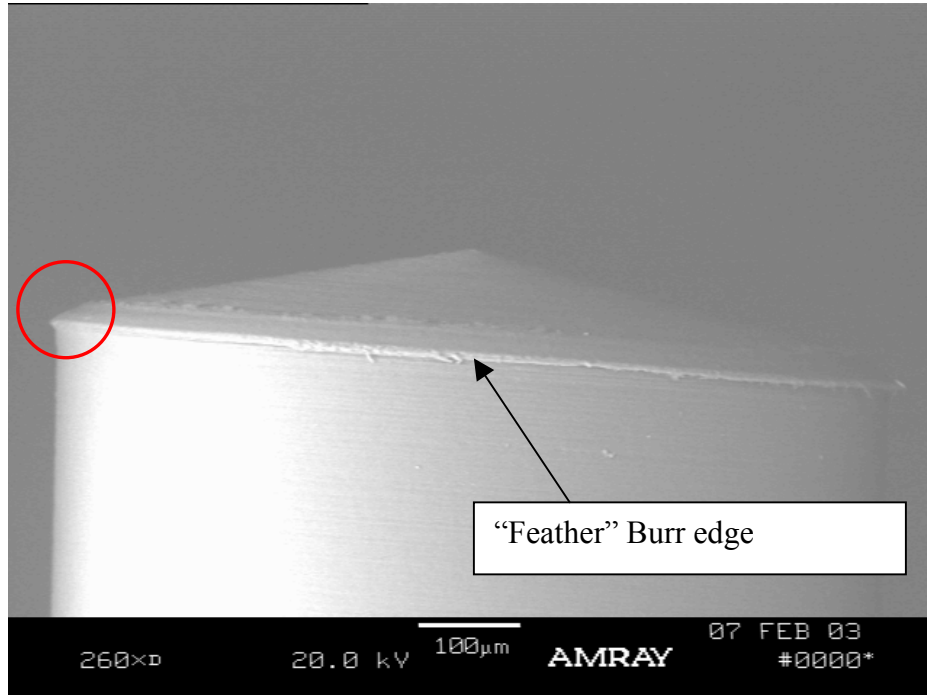


51E265 Poppet sealing surface viewed with Lockheed Martin SEM. Note localized high and low spots and scratches. Poppet never installed.

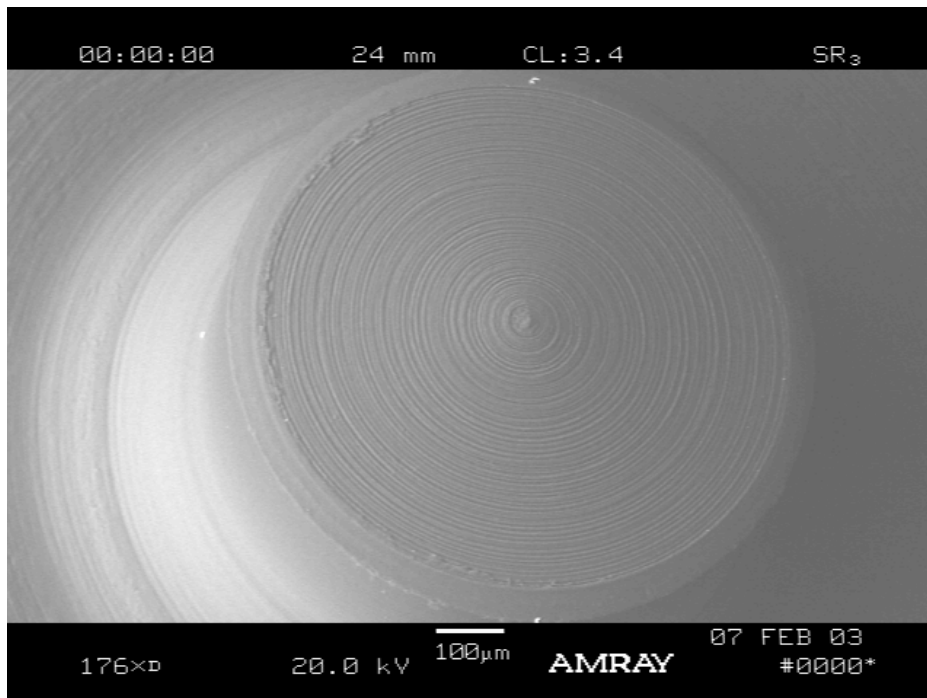
MOOG INC. FAILURE ANALYSIS REPORT
(CONTINUATION SHEET)

P/N: C58800	S/N: 001	CUSTOMER: Stanford University	FAR NO. FAR(M)-2002-063 Rev A

SN022 Poppet



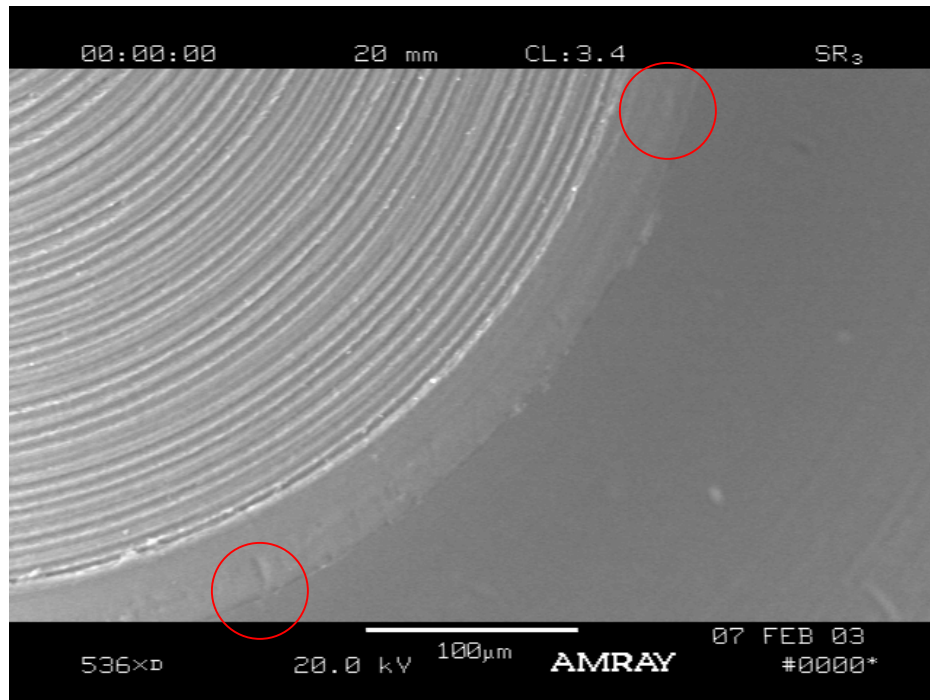
51E265 SN022 Poppet tip viewed with Moog SEM shows coined edge



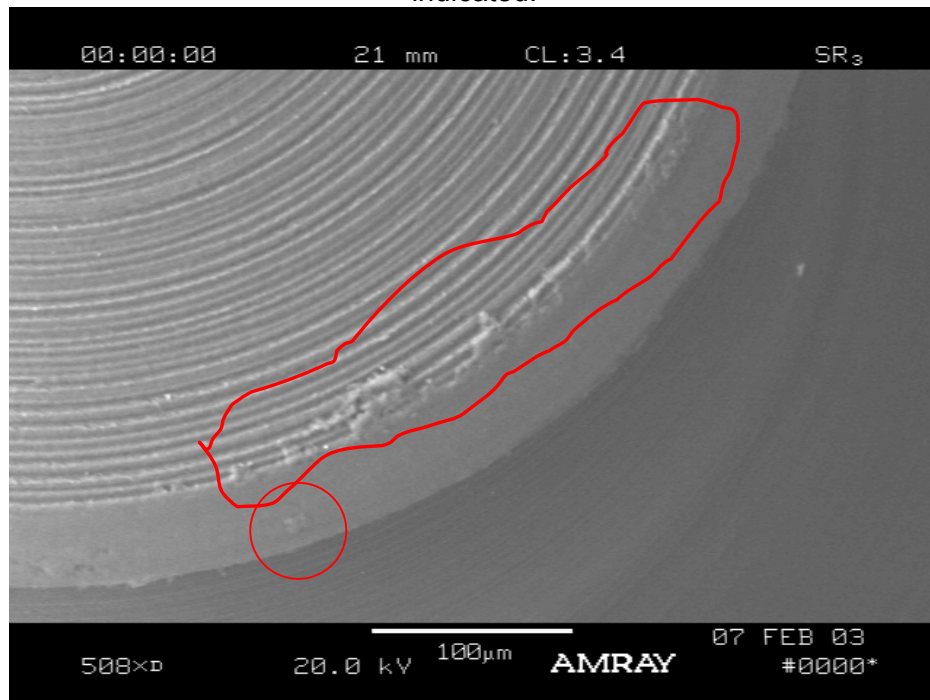
51E265 SN022 Poppet tip viewed with Moog SEM shows coined edge

MOOG INC. FAILURE ANALYSIS REPORT
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P/N: C58800	S/N: 001	CUSTOMER: Stanford University	FAR NO. FAR(M)-2002-063 Rev A



51E265 SN022 Poppet sealing edge as viewed with Moog SEM. Some surface defects are visible as indicated.



51E265 SN022 Poppet sealing edge as viewed with Moog SEM. Some surface defects are visible. Also inner coining edge is not as uniform as SN007 poppet

Since the Stanford DR database only allows one attachment, a number of files have been compiled into one attachment (DR439Attach.pdf)

file: **Valve Leakage and Root Causes.doc** starts on next page

(Moog Tests and Fault Tree)

Moog Latch Valve Tiger Team Report

July 30, 2002

This documents the current state of the technical investigation which is on going (10/6/02) to isolate the root cause of the failure.
arise.

WORKING FAULT TREE

(Shaded = Closed)

Item	Assessment	Assigned to Test	Result of Test	Status
Contamination				
CONTAMINATION DURING WELD SET-UP (BRAIDED SHIELD)	C/P	6,12		
WELD/ASSEMBLY DEBRIS	C/NL	6,12		
SELF GENERATED	C/P *	1		Status 7/30/02: Observed particulates in 1 of 2 latch valves after vibration means this is still open. Note that the observed particles could have been due to GSE. Needs more work to close.
OTHER COMPONENTS (TANKS, TRANSDUCERS, FLOW ORIFICE)	C/P	4		
FILTER SHEDDING	NC (Cert.)	N/A	CLOSED	N/A (Not Credible failure mode)
FLOW OUTPUT LEADS TO POPPET EROSION	NC	N/A	CLOSED	N/A (Not Credible failure mode)
Valve Design / Process (D = Design, P = Process)				
VIBRATION (D) Qual program was with valves closed, most failed valves were open for vibration)	C/P	1	CLOSED BY TEST Passed test. We consider that the design is qualified to fly.	CLOSED 7/29/02
POPPET MATERIAL (D) (V4 has poppet material that has known problems, but other valves have been retrofitted with appropriate material)	C/L for V4 C/P all others	13,14		Status 7/30/02: Renewed investigation into this issue has resulted in the group establishing that this is a possible issue for all poppets. Tests 13 and 14 were developed for establish whether this is cause of the anomaly.

Item	Assessment	Assigned to Test	Result of Test	Status
INSUFFICIENT LATCH FORCE (D/P) - magnet orientation - loose magnet - insufficient poppet preload	NC	N/A	CLOSED	N/A (Not Credible failure mode)
DIMENSIONAL (P)	C/P	8	Completed audit of build paperwork. No correlation found. Note: standard variations in process or dimensions may contribute to variations in leakage rate.	CLOSED
LOT VARIATION (P)	C/P	8	Completed audit of build paperwork. No correlation found. Note: standard variations in process or dimensions may contribute to variations in leakage rate	CLOSED
ASSEMBLY VARIATION (P) - swage operations - damaged parts -- outlet fittings	C/P	8	Completed audit of build paperwork. No correlation found. Note: standard variations in process or dimensions may still contribute to variations in leakage rate	CLOSED
IMPROPER SWAGE OF CORE (P)	NC	N/A	CLOSED	N/A (Not Credible failure mode)
MECHANICAL DEFORMATION OF OUTLET FITTING DUE TO GMA ASSEMBLY OPERATIONS (added 7/29/02)	NC	N/A	CLOSED	N/A (Not Credible failure mode)

Item	Assessment	Assigned to Test	Result of Test	Status
STATIC CHARGED POPPET ATTRACTING EXISTING CONTAMINATION (added 7/29/02)	P,NL	N/A	CLOSED	CLOSED. This is really just a subset of other contamination items. It is merely a mechanism whereby contamination, if it exists, is more likely to migrate to the poppet seat. It is not, however, the source of the contamination
WELD REPAIR	C/L	N/A	CLOSED	CLOSED. Detail review of this process indicates that there is very little opportunity for additional particles because of this operation. Although it it may have introduced additional opportunities for contamination, it is closed to the more general contamination due to welding node in this tree.
VALVE DESIGN PERFORMANCE IS NOT 1E-6 * New 7/29/02	C/P	15	There are definitely indications that valve performance after system integration can be 1e-4. One previous program (w/ aprox. 20% the number of valves as the GMA) had a similar percentage of valves in the 1e-4 range after system vibration (in spec for that program). Valves went on to perform nominally.	OPEN.
KEY CHARACTERISTICS VS. SERIAL NUMBER – preload – latching force – stroke (arm-poppet)	C/P	8	CLOSED	CLOSED. For all parameters investigated (see Test #8), no correlation was found to the failed valves.

Item	Assessment	Assigned to Test	Result of Test	Status
Testing Procedure				
TRAPPED GAS *	C/P	2,10	CLOSED BY TEST	N/A
GDS	C/P	2,10	CLOSED BY TEST	N/A
VALVE SEQUENCE *	C/P	2,10	CLOSED BY TEST	N/A
IMPLEMENTATION	C/P	2,10	CLOSED BY TEST	N/A
LOW VOLTAGE ACTUATION	C/P			
MASS SPECTROMETER USAGE *	C/P	2,10	CLOSED BY TEST	N/A
MASS SPECTROMETER CALIBRATION *	C/P	2,10	CLOSED BY TEST	N/A
EXTERNAL TO INTERNAL LEAK *	C/P	2,10	CLOSED BY TEST	N/A
FLOW METER LEAKAGE RESIDUAL	C/P	2	CLOSED BY TEST	N/A
TURBO PUMP *	C/P	2,10	CLOSED BY TEST	N/A
VIBRATION LEVEL ON VALVES	C/P	1		Status 7/30/02 Need further analysis of vibration data obtained during latch valve vibration.
TRAPPED GAS, MOTT SPECIFIC *	C/P		CLOSED BY TEST	N/A
VIBRATION SETS POPPET OFF CENTER	C/NL	1	CLOSED BY TEST	N/A
WELD TECH. VS. CONFIGURATION	C/NL			Status 7/30/02 Still under investigation.
TEST ORDER: 2000 – 20 PSIA, THEN 20 PSIA (do you need 2000 psi to seat it properly?)	C/P	9,1	CLOSED BY TEST	Status 7/30/02 Combination of Tests 9 and 1 exposed valves to suspect operations, and valve sealing performance remained nominal.
HIGH BACKGROUND *	C/P	2,10	ITEM CLOSED	N/A

Assessment Categories:
Credible (C) or Not Credible (NC) /
Likely (L), Possible (P), Not Likely (NL)
* = Test operator dependent

TEST MATRIX

(Shaded = closed)

Test	Expected Results	Test Hardware	Schedule	Results (if complete)
1. Vibration of two spare flight valves in double deck configuration to GMA protoqual level of 11.1 grms (GMA has fixtures which stack two valves on top of each other, but valves were qualified in single configuration).	- Instrument for accel - Effect on leak - Leak -> Vib -> Leak -> Cleanliness Check - Leak @ 20 psi - 1 data point before - 5 data points after each vibration (Possibly vib two more of the flight spares pending the results)	SN7 + 22 Vib table Vib fixture Need valves certified clean prior to start	Morning plus one shift (Sat a.m.)	Status 7/27/02 The vibration test was completed on 7/27/02. The two valves used for the 500 cycle test (S/N 7 and S/N 22) were shook to 11.1 grms (input) for 1 minute each axis. After each shake, the valves were cycled 5 times with the leakage rate measured at each cycle. Results: The valves consistently performed in the low 10^{-7} to high 10^{-8} sccs range. No degradation in leakage rate has been observed as a result in the 500 cycles/random vibration combined test. However, note that the “top” valve in the pair saw a very high acceleration (~41 grms) due to a resonance in the structure near 1 kHz. For the flight GMA, this would have been mitigated by the presence of the rigid plumbing between the valves. However, it may have been exacerbated by the fact that some of the output valves are connected to the output bracket, which experienced a known very high g-load in random vib. However, the general consensus of the group is that the test performed on the spare valves today should be a “worst-case” test, and no degradation was seen. Status 7/30/02: First flush on lower valve (S/N 7) was discrepant (300 100 micron particles). On second flush it passed. Second one passed on first go around. ONGOING. The high g-loads of the top valve need to be further investigated
2. Cal leak with GDS attached 2.5e-6	- Does GDS add to known leak rate - All GMA valves closed - Pull from GMA outlet through GDS	Cal Leak GDS Mass spectrometer GMA	Sat a.m.	Status 7/27/02 This test was performed as part of the ATP review and run through on Saturday. The results were as expected, and indicated that the GDS was not contributing to an error in the measurement of GMA leakage rates. COMPLETE

Test	Expected Results	Test Hardware	Schedule	Results (if complete)
3. Bubble test V21	- Feel good to verify mass spectrometer data Would need to break into system N2 or He?	GMA Bubble test apparatus	TABLED	Status 7/27/02 The days activities have resulted in increased confidence by the group that the results being measured are real. This makes the “bubble test” much less valuable, and there is no plan to perform it soon.
4. Contamination from Moots flow orifice in Vib?	Does vibration release contamination from moots? Cleanliness Verification -> Vibration -> Cleanliness Verification Perform as part of Latch Valve vibration	Motts Vib fixture Vib table	Sat Morning	Status 7/27/02 Random vibration test was performed. Cleanliness verification will be witnessed by DeWitt Burns and will be complete Monday 7/29/02. ONGOING. Expect closure Tuesday 7/30/02 with completion of cleanliness verification.
4a. Contamination from Pressure Transducer	- Shake spare pressure transducer and examine cleanliness of container	Vibration hardware, spare pressure transducer	TBD	Status 7/30/02 Start effort to prepare for this, but it is unlikely results we come in this week. This test is a lower priority than 6, 12, 13, and 14.
5. Valve contamination (intentional) w/ weld debris	Is weld susceptible to debris generated by weld? -> Sacrificial valve	Requires a non-flight valve	TABLED	This requires sacrificing a flight backup or flight-like valve. These are in very limited supply, and the group feels right now they should be saved for other applications. COMPLETE (TABLED).
6. Weld sample (preps for potential valve replacement) - cut existing tube assembly w/ tube cutter, debur edge, reweld - Demonstrates valve removal & reweld - Allows cleanliness check of weld process - Test Hardware: tube assembly, tubing cutter, TIG welder	Data to contribute to certification of valve replacement process (should this be necessary)	Misc. spare hardware	TBD	IN PROCESS Status 7/30/02: Preparations for this work are still in process.

Test	Expected Results	Test Hardware	Schedule	Results (if complete)
7. Interview Kevin Neff about valve lead braided shield handling during weld - Covers orbital tube welds (used for GMA integration)	- Get an idea of whether the welding process is likely to have introduced contamination into the valves.	None	Monday July 29	Status 7/27/02: Interview with Kevin Neff scheduled Monday 7/29 a.m. Status 7/30/02: Establish bagging order and welding order. Note that vent quad was the first welded, increasing the probability that the leads were still bagged. At this point, we know there was a change in the weld process at some point to correct for the exposed particulating shield, but we don't know exactly when that happened. There is a high probability that the vent quad (which has the highest anomaly rate) was welded before the fix in the process was implemented. COMPLETE
8. Build Paperwork Review	Latching Force (OP 150) Preload Poppet (OP 180) Pull-in Voltage open/close (OP 460) Cleanliness Verif (Op 480) Armature stroke (Op 210) Poppet Stroke (OP 220) Vs. Serial #	None	By Monday	Status 7/27/02 The review has been completed by Dan Balon ahead of schedule. He presented the results in matrix form to the group. No significant issues were seen in the build paperwork that differentiates the valves with high leakage rates from others. One of the failing valves did have particle counts a factor of 2 higher than the others, but they were still in spec, and the size of the particles was less than could interfere with the sealing process. Finally, some of the discrepant valves had very low particle counts, so that no correlation could be found. Note that Dan Balon will enter the results into a table on his computer on Monday for distribution to interested parties. COMPLETE. However, review of build paperwork is expected to remain an on-going process through the investigation as required.

Test	Expected Results	Test Hardware	Schedule	Results (if complete)
9. 500 cycle test Cycle two of the spare flight valves 500 times each, with periodic leakage checks to see if valves have a tendency to degrade with cycles.	- Measure variation in leakage as a function of # of cycles. - Measure contamination as a result of cycles		Complete 7/24/02	Status 7/27/02: <u>SN#7</u> Cycled with leak check at 0, 10, 15, 25, 100, 150, 200, 250 300, 350, 400, 450, 500. At cycle 0 cleanliness failed, checked with new process. Failed with new process at 25-50 micron range. <u>SN#22</u> New cleanliness process -> passed 500 cycles passed leakage failed cleanliness after cycling -- hookup debris -- self generating -- packing material (found some debris visually clearly looks like packing material) Status: COMPLETE

Test	Expected Results	Test Hardware	Schedule	Results (if complete)
10. ATP Review / Walkthrough of valve leakage rate measuring process	“Are we measuring what we think we are?” - Trapped gas - valve sequence - Procedure implementation - mass spec usage - mass spec calibration - high background - inadequate vacuum - residual leakage in flow meter, turbo pump, etc. - steady state vs. transient	GMA, GDS, and all other standard GMA test equipment.	Sat Morning 7/27/02	Status: 7/27/02 The group has not found anything in the test sequence for the valves which could yield significantly elevated leakage rates. However, Moog did identify a mechanism in the current procedure which could result in slightly elevated leakage rates. A modification to the test procedure was incorporated into the Saturday test to keep this from occurring. The test resulted in some improvement for the valves that were “in-spec”, i.e. many of the valves tested in the 10^{-7} sccs range. Several valves that had previously tested bad (e.g. V11 and V15) were in spec. Some others (e.g. V4/V6 and V21) still performed in the 10^{-7} range. Finally, one valve on the GMA vent to space (V30) which had never previously shown a problem now tests out of spec. This means that all 4 valves in the GMA vent quad have at some point displayed high leakage. Note that this quad is not mission critical, and in principle it can be capped on the pad so as to avoid air incursion into the GMA. If this choice were taken, then conceivably other valves in the GMA could be double strapped to ECU valve drivers so as that the same valve could be operated off of the A or B-side ECU. This could be used, for example, to regain some system redundancy if we decide to fly the GMA with all valves closed. Note that the results as indicated at this time are preliminary, and a complete data review needs to be performed. They will be confirmed in the 7/29 status report. STATUS: Complete. Data Review has been completed.

Test	Expected Results	Test Hardware	Schedule	Results (if complete)
11. Verification of V1/V2 leakage rates by pumping through MV3 and MV4 (plumbed to the interstitial space between the regulators). (New 7/27/02)	Background: The V1/V2 valves have never yet measured out of specification. Currently, this leakage rate is performed by pumping through the rest of the GMA to the leak detector. The Helium background for the test as it has been performed is expected to be quite high. These valves have been measured in the mid 10^{-5} range, but it is suspected that the valves might actually be performing much better than this, and we are simply observing background. This new test will connect the leak detector to a location much closer to V1/V2, decreasing the background and allowing for a more sensitive measurement of the V1/V2 leakage rates. Rationale: If V1/V2 measure in the 10^{-6} or 10^{-7} range, <i>and</i> we can find a way to fly the regulator locked open and evacuated (rather than locked shut and pressurized to 300 psia as in the current configuration), then all He gas would be buffered by those two valves, and the ground hold requirement could be met utilizing only V1/V2. In this scenario, the leakage rate of all other valves would not contribute (to first order) to the ground hold requirement. At this point, flying the GMA in this configuration probably requires some way to shock mount the entire GMA assembly plus some delta qual tests on the regulator (which might fail). Finally, note that V1/V2 are not mounted as part of the stacked pair assembly, so if there is any issue resulting from high g-loads on those pairs, then presumably the V1/V2 pair is unharmed.	GDS must be plumbed to the MV3 and MV4 ports of the GMA.	Monday 7/29/02	COMPLETE 7/29/02. Previous leakage data from one of the two valves was found to be dominated by He background in the measurement. However, one of the two valves is still performing in the 1e-5 range. This experiment was performed to give data as to the potential efficacy of several mitigations, and does not directly address the issue of root cause of the anomaly.

Test	Expected Results	Test Hardware	Schedule	Results (if complete)
12. Weld two spare latch valves together and measure performance.	Measure valve leakage rates before and after the weld. Assess whether the welding process affects valve sealing.	Two backup flight valves, weld components, procedures	Approx 8 days to perform the weld	Status 7/30/02 The decision has been made to perform this test. Note that this supplements Test #6 which examines the cleanliness of the weld process from purely a contamination point of view. This test is a more general repeat of the steps which were performed on the flight valves in order to find any way the process harmed the valve leakage rates.
13. Valve lifetime test under vacuum at 140 degrees F	Examine whether the	Welded flight spares from Test #12, oven, paperwork, misc. manifold H/W.	2-3 weeks after the completion of 12.	Status 7/30/02 This test was determined to be important in order to confirm that the poppet Vespel is not degrading over time. It will be performed after Test #12, primarily because we need to accomplish 12 (or something that is roughly the schedule equivalent) in order to perform the test. Also, the combination of (12) and (13) most closely represents the actual path the flight valves went through.
14. Measure change in Vespel mechanical properties in heat and vacuum	Details defined by Jim Bush. This is a measurement on the change in mechanical properties of the Vespel used on the valve poppet when exposed to heat and vacuum. Changes in certain key parameters known to be important for the valves to function properly will be measured as part of the lifetime test.	Vespel from the same lot that was used to manufacture the latch valves, misc. test equipment.	TBD	Status 7/30/02 This test will be performed as detailed by Jim Bush. There is some question who should perform the actual analyses. Moog will look at the test definition which Jim Bush developed and assess whether it should be performed in house. This data will likely be available before Test #13.

Test	Expected Results	Test Hardware	Schedule	Results (if complete)
15. Review of latch valve history in other Moog programs	Establish what the expected baseline for valve performance should be.	None	First stage completed, second stage in approx 1 week.	Status 7/30/02 Review of the data from one previous program indicated that approximately the same percentage of latch valves on that system had leakage rates in the 1e-4 range after vibration as we are seeing in the flight GMA. Note that in that case the leakage rates improved during the system thermal vacuum test. Moog has agreed to provide a spreadsheet summary for other valves. However, it was stated verbally during the meeting that of the approx. 25 valves delivered prior to the GMA, a total of 3 had leakage rates in excess of 1e-4 at some point in the test program. However, most of these were delivered as components and Moog did not integrate them into a system. ONGOING. Will close when receive spreadsheet details from other valves.

