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The Biggest Myth about the First Moon Landing

Paul Fjeld, Space Artist

Also, Continuing in this Issue! Part 6 of 8:
Man Will Conquer Space Soon!
(Collier's 1952-54)

The Biggest Myth about the First Moon Landing

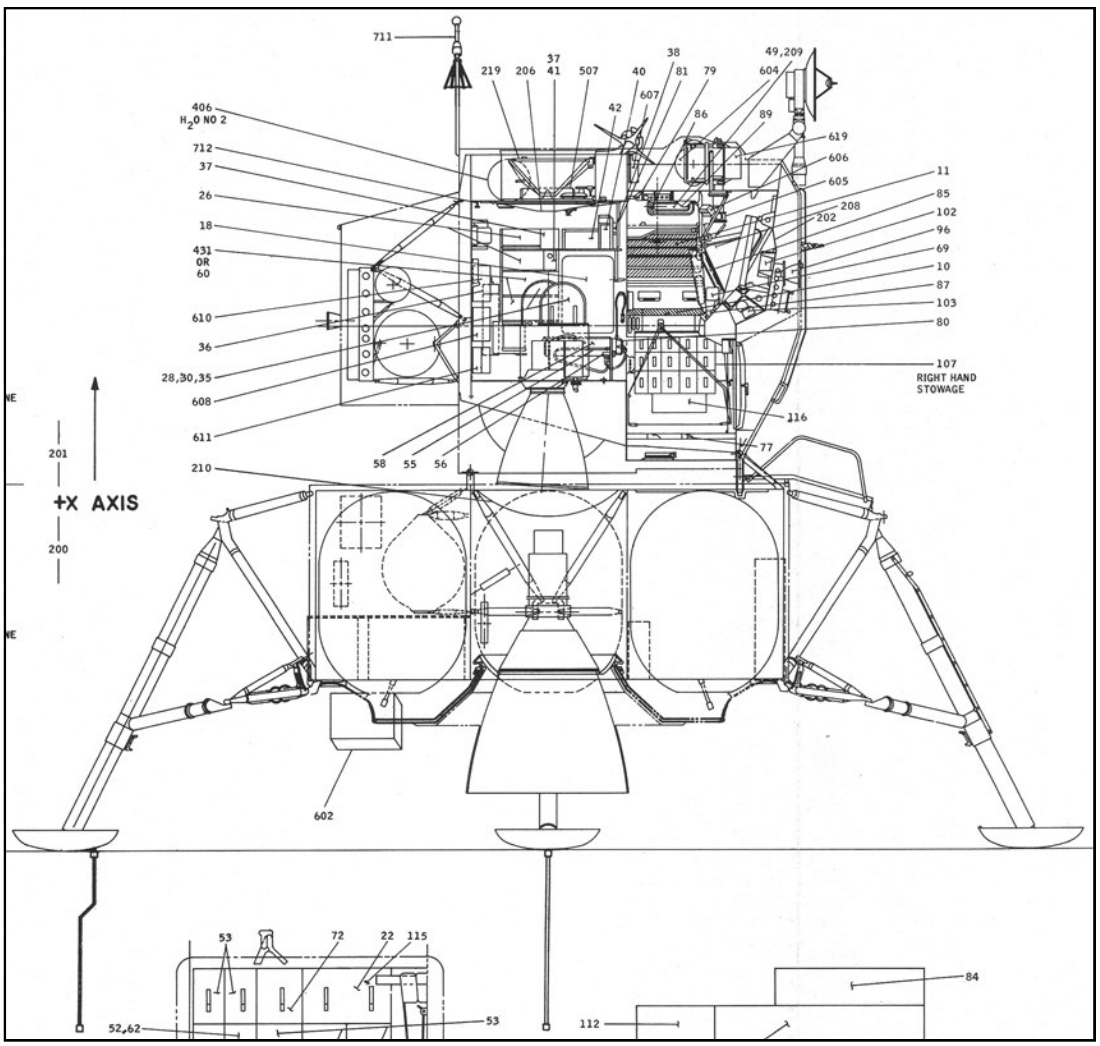
Cover Story

PAUL FJELD, SPACE ARTIST

We all know the Apollo 11 story. Many of us were "there." If you're older than 44 years, you were watching TV that summer of '69, even if you were a baby, though babies didn't understand what all the fuss was about. Neil Armstrong was guiding himself and his crewmate, Buzz Aldrin, in that odd creation of the early space program, Eagle, the Lunar Module (LM), nearer and nearer to the Moon's surface. It was very exciting to listen. Aldrin was calling out numbers relating to where they were and how fast they were going as they worked to make that final first touch by humanity on a celestial object. The other voice was that of Houston (NASA Mission Control), CAPCOM (capsule communicator) Charlie Duke, mostly saying that things were going okay, but, at the end, doing a countdown. "Sixty seconds." Then, "Thirty seconds!" Finally we heard, "Contact light!"

Ever since then the story headline has been, "The dramatic first Moon landing of Apollo 11 succeeded with only twenty seconds of fuel remaining!"

No! The biggest myth about the first Moon landing is those twenty seconds. Armstrong and Aldrin could have stopped their approach a few feet above the lunar surface and stayed there for more than a minute before letting Eagle drop safely to the surface.



