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A PERSONAL VIEWPOINT ON THE DEVELOPMENT OF CHINA'S LIQUID PROPELLANT ROCKET ENGINES

by

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SUMMARY This article attempts, on the basis of lifting rocket or launch vehicle and spacecraft requirements, to analyze development trends in liquid rocket propulsion technology. It makes a simple introduction of the Long March (Chang Zheng) lifting rocket or launch vehicle liquid propulsion system's current status and technological development. It makes a discussion of various types of liquid rocket motor development processes.

KEY TERMS liquid propellant rocket engine, propulsion system, booster, upper stage, attitude control

I. INTRODUCTION

Ever since the Soviet Union launched the first man made earth satellite on October 4th, 1957, space flight technology has made startling progress. For the last more than thirty years, various nations of the world have already launched over 3,000 spacecraft into space for various uses. These have made great contributions in such areas as communications, weather, flight navigation, national defence, and scientific experiments. Space flight technology is one of the principal indicators that the level of development in science and technology of each of the individual countries has currently already succeeded in reaching a balance.

Relying on liquid rocket motors has advantages and inherent special characteristics in such areas as capabilities, adaptability, economic considerations, and reliability. Moreover, it is widely used in space flight lifting and space systems. It is possible to predict that, in the next quite long period of time, the influence of the level of liquid fuel rocket propulsion technology will prove decisive in space flight projects.

In order to adapt to the requirements of the vigorous development of space flight technology, liquid rocket propulsion technology will, on the foundation of what exists now, make new and even greater progress. Because of this, the earnest drawing up of programs for the long term development of liquid rocket motors is very necessary and important. This article attempts, on the basis of the requirements of space flight technology in propulsion systems as well as the status of technological progress with the proplusion systems of the Long March (Chang Zheng) lifting rocket or booster, to analyse future trends in the development of liquid rocket propulsion technology. It will, respectively, carry out discussions on various types of liquid rocket motors corresponding with uses in lifting rockets and spacecraft.

II. LONG MARCH LIFTING ROCKET LIQUID FUEL PROPULSION SYSTEMS

Since the Long March No.1 (Chang Zheng) lifting rocket (CZ-1) launched the East Is Red No.1 satellite on April 24th, 1970, Chinese space flight technology has also achieved very great progress. Scientific experiment satellites, recoverable remote sensing satellites, and earth synchronous communications satellites have been launched successfully one after the other, drawing widespread and serious attention from various nations of the world. At the present time, China's Long March No.2 (CZ-2) and Long March No.3 (CZ-3) lifting rockets have already entered the international marketplace, undertaking international satellite launches and load missions. On September 7th, 1988, China used the newly researched and manufactured Long March No.4 (CZ-4) lifting rocket and successfully launched the Fengyun No.1 solar synchronous weather satellite.

The Long March No.1 is a three stage rocket. The first and second stages opt for the use of liquid propellants--red fuming nitric acid/unsymetrical dimethylhydrazine. The third stage is a solid fuel rocket. The take off weight of the rocket is 81.6 tons. The take off thrust is 1098 kilonewtons. The diameter is 2.25 meters. The overall length is 29.45 meters. Its near earth orbit load carrying capability 6 *
is approximately 300 kg. It has launched scientific experiment satellites. The first stage propulsion system is formed by the combining of four autonomous and independent systems. The second stage motor opts for the use of jet tube extension sections manufactured from glass fiber reinforced plastic in order to increase the jet tube surface area ratio. Turbine exhaust gases are used to carry out cooling.

* Numbers in margin indicate pagination of foreign text.