(shaded items are considered complete)

file: **FAR__Latch_Valve.doc** starts on next page

(Moog Failure Analysis Report)

 FAILURE ANALYSIS REPORT	<u>Customer:</u> Stanford University	<u>Product Name:</u> Gas Management Assembly (GMA)	Moog Report No. FAR(M)2002- 063
			Originator: Paul King
			Quality: John Bonanno
	<u>How Reported:</u> MDR 449854 FR(M) 2002-047	<u>Model Number:</u> 50E961 (51E265)	Engineering: Paul King
	<u>Test Document</u> MRA13238 Para. 3.3.4	<u>Serial Number:</u> 001	Customer Rep (If Req'd): N/A
		<u>Moog Part No.:</u> C58800	DCMC (If Req'd): N/A
<u>Date of Analysis:</u> 6/28/02 – 9/6/02	<u>Cust. Report No.:</u>	<u>Customer Part No:</u> LMSSC 8A02681-101	<u>Issue Date:</u> September 3, 2002

Report Sequence: (1) History (2) Analysis (3) Conclusions (4) Corrective Action

HISTORY:

Immediately after completing vibration testing per MRA13238 of Moog Model 50E961, Gas Management Assembly (GMA), the internal leakage rates of Moog Latch Valves (Model 51E265) V27 and V29 were measured because of earlier high leakage rates collected during bubble leak testing and post proof internal leak testing. The post-vibration leak rates from both valves exceeded the GMA specification limit of less than 1.0E-04 sccs GHe. These results lead Moog to measure the leakage of all the GMA latch valves. This testing revealed that the V4/V6 valve pair (configuration permits the leakage testing of the valves as a pair only), V11 and V15 exceeded the leakage specification requirement. With concurrence from Stanford University, a series of leakage tests, which required cycling valves, were performed. The V4/V6 valve pair and V15 continued to indicate high leak rates. In order to determine the overall health of the GMA, Moog proceeded with the remainder of the post-vibration testing of the GMA, which included additional internal leakage testing of the latch valves. This testing revealed that valves V21, V27 and V28 also indicated leak rates greater than the specification requirement. At this point GMA testing per MRA13238 was halted. Upon completion of the testing up to this point, the following valves presented suspect/non-conforming performance: V4/V6 pair, V11, V15, V21, V27, V28, V29.

A "Tiger" team was formed consisting of Moog, Stanford University, NASA-MSFC and Lockheed Martin. At the direction of the Tiger team, some additional leak testing was performed to investigate the testing method, to characterize the valve leakage behavior versus pressure (see attached plot) and better characterize helium background levels. The Tiger team also concluded that removing the non-conforming valves from the GMA is a worse case exercise warranted by degradation of additional valves and/or additional degradation of internal leakage performance of the valves in question. The basis for this conclusion was the inherent contamination risks to the GMA resulting from cutting valves out of the GMA. However, this course of action does not permit a disassembly/inspect of the questionable valves. The Tiger team also agreed to go forward with testing of the GMA per MRA13238, which included thermal/vacuum testing and several more latch valve internal leakage tests. This testing was completed. An important observation from the all data is that no additional latch valves degraded and the valves were generally consistent in leakage rate from test to test. Some valves also showed some improved performance. Also, the valves in question (V4/V6 pair, V11, V15, V21, V27, V28, V29) did not get any worse. The data from all the additional internal leakage testing and the internal leakage testing per MRA13238 are summarized in the Summary GMA PTP MRA13238 and AVO Internal Leakage Data matrix attached.

Per the direction of the Tiger team, two spare GMA latch valves were subjected to a series of tests including cycle testing and vibration testing. These valves were also subjected to cleanliness sampling to determine the level of particulate in the valve after certain tests. The internal leakage was measured throughout these tests. The valves were also welded into a mini assembly similar to sub-assemblies used in the GMA. Internal leakage was measured after

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assembly and the mini assembly (see attached Moog C78437) was subjected to additional vacuum and thermal testing to determine if this type of exposure can degrade sealing characteristics of the Vespel SP-1 poppet material in each valve. Samples of this material were also exposed to these conditions and then tensile tested by an outside lab to determine if the material properties (yield strength, %-elongation) of the Vespel are affected.

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ANALYSIS:

For reference a functional cross-section of the 51E265 is included at the end of this report as well as a schematic of the GMA and a top view of the GMA indicating valve locations. To facilitate the search for a root cause(s) of these non-conformances, a fault matrix was created, which identifies the subject valves (V4/V6 valve pair, V11, V15, V21, V27, V28 & V29). This matrix is attached. Many of the potential causes are deemed not credible since many of the causes would result in gross leakage or would affect other performance parameters of the valve such as valve response. The Tiger team also used this matrix to determine a pathway for additional investigative testing.

The main focus of the Tiger team effort was to determine why the leakage performance of the valves, in general, degraded from ~1.0E-07 sccs GHe leakage at the component level to >1.0 E-06 sccs GHe at the GMA level and to determine why the valves in question degraded to ~1.0E-04 sccs GHe. The key concerns with regard to excessive latch valve internal leakage are:

1. Loss of lock-up pressure for the GMA regulators prior to launch, which could result in damage to the regulators during the launch shock environment.
2. Helium leakage into the science probe prior to launch, which could degrade the science probe.
3. Leakage of air into the GMA through the vent valve prior to launch, which would degrade the GMA helium purity.

In addition to investigating the causes for excessive leakage of the latch valves, the team also discussed ways to allow the GMA to be used "as-is" provided the internal leakage performance did not get worse after completion of the testing per MRA13238. Stanford would also need to determine ways to mitigate any risks related to the higher leakage rates from the six questionable valves. The mitigation methods discussed at the Tiger team meeting included selecting which valves would be open or closed during launch to minimize leakage into the probe, but maintain ECU redundancy, keep the vent line capped for as long as possible, maintain 300 psia helium throughout the low-pressure side of the GMA and keeping all the valves closed as long as possible before launch. The results of this portion of the investigation are available from Stanford University.

As a result of Tiger team discussions, some additional testing was deemed worthwhile to help with resolving the likelihood of specific causes. These tests/investigations include:

- A. Cycle testing of two spare latch valves (51E265, SN007, SN022) to determine if self-generated contamination is a cause: See attached MRA16475 summary matrix. The first 1000 mL effluent IPA sample was collected from each valve and passed through a filter patch. The particles on the patch were then categorized by size and counted under a microscope. After sampling, the valves were certified clean to the GMA requirement before proceeding to the next test. The two latch valves tested did indicate particulate counts greater than the certified clean limits established for the GMA program. The concern for Moog is particle size greater than 100 microns. Some particles of this size were found during this testing and in subsequent cleanliness sample tests performed after the tests described below. Several of these particles were isolated and examined by Moog Material Process Engineering using FTIR and SEM/EDS analysis. These particles were identified as follows: polyurethane polymer (e.g. Spensol L-44, source unknown), nitrocellulose (source: filter patch material), secondary amide (source: human skin), PH stainless steel (source: fixturing, inlet fitting of latch valve). With the exception of the polyurethane polymer, these particles are consistent with contamination from handling and hook-up debris. These materials may have been in the valves or could have been introduced during the sampling procedure. There was no evidence of Vespel, EPR (o-ring), Teflon (bearing rings on armature), CRES 430 or CRES 300 series or braided shielding, all of which are possible materials from the latch valves. The only exception was the PH stainless, which could have come from the

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inlet of the latch valve. However, the inlet fitting is upstream of the 5-micron filter and the particles in question are greater than 100-microns in size. Note that when a valve is certified clean, IPA is flowed through the valve for two minutes prior to taking a sample. Comparing the first 1000 mL to the certified clean standard is a very conservative approach. The valves did not show any sign of leakage performance degradation. While the spare valves tested were not affected by the presence of these particles, Moog cannot rule out some form of contamination as a root cause for the six valves in question.

- B. Vibration testing of two spare latch valves to determine if the valves are damaged in any way: See attached MRA16475 summary matrix. The two latch valves (SN007 and SN022) were vibration tested in the open condition (see item D below) while mounted in the "stacked" GMA configuration. The GMA level random vibration spectrum was the test input. The valves were cycled and leak tested after each axis. The testing did reveal that the upper valve was subjected to vibration levels of ~40 Grms. The valves did not show any sign of leakage performance degradation or any other valve performance degradation. Since the two spare valves and the majority of the GMA valves continue to perform within specification, Moog does not believe that the vibration testing was a root cause. However, the vibration testing could be coupled with a contamination issue, i.e., vibration freed trapped contamination.

Two Mott flow restrictors were also exposed to vibration testing. The restrictors were then sampled for particles. No metallics were generated from exposure to the vibration environment indicating that the sintered material was not damaged and did not shed. The particle counts were high on one unit, but this is attributed to the sampling technique. The technique was altered on the second unit, which indicated a very "clean" unit. The Motts are not viewed as a source of contamination.

- C. Investigate helium background of GMA and test methodology: See the attached GMA Latch Valve Internal Leakage Fault Analysis matrix. A calibrated leak device (1.5E-05 sccs GHe) was plumbed into the GMA at the GMA vent line. The mass spectrometer was capable of measuring the calibrated leak. The calibrated leak device was subsequently removed from the GMA vent line. Also, the sequence in which valves are leak tested and evacuated to testing was found to have some affect on the leakage measurements when measuring the internal leakage of individual valves. Subsequent testing instructions addressed this issue. However, the magnitude of this adjustment was minor and is not considered a cause for the excessive leak rates.
- D. Review the build paperwork and As-Built-Configuration-Records (ABCRs) from all the valves: All the build data was reviewed to determine if there was any trend in the data to suggest that the valves in question had something in common that would point to a root cause. No trend could be identified with regard to:
- Material/part lots, i.e., material/poppet lots from the valves in question were also used in valves with leakage two orders of magnitude better. This included the poppets, outlet fittings (seats), armatures, poppet springs and cores.
 - Build/performance parameters, e.g., spring preload, valve and poppet stroke, latching force, response, pull-in current.

A trend with regard to weld reworks was noted for valves V27, V28 and V29. All valves except V1 and V2 had the filter body weld reworked. However, V27, V28 and V29 were reworked twice, which exposed these valves to an additional deburring operation. The handling of these valves was consistent with other rework operations. Another trend associated with these particular valves is the fact that they are located in the vent line. The vent line is the primary purging line for GMA testing. This level of gas throughput may offer more opportunity for contamination of the valves. Beyond identifying these trends, no other conclusion can be drawn.

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The only other trend identified is the valve open/close status and position in the mounting brackets during vibration testing. The V4/V6 pair, V27 and V29 indicated leakage performance problems prior to vibration. However, V11, V15, V27 were open during vibration and located in the upper portion of the mounting bracket. It is important to note that V11 and V15 have a history of intermittent leakage performance, which implies that any acceptable leakage data taken prior to vibration was a random occurrence. Additional testing prior to vibration testing may have revealed unacceptable values, as well. V21 was located in the upper portion of the bracket, but was closed during vibration. Also, the valve had acceptable leakage values immediately after vibration testing.

E. Investigate the weld assembly process of the GMA latch valve sub-assemblies as a source of contamination: See attached MRA16475 summary matrix. Using valves SN007 and SN022, Moog welded a mini-assembly per C78437 using the same processes and procedures used when welding the GMA latch valve quad and double valve sub-assemblies. This included not protecting the weld process from potential handling contamination from the latch valve lead wire shielding (It was noted during the GMA build that the shielding harbored contaminants. After this was noticed, the shielding was bagged to reduce risk of contamination). Immediately after assembly, the leakage performance of both valves measured $\sim 1.0E-05$ sccs GHe. After cycling, the valve leakage performance improved and returned to a level of leakage consistent with the component level leakage performance. The valve was also sampled for cleanliness. The particle analysis is detailed in the above discussion. While the investigation did not lead to a repeat of permanent internal leakage performance, Moog cannot rule this item out as a root cause.

F. Investigate the potential degradation of the Vespel poppet material as a result of exposure to vacuum and helium at elevated temperatures (104 F to 140 F): During the build of the GMA latch valves, Moog determined that the %-elongation of Vespel appears to have an affect on the sealing characteristics of the latch valve poppet. The theory with regard to %-elongation is that the lower the % elongation, the more "brittle" or less compliant the Vespel material is for sealing purposes. A concern was raised that the Vespel could be affected by long-term exposure vacuum (via outgassing of Vespel constituents) and/or helium in such a way that the %-elongation of poppets in the valves could be affected, or otherwise embrittled, in such a way to degrade leakage performance. To investigate this concern, the valve mini-assembly was exposed to vacuum and helium. The valves did not show any sign of leakage performance degradation. Lockheed Martin (LMSSC) also subjected the poppet material (VESPEL SP-1) to an outgassing test. Below is an e-mail response from Jim Bush from LMSSC regarding the results of this test:

"Jeff Garrett (one of the original designers of the ASTM 1559 test apparatus) runs his own commercial company which runs outgassing tests for a variety of companies. The name of the company is Outgassing Services International in Palo Alto. He has recently tested Vespel SP-1 for a commercial customer. Vespel is seeing some use in GC/MS instruments and high vacuum systems. The test was run at 125 C for a 24-hour period under vacuum conditions of 10⁻⁷ or 10⁻⁸ torr. The results of the test show the following. 1) 99.998% of the outgassing product was water, 2) The VCM for two different runs were 0.001 and 0.002% 3) the outgassing curve was fairly steep with all of the water coming out very rapidly at 125 C and going asymptotic at 24 hours. There was no mass spec data taken to ID the off gassing products but they were at such low levels that the customer did not feel it was important.

Unfortunately since the testing was done for a commercial customer Jeff could not give me a copy of the data since it belongs to that customer. With just the verbal information it was very apparent that with the data that Jeff gave me it would not make sense to run outgassing tests on the material at 40 C or 140 F since the data above was at an even higher temperature and it did not drive off significant outgassing products.

Since outgassing under temperature and vacuum does not seem to be significant the next question is how does helium affect the material and/or does temperature/vacuum cause any changes in physical surface properties which would affect the shoulder sealing area of the poppet. These questions should be answered in the aging studies you are conducting with the testing at the end."

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Exposure to vacuum and helium did not have any affect on the valve internal leakage performance. Moog also performed a Vespel SP-1 aging investigation of vespel samples. These samples were exposed to vacuum and helium for an extended period of time at temperatures between 104 F and 140 F to "age" the Vespel. These samples are to be tensile tested to determine if the properties of the vespel (yield strength, %-elongation) are affected by this exposure. The results from this testing will be available after the GMA Acceptance Data review.

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CONCLUSIONS:

The conclusion of the Tiger team meeting in July was that the status of the GMA would be “use-as-is” provided that the performance of the GMA latch valves in question did not degrade further and that no additional valves degraded. The testing to date has demonstrated that this is the case. Despite a great deal of investigation and testing, no clear root cause(s) has been identified for the out of tolerance leakage values measured for valves V4/V6 pair, V11, V15, V21, V27, V28, V29. All of the testing performed as a result of these investigations (cycle testing, vibration testing, review of build paperwork and ABCRs of all the valves, helium background investigation, weld assembly process investigation, vacuum/helium exposure) did not result in a repeat of the high leakage values that we are observing with the six GMA valves. The Summary/Comments section of the Fault Analysis indicated probable causes for the out of tolerance performance of these valves. Moog believes that the most likely cause is related to some form of contamination, but Moog cannot be determined what the source or nature of this contamination may be without removing the valves from the GMA and performing a disassembly and inspection. The exceptions to the contamination theory are the suspect poppet in V4 and the mark recorded on the seat of V15. Also, V11 and V15 present intermittent pass/fail data. We cannot be sure that this behavior was or was not present prior to vibration testing.

Having met the requirement set forth by the Tiger team, Moog recommends a use-as-is disposition for the GMA. Moog will work with Stanford University to determine the best ways to mitigate the additional risks associated with the out of tolerance leak rates observed in valves V4/V6 pair, V11, V15, V21, V27, V28, V29 and any further risks associated with latch valves which are out of tolerance due to internal leak rates.

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CORRECTIVE ACTION:

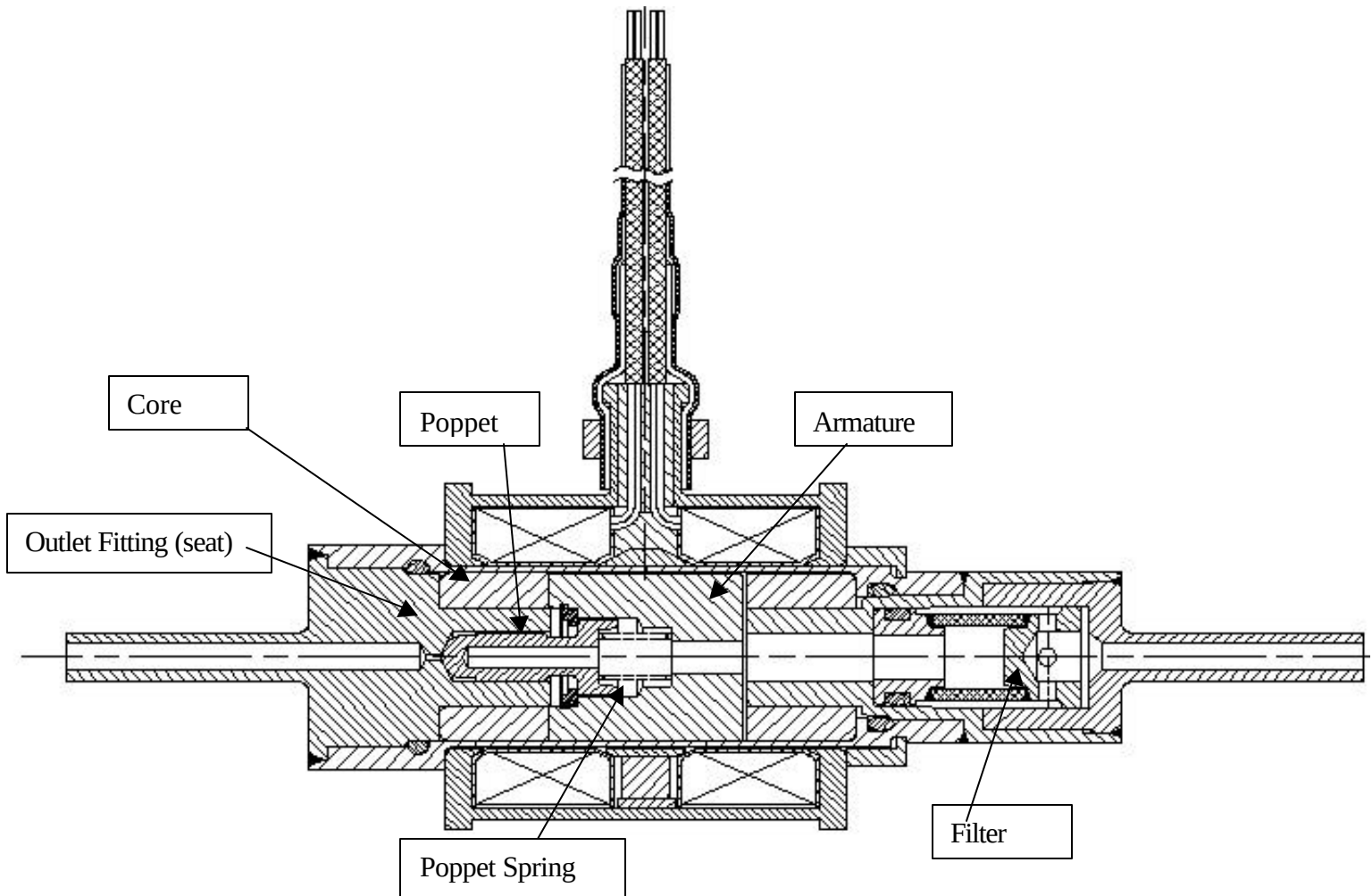
Without a confirmed root cause Moog cannot offer a corrective action for mitigating the latch valve leak rates in excess of 1.0E-04 sccs GHe. The investigations that have been conducted have revealed ways to improve our general processes for building and testing of valves and sub-systems and these will be implemented. These improvements include test methodology and procedure for internal leakage testing of the GMA, proper covering of shielded leads to prevent contamination during assembly and valve cleanliness certification.

DISTRIBUTION:

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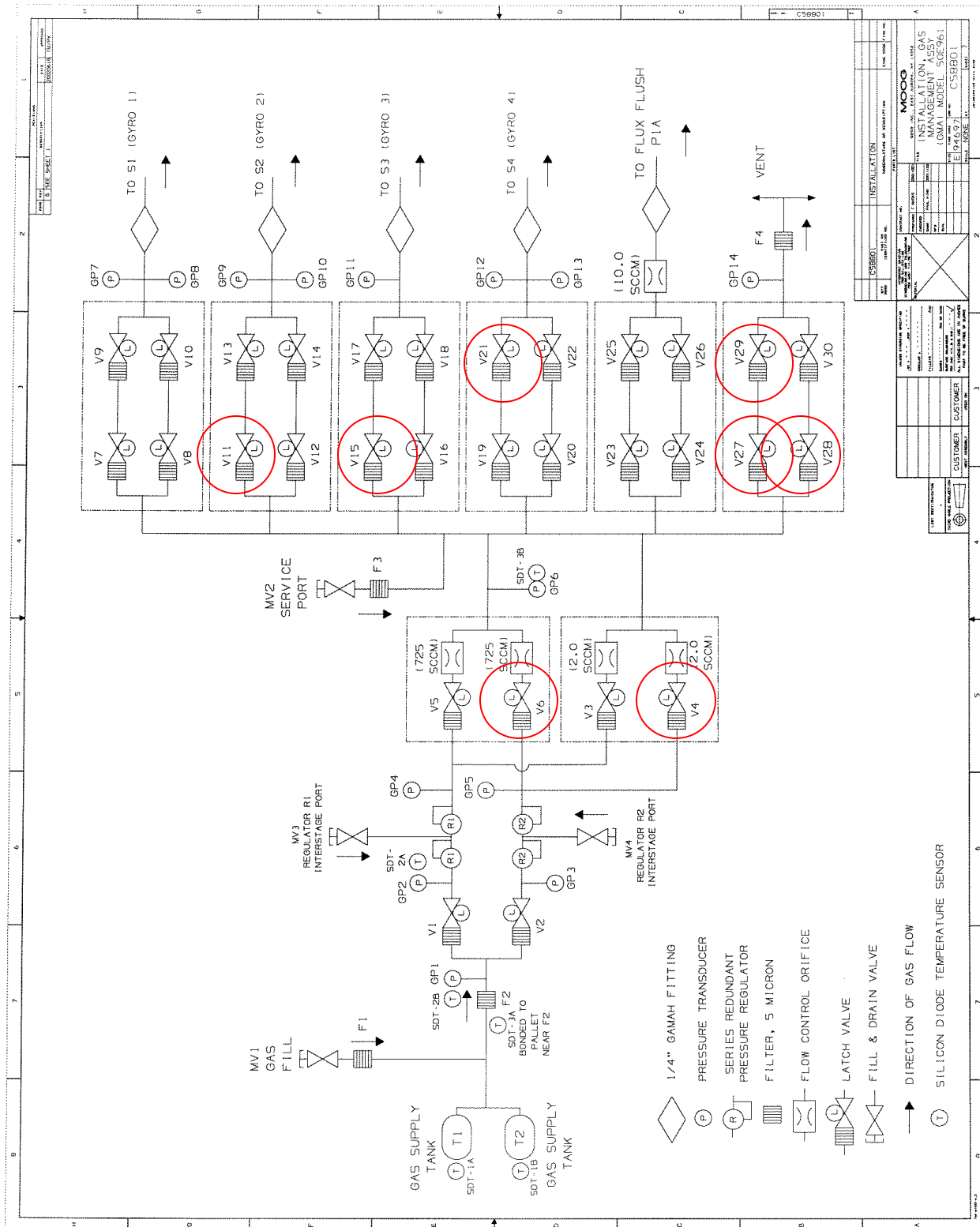
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**GMA: Functional Cross Section of the 51E265
Latch Valve**