Above: Side profile showing the Lunar Module Ascent and Descent Stages with the Descent Propellant Tanks surrounding the main engine. For complete drawing set go to: *http://www.ibiblio.org/apollo/Documents/LM_Structures/*

The countdown that Charlie Duke was radioing to the crew was actually to a "bingo" point, a modified version of a call that many pilots on combat missions have heard, "Turn back now or you won't have enough fuel to get home!" The Lunar Module had two options worth thinking about during its descent, a touchdown and an abort. Its main propulsion system was a 9,700-pound-thrust throttleable engine. During final descent, it needed to put out about 2,600 pounds of thrust, 25% of its design maximum of 10,500 pounds of thrust, to hover the LM in its half empty state under lunar gravity. If that descent engine suddenly quit, Armstrong would punch an "Abort Stage" button, initiating a sequence that would cut loose the descent stage from the ascent stage, where the crew lived, and ignite the ascent engine.

This abort was a tricky thing. It would take a couple of seconds for the sequence to complete, and all the while the Moon would be pulling them down closer to a potential crash landing. If for some reason they knew they had to abort, the best way would be to burn full throttle on the big descent engine until it ran out of propellant, then separate from it and ignite the smaller 3,500-pound-thrust ascent engine. If, during a landing, they were in trouble and got near the point where the descent engine would be starved of fuel, the mission planners saved five seconds of descent engine burn time at full throttle to loft them to a safer alti-

