Go For Lunar Landing Conference, March 4 -5, 2008, Tempe, AZ

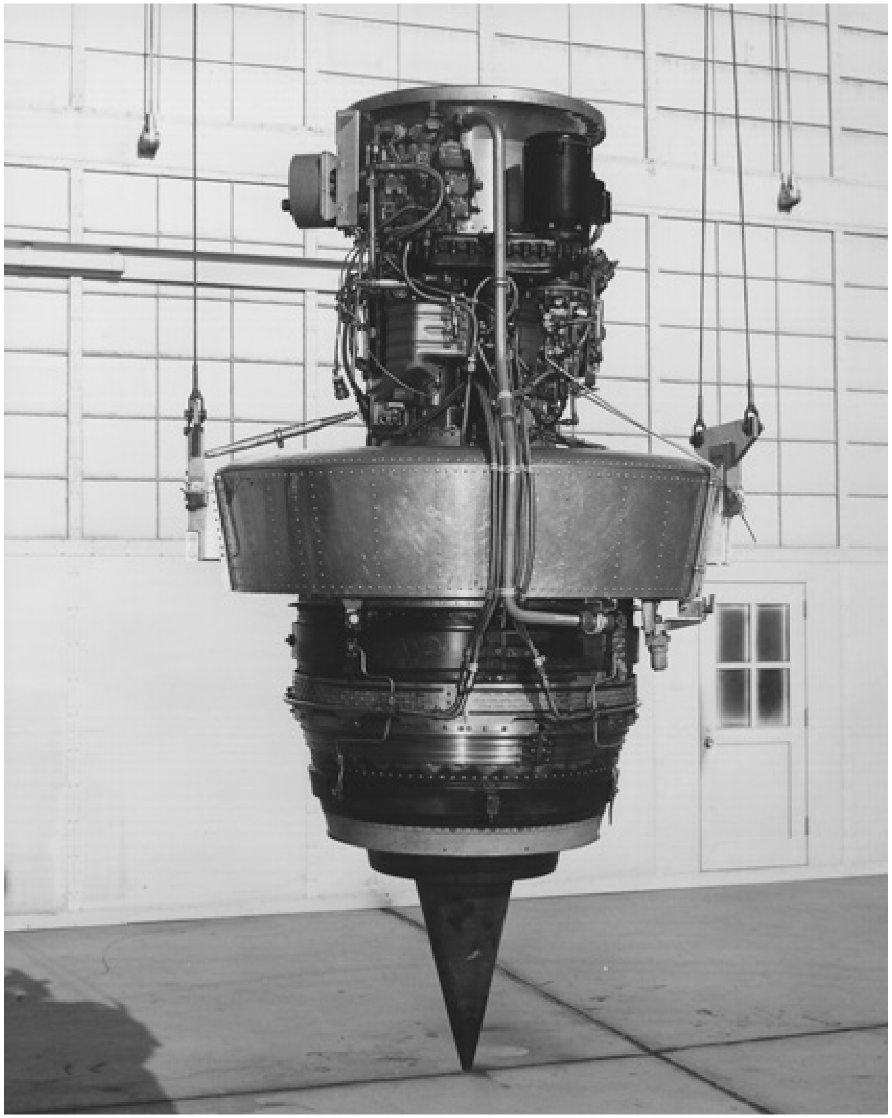
This Presentation is a collaboration of the following Apollo team members (Panel #1):

- Dean Grimm, NASA MSC LLRV/LLTV Program Manager
- Cal Jarvis, NASA FRC LLRV Controls Engineer
- Gene Matranga, NASA FRC Program Manager
- Warren North, NASA MSC Flight Crew Support Division Director,   Mercury, Gemini, Apollo
- Wayne Ottinger, NASA FRC LLRV Project Engineer, Bell LLTV Technical Director
- Kenneth Szalai, NASA DFRC Director, 1990-1998 provided inputs on simulation and flight experience, including the PIO on Free Flight 5 of the Shuttle ALT Program and the F-8 PIO.

Part One: Presented by Matranga, North, & Ottinger

Part Two: Backup for discussions and archival.

The General Electric CF700 turbofan was unusual in having an aft-mounted fan section. The special -2V variant of this engine, used in the LLRV/LLTV, was optimized for vertical installation. (E-12611)



General Electric CF700 -2V Turbofan Engine Specifications

Parameter	LLRV	LLTV
Takeoff #s thrust	4,200 pound	4,200 pound (plus 50 to 100)
Exhaust gas temp.	710°C (1300°F)	729°C (1345°F) (takeoff)
Gas generator speed	16,500 rpm	16,700 (101.2%) rpm
Fan speed	9,300 rpm	9,300 rpm
Max continuous thrust	4,000 pounds[18]	4,000 pounds[19]

It is estimated that the hot-day thrust was increased by 50 to 100 lbs for the LLTV version of the engine.

On extra-hot days, extra jet engine burn-off of fuel before take-off would be required.

Lunar Landing Research Facility (LLRF), NASA Langley

Lacked fidelity of simulation due to cable forces

Quotes from Pete Conrad, NASA MSC Minutes of Meeting Flight Readiness Review Board Lunar Landing Training Vehicles, Houston, Texas, January 12, 1970

- "I guess I don't have a formal presentation, but I guess the question is, one, that after we made some lunar landings, is the vehicle a requirement for training for subsequent crews? And I have to preface my remarks by saying **-- were I to go back to the moon again on another flight, I personally would want to fly the LLTV again as close to flight time as practical.**
- The LMS is certainly an adequate vehicle to do your instrument training necessary to land, to go all the way down and land. I'm not sure that everybody is aware of the fact that the probes on the L&A normally shuts you off visually at an altitude of about 100 feet and so you don't get the last part of it, nor do you get the transition part of flying. **It doesn't do the job of flying safe velocities of 80 feet per/sec on down into this area of going into a hover.**
- **The problem of determining proper pitch attitude is one that I feel I got most benefit out of the LLTV**, and if you will look at the films very closely of my landing, you will see some pretty healthy pitch attitude excursions or changes right down in the area of the heavy dust and this was strictly when I was going from outside the cockpit to inside the cockpit.

Quotes from Pete Conrad, NASA MSC Minutes of Meeting Flight Readiness Review Board Lunar Landing Training Vehicles, Houston, Texas, January 12, 1970

- One of the comfortable things of my landings was to make that lateral translation, and I put all the confidence, and if you will listen to the tapes, even A1 Bean remarked that about how we were doodling around in the sky, because he had not flown in a real vehicle. **He is not used to those kind of physiological feelings and sensations that you get by flying the LLTV, and it's probably one of the more uncomfortable vehicles to be rolled about 10 or 15 degrees and pitched up about 20 degrees and you don't get that in a Langley simulator either**, because you are at low horizontal velocities and you make a very quick transition to a hover and come down.

Quotes from Neil Armstrong, NASA MSC Minutes of Meeting Flight Readiness Review Board Lunar Landing Training Vehicles, Houston, Texas, January 12, 1970

- Our own problem was getting into a small area. I felt that we would never find a spot that was good enough to land in. That's a kind of problem that's impossible to duplicate in the LMS, or in the LLRF. It's even that difficult to do in the LLTV unless you sort of play the game to yourself, as you fly into a touchdown area and you say no, I don't want to land there -- I want to land over there. As you get a little closer you say no, I really want to land over there, and make yourself do that. So you have to force yourself to do that problem.
- In general, I guess what we all have to ask ourselves is, do we want to keep buying this insurance policy? We've paid a lot of money to buy this insurance policy to improve our ability to do the landing job, and in a couple of times, we've had to pay excess premiums. Premiums that we felt that we were really unwilling to pay or at least to continue paying. And now, we are at the point where we say maybe, at this point in time, we don't need to buy the policy at all. Discontinue the premiums on it and avoid the possibility of these excess premiums that might burden us in the future with another crash or something like that. My own conclusion is that we still can't afford not to insure against this particular catastrophe. A catastrophe of one sort or another, on final approach at the moon, and I think, we should continue to buy the policy.