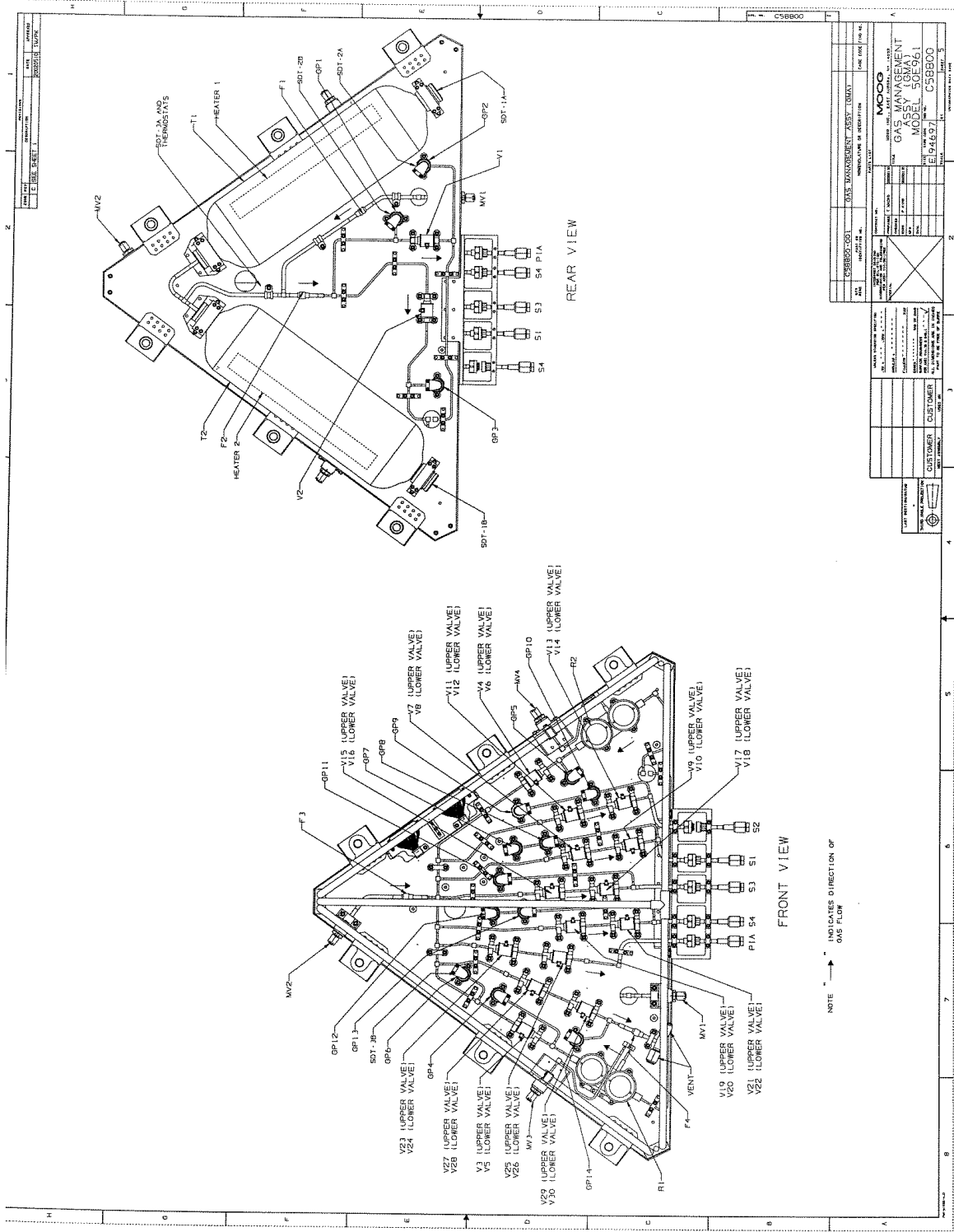
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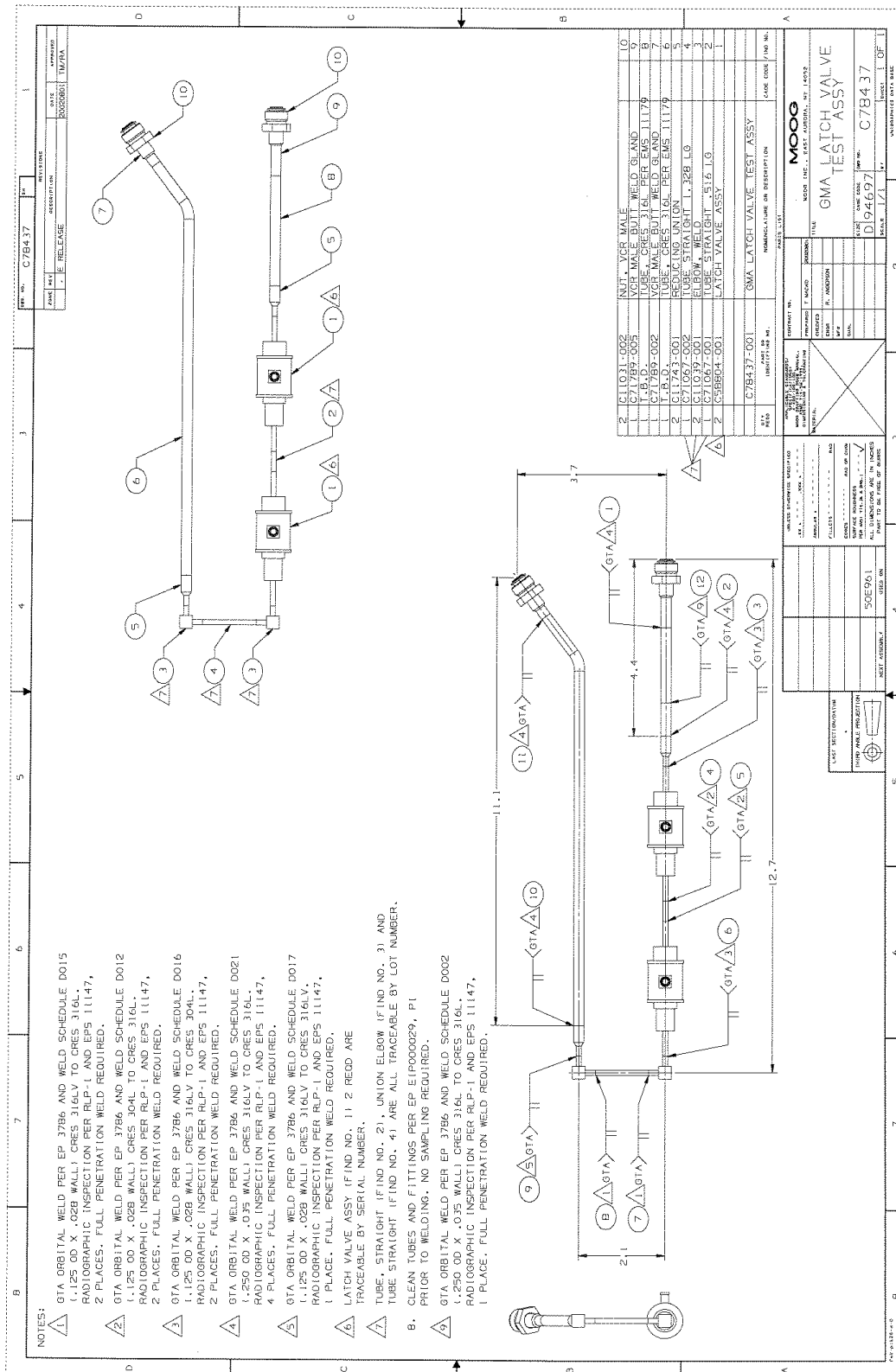
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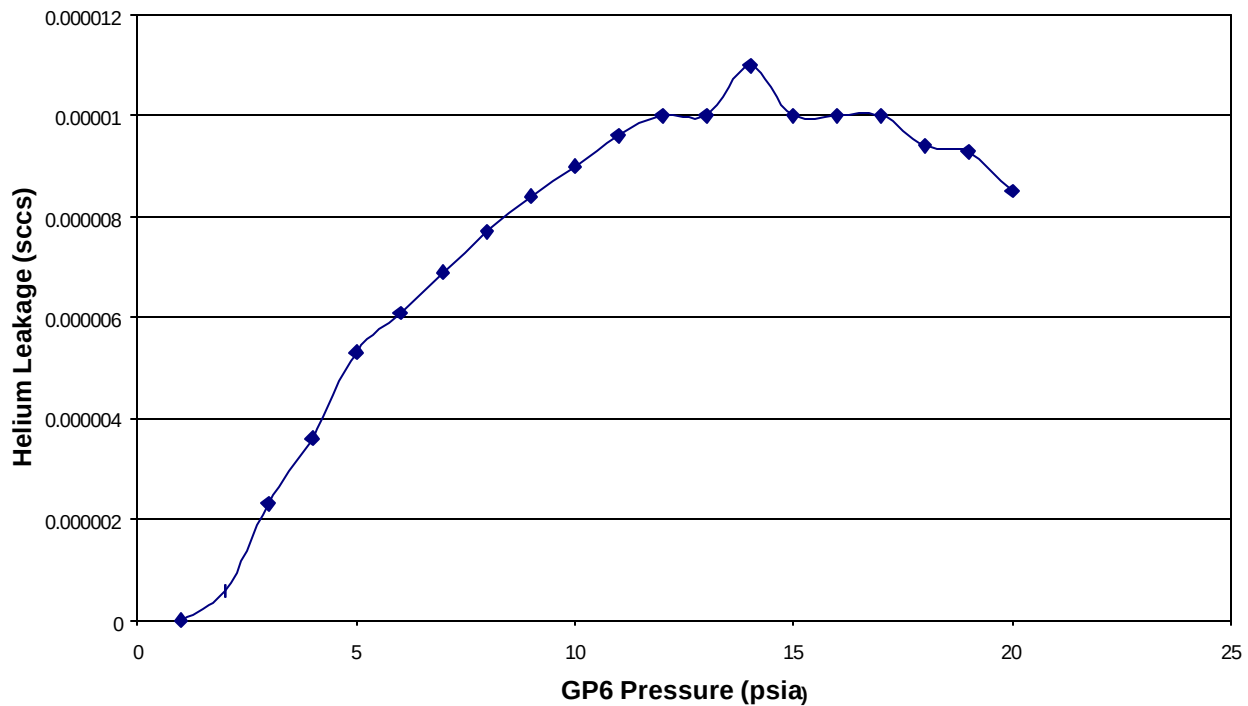
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GMA system internal leakage performance as measured at the outlets of GMA lines S1-S4, P1A and Vent, while the GMA latch valves are configured for launch. The aggregate leak rate of the GMA peaked to a value of 1.1E-05 sccs GHe at 14 psia

GMA System Internal Leakage in Flight Configuration

As Tested 7/30/02 at Moog Inc. per AVO50E961RA16



file: **GMA LEAKAGE PERFORMANCE DURING
TESTING.doc** starts on next page

(Results from the Stanford Testing)

GMA LEAKAGE PERFORMANCE DURING TESTING AT STANFORD UNIVERSITY

1. Observed Leakage Rates

The GMA valve leakage rates were measured during GMA testing at Stanford University on 9/29 – 9/30/2002 using Stanford procedure P0931 Rev A. The results are indicated in the table below.

Valve	Leakage		Valve	Leakage
V1	2.4×10^{-6}		V17	2.0×10^{-8}
V2	8.2×10^{-4}		V18	5.0×10^{-5}
V3 + V5	2.2×10^{-8}		V19	4.4×10^{-8}
V4 + V6	5.2×10^{-3}		V20	4.2×10^{-8}
V7	7.6×10^{-8}		V21	7.8×10^{-5}
V8	1.2×10^{-5}		V22	5.6×10^{-8}
V9	1.8×10^{-8}		V23	5.4×10^{-8}
V10	7.4×10^{-8}		V24	4.4×10^{-8}
V11	4.6×10^{-5}		V25	2.0×10^{-8}
V12	8.6×10^{-8}		V26	8.2×10^{-8}
V13	1.0×10^{-7}		V27	1.2×10^{-5}
V14	1.6×10^{-7}		V28	1.0×10^{-6}
V15	2.4×10^{-7}		V29	6.2×10^{-5}
V16	1.4×10^{-7}		V30	3.2×10^{-5}

Although the V4/V6 pair and V2 show a degradation from the results reported at Moog, the overall system performance has improved. This is summarized in the next few sections.

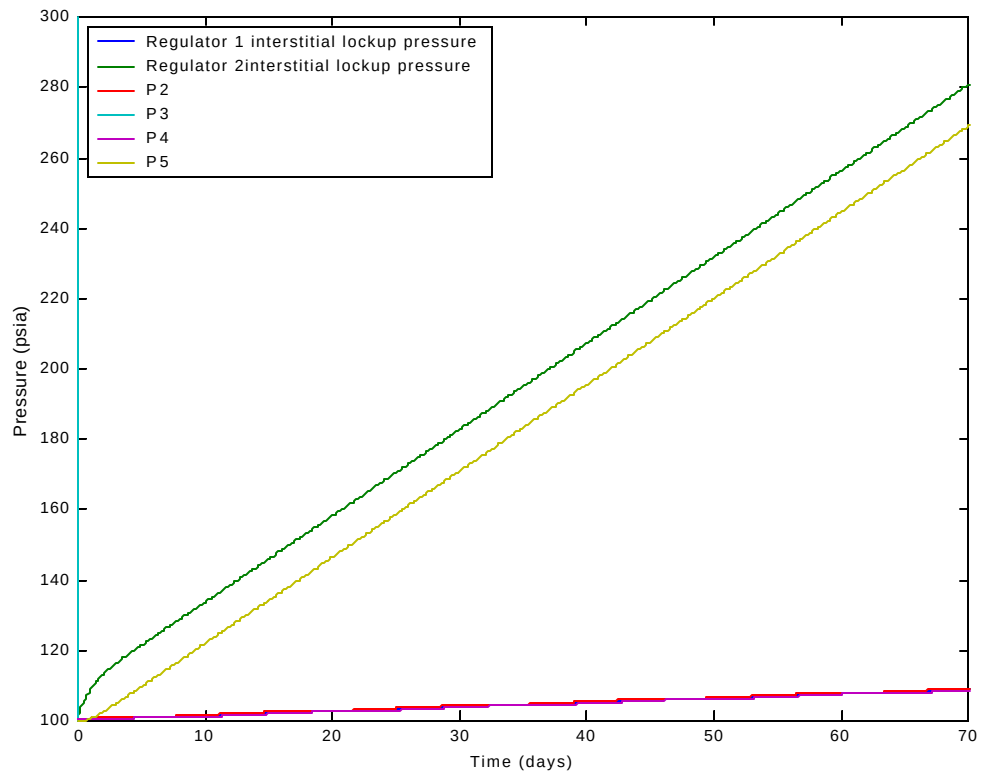
2. The GMA Simulation

A simulation was developed to calculate the evolution of various pressures and gas volumes during a GMA hold period with leaky valves. The simulation was developed in Simulink. Appendix A shows a high-level diagram of the simulation, Appendix B is the specific parameter file for the plots that will be shown in this report, and Appendix C is the actual command file that generates the simulation pictured in Appendix A.

3. Regulator Lockup

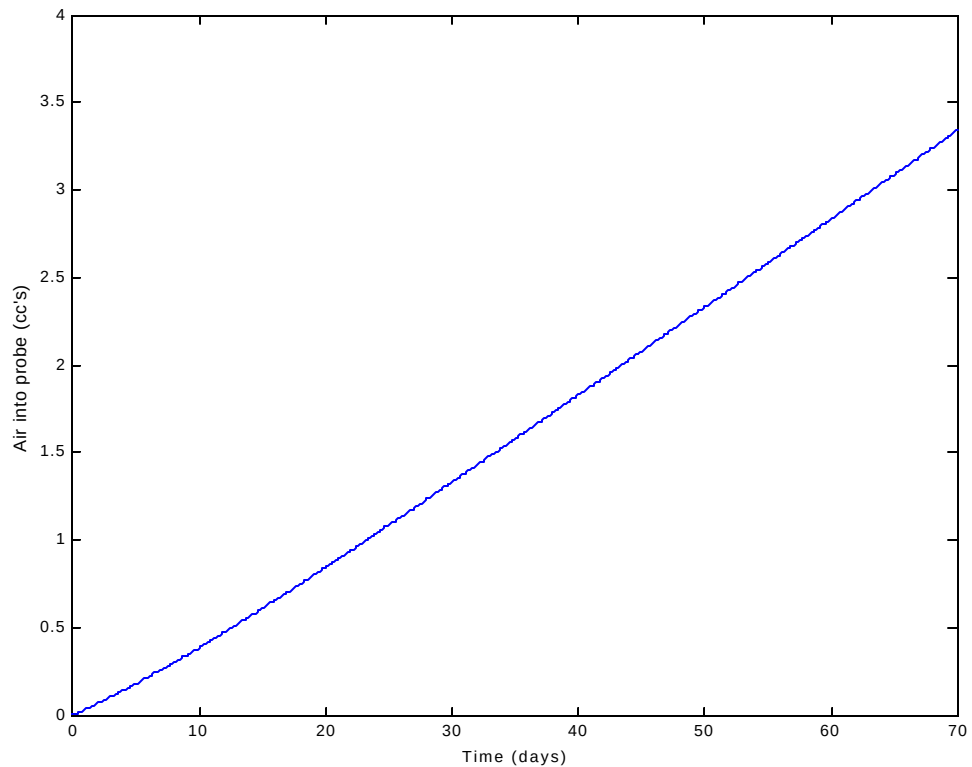
There is a requirement that the regulator lockup pressure be maintained between 100 and 300 psi during launch. The requirement for the dewar hold time is 90 days, but since the GMA can be serviced 20 days after the final dewar servicing, the equivalent hold time requirement on the GMA is 70 days.

The following graph shows all pressures pertaining to GMA lockup. Note that they remain within specification for the required time.



4. Gas Leakage into Probe

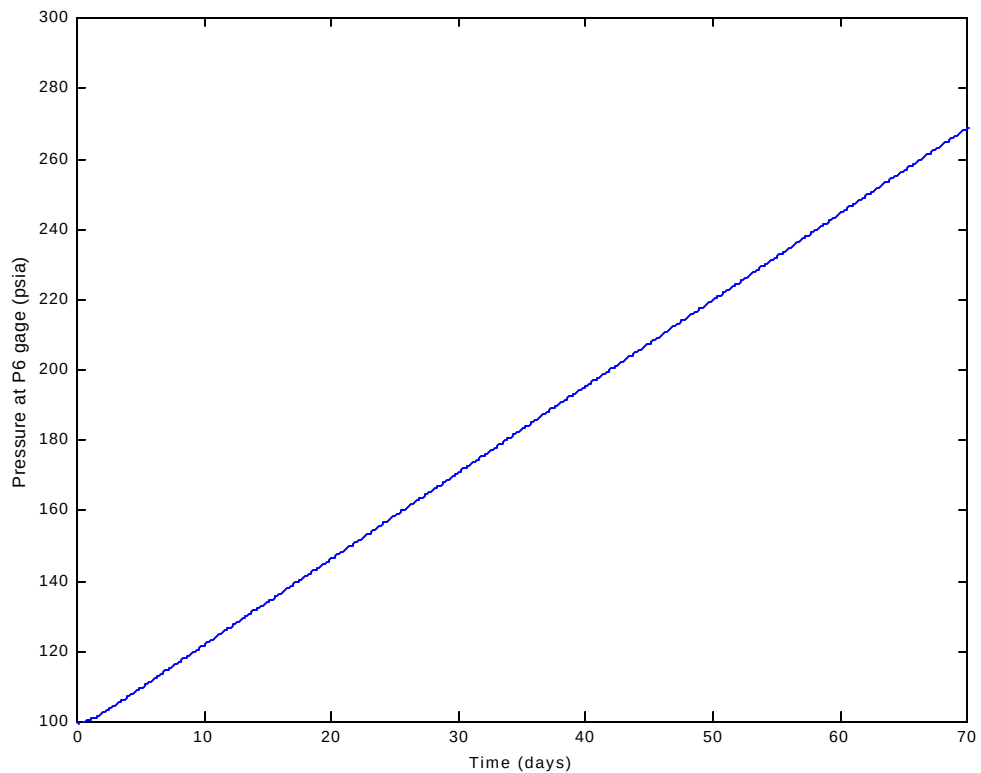
The GMA can not leak more than 100 cc's of Helium into the probe over the 70 day period. This is to avoid providing a thermal "short" that would result in an increased heat load into the dewar that would threaten its launch pad hold time. The following plot shows the air incursion over the 70 day period.



The air that would leak into the probe is less than 4% of the total allowed value. Note that the Helium background level for the Stanford leak tests was lower than was achieved at Moog, meaning that the leakage rates of many of the valves (those that measured in spec at Moog) are substantially better than was measured at that time.

5. **Air in the GMA**

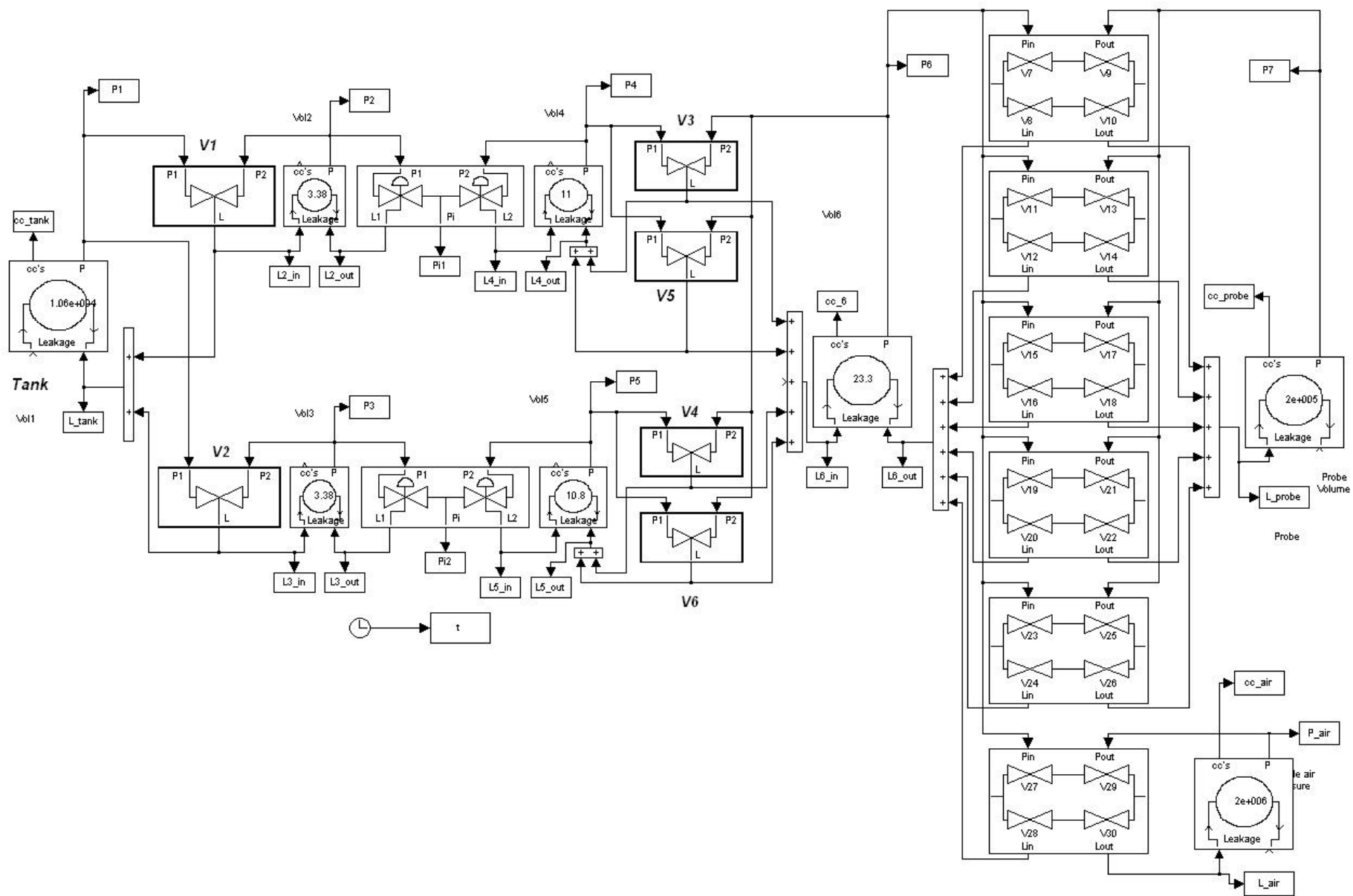
The third main requirement area which must be examined when determining the impact of valve leakage on system performance is air incursion into the probe. The following plot shows the pressure in the region of the GMA measured by the P6 pressure gage. If this pressure remains greater than 14.7 psia, then Helium will tend to leak out of the GMA, as opposed to air leaking in. From the plot it is clear that air incursion into the GMA is not a concern.



Overall, approximately 90 cc's of air leaks out of the GMA during the 70 day hold period, so there is no concern about overall depletion of the gas supply in the tanks.

6. Conclusion

GMA performance as measured at Stanford meets all system level requirements for ground hold operation. The system also meets all on-orbit requirements for valve leakage (which are much less stringent than the ground hold requirements). Therefore current GMA performance meets all program objectives. However, this conclusion could change dramatically if the leakage rate in several valves were to worsen significantly. Therefore system-level mitigations should be investigated that would allow for the space vehicle to meet the ground hold requirement in this eventuality.



GMA LEAKAGE PERFORMANCE DURING TESTING AT LOCKHEED

Observed leakage rates:

The GMA valve leakage rates were measured after Space Vehicle integration at Lockheed Martin Building 159 on 10/12/02 per Stanford procedure P0931 Rev A. The results are in the table below.

Valve	Leak rate (sccs)		Valve	Leak rate (sccs)
V1	3.0e-4		V17	1.0e-8
V2	6.5e-4		V18	2.5e-3
V3 + V5	2.4e-4		V19	6.0e-8
V4 + V6	2.5e-3		V20	3.5e-7
V7	5.0e-8		V21	2.5e-3
V8	1.7e-6		V22	2.5e-3
V9	3.2e-9		V23	6.0e-8
V10	8.0e-9		V24	4.0e-7
V11	2.6e-4		V25	5.0e-9
V12	1.7e-6		V26	2.5e-9
V13	3.0e-5		V27	3.5e4
V14	1.0e-5		V28	5.0e-4
V15	6.8e-6		V29	4.0e-3
V16	3.0e-7		V30	4.0e-3

GMA Pressure Rate of Rise Evaluation

This table represents the GMA internal leak rates as calculated from the GMA Rate of Rise evaluation. This test was performed from 1/17/03 to 1/24/03 at Lockheed Martin Building 156 after the Thermal Vacuum Test. These data show leak rates that are considerably lower than those measured in previous leak tests performed with a Helium leak detector. See the GMA mitigation plan for a full report of the testing.

Leak rates measured during the rate of rise evaluation performed 1/17/03 thru 1/24/03 at Lockheed B156							
	into	into	into	into	into	into	into
all values in sccs	S1	S2	S3	S4	P1A	Probe Sum	Vent
Leak rate, ground state:	1.05E-07	1.50E-07	3.01E-07	3.63E-07	3.41E-07	6.28E-06	-7.92E-06
Leak rate, Launch state (V17,V18 closed):	2.65E-07	4.02E-07	3.49E-04	3.26E-07	2.10E-06	1.77E-03	2.64E-04
Leak rate, Alternate launch state (V15,V16 closed):			2.45E-05			2.76E-05	2.64E-04
Leak rate, Launch state (V17,V18 closed) run 2			4.31E-06			7.41E-06	2.64E-04
	out of	out of	out of	out of	out of	out of	
	Zone 5	Zone 3A	Zone 3B	Zone 2A	Zone 2B	Zone 1	
	MV2	MV3	MV4	GP2	GP3	GP1	
Leak rate, ground state:	7.92E-06	1.25E-06	7.11E-07	no data	no data	no data	
Leak rate, Launch state (V17,V18 closed):	3.68E-04	-4.47E-07	-3.23E-08	-3.17E-07	-7.09E-06	3.41E-04	
Leak rate, Alternate launch state (V15,V16 closed):	2.58E-04	9.25E-05	1.18E-04	9.33E-06	3.92E-05	6.37E-03	
Leak rate, Launch state (V17,V18 closed) run 2	1.26E-04	-2.92E-06	-6.39E-06	3.30E-07	-1.60E-05	5.33E-05	

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			Originator: Paul King
			Quality: John Bonanno
	<u>How Reported:</u> MDR 449854 & 449858 FR(M) 2002-047	<u>Model Number:</u> 50E961 (51E265)	Engineering: Paul King
	<u>Test Document</u> MRA13238 Para. 3.3.4	<u>Serial Number:</u> 001	Customer Rep (If Req'd): N/A
		<u>Moog Part No.:</u> C58800	DCMC (If Req'd): N/A
<u>Date of Analysis:</u> 6/28/02 – 2/11/02	<u>Cust. Report No.:</u>	<u>Customer Part No:</u> LMSSC 8A02681-101	<u>Issue Date:</u> Original: September 5, 2002 Revision A: February 11, 2003

Report Sequence: (1) History (2) Analysis (3) Conclusions (4) Corrective Action

HISTORY:

Immediately after completing vibration testing per MRA13238 of Moog Model 50E961, Gas Management Assembly (GMA), the internal leakage rates of Moog Latch Valves (Model 51E265) V27 and V29 were measured because of earlier high leakage rates collected during bubble leak testing and post proof internal leak testing. The post-vibration leak rates from both valves exceeded the GMA specification limit of less than 1.0E-04 sccs GHe. These results lead Moog to measure the leakage of all the GMA latch valves. This testing revealed that the V4/V6 valve pair (configuration permits the leakage testing of the valves as a pair only), V11 and V15 exceeded the leakage specification requirement. With concurrence from Stanford University, a series of leakage tests, which required cycling valves, were performed. The V4/V6 valve pair and V15 continued to indicate high leak rates. In order to determine the overall health of the GMA, Moog proceeded with the remainder of the post-vibration testing of the GMA, which included additional internal leakage testing of the latch valves. This testing revealed that valves V21, V27 and V28 also indicated leak rates greater than the specification requirement. At this point GMA testing per MRA13238 was halted. Upon completion of the testing up to this point, the following valves presented suspect/non-conforming performance: V4/V6 pair, V11, V15, V21, V27, V28, V29.