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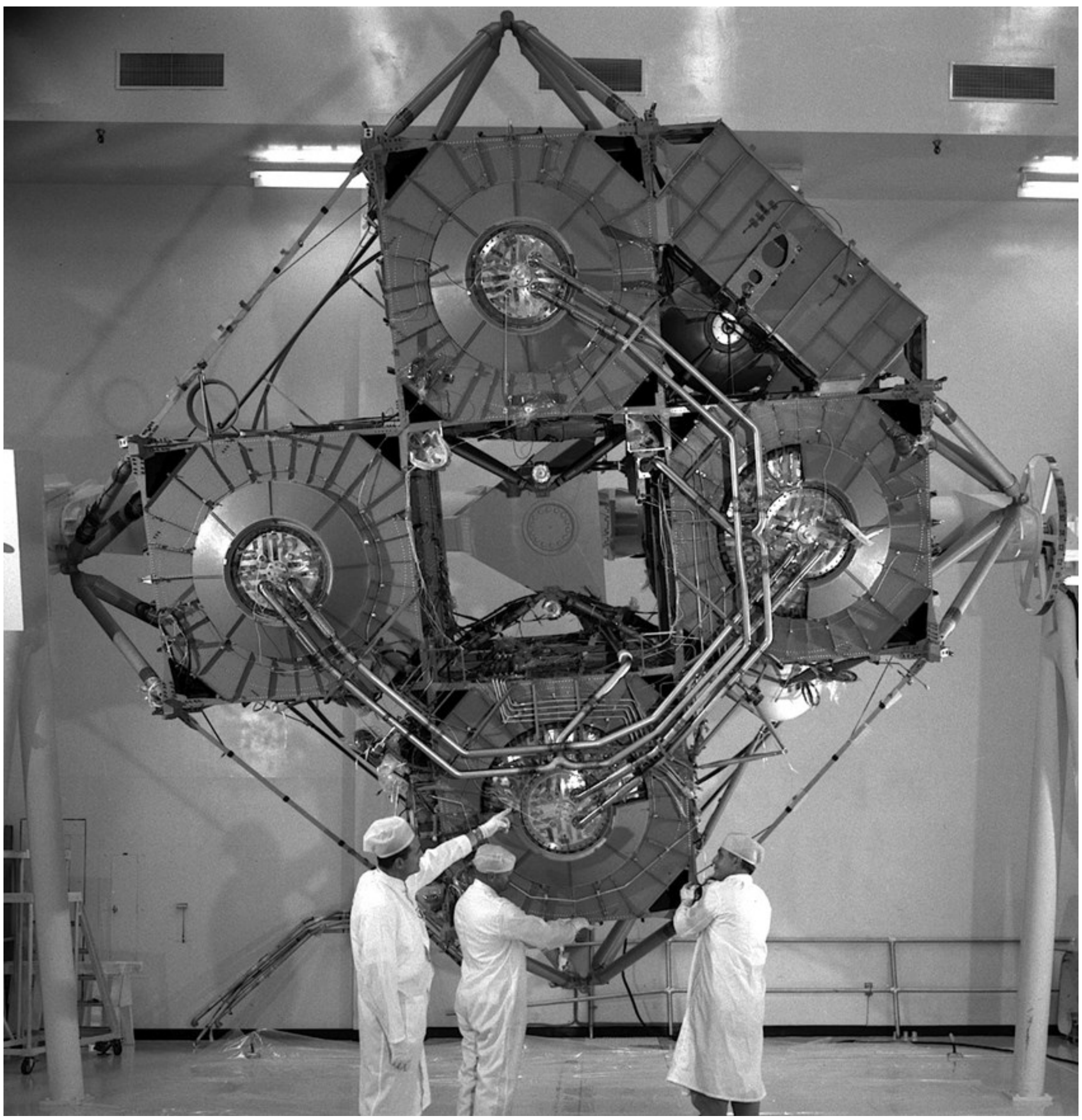
tude. During those five seconds, they would have time for staging, pressurizing of the ascent tanks, and ignition of the ascent engine.

Five seconds of thrust at full throttle corresponds to twenty seconds of thrust at 25% of full throttle. This is why the bingo call was actually a "Land in twenty seconds or abort now!" decision point. For example, if Armstrong had been flying when Duke's countdown reached zero and Armstrong was still 60 feet above the lunar surface, but coming down smoothly with a three-feet-per-second velocity to a safe spot, his decision would definitely have been to continue with the landing.

That adds another twenty seconds to the mythical twenty seconds, getting us to forty seconds of flight time left at landing. The remaining part of that "more than a minute" is a tale of slosh in the propellant tanks.

When Grumman engineers designed the LM propellant storage, they settled on four domed cylindrical tanks mounted in the descent stage's cruciform structure (cross-shaped as seen from above), two tanks for the oxidizer (one in front and one in back) and two tanks for the fuel (one on the left side and one on the right side). Each tank was identical. Propellant in a tank is excited by sharp movement or rhythmical pulses. The propellant can swirl, rock or even plunge up and down relative to the bottom exit. This was understood at the beginning of the Apollo program. Grumman built a plexiglass half-tank to study these motions. After eight months of testing in 1965, Grumman decided that a small anti-vortex baffle surrounding a zero-g can, where the propellant was pushed into the engine feed lines, would be sufficient to keep the fluid from sloshing about too much.



