Interview with Aaron Cohen, Command and Service Module Manager, Manned Spacecraft Center, Houston, by RS. Conducted during Apollo 16 mission, 23 Apr. 72.

Aaron Cohen is universally conceded to be one of the most brilliant engineers at MSC -- or anywhere else in the world of space engineering; Bill Tindall can't speak too highly of him. He has been in the Apollo program since the Manned Spacecraft Center was inaugurated, having joined NASA at the time of the move to Houston. I had long intended to talk to Cohen, whom I have known slightly for about three years, and this was a good time -- ~~just~~ after the failure of the burn of the CSM that was to circularize the spacecraft on 20 April so that the LM could go ahead and land. The failure delayed the moon landing by six hours. I asked Cohen to explain the happendings.

Nobody knew anything was wrong until Mattingly came from behind the moon. In the CSM he was to have done a circularization burn -- a six-second burn with the SPS. The plan was for Mattingly to go through his normal procedures, including a gimbal actuator check. To do this he turns on the primary gimbal actuators, and he checks those out; then he goes to the secondary gimbal actuators. In order to make a burn, both sets of gimbal actuators have to be operating, both pitch and yaw for the primary and pitch and yaw for the secondary. This had to be done on the back side of the moon because the burn had to be done back there. As he came around, and mission control acquired him again, via communications, he reported "No circ burn."

In other words, he did not accomplish his six-second circularization burn. The first thing Mission Control had to do was wave off LM descent until it was understood what had happened. Mattingly reported that he got oscillations on the secondary yaw actuatorThe reason this is critical is: if you lose the SPS actuator you cannot control the SPS engine. The rule states that you should have your primary system and secondary system or one of the two system and the LM to get you out of lunar orbit. So, once the LM was committed to descent, one of the back-ups would have been lost to get out of lunar orbit. Mission Control had to be sure it had not lost its back-up.

The Flight Director passed the order to CapCom who sent it on to Mattingly: go through a series of gimbal checks in all the control modes: G and N, and the Stabilization and Control System Control mode. Exactly as Ken had reported, they did get yaw gimbal oscillations. It appeared at that time that the yaw gimbal actuator had been lost 'there are four actuators: pitch and yaw in the primary and pitch and yaw in the secondary. Ken went through every control mode, doing a check-out, commanding the gimbals in those control modes (about five in all). That data was recorded on the tape recorder in the spacecraft and played back to the ground, where the data was recorded concerning the response of the actuators. The ground got the data and assembled the subsystem manager from MSC, the North American subsystem manager, the MIT people -- all were in the back rooms of Mission Control supporting the mission. George Jeffs of NAR was there, and looked at the data, along with Cohen, Jim McDivitt.

"The idea that was going through our head was that it possibly

was that it was the ~~right~~ rate ~~2~~ feedback -- the data comes out in traces, gimbal position with frequency ~~of~~ position; this provided gimbal position versus time --- the conclusion was we were getting plus or minus one degree oscillation of the gimbal position, at approximately two cycles per second (two hertz). The gimbal actuator is a classical servo ~~(2)~~ system , and it has rate feedback and position feedback for servo ~~(2)~~ control. The conclusion that people came to very quickly from the traces, from the plots that we saw, is that it appeared to be a rate feedback loss of signal, rather than a position feedback.

"Position feedback just tells you that when the gimbal moves you get a certain position fed back into the servo ~~(2)~~ loop. The rate feedback would be the speed, or the velocity in which the gimbal moves, and that would be fed back. If it was a position feedback, it would be unbounded and would diverge. The traces we saw from the tests run in flight were actually oscillating around this plus or minus one degree. It would increase to its full limit; it would go to one side and go back -- would go the full swing, six degrees. It would really be ~~uncrollable~~ uncontrollable. It would be random; it wouldn't be any position. We still maintain position control because the position feedback was still operating. So, we had our hardware evaluator at North American, which is a simulator. It is hardware included in the simulator. It has, for instance, a real, true gimbal actuator. It has typical stabilization and control hardware. It has guidance and navigation hardware. It has everything but actually firing the engine -- all the control electronics and all the wiring. Of course, you do not fire the engine.