A "Tiger" team was formed consisting of Moog (Paul King, Ron Anderson, John Bonanno), Stanford University (Rob Brumley, Chris Gray, Ken Bower, Ray Pressburg, Bill Wissert), NASA-MSFC (DeWitt Burns, Kent Chojnacki) and Lockheed Martin (Jim Bush). At the direction of the Tiger team, some additional leak testing was performed to investigate the testing method, to characterize the valve leakage behavior versus pressure (see attached plot) and better characterize helium background levels. The Tiger team also concluded that removing the non-conforming valves from the GMA is a worse case exercise warranted by degradation of additional valves and/or additional degradation of internal leakage performance of the valves in question. The basis for this conclusion was the inherent contamination risks to the GMA resulting from cutting valves out of the GMA. However, this course of action does not permit a disassembly/inspect of the questionable valves. The Tiger team also agreed to go forward with testing of the GMA per MRA13238, which included thermal/vacuum testing and several more latch valve internal leakage tests. This testing was completed. An important observation from the all data is that no additional latch valves degraded and the valves were generally consistent in leakage rate from test to test. Some valves also showed some improved performance. Also, the valves in question (V4/V6 pair, V11, V15, V21, V27, V28, V29) did not get any worse. The data from all the additional internal leakage testing and the internal leakage testing per MRA13238 are summarized in the Summary GMA PTP MRA13238 and AVO Internal Leakage Data matrix attached.

Per the direction of the Tiger team, two spare GMA latch valves were subjected to a series of tests including cycle testing and vibration testing. These valves were also subjected to cleanliness sampling to determine the level of particulate in the valve after certain tests. The internal leakage was measured throughout these tests. The valves

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were also welded into a mini assembly similar to sub-assemblies used in the GMA. Internal leakage was measured after assembly and the mini assembly (see attached Moog C78437) was subjected to additional vacuum and thermal testing to determine if this type of exposure can degrade sealing characteristics of the Vespel SP-1 (unfilled) poppet material in each valve. Samples of this material were also exposed to these conditions and then tensile tested by an outside lab to determine if the material properties (yield strength, %-elongation) of the Vespel are affected. During this investigation using the spare latch valves and Vespel samples, the GMA was shipped to Stanford University since the GMA test results met the Tiger Team requirements for use-as-is: the performance of the GMA latch valves in question did not degrade further and no additional valves degraded upon completion of protoflight testing.

Spare latch valve SN007 exhibited a general shift in leakage performance from the 1E-07 sccs GHe range to 10E-06 sccs GHe range after integration into the mini assembly. This valve also presented several leakage measurements in the 1E-05 sccs GHe range and one value at 2.0E-04 sccs GHe. Although the performance of this valve was very good, the general shift and outlying data points raised suspicion about the valve. The valve was disassembled and inspected. Spare latch valve SN022, which did not exhibit any shift in internal leakage performance, was also disassembled for comparison.

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ANALYSIS:

For reference a functional cross-section of the 51E265 is included at the end of this report as well as a schematic of the GMA and a top view of the GMA indicating valve locations. To facilitate the search for a root cause(s) of these non-conformances, a fault matrix was created, which identifies the subject valves (V4/V6 valve pair, V11, V15, V21, V27, V28 & V29). This matrix is attached. Many of the potential causes are deemed not credible since many of the causes would result in gross leakage or would affect other performance parameters of the valve such as valve response. The Tiger team also used this matrix to determine a pathway for additional investigative testing.

The main focus of the Tiger team effort was to determine why the leakage performance of the valves, in general, degraded from $\sim 1.0\text{E-}07$ sccs GHe leakage at the component level to $>1.0\text{E-}06$ sccs GHe at the GMA level and to determine why the valves in question degraded to $\sim 1.0\text{E-}04$ sccs GHe. The key concerns with regard to excessive latch valve internal leakage are:

1. Loss of lock-up pressure for the GMA regulators prior to launch, which could result in damage to the regulators during the launch shock environment.
2. Helium leakage into the science probe prior to launch, which could degrade the downstream science probe.
3. Leakage of air into the GMA through the vent valve prior to launch, which would degrade the GMA helium purity.
4. General loss of helium that may result in insufficient gas for the mission.

In addition to investigating the causes for excessive leakage of the latch valves, the team also discussed ways to allow the GMA to be used "as-is" provided the internal leakage performance did not get worse after completion of the testing per MRA13238. Stanford would also need to determine ways to mitigate any risks related to the higher leakage rates from the six questionable valves. The mitigation methods discussed at the Tiger team meeting included selecting which valves would be open or closed during launch to minimize leakage into the probe, but maintain ECU redundancy, keep the vent line capped for as long possible, maintain 300 psia helium throughout the low-pressure side of the GMA and keeping all the valves closed as long as possible before launch. The results of this portion of the investigation are available from Stanford University.

As a result of Tiger team discussions, some additional testing was deemed worthwhile to help with resolving the likelihood of specific causes. These tests/investigations include:

- A. Cycle testing of two spare latch valves (51E265, SN007, SN022) to determine if self-generated contamination is a cause: See attached MRA16475 summary matrix. The first 1000 mL effluent IPA sample was collected from each valve and passed through a filter patch. The particles on the patch were then categorized by size and counted under a microscope. After sampling, the valves were certified clean to the GMA requirement before proceeding to the next test. The two latch valves tested did indicate particulate counts greater than the certified clean limits established for the GMA program. The concern for Moog is particle size greater than 100 microns. Some particles of this size were found during this testing and in subsequent cleanliness sample tests performed after the tests described below. Several of these particles were isolated and examined by Moog Material Process Engineering using FTIR and SEM/EDS analysis. These particles were identified as follows: polyurethane polymer (e.g. Spensol L-44, source unknown), nitrocellulose (source: filter patch material), secondary amide (source: human skin), PH stainless steel (source: fixturing, inlet fitting of latch valve). With the exception of the polyurethane polymer, these particles are consistent with contamination from handling and hook-up debris. These materials may have been in the valves or could have been introduced during the sampling procedure. There was no evidence of Vespel, EPR (o-ring), Teflon (bearing rings on armature), CRES 430 or CRES 300 series or braided shielding, all of which are possible materials from the latch valves. The only

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exception was the PH stainless, which could have come from the **filter housing** (15-5 PH) of the latch valve. Note that when a valve is certified clean, IPA is flowed through the valve for two minutes prior to taking a sample. Comparing the first 1000 mL to the certified clean standard is a very conservative approach. The valves did not show any sign of leakage performance degradation. While the spare valves tested were not affected by the presence of these particles, Moog cannot rule out some form of contamination as a root cause for the six valves in question.

- B. Vibration testing of two spare latch valves to determine if the valves are damaged in any way: See attached MRA16475 summary matrix. The two latch valves (SN007 and SN022) were vibration tested in the open condition (see item D below) while mounted in the “stacked” GMA configuration. The GMA level random vibration spectrum was the test input. The valves were cycled and leak tested after each axis. The testing did reveal that the upper valve was subjected to vibration levels of ~40 Grms. The valves did not show any sign of leakage performance degradation or any other valve performance degradation. Since the two spare valves and the majority of the GMA valves continue to perform within specification, Moog does not believe that the vibration testing was a root cause. However, the vibration testing could be coupled with a contamination issue, i.e., vibration freed trapped contamination.

Two Mott flow restrictors were also exposed to vibration testing. The restrictors were then sampled for particles. No metallics were generated from exposure to the vibration environment indicating that the sintered material was not damaged and did not shed. The particle counts were high on one unit, but this is attributed to the sampling technique. The technique was altered on the second unit, which indicated a very “clean” unit. The Motts are not viewed as a source of contamination.

- C. Investigate helium background of GMA and test methodology: See the attached GMA Latch Valve Internal Leakage Fault Analysis matrix. A calibrated leak device (1.5E-05 sccs GHe) was plumbed into the GMA at the GMA vent line. The mass spectrometer was capable of measuring the calibrated leak. The calibrated leak device was subsequently removed from the GMA vent line. Also, the sequence in which valves are leak tested and evacuated to testing was found to have some affect on the leakage measurements when measuring the internal leakage of individual valves. Subsequent testing instructions addressed this issue. However, the magnitude of this adjustment was minor and is not considered a cause for the excessive leak rates.
- D. Review the build paperwork and As-Built-Configuration-Records (ABCRs) from all the valves: All the build data was reviewed to determine if there was any trend in the data to suggest that the valves in question had something in common that would point to a root cause. No trend could be identified with regard to:
- Material/part lots, i.e., material/poppet lots from the valves in question were also used in valves with leakage two orders of magnitude better. This included the poppets, outlet fittings (seats), armatures, poppet springs and cores.
 - Build/performance parameters, e.g., spring preload, valve and poppet stroke, latching force, response, pull-in current.

A trend with regard to weld reworks was noted for valves V27, V28 and V29. All valves except V1 and V2 had the filter body weld reworked. However, V27, V28 and V29 were reworked twice, which exposed these valves to an additional deburring operation. The handling of these valves was consistent with other rework operations. Another trend associated with these particular valves is the fact that they are located in the vent line. The vent line is the primary purging line for GMA testing. This level of gas throughput may offer more opportunity for contamination of the valves. Beyond identifying these trends, no other conclusions were drawn.

The only other trend identified is the valve open/close status and position in the mounting brackets during vibration testing. The V4/V6 pair, V27 and V29 indicated leakage performance problems prior to vibration. However, V11, V15, V27 were open during vibration and located in the upper portion of the mounting bracket. It is important to note that V11 and V15 have a history of intermittent leakage performance, which implies that any

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acceptable leakage data taken prior to vibration was a random occurrence. Additional testing prior to vibration testing may have revealed unacceptable values, as well. V21 was located in the upper portion of the bracket, but was closed during vibration. Also, the valve had acceptable leakage values immediately after vibration testing.

Valve Location	Open/Close Status During Vibration/Launch	Mounting Bracket Location	Non-Conforming Valve
V1	Closed	Lower	
V2	Closed	Lower	
V3	Closed	Upper	
V4	Closed	Upper	X (paired with V6)
V5	Closed	Lower	
V6	Closed	Lower	X (paired with V4)
V7	Open	Upper	
V8	Open	Lower	
V9	Closed	Upper	
V10	Closed	Lower	
V11	Open	Upper	X
V12	Open	Lower	
V13	Closed	Upper	
V14	Closed	Lower	
V15	Open	Upper	X
V16	Open	Lower	
V17	Closed	Upper	
V18	Closed	Lower	
V19	Open	Upper	
V20	Open	Lower	
V21	Closed	Upper	X
V22	Closed	Lower	
V23	Open	Upper	
V24	Open	Lower	
V25	Closed	Upper	
V26	Closed	Lower	
V27	Open	Upper	X
V28	Open	Lower	X
V29	Closed	Upper	X
V30	Closed	Lower	

- E. Investigate the weld assembly process of the GMA latch valve sub-assemblies as a source of contamination: See attached MRA16475 summary matrix. Using valves SN007 and SN022, Moog welded a mini-assembly per C78437 using the same processes and procedures used when welding the GMA latch valve quad and double valve sub-assemblies. This included not protecting the weld process from potential handling contamination from the latch valve lead wire shielding (It was noted during the GMA build that the shielding harbored contaminants. After this was noticed, the shielding was bagged to reduce risk of contamination). Immediately after assembly, the leakage performance of both valves measured ~1.0E-05 sccs GHe. After cycling, the valve leakage performance improved and returned to a level of leakage consistent with the component level leakage performance. However, the internal leakage performance of SN007 did present a general shift from the 1.0E-07 sccs GHe range to the 1.0E-06 sccs GHe range. Valve SN022 did not present this same performance shift. The assembly was also sampled for cleanliness. The particle analysis is detailed in the above discussion.

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While the investigation of the integration process did not lead to a repeat of permanent internal leakage performance degradation on par with the GMA valves, Moog cannot rule this item out as a root cause.

- F. Investigate the potential degradation of the Vespel poppet material as a result of exposure to vacuum and helium at elevated temperatures (104 F to 140 F): During the build of the GMA latch valves, Moog observed that the %-elongation of Vespel might have an affect on the sealing characteristics of the latch valve poppet. The theory with regard to %-elongation is that the lower the % elongation, the more "brittle" or less compliant the Vespel material is for sealing purposes. A concern was raised that the Vespel could be affected by long-term exposure vacuum (via outgassing of Vespel constituents) and/or helium in such that that the %-elongation of poppets in the valves could be affected, or otherwise embrittled, in such a way to degrade leakage performance of SN007. To investigate this concern, the valve mini-assembly was exposed to vacuum and helium. The valves did not show any immediate sign of leakage performance degradation. **However, additional cycling (500 cycles total, leakage measured at 100 cycle intervals) of the valves per AVO51E265RA20 showed additional degradation in leakage performance. Several internal leakage measurements were in the 1.0E-05 sccs GHe range and one measurement was 2.0E-04 sccs GHe. In an attempt to improve leakage performance, the mini assembly was flushed with 300-psig helium per "AVO-PTK-100402-Latch Valve GHe Flush at 300 psig" in an effort to remove possible contaminants at the valve seat. No change in performance was noted. Next, SN007 was exposed to 300 psig in the closed position for 48 hours while at 145 F per AVO-PTK-GMA Valve Heating, in an attempt to recoin the seat. No change in performance was noted.**

Lockheed Martin (LMSSC) also subjected the poppet material (VESPEL SP-1) to an outgassing test. Below is an e-mail response from Jim Bush from LMSSC regarding the results of this test:

"Jeff Garrett (one of the original designers of the ASTM 1559 test apparatus) runs his own commercial company which runs outgassing tests for a variety of companies. The name of the company is Outgassing Services International in Palo Alto. He has recently tested Vespel SP-1 for a commercial customer. Vespel is seeing some use in GC/MS instruments and high vacuum systems. The test was run at 125 C for a 24-hour period under vacuum conditions of 10⁻⁷ or 10⁻⁸ torr. The results of the test show the following. 1) 99.998% of the outgassing product was water, 2) The VCM for two different runs were 0.001 and 0.002% 3) the outgassing curve was fairly steep with all of the water coming out very rapidly at 125 C and going asymptotic at 24 hours. There was no mass spec data taken to ID the off gassing products but they were at such low levels that the customer did not feel it was important.

Unfortunately since the testing was done for a commercial customer Jeff could not give me a copy of the data since it belongs to that customer. With just the verbal information it was very apparent that with the data that Jeff gave me it would not make sense to run outgassing tests on the material at 40 C or 140 F since the data above was at an even higher temperature and it did not drive off significant outgassing products.

Since outgassing under temperature and vacuum does not seem to be significant the next question is how does helium affect the material and/or does temperature/vacuum cause any changes in physical surface properties, which would affect the shoulder sealing area of the poppet. These questions should be answered in the aging studies you are conducting with the testing at the end."

Moog also performed a Vespel SP-1 aging investigation of vespel samples machined for tensile testing and two poppets. These samples were exposed to vacuum and helium for an extended period of time at temperatures between 104 F and 140 F to "age" the Vespel.

The poppet samples exposed to the vacuum/helium conditions were examined using the Moog Scanning Electron Microscope (SEM). These were compared to two poppets not exposed to vacuum. No difference was noted between the four poppets, e.g., no crazing or other surface disruption. This result agrees with information from Dupont, the manufacturer of Vespel, which states that vacuum/helium exposure would not significantly reduce Vespel properties.

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In the case of the Vespel tensile samples, two different lots (3/8"-OD and 1/4"-OD rod samples) were tested. Two from each lot were exposed to the vacuum/helium environment, while two from each lot were used as control samples. The data from the tensile testing are included in this report. The data indicate a relatively wide spread in tensile strength (UTS= UYS) and %-elongation within a lot of material.

- The 3/8" OD lot of material was certified to a tensile strength of 14,777 psi and %-elongation of 13.3%.
 - The control samples tested: 14296 to 14691 psi and 10.65% to 11.44%.
 - The test samples tested: 12,338 to 14,306 psi and 5.7% to 8.8%.
- The 1/4" OD lot of material was certified to a tensile strength of 14,396 psi and %-elongation of 10.3%.
 - The control samples tested: 10,615 to 14,664 psi and 4.21% to 13.18%.
 - The test samples tested: 13,254 to 14,031 psi and 6.73% to 6.95%.

In both lots tested, the samples exposed to the vacuum/helium environment exhibited much lower %-elongation values than the %-elongation recorded in the vendor material certifications. However, the control samples also exhibited %-elongation values both greater and less than the %-elongation recorded in the vendor material certifications. While some variation is expected, this range of variation is larger than typical according to Dupont, especially for the control samples for the 1/4" OD lot. Dupont believes that the large variation was due to specimen geometry and/or measuring technique. Moog M&PE agreed that the variation is related to the geometry of the sub-sized tensile bars. However, Moog cannot rule out variation in material properties as being a contributing factor in leakage performance. Moog also believes that the test was inconclusive in determining that the vacuum/helium exposure played a role in degraded leakage performance.

G. Disassembly of 51E265, SN007 and SN022: Since SN007 displayed a general trend towards degraded leakage performance; the valve was disassembled per the instructions of Moog AVO-GMA-10-18-02 Latch Valve SN007 Removal. Note however, that the valve leakage performance was typically in the mid 1.0E-06 to mid 1.0E-05 sccs GHe range. Upon completion of the disassembly and inspection of SN007, SN022 was also disassembled for comparison. Valve SN022 did not exhibit any shift in performance. The disassembly of SN022 was performed using the same instructions used for SN007.

The outlet weld was machined in such a way as to reduce the potential of machining debris from entering the valve's wetted area. The condition of the outlet fitting/seat, armature/poppet assembly, core pieces and filter were inspected. The following noteworthy observations were recorded. Unless otherwise noted, inspections were performed using 20-30X magnification. Photos of SN007 are included at the end of this report. Photos of SN022 are also included, but these photos are limited to Moog SEM photos since the piece parts generally looked the same except where noted below. All piece parts are in storage at Moog.

1. Outlet fitting/seat:

SN007: appears normal with no obvious leak scratches that could contribute to leakage. Using the Moog SEM, some surface staining of the seat was observed in the approximate area where the poppet seals on the seat. The stains do not appear to alter the surface and are ~10-microns in size. These stains could also be thin films of Vespel transferred from the poppet. This observation is based on the fact that non-metallics/organics appear as dark spots when viewed with the SEM and the fact that the stains are in a circumferential pattern that would correspond to the poppet sealing surface. Location, size and thickness of these stains make it impossible for Moog's equipment to identify the chemical nature of the stains. The EPR o-ring was also in good shape and did not show evidence of nicks, missing material or trapped contamination.

SN022: appears generally the same as SN007 except no stains were observed. The seat also exhibited a scratch that was located outside of the sealing area. The o-ring as was also in good condition.

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2. Outlet core:

SN007: swage appears normal with no evidence of burrs. The surface of the core that contacts the armature face showed signs of polishing/burnishing from repeated cycles. The shape of the burnish marks also suggests that the armature rotates, either due to cycles or from vibration testing (see below).

SN022: swage appears typical. Also exhibited burnish marks from cycling.

3. Inlet core:

SN007: swage appears normal with no evidence of burrs. The surface of the core that contacts the armature face showed signs of polishing/burnishing from repeated cycles, but to a lesser degree than the outlet core.

SN022: appears typical.

4. Armature assembly:

SN007: armature surfaces show polish/burnish marks corresponding to the marks observed on the inlet/outlet cores. The Teflon bearings appeared normal, i.e., no signs of heavy wear or nicks, missing Teflon or trapped contamination. The poppet retainer, coil spring and shims all appeared in nominal condition. No signs of contamination or damage.

SN022: armature presents similar burnish marks. The Teflon bearings, coil spring, shims and retainer appear typical.

5. Poppet:

SN007: The sealing surface of the poppet showed evidence of coining. The poppet was examined in the Moog SEM and compared to a poppet that was never used. The coining was very apparent, but no signs of chipped Vespel at the sealing edge or cracks were observed at high magnification. The poppet was sent to Lockheed Martin in Sunnyvale (Jim Bush) for additional analysis. Lockheed performed some visual inspections of both the SN007 poppet and the unused poppet at even high magnification using a SEM. Both poppets presented surface defects on the order of 20-microns or less at the sealing surface. These features appear as scratches/crevices/cracks and localized high and low spots. The SN007 poppet also presented some areas that appear as long, narrow burrs. Moog does not know how significant these features are to the sealing capability of the poppet other than they probably do have some adverse effect on the local stresses in the poppet. The similarities between the SN007 poppet and the as-machined, but never installed poppet leads Moog to believe that these features do not play a major role in the out of tolerance leakage performance.

A white residue was observed on the poppet shaft immediately upstream of the sealing surface. Moog's attempts to identify the residue were inconclusive. However, the residue appears to have entrapped some 300 series CRES and aluminum. The residue itself also contains traces of zinc and chlorine. Lockheed identified the residue as aluminum silicate in a hydrated form using micro-FTIR and EDS (Lockheed Lab Report, Evaluation of Foreign Residue and Seal-Surface Irregularities on Poppet (Gravity Probe B Program, Lab Request/Job AJ9029). Forms of aluminum silicate are used in many different products. It is commonly identified as a clay, e.g., kaolinite or china clay, and is used as a filler in paint, rubber and plastics and is widely used in the paper industry to produce glossy paper used in magazines. Moog has attempted to identify sources of aluminum silicate in the build and test process, but has been unsuccessful. While this residue is not found on the sealing surface of the poppet, the residue or the particulate trapped in the residue

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could affect the sealing performance of the valve by periodically breaking free from the poppet and relocating at the poppet/seat interface. This could explain the variation in the leakage performance of this valve. No evidence of the aluminum silicate was found anywhere else in the valve.

SN022: The sealing surface of the poppet shows evidence of coining. The inner side of the coined surface appears less uniform than the SN007 poppet. Also the outer surface exhibits a thin circumferential "feather" burr, probably resulting from the coining process. The poppet was examined with the Moog SEM. The sealing edge did not show signs of any damage at high magnification other than localized high and low spots similar to the features seen on the SN007 and unused poppet. No white residue was evident on the poppet or any other piece parts. The poppet has not been viewed with the Lockheed Martin equipment, which can produce images at higher magnification.

6. Valve Housing:

SN007: The housing appeared normal with no evidence of abnormal wear from armature cycling.

SN022: The housing appeared normal with no evidence of abnormal wear from armature cycling.

7. Filter.

SN007: The filter did not show any signs of contamination on the outer or inner surface. The EPR o-ring did present several white particles less than 50-microns in size. Moog FTIR analysis indicated that the particle was a secondary amide, most likely skin. Otherwise the o-ring was not damaged.

SN022: The filter appeared typical. No signs of contamination were observed. The o-ring was in good condition.

8. Filter Housing & Inlet Fitting:

SN007: A large (~200 micron) white particle was adhered to the inner surface of the inlet fitting immediately upstream of the filter. Moog FTIR analysis indicated that the particle was a secondary amide, most likely skin. This is consistent with the particles found on the filter o-ring. Moog cannot verify if this particle was in the valve since assembly or if it was introduced during the disassembly/inspection process. Both processes require personnel to wear cleanroom gloves while handling the hardware.

SN022: The filter and inlet assembly appeared typical. No evidence of contamination was found.

The results from the disassembly and inspection process support the contamination theory as a root cause. The aluminum silicate with entrapped particulate, the skin particle and the white particles located on the filter o-ring are evidence of contamination in the valve.

H. Armature/Poppet Rotation Experiment: A development valve similar to the 51E265 valve was built, but not welded to determine if the armature and/or poppet does rotate during normal valve cycling. Rotation of the sealing surfaces of the poppet relative to the seat could affect sealing performance. The valve housing, armature and poppet were scribed to provide reference points. All three scribe marks were aligned with each other prior to threading the outlet fitting into the valve. The valve was cycled several times. Upon removing the outlet fitting, it was noted that the scribe lines were still aligned. This was repeated several times with the same result. This result is contrary to the burnish marks noted above in the description of the disassembly and inspection of SN007. Nonetheless, Moog does not believe that poppet rotation is cause in degraded leakage performance based on the fact the experiment does not indicate that the poppet does rotate and the fact that there is no history of leakage problems associated with poppet rotation.

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CONCLUSIONS:

The conclusion of the Tiger team meeting in July was that the status of the GMA would be “use-as-is” provided that the performance of the GMA latch valves in question did not degrade further and that no additional valves degraded. The testing up to shipping the GMA to Stanford has demonstrated that this is the case. Despite a great deal of investigation and testing, no clear root cause(s) has been identified for the out of tolerance leakage values measured for valves V4/V6 pair, V11, V15, V21, V27, V28, V29. All of the testing performed as a result of these investigations up to the date of GMA shipment (cycle testing, vibration testing, review of build paperwork and ABCRs of all the valves, helium background investigation, weld assembly process investigation, vacuum/helium exposure) did not result in a repeat of the high leakage values that we are observing with the six GMA valves. The Summary/Comments section of the Fault Analysis indicates probable causes for the out of tolerance performance of each valve.

Moog believed that the most likely cause is related to some form of contamination. The exceptions to the contamination theory are the suspect poppet in V4 and the mark recorded on the seat of V15. Also, V11 and V15 present intermittent pass/fail data. We cannot be sure that this behavior was or was not present prior to vibration testing.

Having met the requirement set forth by the Tiger team, Moog recommended a use-as-is disposition for the GMA, which was shipped in September 2002. Moog has continued to work with Stanford University to determine the best ways to mitigate the additional risks associated with the out of tolerance leak rates observed in valves V4/V6 pair, V11, V15, V21, V27, V28, V29 or any other valves that later exhibit this behavior.

The post GMA delivery investigation using spare valves SN007 and SN022 did not result in determination of a root cause or result in any new findings that would change Moog’s belief that the most probable root cause is contamination. However, the post delivery investigation did make the following findings:

- The weld assembly process did result in a temporary increase in leakage rate for SN022 and an order of magnitude shift in leakage performance of SN007 from 1E-07 sccs GHe to 1E-06 sccs GHe and also presented higher leak rate ranging from 1E-05 to 1E-04 sccs GHe. This finding supports a root cause of contamination introduced at the time of integration.
- Variations in Vespel properties may be a contributor to leakage performance. Most notable was the variation in %-elongation of Vespel samples tested. However, test sample geometry may have played a factor in this variation.
- A white residue, identified as aluminum silicate, was found on the poppet of SN007 immediately upstream of the poppet sealing surface. As noted above, this valve also exhibited a shift in leakage performance. This aluminum silicate residue also entrapped particles of aluminum and CRES. The source of this contamination is still unknown. This finding supports the root cause of contamination.

At this point, Moog does not have any reason change the past recommendation for “use-as-is” provided Stanford University implements mitigation efforts to prevent or minimize the effects the excessive leakage from the GMA valves has on regulator lock-up, the downstream science probe and gas purity. Moog will continue to support the mitigation efforts.