Quotes from Neil Armstrong, NASA MSC Minutes of Meeting Flight Readiness Review Board Lunar Landing Training Vehicles, Houston, Texas, January 12, 1970

- It is the only device we've had. The only simulation at all where you can allow the process to take place, of a closed loop process where you infer the velocities from attitude, velocities over the ground, and the actual vertical velocities coming into the picture at the appropriate velocity. **I'm talking of 50 feet per/sec. over the ground which is the transition phase. That phase from breaking where you are essentially, just watching out the window and pre-designating and doing those things, to come into a hover. That's the 150 feet per/sec. to 10 feet per/sec. region --that's where you really have a lot of flying.**
- The forcing function of a limited time is in many respects quite radical. [LM] Still it didn't really worry me, because I knew just what 10 seconds or 20 seconds were in terms of a flight situation. [LLTV]

Quotes from Don Mallick, NASA SP-2004-4535 Unconventional, Contrary, and Ugly: The Lunar Landing Research Vehicle, Page 159 (Appendix A)

Lunar Simulation:

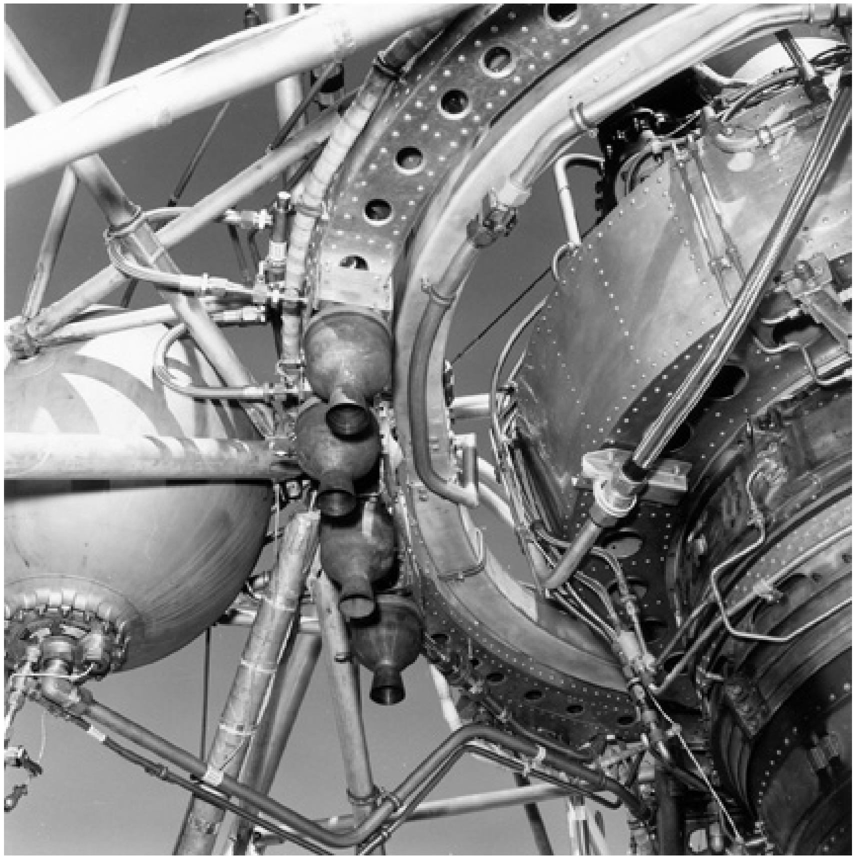
- **This was a different world to fly in. The attitude control was similar as far as response, but very large pitch and roll attitudes were required along with what seemed to be long waiting periods to begin or arrest any translational motion. either along or to the left or right of the flight path. It took some getting used to, and a different amount of anticipation to fly and bring the LLRV to a hover and landing over a desired spot.** It was possible and like all tasks, the more you did it the better you became. The control of the vertical descent with the lift rockets was different, too, in that it took a longer time to arrest a given vertical velocity as you approached the ground. **It was apparent that a pilot or astronaut could fly a vehicle in the lunar environment of 1/6 the Earth's gravity and no atmosphere. It did require some adaptation by the pilot.**

Quotes from Don Mallick, NASA SP-2004-4535 Unconventional, Contrary, and Ugly: The Lunar Landing Research Vehicle, Page 159 (Appendix A)

- Our major evaluations were in the area of control power, or just how little control moment could we live with and still safely control this machine, which extrapolated to safely landing on the moon. The "test" set of attitude control rockets would be adjusted prior to flight to lower and lower levels as we probed the minimum level that we would accept. Joe Walker and I would then fly the standard lunar landing profile and evaluate the acceptability of the control power level. We always had the second set of attitude controls and a known nominal control power that could be selected if a control problem occurred. If we entered a dangerous control situation, we would rotate a switch located on the left-hand side panel to basic control or both, in order to restore a more powerful attitude control and allow us to recover the LLRV safely. Joe and I would each fly the various control powers settings and make qualitative pilot ratings on the Cooper-Harper rating scale. The ground personnel and engineers also had extensive recorded quantitative data to verify our feelings about a particular control setting. They could tell by pilot input and vehicle responses just how well the pilot and control system were doing.

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.



(4) 500 lb H_2O_2 Lift Rockets

(4) 90 lb H2O2 Attitude Control Rockets

Link to Monograph

NASA SP-2004-4535
Unconventional, Contrary, and Ugly:
The Lunar Landing Research Vehicle

Gene J. Matranga
C. Wayne Ottinger
Calvin R. Jarvis

With Christian Gelzer

NASA History Division
Office of External Affairs
Washington, D.C. 20546

Monographs in
Aerospace History
Number 35
2006

http://www.nasa.gov/centers/dryden/history/Publications/index.html

Additional Information to Supplement the Monograph

1. **Corrections**

   a) **Page 71, Photo E-11942, mis-identified as the Attitude-Control System Test Fixture**

   This fixture should have been identified as the Single-Axis Test Fixture (Pitch or Roll) for the Attitude Control Rocket System integrated with the corresponding Pitch or Roll of the jet engine hydraulic gimbal system – jet engine running, gimbal operation simultaneous with the attitude rockets firing. The next slide is a clip of the C.G. fixture hot firing of the attitude control system with pitch and roll combined but no jet engine running.

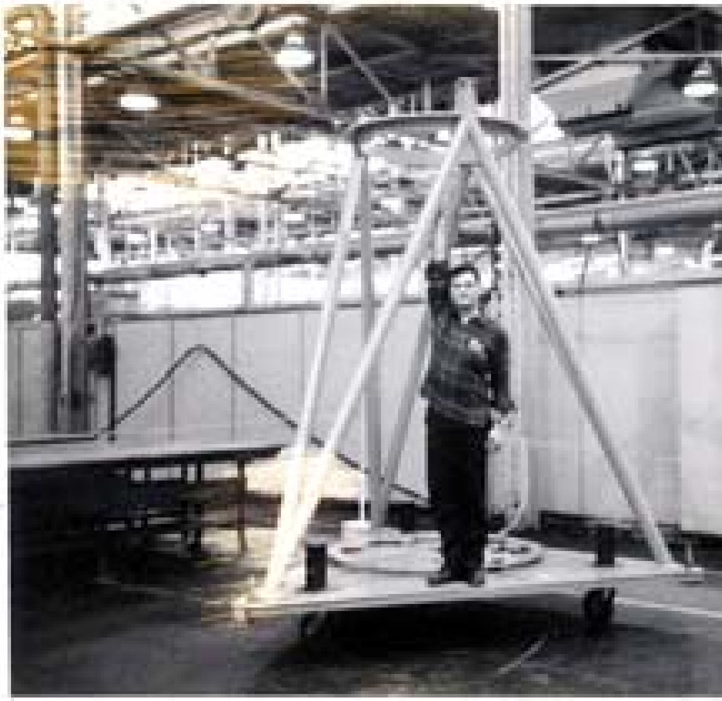
   b) **Page 172, Appendix D, NASA MSC Minutes of Meeting Flight Readiness Review Board Lunar Landing Training Vehicles, Houston, Texas, January 12, 1970**

   There were several paragraphs inadvertently omitted from the monograph that were in the original transcript. These are included after the video clip of the C.G. fixture.

