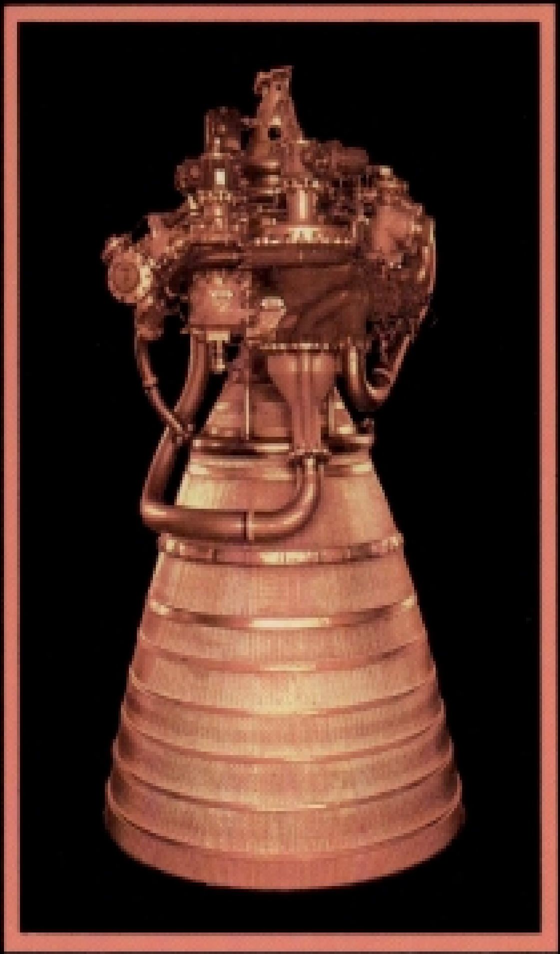


RL10 Rocket Engine

A National Historic Mechanical Engineering Landmark

The RL10 World's First Liquid Hydrogen-Fueled Rocket Engine

The Pratt & Whitney Aircraft RL10, powerplant for the National Aeronautics and Space Administration/General Dynamics upper-stage Centaur space launch vehicle, was the first rocket engine in the world to use high-energy liquid hydrogen as a fuel. It was the technological pathfinder in hydrogen rocketry and led to the development of larger engines that made possible man's greatest engineering achievement, the lunar landing in July 1969.

Design of the RL10, originally an Air Force powerplant designated XLR115, began in the fall of 1958 at the Pratt & Whitney Aircraft Florida Research and Development Center (now the Government Products Division) in Palm Beach County. A number of difficult technical problems had to be solved, not the least of which was that liquid hydrogen boils at minus 423 degrees Fahrenheit. Yet the first engine firing was conducted on a test stand less than a year later.

While the RL10 resembles most other liquid-fueled rocket engines outwardly, internally it embodies numerous advanced design features, including the method by which it achieves multiple utilization of its fuel. Liquid hydrogen performs two important functions before it is mixed with liquid oxygen and burned to produce thrust. First, it acts as a coolant by passing through a series of tubes that form the thrust chamber where the combustion temperature is over 5,000 degrees during engine operation. In its second role, the hydrogen, which has been heated as a result of cooling the chamber, is expanded through a turbine to provide power to pump both propellants into the system and to drive engine-mounted accessories. The RL10's mode of operation is called the "bootstrap cycle" because, once the propellant valves are opened, the engine accelerates itself and its operation is self-sustaining. The RL10 is capable of multiple restarts in space. In fact, the engine was started seven times in one mission. The engine has also been throttled to less than 10 percent of rated thrust.