MOOG INC. FAILURE ANALYSIS REPORT
(CONTINUATION SHEET)

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CORRECTIVE ACTION:

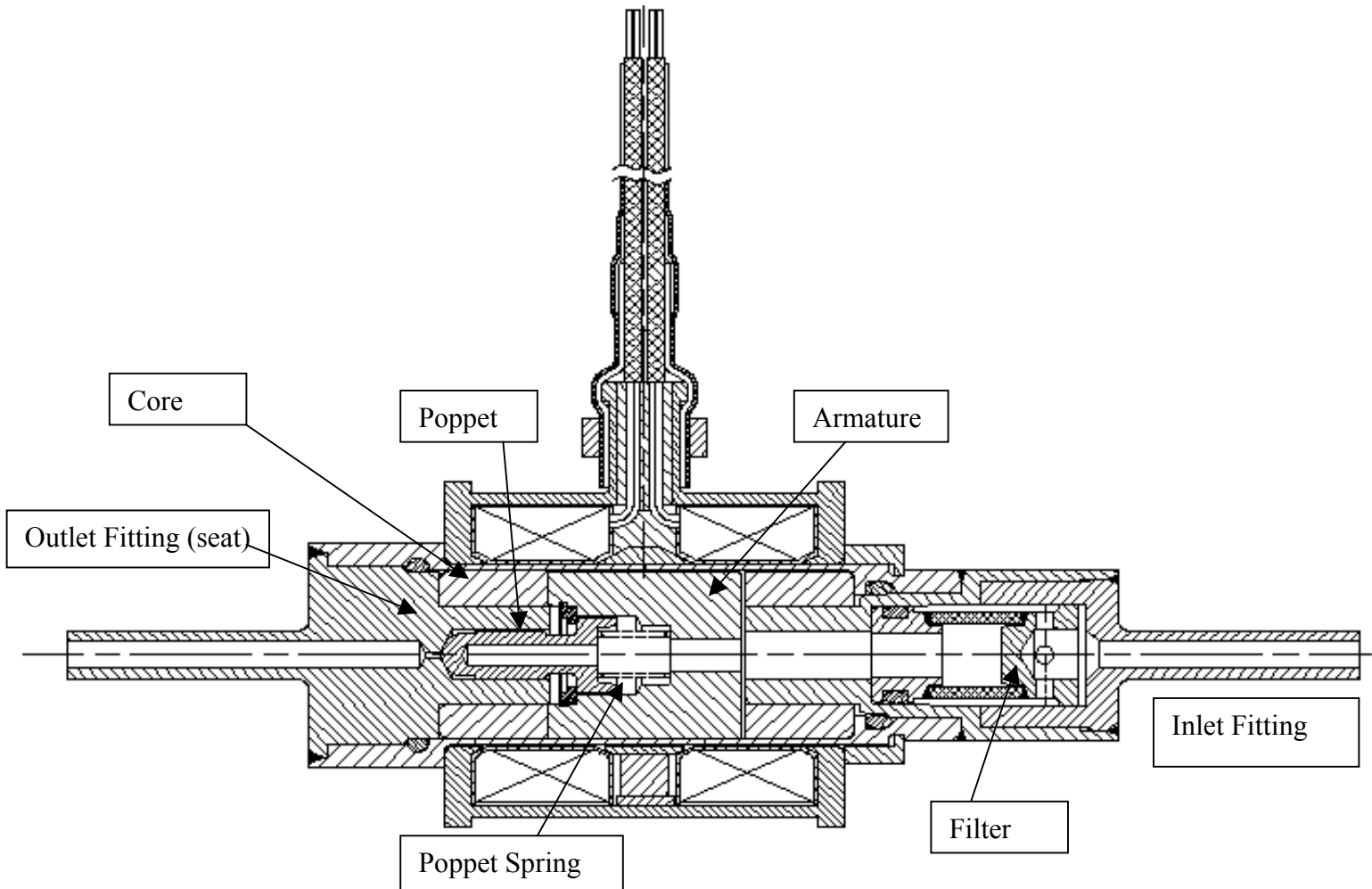
Without a confirmed root cause Moog cannot offer a corrective action for mitigating the latch valve leak rates in excess of 1.0E-04 sccs GHe. The investigations that have been conducted have revealed ways to improve our general processes for building and testing of valves and sub-systems and these will be implemented. These improvements include test methodology and procedure for internal leakage testing of the GMA; proper covering of shielded leads to prevent contamination during assembly and valve cleanliness certification.

DISTRIBUTION:

J. Bowen
J. Bonanno
D. Bushway
D. Finucane
P. King
D. Marten (2)
J. Nayda
K. Neff
B. Vogt
L. Wisher

MOOG INC. FAILURE ANALYSIS REPORT
(CONTINUATION SHEET)

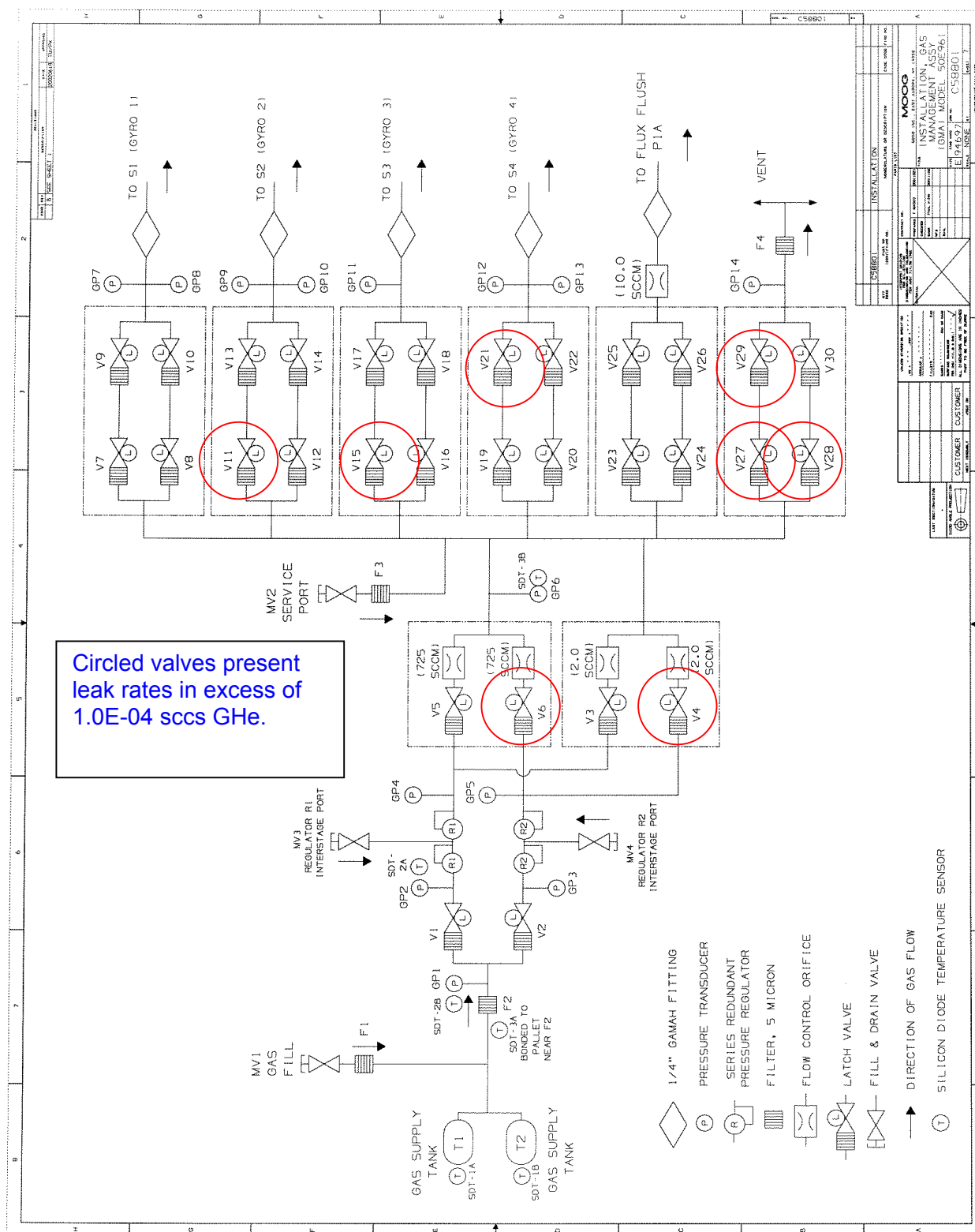
P/N: C58800	S/N: 001	CUSTOMER: Stanford University	FAR NO. FAR(M)-2002-063 Rev A



**GMA: Functional Cross Section of the 51E265
Latch Valve**

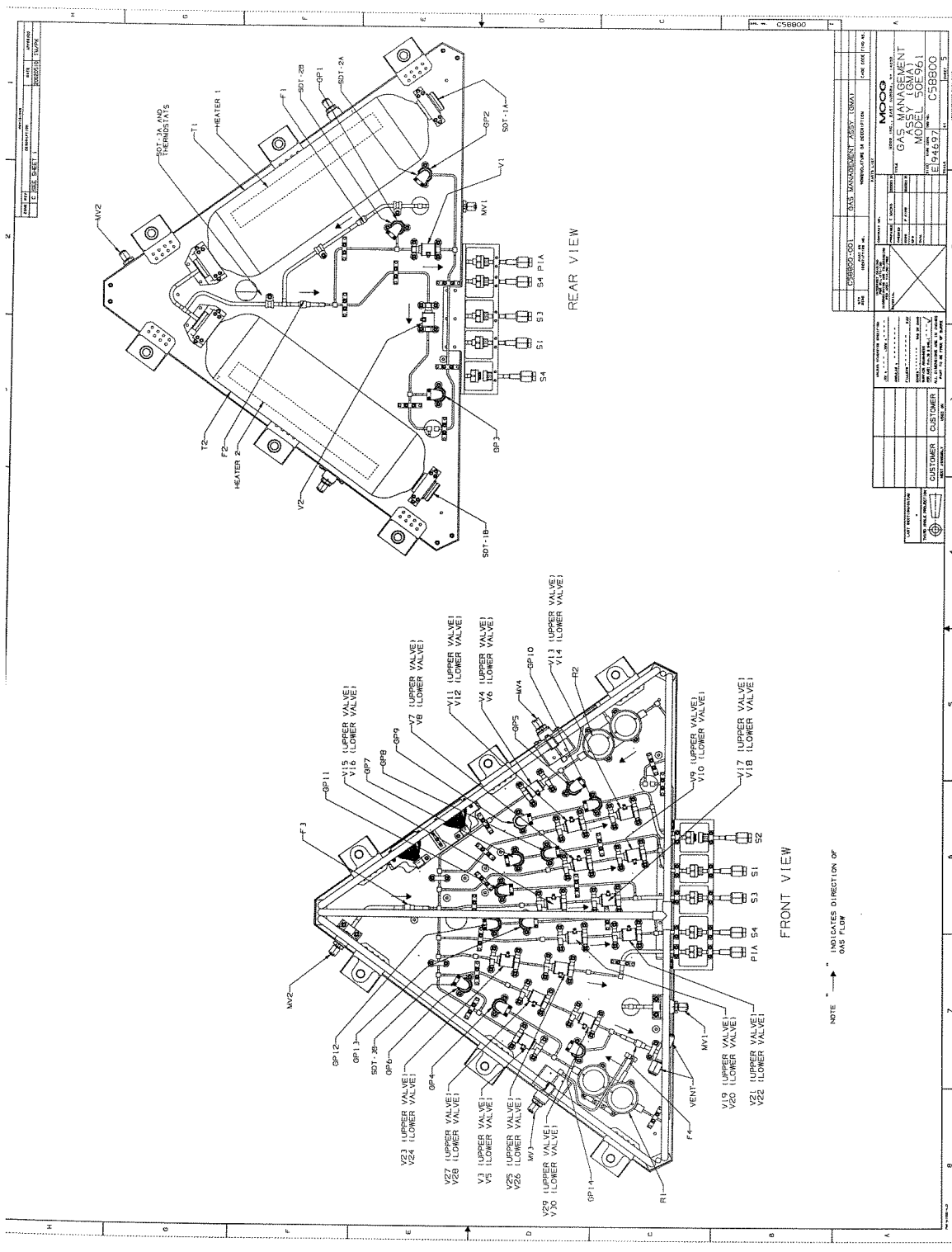
MOOG INC. FAILURE ANALYSIS REPORT (CONTINUATION SHEET)

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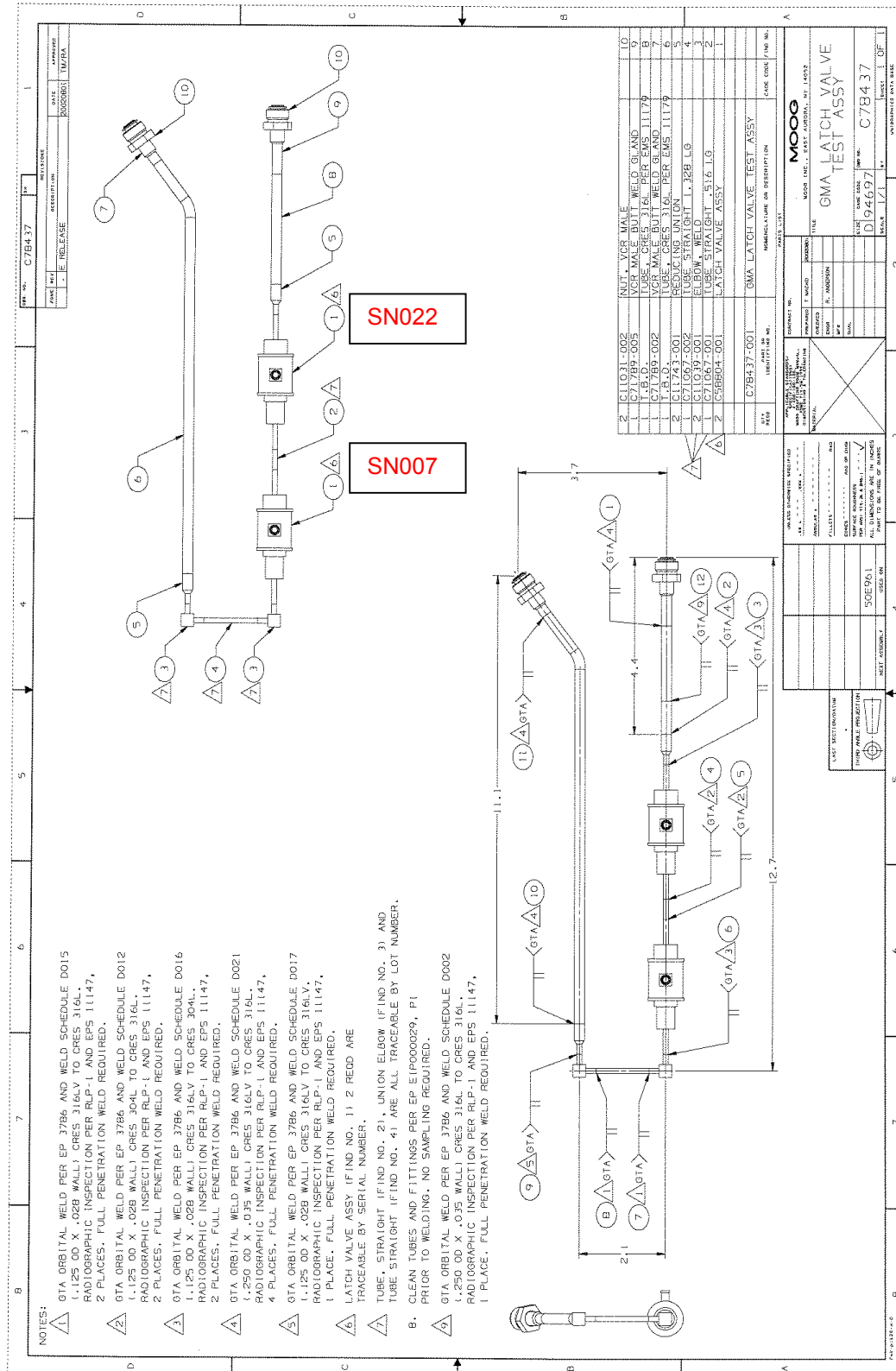
MOOG INC. FAILURE ANALYSIS REPORT (CONTINUATION SHEET)

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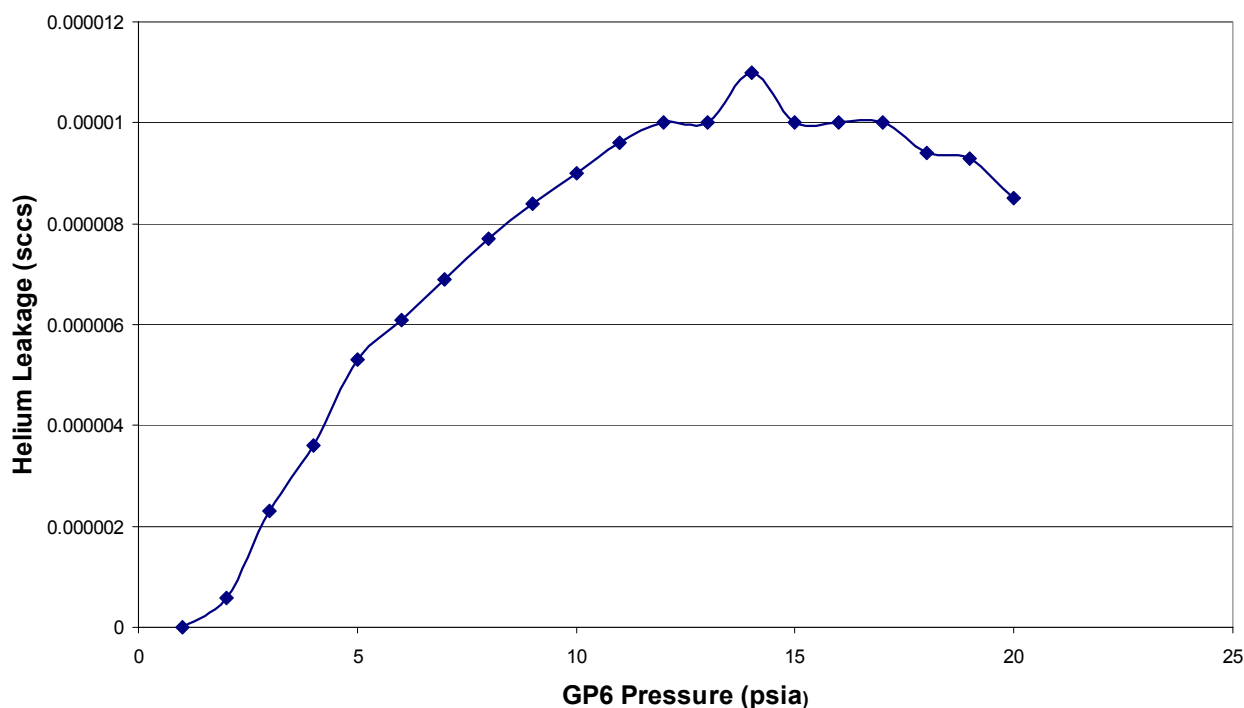


MOOG INC. FAILURE ANALYSIS REPORT
(CONTINUATION SHEET)

P/N: C58800	S/N: 001	CUSTOMER: Stanford University	FAR NO. FAR(M)-2002-063 Rev A

GMA system internal leakage performance as measured at the outlets of GMA lines S1-S4, P1A and Vent, while the GMA latch valves are configured for launch. The aggregate leak rate of the GMA peaked to a value of 1.1E-05 sccs GHe at 14 psia, which is better than the internal leakage rate required for a single valve.

GMA System Internal Leakage in Flight Configuration
As Tested 7/30/02 at Moog Inc. per AVO50E961RA16



MOOG INC. FAILURE ANALYSIS REPORT (CONTINUATION SHEET)

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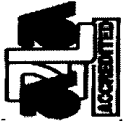
09/09/2002 12:59 17245373151

TENSILE OFFICE

PAGE 02



MATERIAL TESTING LABORATORY
FASTENER TESTING



921-01 & 921-02

Section 1 of 1

WMT&R Report No. 2-31770

P.O. No. 0208120101

WMT&R Quote No. 292247

Packing Slip No. 277039

CERTIFICATION

September 9, 2002

Moog Aircraft Group
Aircraft Group
East Aurora, NY 14052-0018

Attention: Mr. Tim Mascarella

Subject: All processes, performed upon the material as received, were conducted at WMT&R, Inc. in accordance with the WMT&R Quality Assurance Manual, Rev. 9, dated 4/1/2000.
The following tests were performed on this order: TENSILE

TENSILE RESULTS: D638-01

SPEED OF TESTING: 0.2000 in./min.

MATERIAL: Plastic VespeI SP-1

UTS = UYS => VESPEL DOES NOT EXHIBIT
A TRUE YIELD POINT

VespeI Tensile Test Data

- 2 lots of material
- 4 tensile samples from each lot
- 2 control & 2 test samples

DISPOSITION: Report									
Sample	Test Log	Temp.	UTS	Breaking	UYS	UYS Strain	Modulus	Util Load	Break
	Number	F	PSI	Str. PSI	PSI	%	KSI	LBS	Load LBS
3/8 OD-1	794052	Room	14697.99	14691.76	14697.99	10.660	437.28	707.70	707.40
3/8 OD-2	794053	Room	12338.10	12338.10	12338.10	5.7260	419.31	610.50	610.50
3/8 OD-3	794054	Room	14306.54	14298.43	14302.50	8.8430	448.26	707.90	707.40
3/8 OD-4	794055	Room	14820.49	14814.44	14814.44	11.440	418.30	734.50	734.20
1/4 OD-1	794056	Room	14031.96	14031.96	12891.07	6.7328	425.88	287.80	287.80
1/4 OD-2	794057	Room	10615.65	10615.65	10615.65	4.2109	461.25	218.0	218.0
1/4 OD-3	794058	Room	13254.30	13254.30	13254.30	6.9563	454.76	269.50	269.50
1/4 OD-4	794059	Room	14664.42	14664.42	14664.42	13.1851	411.94	300.40	300.40

Machine Number

Orig. Area

Orig. Dia. (in.)

UYL LBS

Break Load LBS

Machine Number

Orig. Area

Orig. Dia. (in.)

UYL LBS

Break Load LBS

Machine Number

Orig. Area

Orig. Dia. (in.)

UYL LBS

Break Load LBS

Machine Number

Orig. Area

Orig. Dia. (in.)

UYL LBS

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UTS = UYS => VESPEL DOES NOT EXHIBIT
A TRUE YIELD POINT

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UNOFFICIAL DATA
NOT APPROVED

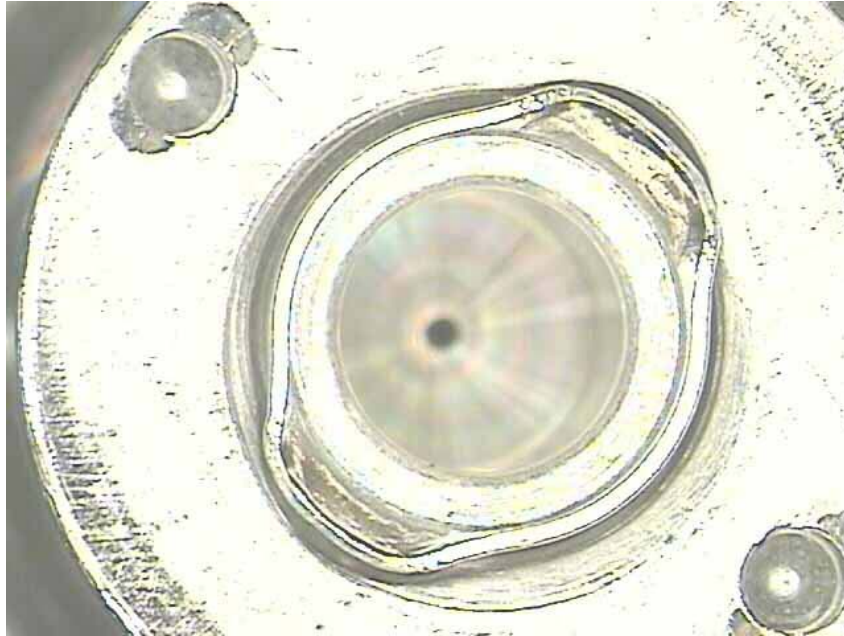
KNOWINGLY OR WILLFULLY FALSIFYING OR CONCEALING A MATERIAL FACT ON THIS FORM OR MAKING FALSE, FICTITIOUS OR FRAUDULENT STATEMENTS OR REPRESENTATIONS HEREIN COULD CONSTITUTE A FELONY PUNISHABLE UNDER FEDERAL STATUTES.
THIS CERTIFICATE OR REPORT SHALL NOT BE REPRODUCED EXCEPT IN FULL, WITHOUT THE WRITTEN APPROVAL OF WMT&R, INC.