   c) **Page 45, Photo EC-93-1221-4, one Rocket Missing from Cluster**

   d) **A number of system schematics were omitted from the original manuscript and are included in the later slides.**


LLTV on CG
Fixture Hot
Firing ACS
Pitch/Roll
Simultaneously



Center of Gravity Test Fixture

LLRV Mounted on the C.G. Fixture

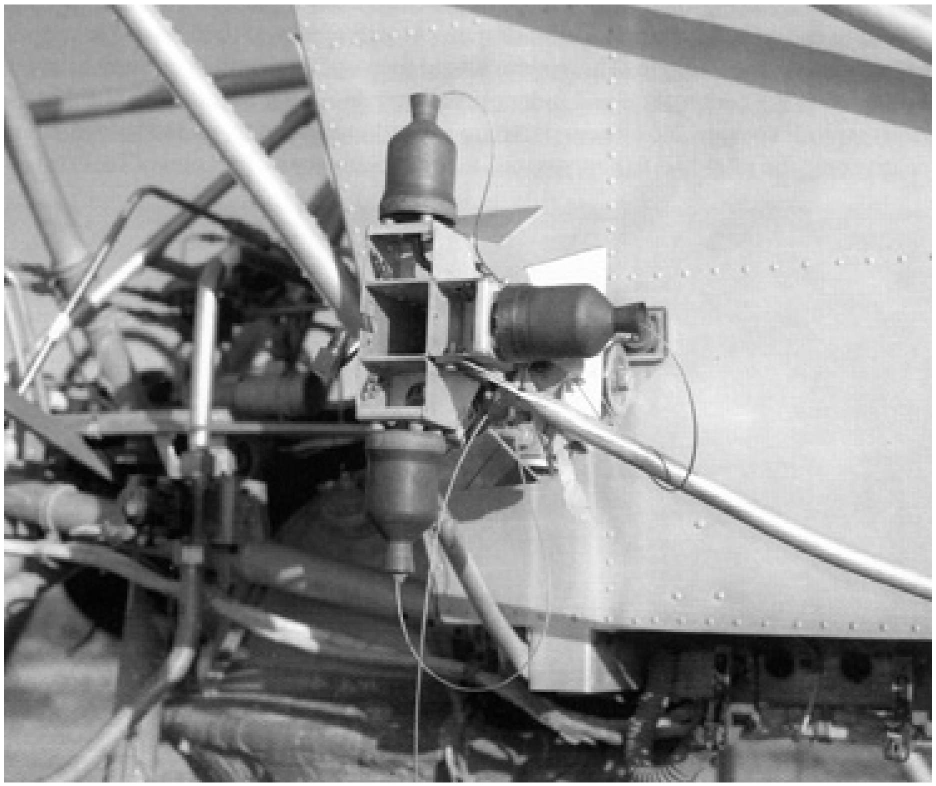
Center of Gravity (CG) Challenges

(Required to enable research of attitude control system acceptable low control authority boundaries while still compensating for aerodynamic conditions including winds aloft.)

1. Provide a system of measuring the LLRV's dry CG within a **One-tenth of an inch sphere**.
2. Ensure the dry CG for the LLRV with pilot and all equipment lies within a **One-quarter of an inch sphere**.
3. Ensure the in-flight wet CG lies within a **One-half inch sphere**.
4. The initial design provided adjustment of the avionics rack position at the rear of the vehicle, this was replaced during flight operations with small canisters containing the required amount of lead shot to account for differences in pilot weights or equipment changes.
5. Flight operations required the draining of all the rocket and jet fuel tanks and the measuring of the residual weights to log the unbalance after each flight.

Missing paragraphs from page 172

- **But the other problem with the dust is the fact that it is a dynamic moving field that is of varying intensity, and every time you look out of the window to do something you cannot help but physically be -- your eyes are physical1y attracted to a darker cloud that just went off that way, from one that went off that way. And I think that the two factors on pitch: one, that you don't have it, but if you put a boom or you put a device out there that would put some structure out there to give the normal physical clues of pitch, that the dust would still be distracting whether it obscures the ground or whether it doesn't obscure the ground, and I felt much more comfortable with my head in the cockpit. And as I stated, the only reason that I continued to put pry head out of the cockpit was because I, in retrospect, it was a mistake, and we should have added it to the checklist, to verify that our horizontal and lateral velocity indicator was in fact working, and it was.**
- It's just that up --high enough. I killed off all of, the lateral and horizontal velocities, to the point where it was not registering on the gauges. I probably really wanted that gauge in what Al called out in my ear in the neighborhood of 50 to 60 feet. When I first looked at it, and I think the data shows that we were pretty well in a hover at 50 feet, actual attitude. And had I felt that gauge was working, I probably would never have looked out that window again and I was perfectly satisfied that we were in a clear enough spot that I didn't need to look out anymore. And the only reason I did, and the other thing I did, had not gone back to look at my data, and I don't understand why I made 10 degrees attitude excursions right at the end, but they were plus or minus, but I don't remember. which way it was exactly, but the first time that I came back in the cockpit, I was pitched up 10; and I leveled it and I looked back out the window and it was very plain on the film, and I looked back out the window and I was pitched down 10° when I brought my head back in the cockpit and brought the vehicle back level when it was just about that time --that we got lunar contact.
- Now I don't know whether I made control inputs or whether some slosh actually disturbed the vehicle's yaw and attitude hold mode. I suspect that I physically put some control inputs in, and I suspect that I may have done it instinctively when I was looking out the window thinking I was keeping things level. As I say, you have to look at the film three or four times, but the pitch experience is very plain in the film right at the end. The pitch was down the first time. That's because I went back into the cockpit, and I looked out the window again, and when the pitch was back up, I put my head back in the cockpit and leveled away.
- It is very difficult to say, and I know that it was a very difficult thing to do in the LLTV, but I think Joe or Bud will remember. I think I made my first three landings that went in backup auto pilot in the LLTV on my training runs just before the flight because of this pitch attitude, and the only way I can tell in the LLTV is to put my head in the cockpit. You can't guess it sitting in there and looking out. As slow as you want to come down, you'll screw it up every time unless you cross check that attitude ball. You can't convince yourself to do this properly in the LMS. You just don't have enough visual, and you pretty nearly fly the last part of the approach in the LMS on the gauges only, to stay within the constraints so you don't bomb out the simulator.



As Shown on Page 45 in Monograph (1 Rocket Missing)

Complete Cluster

LLTV Rocket Propulsion System

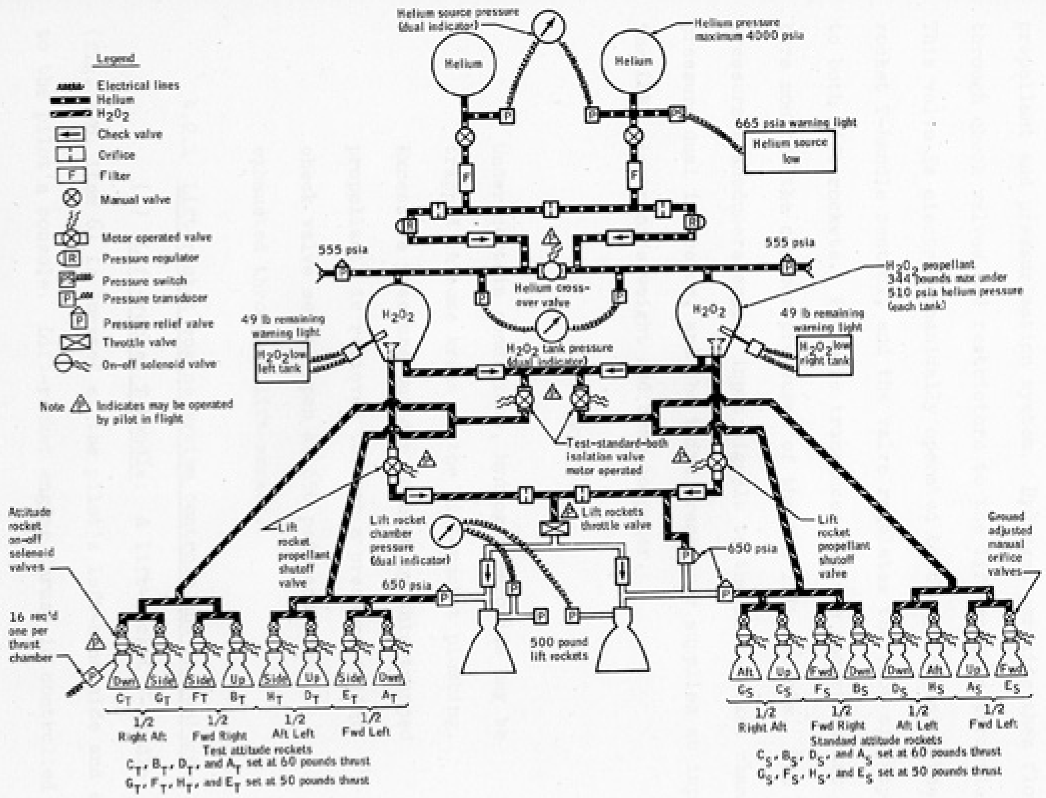


Figure 4-1.- LLRV rocket propulsion system schematic including the rocket propellant and pressurization schematic.

