APOLLO XIII

Glynn S. Lunney

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In the Apollo flight campaign for the exploration of the Moon,

Apollo XIII was planned as the

third lunar landing mission.

It was targeted to land and explore a large crater

named Fra Mauro in the Imbrium Basin.

Apollo XIII
by Glynn S. Lunney

After the Countdown Demonstration Test [CDDT], which started on March 13, 1970, a detanking of the two cryogenic tanks commenced. The first tank quantity dropped normally while the other tank only drained eight percent out—a very small amount. This was attributed to an internal leak path (probably caused by some separation of the fill line coupling from the fill line) and it prevented a normal detanking. There had been an earlier incident in handling the tank, well before installation in the vehicle, and it had dropped two inches. This supported the scenario of a mechanically caused separation and an internal leak path.

Now, for the first time, the heaters in the tank were used to expel the lox (liquid oxygen) by boiling it off.

Back in 1966, the voltage for the heater was increased from 28 volts to 65 volts in order to aid in faster pressurization. The 65 volts were supplied via a "ground test-only" harness. However, the 65 volt GSE (ground support equipment) harness also powered two thermostatic switch circuits; their function was to protect the heater assembly and tank temperature from exceeding 80 F by opening and unpowering the heater circuit. But, the thermostatic switches were never modified, qualified or acceptance tested at 65 volts. It was a serious error in our system of making changes and a reminder of how seemingly minor changes can propagate into something much worse than the situation you think you are improving.

As the tank was drained with the heaters on, the tank warmed and the thermostatic switches tried to open but were welded closed by the 65 volt arcing. Therefore, the heaters continued to draw power for hours and the Teflon insulation protecting the fan motor wires routed through the heater assembly were mostly melted and destroyed.

A partial fill test was conducted on March 30 with the same signature of slow drain of the second tank. It was concluded that the leak was internal to the tank—partially refilling instead of draining—and we would not be draining the tank during flight. Therefore, there was not sufficient reason to replace the tank.

And so, the stage was set for the failure to come during Apollo XIII.

It also became more apparent that the media coverage and perhaps the public interest had cooled noticeably from the run up to Apollo XI. The timing was ironic because after some long period of deliberation—maybe years—NASA had agreed to allow two journalists to sit in a small booth within the viewing room, overlooking the floor of the Mission Control Center [MCC]. This was never much of an issue for us because the media had full-time access to the air/ground loop with astronauts/capcom traffic and the flight director loop. So the granting of access added a real visual of the room, available to two journalists and, presumably, more personal than the ever present TV coverage of the operations floor of MCC.

Certainly, to me, and I would say most others, it simply did not matter. We were familiar with some regular visitor traffic through the viewing room and we all just ignored it. The journalists' presence made no difference to us. However, it was disappointing to some that the intensity of coverage diminished after Apollo XI. I thought it was a somewhat natural reaction by the media and it did not bother me. The intensity of Apollo XI media coverage could not be maintained indefinitely.

The Apollo XIII crew was Jim Lovell, Fred Haise, and Ken Mattingly through many of our training runs. However, late in the flow, Ken was replaced by the backup Jack Swigert as the CM [Command Module] pilot, because of a medical concern for Ken's exposure to a child with measles. Jim Lovell was the veteran of two Gemini flights and Apollo VIII. As with all other astronauts, the term "rookie" is really not applicable to the other two crewmen because of their total involvement and training in all the steps leading to this flight and their test flight pilot experience. For example, Fred Haise made it his business to know all about the LM, even to knowing where all the critical wires in the LM [Lunar Module] were routed behind the close-out panels and how to use that knowledge for a hot start if necessary. Jack Swigert was the astronaut office initiator of the malfunction procedure methodology for the CSM [Command Service Module].

It turned out that Ken never developed measles, but a bias to the cautious side led to his being bumped from the flight and later assigned to Apollo XVI. Although never done before, the CM pilot was the easiest person to swap out because his critical role at the Moon was the solo tending of the CSM while the other two crewmen landed. Nevertheless, I am sure it gave Jim and Deke [Slayton, Chief of the Astronaut Office] a serious round of discussions.

Milt Windler was the lead flight director for XIII and was on duty for the launch phase. The countdown was normal and the Saturn V [SIVB] rumbled off the pad at 2:13 pm EST on April 11, 1970. Then, shades of Apollo VI, the second stage center engine shut down more than two minutes early. The Trench was able to verify that the guidance would perform well and the vehicle should burn all the propellant through the other four engines and end up close to a normal orbit, which it did.

Then, a GO for TLI [trans lunar injection], the SIVB burned and we had the prospect of a quiet coast out to the Moon.

