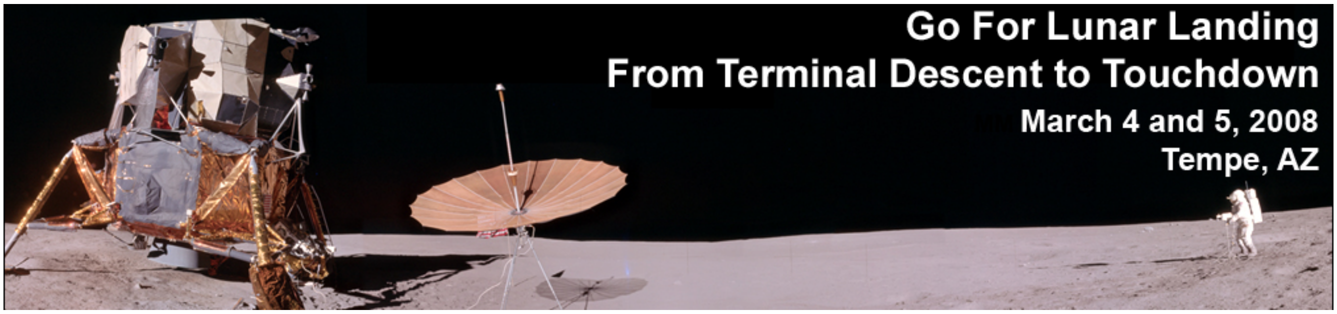

CONFERENCE REPORT

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REPORT OF THE GO FOR LUNAR LANDING: FROM TERMINAL DESCENT TO TOUCHDOWN CONFERENCE

March 4-5, 2008
Fiesta Inn, Tempe, AZ

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EXECUTIVE SUMMARY

The Apollo program employed a platform of systems, engineering, and training strategies that modern-day engineers can build upon for future lunar landings. History has shown that we can land on the Moon, and that we can do so at very challenging sites. The current focus on lunar touchdown must apply the flexibility and complexity of modern technology towards the challenges of specific landing site location and hazard mitigation issues. There is widespread agreement that under-funding is a clear threat to Project Constellation and the Altair program specifically. In particular, clear near-term funding pathways must be made available for design activities, operational trade studies, and the development and testing of alternative components and systems to ensure long-term success. Launching these new trade studies now to correct these deficiencies will help to mitigate the waste of limited resources by strengthening the due diligence early in the program.

There is universal agreement that a continuum of training aids will be required to prepare astronauts for the landing task, whether Altair has an autonomous landing capability or not. NASA must perform comparative studies that engage industry, academia, NASA centers, and Apollo legacy team members to investigate the full spectrum of simulation technologies (including fixed-base simulators, moving-base simulators, and free-flight trainers) in order to determine the appropriate mix of methods and approaches that will most effectively support the development of Altair flight systems, crew training, and operational procedures.

Automated hazard avoidance and landing systems need to be developed to facilitate routine outpost resupply missions as well as robotic precursor missions. Although the notional south polar outpost has a great deal of merit, there are numerous additional locations on the lunar surface where human missions or outposts would contribute both to scientific advancement and to moving along the path to Mars. Automated hazard avoidance systems will be especially important for both the early outpost missions as well as sortie missions into scientifically or economically important regions where infrastructure has not yet been developed. However, the desired degree and operational details of interaction between astronauts and landing systems needs to be rigorously tested and clarified. Some level of automation coupled with advanced astronaut avionics displays (including real-time hazard avoidance sensors and selected video displays) is necessary, but the appropriate division of control between astronaut and landing systems must be defined. In the short term, development work by NASA and industry is underway on lunar avionics and GNC systems, and NASA's industrial partners should be provided with guidance on the appropriate areas to focus their research activities in order to most effectively complement ongoing NASA development efforts.

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.

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.

INTRODUCTION

This report summarizes the proceedings and conclusions of the "Go for Lunar Landing: From Terminal Descent to Touchdown" conference held March 4th and 5th, 2008, at the Fiesta Inn Resort in Tempe, Arizona, under the auspices of Arizona State University, the Lunar and Planetary Institute, and the University of Arizona. The conference brought together Project Constellation personnel, management, and potential industry partners to discuss and leverage the experiences and lessons learned from the six Apollo lunar landings as new lander designs and operations are considered. The conference was conceived to specifically consider the last few hundred feet of the landing trajectory to touchdown, and all aspects of design, training, and operations that relate directly or indirectly to the success of touchdown. "Go for Lunar Landing" provided a forum for direct communication between the Apollo and Constellation generations as well as interactive comparisons between past, present, and future technologies.

The planned Lunar Surface Access Module (LSAM), or Altair, will undoubtedly have some degree of automated landing capability. Due to advances in technology since the last manned planetary landing four decades ago, it is now possible to place even more reliance upon automated descent modes. In fact, both the resupply of a permanent lunar outpost as well as robotic precursor missions to the lunar surface will require extensive use of automation. However, the experience gained in both the Apollo and Shuttle programs has shown that manual control to touchdown is not only a very desirable backup capability, but has been preferred to date as the primary means for landing. This is true for military and commercial aviation, where superlative levels of ground based simulation are available. The known difficulties of landing on Mars, however, require that we develop full understanding of the integration of human and automated capabilities [1]. In this light, some key questions concerning astronaut training for manual descent to the Moon and ultimately to Mars need to be addressed as the 21st-century architecture for a human lunar return matures. These questions include:

- What will design and operation of the Altair development and training hardware and/or simulator(s) entail?
- What are the technical requirements and specifications of the Altair vehicle?
- What is the required initial operational capability (IOC) date?
- Can sufficient fidelity/realism be achieved with ground-based simulation, or is an actual flying vehicle (such as the Lunar Landing Research vehicle (LLRV) and Lunar Landing Training Vehicle (LLTV) employed in Apollo) required?
- What are the operational and training implications of having in-situ refueling and reusability of the landing systems as a design criterion?

To address these questions, the Go For Lunar Landing conference was structured to facilitate discussion amongst all of the stakeholders and offer valuable input to the initial definition phase for the new Altair spacecraft. The conference panelist expertise included cartography and lunar surface imaging, avionics, simulation, and guidance, navigation, and control (GNC). Panelists gave short summary presentations on relevant topics followed by extensive question-and-answer sessions from the attendees. This report includes contributions summarizing the panel sessions and selected transcripts from the discussion period in order to capture a flavor of the proceedings and record the key points made by the participants.

Notes

Powerpoint slides and associated audiovisual materials from the conference have been archived on the conference's World Wide Web page and can be accessed online at:
http://ser.sese.asu.edu/GO and http://www.lunarlanding.info

The conference audio was recorded for posterity, and can be accessed online at http://www.lunarlanding.info. At the time of this writing, transcripts of the conference proceedings are being prepared will be posted upon completion.

This document is optimized for use as an Adobe Portable Document Format (PDF) file, and includes hyperlinks for convenient navigation within the document and external links to relevant documents, including World Wide Web archives of the slides used by the speakers at the conference.

References

[1] Final report, Human Planetary Landing Systems Roadmap,
[http://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20050205017_2005206841.pdf]

THE APOLLO EXPERIENCE

Panelists

Harrison Schmitt (Moderator)	*NASA, retired*	Apollo 17 LM Pilot
Richard Gordon*	*NASA, retired*	Apollo 12 CM Pilot Apollo 15 Backup Commander
Warren North	*NASA, retired*	NASA MSC (JSC) Mercury, Gemini, and Apollo Flight Crew Support Division Chief
Gene Matranga	*NASA, retired*	NASA DFRC LLRV Program Manager
Wayne Ottinger	*NASA, Bell (retired)*	NASA DFRC Project Engineer Bell Aerosystems LLTV Technical Director
Donald J. Lewis	*NASA, retired*	Apollo pyrotechnics
Dean Grimm*	*NASA, retired*	NASA MSC (JSC) Project Engineer
Cal Jarvis*	*NASA, retired*	LLTV Flight Control Systems Engineer

**Participated via telephone link*

Panelist Discussion

The Apollo Team, led by moderator Harrison Schmitt (Apollo 17 Lunar Module Pilot), provided a first-hand overview of the experience of landing on the Moon, as well as historical perspectives on the design, development, and operation of the Lunar Landing Research Vehicle (LLRV) and the Lunar Landing Training Vehicle (LLTV).

Harrison Schmitt [click here for talk slides] used his own Apollo 17 descent into the Taurus-Littrow valley to vividly illustrate the Apollo lunar landing experience, making the point that all of the descent data that he had to read to Apollo 17 Commander Gene Cernan during the descent should be displayed on a HUD in the next lunar lander. Richard Gordon offered valuable insights and commentary via a telephone link, stressing the importance of the LLRV/LLTV towards the Apollo-era training and success.

A broad historical overview [slides from Part 1 and Part 2], led by Wayne Ottinger and Gene Matranga, of the LLRV and LLTV programs followed. This information is summarized in the Historical Background section, below.

In their discussion and in the question and answer period, the Apollo Team expressed broad agreement on the following points:

- According to contemporary interviews and recent communications, seven out of the nine Apollo astronauts that trained with the LLTV believe that such training was an important factor in increasing the probability of successful lunar landings, absent a prepared landing site. One of the nine who did not agree with this conclusion did not have the experience of an actual lunar landing for comparison and another believes that simulator technology has advanced to the point that such training is not necessary now but was important in the case of Apollo. Lunar module pilots supported having the commander train with the LLTV.