4-2

LLTV Turbofan Engine Fuel and Power Control System

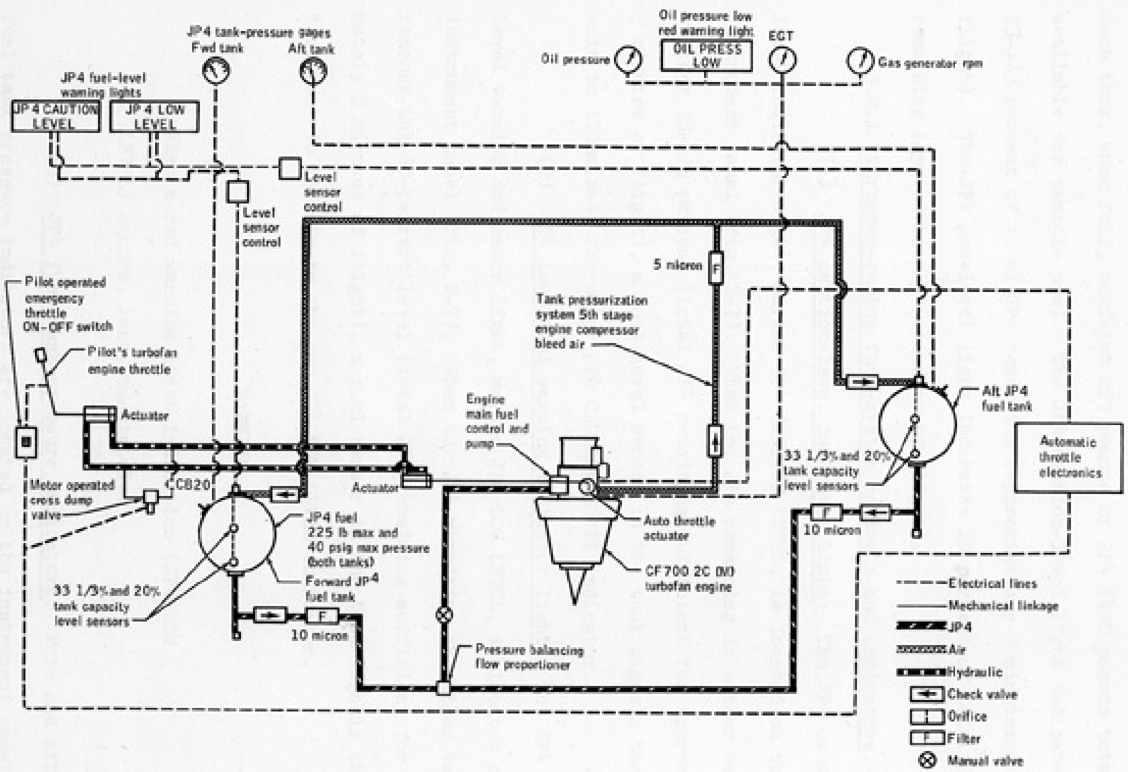


Figure 3-2.- LLRV turbofan engine fuel and power control system schematic.

3-13

LLTV Hydraulic System Schematic, Jet Engine Gimbal

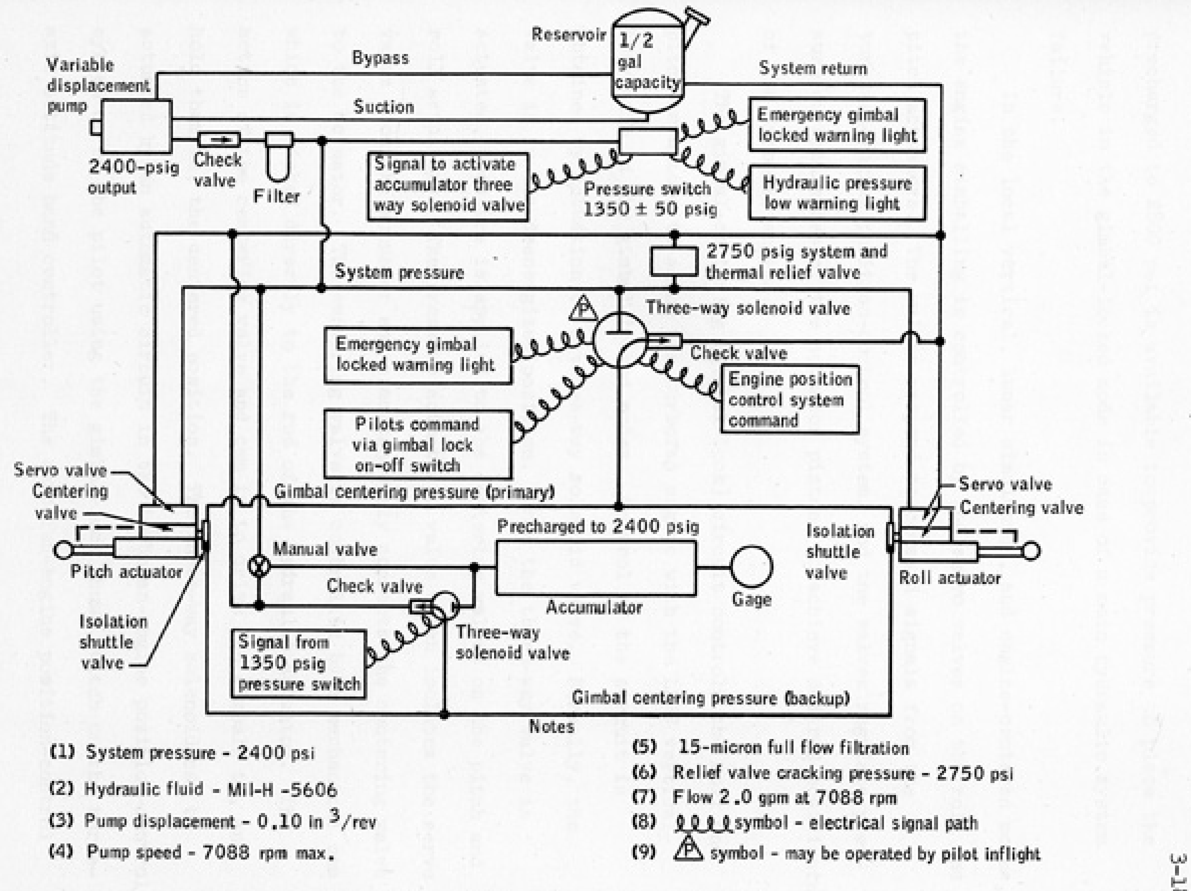


Figure 3-3.- Hydraulic system schematic.