"So it is a very typical flight control system. We had an idea that it was this rate transducer feedback, so what we did was actually cut the wire. We actually disabled this rate feedback transducer. We cut it at the transducer, so you got no rate feedback into the servo ~~(2)~~ loop. Of course, we had the plots on a recorder, the same type of plots that we got from the spacecraft. The traces showed that we were getting a plus or minus one degree, and approximately two cycles per second. So the signature of the hardware evaluator compared to the signature of the flight vehicle compared almost exactly -- as exact as you can get. At some time in 1969 we had done similar studies and we actually looked at them, at the rate feedback transducer and at the position feedback transducer. So we knew what the signature of the position of the feedback transducer would be. (This was off-limit testing just to understand failure modes of hardware; it was no Apollo 9). What if you've got this type of failure, and that type of failure?) There was the conclusion at that time if we lost the rate feedback transducer -- and there was a report written -- that there would be no concern in trying to control the service module propulsion engine. So, with this information we also did some thinking: what other problems could have caused this? Could it be the control wiring? If it was the control wiring you could not control. As I said before, Ken Mattingly went through all the control modes and, yes, the gimbal did respond to the control modes. So we knew it was not in the control wiring. We knew it wasn't in the position feedback because the signature wouldn't be the same.

So the only other thing it could be would be the rate feedback transducer. And that truly matched the signature of the spacecraft test. ~~Ws~~ So, with that information we knew the frequency, we knew the amplitude, we knew what the failure mode was. Then the question was: was there any structural problem associated with the engine burning with these types of oscillations?

"On Apollo 9 we did do a stroking test, where we actually went in and purposely caused the engine (through the computer) to do what we saw now. The frequency was slightly less, about 1.5, but the amplitude was about the same. On top of it, we did have the lunar module attached to the spacecraft. So we had done an in-flight test of this, plus the analysis ~~showedx~~ shows that with the two cycles per second frequency, we are about three times less than the first resonance frequency on the command and service module. Six or seven cycles per second are the first resonan~~ce~~t frequency. (CPS equals hertz). So we were far from the resonan~~ce~~t frequency of the spacecraft and structurally there were no concerns. Plus, we had proved that out in flight.

"Now the next thing we had to understand was: had we qualified the SPS engine and its mounts and the actuator itself for this type of amplitude and frequency? Looking at the data we did at the Arnold Engineering Development Center, Tullahoma, Tenn. for qualifying the engine, we found that we had ~~done~~ gone through a spectrum of frequencies and a spectrum of amplitudes much more severe and many more times at altitude than we would see during the burn. The burn for trans-earth injection is approximately 150 seconds, and we did our qualification at 550 seconds twelve times. So we had gone through a much longer duration than this would experience.

"So in that regard we cleared the structure by the Apollo 9 testing, by the analysis that we did. We cleared the qualification just by reviewing our data. So we felt very confident that we had a system that was truly a back-up system. We did one more thing -- we took the frequency responses and the amplitude, and we superimposed that ~~xmxthmxm~~ into the guidance and navigation simulation at MIT. And the guidance system was able to control with these types of responses and characteristics. So we truly had a guidance and navigation system that would handle this type of service ~~xxd~~ propulsion oscillation. We also did those same types of simulations at North American in the hardware evaluator in the guidance and navigation mode and in the stabilization and control system mode, and the manual thrust vector control system mode. We also did these simulations on our traineer here in Houston, where we simulated this type of . So they verified it. Again, in summary, we were able to define the problem, knowing how to bound the problem. Since we found the cause of the problem, we ~~found~~ control the effects of the problem. Knowing the signature, we could clear the structures, we could clear the qualification of the engine and we could show that we could control it either with the guidance and navigation , the SCS or manual thrust vector control.

So, that led us to the conclusion -- and this was all done between 2:15 and 5:15, when we had to make the decision. So this was all put together within about a three-hour time period, where we proved to ourselves that we had a degraded system but truly a back-up system that would allow us, if we should fail, our primary gimbal actuator, we could use

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the back-up gimbal actuator system to get us out of lunar orbit. So, with that conclusion we felt that we could commit the lunar module to descent and give up that capability of getting us out of lunar orbit."

Sherrod: "Well, if it had been a position feedback then that means you wouldn't have been able to fire to get out of lunar orbit?"

Cohen: "If it was a position feedback, we truly would not have control over the vehicle, so we would have to say that we did not have a back-up system."

Sherrod: "But you would still be able to dock and come home on the LM..."