I came out to MCC for my shift as Black Team Flight Director at about 8:30 pm CST on the evening of April 13, 1970, about two and a half days into the flight. I expected a quiet night on the console. Gene Kranz's White Team was coming to the end of a long day for the crew that ended with a narrated TV tour of the LM. The crew was back in the CSM getting ready for a sleep period. After reading the Flight Director Log and catching up with Gene, I went on a walk-around through the back rooms to take the pulse of the team.

As a routine procedure at that time, the crew was asked to turn on the fans in the cryo tanks to get a uniform mixture in the tanks for the sleep period. The vehicle was 205,000 miles from Earth, 80 percent of the way to the Moon and just beginning to fall into the influence of the lunar gravity.

And this was the moment when the bare, and now-powered, fan wires contacted a metal surface in the tank, discharged in the oxygen rich environment of the tank, and caused an explosion.

55:55 GET (Ground Elapsed Time [GET] since liftoff) The crew report of "*Houston, we've had a problem here*" changed the narrative from the start of a crew sleep period to something else—uneasy, but still not clear. Somebody turned to me and said, "Glynn, you may want to get back to the front room, NOW." I did and plugged in at the flight director console to hear a confusing array of multiple indications of problems such as, "Main bus B under volt, fuel cell disconnect, O2 tank low pressure." At first, it was necessary to be careful and rule out the possibility that some electrical/instrumentation problem was creating the appearance of a bad situation.

56:14 GET (:19 minutes since problem start) The fact of a really serious condition began to dawn on the team as the crew reported the spacecraft venting particles as seen out the window (that's where the O2 is going and why the O2 tank pressure is so low, and that could be associated with the loud bang initially reported by the crew.) We soon realized that this was not a matter of preserving the landing mission, but this was now about saving the crew. Gene's team struggled to save what they could of the CSM cryo/fuel cell systems for further use and to reconfigure some of the systems so they would operate properly in the face of the electrical system failures. A CSM power down was started at 56: 22 GET and reached a level of 41 amps.

56:25 GET (:30 minutes since problem start) EECOM was concluding that this was not an instrumentation problem and two fuel cells were indeed lost. At about this point, the crew became involved in trying to control some unexpected vehicle rates which were assumed to be due to the venting.

56:31 GET (:36 minutes since problem start) The pressure in the other oxygen tank, O2#1, was reported low and still dropping. More power down was needed. MCC had the crew turn on tank heaters and then the fans to try to arrest the pressure loss, but to no avail. Minutes later, the CM O2 surge tank was isolated to conserve it for entry. We had only one fuel cell and its supply tank of cryo oxygen was expected to go to zero in two hours or less. It was near time to start using the LM as a lifeboat. *But* a few things remained to be done first.

In trying to find a way to assist Gene and his team, I was already engaged with Jerry Bostick who was sorting options with the Trench for how to return home from this point. Jerry guided the

Trench team through the options. John Llewellyn was also on scene to ride shotgun with Tom Weichel. John was able to focus on this downstream decision while Tom was occupied with the immediate aftermath of the problem. It is very easy to understand that there was a very strong sentiment in MCC not to go to the Moon, but to turn around and get on the way home ASAP.

Understandable as that attitude was, it would take about 6000 fps to perform the necessarily very large maneuver. The only propulsion system with that much power was the Service Propulsion System [SPS] located in the service module. We had some real concern that the Service Module had been damaged in whatever had caused the original loud bang. But more importantly, there was a limited amount of power in the CSM entry batteries which would have to be used for a powered-up SPS propulsion maneuver, about 50 amps.

A major burn is done normally with the higher power capability of one or more fuel cells, but the last fuel cell was fading fast. The necessary electrical power drain would probably come close to depleting the small entry batteries (the only power available for entry), and we did not yet know if they could be recharged. As another decisive negative consideration, in order to make the burn achieve 6000 fps, it would be necessary to jettison the mass of the LM descent stage, which contained most of the batteries and cooling water needed for the trip home.

I summarized this situation for Gene, as described above, with Jerry's help and the Trench confirming the situation and our assessment of options. This was not even a close call. We had to go around the Moon.

56:48 GET (:53 minutes since problem start) Gene agreed and announced the go-around the Moon decision to the team.

57:05 GET (1 hour:10 minutes since problem start) With full recognition of how demanding this situation was, the Black Team and I came on duty. Positions were manned by Jack Lousma at capcom, Larry Keyser at AFD, Gary Scott and Ed Fendell at INCO, Bill Boone and Maurice Kennedy at FIDO, Tom Weichel at Retro, Gary Renick and Will Presley at GUIDO, Merlin Merritt at TELMU, Hal Loden at LM Control, Clint Burton at EECOM, Jack Kamman at GNC, and Spencer Gardner and Elvin Pippert at FAO.