Above: Descent Stage cruciform structure mounted in a rotate and clean facility at Grumman plant. Four propellant tanks surround a central opening where the Descent Engine will be installed. Note the feed and balance lines leading to a single Oxidizer line (upper) and Fuel line (lower) in the center. (Courtesy Northrop Grumman History Center)

A propellant quantity measuring gauge was bolted to the bottom of each tank near the feed port. It sensed how much remained in the tank and would latch a low-propellant-level light in the cockpit when there was 5.6% of the propellant left. For the first Apollo Moon landing, as Armstrong maneuvered past a boulder field, the low-propellant-level light was latched to the on position well before touchdown. Flight controllers had expected the fuel gauge's low-propellant-level light to turn on at about the time of touchdown. That's what happened during the training runs.

For this first Moon landing, Armstrong flew the Eagle LM for more than a minute past a nominal (as designed) descent trajectory. But there is more to this part of the story. When Armstrong made some vigorous control inputs during the final landing phase, fuel slosh uncovered the DES 2 (Descent #2) tank gauge. Well after the flight, engineers concluded the low-propellant-level light was turned on between 30 to 45 seconds early!

So we now know that Armstrong had at least 20 + 20 + 30 = 70 seconds of flight time

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Above: Lunar Module Eagle moments after the left-hand probe contacts the moon's surface (shown on right) still nearly five feet up, its engine blasting a dust sheet in all directions. The spacecraft attitude is shown four seconds before final touchdown as Neil Armstrong has arrested a leftward drift (north) but overcorrected so the LM is here beginning to slide to the right (south) in the picture. Original acrylic painting by Paul Fjeld.

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remaining (even though the LM crew and Houston could only count on 40 of them) before he would have crashed into the Moon in an Eagle LM starved of vital fuel.

The Apollo 11 Moon landing was nonetheless very dramatic for many reasons, including:

- When the Eagle LM separated from its mothership Columbia and spent an orbit preparing for the landing, a combination of single jet maneuvering (uncoupled firing) and un-modeled lunar mass concentrations (mascons) put the LM slightly off of its expected orbit plane. When Houston controllers put a measured velocity into Eagle's computer without updating Eagle's position, it approached an abort boundary early.
- Later, a poor interface between how the primary and abort guidance systems reported some unneeded radar pointing angles caused the Eagle LM guidance computer to waste more than ten percent of its cycles and overload five times.
- As Armstrong began the final landing in earnest, his maneuvering was “flinging” the Inertial Measurement Unit (IMU) fore and aft about the center of mass of the LM, causing the guidance computer to calculate a wildly fluctuating throttle command for a fictitious drop or rise of the spacecraft. This “IMU bob” was the first indication of a serious instability in the throttle control logic of the LM’s computer.
- This instability was exacerbated by a bad constant number the computer used for the lag between when it issued a throttle command and when it expected the command to be realized by a certain thrust. The computer’s lag value was 0.2 second when the real lag was only 0.075 second. It's quite possible that the computer would have commanded full throttle at some point, wrecking the landing and causing an abort, if Armstrong had been flying