Cohen: "Well, we still could come home on our primary system. See, our primary system was still good. But, yes, we could come back on the lunar module had we failed the primary system /NOTE THAT HE USES 'FAIL' AS A TRANSITIVE VERB/ in the service module." Once you commit to descent, you lose your back-up capability with the lunar module.

There is no back-up for the SPS engine itself. But it wasn't the engine that had malfunctioned; it was the control of the engine. And the control of the engine is redundant.

Is it possible to find out what caused this wire to break. "Not exactly," said Cohen, "although we know if you look at the design of it, you know that the rate feedback transducer does rotate, and it does have some wiring in there, -- the wiring is, I imagine, about six to eight inches long in that particular area -- that it could rub on a little pot on the transducer and by rotating it could wear out. There is a possibility that could happen. We X-Ray and we take precautions against that, but .."

Cohen didn't think the accident happened because the spacecraft had been in storage a long time. It could be just a stack-up of tolerances on this wiring.

This is spacecraft 113.

"After we assured ourselves that we truly had a back-up system, we did not have any concerns about going ahead with the lunar landing mission."

Mattingly made the burn on the primary system -- and today (23 April) he made the plane-change burn on the primary system. So the back-up system had not been used, and there was a good chance it wouldn't be used. The degraded mode of operation exists in the secondary, not the primary system.

Why use the secondary system? "The rule says that prior to a burn, you do gimbal checks. That includes checking both the primary and the secondary prior to every burn. And that's how he found it out."

He did the primary first, and it went fine, and then he went to the secondary, so he did the right thing by holding up -- he had an anomaly in the secondary. If we do have to use the secondary, it's adequate. If the primary should fail, it's there to be used."

The only SPS burn needed on the way home is the transearth injection. Because of the lighter weight the midcourse burns will probably be done with the RCS. You can't get enough low minimum impulse -- the lowest delta V you can get out of the vehicle coming back from the moon without the LM is something like 10 ft. per second. If you had to make a large midcourse correction you'd use the SPS, but 10 ft. per sec. or less, you'd use the Reaction Control System. The lighter the vehicle gets, the higher the minimum impulse velocity becomes. Going out, we can make midcourse corrections several feet per second because you've got the LM on and you've got full SPS tanks. Coming back, any little impulse will give you a large delta V.

There will be a report on this incident, with details. GET IT. Flight Evaluation Team, with MSC and NAR personnel participating, will write it and it will be signed out by the Apollo Program Manager (McDivitt or his successor).

End of Crisis portion of interview.

Cohen, a native of San Antonio, came to NASA when MSC moved to Houston, approximately 1961. He had worked on the Apollo study at General Dynamics at San Diego, and it was the Apollo program that appealed to him. He had worked on the Atlas and Centaur during his four years at General Dynamics. Cohen graduated from Tex A & M in 1952.

I asked Cohen why one never saw any Princeton engineers at NASA installations. Cal Pirine was the only one he had known, either at NASA or working for a contractor, he said. Maybe Princeton men stay on the East Coast.

Owen Morris is the LM manager, corresponding to Cohen's CSM job.

Cohen worked on the redesign of the CM, heading up engineering for Frank Borman after the 204 fire.

The two CSM flights before the fire were 009 and 011.

Would it have been better to forget Block I (which burned) and use only Block II spacecraft? No, said Cohen, "we learned quite a bit from Block I. Basically, we proved out our structural integrity. Which is what we were trying to do. Bonding, the way we put the vehicle togather; the pressure vessel capability of the vehicle was proved out in those flights, along with the heat shield. The systems [in Block II] I have to agree were different." Cohen recognizes that some believes Block I should never have been used.

Would Block II have had a better hatch than Block I but for the fire? "No, the hatch change didn't really come about until after the fire. The Block II hatch would have been inward-opening, which was really the concern, and that wouldn't have been changed." IMPORTANT POINT.

Critical Design Review of 012: Cohen headed up the guidance and control team. He had started out at MSC with guidance and control. He doesn't recall any special problem with G & C on 012 (WHERE DID I READ IT HAD TO BE SENT BACK TO MIT MANY TIMES?). He does recall trouble on Apollo 7, when electro-magnetic interference was a problem (340 on the counter).

