July 3, 2008

To: Bill Gregory
From: Dave Scott
Subject: "Go for Lunar Landing" – <u>Conference Report</u> – <u>Comments</u>

The following comments are offered on the "Go for Lunar Landing Conference Report" (V 1.13), June 3, 2008. These comments are in addition to those comments included my Memo of February, 26, 2008 (pp. 36-38 of the Report); which still hold. As mentioned in the Report, volumes can be written on this subject; therefore this Memo will be limited to comments on only a few important issues (as identified by excerpts from the Report shown in dashed boxes).

<u>Objectives and Attendees</u>. The objectives of the Conference appear to have been primarily flight operations-oriented; however most of the approximately 150 attendees appear to have been engineering-oriented. Therefore, it is recommended that subsequent gatherings on this subject include a greater proportion of flight operations experience such as a minimum of six people from Dryden (e.g., two test pilots, two flight test engineers, and two project mangers). Those attending from the "space" side of NASA should include the same mix, but also a Flight Director (or two).

By Conference Topic – Notable Comments and Recommendations

EXECUTIVE SUMMARY

<u>Page 1</u>

> Finally, the next lunar landings need to be approached with forward traceability to human Mars exploration as a prime consideration. An "Abort to Surface"[1] mentality is especially important to maximize applicability to future Mars expeditions, where abort to orbit modes will not be possible or programmatically desirable. The avionics and GNC systems for the Altair spacecraft need to be directly transferable to future human Mars landers in order to fully develop an appropriate industrial base and experience reservoir for ongoing direct human planetary exploration.
>
> There is widespread agreement that under-funding is a clear threat to Project Constellation and the Altair program specifically.

The order of these paragraphs is reversed, but trey send a particular message about Mars (one of many in the Report – this comment applies to all). Attempting to combine lunar and Mars requirements in the design, development, and operations of a lander will compromise both, just as such expansion of capabilities has so many times in aircraft programs. Go for a <u>lunar</u> landing – let the Mars folks design and develop their machine when the time comes (most likely decades from now) – many "things" will have changed, especially "computers" and "software" (or whatever they are called then).

Three things will happen if Mars capabilities are required in the lunar mission "architecture" (whenever it is formulated), the lunar program will experience:

1. Increase in cost (a further sever burden to "under-funding")
2. Increase in schedule
3 Increase in **<u>Risk</u>**

- Having a backup guidance and navigation system that is "common mode failure" independent of the primary system, such as the LM Abort Guidance System, is required and should be capable of "abort to surface."

1 **Abort to surface**: In the case of off-nominal events during powered descent that still permit a successful landing, continuation to a less-challenging or more accessible secondary landing site would be the preferred decision rather than an abort to an orbiting craft.

Of course – and this is exactly what we had on Apollo – find a place to land, and land, call it what you will. If we could not find an acceptable place to land, the only option would have been to abort to orbit. If we had a major systems problem that precluded landing, we would have aborted to orbit ("abort" means premature termination). Remembering also that propellant was (will most likely be) limited and you could not fly around looking for a less-challenging landing site over the hill or across the valley.

THE APOLLO EXPERIENCE

Page 5

- Heads-up displays of current flight information for both the commander and the pilot is much preferred over the relatively cumbersome verbal transfer of information employed during the Apollo landings.

The verbal transfer of information was not cumbersome and in fact optimized the landing technique – that is, "we" landed on the Moon – the machine (LM), the CDR (eyes outside), the LMP (eyes inside), and MCC (many eyes). Therefore, an LPD on a HUD would be fine. Otherwise, don't block the CDR's view or distract him with information that can be provided through his ears by the LMP and MCC.

As an example, on A-15, we found that the optimum technique was for the CDR to focus out the window and the LMP to focus inside the cockpit. The CDR maximized the landing point information through his eyes while absorbing the LM gages and systems through his ears (LMP and MCC); thus optimizing all sensors available. The verbal transfer of information from the LMP to the CDR was a most effective technique to optimize the use of all of the information available – that is, with proper training and coordination, each of the LMP and CDR could focus on assigned tasks without dilution, confusion, or subtracting from the maximum use of available information.