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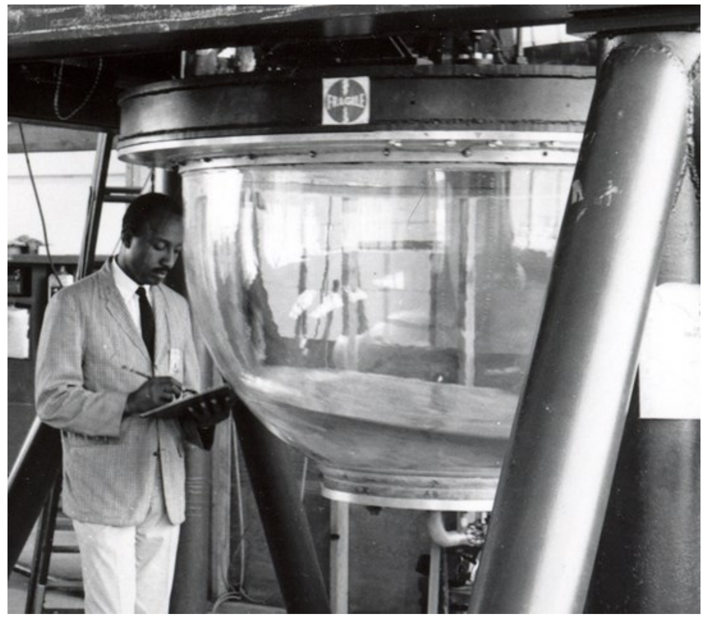
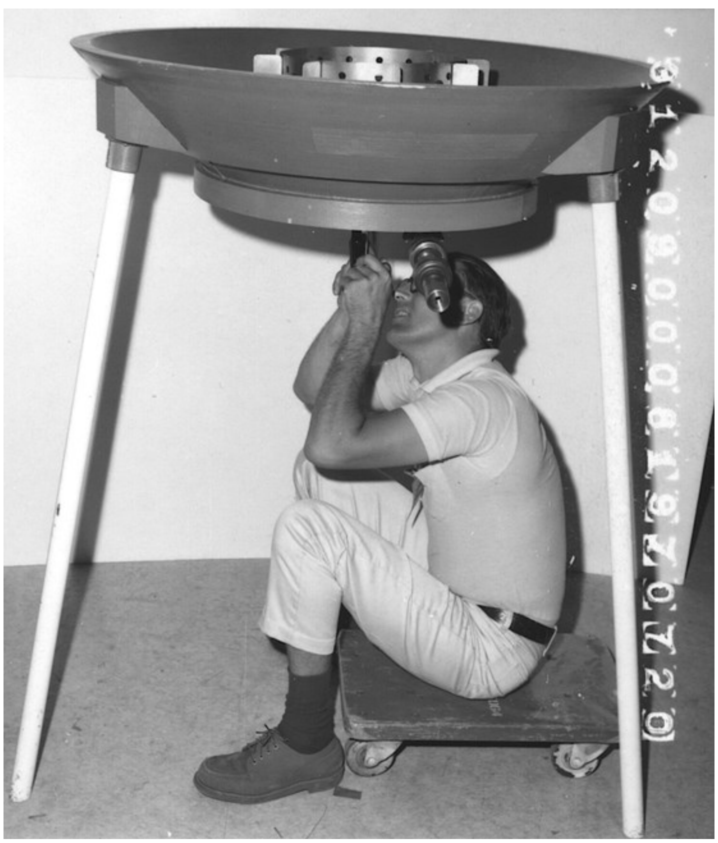


Above: Plexiglas slosh rig at Grumman, 1965. Results from these tests led to the small anti-vortex baffle which was insufficient to cope with propellant slosh. (Courtesy Northrop Grumman History Center)



Above: Technician demonstrating “ship in a bottle” installation of a slosh baffle in a tank mockup at Grumman, Bethpage NY on August 19, 1970. (Courtesy Northrop Grumman History Center)

Above: Technicians demonstrating the baffle install technique on a LM Test Article at White Sands, New Mexico. Note the small 2.4 inch diameter hole where the Propellant Quantity Gauge is bolted to the bottom of the tank. (Courtesy Northrop Grumman History Center)

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more erratically than what he admitted to.

- Armstrong was confused by the dust streaming away from the descent engine's plume slamming into the Moon, which made it difficult to judge his real speed relative to the surface. He ruefully called his control just before touchdown "spastic," overcorrecting for a right drift and landing with a velocity of two feet per second going left. His LM had also drifted in yaw, turning slightly more towards the Sun, putting the shadow of Eagle to the right of his window, depriving him of a useful guide to his final seconds before landing.