Chris Kraft and Sig Sjoberg were also in there by this time. All the other off-shift flight controllers and astronauts gathered to help within less than an hour of the problem. (Consoles had four jacks for headsets to plug in and they were all occupied.) This flight control team was a solid set of operators, but hardly any had been in this kind of circumstance. Besides the flight controllers, we also had the best brains available through our offline SPAN communications and data network with all of the engineering and program organizations, both in NASA and industry, and from all regions of the country.

The MCC was full. Even so, the Comm loop discipline was good. No illusions by now—we all knew that this was a very big hill to climb. It was time to get on with it. The situation was:

- A loud bang was reported at the start of this problem and eventually the crew reported particles venting from the Service Module.
- O2 tank #2 was at 0 pressure. O2 tank #1 was predicted to last no more than 2 hours.
- Fuel cells 1 and 3 were not supplying power.
- Main bus B and AC bus 2 were zero, since both were fed by fuel cell 3.
- Considerable reconfiguration had been performed to get enough thrusters on main Bus A.
- The trajectory was *not* on a free return to the entry corridor and it needed correction.

To help in understanding our response, actions can be considered in two categories:

> MANAGING THE CONFIGURATION OF THE SPACECRAFT SYSTEMS. Sometimes configuration choices were driven by troubleshooting problems (e.g. leak isolation, switching redundant paths, preserving capability, etc.) to support a mission need (e.g. a propulsion maneuver, a power down, the optimum control system capability, etc.). The mission need to operate within the reduced consumables also stressed the configuration choices well beyond the normal. The choices also required closer coordination among the flight controller positions in the MCC because the window was much narrower for an integrated solution (balancing the demands of propulsion, electrical power, time, coolant water, guidance equipment, communications, etc.).

> RETURN HOME STEPS. These were the necessary mission steps to safely return the crew. In the minute-by-minute voice traffic within MCC and with the crew, the return home steps provided an overall mission framework. But, the majority of time and interactions was spent evaluating, deciding and implementing the spacecraft configuration choices to stabilize and/or improve our posture to support the crew and accomplish the return steps. Burned into us from years of training and operations was the CARDINAL rule: ***Don't screw anything up and make the situation worse than it already is.***

It also helps to understand the evolution of the return home plan as an incremental process. We did not begin by having a comprehensive plan, but rather took steps as we judged them to be necessary, appropriate, or kept us with the best range of forward options.

Think of the process as the fog clearing enough to commit to the next step. For example, the first of the RETURN HOME steps was the decision at 56:48 GET to go-around the Moon rather than attempting a direct return. Step #1 was driven by a fact- based analysis of options illustrating that the go-around option was the only workable one. Some of the next steps were more based on the judgment (without a full factual analysis) of what was best. I will highlight each of the return-home steps as our shift and the flight progressed, with the first one being Gene's earlier decision to swing around the Moon.

With the vehicle rates under control with a new RCS configuration, the Black Team first focused on the last-ditch steps to try to save some of the CSM cryo-fuel cell capability. The last step was to close the reactant valves to the non-performing two fuel cells in an attempt to isolate the possibility of an O2 leak inside the fuel cell itself. Once closed, the fuel cell was without the fuel to run and could not be restarted. No joy on the first cell. Then, the second one ended up with the same negative result. The O2 leak continued.

57:35 GET (1 hour:40 minutes since problem start) The two LM crew members were making their entry into the LM at the same time we were calling up that recommendation. “We're already on our way,” was the reply. At this time, we had one good fuel cell #2 but the oxygen pressure to feed it was still dropping. The crew began the initial activation of the LM designed to get the batteries, life support systems, and communication/instrumentation systems online. MCC received the initial LM telemetry signal at 57:57 GET. (In managing and prioritizing the flow of comm traffic, Jack Lousma was a pillar of stability for this team over the course of a very long night.)

During the power-up, I had a short time to consider options. My first strong inclination was to power down quickly, conserve LM consumables, and work out a plan. But, I also had serious concern that the venting particles would preclude getting a good guidance platform alignment for the burns that would be required later. Tom Stafford was intense about getting and maintaining the alignment in the LM. There were confirming nods from Jack Lousma and other Apollo crewmen. This was now our only opportunity to get the CSM inertial guidance alignment transferred to the LM guidance system, even if we later decided that we did not want to use it and powered the LM platform down. I decided to take the time and electrical power from both vehicles to accomplish that transfer and then decide what was next. If not done now, this opportunity would be lost and no longer available. It was much too early to foreclose this option going forward.