- Whatever infrastructure is created to fix a landing site in inertial space for final targeting, landmark tracking should be included in the Orion capabilities as an adjunct to star sighting alignments.

- 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.”

- 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.

- 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.

- Additional definition of potential hazards in sun lit areas could be accomplished by planned landings on sun facing slopes of 5-7 degrees greater than the sun angle but less than the operational limit on tilt of a landed craft.

- Anthropomorphic limits for cabin and control design are currently serious design issues. These limits should be narrowed. Not everyone can become an astronaut for various physical reasons, and height and mass have been only one of those reasons.

- 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.

- The reservoir of untapped, but vital, Apollo knowledge is shrinking daily. Systematic knowledge retention efforts should be performed as soon as possible to capture relevant knowledge.

Participant Discussion

Q1: Lauri Hansen, Altair project, couple of questions for you. We've actually talked to a lot of Apollo astronauts on LLTV and simulations versus LLTV, it would probably be a long discussion for several hours. Interestingly enough, there was one, John Young, who came down clearly on the side of simulations have advanced enough, you ought to be able to do this entirely with simulations. Everybody else came down on the side of you need something with real consequences, a real vehicle of some sort, and I guess of some sort is what I would like to explore just a little bit more with you. Understand what you were saying about helicopters not cutting it in the 1960s, do you see any possibility for the constraints we have today of combining a simulation experience with an existing craft, like an Osprey, obviously Harriers although nobody's fond of the maintenance and the costs that go along with that, but any possibility that makes sense from your perspective of combining an existing craft with simulation simulating a lunar field or whatever?

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

[*Eds. Note: The following additional comment was prepared by Wayne Ottinger for the record*]
Reaction control system flight control handling qualities are well defined for the LLRV/LLTV, LM, and the Space Shuttle Orbiter, all with large disparities in size and mass. This knowledge base should enable the Altair design team to establish requirements for RCS handling qualities that can be evaluated with those of existing VTOL aircraft for potential use of the VTOL's aerodynamic attitude controls to be used for both safe VTOL operations interchangeably with lunar simulation modes. If that evaluation demonstrates feasibility, then the next challenge will be to:

1. Determine the likelihood of achieving the desired fidelity of lunar g simulation.
2. Masking of all perceptible aerodynamic forces acting on the vehicle during the lunar simulation mode.
3. Achieving both 1 & 2 above without degrading flight safety to an unacceptable level.
4. Scope the total cost of development of an existing VTOL free flight simulator, including the acquisition of the basic VTOL system, modifications, operations and maintenance.
5. Scope the total cost of development of a gimbaled jet engine free flight simulator based on the LLRV/LLTV and integration of new technologies, including the operations and maintenance.
6. Evaluate the risk of abandoning the proven gimbaled jet engine concept that could be provided with updated technology and operations enhancements that would yield more confidence in delivering the highest level of not only lunar g simulations, but variable g simulations for a wide range of gravity levels.

Lessons Learned by the Apollo Team: Historical Background Material

Overall summary of the LLRV/LLTV Program

Extensive effort was required throughout the 11 years of the LLRV/LLTV programs to first obtain, and then sustain, both technical and financial support. In our view, the Apollo training requirements were substantially compromised due to:

1. Lack of adequate planning

2. Recognition of the lead times and complexity of the vehicle design infrastructure required to support flight operations.

3. Lack of adequate training of flight operations personnel to conduct safe flight operations outside of the flight research environment at the Flight Research Center (FRC). This accounted for two of the three vehicles lost at Ellington and masked the essentially good safety record in which all three pilots escaped without injury, an excellent record for VTOL research and training operations, including 204 flights at FRC and 591 flights at MSC for a total of 795 flights. (NASA SP-2004-4535).

However, in spite of the above handicaps, the research results made essential contributions to the LM design. The astronaut training did make a key contribution to the success of all six lunar landings. All were made under manual control, with positive feedback from the astronauts about the quality of the LLTV flight training in its representation of the real landing experiences.

Simulation of the Subtle

[*Eds. Note: The following information was provided by K. Szalai*]

The degree to which a given simulator provides the critical training for a specific configuration and task is difficult to gauge prior to operation of the actual flying vehicle. This is especially true in high-gain tasks or in conditions where there is little or no actual flight experience. One must also be aware that simulation, if missing some subtle feature, can provide negative training, as well.

The initial descents to the lunar surface were in this category. Lunar landings were unencumbered by aerodynamic uncertainties which are first order issues for vertical landing tasks in the atmosphere. But the combination of fuel reserve, landing area suitability, visual perception, and maneuvering in lunar gravity is especially challenging.

In addition to the training and familiarity that the LLTV provided to the Apollo Commanders in terms of rates, attitudes, and control dynamics, the LLTV must have provided calibration of fuel remaining, time remaining, and altitude intrinsically, in a way that was not simulated. This “calibration training” came with the LLTV simulation.

In the X-15 and lifting body simulations at the Flight Research Center in the 60's, it was found that apparent time was faster in flight than it was in the fixed base simulator:

Excerpt from SP-4220 Wingless Flight: The Lifting Body Story
In his book At the Edge of Space, Milt Thompson discussed how this difference between simulator seconds and seconds as perceived by pilots in actual flight was first discovered during the X-15 program.

> *"Regardless of how much practice we had on the simulator, we always seemed to be behind the airplane when flying the real flight. We could not easily keep up with the flight plan.....Jack Kolf came up with the idea of a fast time simulation, wherein we compressed the time in the simulator to represent the actual flight. This technique seemed to make the simulation more realistic."*

The lifting body pilots were unanimous in reporting that, once in flight, the events of the mission always seemed to progress more rapidly than they had in the simulator.

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.

The calibration of the ground simulator was done on the basis of actual flight experience in the case of the X-15 and lifting body programs.

For an as-yet to be flown vehicle and mission such as the lunar landings, a free flight simulator provided inherent time and distance calibration, since the consequences of fuel exhaustion were nearly the same for the LLTV mission as for the LM landing.

Historical Background Comments from Apollo Astronauts

Neil Armstrong and Pete Conrad Comments Summarized from Flight Readiness Review on LLTV, January 12, 1970

- Factors that Contributed to High Level of Confidence:
  - Knowledge/experience of physiological effects and sensations of large pitch and roll maneuvers during translations near lunar surface.
  - Large number of realistic, high fidelity landing simulations as close to actual mission a possible. (Same basic approach used in developing confidence for checkout in any new aircraft).
  - No replacement for training in dynamic vehicle from 200 feet to touchdown. (500 feet even

more desirable).

- Requirements for establishing adequate level of confidence:
  - Imperative to train with in-flight landing simulator as close to actual mission time as possible.
  - In flight simulation of transition from landing trajectory to hover at 500 feet is required for adequate landing sight recognition and basic flying.
  - Dynamic motion simulation necessary to enhance confidence level below 500 feet to touchdown especially if unplanned transition is required.
  - In-flight simulation training important in developing physiological relationships and sensations between pitch/roll attitude and vehicle translations in lunar gravitational environment.

- Mission success for landing maneuver based on "No Mistakes Criteria" for "First" Landing. Critical Factors Include:
  - Always a new pilot, i.e. always landing for first time.
  - Always a new unknown landing site/terrain.
  - Each mission generally more difficult than previous landings in terms of area, terrain, surface environment, etc.
  - The more difficult the landing site, the greater the "level of confidence" required.
  - Landing on instruments requires even greater "level of confidence factor" (errors inherent in inertial system updates & errors in the update program device and the radar altimeter were of significant concern.

Apollo 15 Mission Report, David R. Scott (SETP Proceedings, Pages 115 -118, dated October, 1971)

> *"Sensations after manual takeover at 400 feet were almost identical with those experienced in LLTV operations. The combination of visual simulations and LLTV flying provided excellent training for the actual lunar landing. Comfort and confidence existed throughout this phase."*

Input from David R. Scott, February 26, 2008 [Complete Memo Provided as Appendix B]

1. In his opinion, a free-flight LLTV-type vehicle is absolutely mandatory.
2. The maximum probability of success for a "manned" lunar landing can be achieved by a "manual" landing using proven Apollo techniques, procedures, and GNC principles (i.e., manual control using an RHC and a throttle, with semi-automatic assistance by LPD and ROD functions).
3. The addition of any autonomous, automatic, robotic, or Artificial Intelligence (AI) functions will increase the cost, schedule, and most importantly, the risk of a successful landing(s).

IMAGING: REAL-TIME, PREFLIGHT, AND CARTOGRAPHY

Panelists

Chirold Epp (Moderator)	*NASA Johnson Space Center ALHAT Project Manager*	Real-time imaging technology development for the return to the Moon
Andrew Johnson	*Jet Propulsion Laboratory*	Onboard real-time techniques for safe and precise landing
Raymond French	*NASA Marshall Space Flight Center*	Proposed lunar mapping and modeling products for Constellation
Mark Robinson	*Arizona State University*	Apollo Data and LRO imaging
Brent Archinal	*United States Geological Survey*	Images and cartographic products to support lunar simulations, training and landing
Michael Broxton	*NASA Ames Research Center*	Digital techniques from imaging and the development of lunar digital elevation maps

Panelist Discussion

Chirold Epp [click here for presentation slides] discussed the NASA ALHAT (Autonomous precision Landing and Hazard detection and Avoidance Technology) project which he manages at NASA-JSC. He made several points. First, the biggest challenge for safe landing is having a real-time system that can detect hazards, identify safe landing areas and perform Hazard Relative Navigation (HRN) to support safe precision landing. Second, the relative elevation data of surface features is the most important information needed from imaging and LIDAR sensors appear to be the best candidate 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.