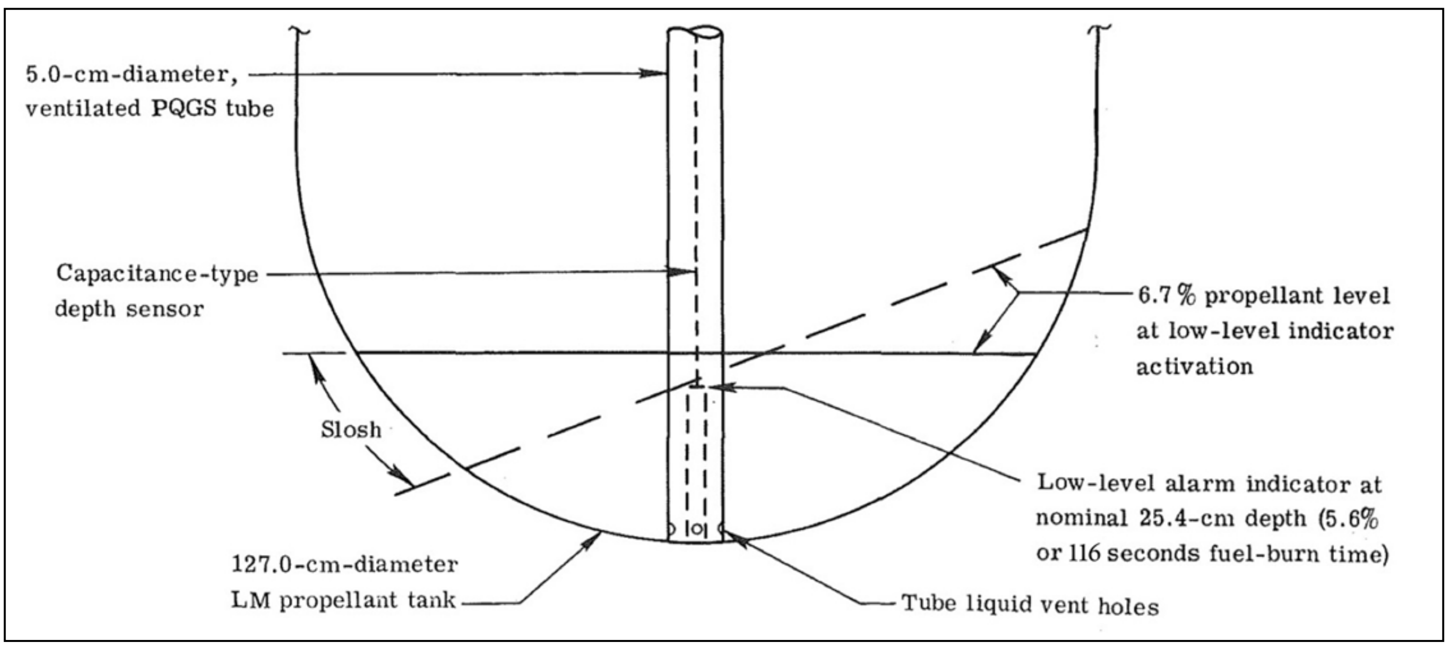
There is plenty of drama in the real story of Apollo 11. The fact that Neil Armstrong landed Eagle with more than a minute (much more than twenty seconds) of fuel remaining does not diminish the thrill of the accomplishment.

Lunar Module Propellant Slosh after Apollo 11

The loss of half a minute of flight time due to slosh was important. NASA engineers had planned for some contingencies in the delta-V (change in velocity) budget for the LM, but the weight of the spacecraft was so critical that nothing could be wasted. On the next flight after Apollo 11, Pete Conrad and Alan Bean landed their Apollo 12 LM, but the low level light was turned on early again. Apollo 13 went to the Moon with its LM propellant tanks wired for high-rate telemetry that would characterize the slosh dynamics, but the moon landing never happened. (Apollo 13 astronauts Jim Lovell and Fred Haise were even more disappointed than the propellant tank engineers.)

By that time, Grumman and Langley Research Center engineers had done more exhaustive tests than those done with a plexiglass slosh rig five years earlier. They came up with a design for baffles that they believed would work, but now they faced the remarkable problem of how to get that design into the already-built tanks for the next LM to fly. The final three LMs (for Apollo 15, 16 and 17 missions) were to have their tanks expanded for extended-stay flights, so baffles could be installed when the tanks were cut open, but the Apollo 14 LM needed a special solution.

In August of 1970, Grumman technicians demonstrated a way to build a 17-inch-diameter, 8-inch-high multi-finned baffle through the hole where the propellant quantity gauge was bolted and secure it to the base of the tank. The hole was 2.4 inches in diameter! NASA program managers were impressed after witnessing this clever design and careful work. It was like building a ship in a bottle. Grumman installed the baffle in a flight configuration LM at their test site in White Sands, New Mexico, before committing to installing it in the next LM in the NASA Kennedy Space Center clean room. When Apollo 14 flew with Alan Shepard commanding, his LM Pilot Ed Mitchell remarked on how smooth their descent was with very little thruster firing needed to counter any wayward torque. They landed with no loss of nominal flight time.