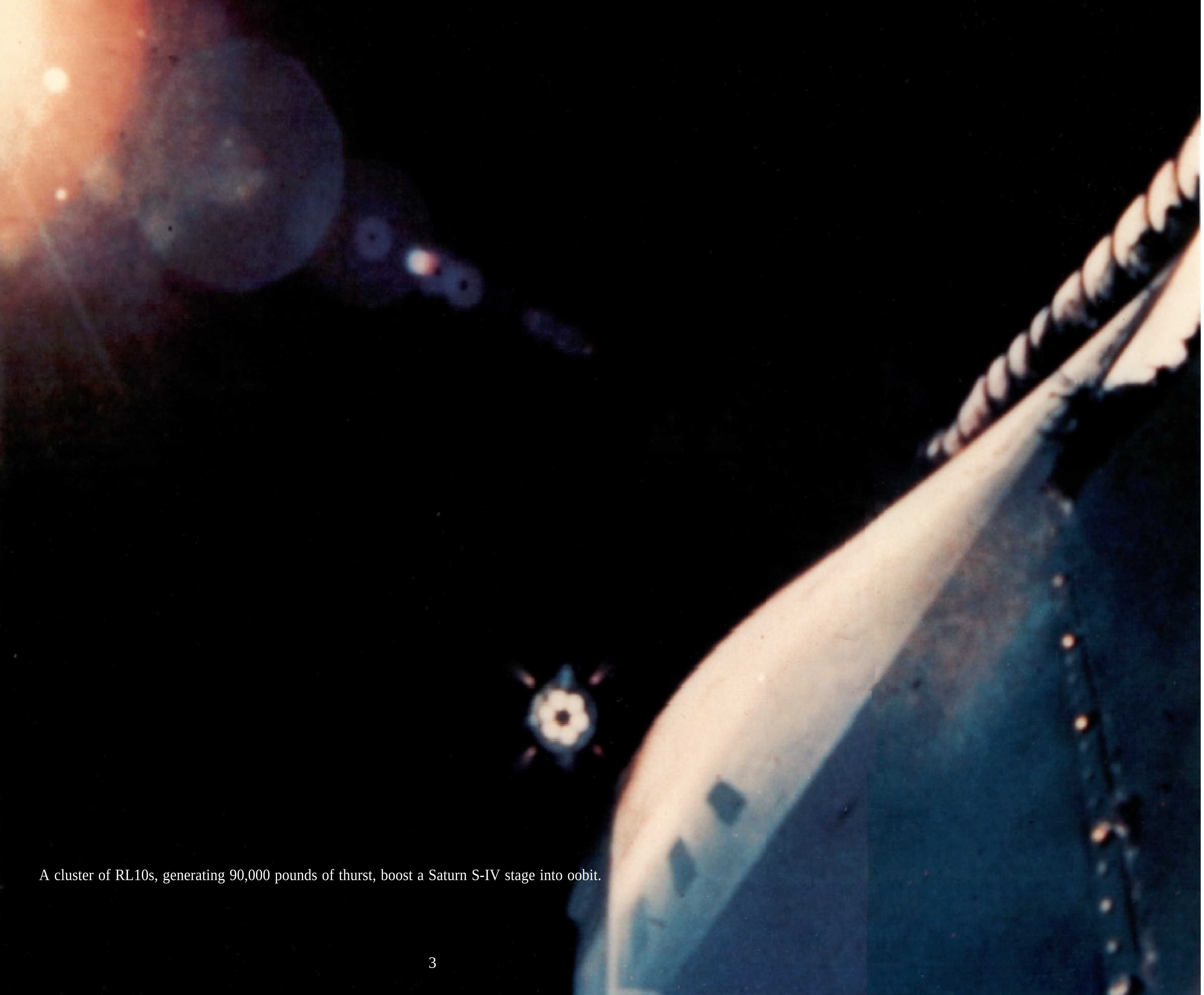
The American Society of Mechanical Engineers

In an endurance test conducted during the development program, an RL10 engine ran continuously for 28 minutes. The test was terminated at that point only because the propellant supply was exhausted. The engine operates for about seven or eight minutes in a typical Centaur flight. The RL10 has the highest specific impulse — the amount of thrust realized from a given flow rate of fuel — of any operational rocket engine in the world.

While launching an array of the nation's most sophisticated unmanned spacecraft, the RL10 has compiled a perfect flight record: not a single engine failure. More than 140 of these 15,000-pound-thrust engines have operated in space to date.