57:54 GET (1 hour: 59 minutes since problem start) The CMP powered down as much in the CSM as he could while keeping the CSM guidance system up. Because of the decreasing O2, Clint Burton at EECOM was watching to see a degradation in fuel cell 2 in order to know when to put an entry battery on to support the electrical bus. We intended to stay 'up' in the CSM until a LM guidance alignment was transferred. Once we were on entry battery A, we wanted to minimize the number of amp hours withdrawn from it since we did not know if we could charge it from the LM for later use. The alignment transfer itself was a tedious process of crew/MCC coordination and the reading and checking of a lot of numbers as they were entered into the LM guidance computer. During the period of transferring the alignment, there was a short period with neither of the attitude control systems on. This was quickly recognized and corrected.

Around the time of these final CSM closeout steps, I had a brief period when the severity of the problem really struck home. For the first and *only* time in 10 years of console experiences in training and actual flights, I had the sense of the bottom falling out from under me and my stomach heading for that dark hole. I would like to believe that it was due to an acute intellectual awareness of the "Abandon Ship" situation, but the response to myself—*Holy Shit. I can't believe this is really happening*—was all emotional, not intellectual. Scary. But the 10 years of experience kicked in and it took about 10-20 seconds for me to return from that place. Nobody else even seemed to notice.

58:40 GET (2 hours:45 minutes since problem start) Jack Lousma helped get the team back to tailoring an existing checklist for LM power-up; it was now time to turn off the CSM power. We had used about 20 amp-hours or 15 percent of total entry battery power before power-down. The CSM cabin was going to get very cold and uncomfortable and we still needed *Odyssey* to get home.

I considered the decision to transfer the CSM platform alignment to the LM as key to maintaining our future options and it was RETURN HOME Step #2 in our still evolving plan. We still had the choice to power it all down and reconsider later. At this point, keeping the LM alignment was a good trade for accurate, reliable control of future propulsion burns against a modest amount of LM power being used for a near-term midcourse maneuver in a few hours to get back on free return. The free return midcourse would also verify that the alignment and the propulsion systems were in good shape. Also significant, the fact of being on a free return should be a psychological lift for the entire team.

With respect to using the LM consumables, my judgment was that this team would find a way to stretch a nominal 2+days of powered up LM consumables to a 4 day, powered down survival mission. It still made us all nervous, some more than others. And after the midcourse in the next 2 hours, we would have more accurate consumable forecasts available to decide whether to power down or stay up after that. This was a good example of the incremental development of the return-home plan. Take the bird-in-hand especially when the tradeoff—in this case, the consumable cost—was reasonably low.

58:54 GET (2 hours: 59 minutes since problem start) Jim Lovell reported, "I still see a lot of particles and I cannot identify any constellations, at least in this attitude." This strengthened my resolve to save the alignment reference in the LM until the propulsion maneuver and consumable picture became more clear. At about this time, we had more time to confer with the flight controllers studying the return-to-Earth options.

The LM coolant water was the critical item and the initial cooling water usage was high, about double what was normal for the electrical load, because it was cooling down the entire loop. The usage rate would soon slow down. But, the first estimates would have depleted the coolant water by 94:00 GET at current usage rates, some 50 hours short of what was needed. Obviously, this was not good enough but the estimates also had been made for a very high power level in the LM, about 35 amps, for the remainder of the flight. Both of these assumptions were much too conservative. Merlin Merritt at the TELMU position pressed for a quick power down. I told him, “Merlin, I appreciate your concern, but I am still waiting for an overall plan from Control on the control system options.”

In order to move the attention from *conservation-only* to the primary objective of a safe return home, I selected what seemed to be the most promising option of those provided by the Trench. Then I asked for LM consumable forecasts, assuming a continued power-up but at more nominal H2O usage rates. The power-up would continue until a major propulsion burn at pericynthion (closest approach to the Moon) plus 2 hours, and then reduce the LM power to 15 to 18 amps for most of the trip home, allowing 2 midcourse opportunities. I asked for a range of variations in power levels around that timeline so we did not wait for “perfectly accurate” answers. For now, the approach should be based on faster results including reasonable variations in order to enable the selection of the return home plan. We knew that the CO2 fix was needed, but definition of it was not urgent and the engineering team was on it.

While that was being done, there was time to refine our near-term maneuver options. We could do a midcourse correction quickly to establish free return and then choose to power down or not. I decided to take the option of getting on free return as soon as practical. We then began to select a time for the midcourse which was adequate for the team to assure proper checklist procedures. We offered 61 hours GET and the crew wanted a little more time, settling on 61:30 GET.

