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Gravity Probe B Relativity Mission

GMA Recovery Plan

S0590 Rev. –

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ITAR Assessment Performed — Date

GMA Recovery Plan

There are several issues with the original GMA that have been identified by Stanford University and Marshall Space Flight Center personnel. This document outlines the recovery plan for each of these issues, identifying potential fixes and estimating the effort necessary to effect the repairs.

Issue #1: The High Pressure Latching Valves do not operate at required pressures

The root cause for this anomaly has been found to be a design flaw in the valves, in which outlet pressure greater than 800 psi exerts sufficient force to close the solenoid valve. Although it is possible to modify the internal design of the valve to overcome the problem, this has been determined to not be a viable solution from both cost and schedule viewpoints. We identify two potential fixes to this issue. Option #1 (discussed below) is the preferred option. However, some additional work must be performed to show that it is viable and meets requirements. Option #2 is a backup plan.

Option #1: Remove high-pressure solenoid valves from GMA architecture

The first is to remove the two high-pressure solenoid valves (one for each parallel path) which are one the tank side of the high-pressure regulators. Figure #1 shows the change in architecture (only one of two redundant paths shown).

In this scenario, SV3 serves as the shutoff valve for the system, and the regulator flies with Helium gas on both sides. There are two things which must be demonstrated before this can be adopted as the new baseline.

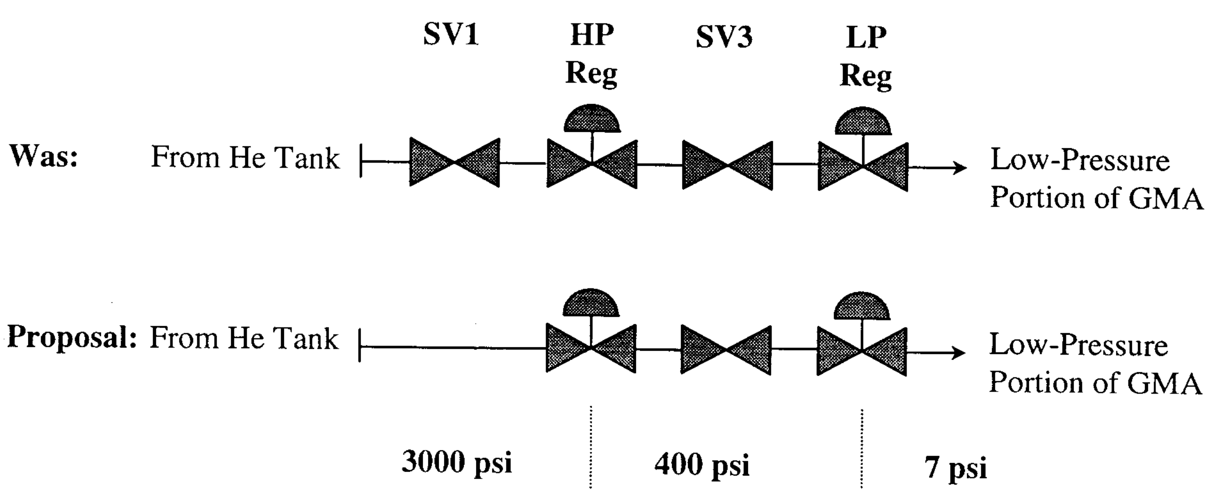


Figure 1: Proposed Change to the GMA Architecture

- Having Helium on both sides of the regulator alters the force margins at launch, so the regulator design must be qualified to operate in this mode. This qualification should consist (1) of analysis to understand the force margins and arrive at the viable pressure configuration, and (2) a set of qualification tests on a backup flight regulator to demonstrate the design meets requirements. The general plan is to build a manifold as outlined in Figure 1 using spare flight parts and conduct the qualification tests on the whole manifold, to properly include all possible system-level effects.

- Demonstrate that the input of the low-pressure regulator can accommodate the maximum pressure to which it may be exposed. Here, a worst-case analysis must be performed which assumes that the HP regulator-SV3 space is at 3000 psi (the highest pressure is any portion of the system), and then it should be shown that the LP regulator can handle the resultant pressure when SV3 is opened. Note that inspection of the design indicates this should not be a problem, although excessive pressure at the *output* of the LP regulator would be cause for concern. Experimentally, this will be verified with the qualification test mentioned in the previous bullet.