Andrew Johnson [click here for presentation slides] discussed Terrain Relative Navigation, or TRN, and Hazard Detection Avoidance, or HDA. TRN techniques compare data collected on-board (i.e., imagery, range images from LIDAR) to reference maps stored on-board to derive estimates of vehicle location relative to known landmarks, thereby enabling precision landing. TRN may involve significant variations in resolution (5x or greater) due to changes in vehicle altitude during the trajectory. Passive optical TRN has been demonstrated via sounding rocket tests. HDA techniques collect on-board sensor measurements and process them to detect landing hazards (e. g., craters, rocks, slopes) in real-time. The sensitivity of sensor performance to vehicle design parameters has been established, but the range accuracy and resolution requirements for hazard detection sensors have not yet been fixed. Sensitivity studies have shown that hazard tolerance of the lander designed is a major factor. LIDAR-based hazard detection has been demonstrated at descent velocities using a rocket sled. The necessary range accuracy and resolution for hazard detection sensors have not yet been established. Hazard tolerance of the lander designed is a major factor.

Raymond French [click here for presentation slides] discussed the Lunar Mapping and Modeling effort being developed to consolidate lunar datasets in a fashion that is useful to Project Constellation program personnel.

Mark Robinson [click here for presentation slides] discussed current and planned lunar remote sensing datasets useful for exploration planning. The best of the Apollo-era Lunar Orbiter spacecraft photographs have been digitized by the United States Geological Survey and will soon be available for public use. Arizona State University has partnered with the NASA Johnson Space Center to digitize all of the original Apollo flight films at the full grain resolution. The first set of these files, the Apollo metric mapping camera photographs, are being made available through an easy-to-use web interface [HTTP://apollo.sese.asu.edu] for public download. As part of this project, ephemeris information for the Apollo missions has also been digitized, so the metric frames can be accurately located in cartographic space. Robinson gave an overview of the forthcoming Lunar Reconnaissance Orbiter Camera, which will photograph much of the lunar surface at 0.5 m/pixel to detect small objects at potential landing sites and map polar illumination conditions.

Brent Archinal [click here for presentation slides] discussed how existing and forthcoming lunar datasets could be used to do topographic mapping at landing site to global scales. Local (landing site scale) mapping should be possible in sunlit areas using data from the NASA Lunar Reconnaissance Orbiter (LRO) mission, with 0.5-2 m image resolution and 1.5-6 m (elevation) post spacing. The topographic data from the LRO mission and either the ISRO Chandrayaan-1 or JAXA Kaguya mission could be used to generate a global lunar topography model with 5-10 meter image resolution and 15-30 m post spacing. Although automated image processing techniques are very effective, manual editing and quality control is absolutely essential for critical datasets, such as landing site areas. The key part of this work is post-mission processing and geodetic control of the data, a step for which there are still essentially no committed resources.

Michael Broxton [click here for presentation slides] discussed how current image processing techniques take years to complete, even for datasets that are much smaller than the huge volumes of images that will be collected during future lunar orbital missions. NASA high-speed computing assets need to be leveraged in the future to provide timely image processing. In addition, current automated image search techniques require further research and refinement. Finally, Web-based geospatial information platforms need to be fully utilized to provide easy, intuitive access to important data products.

Participant Discussion

Comment by Harrison Schmitt: The surface Hasselblad stereo photography should be integrated with the growing sets of lunar digital maps in order to support exploration training, crew landing, rover design, hazard statistics, etc. Contingency plans should be formulated in the case that LRO does not provide the currently planned data for operational use.

Q1: With respect to the objective of landing on the Moon with 10 meter accuracy: How good will the lunar map be? What kind of accuracy can we achieve? How good is the baseline map?
A1: [Archinal] Map quality is tied to accuracy of orbital reconnaissance altimetry. The LRO altimeter (LOLA) will provide accuracy on the order of 40 to 50 meters. Post-processing can improve this accuracy, particularly with improved lunar gravity data, and we may want to reprocess the LRO data in the future as our lunar gravity knowledge improves. Around the Apollo landing sites, will be able to locally achieve much better accuracy by tying to the locations of the laser retroflectors.

Q2: LRO data is taken with a push-broom scanner. What is the LRO along-track accuracy? Registration of LRO stereo data and knowledge of ground velocity?

A2:[Robinson] LRO includes two cameras with an offset of ~50 pixels and overlap to address orbiter swaying. Ground track speed is about 1640 m/s. At that speed, correlation of overlapped areas with a 300 microsecond integration time yields 50 cm of downtrack motion during each integration cycle.
Tracking using Earth-based lasers will provide highly accurate ground speeds for lunar orbiters with errors in the range of 50 cm/s. Kaguya will also offer an improved gravity model as an aid to post-processing for trajectory reconstruction.

Q3: Quality control on geometric factors from scanned Apollo image data? Geometric calibration and accuracy? Any distortion of the negatives after decades of storage?
A3: [Robinson] Apollo data was taken with photogrammetric cameras that were developed and calibrated specifically for that function. Optical distortion is very small. Film was designed especially for the Apollo photogrammetric camera with reference marks to minimize film distortion – possibly three pixels of error.

Q4: What is the input from the simulation community on necessary terrain accuracy for LRO?
A4: [Robinson] Requirement to identify sub-meter hazards when proposal was written.
[French] The simulation community will not get what they really want to see, which is centimeter-level accuracy. Will need to use interpolation to get better than sub-meter.

Q5a: What method is used to fill in points to generate an interpolated terrain DEM?

A5a: [Broxton] Interpolation using two-dimensional b-spline. The key thing is to point out where the data is interpolated so that users of the data know.

Q5b: Follow-up question – have you ever had a case where you interpolated DEM data and then subsequently got good measurements with which to check/verify?

A5b: [Broxton] Closest would be for data around the Apollo 17 landing site. The interpolated results looked good when compared with photos taken on the surface.

Q6: For Kaguya data, shouldn't we be negotiating with JAXA to get access to the data earlier than one year after end of its nominal mission?

Q6: [Robinson] There is an agreement to release the data at that time. It may be possible to negotiate earlier releases of parts of the JAXA dataset. Gravity data will be used for planning purposes - may get it sooner. An MOU is in place for NASA to acquire JAXA gravity data for internal use to support LRO.

Q7: How well do we need to know the lunar gravity field to get by without landmark tracking?

A7: [Epp] I believe that we need landmark tracking. It is not clear how good the lunar gravity information will be.

[Archinal] If you want better than 100 meter level of accuracy, then you need another method to supplement basic navigation, such as landmark tracking or a beacon, even with a great gravity model.

[Schmitt] Every time that we took data on Apollo, we took a stereo pair - useful for building models. There is considerable stereo lunar surface photography available to support various needs, including virtual reality. This imagery is being digitized.

Appeared to be general agreement among the panel members and key members of the audience regarding the importance of landmark tracking for lunar missions.

Q8: General panel discussion of the actual Apollo LM slope tolerance limit and the rationale behind that value.
A8: Schmitt stated that he believes the LM tilt specification was 15 degrees rather than the 12 degrees mentioned in one of the presentations. Multiple potential drivers for the LM slope tolerance limit were mentioned, including possible binding of latches between the ascent and descent stages, ascent separation/control issues associated with the fixed main engine and RCS control authority, and even crew egress/ingress concerns. The driver for the LM slope tolerance specification remains unclear. The actual/operational LM slope tolerance also remains to be verified.

Q9: What is the level of validation of the digital elevation maps (DEMs) from photoclinometry? Is there a terrestrial test that would validate this approach?
A9: [Panel] Stereo photoclinometry has the potential to provide DEM resolution at the same level of accuracy as the source data. Other methods are about half as accurate. Stereo photoclinometry can also provide albedo information. Need more time and experience with this technique to validate. Recommend testing against data derived using existing stereo datasets.

Q10: Some images correlate well optically, but not digitally, and vice versa. Should we utilize older methods, such as human image matching and stereo plotters, in addition to digital correlation techniques?

A10: [Broxton] Yes, still need human involvement.

[Robinson/Archinal] Sometimes humans can perform image matching when computer processing does not work. There are also cases in which humans should be utilized to provide images of the highest quality, such as landing site maps.

[Randy Kirk/USGS] Trained personnel are looking at images and performing quality control. The old stereo plotters are being used. Humans are better than computers at retaining surface features that make geologic sense, and eliminating artifacts. Digital algorithms have improved over the years, and datasets produced using digital techniques that exhibit high correlations are considered to be good quality. But interactive methods remain important.

Q11: Schmitt comment regarding hazard detection and landing approach – We may find that we need much more thorough hazard detection capability when fully automated than when there is also a human looking out the window. Need to consider human perception and the human ability to pick out the important features and focus in on a desirable area. In terms of automated versus human-controlled landings, the risk mitigation needs are greater for automated hazard detection and avoidance (HDA) techniques than for human HDA.