The lunar landing as we implemented it on A-15 was not unlike landing in formation during bad weather – one pilot has his eyes in the cockpit scanning all of the information available and the other has his eyes outside searching for the runway – when the outside eyes see the runway, "contact" is called and the lead comes out of the cockpit and begins the flare to touchdown. Prior to that, the lead is completely inside the cockpit "on the gages." Both hear ground control, e.g., GCA, and the lead reacts to the information provided.

Similarly, during our landing on A-15, Jim Irwin kept his eyes inside the cockpit and fed me appropriate information as he gathered it; and if any "unplanned" information appeared, he would recognize it immediately and either take action or inform me. At the same time, my eyes were focused on the landing area searching for an appropriate touchdown point – this is, as reported by all, quite a challenge. The only visual aid was the LPD which was very effective. Anything else in the view would be distracting. I want my LMP's eyes inside watching <u>everything</u>; and he wants my eyes outside to find the best touchdown point. Of course, we each also occasionally made a quick cross-check inside or outside, just like airplane drivers in formation -- an occasional quick scan of the crrosspointers (which had been precisely located to support this concept) and then also focused on the 8-ball when we went IFR.

MCC, at the same time, was tightly in the loop, whereby both of us could hear their inputs and each of us would act and respond accordingly – sometimes the CDR and sometimes the LMP. From our training, especially integrated sims with MCC, we each knew our areas of responsibility and MCC did as well. In general, when the CapCom made a call, we both know to whom it was directed.

Within the Lunar Module there were 129 indicators and warning lights as well as 396 switches and circuit breakers. All told, there were 525 specific "functions" that the crew had to understand, evaluate and operate either in primary modes, backup modes, emergency modes, or trouble-shooting to determine the cause of a failure or an anomaly. I want my LMP to focus on all of these, I want his undivided attention inside the cockpit so that I can focus out the window and select a proper touchdown point; we can talk about the dust once we are safely down.

For more discussion on this see the ALSJ (e.g., A-15 beginning at 104:38:38) as well as *Digital Apollo* (especially pp 258-261).

Therefore, an LPD as a HUD in the CDR's window would be fine. Otherwise, don't block the CDR's view or distract him with information that can be provided through his ears by the LMP and MCC.

- Ground simulators "time" probably needs to be faster than real time (2:3, respectively) to provide practical representation of the flight working and psychological environment.

Absolutely…!!! And never understood why NASA did not do this during Apollo, especially after so many astronauts experienced the "fast-time factor" during flight.

- Future simulations using free-flight vehicles could be performed at much safer altitudes for high-risk conditions and drogue chute deployment, if provided under emergency conditions where loss of flight control occurs, might recover the vehicle safely. No jet propulsion or lift rocket system failures were ever a factor in the 3 accidents of the LLRV and LLTV's, which all resulted from of a loss of vehicle attitude control.

Is this to place the landing point on a platform – high enough for a drogue chute to deploy in an emergency? Otherwise, if the simulation is performed at "much safer altitudes," how does the pilot practice selecting a touchdown point (the object of the exercise)? With the LLTV, at an initial hover over touchdown, I normally maneuvered to a second touchdown point, to essentially simulate Neil's challenge on A-11.

Page 6

> A1: Gene Matranga: I am not sure about the response of the new systems that would tilt their propulsion systems in order to do that, like the Harrier or the Osprey. I am just not familiar enough with their response systems to know whether they would do that. I would be skeptical, just from what I know of them, that those things are not intended to move quickly, and in some of these things you can move quickly, we moved the LLRV or LLTV to fairly significant attitudes in a short time period. I think they would have difficulty in doing that. Just my own personal opinion, based on intuition

Gene is correct. “Aircraft” do not have the dynamic response or handling qualities of a lunar lander, and they are also subject to aerodynamic forces that would be difficult to filter or cancel – not practical for lunar landing simulations. However, helicopters are quite useful in becoming familiar with steep descents and are a valuable precursor to an LLTV type vehicle.