This option has been considered carefully, and there is high confidence that if those two items are successfully shown, then the new design will meet all requirements. This will, of course, be further demonstrated using system-level environmental and functional testing on the flight unit.

As a final note, Range safety has no problem with wet regulators according to Gaylord Green and section 3.12 of "Eastern and Western Range 127-1".

Option #2: Use Moog valves as the high-pressure shutoff valves (contingency)

In this scenario, the GMA would be connectorized at the HP regulators and at the He tanks so that a Moog valve could be inserted as the shutoff device. This would be the same valve that would be used in the Moog GMA. The GMA would be integrated and tested without this flight valve and stored for use as a contingency. The idea is that if something happens which keeps us from using the Moog GMA (i.e. it is damaged beyond repair in transport), that spare Moog valves could be used to retrofit the original GMA so that it would not be a program ending event.

Since the Moog valves can not operate at 3000 psi, the bottles would have to be filled to a lower pressure. Currently, the plan is to have enough gas in the GMA to accommodate two complete science missions. Retrofitting the current GMA with Moog valves would reduce the amount of gas to approximately 1.5 science missions.

Issue #2: All valves and regulators need poppet re-attachment.

Poppet rework is nearly completed by Honeywell. This rework is being done at no cost to Stanford. Once the poppets are returned to Stanford, it will likely take less than 3 days to reinstall them, if the GMA is prepared. The poppet problem has been thoroughly researched by Honeywell, and they are making a great effort to give us completely functional poppets. Note that the root cause of the poppet delamination has been found to be a process error which has been corrected. Therefore the fix for this issue is robust and requires minimal Stanford effort.

Issue #3: The vendor considers GMA valves and regulators as 'engineering hardware', not 'flight hardware'.

Allied Signal manufactured the valves as flight hardware, knowing that they were to be installed on a spacecraft and the intent. Originally, Allied Signal designated the valves as "E4 hardware." This is non-production hardware with QA configuration control. Then it was "decided verbally to downgrade from E4 to E3 in order to give more flexibility to the engineers during production." E3 is similar to E4 in that it still invokes quality control standards, but hardware can be machined to redlined drawings. It does not, however, mean that those drawings must be maintained to maintain proper configuration control and documentation of what was produced.

Clearly, Allied Signal sought to pursue flight standards in the production of this valve. This is evidenced by the fact that all components came with material certifications, dimensional inspections, certificates of compliance with QA buyoff, and other paperwork which is typically only provided for flight hardware.

There has been quite a bit of misunderstanding regarding the GMA "engineering hardware" designation. For companies like Allied Signal, *all* non-production hardware (i.e. "one of a kind") is considered to be engineering hardware, regardless of whether it is flight hardware or not. A good example is the new GMA being built by Moog, which is also designated as engineering hardware. So it really means that it is unique, not that it was not manufactured according to flight standards.

With this said, as of this date Allied Signal has not met their contractual obligation to provide adequate build paperwork for the assembly of the various subcomponents to the flight valve. The intent is to still obtain this paperwork from them. Also, since the valves have since been disassembled, all hardware will be re-inspected, and the new build will be completely documented.

Issue #4: The pressure sensors are not flight hardware.

This is not a true statement. The pressure sensors were originally procured as flight hardware. In fact, ONR bought them off as such. However, Stanford has audited the tests which were performed during assembly, and found that some tests which we consider important were not performed. Since then, a quote has been submitted for new sensors, and they can be replaced in a matter of weeks with a total price tag of $20,000. These sensors will be quite similar to the old ones, but more thorough records will be kept of the work, and weld tests will be performed. Note that these sensors are being obtained from the same manufacturer that is providing them for Moog.

Issue #5: The regulator bellows is inadequate for the required pressure.

Actually, the regulator bellows is completely adequate for the required pressure. The MEOP for the downstream section of the GMA is 7 psia. This is half the pressure that the bellows experience when sitting on the workbench in the lab. The worst case scenario if the high-pressure regulators completely fail is that a high pressure will build up on the upstream side of the low-pressure regulator. This situation will lock the regulator closed as soon as the downstream side gets above 7 psia. If the pressure becomes high enough, the regulator may get stuck in the closed position, but the bellows will never see the high pressure, as it is on the outlet side. This eliminates any chance of the regulator being permanently damaged. Finally, the GMA has two redundant regulator paths, so if one low-pressure regulator locks up, it is not a single point failure (see section 8).