61:30 GET (5 hours: 35 minutes since problem start) The midcourse was performed and delivered a 40 ft/sec correction with the descent engine. Burn parameters were nominal and the tracking confirmed the maneuver. The accuracy of the burn also verified that we had a good alignment in the LM. This decision to go ahead with the midcourse to re-establish free return was RETURN HOME Step #3 and served as an emotional lift for the crew and team. We were back on free return, but still a long way to go. LM current was decreased from about 32 amps to 25 amps in the period before the PC+2 burn.

Through all this, Chris and Sig were present all the time and it was so easy to communicate with them. They followed all the traffic on the comm loops. Sometimes, we would sum up a situation and give them a “how-I-am-thinking-about-this-subject” before it came to decision time. Sometimes, the understanding was conveyed by a look or a thumbs up or down. I don't really remember any questions that they had as we went along. I do remember a strong feeling of support. I always felt completely in sync with them, even with very little explanation communications.

Once the free return midcourse burn was performed, an attempt was made to setup passive thermal control (PTC) to control the thermal balance of the spacecraft. This was going to be attempted with its usual difficulty made worse by the fact that we were doing this with the LM control system for the first time versus the CSM as on past missions. The PTC was designed to cycle cold (away from the Sun) and hot environments (facing the Sun) uniformly around the CSM/LM stack to avoid extreme temperatures anywhere. The technique was to stand the stack perpendicular to the Earth/Sun plane and spin it slowly, about one revolution every couple of hours, to spread the heating and cooling throughout the vehicle in a uniform way. It is a delicate maneuver in that the vehicle tends to wobble off like a top slowing down and not spin on the same axis for very long.

63:05 GET (7 hours:10 minutes since problem start) After more trajectory and consumable discussions, I was confident enough to confirm the most reasonable return option in terms of propulsion, configuration, and landing time and location. MCC passed a preliminary advisory for a PC+ 2 hour LM descent maneuver of about 890 fps designed to land at the mid-Pacific recovery site at 142:40 GET, 12 hours better than the present free return landing time. These advisories were regularly sent so that the crew always had the best return-home info, in case of communication loss. This was RETURN HOME Step #4 (preliminary) and basically the same plan we confirmed as the final plan to the crew about 7 hours later.

63:20 GET (7hours:25 minutes since problem start) We were able to soon reconfirm that the earlier advisory message sent to the crew would have adequate consumables. The time margin for the two most limiting consumables would be 20 hours of electrical power and the water margin would be 12 hours. This all assumed a continued power up through the PC 2 time of 79:30 GET, and then powering down to a life support and communications mode using about 15.5 amps and with 2 power-up midcourse opportunities. We had a workable plan and expected that it would continue to improve as we had more chance to refine it.

At about this time, we got back to the CO2 removal concern, which was not immediately urgent. SPAN reported that they were already working with the Crew Systems Division on how to use the CSM canisters in the LM and planning to test the configuration. They expected a solution in a couple of shifts. I knew from past experience that they would succeed. They were very good at improvising; no worry about that one.

63:50 GET (7hours:55 minutes after the start of problem) The attempt to set up the rolling PTC was given up because of the difficulty in setting up a stable, slowly rolling spacecraft. With a crew man awake at all times, the simpler PTC attitude hold for an hour and then roll 90 degrees to a new attitude for another hour was selected. The Guidance team began looking ahead to later darkness opportunities while in the shadow of the Moon to permit guidance system alignment checks or a new Earth/Sun technique for checking the present alignment. This Guidance initiative was typical of a fairly steady stream of configuration choices and future possibilities to consider and plan for. All shifts had some level of traffic like this as the mission progressed.

SPAN was also considering the pros and cons of jettisoning the SM in order to burn most of the descent fuel and achieve a one-day landing earlier time of 118:00 GET time. The two concerns for this option were the cold environment to which the head shield and the CM RCS would be exposed and the fairly small amount of descent fuel which would be left. None of us liked the idea of jettisoning the SM and dealing with the uncertainty of the cold environment. Unless we could get a lot more confidence, that option would not be exercised. Still, there was not a real urgency to decide that issue at this time and they continued with the analysis of that configuration.

67:00 GET (11:05 11 hours: 5 minutes since problem start) Near the end of the Black Team shift, the consumable projections were solid and MCC was comfortable with the plan. Three open issues were: SM jettison, CO2 removal and the entry procedures. Gerry Griffin and the Gold Team were coming on duty and were well up to speed because they were following in MCC for hours before their on- duty call.

A number of flight controllers and I went to a press conference at about 9 am CST for the regular change of shift briefing. At the press conference, the decision on the exact return plan was left open because we had a management briefing to discuss it scheduled after the press conference. I have never been to a press conference when the press, many of whom we knew well and by first names, was so supportive. They all cared as much for the safety of the astronauts as any of us doing the briefing.