Page 8

> As a result, engineers and pilots experimented with speeding up the simulation's integration rates, or making the apparent time progress faster. They found that the events in actual flight seemed to occur at about the same rate as they had in the simulator once that simulation time was adjusted so that 40 simulator seconds was equal to about 60 "real" seconds. Only the final simulation planning sessions for a given flight were conducted in this way.

Absolutely correct approach (see above). I can think of many missions that would have benefited from this, beginning with Mercury. This is another reason that the flight operations folks (e.g., Dryden) are so important…!!

IMAGING

Page 10

> sensors for acquiring the needed real-time hazard information. Third, despite significant pre-mission planning, orbital reconnaissance, and training efforts, combined with trajectories and lighting conditions designed to facilitate surface hazard detection and avoidance by lunar crews, two of the Apollo landings occurred in close proximity to potential hazards. These considerations drive the hazard detection, avoidance, and precision landing capabilities needed for an lunar descent and landing systems.

The main difficulty during Apollo was a lack of high-resolution imagery to assist in identifying and training for a precise touchdown point, or better, a touchdown area. A high-resolution virtual reality view of the touchdown area would be a solution to this problem – the pilot could easily plan to avoid the danger areas from eyeball-resolution altitudes. Something like the CAVE at Brown would be a good start.

Page 14

> A13: [Schmitt] Apollo 12 (Conrad/Bean) mission experienced considerably more dust than other missions. Possibly Apollo 15 (Scott/Irwin) did, as well. These were young sites, which is counter-

See the ALSJ for a discussion on dust. Maybe dust -- Maybe no dust? Learn to fly in the dust. The LM instruments were just fine for an IFR landing – make sure that the future LMs have such; then dust is no big deal; as long as a reasonable touchdown area can be selected before dust is encountered, even if rates are not yet nulled.

AVIONICS

Page 17

> sort of voting system. Orion is relying on a self-checking pair with a backup. For Altair, there will be a continued emphasis on size, wight, and power. One fault tolerance is the current design criteria.

Yes, of course – keep this in mind throughout the planning, but include cost.

Page 18

> *One has to assume that there will be some degree of manual control available to the pilot. No pilot will want to completely trust a system flying their vehicle for which they have no authority to command—especially one which is landing on an alien world for the first time.*

Absolutely..!!

SIMULATION AND TRAINING TECHNOLOGIES

Page 22

> became unnecessary. He reiterated Lauri Hansen's point from the Tuesday keynote address that many hardware mockups were constructed during the Apollo program, which will not be possible in current program. A number of tests were conducted with the initial versions of the LM to ensure astronauts

Then it's going to be terribly crowded in the mock-ups they do build. These were invaluable for engineering analysis, design reviews, procedures development, stowage planning, and a host of other vital activities. It would behoove them to find the money for these (a good trade for some of the other "things" they are planning, even considering the excellent 3-D VR images that are available today).

> The use of hybrid analog/digital computers in their simulator testing was discussed, which could include hardware in the loop. Also showed a cockpit mockup, out the window views (artists

An excellent subject for further analysis. One of the major difficulties during early Apollo was the availability of the crew-training simulators, in particular two major problems: (1) the computers that ran the simulators -- they just could not keep them running; and (2) the software representation of hardware -- they could not keep up with the hardware changes in the actual spacecraft. And even when these simulators did run, we could not be positively sure of the flight software (due to changes as well as the software-AGC). Two examples: (1) prior to A-9, Rusty and I developed almost all of the LM/CSM and CSM/LM rendezvous procedures on the hybrid at Downey (which had an actual AGC);

and (2) the 1201s…!! Hybrids also exercise certain hardware elements and can accommodate hardware changes as they occur.

Page 24.

you do about it? Technology has improved, but human brains have not. What, then, is the proper allocation of tasks between human and computer? Apollo workload was very (too) high. On who's in charge: who should have final control authority, the pilot or the computer? Should the pilot simply have a vote? His thought is that the pilot should have final say. Points out that the automation itself is

However, we have learned a lot about the brain, which makes it much more "useful," e.g., zoning. And the Apollo workload was not too high, no more than a fighter in bad weather and low fuel – other than the consequences of a lunar landing. As Pete Conrad once remarked (*Digital Apollo*, page 181):

> *"We are banking our whole program on a fellow not making a mistake on his first landing."*

tasks, and that will require a simulator. Thinks that handling qualities for Altair would be superior to Apollo LM (and assumed RCAH of some sort). Other problems that will need simulators to overcome

The LM descent handling qualities were excellent, and for the Ascent Stage only, superb.

and could do simulations at 2000 ft over simulated lunar terrain. Does not think that an LLTV is necessary simply to increase pucker factor, that he's seen plenty of instances where pilots are under a lot of stress in simulations. "It's like doing bombing training with real flak."