Q12: As an alternative to processing sensor data through computer algorithms, is there value in simply providing mapping/hazard detection sensor data to the crew and allowing them to identify hazards and define safe landing sites?
A12: Jack Schmitt agreed that providing sensor data to the crew would be useful if the data is in a form that can be readily assimilated. A pilot wants as much well organized and user-friendly information as possible, but don't be distracting, be helpful. That is essentially the function that he performed for Gene Cernan during their Apollo 17 landing. An example of sensor input to the crew during Apollo was the use of the radar altimeter. The altitude channel of the inertial system always had significant dispersion until the radar altimeter data became accessible. During Apollo 14 the radar data came in late. Chirold Epp noted that in this context, the ALHAT Project is investigating technology for a high precision velocimeter to enable a vehicle to land through the potential dust obscuration using an inertial system by accurately zeroing or setting horizontal velocity before terminal descent. ALHAT is developing a Doppler LIDAR velocimeter that should provide three-dimensional velocity data with an accuracy of approximately 5 cm/s.

Q13: Suggestion by Jack Schmitt to develop a quantitative or semi-quantitative measure of dust levels observed at each of the Apollo landing sites.
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-intuitive. It seems like more fine particles would be present at older sites. Could dust levels possibly be

related to the age of a landing site? Need to investigate possible correlation between observed dust levels and the mineralogical characteristics of the regolith at the landing sites. Might be able to predict dust levels. Schmitt questioned whether an abundance of olivine at a landing site might result in higher levels of dust? Chirold Epp said that Sun angles may affect visibility through dust. Schmitt concurred that the solar illumination has a longer optical path length through dust at lower sun angles.

AVIONICS

Panelists

Mitch Fletcher (Moderator)	*Honeywell International*	Human Spaceflight Avionics
David B. Smith	*Boeing*	Advances in Lunar Guidance and Descent
Mike Aucoin	*Draper Laboratory*	Evolution of Avionics Processing
Dick Van Riper	*Honeywell International, retired*	LLTV Avionics
Glenn A. Bever	*NASA Dryden Flight Research Center*	Avionics, displays, instrumentation, testing
Graham O'Neill	*United Space Alliance*	Apollo software and training

Panelist Discussion

The panel presentations centered around prior avionics implementation and an update on the current state-of-the-art.

Mitch Fletcher [click here for presentation slides] discussed the state of avionics technology in the mid-1960s, discussing the 4-function "Cal-Tech" calculator, the Saturn I Block II analog flight control computer, the Apollo Guidance Computer as steps to the Moon.

Mike Aucoin [click here for presentation slides] discussed the evolution of Avionics processing. Apollo was designed for minimum risk. The Apollo Guidance Computer (AGC) relied on a highly dependable single-string system using a contingency backup. No unexplained test failures were allowed. For Apollo, the AGC pushed and drove the state of the art. The development of the GNC and AGC systems proceeded in parallel, as the up-front requirements were not in place, and commonality was a major driver. At the time, there was disagreement as to whether the system should be autonomous, manually operated, or remotely controlled. There was also a strong emphasis on making sure that there were long-term, stable suppliers available. For the Space Shuttle, all of the subsystems were designed to be operable in case of failure, but also to fail safely. This was accomplished through redundancy and built-in test routines. There was no explicit quantitative reliability standard. Less testing for Shuttle was performed than for Apollo. The Shuttle's computers had a requirement for integrated computing and had more densely packed processing, increasing their vulnerability to radiation. Ascent and entry employs four Primary Flight Control Systems (PFCS) and one Backup Flight Control System (BFCS). The X-38 employed COTS components and was dual-fault tolerant. It maintained processing system reliability while using COTS processor boards that were less reliable. X-38 also employed redundant power supplies, cross channel data links, and voting systems to carry out redundant calculation while protecting against Byzantine failures. Its systems only had to be active during one critical flight phase-reentry, and was designed to specific reliability requirements. The ISS for on-orbit operation employs the Russian Service Module TC computer for GN & C (thruster control), which is two-fault tolerant. The U. S. Module flight processor that handles attitude control employs failover operation, but not fault tolerance. All processing is on orbit, and does not involve critical flight phases such as ascent or reentry. For Constellation (Altair and Orion) weight is the defining factor. The current design criterion is one fault tolerance. A variety of flight modes have to be addressed (e. g., ascent, on-orbit, rendezvous, descent). Ares avionics are progressing towards some 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. There are several flight phases requiring varying levels of necessary reliability, and several systems will be involved (e.g., Orion, Altair, Ares I, Ares V, Earth Departure Stage, etc.). The processing requirements of the system of systems change with mission phase and connectivity. We should explore architectures that are insensitive (less sensitive) to common mode failures. Continuing needs are trading the use of COTS components with the required reliability, and trading the required reliability with the amount and kind of testing employed.

Glenn Bever shared his insights based on his extensive flight test participation. He began his remarks by quoting former NASA Deputy Director Hugh Dryden, who said that "The purpose of flight test was `to separate the real from the imagined, and to make known the overlooked and unexpected problems.`" He continued:

> *One of the principles of flight test is envelope expansion. You test in increments that are small enough to better identify risks—and fixes—while ever moving towards more unexplored regions of higher-risk flight. Simulation is a marvelous, indispensable tool in this process. But simulation is only as good as its models. Flight test provides a synergism with simulation in that it helps to validate the the models. There are other reasons that flight test is useful. Pilot training in a more "real" environment or avionics testing/validation are other reasons. Much testing can and should be done on ground-based systems. Hardware in-the-loop (HIL) testing has a higher payoff than modeling the hardware, given the option. Full-up integration testing in a flying vehicle is even more desirable, for this is where more unexpected problems are made known. It's all about risk —in cost, schedule, and safety. You have to make the trades—given today's technology and available methods. Risk mitigation can be more complex for automated systems—especially validating adaptive control systems. In the discussion comparing manual to automatic landing, you have to define what is meant by "manual." In a modern fly-by-wire system, the pilot is not directly coupled to the control surfaces or to the propulsion system. The computer is. The pilot, in a the words of a GNC friend of mine, "gets to vote." The pilot inputs commands to the computer which, via control laws and programmed rules, decides how to command the control actions. In UAVs, some are remote piloted vehicles, such as the Predator. The pilot sits on the ground and flies the vehicle with a stick. It is flown, essentially, as if the pilot were sitting in the cockpit of the aircraft. On the other hand, Global Hawk does not have a direct piloting mode. It is commanded by waypoints or higher level commands, such as 'fly to these coordinates" or "land at this location." The "piloting" (commanding the ailerons, empennage, throttle, etc.) is all done autonomously*

by the vehicle. It just accepts directions. So "manual" might mean allowing the pilot to inject new commands. If it means piloting in the conventional sense, then many of the training arguments for a fee-flying trainer come to the fore. Depending on what cues the pilot needs for "commanding" a semi-autonomous vehicle, training might be effectively accomplished with a UAV from sensor and synthetic vision cues. Even in the RPV case, I quote from a handling qualities paper written a number of years ago: "The loading effects of remote flying were indicated in the pilot's post flight comments. A veteran of many thousands of hours in simulation flying and first flights in exotic experimental vehicles such as the first lifting bodies, he nevertheless was stimulated emotionally and physically as much as in live first flights. There was no chance to hit the reset button, discuss the problem, and try again. There was only one chance, and its success was entirely his responsibility. Further corroboration that responsibility was a greater driver of physiological response than fear for personal safety was obtained in many later RPRV flights." [NASA TM 84913]. The task, ultimately, is one of pilot integration of information. 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.

Graham O'Neil [click here for presentation slides] discussed the software, training, and lessons learned from Apollo and previous experience. Apollo offered examples of human crew integration and training, as well as avionics lessons and applicable error sources. Some of the principles learned included the separation of criticalities, appropriate levels of redundancy, robustness of resources, desired simplicity, situational awareness, and the benefits of a training cycle based on credible simulations, failures, diagnostic signatures, recovery strategies, and the proactive identification of failure. Also discussed were the potential operational modes, including normal, simulator, independent, emergency, and unusual operations. A need was identified for computer and network architectures that can support fault tolerant data communications, as well as appropriate life-cycle requirements.

David Smith [click here for talk] discussed the Apollo Lunar Module Guidance and Navigation Lessons for LSAM. The Apollo-era LM contractors (e.g., Northrup Grumman as prime contractor for LM, Hamilton Standard for the Abort Guidance System, etc.) were reviewed, and an overview of the LM avionics was provided. The LM was flown with three inertial gyroscopes and 3 accelerometers to provide internal motion measurements. The DSKY interface provided the crew interaction with the LM and CM's guidance computers.

GUIDANCE, NAVIGATION, AND CONTROLS

Panelists

Doug Zimpfer (Moderator)	*Draper Lab*	Apollo GNC System
Ron Sostaric	*NASA Johnson Space Center*	Current NASA Technology Development Efforts
Miguel SanMartin	*Jet Propulsion Laboratory*	Evolution of Lunar to Planetary Landing
Shyama P. Chakroborty	*Northrup Grumman*	From Apollo to Today
Ian Gravesth	*Ball Aerospace*	Current Sensor Technology
Tom Gardner	*Raytheon*	Precision Landing
David B. Smith	*Boeing*	Lunar Guidance and Descent
Rongxing Li	*Ohio State University*	Lander, vehicle, and astronaut localization, navigation, and communication

Panel Discussion

The Guidance, Navigation and Control (GNC) panel discussion centered around the problem of safely and precisely landing crew and cargoes on the lunar surface and addressed the following issues:

1. Compare/Contrast Apollo to Constellation, including similarities and differences in both mission and technologies.
2. Provide insights into the current state of landing GNC technology development efforts at NASA, industry and academia.
3. Provide insights into what aspects of landing GNC could benefit future planetary landings.
4. Discuss Human Role in Precision Automatic Landing (manual and supervisory control).

