**HOW DID IT HAPPEN THAT THE APOLLO LMDE WAS MADE BY STL/TRW?**

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LMDE inventor and Program Director

**Fifty-eight and a half years ago** on May 26, 1961 President John Kennedy, frustrated by America’s relative slow progress in exploitation of space, and by propaganda ridicule of the USA’s technical capability by the USSR, arranged to address a joint session of Congress. In that session, he presented an incredible challenge to our country:

 **“Before this decade is out, land a man on the moon and return him safely to the Earth.”**

An astonished Congress finally agreed and committed to fund what NASA had been calling its system studies to go to moon: the **“APOLLO PROGRAM”.**

By mid-1962, NASA finally chose **“Lunar Orbit Rendezvous”** as the vehicle system configuration and flight profile with the highest probability of meeting that challenge. That configuration planned to use a yet to be developed huge three-stage launch vehicle design NASA called SATURN-V. Above the third stage of that launch vehicle would be a large three-unit spacecraft. That new spacecraft design had a Propulsion Service Module attached to a manned Command Module which was to be coupled during the trip to the Moon via hatches to a complex spacecraft called the Lunar Excursion Module. NASA selected Grumman Aircraft Co to develop and build that Lunar Module spacecraft.

At the time of that commitment to **“Lunar Orbit Rendezvous”,** there was explicitly identified **a** **major technological challenge**. Deorbiting and Landing the 35,000 LB Lunar Module required a large rocket engine having on-demand variable-thrust over a 10:1 range. It had to be capable of operating without active coolant over a very long total burn-time, (12 minutes), and be restartable many times in space. No such large rocket engine had ever even been designed, let alone demonstrated. Grumman Putout an RFP to 4 big rocket engine companies, and chose **Rocketdyne,** the most experienced rocket engine company of that era, to develop the Lunar Module Descent Engine **(LMDE).**

 **SO HOW DID IT HAPPEN**

that on July 20,1969 Neil Armstrong and Buzz Aldren were standing in the Lunar Module EAGLE on top of a deep-throttling rocket engine developed by a few young engineers at a new company called **Space Technology Laboratories?** In retrospect over the last 60 years, one answer to that question that has often entered my mind is that I seemed to have been propelled along an education and career path that led inevitably to that highly improbable event.

Following discharge from the Army Air Corps in 1946, I received a **Bachelor of Physics** degree from the **University of Minnesota** in August 1949. After searching in vain for a company in the Minneapolis area that wanted a physicist, I paid $25 to share expenses for a ride to California**.** After a couple weeksIn California I saw a tiny ad for a physical chemist at the **“Jet Propulsion Laboratory”** in Pasadena. In a career destiny event, I talked my way into the job.Amazingly, many of the pioneering rocket propellant and combustion technologies I researched during the next 10 years at **JPL** turned out to be exactly those permitting me to design a unique throttlable rocket engine just when it was needed to accomplish the **Apollo Moon Mission**. During one extended research project, I was using a pair of small diameter concentric tubes to study the energy released during the liquid phase mixing of storable reactive propellants. It became clear that for hypergolic propellants such as N2O4 with N2H4 that enough energy was released to disperse and vaporize the propellants throughout the head end region of a rocket motor. That led to the possibility that a single coaxial set of tubes at the center of a chamber head plate could replace hundreds of holes distributed uniformly across an injector faceplate.

 **Chart {1} Concentric Tube Reactor**

In the fall of 1958, the Director of **JPL** left to become president of a newly formed company named **“Space Technology Laboratories” (STL)** in El Segundo, CA. I was motivated to join **STL** in January of 1959 as head of the Advanced Propulsion Section**.** One of thefirst things I submitted as an **IR&D Program** was to develop a rocket engine using storable propellants that could be throttled over a wide range of thrust for maneuvering spacecraft around in orbitBy the middle 1960, I had invented a unique design for such a rocket engine. It used a central element pintle type injector with a single movable sleeve to vary the injection areas of both the oxidizer and fuel. That was fluidly coupled to a pair of variable throat area cavitating venturi flow control valves. The movable injector sleeve was mechanically coupled to the movable valve pintles. The basic operating Pressure profiles of such a combination is shown in **Chart {B}.**

  **Chart {2} Operating Pressure Profile With Cavitating Valves**

That engine concept was embodied in a small rocket engine with a maximum thrust of 500 pounds which could be throttled down to as low as 20 pounds.

 **Chart {3} Isometric of the 500 LB Thrust Engine**

My rocket engine development team was demonstrating that engine at a small **STL** rocket test facility in Inglewood, CA by the time Kennedy made his speech on May 26, 1961.