LLTV Electrical Power Supply System

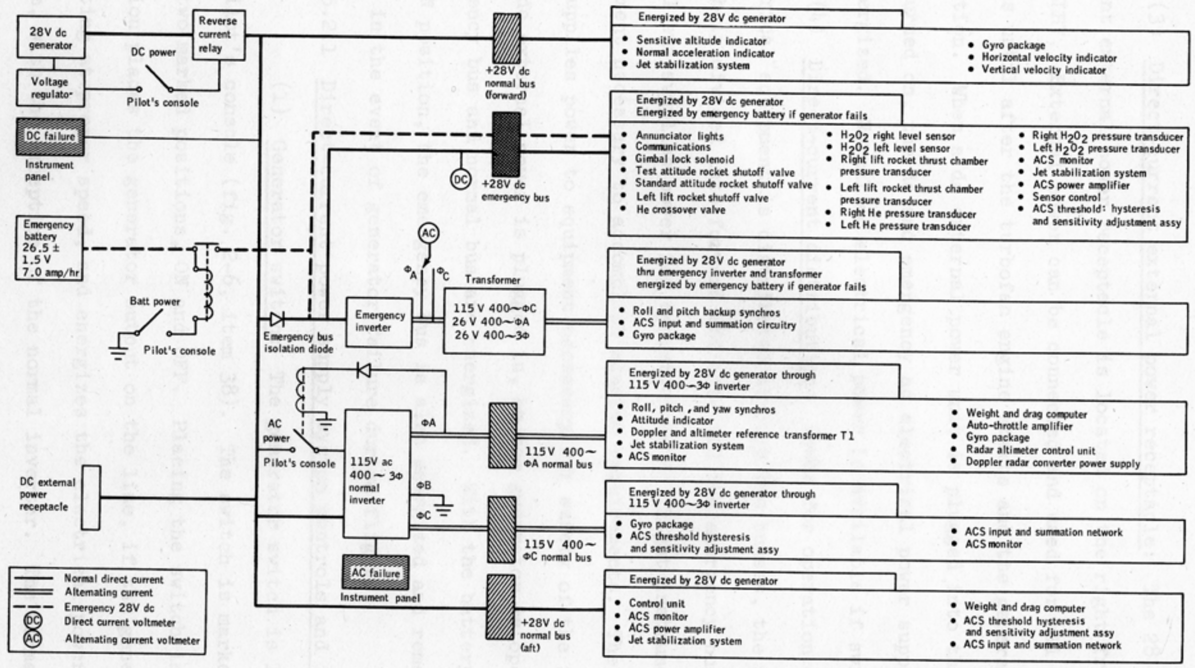


Figure 5-1.- Electrical power supply system schematic.

5-3

Appendix G **NASA SP-2004-4535 Unconventional, Contrary, and Ugly: The Lunar Landing Research Vehicle**

Milestones: The following table provides an overview of the key events in LLRV and LLTV operations at Ellington Air Force Base, Texas. To put the LLRV and LLTV astronaut training deadlines in perspective, the table includes Apollo launch dates.

Events	Date	Remarks
LLRV No. 1 Delivery	13 December 1966	
LLRV No.2 Delivery	25 January 1967	
LLRV No.1 First Flight	3 March 1967	FRC crew did the preflight. (Kluever)
Armstrong's First LLRV Flight	After 23 March 1967	First astronaut flight
LLTV No. 1 Delivery	9 October 1967	After extensive delay due to disputed interpretation of x–rays on structural aluminum welding
LLTV No. 2 Delivery	7 December 1967	
LLTV No. 3 Delivery	10 December 1967	
Crash of LLRV No. 1	8 May 1968	Loss of helium pressure. Neil Armstrong, pilot
LLTV No. 1 First Flight	3 October 1968	Joe Algranti, pilot
LLTV No.2 First Flight	5 December 1968	Bud Ream, pilot
Crash of LLTV No. 1	8 December 1968	Joe Algranti, pilot
LLTV Armstrong training	14–16 June 1969	
Launch of Apollo 11	16 July 1969	Armstrong, Aldrin, Collins
Launch of Apollo 12	14 November 1969	Conrad, Bean, Gordon
Launch of Apollo 13	11 April 1970	Lovell, Haise, Swigert
Launch of Apollo 14	29 January 1971	Shepard, Mitchell, Roosa
Crash of LLTV No. 2	31 January 1971	Stuart M. Present, pilot
Launch of Apollo 15	26 July 1971	Scott, Irwin, Worden
Launch of Apollo 16	16 April 1972	Young, Duke, Mattingly
Final LLTV Flight	13 November 1972	Gene Cernan, pilot
Launch of Apollo 17	7 December 1972	Cernan, Schmitt, Evans

<u>Appendix G</u> NASA SP-2004-4535 Unconventional, Contrary, and Ugly: The Lunar Landing Research Vehicle Milestones:

Milestones for LLRV/LLTV Operations at Ellington AFB LLRV No. 1

Initial Astronaut-Training Plan

The initial LLTV astronaut training plan had seven requirements to be completed before the astronaut flew an LLTV for the first time:

- Complete 100 hours total helicopter time, with a minimum of five hours completed in the 30 days before LLTV checkout flights. (This requirement applied to all LLTV pilots.)
- Complete 10 training flights in the LLRF at NASA Langley.
- Complete 10 hours in the LLTV fixed-base simulator.
- Complete systems ground school on the LLTV.

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Appendix G NASA SP-2004-4535 Unconventional, Contrary, and Ugly: The Lunar Landing Research Vehicle Milestones:

- Use swing to determine ejection–seat cg at Weber Aircraft Company facilities in Burbank, Calif., to establish cushion thickness to optimize seat trajectory during ejection.
- Use LLTV cg fixture for attitude-rocket live firing closed loop attitude-control system hot firings in pitch and roll.
- Do LLTV tie-down combined systems run with jet engine and rocket systems

The initial LLTV transition syllabus required thirteen flights under the supervision of a staff instructor pilot. Later, the number of flights was lowered to eleven.
For pilots already checked out in the LLRV, the initial LLTV transition plan included three requirements:

- Complete systems ground school on the LLTV.
- Complete five hours in the LLTV fixed-base simulator.
- Do LLTV cg stand–closed loop attitude-control system hot firings in pitch and roll.

Five flights would be completed as a transition syllabus under the supervision of a staff instructor pilot, the syllabus defined after the LLTV No. 1 flight test. There were four post-checkout training requirements

- Eight flights, open cockpit front (no LM window) in full lunar simulation.
- Five plus flights with window in full lunar simulation.
- Currency flying, biweekly or two per month in full lunar simulation.
- Recurrency–helicopter currency; two flights minimum in vehicle with gimbal locked in first flight.

Appendix G NASA SP-2004-4535 Unconventional, Contrary, and Ugly: The Lunar Landing Research Vehicle Milestones:

The following table summarizes the required training plus LLRV and LLTV flights of all Apollo astronauts, listed in numerical order of the Apollo missions. With the exception of Anders and Borman–who made LLRV flights before mission assignments were firm–only prime and backup LM commanders flew the LLRVs or LLTVs. However, Lovell, backup commander on Apollo 11, had no LLRV or LLTV training at all before Apollo 11 launched due to the crashes of LLRV No. 1 and LLTV No. 1.

LLRV and LLTV Training of Apollo Astronauts

Name	Role	LLRV Flights	Required	LLTV Flights
Armstrong (Launched 7/16/69)	Apollo 11 Commander	21	All available	6
Lovell	Apollo 11 Backup Commander	None	All available	None
Borman	Unassigned	1	[Too early]	None
Anders	Unassigned	11	[Too early]	None
Conrad (Launched 11/14/69)	Apollo 12 Commander	13	11	10
Scott	Apollo 12 Backup Commander	None	22	22
Lovell (Launched 4/11/70)	Apollo 13 Commander	None	22	22
Young	Apollo 13 Backup Commander	None	22	22
Shepard (Launched 1/31/71)	Apollo 14 Commander	None	22	22

Appendix G NASA SP-2004-4535 Unconventional, Contrary, and Ugly: The Lunar Landing Research Vehicle Milestones:

Name	Role	LLRV Flights	Required	LLTV Flights
Cernan	Apollo 14 Backup Commander	None	22	22
Scott (Launched 7/26/71)	Apollo 15 Commander	None	11 or fewer	11 or fewer
Gordon	Apollo 15 Backup Commander	None	22	22
Young (Launched 4/16/72)	Apollo 16 Commander	None	11 or fewer	11 or fewer
Haise	Apollo 16 Backup Commander	None	22	22
Cernan (Launched 12/7/72)	Apollo 17 Commander	None	11 or fewer	11 or fewer
Young	Apollo 17 Backup Commander	None	11 or fewer	11 or fewer

The next table lists the five MSC Aircraft Operations Division and FRC pilots, their roles, and the number of LLRV and LLTV flights each made at the MSC.