Issue #6: The venting plan is unproven for the honeycomb mounting plate.

Stanford plans on drilling vent holes in the backside of the plate in a manner analogous to the venting strategy for numerous honeycomb plates that Lockheed uses. In fact, it will provide for more venting than the Lockheed standard. A Lockheed structural engineer looked at the plan and confirmed that there will be no strength degradation in the plate. Also note that the GMA faceplates are thicker than the Lockheed standard, thereby giving an added margin of safety.

Issue #7: There are serious deficiencies in the hardware specifications and corresponding acceptance/qualification documentation; furthermore, several of the components have never been qualified.

All of the GMA components have some level of qualification. The solenoid valves (and, by similarity, the regulators) have been qualified in-house in addition to Honeywell's acceptance testing. Also, Honeywell has provided us with materials certifications etc. for the components. Many of the solenoid components have since been replaced with new ones that were manufactured by Stanford to full flight quality levels. The non-Honeywell GMA components all have individual certifications, as well, that have been bought off by ONR.

It is true that vendor qualification data for the design is not sufficiently complete. However, a solenoid valve qualification program was undertaken at the time of the poppet redesign (see DR 305). If MSFC reviews this suite of tests and finds it to be incomplete, than additional tests can be performed on flight backup valves.

Finally, the GMA as a system will undergo a rigorous acceptance test regime at Stanford and Lockheed before it is bought off. This test will repeat all component-level tests in addition to verifying system-level performance. So even if valve-level acceptance tests were never performed, the system-level test is complete and insightful enough so no information would be lost.

Issue #8: The cross-strapping of the high pressure sensor (just downstream of the high pressure regulators) is a single point failure.

A simple welding procedure can easily rectify this situation. The vendor has been contacted and has assured that it can be done in a matter of days. When this is complete, the GMA will have two completely redundant gas paths, thus removing the possibility of a single point failure.

Issue #9: There is no ongoing vendor support for components.

Actually, the vendor has been very helpful. When the poppet design was found to be insufficient due to a tolerance stack, they created a new design and manufactured a whole new set of parts. More recently, when the solenoids were found to be faulty, Honeywell sent a team to help investigate. This led to their reworking the poppets. They will support the hardware they delivered, but they are not interested in undertaking new design projects.

Issue #10: The cleanliness verification data is [sic] inadequate, both to support initial surface cleanliness level and also to address contamination introduced during subsequent disassembly and reassembly.

All of the GMA components will be cleaned prior to assembly, as will the assembly as a whole as part of the rework plan. This cleaning and assembly will be heavily based upon the procedures used to insure the cleanliness of the probe itself. The cleanliness will be verified by particle checks in the same manner as the probe was verified. This is something that is very easily rectified.

Issue #11: The valves are contaminated with lubricant.

This will be rectified in the cleaning procedure as outlined above. Solvents that will clean the lubricant will be incorporated into this plan. Again, this is something that is very easily rectified.

