NASA Dryden Flight Research Center • P.O. Box 273 • Edwards, CA. 93523 • Voice 661-276-3449 • FAX 661-276-3566 • technology@dfrc.nasa.gov

TF-2004-08 DFRC

Lunar Landing Research Vehicle

Contributions to the nation's early space program by NASA's Dryden Flight Research Center can be measured in several engineering disciplines, but none are as significant as the two Lunar Landing Research Vehicles (LLRV) created and flown by the Center in the 1960s.

The spider-like LLRVs were used to develop control and landing techniques needed by Apollo astronauts to safely land lunar modules (LM) on the moon where there is no air to support a winged vehicle, and where gravity is only one-sixth that of Earth.

Dryden's two LLRVs were prototypes for a pair of Lunar Landing Training Vehicles (LLTVs) flown by Apollo astronauts at the Manned Spacecraft Center (later renamed the Johnson Space Center) in Houston, Tex.

A Lunar Landing Research Vehicle is maneuvered during a test flight in 1964.
NASA Photo ECN 506

The Dryden LLRVs were first thought of as tools to be used exclusively for research. After amassing many hours of successful test flying in California, they became full-fledged training vehicles at the Manned Spacecraft Center for the teams of Apollo astronauts who would make the journey to the moon's surface.

Neil Armstrong, the first human to walk on the moon and a NASA research pilot at Dryden before he became an astronaut, said the LLRVs did "an excellent job of actually capturing the handling characteristics of the lunar module in the landing maneuver."

Donald "Deke" Slayton, who headed the NASA astronaut office during the early Apollo days, also praised the LLRVs. He said there was "no other way to simulate moon landings except by flying the LLRV."

The basic idea of the LLRVs was to give pilots a platform that simulated the descent profile of the lunar module as it approached the moon's surface. A gimbaled jet engine with the exhaust nozzle facing the ground supported 5/6ths of the LLRV's weight to compensate for the moon's weaker gravitational force. Small rockets supported the remaining 1/6th of the vehicle's weight and provided controlled ascent, descent, and horizontal movements. A system of 16 attitude thrusters (reaction controls) mounted in pairs around the open-framed LLRV gave pilots roll, pitch, and yaw control. An electronic fly-by-wire flight control system linked to a control stick was originally used for pitch and roll control, while rudder pedals provided yaw control. The controls were later incorporated into a single three-axis side-arm controller similar to the actual LM.

The precise fly-by-wire system simulated the motions and control system response Apollo astronauts would later face while nearing the moon's surface in the LMs.

Development of the LLRVs

President John F. Kennedy triggered an unprecedented wave of activity throughout NASA on May 25, 1961, when he challenged America to send humans to the moon and safely return them to Earth by the end of that decade. Although the first suborbital Mercury flight had just been carried out, the only activity at that time directed towards missions to the moon were internal NASA studies. Now, with the President's historic announcement during a joint session of Congress, NASA had the budget and national backing for the largest scientific commitment in history. Suddenly, many technical issues loomed.

In the airless environment of the moon, wings, propellers, and other aerodynamic features could not be used on a lunar landing vehicle. All movement -- pitch, yaw, roll, plus descent and ascent -- would have to come from a complex propulsion system that could be safely operated where the pull of gravity is just one-sixth that of Earth. By the end of 1962, Grumman Aircraft Corporation had been selected to build the four-legged LMs, but NASA knew that astronauts would need some type of trainer to learn how to operate the LM, a machine designed for the true vacuum of space.

Three training methods had already been looked at when the Presidential announcement was made, and NASA quickly took a conservative approach and implemented all three. One would be an electronic simulator at the Manned Spacecraft Center in Houston, Tex. Another would be a tethered test unit in a large gantry at the NASA Langley Research Center, Hampton, VA. The third would be a free-flight vehicle developed from an idea offered by Dryden engineer Hubert "Jake" Drake -- the Lunar Landing Research Vehicles.

Similar vehicles had been developed years before to test the concept of vertical takeoff and landing aircraft (propulsive lift), but nothing had been developed for the airless environment of spaceflight. One company with extensive experience in the propulsive lift field was Bell Aerosystems Company (formerly Bell Aircraft Corp.) and engineers there had begun looking into the concept of a free-flight simulator concept for the Apollo program. Because of its early studies, the company received a $50,000 NASA contract in December 1961 for a conceptual study of the proposed vehicles. After reviewing study results, NASA awarded Bell a $3.6 million production contract on Feb. 1, 1963, for two LLRVs.