Above: Schematic showing a slosh wave uncovering a low light sensor in the Propellant Quantity Gauge System indicating 5.6% remaining instead of 6.7%. (From: NASA TM X-2362: "Investigation of Slosh Anomaly in Apollo Lunar Module Propellant Gage")

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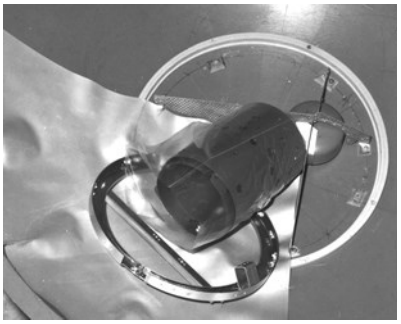
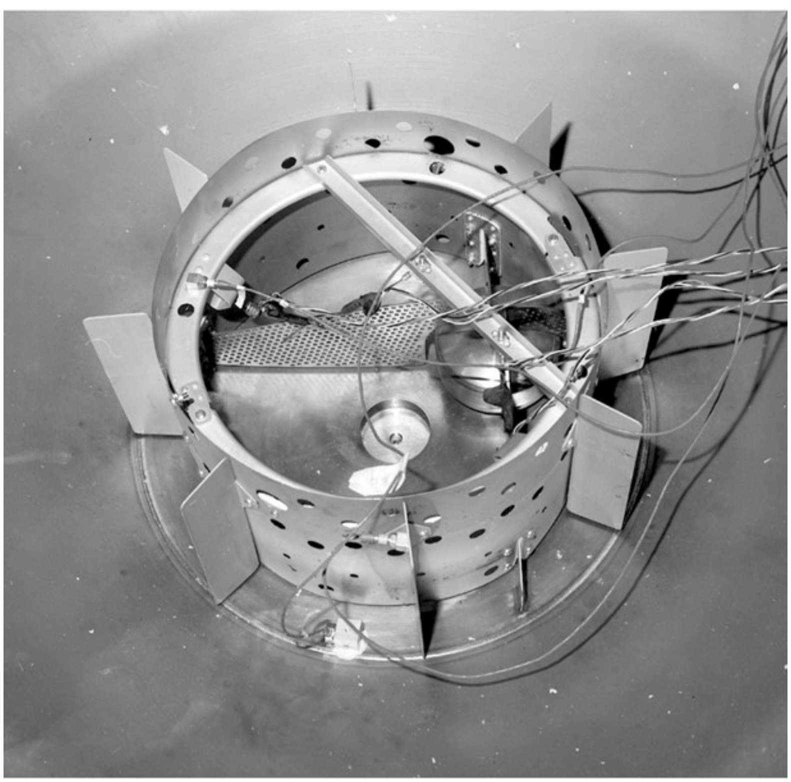


Above: Slosh baffle halfway installed in a Grumman tank mockup. The thin wall of the cylindrical baffle structure permitted it to be rolled up and inserted through the 2.4-inch diameter hole at the base of the tank. Note the small zero-g can and perforated anti-vortex baffle which was part of the original design. (Courtesy Northrop Grumman History Center)

Above: Author Paul Fjeld in 2001 trying out the KSC Lunar Module Simulator, now displayed at the Cradle of Aviation Museum, East Garden City, New York. Fjeld was the LM-13 spacecraft exhibit manager there. He was also the last NASA Artist of the Apollo program. He is currently working on a series of paintings showing the drama of the early US manned space program from Mercury to Apollo. Image: J. Randy Attwood.

Above: The author Paul Fjeld in front of the Lunar Module #13 display at the Cradle of Aviation Museum in East Garden City, New York. Fjeld was the spacecraft manager for the exhibit. Image credit: Alan Contessa.



Above: 17-inch diameter flight baffle installed in LM-10 (for Apollo 15) before the propellant tank was enlarged and re-welded. (Courtesy Northrop Grumman History Center)

Above: Neil Armstrong in the NASA KSC (Cape Canaveral) Lunar Module (LM) simulator in June of 1969. Image credit: NASA.