69:30 GET (13 hours:35 minutes since problem start) A meeting was held with all of the executive management from NASA HQs, all the major NASA and contractor executives at JSC and representatives from other centers and the DOD recovery manager. Gerry and I attended and I recapped the events of the night before with the stipulation that we did not know the exact root cause of the original problem. But I did recount all the downstream effects and what the team did to cope with them. This got us to our present posture, still about 10 hours to go before the PC+2 burn. Continuing with the RETURN HOME options, they encompassed the total range of possibilities. All speed up burns were scheduled right after the most efficient time, i.e. behind the Moon, plus 2 hours to be well around the Moon and in sight of our Earthbound communication coverage. The options were the same as our earlier review at 63:05 which resulted in the preliminary plan being selected and sent to the crew:

Option #1 No speed up maneuver, landing in Indian Ocean at 155 GET.

Option #2 Descent burn of 850 fps, landing in primary mid-Pacific at 143 GET.

Option #3 Descent burn of 2000 fps, landing in South Atlantic at 133 GET.

Option #4 Descent burn of 4800 fps, landing in mid-Pacific at 118 GET.
Requires SM jettison.

Option #5 SPS burn of 4800 fps, landing in mid-Pacific at 118 GET.

The recovery capabilities were much stronger in the planned mid-Pacific with a carrier and helicopters.

Option #1 was the longest return time to a difficult area with only aircraft support. *Recommendation—NO.*

Option #2 was conservative on fuel, leaving a large reserve for midcourses, best recovery posture, solid plan for consumables. *RECOMMENDED.*

Option #3 left LM descent prop nearly depleted, not much margin for midcourses, South Atlantic recovery posture is only aircraft, no surface ship coverage. Saves 10 hours over option #2. Not enough gain vs. downsides. *Recommendation—NO.*

Option #4 improves return time by a day, 24 hours. But the SM jettison introduces new failure potential. *Recommendation—NO.*

Option # 5 improves return also but requires a power up and likely depletion of the CSM entry batteries which may or may not be rechargeable. Also requires using the SPS engine where the problem started. *Recommendation—NO.*

Our recommendation was Option #2. Deke Slayton had a question about one of the faster return options. I answered. Gerry and I were still bracing for a prolonged discussion. The senior NASA official was Dr. Thomas Paine, the NASA Administrator. He did not know us but, of course, George Low, his deputy, did. After the one question from Deke, Dr. Paine took over and thanked me for the discussion and the clarity of the situation report and then he said, "I only have one question. What can we do to help you men?" WOW. Gerry and I looked at each other and I replied that we believe that we have all the needed support in place, but, "Thank you for the offer. We will certainly ask if we ID something needed."

The meeting was over. The Administrator was satisfied and offered his full support. It was only later that I had time to reflect on that simple exchange and what it displayed about how NASA operated in those days. Also, I can only assume that George Low "sold" the MCC team to his boss, probably on the airplane ride to Houston. It was an empowering conclusion to what could have been a much tougher meeting. I have thought about it often in later years and marvel at the delegation of trust which Dr. Paine bestowed on our team. Quite a man. Quite a leader. And that was the way NASA operated in those times.

About 70 hours GET (14 hours since problem start) The RETURN HOME Step # 4 (final) plan was confirmed with the same plan which we preliminarily sent to the crew at 63:05 GET (7:10 since problem start). We still had the CO2 fix and the entry procedures to solve. Plus, a raft of non-standard operations and procedures for the spacecraft, crew and mission still needed near continuous attention. The team was in full-court press mode.

Outside the MCC floor, the engineering talents of every involved organization and company were fully engaged, from the prime contractors—North American Rockwell and Grumman—to the flight software at MIT, the space suit builders, and to the laboratories and simulators across the country. Most of the crews assigned to upcoming flights, plus Ken Mattingly, were verifying procedures, duplicating the planned propulsion burns and the entry scenarios in the simulators and trainers. Another recovery ship was being added for the mid-Pacific landing site. And when people showed up and were un-busy, they would always get coffee for others. This was "whatever-it-takes-time."

Outside the team, we gradually became aware of the outpouring of concern, support, and prayers from fellow humans across the globe. It seemed to grow in intensity and scale all the way through landing and recovery.

As the time for the PC+2 maneuver approached, Gene and his White Team went through a review of the mission rules for the burn and the attendant variations. The burn went just fine, the power down started to about 12 amps, equivalent to three 100 watt light bulbs. Apollo 13 was on the way home. After this shift, Gene took the entry team offline and continued the work of detailing the CSM and LM plans for the end of mission phase.

