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THE DEVELOPMENT OF LOX/LH2 ENGINE IN CHINA

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Because of its high specific impulse and environmental-friendly feature, LOX/LH2 engine has a special standing in aerospace propulsion domain, and has gained great attention worldwide. Since 1960's, China has been working on the development of LOX/LH2 engine. Developed from nothing, China has broken through a great number of key technologies and accumulated abundant experiences. In 1984, we successfully launched China's first geosynchronous communication satellite using 4 tonne thrust LOX/LH2 engine as the upper stage propulsion of CZ-3 Launch vehicle. Since then we developed 8 tonne thrust YF-75 engine with higher performance as the upper stage engine of CZ-3A launch vehicle. Preparing for the new generation launch vehicle CZ-5, we are developing 9 tonne thrust expander cycle upper stage engine YF-75D and 50 tonne thrust main engine YF-77. Till now we have made some major breakthrough in terms of their design, material, manufacture, and test. In the future, the developing of LOX/LH2 engine with higher thrust is inevitable. Thus, we are now having deep studies of key technologies concerning its system, thrust chamber, turbo pump, valves, etc.

I. INTRODUCTION

Early in January 1961, due to the suggestion of academician Qian Xuesen, China started the research of using liquid hydrogen as the rocket propellant. It symbolized the start-point of the development of LOX/LH2 engine in China. In March 1965, cooperated with the Mechanics institute of Academia Sinica, we designed 200kg thrust liquid oxygen/gaseous hydrogen thrust chamber and successfully conducted several fire-tests. In 1970 we designed 800kg thrust liquid oxygen/liquid hydrogen thrust chamber and finished the pressured system ignition tests. This is a milestone of our engineering development for LOX/LH2 engine. Through half century's effort, now we have different kinds of LOX/LH2 engine, they do well in our aerospace missions.

II.YF-73 ENGINE

According to Academician Ren Xinmin's instruction, in October 1970 we started to work on a 4 tonne thrust LOX/LH2 prototype engine. The engine was designed as a pump supplied gas generator power cycle engine, and was successfully fire-tested for 20s on 25th January 1975. In March 1975, China officially initiated the "311 project" and started the engineering work of our first LOX/LH2 engine, coded as YF-73(see fig.1). The engine is designed as the upper stage propulsion of CZ-3 launch vehicle. It is a gas generator cycle engine with 420s specific impulse, 5.0 mixture ratio, 40:1 nozzle area ratio, and capable of restart. The thrust chamber can gimbal in one direction. After 8 years hard work, on 8th April 1984, the engine successfully sent China's first synchronous experimental communication satellite Dongfanghong2, into geosynchronous orbit [1].

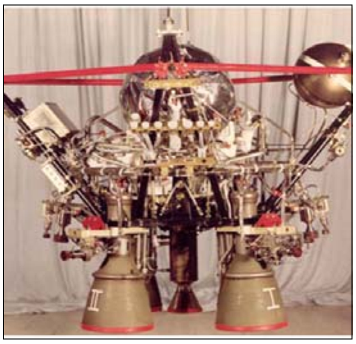

Fig.1 YF-73 engine

Through the development of YF-73 engine, we had mastered many key technologies of the cryogenic engine which set a firm foundation for our further development. They are:

- The structures, sealing, light weight foam heat isolation, and porous transpiration cooling materials used in liquid hydrogen environment
- High speed bearing and cryogenic wheel with high gear ratio used in liquid hydrogen environment. We solved the sub synchronous whirl motion problem of high-speed hydrogen turbo pump by adopting elastic supports;
- A set of procedures for gas exchanging, purging and precooling of the engine's oxygen and hydrogen system circuits;
- The production, storage, transportation and safety usage of the liquid hydrogen.

YF-73 engine took part in flight 13 times in total (with 3 failure) and was out of service on 26th May 2000 due to the low reliability and the poor payload capability.

III. YF-75 ENGINE

To meet the growing trends of geosynchronous communication satellite's mass and size, China began to work on the LOX/LH2 engine with higher thrust since 1982. The engine was planned to use on the third stage of CZ-3A\B\C launch vehicle, coded as YF-75(see fig.2), enhancing the payload capability from 1.5t to over 2.6t [2].

