# Cryogenics- Birth of An Era

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## ABSTRACT
This paper presents a review of cryogenics technology in concise form.

## 1. INTRODUCTION
Cryogenics originated from two Greek words “kyros” which means cold or freezing and “genes” which means born or produced. Cryogenics is the study of very low temperatures or the production of the same. Liquefied gases like liquid nitrogen and liquid oxygen are used in many cryogenic applications. Liquid nitrogen is the most commonly used element in cryogenics and is legally purchasable around the world. Liquid helium is also commonly used and allows for the lowest temperatures to be reached. These gases can be stored on large tanks called Dewar tanks, named after James Dewar, who first liquefied hydrogen, or in giant tanks used for commercial applications.
The field of cryogenics advanced when during world war two, when metals were frozen to low temperatures showed more wear resistance. In 1966, a company was formed, called CyroTech, which experimented with the possibility of using cryogenic tempering instead of Heat Treating, for increasing the life of metal tools. The theory was based on the existing theory of heat treating, which was lowering the temperatures to room temperatures from high temperatures and supposing that further descent would allow more strength for further strength increase. Unfortunately for the newly-born industry the results were unstable as the components sometimes experienced thermal shock when cooled too fast. Luckily with the use of applied research and the with the arrival of the modern computer this field has improved significantly, creating more stable results.
Another use of cryogenics is cryogenic fuels. Cryogenic fuels, mainly oxygen and nitrogen have been used as rocket fuels. The Indian Space Research Organisation (ISRO) is set to flight-test the indigenously developed cryogenic engine by early 2006, after the engine passed a 1000 second endurance test in 2003. It will form the final stage of the GSLV for putting it into orbit 36,000 km from earth.
It is also used for making highly sensitive sensors for detecting even the weakest signals reaching us from the stars. Most of these sensors must be cooled well below the room temperature to have the necessary sensitivity, for example, infrared sensors, x-ray spectrometers etc. The High resolution Airborne Widebandwidth Camera, for SOFIA (Stratospheric Observatory For Field Astronomy) which is a Boeing 747 flying observatory, a project of the University Of Chicago, Goddard Space Flight Center and the Rochester Institute Of Technology, which when enters into operation will be the largest infra-red telescope available, is cooled by an adiabatic demagnetization refrigerator operating at a temperature of 0.2K.
Another branch of cryogenics is cryonics, a field devoted to freeze people, which is used to freeze those who die of diseases, that they hope will be curable by the time scientists know how to revive people.

## 2. CRYOGENIC ENGINES
The use of liquid fuel for rocket engines was considered as early as the beginning of this century. The Russian K. E. Ziolkowsky, the American H. Goddard and the German-Romanian H. Oberth worked independently on the problems of spaceflight and soon discovered that in order to succeed, rockets with high mass-flow were mandatory. Already then the combustion of liquid fuels seemed the most promising method of generating thrust.
However it was not later until these pioneers made their attempts, the first big liquid powered rocket the German A-4 became reality in the mid-forties. This rocket became successful as the V-2 weapon. Liquid oxygen was used as the oxidizer and ethyl alcohol as the fuel which gave the rocket more than 300KN of thrust. It`s range was 300km.
As the development of rocket engines continued, higher thrust levels were achieved when liquid oxygen and liquid hydrocarbon were used as fuel. This allowed the construction of the first intercontinental rocket with a range of more than 10,000km.
The fuel combination of liquid oxygen and RP-1 a kerosene-like hydrocarbon compound, was the basis for the American intercontinental rockets like Atlas and Titan-1 as well as the boosters for the Saturn family of the Apollo Moon Program. Combinations of oxygen or fluoride as oxidizer and hydrogen or methane as fuel make them attractive fuel mixtures for rockets. The real disadvantage is, their low density.
Under normal atmospheric conditions, at temperature 300k and pressure 1 bar, these substances are in gaseous state. One cannot remedy the low density by increasing the pressure because the required tank structures would end being too heavy. The answer is to liquefy the fuels by cooling them down. This is why the fuels are also called cryogenic fuels.
In the sixties, the steadily increasing payload weights and the corresponding demand for more thrust of the launcher lead to the use of liquid hydrogen for the Centaur upper stage. At the peak of this development was the US Space Shuttle Main Engine (SSME).
In principle, cryogenic rocket engines generate thrust like all other rocket engines-by accelerating an impulse carrier to high speeds. In conventional aircraft engines the surrounding air is the main impulse carrier and fuel is the energy carrier. This is why such an engine requires the atmosphere not only to burn the fuel but also to generate thrust. But in rocket engines the

impulse and energy carriers are identical and are present as fuel in the launcher. The chemical energy stored in the fuel is converted into kinetic energy by burning it in the thrust chamber and subsequent expansion in the nozzle, in the process creating thrust.