The contract required the vehicles to takeoff and land on their own power, reach an altitude of 4000 feet, hover, move horizontally, and remain off the ground 14 minutes. The first vehicle was to be delivered to Dryden within 14 months to begin the lunar landing flight research program.

Each vehicle was equipped with a zero-zero pilot ejection seat, meaning that a safe ejection with a parachute was possible at any speed and any altitude.

Flying Bedsteads

Both LLRVs -- often referred to as "Flying Bedsteads" -- arrived at Dryden from the Bell factory in April 1964. Vehicle No. 1 became the program's workhorse and installation of instrumentation soon began to prepare the machine for its first powered trials on a ground-mounted tilt-table the following September. The tests were successful and set the stage for the first free flight on Oct. 30, 1964.

The South Base area of Edwards AFB, where the historic XS-1 program had been located, was the setting when NASA research pilot Joe Walker flew the ungainly LLRV off the ground for the first time. Walker, following the traditional stepping-stone approach, flew the machine three times that day, reaching a height of 10 feet while staying aloft a total of just under one minute. But Walker reported that the awkward-looking machine flew as expected and described its vertical ascent as "just like going up in an elevator."

NASA research pilot Joe Walker, in the cockpit of a Lunar Landing Research Vehicle, prepares for a test flight in 1964.
NASA Photo ECN 453

Others witnessing the event said the LLRV sounded like a broken calliope as the hydrogen peroxide reaction control system hissed loudly while competing with a screaming turbojet that furnished anti-gravitation power.

Don Mallick, a NASA research pilot who transferred to Dryden from Langley, and later by U.S. Army pilot Jack Kleuver, soon joined Walker in the LLRV program. In less than two years, 175 flights had been logged by LLRV No. 1 and successfully demonstrated that a free-flight vehicle could safely simulate lunar descent conditions and could be used as a training vehicle.

After assessing LLRV flight data and recommendations from Dryden and the Manned Spacecraft Center, NASA Headquarters ordered three Lunar Landing Training Vehicles (LLTVs) from Bell in mid-1966. Bearing new names, the

LLTVs were nearly identical to the Dryden vehicles except for a few minor improvements to more closely match the LMs. The new vehicles were designated LLTV B1, B2, and B3 and cost $2.5 million each. Manned Spacecraft Center pilots who had already accumulated experience in the LLRVs at Dryden made initial flights with each vehicle.

Meanwhile, to make the Dryden LLRVs more comparable with the real Apollo lunar modules, controls for the reaction control systems were incorporated into a single three-axis side arm controller and the control panels were also relocated from the center of the pilot stations to the right sides. Later, the cockpits were enclosed and the window visibility was restricted to match the LMs.

At the end of 1966, NASA centralized its lunar landing training program at the Manned Spacecraft Center and LLRV No. 1 was shipped to Texas on Dec. 12.

The first free flight of LLRV No. 2 was made at Dryden in January 1967 with Kleuver in the cockpit. It flew at Dryden five more times and then joined its sister ship, LLRV No. 1, in Texas where both received modifications in controls and cockpit configuration to match the three newer LLTVs. At that point, Dryden's two LLRVs were redesignated LLTV A1 and A2.

From Research to Training

All Apollo mission commanders and their backups flew many hours in the LLTVs before their Apollo flights. Their lunar landing training also included a three-week helicopter flight school, training on the tethered lunar landing simulator at Langley, and practice on the electronic ground simulator at the Manned Spacecraft Center.

Nearly all of the Apollo astronauts offered high praise for the experience -- and confidence -- they gained from their LLTV flight time.

As they gained this experience, the astronauts -- and also the instructor pilots -- learned to respect and be watchful of the complicated training machines. Out of the fleet of five, only two remain: LLTV A2, the No. 2 vehicle from Dryden, and LLTV B3. The other three were lost in training accidents, but fortunately all of the pilots ejected safely and uninjured.

The most celebrated ejection was by Apollo 11 astronaut Neil Armstrong. On May 6, 1968, Armstrong was about 30 feet off the ground in LLTV A1 -- the No. 1 vehicle from Dryden -- when helium pressure in the propellant tanks failed and caused the attitude control system to quit. As the vehicle began pitching up and rolling, Armstrong ejected. The trainer fell to the ground and exploded.