Fig.2 YF-75 engine

YF-75 consists of two same single engines and each of them is a gas generator power cycle engine and capable of producing 8 tonne thrust. Its LOX and LH2 turbo pumps are designed in series and to gimbal with the whole engine. The engine's specific impulse is 438s with 80:1 nozzle area ratio, 5.1 mixing ratio, and re-start capability. YF-75 engine took part in first flight on 8th February 1994 and successfully sent two satellites into the geostationary transfer orbit（GTO）. Till now, it has been used successful for 56 times. In the ground test, the YF-75 engine had tested 12 start-ups and accumulated to 3000s firing time without malfunction.

The inner wall of the thrust chamber of YF-75 engine is made of zirconium copper alloy. It is first forged and rolled to shape, then machined to form the cooling channels (see fig.3); the outer wall is nickel electroformed. The nozzle extension is made of welding in spiral tubes bundle in order to reduce its mass.

Fig.3 YF-75 thrust chamber liner

The hydrogen turbopump of the YF-75 engine operates at 42000rpm. The dual elastic support is applied and hence enhances the stability of the rotor. Meanwhile, the hydrogen turbo rotor is designed to integrate its blade, rotary table and spindle all together. It has the advantages of simple structure and good concentricity.

Using the second throat ejector which can create high-altitude environment(see fig.4), we can now acquire the high-altitude performance of the nozzle with 80:1 area ratio and the accurate engine performance data through ground tests.

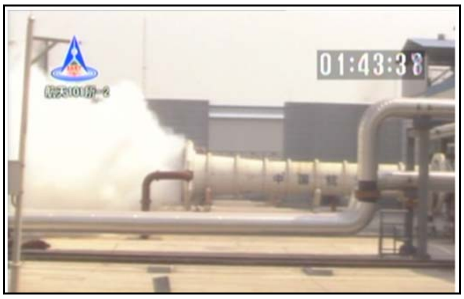

Fig.4 High altitude simulation test

IV. YF-75D ENGINE

To meet the future aerospace development, in 2006, based on the YF-75 engine, we started the developing work of the YF-75D engine (see fig.5). YF-75D is a LOX/LH2 closed expander cycle engine. The engine is designed to meet the requirements of second stage propulsion of the new generation launch vehicle CZ-5 for its performance, reliability, developing cost, schedule, etc. YF-75D engine is capable of throttling its mixture ratio and multi-start, so that it will be suited to various missions.

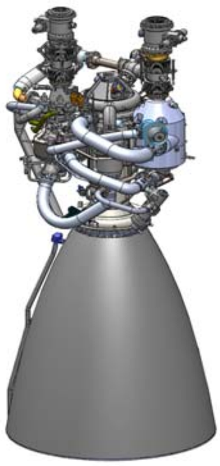

Fig.5 YF-75D engine

YF-75D engine has two turbopumps driven by gaseous hydrogen. They are designed in series and gimbaled with the whole engine. The engine specific impulse is 442s with 80:1 area ratio, 6.0 mixing ratio. The engine is capable of multi-starts. Till now, the firing time of YF-75D engine has accumulated to 21455s in total. One of them has tested 8 starts and 4320s firing time.

The redesigned hydrogen turbopump now operates at 65000rpm, which is between the second and third critical speed. The double elastic support with metal rubber damper is applied so that to guarantee the dynamic characteristics of the rotor over critical speed. Each elastic support surrounds a couple of hybrid ceramic ball bearings. The hydrogen turbine is a two-staged low-pressure ratio subsonic turbine. At the beginning, the axial flow and radial flow turbines were both designed and tested, finally the axial flow turbine was chose for its better effects(see fig.6).

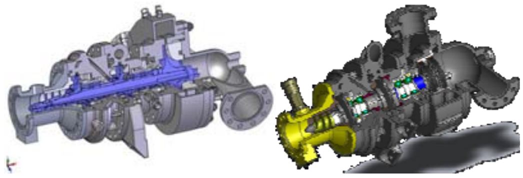

Fig.6 YF-75D turbopumps with radial flow and axial flow turbines

To keep the power balance of the expander cycle, the thrust chamber must be lengthened so that to meet the requirement of heat-transfer performance (see fig.7); the cooling channels are redesigned to meet the needs of heat transfer and cooling requirements.