9-9-2
September 9, 2002
Roy E. Stanford A. Stape

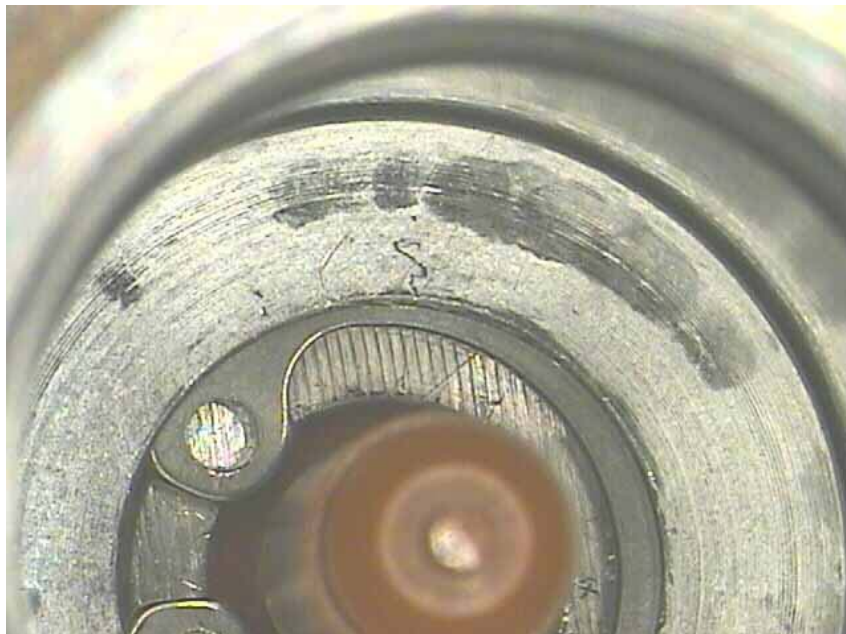
MOOG INC. FAILURE ANALYSIS REPORT
(CONTINUATION SHEET)

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Photos from 51E265 SN007 Disassembly



51E265 SN007 Outlet Core swaged to outlet fitting

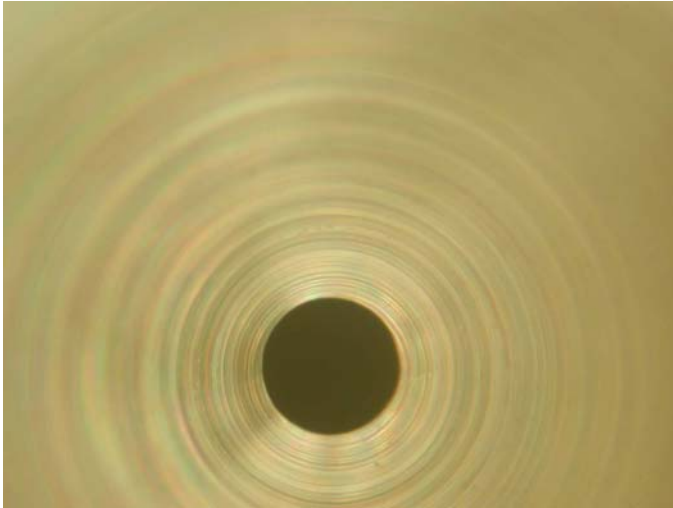


51E265 SN007 Armature Outlet side burnish marks

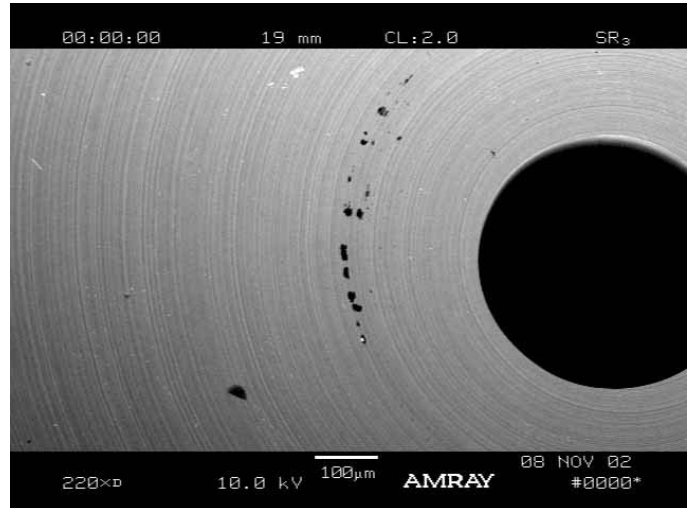
MOOG INC. FAILURE ANALYSIS REPORT
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P/N: C58800	S/N: 001	CUSTOMER: Stanford University	FAR NO. FAR(M)-2002-063 Rev A

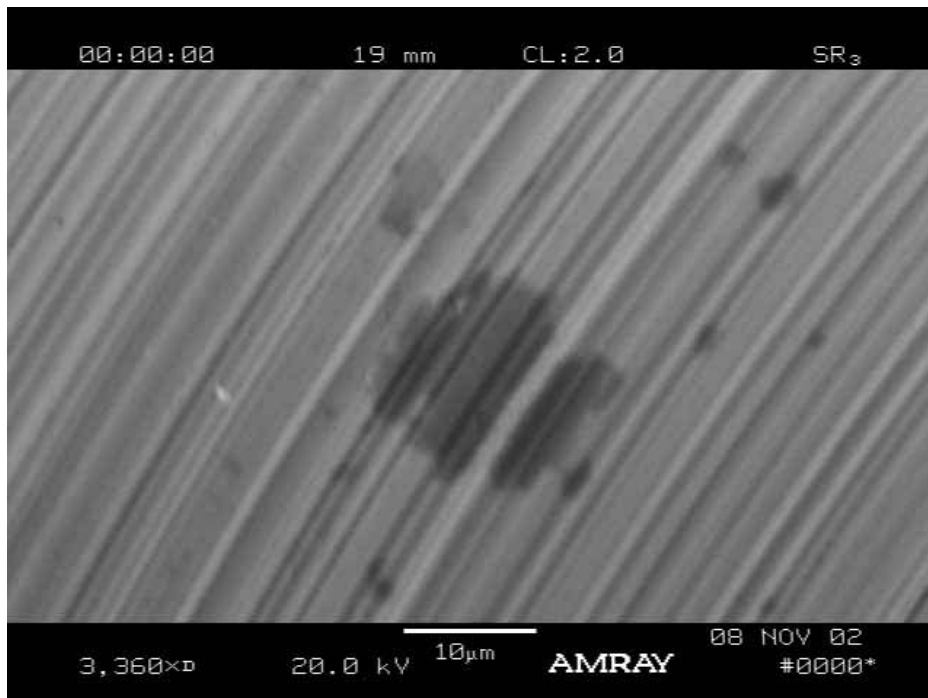
Photos from 51E265 SN007 Disassembly



51E265 SN007 Outlet Fitting Conical Seat with Stains



51E265 SN007 Outlet Fitting Conical Seat Surface Stains viewed with Moog SEM

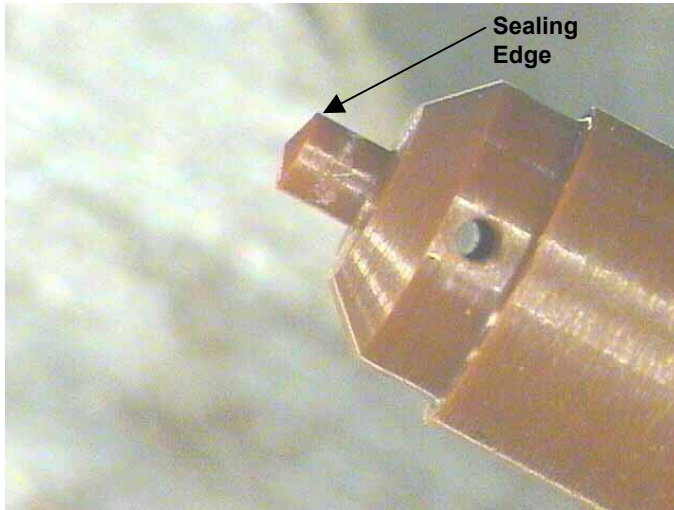


51E265 SN007 Outlet Fitting Conical Seat Surface Stains 2 viewed with Moog SEM

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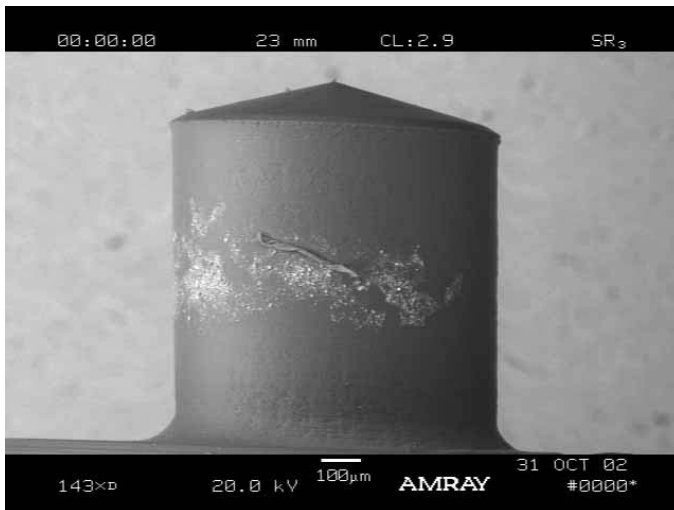
Photos from 51E265 SN007 Disassembly



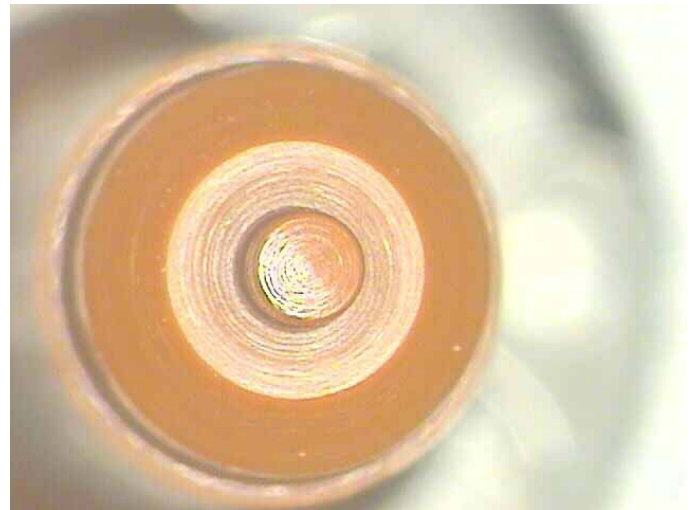
51E265 SN007 Poppet tip showing white residue and flow hole



51E265 SN007 Poppet tip showing white residue (aluminum silicate)



51E265 SN007 Poppet tip viewed with Moog SEM showing white residue and coined sealing edge

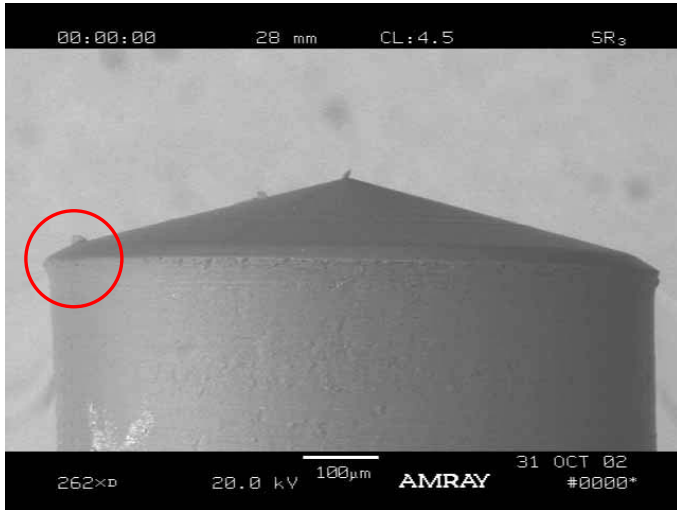


51E265 SN007 Poppet Tip

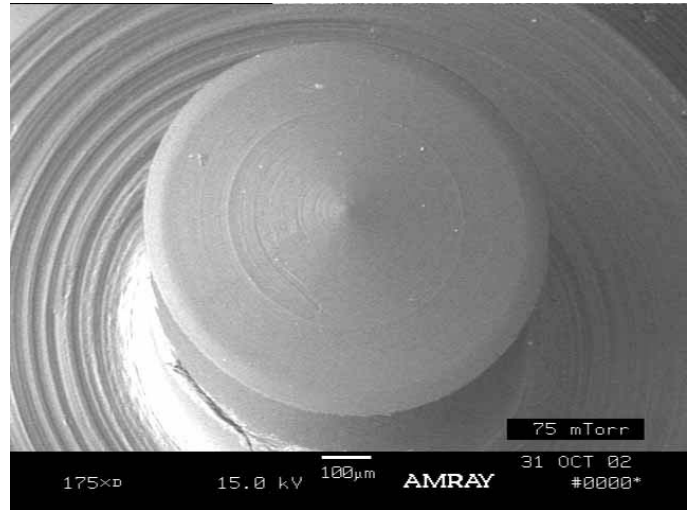
MOOG INC. FAILURE ANALYSIS REPORT
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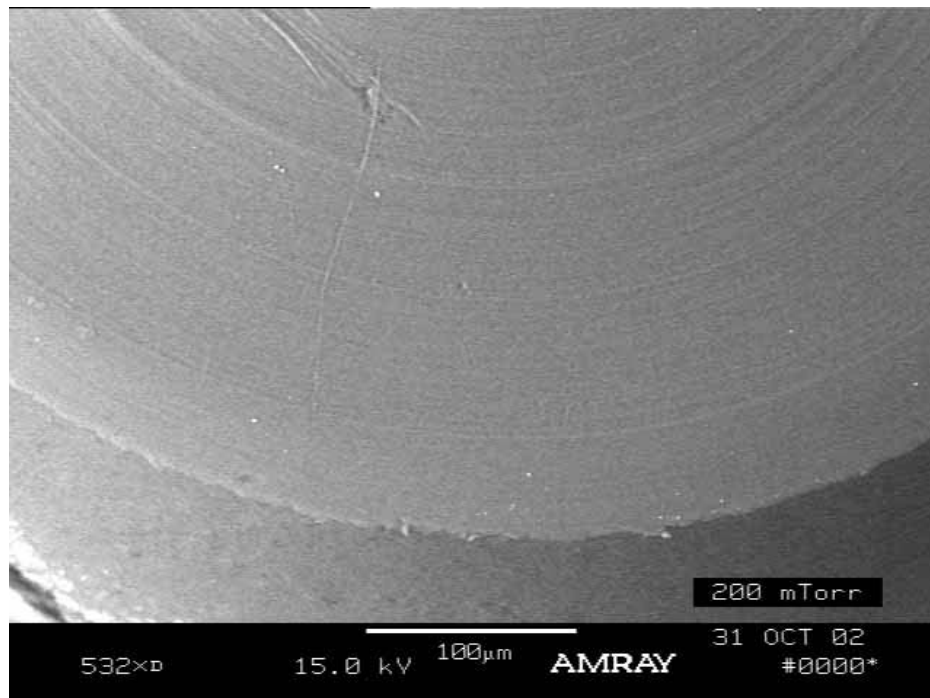
Photos from 51E265 SN007 Disassembly



51E265 SN007 Poppet tip viewed with Moog SEM shows coined edge



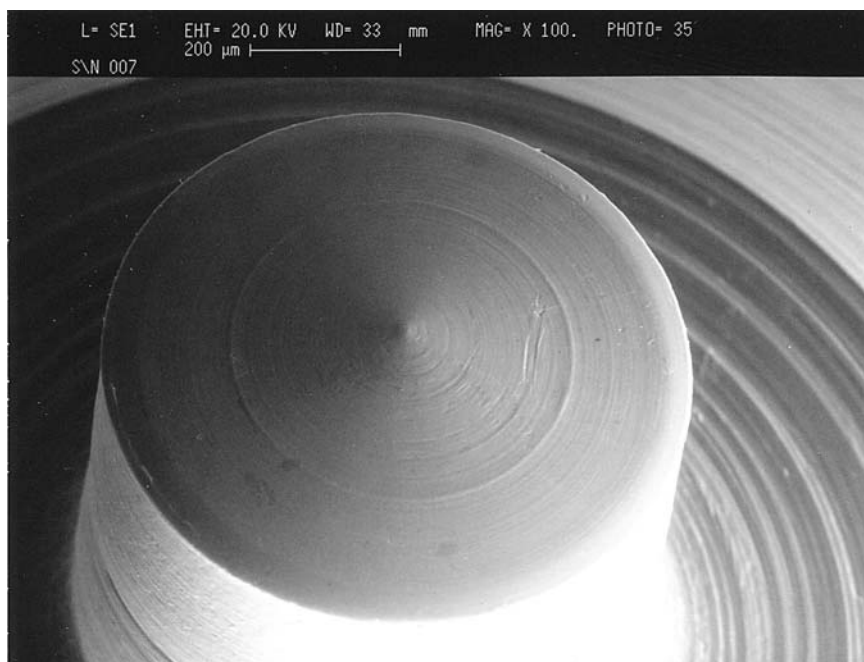
51E265 SN007 Poppet tip viewed with Moog SEM shows coined surface



51E265 SN007 Poppet tip viewed with Moog SEM shows coined edge

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51E265 SN007 Poppet tip viewed with Lockheed Martin SEM



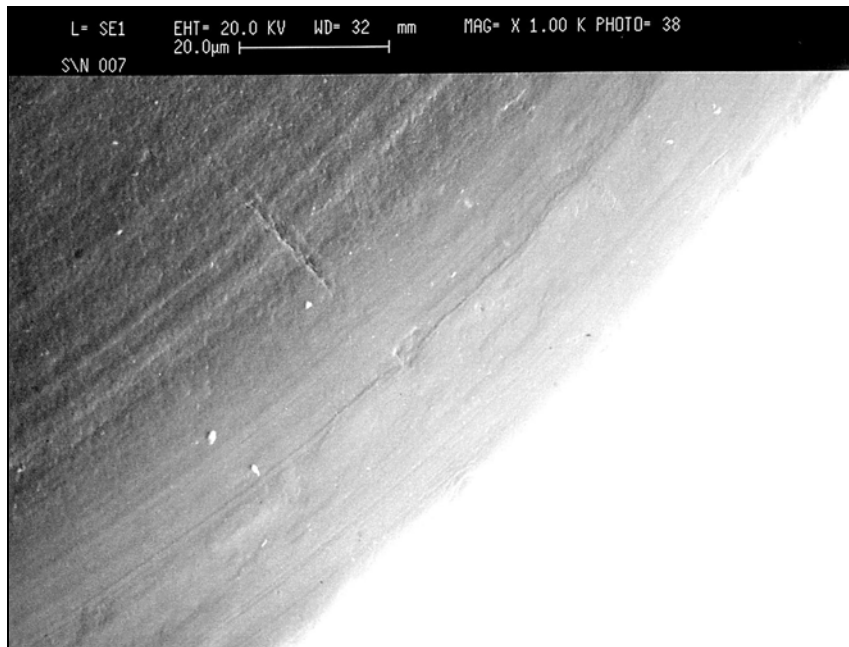
51E265 SN007 Poppet sealing surface viewed with Lockheed Martin SEM. Note scratches.

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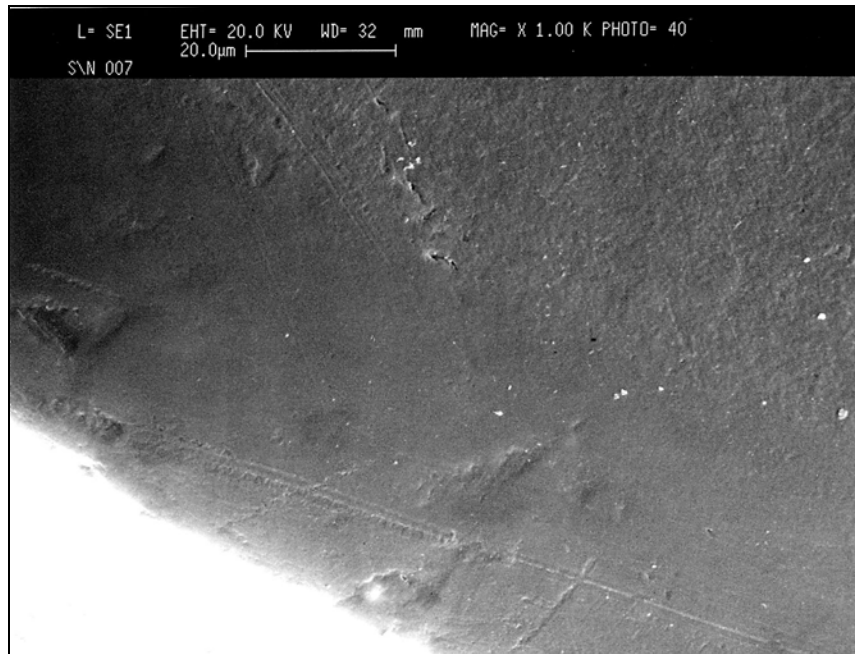
51E265 SN007 Poppet sealing surface viewed with Lockheed Martin SEM. Note burr near sealing edge.



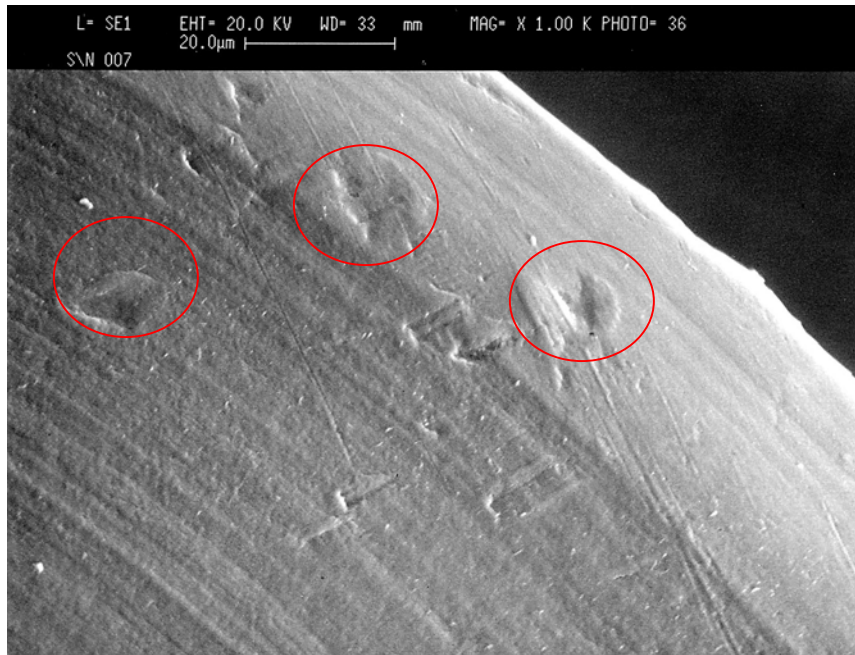
51E265 SN007 Poppet sealing surface viewed with Lockheed Martin SEM. Note localized high and low spots.

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51E265 SN007 Poppet sealing surface viewed with Lockheed Martin SEM. Note localized high and low spots.

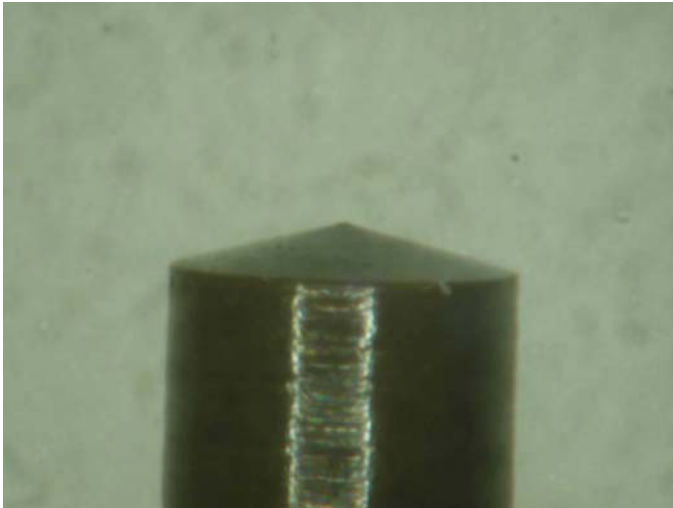


51E265 SN007 Poppet sealing surface viewed with Lockheed Martin SEM. Note localized high and low spots

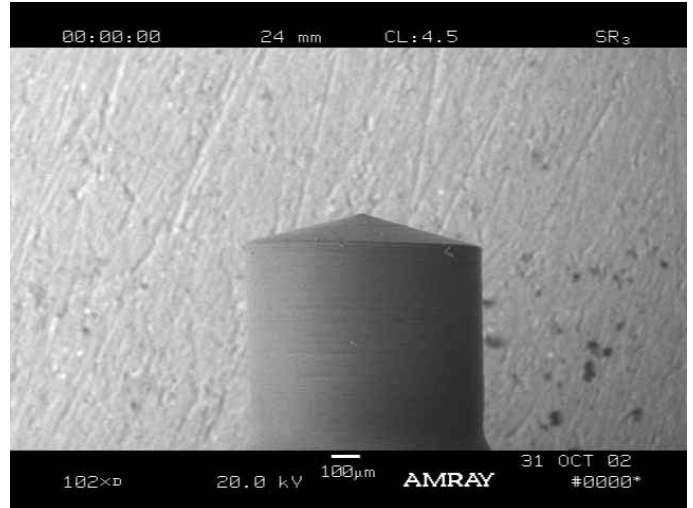
MOOG INC. FAILURE ANALYSIS REPORT
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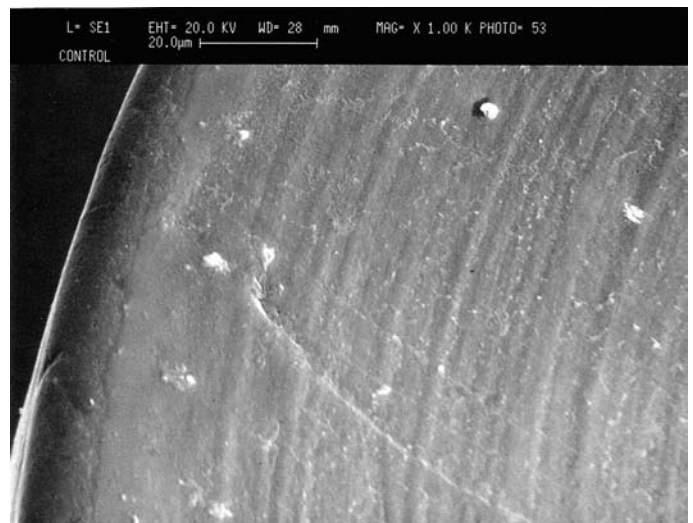
Photos from 51E265 Unused Poppet



51E265 SN007 As Machined Poppet tip – Poppet Never Installed



51E2657 Poppet sealing surface viewed with Lockheed Martin SEM. Poppet never installed.



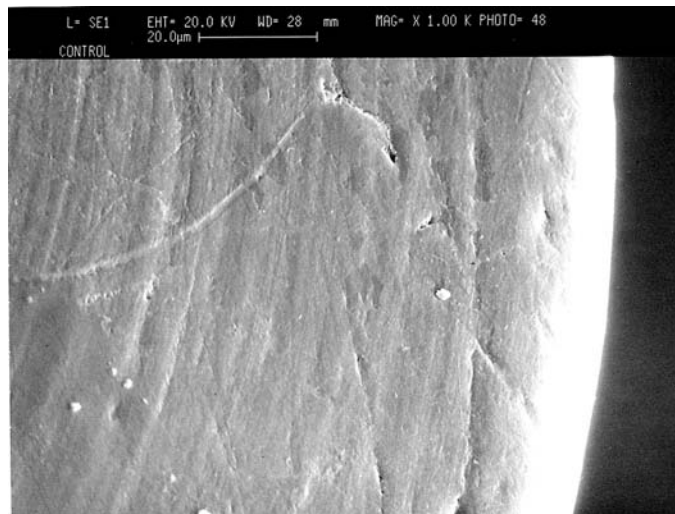
51E265 Poppet sealing surface viewed with Lockheed Martin SEM. Note localized high and low spots and scratches. Poppet never installed.

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(CONTINUATION SHEET)

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51E265 Poppet sealing surface viewed with Lockheed Martin SEM. Note localized high and low spots and scratches. Poppet never installed.

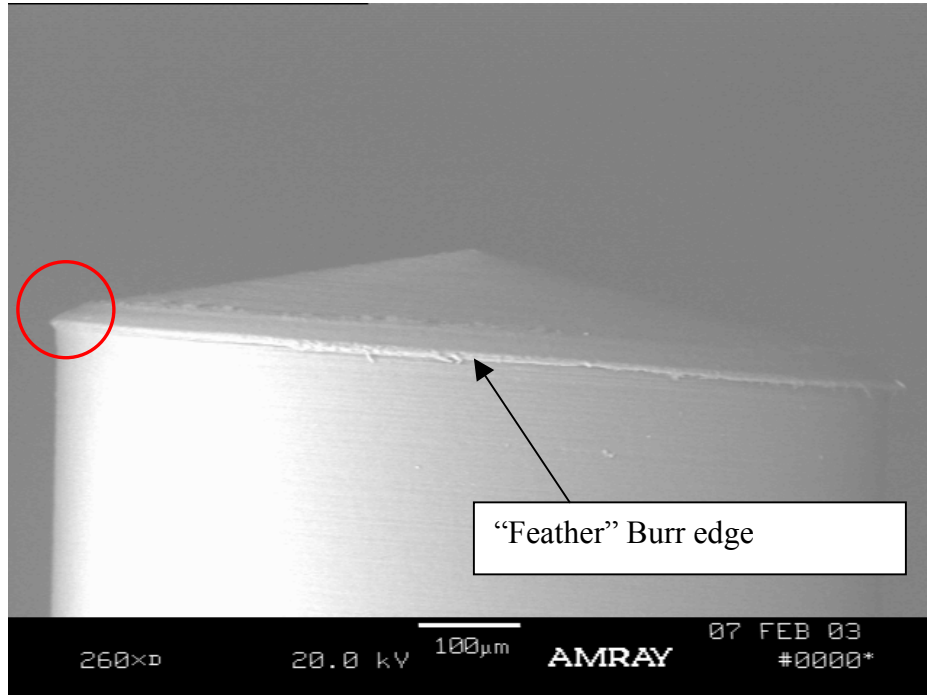


51E265 Poppet sealing surface viewed with Lockheed Martin SEM. Note localized high and low spots and scratches. Poppet never installed.