型号		推进剂	混合比	推力 (kN)	比冲 (m/s)	燃烧室压力 (MPa)
CZ-1	一级	红烟硝酸/偏二甲肼	2.46	1098	2363	6.57
	二级	红烟硝酸/偏二甲肼	2.48	320	2814	6.31
CZ-2	一级	四氧化二氮/偏二甲肼	2.10	2785	2540	6.98
	二级 主机	四氧化二氮/偏二甲肼	2.18	720	2835	6.52
	二级 游动		1.57	46.1	2762	3.29
CZ-3	一级	四氧化二氮/偏二甲肼	2.10	2785	2540	6.98
	二级 主机	四氧化二氮/偏二甲肼	2.18	720	2835	6.52
	二级 游动		1.57	46.1	2762	3.29
	三级	液氧/液氢	5.0	44.1	4168	2.63
CZ-4	一级	四氧化二氮/偏二甲肼	2.12	2942	2550	7.44
	二级 主机	四氧化二氮/偏二甲肼	2.18	720	2835	6.52
	二级 游机		1.57	46.1	2762	3.29
	三级	四氧化二氮/偏二甲肼	2.15	98	2942	4.41

[注]（1）CZ-1 的第三级是固体火箭。
（2）CZ-2，-3，-4 的第二级的推进系统由主发动机和游动发动机组成。

Table 1 Principal Function Parameters for Long March Lifting Rocket Liquid Fuel Propulsion Systems (1) Model Designation (2) Propellant (3) Mixture Ratio (4) Thrust (5) Specific Impulse (6) Combustion Chamber Pressure (7) First Stage (8) Second Stage (9) First Stage (10) Second Stage: Main Engine (Upper Column), Moveable Engine (Lower Column) (11) First Stage (12) Second Stage: Main Engine (Upper Column), Moveable Engine (Lower Column) (13) Third Stage (14) First Stage (15) Second Stage: Main Engine (Upper Column), Moveable Engine (Lower Column) (16) Third Stage (17) Red Fuming Nitric Acid/Unsymmetical Dimethyl Hydrazine (18) Dinitrogen Tetraoxide/Unsymmetrical Dimethyl Hydrazine (19) Liquid Oxygen/Liquid Hydrogen (20) [Note] (1) CZ-1's third stage is a solid fuel rocket. (21) (2) CZ-2, 3, and 4's second stage propulsion systems are made up of main engines and moveable engines.

Long March No.2 is a two stage rocket. It utilizes storable propellant of dinitrogen tetroxide/unsymmetrical dimethyl hydrazine. The rocket's take off weight is 191 tons. The diameter is 3.35 meters. The length is 31.65 meters. Its near earth orbit load capability is approximately 2000 kg. It has already launched several successful recoverable remote sensing satellites in succession. In conjunction with that, it has taken charge of load missions for France and the Federal Republic of Germany. The first stage propulsion system is made up of four motors. Each motor is capable of making a $\pm 10^{\circ}$ swing in a single direction. This supplies moments of force to control rocket flight attitude. The second stage propulsion system is made up from one main motor and four moveable motors. The moveable motors are capable of swinging $\pm 60^{\circ}$ in a tangential direction in order to control rocket attitude.

The Long March No.3 and Long March No.4 both are three stage liquid fuel rockets. The first and second stages opt for the use of storable propellants. The Long March No.3's third stage utilizes liquid oxygen/liquid hydrogen propellant. It has successfully launched several earth synchronous communications satellites. The Long March No.4's take off thrust is 2942 kilonewtons. The third stage is equipped with two storable propellant motors. It has launched solar synchronous weather satellites.

The principal functional parameters for the Long March lifting rocket liquid fuel propulsion systems are shown in Table 1.

III. TRENDS IN THE DEVELOPMENT OF LIQUID PROPELLANT ROCKET ENGINES

Considering the development of future space flight technology, it goes without saying that it lies in launching high capacity applied satellites, or in the launching of man carrying space stations, or space planes, and, in all cases, this requires large model lifting
rockets. Besides this, one also requires systems for orbital 7
mobility, systems for shifting orbits, as well as auxilliary thruster systems, and other similar systems. Below, we will take the specific situations for the various types of liquid fuel rocket motor models targeted for application in lifting rockets and spacecraft in order to analyse the course of and trends in their development.