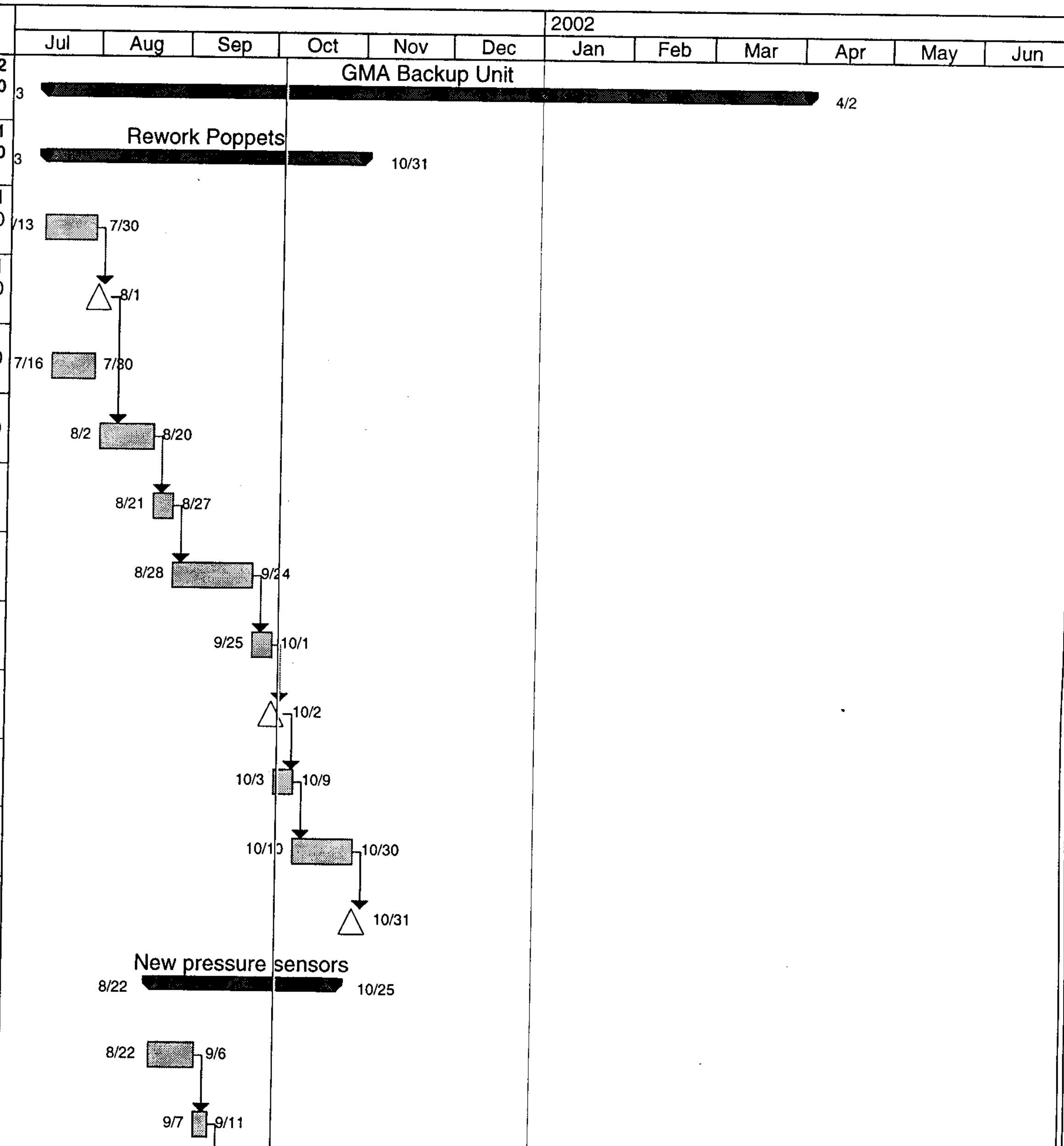
Conclusions

Reasonable fixes are available for all issues. It is believed that with the steps outlined above, the original GMA can be made to comply with all requirements. Aggressive testing at the system level will confirm that the final assembly complies with functional and performance requirements and will survive launch environments. This would make it an extremely valuable thing to have in the event that the Moog GMA was damaged in transport or handling. It is expected the refurbishment process could be concluded in January 2002, and system-level testing completed by April of 2002. The estimated cost is approximately $300,000. It would require one full-time Stanford person, with additional contributions from various Stanford and Lockheed personnel to complete the environmental tests.

GAS MANAGEMENT ASSEMBLY

(Backup)