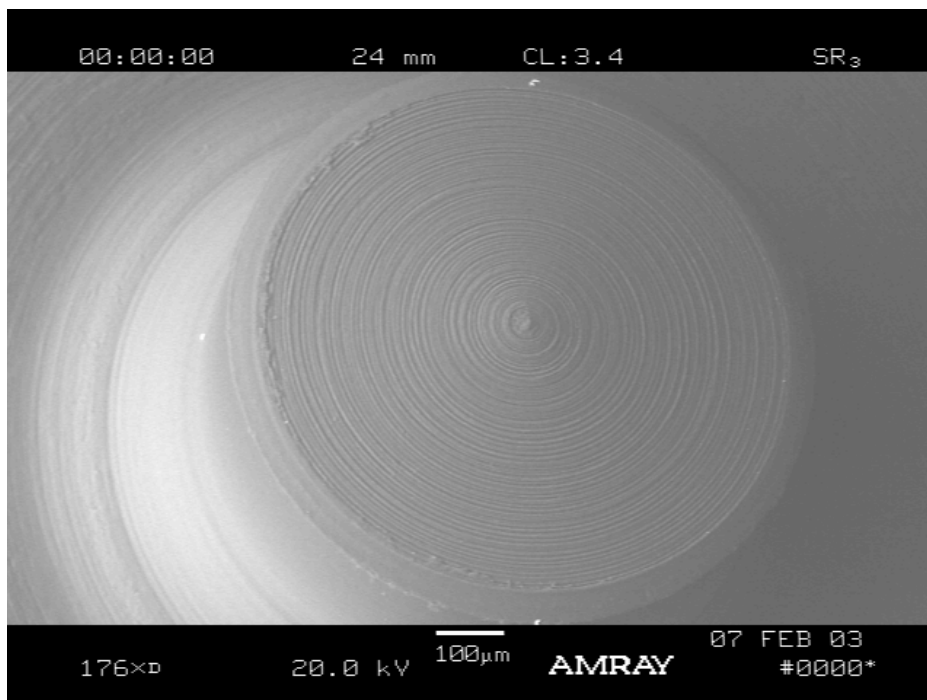
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SN022 Poppet



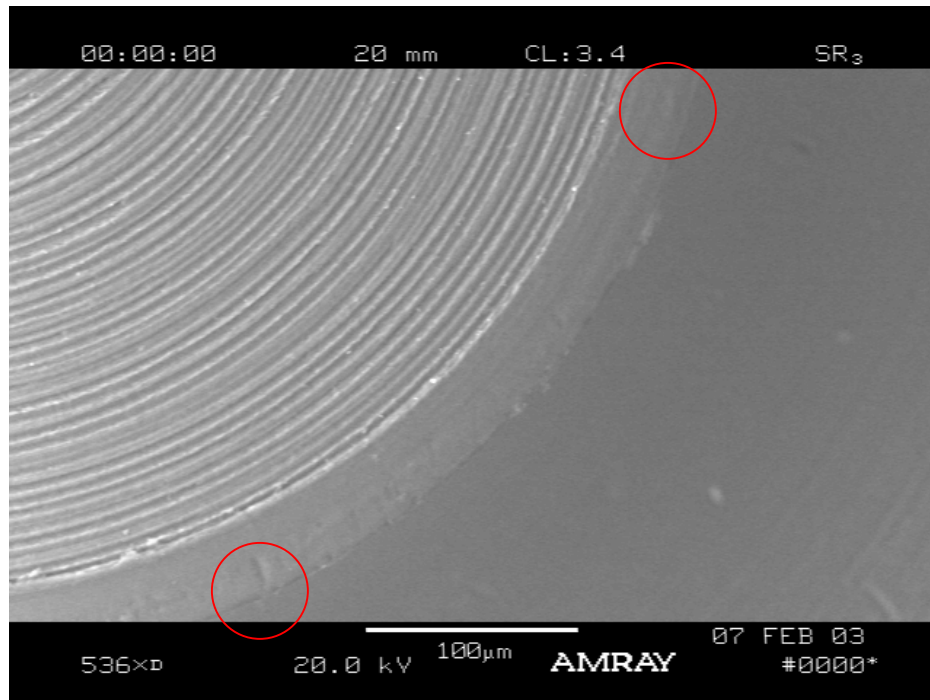
51E265 SN022 Poppet tip viewed with Moog SEM shows coined edge



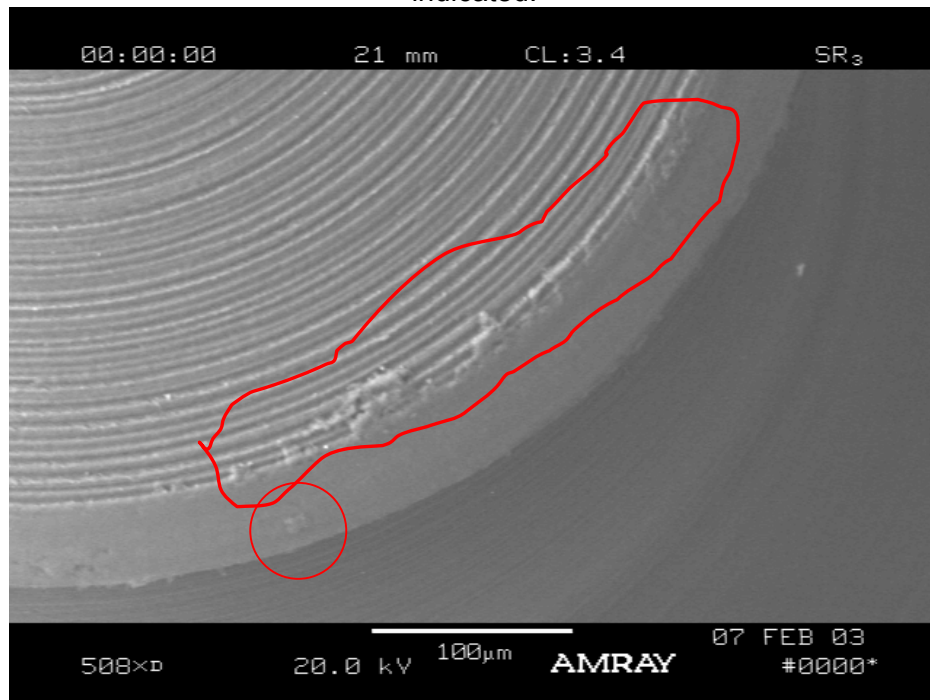
51E265 SN022 Poppet tip viewed with Moog SEM shows coined edge

MOOG INC. FAILURE ANALYSIS REPORT
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51E265 SN022 Poppet sealing edge as viewed with Moog SEM. Some surface defects are visible as indicated.



51E265 SN022 Poppet sealing edge as viewed with Moog SEM. Some surface defects are visible. Also inner coining edge is not as uniform as SN007 poppet

	Valve	Post Proof Internal Leakage Check (6-1-02)	Comment	Post Electrical Integration Internal Leakage Check (Bubble/Min, inverted test tube test) 6-21-02	Post Vibration Internal Leak Rate (scsccs GHe) 6-28-02 (AVO50E961RA04)	Post Vibration Internal Leak Test (scsccs GHe) 6-29-02 (AVO50E961RA05)	Post Vibration Internal Leak Test (scsccs GHe) 7-2-02 (AVO-PTK-070102-Repeat Internal Leakage testing of GMA Latch Valves)
	Limit	scsccs GHe (see comment)		< 1 Bubble/Minute	< 1 X 10 ⁻⁴ scsccs GHe	< 1 X 10 ⁻⁴ scsccs GHe	< 1 X 10 ⁻⁴ scsccs GHe
R1	V1	5.60E-05	Measured V1 & V2 at same time. LR < 2 E-4 scsccs GHe Required.	0		2.50E-05	1.40E-05
R2	V2			0		2.60E-05	1.60E-05
R1	V3 & V5	1.30E-04	Measured V3, V4, V5 & V6 at same time. LR < 4 E-4 scsccs GHe Required.	0		1.70E-05	2.20E-05
R2	V4 & V6			0		1.20E-04	8.40E-05
S1	V7	2.30E-05	Measured V7, V8, V11, V12, V15, V16, V19, V20, V23, V24, V27 & V28 at same time. LR < 1.2 E-3 scsccs GHe Required.	0		1.70E-06	3.00E-06
S1	V8			0		1.40E-06	3.00E-06
S1	V9	2.40E-04	Measured V9, V10, V13, V14, V17, V18, V21, V22, V25, V26, V29 & V30 at same time. LR < 1.2 E-3 scsccs GHe Required.	0		1.00E-06	3.00E-06
S1	V10			0		9.80E-07	3.00E-06
S2	V11			0		1.80E-04	3.10E-06
S2	V12			0		1.80E-06	3.10E-06
S2	V13			0		2.10E-06	3.10E-06
S2	V14			0		2.10E-06	3.10E-06
S3	V15			0		1.50E-03	1.60E-05
S3	V16			0		1.50E-06	8.70E-06
S3	V17			0		1.20E-06	2.70E-06
S3	V18			0		1.40E-06	2.00E-06
S4	V19			0		1.40E-06	3.40E-06
S4	V20			0		2.40E-06	4.30E-06
S4	V21			0		1.10E-06	2.30E-06
S4	V22			0		1.00E-06	2.60E-06
S3	V23			0		1.30E-06	2.90E-06
S3	V24			0		2.40E-06	2.90E-06
S3	V25			0		9.90E-07	1.40E-06
S3	V26			0		1.40E-06	1.40E-06
Vent	V27			0	2.60E-04	1.40E-06	1.50E-06
Vent	V28			0.2	2.70E-05	1.30E-06	3.30E-06
Vent	V29			0.8	1.00E-04	2.20E-05	2.30E-05
Vent	V30			0	4.30E-05	3.30E-05	6.90E-06
	System Internal Leakage (V9,V10,V13,V14,V17,V18,V19,V20,V25,V26,V29,V30)						
	System Internal Leakage (V9,V10,V13,V14,V17,V18,V19,V20,V25,V26)						

Moog Comments:

- 1) Latch valve design qualified to 17 Grms random vibration.
- 2) No evidence of post vibration leakage problems with past valves (2 qualification valves, 5 DS-1 valves, 3 PMA valves).
- 3) V11 & V15 were open during vibration. Reduces possibility that poppet was affected by vibration testing.
- 4) In general, valves were cycled 2-10 times between tests.
- 5) For repeated internal leakage testing on 7-1-02, background measured 1.4E-5 scsccs GHe. Background reading was taken with LV 1 and LV2 closed. No GHe in tanks. All other valves open and under vacuum. Note that when tanks were filled with 200 psia GHe, the leakage rate of LV1 was 1.4E-5 scsccs GHe, i.e., no change from background reading. This suggests that the leakage across the valve was really less than 1.4e-5 scsccs GHe.
- 6) GP6 measured approx. 5-6 psia after vibration testing. Was this from air leaking in from the vent line or from GHe leaking from V3-V6?
- 7) All other 15 psia pressure transducers measured at approx. 0 mV (0 psia) after vibration testing.
- 8) All leakage testing performed at approx. 21 psia unless otherwise noted.
- 9) AVO50E961RA12calibrated leak of 1.58E-05 scsccs GHe plumbed at the vent tee was detected as a 1.5E-05 scsccs GHe leak by the mass spectrometer. GDS is not affecting the leak rate measurement.
- 10) V1 & V2 typically tested at 1800-2000 psia
- 11) V3-V30 typically tested at 20-21 psia except V3-V6could be tested at 300 psia per AVO instructions.

Post Vibration Cycle & Internal Leak Test (scs GHe), Cycle 1, 7-2-02 (AVO-PTK 070102-Cycle and Internal Leakage Testing)	Post Vibration Cycle & Internal Leak Test (scs GHe), Cycle 2, 7-2-02 (AVO-PTK 070102-Cycle and Internal Leakage Testing)	Post Vibration Cycle & Internal Leak Test (scs GHe), Cycle 3, 7-2-02 (AVO-PTK 070102-Cycle and Internal Leakage Testing)	Post Vibration Cycle & Internal Leak Test (scs GHe), Cycle 4, 7-2-02 (AVO-PTK 070102-Cycle and Internal Leakage Testing)	Post Vibration Cycle & Internal Leak Test (scs GHe), Cycle 5, 7-2-02 (AVO-PTK 070102-Cycle and Internal Leakage Testing)	Post Vibration Cycle & Internal Leak Test (scs GHe), 300 psia, 7-9-02 (AVO-GMA-PTK-070302-High Pressure Leakage testing of V3-V6)	Post Vibration Cycle & Internal Leak Test (scs GHe), 7-12-02 (AVO50E961RA07)	Post Vibration Internal Leakage Test per PTP (Valve Pairs tested) 7-17-02
< 1 X 10 ⁻⁴ sccs GHe	< 1 X 10 ⁻⁴ sccs GHe	< 1 X 10 ⁻⁴ sccs GHe	< 1 X 10 ⁻⁴ sccs GHe	< 1 X 10 ⁻⁴ sccs GHe	< 1 X 10 ⁻⁴ sccs GHe	< 1 X 10 ⁻⁴ sccs GHe	< 1 X 10 ⁻⁴ sccs GHe
							5.20E-05
					6.90E-05		2.80E-05
					1.10E-04	2.80E-04	1.60E-04
							1.60E-05
							8.50E-06
4.00E-06	2.30E-06	2.20E-06	2.20E-06	2.40E-06			3.00E-05
							1.10E-05
9.00E-05	3.00E-05	6.60E-05	1.20E-05	1.20E-04			1.10E-05
							7.80E-06
2.20E-06	1.70E-06	1.80E-06	1.60E-06	1.80E-06			1.00E-05
							6.50E-04
2.40E-06	1.90E-06	1.90E-06	1.70E-06	1.90E-06			1.00E-05
							8.50E-06
							2.00E-04
							2.60E-04

Post Vibration Internal Leakage Test per PTP (V3-V6 only) all four valves 7-17-02	Post Vibration Internal Leakage Test (sccs GHe) 7-19-02 (AVO50E961RA11)	Post Vibration Internal Leakage Test (sccs GHe) 7-19-02 (AVO) Cycled Valve	Post Vibration Internal Leakage Test (sccs GHe) 7-19-02 (AVO) Cycled Valve	Post Vibration Internal Leakage Test (sccs GHe) 7-27-02 (AVO50E961RA13)	Post Vibration Internal Leakage Test (sccs GHe) 7-29-02 (AVO50E961RA14)	Thermal Cycle -49 C GMA System Internal Leakage per PTP	Thermal Cycle +40 C GMA System Internal Leakage per PTP
< 1 X 10 ⁻⁴ sccs GHe	< 1 X 10 ⁻⁴ sccs GHe	< 1 X 10 ⁻⁴ sccs GHe	< 1 X 10 ⁻⁴ sccs GHe	< 1 X 10 ⁻⁴ sccs GHe	< 1 X 10 ⁻⁴ sccs GHe	< 1.4 X 10 ⁻¹ sccs GHe	< 1.4 X 10 ⁻¹ sccs GHe
	4.30E-05			1.60E-05 3.90E-05	6.70E-07 1.50E-05		
9.20E-05	4.30E-05			3.10E-05			
	2.10E-04	1.20E-04		1.00E-04			
				9.80E-07 9.10E-07			
				2.40E-07 2.90E-07 2.40E-05 1.20E-06 4.20E-06 7.70E-07 2.40E-05 1.40E-06 5.00E-07 9.80E-07 1.20E-06 9.40E-07			
	6.10E-04 2.10E-06	6.30E-04 2.00E-06	5.10E-04	4.40E-04			
				1.10E-06 1.10E-06 1.20E-06 5.00E-07 7.10E-07 3.20E-04 1.20E-05 5.20E-05 1.20E-04			
						9.70E-05	6.00E-05
						5.60E-06	2.40E-06

Thermal Cycle 0 C Internal Leakage Test per PTP (Valve Pairs tested except V3-V6) 8-8-02	Thermal Cycle +40 C Internal Leakage Test per PTP 3.9.4 (Valve Pairs tested except V3-V6) 8-12-02	Thermal Cycle Ambient Internal Leakage Test per PTP 3.11.3 (Valve Pairs tested except V3-V6) 8-14-02	Thermal Cycle Ambient Internal Leakage Test per AVO (Valve Pairs tested except V3-V6) 8-16-02	GMA Line	Valve	Comment
< 1 X 10 ⁻⁴ sccs GHe	< 1 X 10 ⁻⁴ sccs GHe	< 1 X 10 ⁻⁴ sccs GHe	< 1 X 10 ⁻⁴ sccs GHe		Limit	
2.30E-05	6.80E-05	5.20E-05	2.60E-05	R1	V1	Closed during vibration testing
			4.50E-05	R2	V2	Closed during vibration testing
			1.20E-05	R1	V3 & V5	Closed during vibration testing. Leakage rate for two valves
3.90E-05	5.40E-05	2.00E-04	6.60E-05	R2	V4 & V6	Closed during vibration testing. Leakage rate for two valves
5.50E-06	4.90E-06	1.90E-06	1.90E-06	S1	V7	Open during vibration testing
			1.10E-06	S1	V8	Open during vibration testing
4.30E-06	4.70E-06	5.40E-07	7.50E-07	S1	V9	Closed during vibration testing
1.00E-04	2.90E-05	2.50E-05	8.20E-07	S1	V10	Closed during vibration testing
			2.60E-05	S2		V11 Open during vibration testing.
			1.20E-06	S2		V12 Open during vibration testing
6.20E-06	5.50E-06	7.60E-07	2.50E-05	S2	V13	Closed during vibration testing
			1.10E-06	S2	V14	Closed during vibration testing
4.20E-04	5.10E-06	1.80E-06	1.20E-06	S3		V15 Open during vibration testing.
			1.20E-06	S3		V16 Open during vibration testing
4.20E-06	4.60E-06	3.30E-06	6.40E-07	S3	V17	Closed during vibration testing
			9.40E-07	S3	V18	Closed during vibration testing
4.20E-06	4.80E-06	1.30E-06	9.20E-07	S4		V19 Open during vibration testing
			6.90E-07	S4		V20 Open during vibration testing
5.70E-04	4.50E-04	3.70E-04	2.30E-04	S4	V21	Closed during vibration testing
			1.30E-06	S4	V22	Closed during vibration testing
5.20E-06	4.90E-06	1.40E-06	1.00E-06	S3		V23 Open during vibration testing
			8.60E-07	S3		V24 Open during vibration testing
4.50E-06	4.90E-06	9.10E-07	1.80E-06	S3	V25	Closed during vibration testing
			7.50E-07	S3	V26	Closed during vibration testing
3.00E-04	4.60E-04	1.80E-04	8.00E-04	Vent		V27 Open during vibration testing
			8.00E-05	Vent		V28 Open during vibration testing
9.10E-05	1.20E-04	1.80E-04	1.60E-04	Vent	V29	Closed during vibration testing
			6.20E-05	Vent	V30	Closed during vibration testing
					System Internal Leakage (V9,V10,V13,V14,V17,V18,V19,V20,V25,V26,V29,V30)	Valves selected for best internal leakage performance for launch configuration
					System Internal Leakage (V9,V10,V13,V14,V17,V18,V19,V20,V25,V26)	Valves selected for best internal leakage performance for launch configuration, but does not include vent line

Summary of Mott Contamination Counts before and after Vibration Testing

Particle Size (microns)	Limits per 100 mL sample	C58814-001, SN105 From Stock	C58814-001, SN105 Post Vibration	C58814-002, SN110 From Stock	C58814-002, SN110 Post Vibration		
< 5	unlimited (no silting)	OK	OK	OK	OK		
6 to 15	25	21	130	4	6		
16 to 25	7	5	37	2	2		
26 to 50	1	0	5	0	0		
>50	0	0	0	0	0		

Comments:
 1) Vibrated along with latch valves SN007 & SN022.
 2) No metal found on SN105 patch. High counts on SN105 attributed to sampling technique. Nature of contamination was light colored organics. Technician revised sampling technique to avoid splashing. SN110 sampled with improved technique and passed.
 3) C58814-001 = 2 sccm GHe , C58814-002 = 725 sccm GHe
 4) Moog does see contamination from Motts as a credible cause for degrading latch valve leakage performance.

	Legend					
	Likely		Credible, not likely		Not Credible	
Description of Internal Leakage Nonconformance	V4V6 (SN 004, 008)	V41 (SN021)	V45 (SN 005)	V21 (SN 003)	V27 (SN 023)	V28 (SN 024)
	None per measures 3.0E-05 to 1.2E-04 sccs GHe. No apparent internal leakage was suspect prior to vibration testing.	Valve measured 2.1E-05 to 1.0E-05 sccs GHe. Passing/failing leakage performance was intermittent throughout GMA testing. In general the valve had acceptable internal leakage.	Valve measured 1.1E-05 to 2.3E-05 sccs GHe. Passing/failing leakage performance was intermittent throughout GMA testing. No internal leakage testing was performed on the valves until the GMA was fully assembled. Unable to confirm this cause without disassembly/inspect.	Immediately after GMA assembly, valve leakage measured 1.1E-06 to 2.3E-05 sccs GHe. Leakage degraded after two passing post-vibration leakage tests to 2.4E-04 to 6.5E-04 for remainder of GMA testing.	Valve measured 2.8E-07 sccs GHe immediately after vibration. Subsequent two tests measure 1.4E-06 to 1.4E-04 sccs GHe. Valve eventually degraded to 2.0E-06 to 8.0E-04 sccs GHe.	Valve measured 1.8E-06 sccs GHe after vibration. Mean spec leakage measured 1.3E-06 to 3.3E-05 sccs GHe.
Relevant Assembly/Test History	V4: Installed poppet made from bad 120548401 vessel set. Housing was reworked. Mounted in upper bracket position. V6: Housing was reworked. Mounted in lower bracket position. Note that leakage performance improved during/after thermal/vac cycling. Valves are closed during launch (random vibration testing).	None. Valve open during launch (random vibration testing).	Build book noted machining mark on seat, uneven poppet coning. Poppet was subsequently replaced. Valve is open during launch (random vibration testing). Valve is mounted in upper position of mounting bracket.	Valve is closed during launch (random vibration testing). Valve is mounted to upper bracket position.	Housing was reworked. Housing welds performed three times. Valve located on GMA vent line. Valve is open during launch (random vibration testing). Valve is mounted in upper bracket position.	Housing was reworked. Housing welds performed three times. Valve located on GMA vent line. Valve is open during launch (random vibration testing). Valve is mounted in upper bracket position.
Summary/Comments	Probable cause for V4V6 leakage failure is poppet material in V4. All other poppets from this lot were equipped due to general poor performance from this lot. V4 was already existed together at the time of this discovery and was performing very well. Not reworkable without removal from GMA. Contamination at the seat/poppet interface is also a probable cause. The source of this contamination is most likely from the GMA assembly process. No internal leakage testing was performed on the valves until the GMA was fully assembled. Unable to confirm this cause without disassembly/inspect.	Contamination at the seat/poppet interface is also a probable cause. The source of this contamination is most likely from the GMA assembly process. No internal leakage testing was performed on the valves until the GMA was fully assembled. Unable to confirm this cause without disassembly/inspect. Vibration testing may have also played a role in creating the non-conformance, perhaps by dislodging contamination in the valve. Intermittent nature of leakage rate raises questions about pre-vibration acceptable leak rates.	Contamination at the seat/poppet interface is also a probable cause. The source of this contamination is most likely from the GMA assembly process. No internal leakage testing was performed on the valves until the GMA was fully assembled. Unable to confirm this cause without disassembly/inspect. Vibration testing may have also played a role in creating the non-conformance, perhaps by dislodging contamination in the valve. Intermittent nature of leakage rate raises questions about pre-vibration acceptable leak rates.	Contamination at the seat/poppet interface is also a probable cause. The source of this contamination is most likely from the GMA assembly process. No internal leakage testing was performed on the valves until the GMA was fully assembled. Unable to confirm this cause without disassembly/inspect. Vibration related causes are not suspected since valve had questionable leak rates immediately after vibration.	Contamination at the seat/poppet interface is also a probable cause. The source of this contamination is most likely from the GMA assembly process. No internal leakage testing was performed on the valves until the GMA was fully assembled. Unable to confirm this cause without disassembly/inspect. Vibration related causes are not suspected since valve had questionable leak rates prior to vibration testing.	Contamination at the seat/poppet interface is also a probable cause. The source of this contamination is most likely from the GMA assembly process. No internal leakage testing was performed on the valves until the GMA was fully assembled. Unable to confirm this cause without disassembly/inspect. Vibration testing may have also played a role in creating the non-conformance, perhaps by dislodging contamination in the valve.