The GNC panel was assembled to include experts and engineers from NASA, national labs, universities and aerospace industry. The panel expertise was diverse and covered many aspects of the GNC problem contrasting different approaches taken by the proposing institutions as well as highlighting a wealth of novel techniques that developed over the past few years.

Doug Zimpfer [click here for presentation slides] started the panel discussion by providing an overview of the Apollo GNC system. The presentation included a discussion of the LEM GNC architecture, the description of a typical Apollo descent trajectory (including the relative braking/approach phases) and the functional flow diagram illustrating the modes of interaction between astronauts and on-board computer. It was stressed out that the Apollo GNC was designed with the idea of giving the astronauts multiple options spanning from fully manual to semi-autonomous. The pilot had always the ability to select the appropriate mode of operation.

Ron Sostaric [click here for presentation slides] gave an overview of the Autonomous Precision Landing and Hazard detection and Avoidance Technology (ALHAT). Such project represents the NASA approach to developing a new technology to improve landing capability. Two distinct problems were considered, i.e. a) how to design a trajectory suitable for approach and landing and b) how to execute hazard detection and avoidance. For both cases, the major design drivers were discussed. Major trades are undergoing to understand the best trajectory as function of the sensor performance and entry path angle.

Miguel SanMartin [click here for presentation slides] discussed the lunar landing problem in light of the recent development in Martian landing technology. While showing that various approaches to landing on Mars initiated as evolution from the Apollo landing scheme, SanMartin examined passive landing airbag-based systems and novel solutions devised for the upcoming missions (e.g. Mars Science Lab). More and more planetary scientists recognize the need for precision "pin-point" landing on Mars and the Constellation program might help to closing the gap by improving sensor and software capabilities.

Shyama Chakroborty [click here for presentation slides] analyzed the problem of lunar landing in light of new technological development. Difference between yesterday's approach and today (possible) approaches were contrasted. It emerged that new sensors and software development may provide improved autonomous landing and hazard avoidance capabilities. Northrop-Grumman is currently working on building an autonomous landing and hazard avoidance technology program. Such program aims at utilizing a new generation of sensors, data fusion schemes and image processing algorithms to achieve the desired system performance. Computer simulations were presented to highlight the effectiveness of the proposed system.

Ian Gravseth [click here for presentation slides] gave an overview of the current sensor technology available for navigation during the lunar landing. Visual cameras, flash LIDARs, radars, scanning LIDARs and Geiger counters were compared by analyzing pros and cons. It emerged that flash LIDAR is the most attractive sensor for lunar landing.

Tom Gardner [click here for presentation slides] presented an approach derived from adapting missile technology to the problem of precision landing. The proposed technology relies on high thrust-to-mass ratio diverts adapted from the Raytheon Exoatmospheric Killing Vehicle (EKV) program and the Raytheon DSMAC camera. The latter provides accurate position update using a pre-loaded reference map and a correlation algorithm. Simulations based on lunar images showed high correlation capabilities setting the stage for precision landing within camera spatial resolution limits. Hazard avoidance algorithms have also been devised. Such technology will be provided by Raytheon to Astrobotic to help the team winning the Google Lunar X-Prize.

David Smith [click here for presentation slides] presented an overview of the DC-X guidance scheme. The scheme was derived from the old Q-guidance algorithm. Monte Carlo simulations were performed to show how the DC-X algorithm compares with the Apollo guidance algorithm. Comparisons were presented in terms of propellant usage and landing dispersion.

Rongxing Li [click here for presentation slides] went beyond the landing problem and discussed techniques for astronauts/landers localization and navigation. His team developed techniques for rover autonomous navigation on Mars (The Spirit and Opportunity MER rovers) and he is currently working on lunar communications and navigation architectures. A lunar beacon for position referencing is proposed. Moreover, a novel astronaut spatial orientation and information system is discussed.

Based on the panel discussion it is apparent that:

1. Significant advances have been made since Apollo in sensor technology, image processing and software development that enable autonomous lunar landing.
2. Hazard detection and avoidance will be critical to successful landing at the lunar poles,
3. The primary benefit of lunar landings to future planetary landings would be the development of sensor technology and test/demonstration infrastructure,
4. For Human landers the role of the human will evolve over time, but the technologies for human supervisory autonomous landing are being developed.

In conclusion, while crewed landings will utilize the astronauts in important roles, the technologies for crew supervisory and autonomous landing systems are being developed. The development of free flying or other crew test facilities would benefit the development and test of the GNC technologies.

SIMULATION AND TRAINING TECHNOLOGIES

Panelists

Tom Alderete (Moderator)	NASA Ames Research Center	Simulation facilities
Karl Bilimoria	NASA Ames Research Center	Flight Dynamics and Control
Nilesh Kulkarni	NASA Ames Research Center	Autonomous Control
Robert McCann	NASA Ames Research Center	Human Factors
Charles Oman	Massachusetts Institute of Technology	Man-Machine Integration
Andrew Thomas	NASA Johnson Space Center	Astronaut
Henry Hoeh	Northrup Grumman	Conceptual Design/Legacy
Eric Mueller	NASA Ames Research Center	Dynamics and Control

Panelist Discussion

Tom Alderete began the panel discussion with a reference to Neil Armstrong's comments on the lack of simulation facilities available in 1962, and the consequent decision to use the LLRV, and showed a video of the VMS running the latest Lunar Lander simulation.

Henry Hoeh [click here for presentation slides] discussed the progression in LM design, and drew a parallel with the LLRV/LLTV design evolution. Flyable demonstration vehicles of the LM were canceled in favor of the LLTV/LLRV, and there was close cooperation between Northrop-Grumman and the builders of LLTV. He pointed out the example of the change in EVA hatch on LM from circular to square: The reason for the circular hatch arose from the requirement to allow either the LM or CM to dock with the other in lunar orbit, however, once it was realized that the docking could be done with a different vantage point from the LM (through the roof), the backup circular ring in front 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 could function inside the vehicle. Of the four initial simulations done of the LM, only one was not fixed base and it had only 3 degrees of freedom (2 attitude, 1 translation).

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 renditions), other specifics of the simulation. Showed the "Apollo-era Outpost Concept" in Calverton, NY. Pointed out the wheels, designed to go over rough terrain, and the fact that they were testing pressurized vs. unpressurized rovers.

Transitioned to a discussion of modern simulation, with the F-35 as a case study. Called this the "art of the possible" for how we can bring the most modern flight control and simulation systems to, perhaps, replace the LLRV/TV.

Karl Billimoria [click here for presentation slides] discussed the simulation of lunar lander handling qualities. The simulation looked at guided vs. unguided approaches to a precision landing, and it used the VMS at NASA Ames. Introduced the concept of handling qualities as the "ease and precision with which the pilot can execute a flying task," and talked about what factors it depends on (inceptors, displays, guidance cues, etc.). Referenced fixed and rotary wing aircraft, and the correspondingly lower degree of attention that spacecraft handling qualities have received. Showed the precision landing task: 1350 ft range, 250 ft offset approach, land within 15 ft before fuel runs out. Showed the vertical trajectory on final approach as compared to the unpowered trajectory. Gave parameters on the initial conditions (see slides). Karl discussed the setup of the simulation in the VMS with standing positions for the pilots (a new configuration for the VMS) and the requirements for safely harnessing them in given the large motions of the simulator. Two displays were provided to the pilot, plus two inceptors (rotational and translational hand controllers). Left hand display was an overhead map, right display was a standard ADI plus guidance needles for pitch/roll/yaw. Task began with RHC, which was used to stop the LM above the landing site, then shifted to the THC during the final descent to maintain an accurate position above landing pad.

Objectives of experiment: evaluate basic dynamics and control model of the simulated vehicle, vary the control power (acceleration) of the vehicle and measure CHR as a function of guidance being on vs. off. Hypothesis was that it would be very difficult to land without guidance, and indeed it was virtually impossible to do so with an offset approach (250 ft lateral). However, they generally nailed the task when the guidance was provided, which shows the necessity of guidance for precision landing tasks. Showed results of the control power variation in terms of CHR and TLX. The nominal 100% control power had level 1 HQ, down to about 20% it was generally rated level 2, and for 15% was borderline level 2/3. TLX showed the same trends, with variation between 25 and 55. Karl concluded that the vehicle evaluated was just within the Constellation requirement that TLX be below 30 and that additional realism in the model would push that up. Finally, added the provocative idea that we might perhaps be able to replace at least the LLRV (probably not the LLTV) with the VMS for initial study of handling qualities tradeoffs

Nilesh Kukarni [click here for presentation slides] talked about adaptive control of robotic landers and the associated simulation requirements. Went into the motivations for using adaptive control, including the wide range of payloads being sent to the moon, the need for precision landing, additional uncertainties with robotic landers vs. piloted landers, etc. The probability of failure goes up as your number of missions grows, so there needs to be more attention to dealing with contingency situations, and adaptive control could do this. A big question is, how do you know that the adaptive control system works since it is by definition changing? Adaptive control means you vary the parameters of the control architecture towards satisfying a performance goal while maintaining stable operation. Compared this to the changing mass of the LM and the need to estimate current mass. This would change the associated control system parameters according to a lookup table.