MSC AOD Pilots

Name	Role	FRC Flights	LLRV Flights	LLTVFlights
Joe Algranti	MSC Staff Pilot	13	6	12
Bud Ream	MSC Staff Pilot	12	34	(unknown #)
Stu Present	MSC Staff Pilot	None	None	(unknown #)
Jerry Cobb	MSC Staff Pilot	None	None	(unknown #)
Jack Kluever	FRC Pilot	2	2	None

Appendix G NASA SP-2004-4535 Unconventional, Contrary, and Ugly: The Lunar Landing Research Vehicle Milestones:

The following table gives the calculated vehicle flight log for the first LLRV (at the MSC only) and the three LLTVs. LLTV No. 1 flew 2 hours 8 minutes 35 seconds in 15 flight tests, an average of 8.56 minutes per flight. LLTV No. 2 flew 24 hours 2 minutes 26 seconds in a calculated 206 flights at an average of 7 minutes per flight. LLTV No. 3 flew 33 hours 18 minutes 51 seconds in a calculated 286 flights at an average of 7 minutes per flight. Total calculated flights for LLTV No. 2 and No. 3 are 492 and 216 respective training flights and 276 functional check flights.

Calculated Vehicle Flight Log

Vehicle	Total Flights	Total Training Check Flights	Total Functional Flights	Requirement
LLRV No. 1	84	50	46	38
LLTV No. 1	15	N/A	0	15
LLTV No. 2	206	264	216	116
LLTV No. 3	286	N/A	N/A	160
Totals:	591	N/A	N/A	329

N/A=Not available

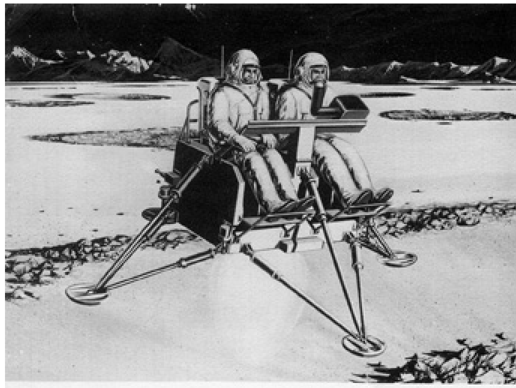
NASA SP-2004-4535 Unconventional, Contrary, and Ugly: The Lunar Landing Research Vehicle, Pages 155/156

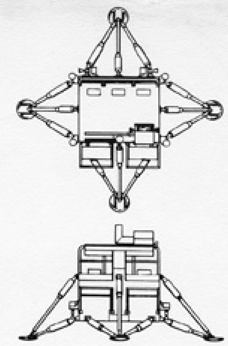
From the Past to the Future

In 1988, near the end of a symposium titled "Wingless on Luna," Neil Armstrong spoke of the future he saw for mankind on the moon.[4] Tongue-in-cheek, he briefly sketched the outlines of what the future might be like with a community of humans on the moon, sharing the environment with rocket-powered flying machines:

Compact flying machines should have good usability. Cruising altitudes above 200 feet should minimize visibility problems due to dust, but higher altitudes may be required to avoid irritating joggers below. Rocket exhausts are noiseless on Luna, so rocketports should be immune from noise abatement [law] suits. As soon as the plaintiff's bar has a Lunar section, however, they can be expected to find some basis for complaint.[5]

Once mankind is living in space, the moon will be a valuable source of raw materials-metals, oxygen, and residues from the solar wind. While "the rocket will carry the brunt of the load" in lunar flying machines, "low gravity and the consequent low divergence rates should make rocket belts more easily flyable than on Earth."
Flying on the moon in the twenty-first century will require the use of rocket attitude controls perhaps different in some design details from those used in the twentieth century, but the applicable laws of physics will be the same. Future designers of flying machines will then benefit from the twentieth century's extensive experience with rocket attitude-control and lift systems. And the LLRV 's groundbreaking accomplishments led the way.
This work is an attempt to preserve a small portion of this technical legacy. As Armstrong wrote, "Some day men will return to the moon. When they do, they are quite likely to need the knowledge, the techniques, and the machine described in this volume."





LFV

During 1964, space and lunar transportation engineers at Textron's Bell Aerosystems Company designed a versatile, rocket-propelled flying vehicle for transporting astronaut-scientists over the lunar surface. The device, called a Lunar Flying Vehicle (LFV), is intended for operation in the vacuum and under the reduced gravity in the lunar environment.

The design concept of the Bell LFV is the result of a study conducted for NASA's Marshall Space Flight Center, Huntsville, Ala.

The missions of the LFV are the return of astronaut-scientists to the Lunar Excursion Module (LEM), if a surface roving mobile laboratory (MOLAB) should be disabled and, to supplement the surface vehicle by permitting flight to areas which are inaccessible to a MOLAB.

The four-legged, 400-earth-pound LFV will be able to fly 50 miles non-stop. It is an open cockpit configuration, rectangular in shape, and is the size of an average desk. Astronauts equipped with backpack life support systems ride in the cockpit above the propulsion unit.

LEM propellants will be used for the five 100-pound thrust lift rockets, and the six 10-pound thrust rockets for attitude control.

Bell has designed and delivered a Lunar Landing Research Vehicle (LLRV) to NASA for training pilots in lunar landing techniques here on earth.

BELL AEROSYSTEMS
BUFFALO, NEW YORK A textron COMPANY

SPECIFICATIONS

DIMENSIONS:	
Open	92 x 92 x 67 inches
Folded	38 x 60 x 61 inches
PROPELLANTS:	
Fuel	50/50 Blend Hydrazine and Unsymmetrical Dimethylhydrazine (N_2H_4/UDMH)
Oxidizer	Nitrogen Tetroxide (N_2O_4)
WEIGHT:	
Dry Mass	Approx. 403 earth-lbs
Gross Mass	Approx. 1548 earth-lbs
RANGE:	50 miles
CREW:	Two Astronauts

LLRV/LLTV Safety Record (3 of 3 safe ejections)

204 LLRV Flights Made at FRC, No Accidents, 591 Flights Made at MSC, 3 Accidents

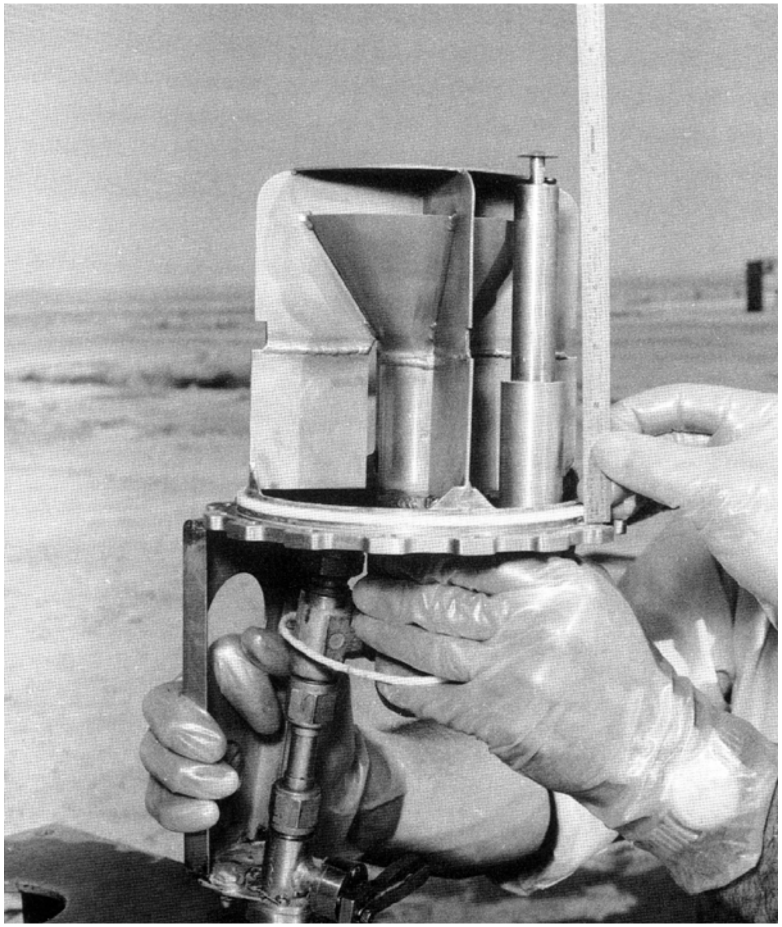
1. **LLRV #1, Neil Armstrong ejection**
   a) **Human error – lack of training certification of ground controller**
   b) **Improved training for pilots for in-flight procedures**
2. **LLTV #1, Joe Algranti ejection**
   a) **Human error --Wind limits stretched too high, wind shear not noticed**
   b) **Aerodynamics of new cockpit not defined adequately for all flight conditions**
3. **LLTV #2, Stu Present ejection**
   a) **In-flight equipment failure, backup failed due to product improvement with lack of failure mode analysis**