On November 27, 1963, a pair of RL10s successfully boosted a Centaur space vehicle into orbit around the earth in the first flight demonstration of this outer space powerplant. Two months later, on January 29, 1964, a six-engine cluster of RL10s, generating 90,000 pounds of thrust, propelled a 37,700-pound payload into orbit to culminate the first test flight of the Saturn S-IV stage which pioneered hydrogen technology on the Saturn I booster.

First successful Atlas-Centaur, launched from Cape Canaveral, Florida, November 27, 1963.



A cluster of RL10s, generating 90,000 pounds of thurst, boost a Saturn S-IV stage into oobit.

The RL10 made its entry into the U.S. space exploration program in May 1986 when an Atlas-Centaur boosted a Surveyor spacecraft on an accurate trajectory to achieve a soft landing on the moon. Atlas-Centaurs launched a total of seven Surveyors — five made successful soft landings — to photograph and analyze the moon's surface in preparation for the Apollo landings that would follow.

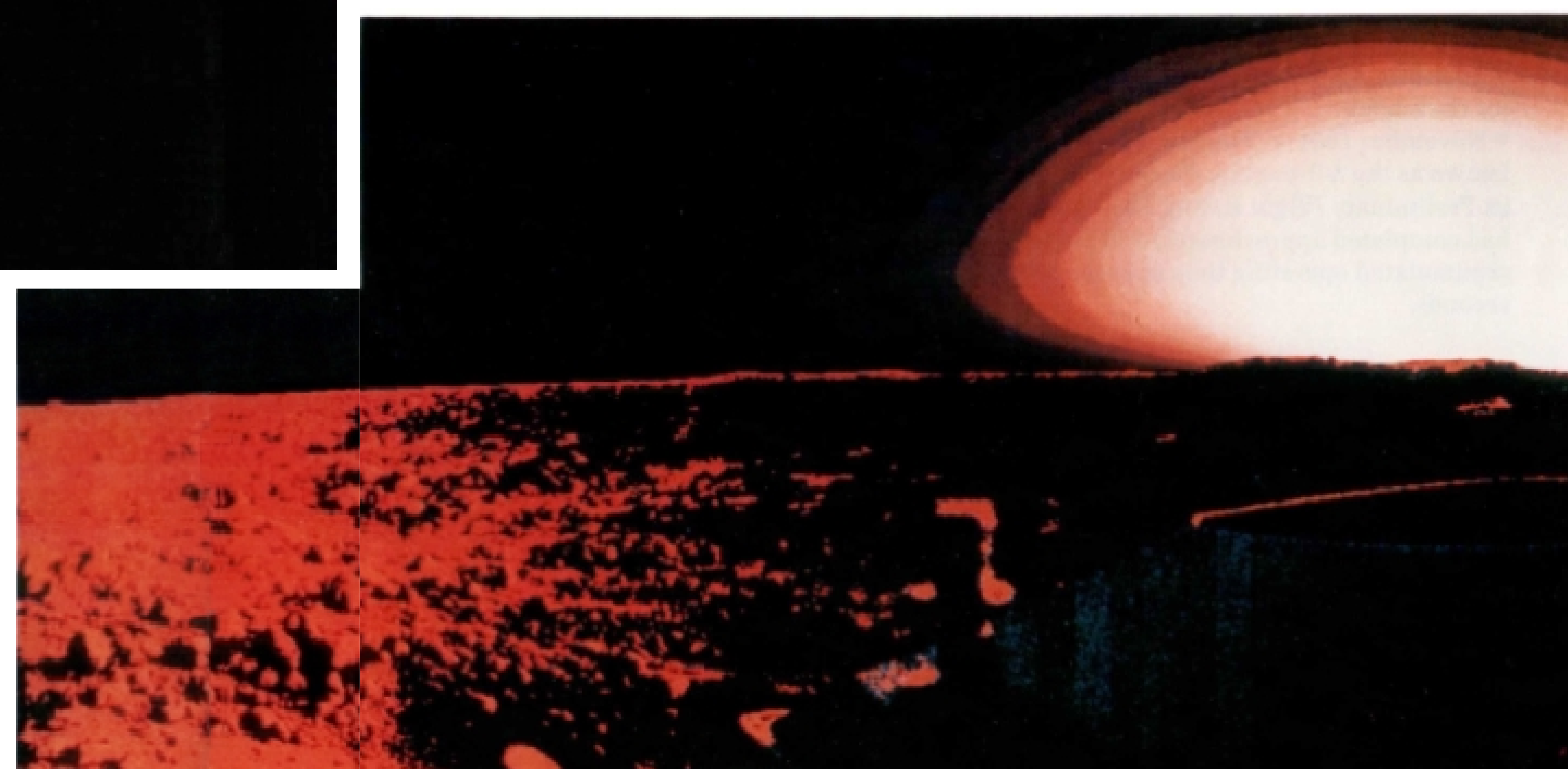
Once operational, the Atlas-Centaur became NASA's workhouse for launching medium-weight payloads on interplanetary or high orbital missions. Besides the Surveyors, it has launched Orbiting Astronomical Observatories, Applications Technology Satellites, Mariner-Mars spacecraft, Intelsat IV and IV-A Commercial Communications Satellites, Comstar Communications Satellites, Mariner-Mars Orbiters, Pioneer-Jupiter explorers, Mariner Mercury/Venus spacecraft, a High Energy Astronomical Observatory, Navy Fltsatcom Communications Satellites, and Pioneer-Venus probes.