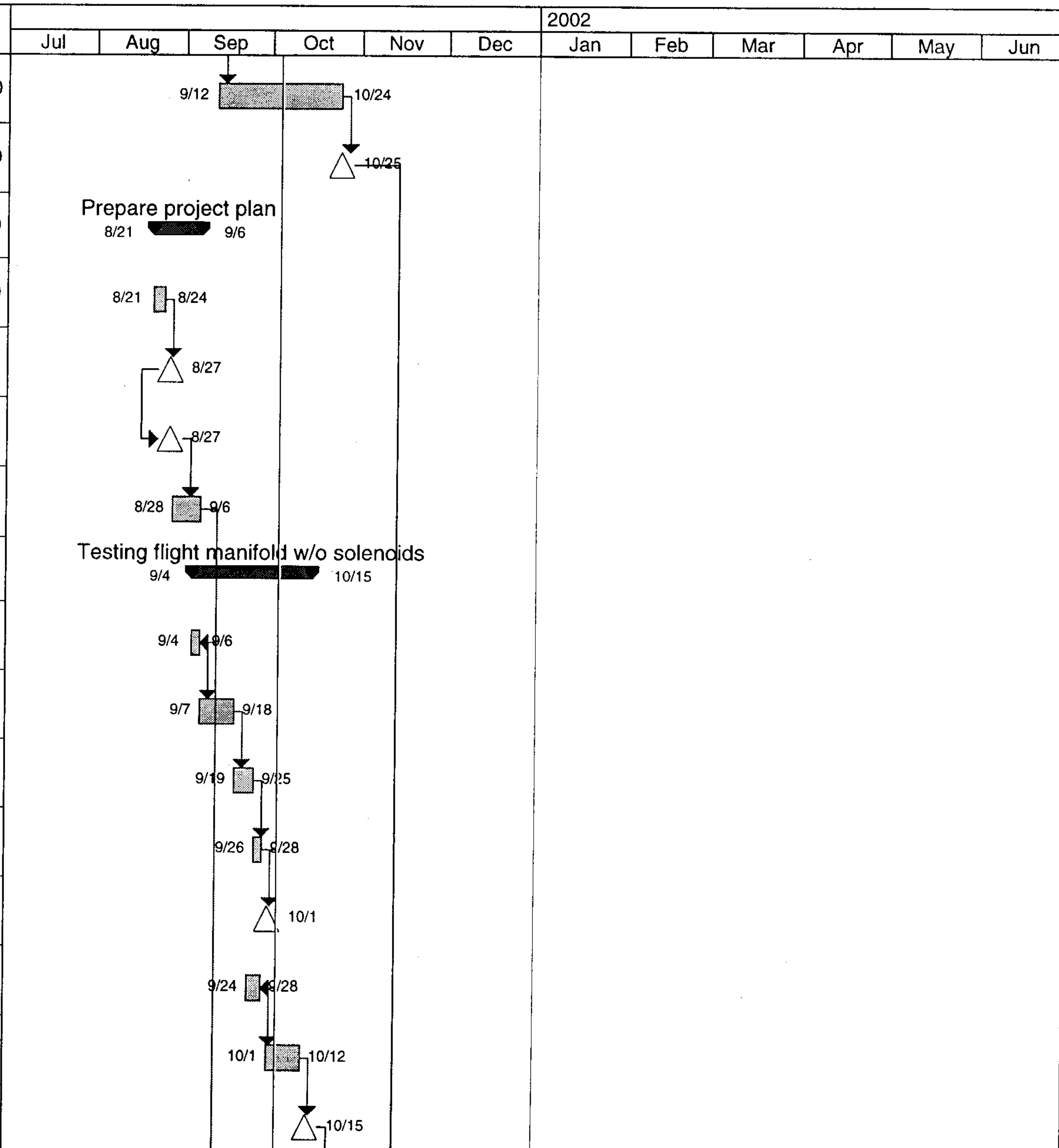
ID	Task Name	Dur.	Start	Finish
9	**GMA Backup Unit**	**187 days**	**7/13/01 08:00**	**4/2/02 17:00**
10	**Rework Poppets**	**78 days**	**7/13/01 08:00**	**10/31/01 17:00**
11	Get poppet plan ready	12 days	7/13/01 08:00	7/30/01 17:00
12	Poppet MRB	1 day	8/1/01 08:00	8/1/01 17:00
13	Quote from Honeywell	11 days	7/16/01 08:00	7/30/01 17:00
14	Remove poppets and ship to hnwl	13 days	8/2/01 08:00	8/20/01 17:00
15	Prep poppets	5 days	8/21/01 08:00	8/27/01 17:00
16	Rebond poppets	19 days	8/28/01 08:00	9/24/01 17:00
17	Inspect poppets	5 days	9/25/01 08:00	10/1/01 17:00
18	Receive poppets	1 day	10/2/01 08:00	10/2/01 17:00
19	Inspect poppets	5 days	10/3/01 08:00	10/9/01 17:00
20	Acceptance test poppets	15 days	0/10/01 08:00	10/30/01 17:00
21	Poppets ready for insertion	1 day	0/31/01 08:00	10/31/01 17:00
22	**New pressure sensors**	**46 days**	**8/22/01 08:00**	**10/25/01 17:00**
23	quote for new sensors	11 days	8/22/01 08:00	9/6/01 17:00
24	PO for sensors	3 days	9/7/01 08:00	9/11/01 17:00