Fig.7 YF-75D thrust chamber liner

The YF-75D engine starts by using its own structure heat capacity, under the tank pressure. Thus, we adopted second throat annular steam ejector for high-altitude simulation test.

V. YF-77 ENGINE

With the popularity of the pollution-free notion and the requirement of higher launch capability, in 2002, we began the developing work of YF-77 engine (see fig.8)). It consists of two single engines with each can provide 52 tonne ground thrust. It will be used as the main engine of the new generation launch vehicle CZ-5. YF-77 is a gas generator cycle engine with two turbopumps designed in parallel and gimbaled with the whole engine. It is ignited on the ground using cartridge to start the turbine. The thrust chamber and the gas generator are ignited by igniters respectively. The adjustment of engine's mixing ratio is realized by using the gas valve which located at the input of the oxygen turbine. The nozzle area ratio is 49:1; mixture ratio is 5.5; Specific impulse is 430s. Up to now, the engine's testing time has accumulated to 25159s.

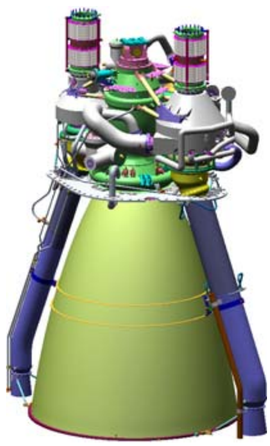

Fig.8 YF-77 engine

The hydrogen turbopump of YF-77 engine is a centrifugal pump consisted of an inducer and a two-staged centrifugal wheel and drove by a two-staged impulse turbine. The rotor of the hydrogen turbopump applies dual elastic support and works between the second and the third critical speed. Floating sealing ring is applied between the pump and the turbine. The axial force is automatically balanced by means of balancing piston system.

To prevent from the combustion instability, baffles with one hub and three spoke are designed, which are formed by protruded injectors. The inner-wall of the combustion chamber uses zirconium copper alloy machined to regenerative cooling channels and the outer-wall is nickel electroformed (see fig.9). The nozzle extension welded in spiral tubes bundle, adopts dump cooling.

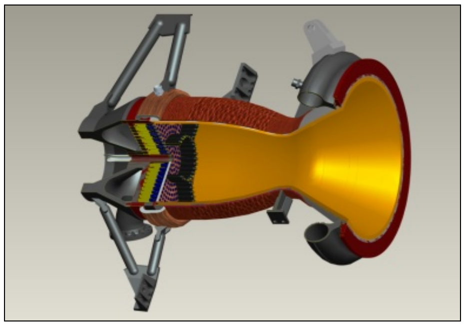

Fig.9 YF-77 thrust chamber

VI. THE FUTURE OF THE LOX/LH2 ENGINE

After decades' development, we have made great technical progress on LOX/LH2 engine in many aspects, such as designing, manufacturing, testing, and etc. However, in order to meet the requirements of China's future aerospace activities, several researches on LOX/LH2 engine still need to be done as follows:

1. High thrust engine

A higher thrust LOX/LH2 engine can provide better and stronger propulsion support for the main stage of the rocket and hence enhance the performance of the whole launch vehicle.

2. High performance and multifunction engine

Develop the LOX/LH2 engine with high Isp; Study the technologies like staged combustion cycle system, wide thrust throttling range and multi-start capability; Enhance the adaptability of LOX/LH2 engine towards future diversified missions; Prolong the life cycle of the engine.

3. LOX/methane engine

The LOX/methane engine has many merits such as abundant nature resource, good performance, lower cost, safety usage, and etc. Thus, LOX/methane engine is definitely going to be an option for the future launch vehicle propulsion. The experience of our LOX/LH2 engine can benefit the development work of LOX/methane engine.

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[2]Wu Yanshen, Wang Xiaojun, "A Prospect over the development of long march launch vehicles in next decade", IAF-00-V1.05