 **Chart {4} Photo of Engine Firing in STL Inglewood Test Facility**

By late 1962, the Rocketdyne engine was having various problems, and **NASA** decided they needed to get a back-up engine under development. When I asked to bid for the backup engine, both **Grumman and NASA** laughed and said “who are you and why are you in our office?” But after I showed them how my design could solve most of the operating and combustion instability problems that drove them to want a back-up program, they agreed to allow us to bid. But Top **STL** management had to agree that if we actually won the back-up competition technically against the three other big rocket engine companies, **STL** would build a complete large rocket test facility at a remote site. That Facility must be able to test full scale engines at vacuum during development, and run final flight engines with a 48:1 columbium nozzle through full duty cycles at vacuum. My boss, Arthur Grant, went to the top STL managers and convinced them that if we won the backup, our design could also win the deliverable flight engine contract. ThebrilliantCAL-TECHengineering trained **STL** Managers agreed!

To support our backup proposal we scaled up the 500 LB thrust engine to 5000 LB thrust, the maximum thrust level we could run at the Inglewood facility. It functioned perfectly. However, NASA and Grumman were not convinced that when the chamber diameter increased to the full diameter of the 10,000 LB thrust flight engine that it would not go unstable. They wanted to see a series of BOMB tests at full diameter. The time allowed to complete our proposal for the back-up was very short. So, we built a mild steel 17-inch diameter chamber to carry out the stability tests with the 5000 LB head-end. It got called the **“iron pig”.**

 **Chart {5} 5000 LB Thrust Motor and “Iron Pig”**

 We scheduled the tests for a Saturday, but by the time we got the engine and bombs set up after working all night, both NASA and Grumman key managers were there before we could even fire a check-out test. My management was not happy about that, but it was either don’t fire and loose, or fire and go unstable and loose, or fire and demonstrate the inherent dynamic stability of our unique engine design. We fired and replaced bombs multiple times at various thrust levels and every test showed almost instant recovery to stable operation!

 **Chart {6} Chamber Pressure Recovery From Bombs**

**That demonstration plus our unique design and throttling performance won STL the back-up program** **in July 1963.**

As committed to Grumman and NASA, **STL** designed, had constructed and made operational in less than a year a very complex rocket test facility adjacent to Camp Pendleton near San Juan Capistrano. We called it the **Capistrano Test Site** [**CTS**]. It had a four-position vertical stand called **“VETS”;** a high altitude steam pumped vacuum enclosure capable of testing the LMDE with a 48:1 Columbium nozzle skirt over the full thrust range of 10:1 called **“HATS”,** and a propulsion system integration stand called **“PITS”.**

 **Chart {7} HATS Facility with Huge Steam Generator Engines**

By December 1964, After 18 months of intense development we had finalized our flight engine design.

 **Chart {8} Head End Injector**

 **Chart {9} Cavitating Flow Control Valves**

 **Chart {10} LMDE Integrated Head-End Assembly**

 **Chart {11} STL Lunar Module Descent Engine Cutaway**

In early December 1964, we installed our final flight development engine into the big vacuum can at the Capistrano Test Site [CTS]. The next day we were scheduled for our final competitive Back-up Contract presentation to the top officials of Grumman and NASA. I was about two hours into my briefing when the conference room entrance phone rang. It was the Grumman representative at STL calling from our Test Site near Capistrano, CA to inform all of us that **STL** had completed a full de-orbit and landing mission duty cycle with complete success. **WOW!!**

***That event was crucial for us to win the Apollo Flight Engine Contract in January1965.***

That decision to go with **STL** was proven to be a good one during the very difficult, but totally successful first Lunar Landing of Apollo XI, and during the subsequent **5 landings**. It was especially true in the return to Earth of the damaged Apollo XIII.

 **Chart {12} Jerry Elverum With His Baby; First Deliverable Engine**

 **Chart {13} Landing Apollo XI on the MOON**

 **Chart {14} The APOLLO XI Descent Stage at TRANQUILITY BASE on the MOON**

 **Chart {15} Bringing Apollo XIII Home.**

 **Chart {16} CHARIOTS FOR APOLLO**

. In the **NASA** History Publication **“Chariots for Apollo”** it states:

**“The Lunar Module Descent Engine was the biggest challenge and the most outstanding technical development of Apollo.”**

By the way, in ten days we will celebrate the 50th anniversary of Apollo XII with Alan Bean and Charlie Conrad.