CDR basically looks at the drawings. Did the drawings truly meet the specs (specifications)? CARR looks at the check-out of the spacecraft compared to its . Cohen attended both the CDR and CARR of spacecraft 12. The data looked pretty good at the CARR; there were some waivers. You've got to look at the spacecraft to see how things really are. Now we have instituted walk-downs, where you actually go through the s/c, "kick the tires, you may say." Cohen did not remember the incident of the astronauts presenting their "praying" photograph to Shea and Storms.

"Now you look at our check-out at Downey, and it's just beautiful. (Cohen is also managing the Skylab vehicles). We just finished the checkout of 116 and 117, which are the first and second Skylab vehicles. We just went through their checkout and it went just beautifully; the crew's praises were so high. There were very few anomalous conditions; the spacecraft were so clean."

Skylab 1 is the workshop, 116 is Skylab 2, 117 is Skylab 3, 118 is Skylab 4. 119 is the rescue vehicle for Skylab -- that's its only mission. (NOTE: DEKE SLAYTON IS FAVORED AS THE RESCUE COMMANDER; he is studying Russian). Those are the last vehicles that will be built. There are other vehicles at Downey under stop-work order, 111, 115 and 115A, which are in various stages of completion.

The last Apollo CSM will be 114. They took 115 and 115A out of the program , so that means 116 is the first Skylab. 111 was an H Series CSM; it was taken out and they went on to the J Series. Skylab is quite different from Apollo -- has one less propulsion tank in SM, RCS system is quite different: has propulsion system module, which adds 1,200 lbs. of RCS propellant; have a different caution and warning system; have two fuel cells rather than three; many of the displays on the display console are different.

The docking mechanism in the rescue vessle willbe different, with modifications to the docking ring. The docking with the Russians will be done where the LM now docks.

Skylab rescue launches with two astronauts and brings back three, so rescue vessel has a five-man capability.

Back to Block II spacecraft, which Cohen pulled together after the fire: "It wasn't really a new spacecraft. The top-level spec didn't involve many differences. Mostly, you'd have to get down to the drawings to see the differences -- system-functionwise -- if you look at what's done, it's a much better, much safer vehicle, with much more capability."

Changeover from pure oxygen to 60 nitrogen, 40 oxygen; our policy

was 100% oxygen was certainly the safest thing to do from a physiological point of view -- five pounds per sq. in. with 100% oxygen was certainly the safest thing to do. You did not have to worry about any mixing, any type of physiological effects. "What we had to do was to convince ourselves, the medical people, that it was safe to start out with 60-40 , then wind up with something like 60 percent oxygen and 40 percent nitrogen and then wind up with 80% oxygen, 20 percent nitrogen at 5 psi. Start off with 60-40 at 14 psi-15 psi and wind up with an 80-20 at 5. Really, when we started pursuing it with the medical people, in showing them how to do it, really it turned out to be very easy to do without changing any spacecraft hardware. We really do not have a two-gas system. Right now in the mission we are (as of 23 April, lift-off time from the moon) 100% oxygen."

By the time the crew goes into the LM, practically all(85-90%) of the nitrogen has been bled out. Nitrogen is bled overboard through the waste compartment, and it is replenished with oxygen. Then once you go into the LM you have dumped everything and you repressurize. You are then essentially 100%.

Nitrogen is pumped in when the vehicle is on the pad: pressurize with 60-40. Waste management compartment is kept open. So, the only nitrogen you have is what you start with. 60-40 on the pad is about equivalent flammability-wise to 5 psi in space, oxygen-wise. That's the way it proved out in flammability tests. "What I was trying to do was to meet a materials requirement, and a physiological. The medical people wanted 80-20, the flammability people wanted more like 50-50.

"We were able to compromise at 60-40 and then run tests to show we met 60-40." It was Cohen who discovered you only needed to start with nitrogen, not to resupply it en route.

Other Crises

Apollo 13: "Real reason we went to three oxygen tanks on Apollo 14 was that we did take the fans out of the tanks. We were concerned that we did not understand zero-g in cryogenics in terms of stratification. We didn't understand how we were going to get the oxygen out of the tanks. On 14, consummable-wise, we did not need three tanks. We didn't know how high we were going to have to run the heaters to get the oxygen out of the tanks. The fans gave us the mixing. Zero-g is very complicated to do calculations, and when you couple that with cryogenics, it becomes more complicated.