The colorful face of Jupiter as photographed by a Voyager spacecraft in March 1979.

The powerful Titan-Centaur rocket became operational in December 1974 when it sent a Helios spacecraft to the center of the solar system to obtain new information on interplanetary space in the region close to the sun. This launch vehicle combines NASA's RL10-powered Centaur upper-stage with the Air Force's Titan III-E booster rocket. Titan-Centaurs also were used to launch a pair of Viking spacecraft that made soft landings on Mars in mid-1976, and Voyager spacecraft that will investigate Jupiter, Saturn, Uranus, and Neptune.

The Atlas-Centaur is scheduled to launch a variety of payloads until the early 1980s. Beyond that, the Centaur stage has potential application as an upper stage used in conjunction with NASA's reusable Space Shuttle.

Martian sunset recorded by a Viking lander spacecraft.



The RL10 Milestones

● October 1958 — Pratt & Whitney Aircraft is awarded a contract to design and develop a liquid hydrogen-fueled upper-stage rocket engine. The contract, awarded by the Advanced Research Project Agency of the Department of Defense, called for an initial expenditure of about $9 million.

● June 1959 — P & W A announces completion of four large-capacity static test stands, marking the first time a private company has made a contribution of this size to U.S. rocket testing.

● July 1959 — First engine firing conducted.

● January 1960 — The RL10 rocket engine, designated by the U.S. Air Force the XLR115, is chosen to power the upper stages of the Saturn vehicle, as well as the General Dynamics Centaur vehicle which will serve as the second stage of the modified Atlas booster.

● November 1960 — P & W A is awarded the first National Aeronautics and Space Administration (NASA) contract for development of the RL10. NASA's Marshall Flight Test Center in Huntsville, Alabama, has contract responsibility for the engine.

● November 1961 — The first engine model, known as the A-1 engine, successfully completes its Preliminary Flight Rating Test. The engine had completed approximately 700 firings for an accumulated operating time in excess of 60,000 seconds.

● August 1962 — The RL10 demonstrates the capability of operating at as little as 10 percent of its rated thrust.

● November 1963 — A pair of RL10 engines successfully boost a Centaur launch vehicle into orbit around the earth in the first flight demonstration of the outer space powerplant.

● January 1964 — A six-engine cluster of RL10s, generating 90,000 pounds of thrust, propel a 37,000-pound payload into orbit to culminate the first test flight of the Saturn S-IV stage, which pioneered hydrogen technology on the towering Saturn I booster.

● And later in 1964 — The National Space Club cites P & W A as the industrial organization making the "most notable contribution to the national space program" during the previous year.