These and many other lessons learned applied in the future will decrease future risks significantly.


LLRV # 1
Neil Armstrong
May6,1968

LLRV #1, Neil Armstrong Ejection

H_2O_2 Tank Standpipe, Funnel top lowest level feed for lift rockets.



LLRV #1, Neil Armstrong Ejection

1. The LLRV operations at NASA FRC at Edwards ran the flights using TM data and nomographs to determine both jet fuel and rocket fuel remaining and did not depend on the fuel low warning lights in the cockpit. The flight controller would advise the pilot of approaching fuel low conditions as the primary mode, as the tank sensors were not regarded as that dependable under many flight conditions.
2. After the NASA MSC crew trained at Edwards, this operational philosophy was not engrained into the their operations at Ellington. Therefore, on Neil's flight, the rocket engineer's warning to the flight controller was not heeded, and Neil ran out of lift rocket fuel. The lift stick controlling the lift rocket fuel flow was inadvertently left up (no call from the flight controller) after the lift fuel ran out, causing the pressurant gas, helium, to vent through the lift rockets and consequently the loss of attitude rockets, as both the lift and attitude rocket systems shared the same tank and pressurizing systems.
3. There were a number of design recommendations made as result of the accident report, however they turned out not to be practical in view of the numerous trade-offs, so the rocket system remained the same, but flight operations procedures were improved for the flight controllers.

LLTV #1, Joe Algranti Ejection at about 95 Ft/Sec Sink Rate from less than 40 feet above the ground, just under a second before impact.

LLTV #3, To Langley Wind Tunnel

In December 1968, NASA pilot Joe Algranti was forced to eject from the LLTV No.1 during a test flight at Ellington Air Force Base. Three-tenths of a second later the training vehicle was a pile of smoking rubble on the ground as he parachuted to safety. During the ensuing investigation this hand controller was removed from the vehicle, and later retained for posterity. The photographs are of the LLTV in flight, rolling out of control, the pilot's ejection, and the ultimate crash and explosion of the vehicle.

LLTV #1, Joe Algranti Ejection

- This flight was the last checkout flight before Neil Armstrong was to start training the next day. The winds had shifted aloft, the winds aloft were not monitored, and the vehicle airspeed exceeded its aerodynamic envelope during a yaw right, which was later identified as a cockpit enclosure effect, losing control. The wind shear was obvious after the accident as the power plant north of the airport was sending a horizontal plume at the altitude Joe lost control.
- There was a significant increase in the allowable wind speeds for flight operations from FRC at Edwards to those used at MSC. MSC was notified of the great concern by FRC on this issue, however, significant schedule pressures and lagging operational readiness negatively impacting training schedules aggravated the situation.
- After wind tunnel testing and examination of the flight operations, a significant upgrading of the flight operations and expansion of the ground controller crews were made. An Air Force meteorological crew was added to better assess winds aloft before flights.

Lunar Landing Training Vehicle (LLTV) #2, Ejection, Stuart Present

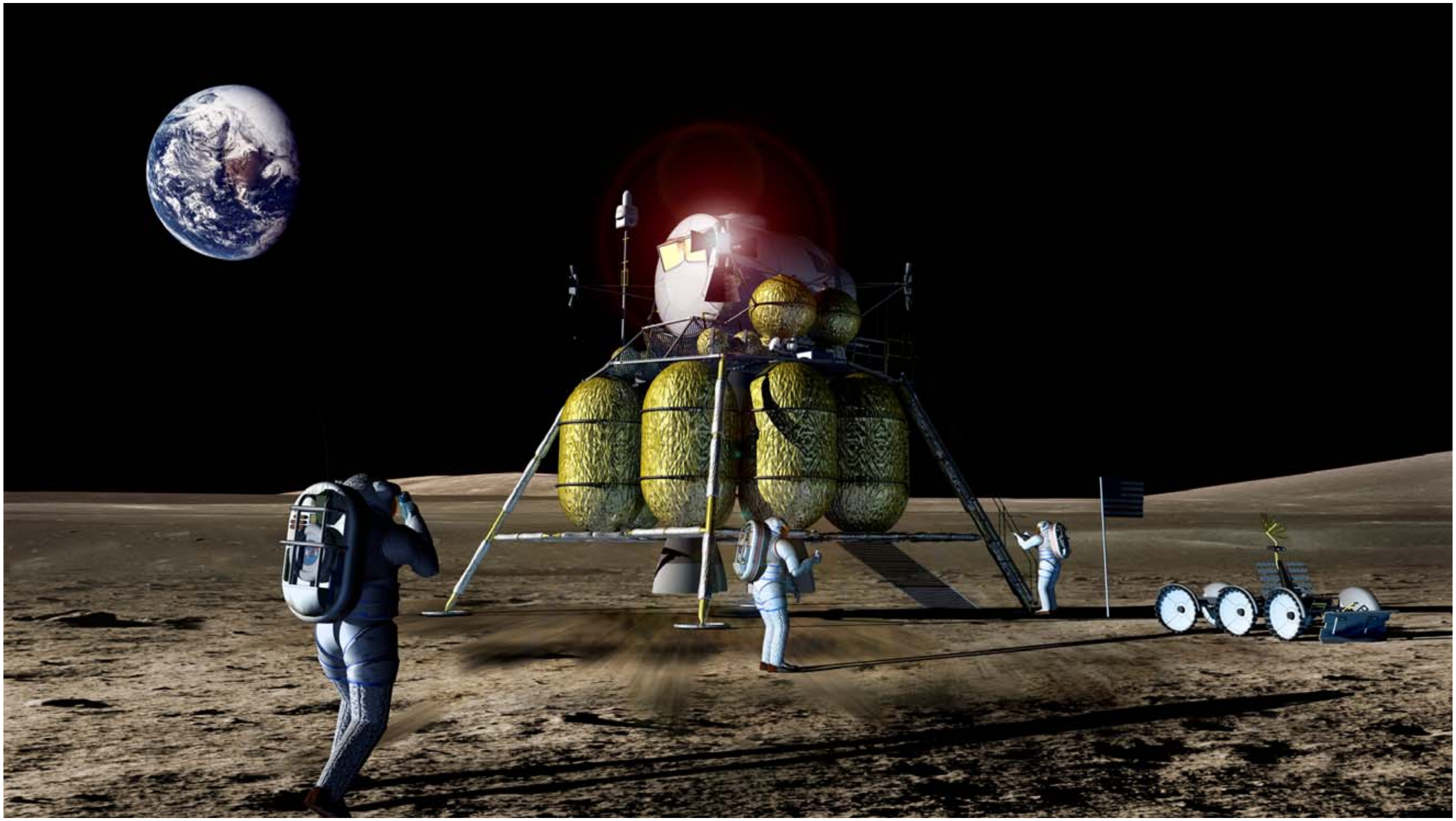
Lunar Landing Training Vehicle (LLTV) #2, Ejection, Stuart Present

1. DC generator was upgraded, had higher residual magnetic field in failure mode, was not identified. Failed in flight and the higher residual field prevented switchover to the emergency bus, lost attitude control as normal bus went down.