Potential Root Cause	Sub-Category	Available Method(s) of Verification and/or Comments	V4V6 (SN 004, 008)	V41 (SN021)	V45 (SN 005)	V21 (SN 003)	V27 (SN 023)	V28 (SN 024)	V29 (SN 001)
Category Contamination	At Poppet/Seat Interface, Introduced During Component Assembly	Cycled spare valves while testing to dislodge contamination (this has been done at low pressures without any significant result) Flush valve with high pressure (500 psia) via MV2 to dislodge potential contamination (does not apply to V4V6 because of regulators and Motts). This was not performed due to the risk of contaminating other "good" valves. Particle count could also be performed at GMA outlet, but based on the number of filters and results from Air Products particle counting, this will probably not yield anything. Also, if contaminant damaged poppet sealing surface then removal of contaminant may not have a significant effect. Disassemble and inspect valve (requires removal from GMA). Perform particle counts prior to valve disassembly.	Credible, not likely. Valve certified clean on first flush and passed leakage testing at component level. However, contamination could be trapped at component level. Repeated valve cycling and/or vibration testing may have dislodged contamination (see below).	Credible, not likely. Valve certified clean on first flush and passed leakage testing at component level. However, contamination could be trapped at component level. Repeated valve cycling and/or vibration testing may have dislodged contamination (see below).	Credible, not likely. Valve certified clean on first flush and passed leakage testing at component level. However, contamination could be trapped at component level. Repeated valve cycling and/or vibration testing may have dislodged contamination (see below).	Credible, not likely. Valve certified clean on first flush and passed leakage testing at component level. However, contamination could be trapped at component level. Repeated valve cycling and/or vibration testing may have dislodged contamination (see below).	Credible, not likely. Valve certified clean on first flush and passed leakage testing at component level. However, contamination could be trapped at component level. Repeated valve cycling and/or vibration testing may have dislodged contamination (see below).	Credible, not likely. Valve certified clean on first flush and passed leakage testing at component level. However, contamination could be trapped at component level. Repeated valve cycling and/or vibration testing may have dislodged contamination (see below).	Credible, not likely. Valve certified clean on first flush and passed leakage testing at component level. However, contamination could be trapped at component level. Repeated valve cycling and/or vibration testing may have dislodged contamination (see below).
	At Poppet/Seat Interface, Introduced During GMA Assembly	Same as above Welded two spare units (SN007 and SN022) together using same processes and procedures used to weld GMA. Some particulate found in assembly and initial leak rates were higher than the component level, but valve leakage performance was not affected permanently; after cycling valves the leakage rate returned to levels comparable to the component level. However, later cycle testing revealed that SN007 showed a general shift of one magnitude in leakage performance. The valve also presented leakage data in the 1.0E-05 sccs range. Disassembly of SN027 indicated a residue of aluminum silicate on the poppet immediately upstream of the sealing surface.	Credible, not likely. Valves were not leak tested after component testing until GMA was fully assembled. Handling procedures were taken to protect valves during assembly process, but it is possible that a valve could be contaminated during orbital welding processes. Spare valve SN007 showed a magnitude shift in leakage performance. Later cycle testing indicated intermittent leakage values in the 1.E-05 sccs range.	Credible, not likely. Valves were not leak tested after component testing until GMA was fully assembled. Handling procedures were taken to protect valves during assembly process, but it is possible that a valve could be contaminated during orbital welding processes. Spare valve SN007 showed a magnitude shift in leakage performance. Later cycle testing indicated intermittent leakage values in the 1.E-05 sccs range.	Credible, not likely. Valves were not leak tested after component testing until GMA was fully assembled. Handling procedures were taken to protect valves during assembly process, but it is possible that a valve could be contaminated during orbital welding processes. Spare valve SN007 showed a magnitude shift in leakage performance. Later cycle testing indicated intermittent leakage values in the 1.E-05 sccs range.	Credible, not likely. Valves were not leak tested after component testing until GMA was fully assembled. Handling procedures were taken to protect valves during assembly process, but it is possible that a valve could be contaminated during orbital welding processes. Spare valve SN007 showed a magnitude shift in leakage performance. Later cycle testing indicated intermittent leakage values in the 1.E-05 sccs range.	Credible, not likely. Valves were not leak tested after component testing until GMA was fully assembled. Handling procedures were taken to protect valves during assembly process, but it is possible that a valve could be contaminated during orbital welding processes. Spare valve SN007 showed a magnitude shift in leakage performance. Later cycle testing indicated intermittent leakage values in the 1.E-05 sccs range.	Credible, not likely. Valves were not leak tested after component testing until GMA was fully assembled. Handling procedures were taken to protect valves during assembly process, but it is possible that a valve could be contaminated during orbital welding processes. Spare valve SN007 showed a magnitude shift in leakage performance. Later cycle testing indicated intermittent leakage values in the 1.E-05 sccs range.	Credible, not likely. Valves were not leak tested after component testing until GMA was fully assembled. Handling procedures were taken to protect valves during assembly process, but it is possible that a valve could be contaminated during orbital welding processes. Spare valve SN007 showed a magnitude shift in leakage performance. Later cycle testing indicated intermittent leakage values in the 1.E-05 sccs range.
	At Poppet/Seat Interface, Dislodged During Vibration Testing	Vibration excited two spare valves. Higher particle counts noted. Leakage performance not affected. Disassemble and inspect valve (requires removal from GMA). Perform particle counts prior to valve disassembly.	Not credible; leakage data is consistent before and after vibration. No history of valve cycling being a problem.	Credible, not likely. Valve was open during vibration & located in top position of bracket. Majority of valves that indicate poor leakage performance were open during vibration and located in top position of mounting bracket. Previous valve vibration testing had valve in closed position only. Spare valve testing did not reveal a problem.	Credible, not likely. Valve was open during vibration & located in top position of bracket. Majority of valves that indicate poor leakage performance were open during vibration and located in top position of mounting bracket. Previous valve vibration testing had valve in closed position only. Spare valve testing did not reveal a problem.	Credible, not likely. Valve performed in specification immediately after vibration testing. After additional cycling and testing the valve leakage performance degraded. Spare valve testing did not reveal a problem.	Not credible; valve was identified as a potential problem before vibration.	Credible, not likely. Valve was open during vibration & located in top position of bracket. Majority of valves that indicate poor leakage performance were open during vibration and located in top position of mounting bracket. Previous valve vibration testing had valve in closed position only. Spare valve testing did not reveal a problem.	Not credible; valve was identified as a potential problem before vibration.

		V1V6 (SN 004, 005)	V11 (SN002)	V15 (SN 005)	V21 (SN 020)	V27 (SN 025)	V28 (SN 024)	V29 (SN 003)
	At Core/Armature Interface, which prevent proper seating of poppet: Introduced During Component Assembly	Cycled spare valves while flowing to dislodge contamination (this has been done at low pressures without any significant result). Flush valve with high pressure (300 psia) via MV2 to dislodge potential contaminants (does not apply to V1V6 because of regulators and Minots). This was not performed due to the risk of contaminating other "good" valves. Particle count could also be performed at GMA outlet, but based on the number of filters and results from Air Products particle counting, this will probably not yield anything. Also, if contaminant damaged poppet seating surface then removal of contaminant may not have a significant effect. Disassemble and inspect valve (requires removal from GMA). Perform particle counts prior to valve disassembly.	Not credible. Would also expect gross leakage for this condition.	Not credible. Would also expect gross leakage for this condition.	Not credible. Would also expect gross leakage for this condition.	Not credible. Would also expect gross leakage for this condition.	Not credible. Would also expect gross leakage for this condition.	Not credible. Would also expect gross leakage for this condition.
	At Core/Armature Interface, which prevent proper seating of poppet: Introduced During GMA Assembly	Same as above Welded two spare units together using name processes and procedures used to weld GMA. Some particulate found in assembly and initial leak rates were higher than the component level, but valve leakage performance was not affected permanently, after cycling valves the leakage rate returned to levels comparable to the component level. Disassemble and inspect valve (requires removal from GMA). Perform particle counts prior to valve disassembly.	Not credible. Would also expect gross leakage for this condition.	Not credible. Would also expect gross leakage for this condition.	Not credible. Would also expect gross leakage for this condition.	Not credible. Would also expect gross leakage for this condition.	Not credible. Would also expect gross leakage for this condition.	Not credible. Would also expect gross leakage for this condition.
	At Core/Armature Interface: Dislodged During Vibration	Vibration tested two spare valves. Higher particle counts noted. Leakage performance not affected. Disassemble and inspect valve (requires removal from GMA). Perform particle counts prior to valve disassembly.	Not credible. Would also expect gross leakage for this condition. Valve part was suspect prior to vibration.	Not credible. Would also expect gross leakage for this condition.	Not credible. Would also expect gross leakage for this condition.	Not credible. Would also expect gross leakage for this condition. Valve was suspect prior to vibration.	Not credible. Would also expect gross leakage for this condition.	Not credible. Would also expect gross leakage for this condition. Valve was suspect prior to vibration.
	Self-Generated Contamination, e.g. Filter shedding, sliding fits, improperly detuned parts	Same as above. Cycled tested spare valves SN007 & SN022. Particles large enough to affect sealing were disassembled. Analysis of particles indicate these may have come from handling and hook-up. The leakage performance of these valves was not degraded.	Credible, not likely, valve design has no history of self-generated contaminants. Filters go through a very aggressive cleaning prior to assembly into valve. All parts cleaned and inspect during prior to assembly	Credible, not likely, valve design has no history of self-generated contaminants. Filters go through a very aggressive cleaning prior to assembly into valve. All parts cleaned and inspect during prior to assembly	Credible, not likely, valve design has no history of self-generated contaminants. Filters go through a very aggressive cleaning prior to assembly into valve. All parts cleaned and inspect during prior to assembly	Credible, not likely, valve design has no history of self-generated contaminants. Filters go through a very aggressive cleaning prior to assembly into valve. All parts cleaned and inspect during prior to assembly	Credible, not likely, valve design has no history of self-generated contaminants. Filters go through a very aggressive cleaning prior to assembly into valve. All parts cleaned and inspect during prior to assembly	Credible, not likely, valve design has no history of self-generated contaminants. Filters go through a very aggressive cleaning prior to assembly into valve. All parts cleaned and inspect during prior to assembly
	Unusually Large Gas Throughput Through valve	Check gas supply for purity and particulate matter. Disassemble and inspect valve (requires removal from GMA)	Credible, not likely, valves have been used as a primary flow path for GMA purging/servicing. Only filtered, high purity gas used.	Not credible, valve was not used as a primary flow path	Not credible, valve was not used as a primary flow path	Not credible, valve was not used as a primary flow path	Credible, not likely, valves have been used as a primary flow path for GMA purging/servicing. Only filtered, high purity gas used.	Credible, not likely, valves have been used as a primary flow path for GMA purging/servicing. Only filtered, high purity gas used.
Damage to Valve Piece parts due to Vibration	Poppet Surface Damage	Cycled valve to recoup poppet. Exposed two spare valves (SN007 & SN022) while immersed in the GMA brackets to the GMA system vibration levels with both valves open. Verified leakage between sees. Leakage performance of valves unaffected. Noted high amplification of valve in top bracket (~40 Gms) Disassemble and inspect valve (requires removal from GMA)	Not credible, leak rate was suspect prior to vibration testing. Spare valve testing did not reveal a problem.	Credible, not likely, no history of poppet damage due to vibration. Valve was open during vibration & located in top position of bracket. Majority of valves that indicate poor leakage performance were open during vibration and located in top position of mounting bracket. Spare valve testing did not reveal a problem.	Credible, not likely, no history of poppet damage due to vibration. Valve was open during vibration & located in top position of bracket. Majority of valves that indicate poor leakage performance were open during vibration and located in top position of mounting bracket. Spare valve testing did not reveal a problem.	Credible, not likely, no history of poppet damage due to vibration. Valve was closed during vibration & located in top position of bracket. Majority of valves that indicate poor leakage performance were open during vibration and located in top position of mounting bracket. Spare valve testing did not reveal a problem.	Credible, not likely, no history of poppet damage due to vibration. Valve was closed during vibration & located in top position of bracket. Majority of valves that indicate poor leakage performance were open during vibration and located in top position of mounting bracket. Spare valve testing did not reveal a problem.	Credible, not likely, no history of poppet damage due to vibration. Valve was open during vibration and located in lower position of bracket. Majority of valves that indicate poor leakage performance were open during vibration and located in top position of mounting bracket. Spare valve testing did not reveal a problem.
	Yielded/Fatigued Poppet Spring	Checked for gross leakage (indicates failed spring only). Disassemble and inspect valve (requires removal from GMA)	Not credible, spring damage would in gross leakage leak rate was suspect prior to vibration testing	Not credible, spring damage normally results in gross leakage	Not credible, spring damage normally results in gross leakage	Not credible, spring damage normally results in gross leakage	Not credible, spring damage normally results in gross leakage	Not credible, spring damage normally results in gross leakage
	Incorrect Manufacture/Assembly	One or More Piece parts Manufactured From Bad Material	Moog & Stanford examined valve As-Built Configuration Record (ABCR) and build folders of all valves. No trend was found with regard to lot numbers or build data.	Lottery: VA contains poppet made from bad stainless steel. Data shows the largest changes in sealing performance can occur with this lot.	Not credible, all material lot numbers used in valve conform to specifications	Not credible, all material lot numbers used in valve conform to specifications	Not credible, all material lot numbers used in valve conform to specifications	Not credible, all material lot numbers used in valve conform to specifications
	Poppet Out of Print	Moog & Stanford examined valve As-Built Configuration Record (ABCR) and build folders of all valves. No trend was found with regard to lot numbers or build data. Disassemble and inspect valve (requires removal from GMA).	Not credible, both valves passed leakage during build	Not credible, valve passed leakage during build	Not credible, valve passed leakage during build	Not credible, valve passed leakage during build	Not credible, valve passed leakage during build	Not credible, valve passed leakage during build
	Core/Armature Out of Print	Moog & Stanford examined valve As-Built Configuration Record (ABCR) and build folders of all valves. No trend was found with regard to lot numbers or build data. Disassemble and inspect valve (requires removal from GMA).	Not credible, both valves passed leakage during build. All cores and armatures measured for valve plugging at time of build	Not credible, both valves passed leakage during build. All cores and armatures measured for valve plugging at time of build	Not credible, both valves passed leakage during build. All cores and armatures measured for valve plugging at time of build	Not credible, both valves passed leakage during build. All cores and armatures measured for valve plugging at time of build	Not credible, both valves passed leakage during build. All cores and armatures measured for valve plugging at time of build	Not credible, both valves passed leakage during build. All cores and armatures measured for valve plugging at time of build
	Outlet Fitting (Seal) Out of Print	Moog & Stanford examined valve As-Built Configuration Record (ABCR) and build folders of all valves. No trend was found with regard to lot numbers or build data. Cycled valves to attempt to recoup poppet. This was done at ambient and hot. Disassemble and inspect valve (requires removal from GMA)	Not credible, both valves passed leakage during build	Not credible, valve passed leakage during build	Unlikely, unusual machining mark, noted in valve historical record. All component testing and GMA pre-vibration tests indicated not valve was healthy	Not credible, valve passed leakage during build	Not credible, valve passed leakage during build	Not credible, valve passed leakage during build
	Impinger Core Stemming/Preload Adjustment	Moog & Stanford examined valve As-Built Configuration Record (ABCR) and build folders of all valves. No trend was found with regard to lot numbers or build data. Disassemble and inspect valve (requires removal from GMA).	Not credible, Spring preload was measured at time of build, armature and poppet stroke measured at time of build, both valves passed leakage during build	Not credible, Spring preload was measured at time of build, armature and poppet stroke measured at time of build, both valves passed leakage during build	Not credible, Spring preload was measured at time of build, armature and poppet stroke measured at time of build, both valves passed leakage during build	Not credible, Spring preload was measured at time of build, armature and poppet stroke measured at time of build, both valves passed leakage during build	Not credible, Spring preload was measured at time of build, armature and poppet stroke measured at time of build, both valves passed leakage during build	Not credible, Spring preload was measured at time of build, armature and poppet stroke measured at time of build, both valves passed leakage during build

			V16 (SN 004, 005)	V11 (SN021)	V15 (SN 005)	V21 (SN 020)	V27 (SN 023)	V28 (SN 024)	V29 (SN 003)
	Improper Sealing of Core which would permit core to unscrew during after repeated cycling and/or vibration testing. This situation would result in loss of poppet spring preload and may not allow poppet to seat.	Moog & Stanford examined valve As-Built Configuration Record (ABCR) and build folders of all valves. No trend was found with regard to lot numbers or build data. -Disassemble and inspect valve (requires removal from GMA).	Not credible. All swagels are inspected at build. Would also expect gross leakage.	Not credible. All swagels are inspected at build. Would also expect gross leakage. Valve non-conformance is intermittent.	Not credible. All swagels are inspected at build. Would also expect gross leakage.	Not credible. All swagels are inspected at build. Would also expect gross leakage.	Not credible. All swagels are inspected at build. Would also expect gross leakage. Valve non-conformance is intermittent.	Not credible. All swagels are inspected at build. Would also expect gross leakage. Valve non-conformance is intermittent.	Not credible. All swagels are inspected at build. Would also expect gross leakage. Valve non-conformance is intermittent.
	Unusual or Additional Handling	Moog & Stanford examined valve As-Built Configuration Record (ABCR) and build folders of all valves. Trends are noted in matrix. -Disassemble and inspect valve (requires removal from GMA). All valves except V1 & V2 had filter body weld repaired since. Majority of valves are performing within specification.	Credible, not likely, although valves were reworked, the affected parts were cleaned as expected per standard procedure. All valves except V1 & V2 had filter body weld repaired since. Majority of valves are performing within specification.	Not Credible No unusual handling occurred	Not Credible No unusual handling occurred	Not Credible No unusual handling occurred	Credible, not likely, although valves were reworked, the affected parts were cleaned as expected per standard procedure. All valves except V1 & V2 had filter body weld repaired since. Majority of valves are performing within specification.	Credible, not likely, although valves were reworked, the affected parts were cleaned as expected per standard procedure. All valves except V1 & V2 had filter body weld repaired since. Majority of valves are performing within specification.	Credible, not likely, although valves were reworked, the affected parts were cleaned as expected per standard procedure. All valves except V1 & V2 had filter body weld repaired since. Majority of valves are performing within specification.
	Improper seating of poppet retaining ring. Normal cycling and/or vibration testing causes ring to become unusual.	Moog & Stanford examined Valve As-Built Configuration Record (ABCR) and build folders of all valves. No trend was found with regard to lot numbers or build data. -Disassemble and inspect valve (requires removal from GMA).	Not credible. Unusual valve response and gross leakage expected. All valves have in family responses.	Not credible. Unusual valve response and gross leakage expected. All valves have in family responses.	Not credible. Unusual valve response and gross leakage expected. All valves have in family responses.	Not credible. Unusual valve response and gross leakage expected. All valves have in family responses.	Not credible. Unusual valve response and gross leakage expected. All valves have in family responses.	Not credible. Unusual valve response and gross leakage expected. All valves have in family responses.	Not credible. Unusual valve response and gross leakage expected. All valves have in family responses.
Testing/Mechanism Error	High Helium Background Levels	Checked background with GMA evacuated and all valves open. -Verified leakage background resolution of mass spectrometer by pluming a calibrated leak device into GMA at vent line. Mass spectrometer was capable of measuring the calibrated leak of 1.0E-05 sccs GMA.	Not credible. Mixing verified that measuring leakage at MV2 and the outlets yielded the same result.	Credible, not likely, however background leak has caused anomalous reading for one data point (1.0E-03 sccs GMA)	Not credible. Other nearby valves yielded acceptable leakage values	Not credible for any testing performed in the GMA and valves are at the outlet of the GMA	Not credible. Other nearby valves yielded acceptable leakage values	Not credible for any testing performed in the GMA and valves are at the outlet of the GMA	Not credible for any testing performed in the GMA and valves are at the outlet of the GMA
	Incorrect Mass Spectrometer Calibration	Check for consistently out-of-spec measurements on all valves. -Verified leakage background resolution of mass spectrometer by pluming a calibrated leak device into GMA at vent line. Mass spectrometer was capable of measuring the calibrated leak of 1.0E-05 sccs GMA.	Not credible. Majority of valves measure ~2.0E-06 sccs GMA	Not credible. Majority of valves measure ~2.0E-06 sccs GMA	Not credible. Majority of valves measure ~2.0E-06 sccs GMA	Not credible. Majority of valves measure ~2.0E-06 sccs GMA	Not credible. Majority of valves measure ~2.0E-06 sccs GMA	Not credible. Majority of valves measure ~2.0E-06 sccs GMA	Not credible. Majority of valves measure ~2.0E-06 sccs GMA
	Improper tubing testing, i.e., test set-up disturbed or set-up improperly	Check leakage using mass spectrometer. This has been performed.	Not credible. Improper set-up would many valves. No reason to believe that test was disturbed.	Not credible. Improper set-up would many valves. No reason to believe that test was disturbed.	Not credible. Improper set-up would many valves. No reason to believe that test was disturbed.	Not credible. Improper set-up would many valves. No reason to believe that test was disturbed.	Not credible. Improper set-up would many valves. No reason to believe that test was disturbed.	Not credible. Improper set-up would many valves. No reason to believe that test was disturbed.	Not credible. Improper set-up would many valves. No reason to believe that test was disturbed.
	Experimental/Statistical Error	Retire via further testing. Additional testing did reveal that the valve sequencing and evacuation procedure does have an effect on the leakage reading, but not enough of an effect to consider this a cause of the non-conforming readings.	Not credible. Multiple leakage measurements show consistent valve performance of good & bad valves.	Not credible. Multiple leakage measurements show consistent valve performance of good & bad valves.	Not credible. Multiple leakage measurements show consistent valve performance of good & bad valves.	Not credible. Multiple leakage measurements show consistent valve performance of good & bad valves.	Not credible. Multiple leakage measurements show consistent valve performance of good & bad valves.	Not credible. Multiple leakage measurements show consistent valve performance of good & bad valves.	Not credible. Multiple leakage measurements show consistent valve performance of good & bad valves.
Normal Performance of valve design	Yes	Review of data from previous programs using the valve design. Perform statistical analysis of past valve performance	Credible, not likely. Review of data from qualification units (2), DS-1 (5), PMA (2) and USERS (3) indicated that the valves typically perform between 5e-05 and 5e-07 sccs. Out of 61 historical data points, 3 data points had (from three different valves) measured ~5e-04 sccs. Higher leakage rate behavior noted occurred 1 time on each valve and did not repeat in future testing. Leakage performance of valves that indicated anomalous behavior returned to leak rate ~5e-05 sccs.	Credible, not likely. Review of data from qualification units (2), DS-1 (5), PMA (2) and USERS (3) indicated that the valves typically perform between 5e-05 and 5e-07 sccs. Out of 61 historical data points, 3 data points had (from three different valves) measured ~5e-04 sccs. Higher leakage rate behavior noted occurred 1 time on each valve and did not repeat in future testing. Leakage performance of valves that indicated anomalous behavior returned to leak rate ~5e-05 sccs.	Credible, not likely. Review of data from qualification units (2), DS-1 (5), PMA (2) and USERS (3) indicated that the valves typically perform between 5e-05 and 5e-07 sccs. Out of 61 historical data points, 3 data points had (from three different valves) measured ~5e-04 sccs. Higher leakage rate behavior noted occurred 1 time on each valve and did not repeat in future testing. Leakage performance of valves that indicated anomalous behavior returned to leak rate ~5e-05 sccs.	Credible, not likely. Review of data from qualification units (2), DS-1 (5), PMA (2) and USERS (3) indicated that the valves typically perform between 5e-05 and 5e-07 sccs. Out of 61 historical data points, 3 data points had (from three different valves) measured ~5e-04 sccs. Higher leakage rate behavior noted occurred 1 time on each valve and did not repeat in future testing. Leakage performance of valves that indicated anomalous behavior returned to leak rate ~5e-05 sccs.	Credible, not likely. Review of data from qualification units (2), DS-1 (5), PMA (2) and USERS (3) indicated that the valves typically perform between 5e-05 and 5e-07 sccs. Out of 61 historical data points, 3 data points had (from three different valves) measured ~5e-04 sccs. Higher leakage rate behavior noted occurred 1 time on each valve and did not repeat in future testing. Leakage performance of valves that indicated anomalous behavior returned to leak rate ~5e-05 sccs.	Credible, not likely. Review of data from qualification units (2), DS-1 (5), PMA (2) and USERS (3) indicated that the valves typically perform between 5e-05 and 5e-07 sccs. Out of 61 historical data points, 3 data points had (from three different valves) measured ~5e-04 sccs. Higher leakage rate behavior noted occurred 1 time on each valve and did not repeat in future testing. Leakage performance of valves that indicated anomalous behavior returned to leak rate ~5e-05 sccs.	Credible, not likely. Review of data from qualification units (2), DS-1 (5), PMA (2) and USERS (3) indicated that the valves typically perform between 5e-05 and 5e-07 sccs. Out of 61 historical data points, 3 data points had (from three different valves) measured ~5e-04 sccs. Higher leakage rate behavior noted occurred 1 time on each valve and did not repeat in future testing. Leakage performance of valves that indicated anomalous behavior returned to leak rate ~5e-05 sccs.
Poppet rotated relative to seat resulting in seat/poppet interface mismatch due to local geometry of parts	Rotation of poppet or preprogrammed sub-assembly due to normal cycling or vibration testing	Disassemble valve to inspect poppet and seat surfaces to normal cycling or vibration testing -Performed experiment on development valve to determine if armature/poppet rotates when the valve is cycled. armature/poppet does not rotate.	Not credible. No history of problem in past and would expect more valves to be affected. Majority of leakage data from all valves is consistent before and after vibration	Not credible. No history of problem in past and would expect more valves to be affected. No data to support cause.	Not credible. No history of problem in past and would expect more valves to be affected. No data to support cause.	Not credible. No history of problem in past and would expect more valves to be affected. No data to support cause.	Not credible. No history of problem in past and would expect more valves to be affected. No data to support cause.	Not credible. No history of problem in past and would expect more valves to be affected. Unit was flagged as a problem prior to vibration	Not credible. No history of problem in past and would expect more valves to be affected. Unit flagged as a problem prior to vibration
Degradation of Poppet Material	Prolonged exposure to vacuum levels ~1.0E-03 torr at temperatures between 104 F and 140 F causes loss of the Vespel material due to outgassing or otherwise degrades sealing interface of poppet	Exposed spare valves to vacuum conditions. SN027 exhibited a general shift in leakage performance from the 1.0E-07 sccs range to 1.0E-06 range. Also presented some values in the 1.0E-05 range and one data point at 2.0E-04 sccs. SN022 performance was unchanged. Performed outgassing testing of Vespel (by MASSCO). Water is the primary outgassing constituent. Not considered a cause. Additional testing using Vespel samples exposed to vacuum and helium will be needed to determine if properties have been affected by exposure.	Credible, not likely SN007 valve did present some degradation. SN022 was unchanged. Testing of samples indicated a wide variation in tensile strength and % elongation. This result may be due to test specimen geometry. Testing deemed inconclusive.	Credible, not likely SN007 valve did present some degradation. SN022 was unchanged. Testing of samples indicated a wide variation in tensile strength and % elongation. This result may be due to test specimen geometry. Testing deemed inconclusive.	Credible, not likely SN007 valve did present some degradation. SN022 was unchanged. Testing of samples indicated a wide variation in tensile strength and % elongation. This result may be due to test specimen geometry. Testing deemed inconclusive.	Credible, not likely SN007 valve did present some degradation. SN022 was unchanged. Testing of samples indicated a wide variation in tensile strength and % elongation. This result may be due to test specimen geometry. Testing deemed inconclusive.	Credible, not likely SN007 valve did present some degradation. SN022 was unchanged. Testing of samples indicated a wide variation in tensile strength and % elongation. This result may be due to test specimen geometry. Testing deemed inconclusive.	Credible, not likely SN007 valve did present some degradation. SN022 was unchanged. Testing of samples indicated a wide variation in tensile strength and % elongation. This result may be due to test specimen geometry. Testing deemed inconclusive.	Credible, not likely SN007 valve did present some degradation. SN022 was unchanged. Testing of samples indicated a wide variation in tensile strength and % elongation. This result may be due to test specimen geometry. Testing deemed inconclusive.
	Prolonged exposure to helium at 5 to 20 psia at temperatures between 104 F and 140 F degrades sealing interface of poppet	Exposed spare valves to helium conditions. No degradation in leakage performance. Additional testing using Vespel samples exposed to vacuum and helium will be needed to determine if properties have been affected by exposure Disassemble valve to inspect poppet.	Credible, not likely SN007 valve did present some degradation. SN022 was unchanged. Testing of samples indicated a wide variation in tensile strength and % elongation. This result may be due to test specimen geometry. Testing deemed inconclusive.	Credible, not likely SN007 valve did present some degradation. SN022 was unchanged. Testing of samples indicated a wide variation in tensile strength and % elongation. This result may be due to test specimen geometry. Testing deemed inconclusive.	Credible, not likely SN007 valve did present some degradation. SN022 was unchanged. Testing of samples indicated a wide variation in tensile strength and % elongation. This result may be due to test specimen geometry. Testing deemed inconclusive.	Credible, not likely SN007 valve did present some degradation. SN022 was unchanged. Testing of samples indicated a wide variation in tensile strength and % elongation. This result may be due to test specimen geometry. Testing deemed inconclusive.	Credible, not likely SN007 valve did present some degradation. SN022 was unchanged. Testing of samples indicated a wide variation in tensile strength and % elongation. This result may be due to test specimen geometry. Testing deemed inconclusive.	Credible, not likely SN007 valve did present some degradation. SN022 was unchanged. Testing of samples indicated a wide variation in tensile strength and % elongation. This result may be due to test specimen geometry. Testing deemed inconclusive.	Credible, not likely SN007 valve did present some degradation. SN022 was unchanged. Testing of samples indicated a wide variation in tensile strength and % elongation. This result may be due to test specimen geometry. Testing deemed inconclusive.