In order to compare a variety of fuel combinations, a quantity known as specific impulse, which determines the thrust per kilogram of emitted fuel per second, is used. For example hydrazine has 230 seconds of specific impulse, for solid propellants it is around 290 seconds. The favourite fuel and oxidizer combination used during the boost phase are Liquid Hydrogen(LH2) and Liquid Oxygen(LOX) which provide a specific impulse of 445 seconds, almost double that of hydrazine. The fuel is environmentally friendly, non-corrosive and has the highest efficiency of all non-toxic combinations. To liquefy hydrogen has to be cooled to a temperature of minus 273°C. It`s boiling point is 20K only just above absolute on the temperature scale. During this process, it`s density increases to above 70kg/m3. Liquefaction of oxygen takes place at a temperature of minus 183°C, it`s then is 1,140kg/m3.

Thus fuelling the booster rockets is a complex and hazardous process, for as soon as oxygen comes in contact with hydrogen, they spontaneously combust in a powerful explosion. Over the years cryogenic engines have become the backbone for boosters, used for placing heavy payloads in space, such as those used for the main engine for the space shuttle.

The major components of a liquid fuel cryogenic engine are the thrust chamber, the fuel pumps with it`s valves and regulators and the tanks. The fuel and oxidizer pump system is the main component and can be divided into two principles. The most simple way is to increase the pressure of the tank with inertial gases to pressurize the tanks against the pressure in the combustion chamber. In this type of engine, the fuel and gas tanks are very heavy and are used in smaller rockets with shorter burning times.

The alternative is to use turbopumps. This can be differentiated into a bypass or a main flow configuration. In the bypass configuration, the flow is split, the main part is used via the combustion chamber to generate thrust, while a small amount of fuel is used to drive the pump through the turbine and is subsequently emitted. In the main flow design, the entire fuel is fed through the turbines, which drives the pumps, and then further to the combustion chamber.

The combustion chamber is a critical component of the engine because of the high output and accordingly high pressures. High pressures over 200 bar and temperatures of more than 3,000°F create a great strain on the combustion chamber and call for effective cooling. Copper combustion chambers are used, in the outside of which cooling channels are milled that are galvanoplastically closed. The SSME creates a vacuum thrust of 2,090 KN and a specific impulse of 452s. The three engines, which are needed for the main stage of the SSME have a combined output of more than 37 million hp or 27,380 megawatts, which correspond to about 30 conventional nuclear power plants.

Over the years there has been talk about designing a cryogenic system that could be used for the heavier upper stages for space systems. This would require cryogenic engines with great thermal insulation to protect the hydrogen and oxygen from friction heating during the boost phase and from solar heating after reaching space. With the ongoing research, one can anticipate a bright future for cryogenics in the field of rocket propulsion in th future.

A **cryogenic rocket engine** is a rocket engine that uses a cryogenic fuel or oxidizer, that is, its fuel or oxidizer (or both) are gases liquefied and stored at very low temperatures.[1] Notably, these engines were one of the main factors of the ultimate success in reaching the Moon by the Saturn V rocket.[1] During World War II, when powerful rocket engines were first considered by the German, American and Soviet engineers independently, all discovered that rocket engines need high mass flow rate of both oxidizer and fuel to generate a sufficient thrust. At that time oxygen and low molecular weight hydrocarbons were used as oxidizer and fuel pair. At room temperature and pressure, both are in gaseous state. Hypothetically, if propellants had been stored as pressurized gases, the size and mass of fuel tanks themselves would severely decrease rocket efficiency. Therefore, to get the required mass flow rate, the only option was to cool the propellants down to cryogenic temperatures (below −150 °C, −238 °F), converting them to liquid form. Hence, all cryogenic rocket engines are also, by definition, either liquid-propellant rocket engines or hybrid rocket engines.[2]

Various cryogenic fuel-oxidizer combinations have been tried, but the combination of liquid hydrogen (LH2) fuel and the liquid oxygen (LOX) oxidizer is one of the most widely used.[1][3] Both components are easily and cheaply available, and when burned have one of the highest entropy releases by combustion,[4] producing specific impulse up to 450 s (effective exhaust velocity 4.4 km/s).