2. Pilot ejected, rocket flamed out jet engine, as jet engine lost RPM, residual magnetic field dropped, emergency bus switching circuit actuated, flight controls came back, vehicle crashed straight and level. TM data analyzed with relatively quick confirmation on cause of the crash.

3. Lesson Learned: Don’t buy upgrades when no record of failures have occurred and if you do, perform exhaustive tests for failure modes and effects before you fly.

Altair for 2019



The Machines Are Getting Much Larger

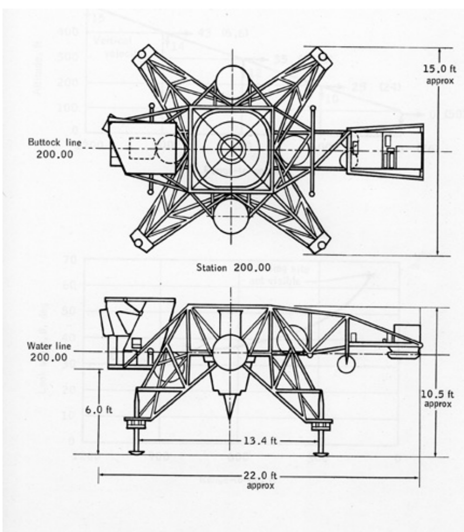


Figure 2-8.- Dimensional two-view sketch of LLRV.

Statistic	**LLRV/LLTV**	**LM**	**Altair**
Height	10 feet	20.9 feet	32 feet
Footprint	13 ft X 13 ft	29.75 ft X 29.75 ft	48.55 ft X 48.55 ft
Weight (on earth)	3,800 lbs	33,000 lbs	101,112 lbs

LLRV Ground Control Van, Overloaded with blocks to support springs

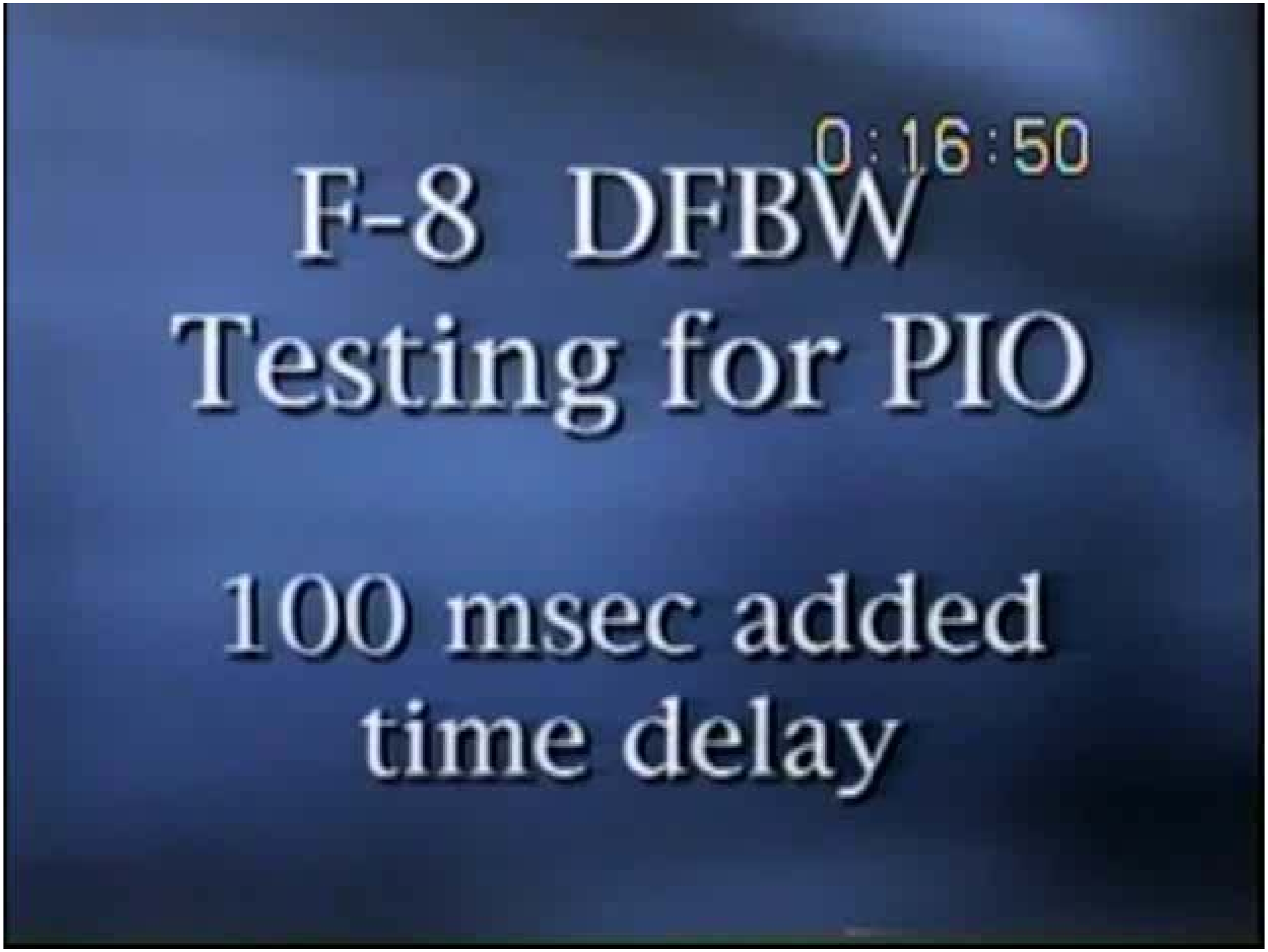
Inside of the LLRV Control Van, (2) Strip Chart recorders in back

NASA MSC LLTV Ground Control Van, came from White Sands

Inside NASA MSC LLTV Ground Control Van

Inside NASA MSC LLTV Ground Control Van


0:16:10
Enterprise Flight #5
to EAFB RW 04


0:16:50
F-8 DFBW
Testing for PIO
100 msec added
time delay

Flight Research Inputs for PIO's Not Detected by Simulators

- ALT FF5 PIO not predicted or seen in any simulation. Roll PIO was more straightforward to fix--had to do with pitch-roll priority for elevons. Pitch PIO was a complex combination of poor pitch attitude reference out the window, pilot location near instantaneous center of rotation, initial reversal of g with large delta wing, and transport time delay.
- Never duplicated in fixed or moving base simulation. Calspan TIFS did the best, with some overcontrol indications, but even there, evaluation pilot gains did not up as high, because they were well aware the safety pilot could knock it off at any time.
- In F-8, 100 msec of pure time delay case is shown in the video.
- Note, wing is down and speeds matched orbiter approach speeds. Gear doors taken off to allow high speed approaches gear down. Stick button immediately took out added time delay
- Three pilots made approaches with this configuration (after build-up flight tests).
- 1. Pilot A waved off at low altitude and rated it 10.
- 2. Pilot B got airplane in the "slot" and did a no-flare open loop landing, thus not "getting in the loop." In a sense, he gave up on the task, but because the airplane at an acceptable glide path, be completed the landing.
- 3. Pilot C stayed in the loop all the way to touchdown (with high workload). Because the nose wheel tire speed was lower than touchdown speed, pilots had to hold it off, but not get nose too high, or you would scrape the tailpipe. This is a high gain task and pilot got into PIO on the go-around. The FCS downmoded to the unaugmented mode in pitch due to abrupt interaction with runway. On second peak, Pilot switched off time delay. On third peak, Pilot upmoded to SAS.
- The 100 msec pure time delay was the "cliff" for CAS and unaugmented mode. This PIO could not be duplicated on F-8 iron bird fixed base simulator, even with larger time delays.
- (P.S. Ultimate fix for orbiter was a Dryden "PIO Suppression Filter" which reduced pilot gain in incipient PIO)