GAS MANAGEMENT ASSEMBLY

(Backup)

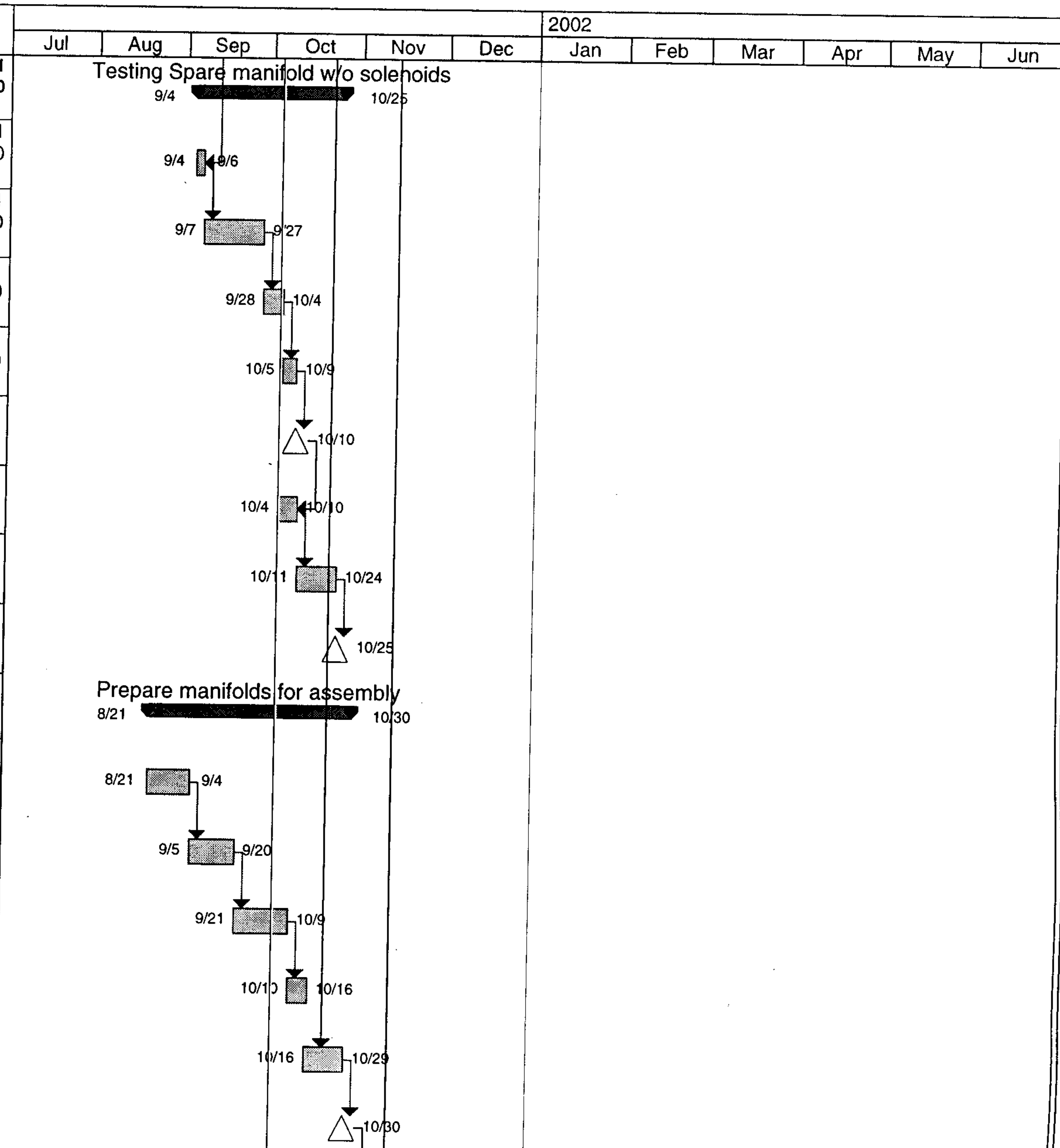
ID	Task Name	Dur.	Start	Finish
25	Make new sensors	31 days	9/12/01 08:00	10/24/01 17:00
26	Receive sensors from STI	1 day	0/25/01 08:00	10/25/01 17:00
27	**Prepare project plan**	**12 days**	**8/21/01 08:00**	**9/6/01 17:00**
28	Redline drawings and prepare plan	4 days	8/21/01 08:00	8/24/01 17:00
29	Fly w/o solenoids MRB	1 day	8/27/01 08:00	8/27/01 17:00
30	SP2 cutting MRB	1 day	8/27/01 08:00	8/27/01 17:00
31	Formalize plan and contact vendors	7 days	8/28/01 08:00	9/6/01 17:00
32	**Testing flight manifold w/o solenoids**	**30 days**	**9/4/01 08:00**	**10/15/01 17:00**
33	Get quote from Vendor	3 days	9/4/01 08:00	9/6/01 17:00
34	Prepare assembly for shake test	8 days	9/7/01 08:00	9/18/01 17:00
35	Shake test assy	5 days	9/19/01 08:00	9/25/01 17:00
36	Prepare assy for welding	3 days	9/26/01 08:00	9/28/01 17:00
37	Regulator assy ready for welding	1 day	10/1/01 08:00	10/1/01 17:00
38	Get quote from Vendor for welding	5 days	9/24/01 08:00	9/28/01 17:00
39	Rework assy	10 days	10/1/01 08:00	10/12/01 17:00
40	Receive assy from welder	1 day	0/15/01 08:00	10/15/01 17:00