Seven months later, a Manned Spacecraft Center pilot, Joe Algranti, was flying LLTV B1 when gusty winds threw it out of control and he had to eject just seconds before it hit the ground.

The last accident was on Jan. 29, 1971, when LLTV B2 was hit by an electrical system failure that knocked out the attitude control system. Instructor pilot Stu Present ejected while the vehicle crashed to the ground.

The final flight in the LLTV program was on Nov. 13, 1972. The pilot was astronaut Eugene Cernan, who was wrapping up pre-launch training for the Apollo 17 flight that was carried out just one month later. It was the final Apollo mission to the moon.

The LLRV Legacy

The staff at Dryden still looks at the LLRV development and research program as an excellent example of how individuals working in an aerodynamic environment can add a large measure of success to a spaceflight project through mutual cooperation and a complete understanding of differing engineering disciplines.

The worth of the LLRV-LLTV program was realized during the final moments before Apollo 11 astronauts Neil Armstrong and Edwin "Buzz" Aldrin completed the first moon landing in the LM named Eagle. As the two men were getting close to the moon's surface, Armstrong saw they were nearing a rocky area. He disregarded the LM's automatic landing system and switched to manual control during the last moments of descent. Armstrong landed the LM on a safer, more suitable spot and was able to report, "Houston, Tranquility Base here...the Eagle has landed."

Armstrong later said his practice flights in the LLTVs gave him the confidence to override the automatic flight control system and control Eagle manually during that epic Apollo 11 mission.

LLTV A1, one of the two original research vehicles, was returned to Dryden where visitors can see it. LLTV B3, the last of the three training vehicles built, is on public display at the Johnson Space Center, Houston, Tex.

The Vehicles

LLRVs were aluminum triangular-shaped frames with four truss-style legs. A pilot platform extended forward between two legs and an electronics platform extended rearward between the two opposite legs.

A turbofan jet engine was mounted vertically in a gimbal ring at the center of the vehicle. During lunar landing simulations, gyros keep the jet engine vertical regardless of the attitude of the vehicle itself. Because the moon's gravity is only 1/6th as strong as Earth's, the engine's thrust supported 5/6ths of the vehicle's weight.

Two hydrogen peroxide lift rockets were mounted on the main frame. They supported the remaining 1/6th of the vehicle's weight, powered the vehicle during ascent and descent, and also gave it horizontal movement. The lift rocket system also had six emergency units. The main rockets always operated as a pair to eliminate uneven thrust. The combined functions of the jet engine and lift rockets simulated the moon's gravitational environment.

The attitude of the vehicle -- pitch, roll, yaw -- was controlled by a system of 16 small hydrogen peroxide thrusters linked to the pilot station through an electronic flight control system.

High-pressure helium, contained in tanks mounted on the vehicle frame, pressurized the hydrogen peroxide propellant systems for the lift rockets and the attitude control system.

The cockpit was about 6 feet above the ground and originally was open on the front, top, and back. Modifications were made later to give the pilot the same basic visibility as the actual lunar module. A control stick was used for pitch and roll control and pedals for yaw control. Instruments displayed on a small control panel included a three-axis ball, and horizontal, vertical, and side velocity indicators linked to an on-board radar unit. Instruments to monitor jet engine operations were also included on the panel.

A simple instrumentation system transmitted engine operation, attitude, and velocity data to a ground receiver station to monitor in-flight operations and to be studied later as the test and research program progressed.

The design and operation of the vehicles dictated that pilot safety was critical during all phases of flight. A pilot ejection system provided ground-level ejection capability. If either of the two main propulsion systems failed, the pilot had control and thrust capability of landing the vehicle manually on the remaining propulsion system.

Description

Main Engine: General Electric CF700-2V Turbojet, rated at 4,200 lbs thrust

Lift Rockets: Hydrogen peroxide fuel, with thrust range between 100-500 lbs

Attitude Control Thrusters: Hydrogen peroxide fuel, with thrust range between 18-90 lbs

Overall Length: 22.5 ft

Overall Width: 15 ft

Overall Tread: 13.3 ft

Overall Height, with footpads attached and struts extended: 10 ft

Maximum Takeoff Weight: 3,702 lbs

Useful Load: 1,192

A Lunar Landing Research Vehicle is flown high over the South Base area of Edwards AFB during a test flight in 1965.

NASA Photo ECN 688