Cryogenics is the study of the production of extremely cold temperatures. This field of science also looks at what happens to a wide variety of materials from metals to gases when they are exposed to these temperatures. Cryogenics is a branch of physics concerned with the production of very low temperatures and the effects of these temperatures on different substances and materials. The temperatures studied in cryogenics are those below -243.67 degrees Fahrenheit (120 Kelvin); such low temperatures do not occur in nature.

These low temperatures have been used to liquefy atmospheric gases like oxygen, hydrogen, nitrogen, methane, argon, helium, and neon. The gases are condensed, collected, distilled and separated. Methane is used in liquid natural gas (LNG), and oxygen, hydrogen and nitrogen are used in rocket fuels and other aerospace and defense applications, in metallurgy and in various chemical processes. Helium is used in diving decompression chambers and to maintain suitably low temperatures for superconducting magnets, and neon is used in lighting.

## 3. CONCLUSIONS

India’s growing prowess in space technology is a nearly invisible, softly-softly adventure of notching up small, incremental successes on a continual basis. Yesterday the Prime Minister announced in the Parliament : “we have been able to successfully develop the cryogenic engine on our own”. Behind that terse statement lies a trail thick with geo political intrigue, complex sciences and quiet Indians at their tasks.

India’s cryogenic engine initiative began in 1993 but when it carried out its nuclear tests in 1998, it also blew a big hole through its network of international relations in diplomacy and trade. Amidst world-wide condemnation India’s scientists were tarred with suspicion and most collaboration with them were severed.

The real reason for withholding cryogenic engine technology was however not ‘global security’ but commerce—big commerce. These engines are required to launch the geo-synchronous satellites that are used in communications. It’s a lucrative business. Russia, Europe and the US have carved out the launch market. Emergence of India as a low cost launcher would have threatened their shares.

Faced with the ostracisation, India chose to develop the engine on its own. It's GSLV launch programme was kept on course with the essential cryogenic engines sourced from Russia. In all ten were contracted for. On April 18,2001 India bustled into the exclusive GSLV launchers' club. It successfully launched a 1.5 tonne satellite and parked it at 36,000 km above, in lock-step with earth's rotation. That was with a Russian engine.

At Mahendragiri in Tamil Nadu, is the Liquid Propulsion System Centre [LPSC]. Here work on developing India's own cryo engines has been quietly moving. The system involves materials working at 250 deg below zero and pumps at speeds of 40,000 rpm. There are also complex metering, monitoring, integrating technologies involved. The engines are required to fire for about 700 seconds during the final stage of a launch providing 7 tonnes of thrust.

First signs of success came on Feb 10,2002 when India 'test-fired' it's home-spun engine for the first time. It ran for a few seconds. Eight months later, on Sep 14,2002 the engine had been run for 1000 seconds on the test bed. This confirmed that the Indian design was sound .

# 4. REFERENCES

[1] Bilstein, Roger E. (1996). Stages to Saturn: A Technological History of the Apollo/Saturn Launch Vehicles (NASA SP-4206) (The NASA History Series). NASA History Office. pp. 89–91. ISBN 0-7881-8186-6.

[2] Biblarz, Oscar; Sutton, George H. (2009). Rocket Propulsion Elements. New York: Wiley. pp. 597. ISBN 0-470-08024-8.

[3] The liquefaction temperature of oxygen is 89 kelvins and at this temperature it has a density of 1.14 kg/l, and for hydrogen it is 20 kelvins, just above absolute zero, and has a density of 0.07 kg/l.

[4] Biswas, S. (2000). Cosmic perspectives in space physics. Bruxelles: Kluwer. pp. 23. ISBN 0-7923-5813-9.

[5] Russell B. Scott, Cryogenic Engineering, D. Van Nostrand Co., Princeton, New Jersey (1959); reprinted Oct. 1959, Aug. 1960, May 1962, and in 1995.

[6] NASA Facts, Next Generation Propulsion Technology: Integrated Powerhead Demonstrator, Technology, FS-2005-01-05-MSFC, Pub 8-40355, 2005

[7] M. Wade, Encyclopedia Astronautica, www.astronautix.com