Nilesh then went into the history of adaptive control systems, starting in 1956 with studies by the US Air Force and continuing with the X-15 program. These efforts arose out of the 1947 crash of a test pilot, the investigation of which showed large variations in roll and yaw just before the tail came off. Adaptive control was thought to be a potential solution to this problem. Subsequently adaptive control was tested much later in 1997 on a tailless UAV, and later on the X-45 UCAV and various missile configurations. He says now the pendulum is swinging back in favor of using adaptive control systems with pilots in the loop, where pilots are themselves adaptive controllers. It is difficult to predict handling qualities when an adaptive control system is changing and the pilot is adapting to that adaptive system; many safety issues arise here.

Showed an architecture for adaptive control systems they designed for the LM, with desired positions and velocities as the inputs. The "adaptive augmentation" block is placed in the inner feedback loop, otherwise everything is basically similar to a standard guidance and control system. The adaptive augmentation system corrects for the constant dynamic inversion that is present in the forward loop (which would introduce errors as the inversion gets worse and worse).

Requirements for simulation include: Monte Carlo studies, stability margin estimation with frozen parameters (rather than adapting ones), and online monitoring simulation studies. Closed with a picture a simulation facility at Ames.

Charles Oman [click here for presentation slides] discussed the human role in a lunar landing. He discussed several themes: who's in charge, who can you trust (instruments, eyes, intuition), what do 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 frequently hard to program, probably because it was designed by engineers without a lot of thinking about the mission scenario. Introduced the concept of "graceful reversion." Rather than shutting off everything when an error is detected and building back up the level of automation, we should be able to fall back to a slightly lower automation instead.

Suggested that everyone agrees that fully automatic landings within 10m of touchdown point at a well surveyed site is "technically possible." Cited the NASA requirement for manual control of flight path angle and attitude, and suggested that manual flight will likely remain the operational baseline - not least because astronauts are pilots and explorers, not cargo. Talked about consistency between the automation and crew situational awareness – what happens when you get out of sync (Apollo 15 example)? When do you trust automation that has better information than you do (e.g. a LIDAR has a much better angular resolution than human eye). Introduced examples of circumstances when humans have difficulty judging surface slope, smoothness, shape and size. Says that we need to practice these 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 include: streaming dust illusions, ability to see terrain directly below, etc. Concludes that early human in the loop simulation is critical for automation development, and this will reduce the need to "train around" problems. This will also require advances in simulation, things like streaming dust models. Suggested that you might consider whether to use the VMS or a LLTV type vehicle to train for these, 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."

Robert McCann [click here for presentation slides] gave a human factors perspective to the need for simulations. What is the driver for a need to look at human factors? A potentially major sea change with Altair is the anytime, anywhere requirement for landing, and the fact that we may not be in communication with Earth during the landing. Made a distinction between machine autonomy and autonomous operations in which all control must be done onboard the vehicle (which may include pilots). Rather than looking at the flying task, consider the overall task – which includes management of onboard systems, mission decision making, etc. and other tasks required of the pilots.

Cited Armstrong's comments that there were 1000 things to worry about on final descent and landing, and this was far and away the hardest part of the flight. There were 2 failures at this time, including the "1202 Program Alarm" that shows up during this phase. Pilots had no idea what was causing it, so within 27 seconds of noticing the problem ground control was already working it, and less than a minute later (not sure how much time) ground control had already made the decision (flight critical) to continue the flight. Second malfunction: Three seconds after the last malfunction they got a light saying that 5.6% of the original prop load remained. This was in fact not true, fuel slosh caused it. But 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 support and monitoring functions. In turn we'll need to think a lot about the operations concepts for level of automation, division of responsibility between crew members and autonomy, criteria to take manual control, and so on. There will be a "combinatorial explosion" of operations concepts decisions we need to make, and lots of validation done on those concepts.

Andrew Thomas began his discussion by observing that "Reading the words in the last presentation conveys how important it is to have crews ready to step up to unpredictable circumstances, which can only be accomplished with adequate training in simulations." The question is whether you can do it with ground-based simulations or only with free flight vehicles. Points out that we need to design a totally automated (pilotless) cargo lander vehicle – he will sidestep this issue. Some kind of simulation capability will be required for dramatic situation pilots will encounter, and will the dramatic increase in computer technology be sufficient to get rid of free flight vehicles. The original robotic arm simulation was a giant, unwieldy monster that could only support basic models and unrealistic lighting situations, while current simulations (computer based) are vastly superior. However, landing situations are much more dynamic than robotic arm operations. A better metaphor is landing the Shuttle itself, which is done in "simulation" with the Shuttle Training Aircraft (modified business jet). It is considered crucial to training, and won't be gotten rid of no matter the budget situation. Problem is that it can't simulate touchdown and rollout, which is done in ground-based simulations on the VMS and a JSC simulator. They also train on those tasks by keeping familiar with T-38 operations, which are only somewhat analogous to shuttle landing. Thinks the same paradigm will be used for Altair: a variety of fixed and 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 Andrew believes we need a free flight simulator to get the correct dynamic response and psychological effects. One option is to develop a vehicle similar to the LLTV, although that might be difficult given the current risk-averse atmosphere and the costs. Another possibility is to fly a vehicle remotely that has the same handling qualities as LSAM, but doesn't think that's a very useful option (might as well just fly a ground-based simulation). Again, thinks that we will need a variety of simulation capabilities including real flying hardware and several types of ground-based simulators. Thinks the results of this conference should get the discussion started on what the agency should do in this regard.

Participant Discussion: Simulation and Training

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

A1a: Andrew Thomas: Good question, should we have all of them involved in the flying task? Could use conventional computer based simulators to decide on the important roles of all four tasks.
A1b: Robert McCann: They could be traditional flight engineers. For Orion, only the pilot and commander will have decision making authority, rest are along for the ride.

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

A2a: Tom Alderete: One part answer is that those facilities exist now, so we don't have to rebuild them.
A2b: Gene Matranga: In 1963, there was a major simulation looking at LM handling qualities, which JSC and Dryden pilots were involved in. He has that report and offered it to panel.

Q3: Question to Karl: did any of the VMS simulations detect the PIO experienced by Enterprise?

A3a: Karl: He believes it was replicated afterwards, but not predicted.
A3b: Howard Law: There were a multitude of factors going on that contributed to the PIO, and that several of those were investigated in the VMS. You can't get the pilot's gains as high in simulation, but that the lateral PIO wasn't a pilot gain issue. The simulations do identify timing problems, like those seen in STS-1. Sometimes lessons aren't learned in the simulator because the simulator is incorrect, other times because you don't believe the simulator.

Q4: Howard Law: Have you though about adaptive control systems that adapt to specific failures, like the loss of an engine? Could they give us more margin.
A4: Nilesh: We haven't created extensive simulations of the kinds you're talking about, but in my experience of adaptive control of aircraft we do that all the time. We can correct for yaw/pitch/roll excursions with ACS authority on the engine.

Q5: Howard Law: On human factors, the human mind hasn't changed but how much has our understanding of the human mind changed?

A5: Charles; it has improved somewhat. Pilot psychological models, etc.

Q6: Howard Law: Given what we know about the mind and errors made in certain circumstances, should we have pilots simply redesignate a landing point or fly to the new landing point?

A6: Charles: If pilots have confidence in the automation they are comfortable with having a higher level role in decision making. Question is whether the pilot has ultimate authority to make flight decisions or whether that's been given to computer.

Q7: Howard: What's the control mode that allows pilot to have as much decision making power as possible (make workload lower)?

A7: Charles; That has to be decided in full mission simulations.
Andrew: agrees with Charles

Q8: Wayne Ottinger: Is the VMS single axis? Significance of washout?

A8: Tom: it is 6 DOF, with all axes independent. 60 ft vertical, 24 ft/s vertical, 40 ft lateral, 18-20 degrees each rotational axis. Washout is incredibly important, need to keep the cab inside the limits but allow the high frequency accelerations through. Going into limits will give false cues.

Q9: Wayne: how does it compare with LLTV?

A9: Tom: would have to see the dynamic response of LLTV, and we could optimize the washout based on that frequency response.

Q10: John Keller: Charles mentioned not trusting the human eye with respect to size, scale and contrast. Alaska bush pilot had same problem, and threw a bunch of pine branches to give reference. What was done in Apollo to give some idea of scale in approach phase?

A10a: Charles: When you get in close to landing site, beyond when you had satellite info, you could get a scale idea with lander's shadow, which is of known side. Some sun elevation angles were very convenient because the shadow was available. Alternate cues will need to be found. These problems also arise in avionics design for synthetic vision systems/displays, e.g. overlays of the runway. But your perception of the runway depends on your expectation of the width of the runway, so some training is still required. These size cues need to be included in a visual HUD, there's no replacement for those cues.
A10b: Karl: Giving the pilots an idea of the size of the pad helped give scale of landing area.