● May 1966 — The RL10 makes its entry into the U.S. space exploration program when an Atlas-Centaur boosts a Surveyor spacecraft on an accurate trajectory for a soft landing on the moon.

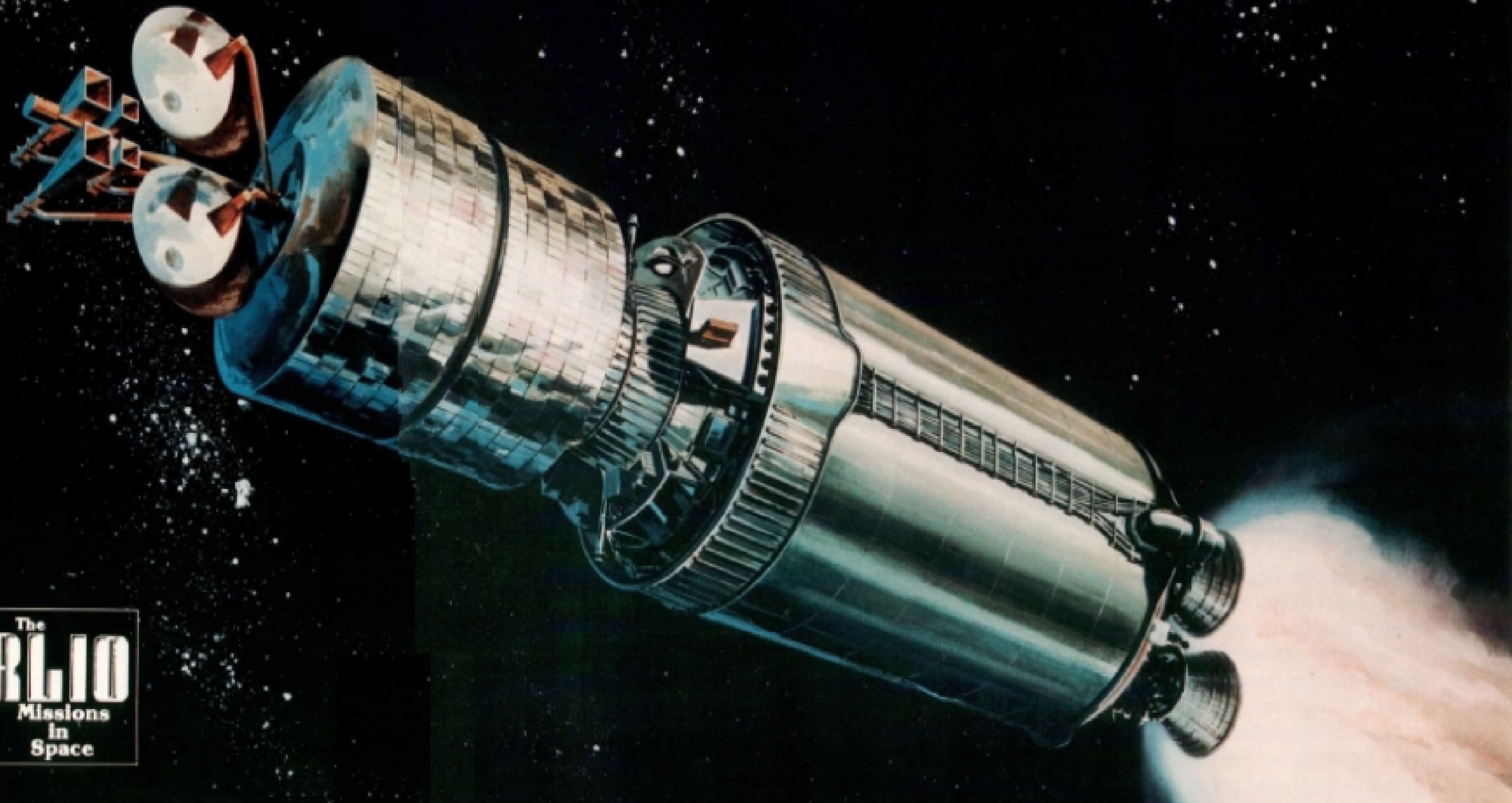
● October 1966 — The RL10 becomes the first hydrogen-fueled engine to complete a "two-burn" mission as NASA's Atlas-Centaur vehicle breezes through a dress rehearsal for future Surveyor launches.