90:09 GET (34 hours:14minutes after the start of the problem) Joe Kerwin, the capcom who followed it the whole time, began to read up the procedure for using the CSM LIOH canisters to scrub the CO2 out of the LM cabin. Once implemented, the CO2 readings dropped from 7.5 mm Hg to 0.7mm in short order. The RETURN HOME Step #5 worked fine, full credit to the Crew Systems Division guys.

A later 7 fps midcourse correction was performed at 105:18 GET. The LM consumable status at 107 GET continued to improve to the point that the required consumables would have been supportable by the lesser LM Ascent stage—only supplies augmented by the PLSS (primary life support system backpack) O2 and H2Oas supplements.

The MCC pipeline was regularly delivering a number of new and non-standard checklists for required activities. There were some very effective leaders of specific areas and probably hundreds of operations and engineering personnel evaluating all options and astronaut crews testing each procedure in the simulators.

Soon after the explosion and the CSM was powered down, Gene had gathered up most of his team offline in one of the staff support rooms and started to assess the situation. Very quickly, John Aaron announced that we did not have enough CSM power onboard. Gene then put John in charge of approving all power usage for the entry phase. John took the challenge and did not go back to front room console duty until time for the entry phase. John was always effective at laying out a concept and power profile as a starting point and then engaging a wider group of experts to buy-in and refine the concept into a workable checklist. In this case, a back room expert named Jim Kelly was the key critical help to John in getting the solution ready for wider participation. A well analyzed timeline was a prerequisite for the detailing of a checklist of involving circuit breakers and switches. In the hours before PC+2, the LM team did not want to commit any power to the CSM. Nevertheless, John still saw his work as having two options—one without a LM recharge of the CSM batteries and one with the recharge.

As a result of PC+2, the return trip was shortened by 12 hours and the team had the opportunity to see the LM power down to 12 amps. The support for a recharge improved. The team first had to devise an entirely new procedure for charging the CSM batteries. Jim Kelly took the lead for this critical invention, with support from Bill Peters of the LM team, while John Aaron continued with the entry plan.

The spacecraft design for normal power transfer was from the CSM to the LM. The new procedure (from the LM to the CSM) had to be ready by the time when there was sufficient confidence in the LM power situation to charge the CSM batteries. Also, the solution was complicated by having to power up a Main DC bus and a Main AC bus, plus its associated inverter in the CSM and live within the current limits of a 7.5 amp circuit breaker on the charging line. It also required careful closeout once done. And it required Jack Swigert to configure the CSM switches and circuit breakers by flashlight and in the cold. This critical checklist was prepared almost entirely by Jim Kelly and Bill Peters. All done successfully and is acknowledged here as RETURN HOME Step #6.

From about 112 GET to 129 GET, LM power was used to bring the half depleted battery A to full charge and, finally, to top off the other two entry batteries. This was a small 15 percent increase, but which proved very helpful in providing John's team with just enough power to ease some of the earlier difficulties in fitting the desired power-up steps to the power available, and resulting in a less time-compressed timeline.

(In retrospect, the LM power was managed conservatively and that was understandable. But we had not been sufficiently sensitive to the crew condition in the cold, cramped spacecraft and the difficult sleeping environment. A fully informed assessment would likely have led us to release more LM power earlier to ease the checklist planning bind and to warm the cabin. We could have provided some improvement on both those counts. Even so, the crew never complained and performed heroically.)

Arnie Aldrich was the chief of the CSM Systems branch and, as part of his responsibilities in SPAN, had been coordinating the approval of the entry checklist with the program engineering and management teams, both NASA and industry. Eagerly awaited by all of us, and especially the crew, Arnie approved the release of the final entry checklist by 125 GET. The checklist was 6 pages and had gone through 6 revisions, every 12 hours.

John Aaron walked it into the MCC. The read-up was delayed briefly to get checklist copies in all the right hands and recommenced at 126:15. With its arrival onboard, RETURN HOME Step #7 was accomplished.

The LM was still cold and the power margins permitted an early power up at about 132 GET, which warmed up the cabin for the comfort of the crew. As a measure of our earlier electrical power management efforts, the LM was able to supply the highest level of electrical power of the entire mission, about 42 amps, and sustained that level for the last 9 hours of the LM operation. The crew performed a LM guidance alignment using the new Sun-Moon technique, as developed with the Trench and the supporting mission planning team. This LM alignment saved time and power later in the CSM timeline because the LM guidance reference could be transferred to the CSM quickly and easily.

The last midcourse was at 137:40 GET. It took FIDO Bill Stoval the whole shift to get the Sun/Earth alignment procedure worked, including involving all three crew men in the execution of the burn, another team innovation. Jack Swigert was the timekeeper to start and end the burn, with the other two crewmen controlling attitude with the hand controller and the translation controller, a trick never done before.