"It becomes more complicated to create a maff (?) model (564) on the counter that gives you confidence. So what we decided to do was to go with three tanks, and to design a test to show that we could get out of the problem of stratification. /One layer being much warmer than the other, in terms of cryogenic temperatures/.

"We finally found that we didn't need the fans for the flow rates in the regime that we were talking about. We do have some stirring of the liquid due to the RCS firings and the SPS firings.

In the hydrogen tanks we still have the fans; in oxygen we do not. We just have the heater and the quantity gauging system. And the heater has metal sheathed wire."

Had there been problems previously with this heater? "Not really with the heater. What we found that we had a thermostat really, which failed until it could not cut the heater off -- the micro-switch was a bad design and it failed. It was from Beech. It allowed the heater elements to overheat, whereas really it should have cut the heaters off. The same thing could have happened on any of the previous missions."

The Skylab vehicles will have two oxygen tanks and two hydrogen tanks. So, the three real crises of the spacecraft have been the 204 fire, the Apollo 13 hair-raiser and this week's affair?
Cohen: "But you know you could go back to every mission and I could tick off a crisis.

"In Apollo 7 we lost both electric busses for a period of time. To me that was one of the most dramatic experiences when Wally Schirra reported he had lost both AC busses I THINK THAT WAS THE SCARIEST INCIDENT THAT I EXPERIENCED. It turned out not to be significant, but at that moment.

"It was a brief glitch but my heart leaped to my throat. That just shocked me something terrible.

"Then in Apollo 8, in all honesty, we did not go through any dramatic experience. That mission in itself was enough to give you enormous concern.

"In Apollo 9 we went through a number of small items, a lot of cautions and warnings and a lot of things going wrong, small things. You can't say that Apollo 9 was a concern mission.

"In Apollo 10, do you recall we lost a fuel cell while we were in lunar orbit.

"Again in Apollo 11 we had some small items but nothing really went wrong.

"In Apollo 12, we had the lightning at lift-off. Apollo 13 we have discussed. In Apollo 14 we had the probe incident , the docking probe. In Apollo 15 we had the switch incident which caused us some concern. And in Apollo 16 we had the gimbal incident. I think you have to say in almost every mission there is an incident that gives us concern."

Sherrod: "Then you always skate on the verge of disaster, don't you?"

Cohen: "Well, as I look at it -- it's interesting to know what I go through prior to a mission. I go through the same activity that the people go through for fourteen days during the mission. I go through every day it's just like a mission. I'm always looking at

hardware, always changing hardware out. Like for this vehicle: I don't know if you recall but we ruptured an RCS tank while we were on the pad. We had to go back to the VAB, and by then back to the NSO. (WHAT'S THAT?).

"That wasn't per se what delayed the launch a month. That actually happened after we decided to delay it a month. I venture to say there are fifty such incidents before I get it off the pad. Every one of those has to be cleared. For example, I was doing a docking ring test for Skylab and found that the docking ring would not fit properly. So I had to go back and make a ~~change~~ modification on the docking ring in Apollo 16.

"So we had to lift the forward heat shield. You have to solve every problem as it comes up. You can't leave any problem unanswered. I guess I feel that there are two things you have to do. Number one, any anomaly that comes up prior to lift-off that can pertain to hardware, whether it's on the spacecraft that you are flying or on another spacecraft, maybe on a Skylab vehicle or maybe on the next vehicle, -- Any failure that occurs on any hardware that you are flying, you've got to understand it and take action on that particular piece of hardware, even if it hasn't failed on that spacecraft. You've got to lift that spacecraft off the pad that is working to the best of your ability. To the best knowledge you have, every piece of hardware has got to be working. I guess what I'm saying is that you've got to rely on the redundancy you have. It's a very unforgiving mission, and you've got to rely on the redundancy to make the mission safe and successful."

Which mission wound up with the most anomalies in the spacecraft? "9 probably had the most, but they happened to be small ones."

COHEN SAID HE WOULD PHONE TO WASHINGTON COMPARISON IN WEIGHTS OF SPACECRAFT SINCE APOLLO 7, CSM and LM. Service Module has many instruments now, and has increased considerably. (I said I thought LM had gained more weight; Cohen was doubtful).

Cohen said he would be willing to answer questions by phone at any time. Phone 713-HU. 3-4655.

Interview lasted about one hour and ended one hour before Apollo 16's Orion lifted off from the lunar surface.