● October 1966 — An advanced version of the RL10, designated the RL10A3-3, successfully completes its qualification test.

● December 1974 — The powerful Titan-Centaur becomes operational when it sends a Helios spacecraft to the center of the solar system to obtain new information on interplanetary space in the region close to the sun. During a second Titan-Centaur Helios launch, the RL10-powered Centaur stage demonstrates the multiple restart and long coast capability of the engine by accomplishing seven firings, with a coast period of 5¼ hours between two firings.

A Titan-Centaur rocket starts into space with a Helios spacecraft to investigate the sun.

The RL10 Missions in Space



- Commercial Communications Satellites
- Pioneer Jupiter Probes
- Marine Mars Orbiters
- Helios Solar Probes
- Viking Mars Landers/Orbiters
- Navy Communications Satellites
- High-Energy Astronomical Observatories
- Mariner Jupiter - Saturn Spacecraft
- Voyager Jupiter - Saturn - Neptune - Uranus Probes
- Pioneer Venus Probes
- Mariner Venus Mercury Probes

Why Hydrogen?

Interest in liquid hydrogen as the "ultimate chemical rocket fuel" is due to the fact that it is nature's most energy-packed substance per unit weight by virtue of its atomic weight and combining ability.

The earliest recognition of the gas hydrogen is attributed to Paracelcus, who, as long ago as the 16th century, found that when iron and sulfuric acid interact, "an air arises which bursts forth like the wind." Henry Cavendish in 1766 determined the true nature of the gas, which he called "inflammable air" and, in 1781, he proved that hydrogen burned in air to form water. It remained for the French genius Antoine Lavoiser, the first scientist to make accurate use of the scale in the study of chemical reactions, to lay the groundwork for the stoichiometric relationship explicit in the now familiar H_2O formula. He also gave hydrogen its name from the Greek, meaning "water forming."

Modern cosmologists say that hydrogen is by far the most abundant element in the universe, accounting for 93 percent of the total number of atoms, and 76 percent of the weight of the universe's matter. Stars, including the sun, generate the immense radiant energies of their fiery cores by a nuclear reaction consuming hydrogen.

On earth in uncombined form, hydrogen is much less abundant since the earth's gravitation is too small to hold very light molecules of high velocity. In combined form, however, in water, in organic tissues, and in their hydrocarbon fossils, hydrogen is abundant and a basic building block of nature.