In any simulator, regardless of the situation, the pilot knows that it can be reset wile he steps out a cup of coffee.

Page 25

he approached the landing site more quickly than he should have because he was worried about the low fuel light. The bottom line is that workload was only manageable because the ground could take up any slack necessary, and that autonomous operations will require a lot of thought about autonomy

Why would he have gone any less quickly? His landing was just fine as it was. And "workload only manageable because the ground could take up the slack" – wrong; the ground was advisory and not on-board "functional" albeit it was great to know the 1201's were "go," but the computers were running fine and he would have most likely landed anyway. The ground (MCC) is critical during earth launch (the data and dynamics are much more time sensitive), but not during lunar landing. I doubt that anybody would have aborted after PDI with a loss of comm from MCC; they would at the least have had a look at pitchover, and then most likely pressed on with the anticipation that at some point comm would be restored (although it was not essential for landing and return).

moving simulators plus some free flight analogs. Suggests that helicopter experience doesn't help very much with piloting a lunar lander. The astronaut office has not taken an official position on this, but

But helicopter experience does help. Becoming comfortable with a near-vertical descent is very beneficial to the pilot of a lunar lander.

Page 26

Q1: Jessica Martinez: difference in this program is the fact that we'll have 4 crew members. What effect will this have?

This is the major fault with the Architecture Study – 4 crew members to the surface, and none in the orbiting spacecraft. There are so many problems with this concept that it's hardly worth commenting…..however, a few thoughts (using Apollo as a "platform").

1. The Commander of the Expedition (CDR) must have absolute command and control of the mission, subordinated to nobody (albeit accountable to many).

2. The orbiting spacecraft must therefore be controlled and operated by a member of the expedition (for example, a "CMP"). Rationale:

> a) When critical decisions must be made, especially as they relate to return to Earth, a qualified CMP must be in the loop. The CDR and CMP have trained together for many years and the CDR has absolute confidence in the CMP's reasoning and judgment.
>
> b) Further, the assessment of risk is most likely the same by CDR and CMP; e.g., should a decision go wrong the CMP and the CDR would end up in the same place (wherever that might be). Conversely, those in MCC however bright, motivated, and qualified, will have a different assessment of risk (e.g., should a decision go wrong, they would feel really bad).
>
> c) Regarding the status of the CSM, the CDR can expect to always receive a full and complete story from the CMP, regardless of the circumstances. Conversely, we know by experience that MCC does not always provide the full and complete status of situations to the CDR (e.g., this was experienced on A-15, see AFJ, Flight Summary).
>
> d) The CDR must make the final decision on the orbiting and return to Earth operations – this is absolute (i.e., the Field Commander must make the field decisions). Without the orbiting CMP in the loop, this would be abrogated to MCC (albeit with the CDR concurrence, but not necessarily with a CDR override) – whereas the likelihood of final decision being exercised by the CDR is much greater when the CMP is in control of the orbiting spacecraft.

3. The Expedition crew must not be in a relationship subordinate to MCC; that is, MCC must not be able to "hold anything over the crew" (other than of course accountability). Consider what happened to Vasili Tsibliyev the Commander of the Soviet Mir space station (yes, of course this will never happen again!):

> N JUNE 25, 1997, THE Russian supply spacecraft *Progress 234* collided with the *Mir* space station, rupturing its pressure hull, throwing it into an uncontrolled attitude drift, and nearly forcing evacuation of the station. Like

> Despite the near collision during the *Progress 233* test, Russian flight controllers elected to repeat the test with *Progress 234*. Potential interference from the Kurs radar was to be avoided by shutting the system down, depriving the cosmonauts of range data! The objective

> ***Social.*** The social factors that could have contributed to the crash include the subordinate relation- ship between the cosmonauts and Russian Mission Control (TsUP) which is

> Collision in Space BY STEPHEN R. ELLIS

4. CSM spacecraft control must be independent of direct control by MCC (as it was on Apollo). Should CSM control be a direct function of MCC, the CSM is exposed to all relevant MCC faults; e.g. (a) power failure; (b) communications loss; (c) weather; (d) terrorist activities; (e) human factors; (f) etc., etc.