Jim Lovell's comments on the state of the SM after jettison were sobering: “And there's one whole side of the spacecraft missing. Right by the high gain antenna the whole panel is blown out, almost from the base to the engine...It's really a mess.”

Later in the CSM power up sequence, the crew reported: “Main Bus A and B up and on.” This report told the MCC and especially the CSM team that the CSM was back from the earlier explosion and from being unpowered for almost four cold days. Now it was ready to do its job. A little later after LM separation, a grateful salute went out: “Farewell, *Aquarius* and we thank you.”

Onto the blast furnace of entry and *Odyssey* had one more surprise for us. For some reason, the end of blackout extended by about two or so minutes past the normal time and we stayed that much longer in our respective “Our Fathers” as an uneasy silence stole the air out of MCC. Then, “2 drogues” pulling out the 3 beautiful main chutes, landing in sight of the carrier [USS Iwo Jima] and onboard her in a fast 45 minutes—the crew of Apollo 13 was safely home.

We all had our reactions to the flight. For me, I felt that the Black Team shift immediately after the explosion and for the next 14 hours was the best piece of operations work I ever did or could hope to do. It posed a continuous demand for the best **decisions** often without hard data and mostly on the basis of judgment, in the face of the most severe in-flight emergency faced thus far in manned space flight. There might have been a "better" solution, but it still is not apparent what it would be. Perhaps, we could have been a little quicker at times but we were consciously deliberate.

During the 87 hours from explosion to recovery, there were likely thousands of spacecraft configuration and mission timeline **choices**. There were numerous new **innovations** imagined, perfected and made available on-time. All of these were a vital part of improving the prospect for a safe and successful outcome.

We built a quarter-million mile space highway, paved by *one **decision**, one **choice**, and one **innovation*** at a time—repeated constantly over almost four days to bring the crew safely home. This space highway guided the crippled ship back to planet Earth, where people from all continents were bonded in support of these three explorers-in-peril. It was an inspiring and emotional feeling, reminding us once again of our common humanity. I have always been so very proud to have been part of this Apollo 13 team, delivering our best when it was really needed.

After the flight there were some extraordinary events that occurred in rapid succession. President Richard Nixon arrived at JSC to award the Presidential Medal of Freedom to the entire Mission Operations Team. The ceremony was held outside on a beautiful Spring day to accommodate as much participation as possible. Sig Sjoberg received the medal on behalf of the team. Speeches appropriate to the event resounded across the campus.

Next, I was assigned to brief the Senate Aeronautical and Space Sciences committee with Senators Clinton P. Anderson. chairman, and Margaret Chase Smith presiding. It was April 24, 1970, just a week after landing. And a very great honor for me to tell the story of what our team did.

I also had a chance to visit with Bill Anders who was now on Vice President Spiro Agnew's staff of the new National Space Council. This was the start of an amazing career for Bill outside of the astronaut role. I was also invited to the home of Ethel Kennedy and family for a small party to commemorate the event. It seemed like everyone wanted to celebrate the successful return of Apollo XIII. Senator Ted Kennedy was there and he was already into “re-ordering our priorities,” meaning less money for the space program which had peaked at 4.5 percent of the federal budget—an understandable reaction even though it was President John Kennedy's goal of the “end of the decade” which drove that funding. (NASA never came close to that level again, more like 0.5 percent in recent times).

I had just got home from that excursion and we—Sig Sjoberg, Apollo XIII astronauts (except Fred Haise who was still on the mend from an infection) and flight directors—were on the Gulfstream, headed for Chicago. What a whirlwind trip that was with a chance to see the legendary Mayor Richard Daley in action and full command. I had my most vivid memory of him from the TV coverage of the 1968 Democratic Convention in Chicago when the protests and the Chicago response filled the streets of that famous city with a very ugly scene. This was different, and the machinery of the city purred like the sleek machine that it was.

Former President Lyndon Johnson had just left the city and we saw access control of the on-off ramps to the main freeway, superbly timed to clear the path of traffic and then re-open as we passed and to resume normal flows. We were on a fast dash to meet many city and state officials, school teachers, and kids. We rushed into a hotel expecting more of the same, and when we got to a beautiful suite with a grand view of the city, the mayor announced that we had 30 minutes to catch our breath and the bar was open, favoring Bloody Marys at this time.

Then we traveled in open convertibles on a parade around the city loop, waving to a multitude of people with American flags and joyful at what we had just pulled off. When we did get back to the plane, we found silver bowls engraved for the occasion for our wives. Pretty classy operation, Mayor Daley; thanks for a spectacular day.