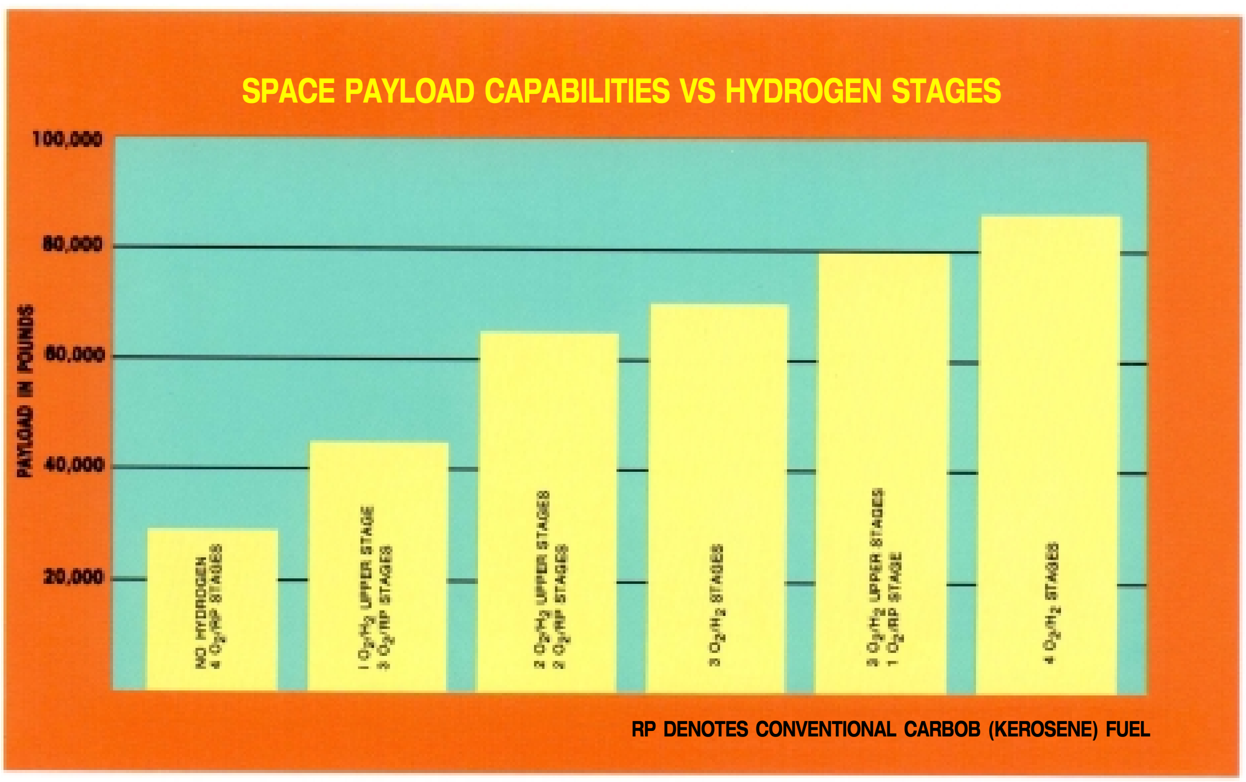
Cryogenic hydrogen is an odorless, colorless, frigid (-423 degrees F) liquid, the lightest there is. It weighs six tenths of a pound per gallon — one fourteenth as much as water. What was once a mere laboratory curiosity has become a modern industrial product of high importance.

Because of hydrogen's high heat of reaction with all oxidizers and low molecular weight of its combustion products, it provides more energy than any other fuel. This energy, or "specific impulse," is measured in pounds of thrust per pound of propellant per second of burning.

Since the thrust developed by a propulsion system is essentially proportional to the exhaust gas velocity which, in turn, depends on the average molecular weight, hydrogen yields higher gas velocities for a given temperature and provides greater thrust.

In 1955, Pratt & Whitney Aircraft, mindful of the performance hydrogen could deliver as both a jet engine and rocket engine fuel, began exploratory studies. During the program, P & W A made numerous contributions to the future development of liquid hydrogen engines and to the handling techniques of the fuel. The super-cold liquid was transferred through specially constructed pipelines, supplied to full-scale engines and engine component test stands at various pressures as required, stored in tanks with only negligible loss and accurately monitored for pressure and temperature under static and dynamic conditions. Concurrently, engine components were developed.

The promise of emerging liquid hydrogen technology led to a U.S. Air Force award to P & W A in 1958 to develop an upper-stage rocket engine using hydrogen fuel. Such a fuel was found to be able to boost twice the payload of previous space propulsion systems.



THE VICE PRESIDENT
WASHINGTON 20501

May 4, 1967

Dear Mr. Anschutz:

As Chairman of the National Aeronautics and Space Council, I extend my personal congratulations to you and your fine associates for the part you played in the success of Surveyor III. I have seen several of the first photographs and was amazed at the results. I know that Surveyor III was successful because of the assistance rendered by you and your personnel.

The pictures with Venus in the background and the fine detailed photographs of our first lunar trench are magnificent examples of the progress being made by your efforts.

Sincerely,

Hubert H. Humphrey

Mr. Richard Anschutz
Florida Research and
Development Center
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The National Space Club cited P&WA for its pioneering accomplishments.

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