Q11: Could you superimpose 3D pictures over the out-the-window view to give an idea of size?

A11: Charles: That's basically what a simulation is.

Q12: Same questioner: If you can generate a "telescope" type display in the cockpit of the landing site that could be very useful.

A12: Yes it would, but there are many issues with getting that correct, and lots of work has been done in that area.

Q13: Charles: Karl, were pilots flying raw data?

A13: Karl: they were flying essentially a flight director. 3 needles on the ADI gave attitude guidance.

Q14: Joel Sitz: Training 16 year old son to drive, who's great at Xbox, but not so much yet at the driving. There's something different when the thing is real. The concept of the unknown is different in a real vehicle and is harder to simulate. We should think about a vehicle that integrates the real systems early on (for training engineers too)

A14a: Charles: We've all flown on a commercial aircraft with a right seat pilot who's doing his initial operational flight on this aircraft. Only experience is in a simulator, although he has lots of experience in other aircraft. Even if you were flying a free flight simulator, you would still have bad visuals since it won't look like the moon. One of the big advantages to VMS is the ability to get into it at any time of day, while the LLTV could only be flown for a limited period each day.
A14b: Agrees that simulations are more flexible, but thinks there will be an appropriate balance between simulation and free flight simulators.

Bill Gregory: Flying Kennedy to the south over the swamps in the STA, only when you have no other visual cues than the runway lights do you get the real sinking feeling that you're in a real system. You get tense as you hurtle towards the ground because it's real, in the simulator he never got that same feeling It was valuable to fly in the VMS, but it's quite different in the real system. That's driven training of mission specialist to be in an operational scenario (i.e. flying) so they know what this is like. You have to learn to trust the automatic systems, but that increases the pucker factor.

Howard Law: There may be a twist to the idea that we need to drive up gains: should we instead give the pilots exactly what they'll see on the moon, or should we just try to make them have a hard time? We shouldn't drive up gains just to make things difficult, we should give them the correct cues. The VMS isn't just a plastic box, it's a very large amplitude simulator. At some point in the project some subsystem won't work, we can make changes to that subsystem in a simulator much easier than a free flight vehicle.

Q15: John Osborn: Would like to ask about implementation. My impression is that the VMS is pretty heavily subscribed, can you talk about how much it's used?

A15 Tom: It's used about 1 shift per day, but is capable of 2 shifts. The operation can be scaled up or down.

Q16: John Osborn: We have 3 STA's, can we even train people on the VMS with only one of those?

A16a: Tom: That is something that would have to be planned for. We used to work at twice the rate we

currently do, so we can scale up.
A16b: Andrew: We would need a variety of simulators in any case.
A16c: Tom: We have a suite of simulators, five cabs that can be interchanged.

John Osborn: People need to think about overarching needs for simulations, and management by default will tend to pick less expensive options. JSC has a bunch of less-expensive simulation options right now. We should consider this sooner rather than later.

Jeff Schroeder: Want to point out that there will be a "simulator continuum" for these vehicles (JSC, Ames, Langley). One thing that's important is that sometimes simulation people don't understand what they've got. Most people can't tell you what your motion cues are in your simulators, and we need to make sure we match the capabilities of the simulator with what we're trying to test. We need to know what we've got so we can get the most out of it.

PROJECTED NEEDS

Panelists

William Gregory (Moderator)	*Honeywell International*	Conference Co-Chair
Gene Matranga	*NASA, retired*	Apollo Team
Wayne Ottinger	*NASA/Bell, retired*	Apollo Team
Chirold Epp	*NASA Johnson Space Center*	Imaging Panel Moderator
Mitch Fletcher	*Honeywell International*	Avionics Panel Moderator
Doug Zimpfer	*Draper Lab, Houston, TX*	GNC Panel Moderator
Tom Alderete	*NASA Ames Research Center*	Simulation and Training Panel Moderator

Panel Conclusions

The final session of the conference was devoted to a summarizing the proceedings. The panel chairs presented viewpoints about consensus conclusions for general discussions involving all of the conference participants.

Apollo Team Panel Comments

Gene Matranga and C. Wayne Ottinger substituted for Harrison Schmitt:

- The Apollo Team is of the opinion that a continuum of training aids is needed for Constellation.
- Adequate funding for the appropriate training aids must be factored into to the Constellation budget now to prevent schedule disruption.
- One of the greatest values of the Shuttle Training Aircraft [STA] is that you can practice approaches to the actual landing runway. A great deficiency of the LLTV is that you are not actually landing on the Moon when you practice. This deficiency is mitigated by the fact that an “LLTV” is a real-world simulation that can include use of realistic control and visual systems.
- Everyone recognizes that today's simulation capabilities greatly exceed those of Apollo.
- We need to approach the Moon with the emphasis on Mars – abort to surface, not orbit. 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. In particular, this concept should be the primary abort mode option when an outpost is established or a surface rendezvous with another habitat or a consumables module is possible.

Imaging Panel Comments

- Who is going to fund this and when?
- Robotic lander precursor missions should be used to test sensors.
- A free-flying trainer could be used to test sensors as well.
- Industry should be provided with more specific areas to concentrate their internal R&D funding.
- Expecting a hardware -in-the-loop simulator in the near future – partial by 2008, full-up by 2009.

Avionics Panel Comments

- There is a need for Shuttle Avionics Integration Lab [SAIL] – type facility.
- Integrated Vehicle Heal Management (IVHM) needs to be designed in and proven on the Altair spacecraft. The first human Mars mission cannot be used as the testbed when human lives are fully depending on it, thanks to the 20 minute communication transit times to Earth.
- The workload will have to be adjusted to the crew health and capabilities, especially looking forward to Mars, which is completely unlike Shuttle. Until we know whether or not 1/6 g eliminates the adverse physiological effects of reduced-g loading, returning from long-term lunar stays may require increased automation, not unlike Mars missions.
- Younger personnel (both in the US and abroad) must be integrated into the workforce to harness new ideas.

Guidance, Navigation, and Control Panel Comments

- Altair GNC work is currently underway
- Altair GNC must be designed with Mars in mind (an abort to surface mentality).
- Sensors are required for hazard avoidance – but then who takes over requires more clarification and research.
- Any new LLTV-type vehicle should also be adaptable for Mars missions/requirements.
- The possibility of using nascent commercial ventures, such as the participants in the Google Lunar X-Prize, to test and further develop new technologies should be vigorously explored.

Simulation and Trainers

- Training aids encompass a continuum of devices (simulators, training vehicles) that should be designed to provide complementary training experiences.
- During Apollo, they started using the "research vehicle" before they had the Lunar Module design specifications, and the lessons learned from the research vehicle fed into the LM design process.

- Now, there is not a lot of time to do pure research before Altair enters the hardware stage – and where will the funding for new lunar mission training aids come from?
- Astronaut travel to/from the VMS at Ames Research Center has become an issue over time due to increasing costs.

Participant Discussion: Conclusions and Projected Needs

Q. How do we transfer the technology to the new generation?

A. Incorporate younger folks to take advantage of their newer communication schemes.

Q. Mentoring – worked in the past…today?

A. Need to get the younger folks up to speed, despite the fact we don't think alike. We need a "BLOG" for them to communicate through.

Q3. What about medical emergencies? What do we need to prepare?

A3. Discussed current training/procedures/technologies in use and how the challenges of Moon and Mars necessitate changes/improvements. Additionally, JSC is formally looking at the problems ["Safe Passage"] – such as dust ingestion, falling into crater, etc.

Q4. People continue to say "We've got time" – do we?

A4. Consensus is: No, we do not, and we need to convince folks to get moving/funding.

Q5. We had six successful Lunar landings in Apollo, some with very timely decisions. Were those decisions evaluated? Or were we just lucky?

A5. Training makes for good decision-making. The decisions were studied/evaluated. In addition, IVHM will greatly aid the speed and accuracy of decision-making with regards to to failure analysis. Buy-in is taking hold in EDL…simulations next.

Q6. Controllers/input devices [RHC/THC] – Will they be similar to Shuttle/Apollo, or more like a video game controller?

A6. Discussion about the reliability vs ergonomics of the STS RHC. Currently CEV/Orion is in a make/buy decision. Landing task is obviously much easier as compared to STS. Feedback will be similar. Crew wants something similar.

Q. Statement made that the Outpost on the Moon will be different than that of Mars. Need to use the Moon to prepare for Mars…not just optimize Lunar benefits.

Q. Statement made that it was great that the conference was held now, considered far in advance by some. There was sentiment that we need to get moving on simulators now and use them to do development work for the actual vehicle. Desktop simulations are operating and the VMS is also being used for Lunar Landing simulations currently.

C. Suggestion that the buildup approach should be used. Small unmanned building up to Altair.

C. Statement made that to lower risk, redundancy should be designed into the chip, while reliability is dealt with through complexity. Watch out for efforts to change proven [tried & true] technology, like removing the lead from solder. Discussion ensued on the "Tin Whisker" problem on Shuttle in the last few years.

Q. How do we ensure the radiation problem is covered? Orion has to go beyond LEO, as does Altair.

A. This is currently being handled by the Orion avionics lead. Obviously not much of an issue for the Ares team, but it will be on the Earth Departure Stage.