GAS MANAGEMENT ASSEMBLY

(Backup)

ID	Task Name	Dur.	Start	Finish
41	**Testing Spare manifold w/o solenoids**	**38 days**	**9/4/01 08:00**	**10/25/01 17:00**
42	Get quote from Vendor	3 days	9/4/01 08:00	9/6/01 17:00
43	Manufacture spare manifold	15 days	9/7/01 08:00	9/27/01 17:00
44	Shake test assy	5 days	9/28/01 08:00	10/4/01 17:00
45	Prepare assy for welding	3 days	10/5/01 08:00	10/9/01 17:00
46	Regul. Assy ready for welding	1 day	0/10/01 08:00	10/10/01 17:00
47	Get quote from Vendor for welding	5 days	10/4/01 08:00	10/10/01 17:00
48	Rework assy	10 days	0/11/01 08:00	10/24/01 17:00
49	Receive assy from welder	1 day	0/25/01 08:00	10/25/01 17:00
50	**Prepare manifolds for assembly**	**50 days**	**8/21/01 08:00**	**10/30/01 17:00**
51	Prepare cleaning plan	10 days	8/21/01 08:00	9/4/01 17:00
52	Clean spinup mnfld w/ solenoids intact	12 days	9/5/01 08:00	9/20/01 17:00
53	Clean components	13 days	9/21/01 08:00	10/9/01 17:00
54	Insert poppets into spinup manifold	5 days	0/10/01 08:00	10/16/01 17:00
55	Clean Regulator manifold	10 days	0/16/01 08:00	10/29/01 17:00
56	Assemblies clean and ready	1 day	0/30/01 08:00	10/30/01 17:00



GAS MANAGEMENT ASSEMBLY

(Backup)

ID	Task Name	Dur.	Start	Finish
57	**GMA Final Assembly**	**30 days**	**10/31/01 08:00**	**12/11/01 17:00**
58	Insert new poppets into Regulator assy	10 days	0/31/01 08:00	11/13/01 17:00
59	Install new Pressure sensors	4 days	1/14/01 08:00	11/19/01 17:00
60	Reassemble GMA on Flight plate	10 days	1/20/01 08:00	12/3/01 17:00
61	Rewire GMA harness	5 days	12/4/01 08:00	12/10/01 17:00
62	GMA Ready for testing	1 day	2/11/01 08:00	12/11/01 17:00
63	**GMA (Backup) acceptance testing**	**80 days**	**12/12/01 08:00**	**4/2/02 17:00**
64	Set flows	10 days	2/12/01 08:00	12/25/01 17:00
65	Acceptance tests	70 days	2/26/01 08:00	4/2/02 17:00
66	GMA (Backup) ready for spacecraft installation	0 days	4/2/02 17:00	4/2/02 17:00