1. Large Model Liquid Fuel Booster Motors

In order to adapt even better to the requirements for the development of space flight technology, it is necessary to raise a step further the lifting capablities of space flight lifting systems. It is possible to go through the process set out below in order to realize this:

1) solid fuel thruster devices and liquid fuel thruster devices must be tied together;

2) research and manufacture of large model liquid fuel booster engines;

3) research and manufacture of high performance liquid oxygen/liquid hydrogen engines;

4) increase propellant capacity and extend engine operating periods;

5) increase the dimensions of satellite cowlings, etc.

The improved model of the Long March No.2--the Long March No.2E (CZ-2E)--is prepared to opt for the use of liquid fuel thruster devices. This will make the take off thrust of the rocket reach 5884 kilonewtons. The second stage main engine and moveable engines go through an increase in the surface area ratios of the jet tubes and cause the specific impulse of the engines to be raised, respectively, from 2835m/s and 2762m/s to 2903m/s and 2835m/s. Programs will make use of the CZ-2E lifting rocket to launch large model Australian and U.S. applied satellites as well as other similar projects.

Another type of technological path is the research and manufacture of new types of large model lifting rockets and their propulsion systems. This is particularly applicable if one is speaking in terms of launching manned space stations, space planes, and various types of large model spacecraft. One must give consideration to cheap research and production costs, lack of pollution, high performance, and reliability of large model liquid fuel rocket propulsion systems.

The selection of appropriate propellants for large model liquid fuel booster motors is extremely important. At the present time, it is possible to supply selected propellants of the three types set out below: (1) liquid oxygen/liquid hydrogen, (2) liquid oxygen/hydrocarbon, and (3) storable propellants. Liquid oxygen/liquid hydrogen possesses very high specific impulse. However, due to the fact that liquid hydrogen's density is very small, it leads, as a result, to an increase in the structural dimensions of the lifting rockets. Liquid oxygen/hydrocarbon and storable propellants, by comparison, have obvious advantages: relatively high performance, low cost, little pollution of the environment, non-corrosive, convenient for reutilization.

It should be pointed out that, if one wants to research and manufacture high performance, large model liquid oxygen/hydrocarbon booster engines, it is necessary to select for use relatively high combustion chamber pressures. Because of this, as far as hydrocarbon type fuels are concerned, special attention is given to a number of idealized properties, for example, ignition characteristics, combustion efficiency, combustion stability, cooling properties, carbon accumulation in combustion products, and coking in regeneration cooling channels, as well as mutual compatibility of materials, etc., etc. Research clearly demonstrates that liquid oxygen/hydrocarbon used as propellant in booster engines of large model lifting rockets is very possible. Methane, propane, and kerosene, respectively, are well suited to different chamber pressure ranges. It is possible, on the basis of engine technology requirements, to come to a considration of engine system designs. In conjunction with this, on the basis of chamber pressure values, one comes to an accurate selection of which type of hydrocarbon fuel to use. In research, consideration was also given to designs which add small amounts of liquid hydrogen to liquid oxygen/hydrocarbon.

2. Liquid Oxygen/Liquid Hydrogen Engines

As far as the combining of liquid oxygen and liquid hydrogen propellants is concerned, due to high specific impulse and clean exhaust gases, its use is growing more widespread everyday. This is partricularly the case with second stage main motors and upper stage engines.

Because of liquid hydrogen having a very low density and its associated ease of evaporation, it must be insulated. Because of this, the aircraft structural dimensions are relatively large. If one wants to adequately take advantage of the strong points of this type of fuel, it is necessary, as much as possible, to raise engine capabilities and reduce structural dimensions and weight. Normally, it is possible to go through a raising of chamber pressures and jet tube surface area ratios, opting for the use of closed type circulating systems (such as supplementary fuel circulating systems and vaporization circulating systems) as well as raising single engine thrust and other similar measures in order to raise engine capabilities.