5. Certain CSM faults and failures can be corrected by a human; not so by robotics; e.g., (a) Apollo 13 (LiOH); (b) Zond 7 (Leonov, *Two Sides*, p 253)

> Q2: Mitch Fletcher (Honeywell International): Is it more or less expensive to have a 6 degree of freedom simulator than a flying vehicle?

This also introduces in the case for fixed-base vs. motion-based simulators. Motion in space is benign (except tumbles); motion during landing is dynamic and time of flight is extremely limited. Fixed-base simulators are fine for the simulation of space operations. As we have discussed, an LLTV is essential for the dynamic elements of a landing simulation – a fixed-base simulator is fine for procedures development and systems training. Therefore, the combination of an LLTV and corresponding fixed-base simulators is optimum; both from training and cost perspectives. That is, fly the LLTV and work procedures and systems in a fixed-base simulator (skip the motion base).

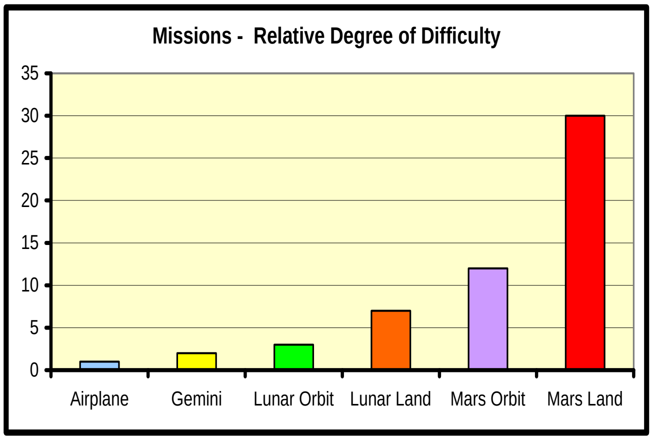
PROJECTED NEEDS

<u>Page 30</u>

> • We need to approach the Moon with the emphasis on Mars – abort to surface, not orbit.

A great idea, mentally, emotionally, and motivationally, but not programmatically. As mentioned above, to add Mars requirements to the lunar requirements would increase cost, schedule, and risk. Mars is not on the horizon now, or even in the distant future; no need to compromise an already difficult task (landing on the Moon) – difficult in cost, schedule and risk as it is anyway. And the use of the term “abort” seems cavalier in these discussions – if the crew decides not to land at a specific point, for whatever reason, they will, if at all possible, land at another point – that is not an “abort;” it’s moving to a contingency, emergency, or secondary landing site. “Abort” means the premature termination of the flight, not modification.

As a final comment, several years ago I was invited by the Royal Society in London to present a public lecture on the “Challenges Facing the Human Exploration of Mars.” In researching my preparation I contacted several colleagues (science, engineering and operations) to ascertain their opinions on the relative "degree of difficulty" of a human Mars mission. A compilation of the results is illustrated in the chart below.



As you can see, based on at least one assessment, Mars is a very, very difficult program, and very long-term in its planning, preparation and funding (which is of course no surprise). However, the "technology" to be used will be very different from the technology of today; e.g., as you might expect the software programs of today will be stored somewhere in a dark corner of a forgotten warehouse (at best) – doubtful that this will be re-vitalized; the people who are fortunate enough to be assigned the Mars program will have their own technology – to them all best wishes, good luck, and bon voyage. For human expeditions to the planets, focus now on the Moon, spend not a penny on Mars (but dreams cost nary a ha'-penny..!!).

Again, well done and congratulations on making something happen – it will surely be appreciated by those who carry forward.

DRS