Q. How do we handle the issue of Manual vs Auto control for landing?

A. Volumes can be written about this issue. The fact of the matter is that Shuttle is flown in Auto from the de-orbit burn, [halfway around the world], right up until rolling on the HAC [final turn for landing], and even then the crew manually flies following guidance until short final, whereupon they rely on visual clues outside the orbiter. The issue comes into play at the end game, where the crew needs to be able to manually avoid obstacles/issues that would deter from a safe landing environment [slope for instance]. The real problem lies in the "smoothness" of transition from Auto to Manual. It needs to be guaranteed as truly seamless, or else the transition to manual must be made at an attitude/altitude which will support/allow a "bobble" during the transition.

APPENDIX A: LIST OF ACRONYMS

ADI	Attitude Display Indicator
AGC	Apollo Guidance Computer
AI	Artificial Intelligence
ALHAT	Autonomous Precision Landing and Hazard Detection and Avoidance Technology project
ARC	NASA Ames Research Center
BFCS	Backup Flight Control Systems
CEV	Crew Exploration Vehicle
CHR	Cooper-Harper Rating
CM	Apollo Command Module
COTS	Commercial-Off-The-Shelf; Also, Commercial Orbital Transport Services
DFRC	NASA Dryden Flight Research Center
DOF	Degrees of Freedom
DSKY	Apollo Lunar Module Display Keyboard
DSMAC	Digital Scene Matching Area Correlation
EDL	Entry, Descent, and Landing
EKV	Exoatmospheric Killing Vehicle
ESAS	Exploration Systems Architecture Study
EVA	Extra-vehicular Activity
FRC	NASA Flight Research Center, now the NASA Dryden Flight Research Center
FRR	Flight Readiness Review
GIS	Geographic Information Systems
GNC	Guidance, Navigation, and Controls
HAC	Heading Alignment Cylinder
HIL	Hardware-In-The-Loop
HUD	Heads-Up Display
IOC	Initial Operational Capability
ISS	International Space Station
IVHM	Integrated Vehicle Health Management
JAXA	Japanese Aerospace Exploration Agency
JSC	NASA Lyndon B. Johnson Space Center
LaRC	NASA Langley Research Center
LEO	Low-Earth Orbit
LLRF	Lunar Landing Research Facility
LLRV	Lunar Landing Research Vehicle
LLTV	Lunar Landing Training Vehicle
LM	Lunar Module

LPD	Lunar Powered Descent
LRO	Lunar Reconnaissance Orbiter
LROC	Lunar Reconnaissance Orbiter Camera
LSAM	Lunar Surface Access Module
MSC	NASA Manned Spacecraft Center, now the Johnson Space Center
PFCS	Primary Flight Control Systems
PIO	Pilot-Induced Oscillation
RCAH	Rate Command Altitude Hold
RCS	Reaction Control System
RHC	Rotational Hand Controller
ROD	Rate of Descent
RPRV	Remotely Piloted Research Vehicle
RPV	Remotely Piloted Vehicle
SAIL	Shuttle Avionics Integration Laboratory
STA	Shuttle Training Aircraft
STS	Space Transportation System (The Space Shuttle)
THC	Translational Hand Controller
TLX	Task Load Index
TRN	Terrain Relative Navigation
UCAV	Unmanned Combat Aerial Vehicle
VMS	Vertical Motion Simulator
VR	Virtual Reality
VTOL	Vertical Take-off and Landing

APPENDIX B: A Memo from David Scott, Commander Apollo 15

[Editor's note: *As one of only six human beings to perform a successful landing on the Moon, Apollo 15 Commander David Scott is highly qualified to comment upon the requirements for the successful terminal descent phase of a human lunar landing. Unfortunately, Col. Scott was unable to attend the Conference in person. However, he provided this detailed memo summarizing his views.]*

February 26, 2008

To: Bill Gregory

From: Dave Scott

Subject: Go for Lunar Landing Conference -- Purpose

The following comments are offered after a review of the "Purpose of the Conference" as posted on the web (HTTP://ser.sese.asu.edu/GO/agenda.php).

An LLTV-type vehicle is absolutely mandatory – not debatable.

Pitchover is the point at which the landing methodology should be evaluated and refined. Pitchover (high gate) provides the first view of the site and is critical during the next minute or so during which the major decisions are made on precisely where to land. For preparation and training in selecting the target point, the surface imagery is most important. The first view of the site also begins the "zoning" period, which peaks somewhat later (see below). This also begins the phase during which proficiency in an LLTV-type vehicle becomes absolutely essential.

The highest probability of success for a "manned" landing on the moon is by using the proven and reliable Apollo-type manual control concepts and functions (with some semi-automatic assistance, e.g., LPD and ROD). This includes standard hand-controllers (i.e., stick [RHC] and throttle).

Lunar Surface. As we now know, the surface of the Moon is irregular in all aspects – rocks, slopes, craters, regolith, undulation, lighting, etc. – there is no clean and level surface area greater than a few feet at most (at least within the areas that might be suitable for lunar exploration). Touchdown-point selection is best made by the human eye (significant pre-flight training assistance could be achieved from VR facilities such as the CAVE at Brown). It would be very difficult for an automatic, robotic, or AI system to select the optimum (or even acceptable) touchdown point. And for landing, dust is not a significant factor (even up to a couple hundred feet, especially for a proficient LLTV pilot) – based on experience thus far, dust occurs well after the touchdown point has been selected, and when dust does occur, Apollo LM-type cockpit displays are quite adequate for an instrument landing.

The motion of a lunar lander is absolutely unique. In particular, the 3-axis horizontal and vertical velocities are strongly and instantly coupled as functions of engine thrust level and vehicle attitude (R, P, and Y). Therefore, only a free-flight LLTV-type vehicle can be used for realistic and efficient simulation. These multi-variable operations cannot be adequately simulated in a fixed-base or moving-base simulator. Further, the LLTV-type free-flight motion cannot be simulated by a helicopter or hovercraft (either of which can however simulate the landing trajectory or path).

Automatic, robotic, and/or AI landing capabilities appear to have quite an emphasis in the conference agenda; therefore some specific comments may be helpful.

a) Automatic (robotic, AI) capabilities are becoming quite advanced, they are challenging and they are fun to develop. But they are not necessary, or even desirable for a "manned" lunar landing -- they will introduce complex and additional failure modes during the mission as well as require the corresponding time and resources necessary for integration; test and checkout; software verification; procedures development (normal, malfunction, and emergency): C&W logic and signals; mission techniques; mission rules; simulation (such as launch abort simulations due to time criticality); training; and real-time mission support,…among other factors (e.g., the age-old problem – if a red warning light flashes, what is at fault: the system or the indicator? And during the time-critical landing phase, the delay in assistance from MCC could cost you the farm).

b) Automatic (robotic, AI) systems are best applied to two areas: (1) to relieve the human burden of repetitious, tedious, and boring activities; and (2) to allow humans to do something that could not be done without assistance from an "automatic" system (e.g., a precision landing on a runway during zero visibility conditions). Landing on the Moon is an entirely different matter –the surface of the Moon is irregular in all aspects and even with precision VR planning and programming, it is unlikely that an automatic system will be able to "see" (interpret) the surface conditions as well as the eye. Automatic (robotic, AI) systems would be great for an unmanned landing, but they are unnecessary and even compromising for a human landing.

Simulators and training should follow closely those concepts and methods developed and proven during Apollo – fixed-base simulators for systems and procedures, and a free-flight LLTV for actual flight dynamics. The Langley LLRF and other electrical-mechanical simulators introduce an undesirable lag in response. And lunar-g simulation for flight operations is unnecessary.

References. To expand on the above comments, many Apollo-era documents are important, if not convincing, including:

1. "Apollo Experience Report - Mission Planning for Lunar Module Descent and Ascent," Floyd Bennett, NASA TN D-6846, June 72

2. “What Made Apollo a Success?”, NASA SP-287

3. Nassiff, S, and Armstrong, N; “Apollo Flight Crew Training in Lunar Landing Simulators,” AIAA 1968-254, March 25-27, 1968

2nd stage effect. The development of a new lunar lander, especially with the computational power available today, must consider and be acutely aware of the programmatic impact and performance degradation caused by the so-called “2nd Stage Effect” (the appearance of which in the Architecture Study [ESAS] and early LSAM concepts is obvious).

Zoning. As a further reference to perhaps better comprehend the benefits of an LLTV-type vehicle, have a look at one of the “zoning” publications; e.g., “Entering ‘The Zone’: A Guide for Coaches” [HTTP://www.thesportjournal.org/VOL2NO3/COSTAS.HTM]. This was not a familiar term during Apollo, but this is what we did, especially during descent and landing -- and because of LLTV experience, just after pitchover we probably entered what is now known as “The Zone”-- for lunar landing.

Attendees. I have not seen a list of attendees, but an Apollo Flight Director(s) should definitely be included in all such discussions, analyses, meetings, etc.– they bring an entirely different and very valuable perspective to the process -- even though they do not make the landing, they know how it works, and they know how to support during such a time-critical phase (need the 1201’s be mentioned?).

And finally, the above comments obviously represent a very strong bias toward Apollo…..it worked. And just like wings and propellers, the basic Apollo configuration and operations established the fundamental principles and concepts by which human landings on planetary bodies can be achieved with the highest probability of success.

Good luck for your well-timed conference, and even better luck to the Constellation folks; they do have a challenge..!!

DRS

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