As far as the liquid oxygen/liquid hydrogen third stage engine of the Long March No.3 lifting rocket is concerned, its thrust is 44.1 kilonewton. Specific impulse is 4168 m/s. It is possible to realize two ignitions. Operations are totally reliable. It has been used with continuous success in the launching of earth synchronous communications satellites.

As far as the liquid oxygen/liquid hydrogen engines which have a thrust of approximately 78.5 kilonewtons and are just in the midst of being test manufactured are concerned, their specific impulse is approximately 4315m/s. Taking two of this model engine and putting them together forms the inmproved Long March No.3 (CZ-3A) third stage propulsion system. It is capable of making the payload capabilities of lifting rockets increase approximately one fold. It is possible to predict that, following along with the daily broadening requirements of space flight technology, it will be possible to promote taking 8
large thrust, high capability liquid hydrogen engines and putting them on the agenda.

3. Storable Propellant Orbit Mobility Engines and Upper Stage Engines

In order to respond to the different requirements of load lifting missions, it is possible to research and manufacture various types of specifications for upper stage engines and put them together with booster rocket series for utilization, using them in order to launch high orbit satellites and interplanetary probes.

Due to the fact that the density of storable propellant combinations is relatively large, and they do not evaporate easily, it is possible to adapt them relatively well to long term flight missions remaining in space several months or several years. Because of this, they have a bright future for development.

As far as the orbital maneuver engines of space flight craft are concerned, they are used to enter and correct orbits, orbital maneuver, orbital intersection or convergence, and orbit exit for reentry, as well as other similar activities. Normally, one opts for the use of storable propellants and extrusion type supply system. Orbital maneuver engines should possess capabilities for multiple operations and adjustments of thrust over a large range. In conjunction with that, they should be able, in high vaccuum, irradiated, and weightless environments, to perform reliably.

The Long March No.4 lifting rocket's third stage opts for the use of a storable propellant pump pressurized type upper stage engine. It is possible to realize two start ups and dual directional swing. Specific impulse is over 2942 m/s. As far as space plane or shuttle orbital maneuver is concerned, it is planned to opt for the use of storable propellants and extrusion supply systems. This facilitates multiple start ups. In conjunction with this, test manufacturing was done of high performance jet injectors and large surface area ratio jet tubes in order to raise engine capabilities.

4. Auxilliary Propulsion Systems

Auxilliary propulsion is an important component part of space flight lifting systems and spacecraft. They have already been developed into an important branch among the fields of liquid fuel propulsion technology. Uses of auxilliary propulsion systems include attitude control, speed correction, orbit transfer and correction, position maintenance, propellant settling, as well as various types of auxilliary power systems, and so on, on spacecraft. This type of propulsion system requires reliable start ups in an environment of vacuum and weightlessness, a capability for continuous and pulse operations, and the number of operational iterations can even reach higher than several hundred thousand.

As far as auxilliary propulsion systems are concerned, except for situations in which overall impulse requirements are extremely small and one opts for the use of gas jets, for the most part one opts for single component or dual component liquid propellant engines. Single component hydrazine catalyzed decomposition engines possess system simplicity, sensitivity of response, steady state, and pulse operation reproducablitiy, as well as other similar advantages. They are already widely used in various types of spacecraft and lifting systems for attitude control and corrective thrust, terminal velocity correction, propellant settling and position maintenance, etc.

Single component hydrazine fuel gas generator devices are capable of supplying operating mass for the turbines of space shuttle auxilliary power systems. Fluid pressure pumps or electric devices driven by turbines are used in order to control the rudders of space shuttles, landing gear, and brake systems, external storage tank separation, as well as the swing movements of solid fuel booster je tubes. Besides this, it is also possible to use them as emergency power systems for aircraft, etc.

China, in the middle 1960's, began the research and manufacture of single component hydrazine catalyzed decomposition engines, using them in the upper stages of lifting rockets and the attitude control of various types of spacecraft.

Currently, they already form a thrust range of 5.5-1000 Newtons in a series of single component engines. Specific impulses are 2059-2206 m/s.

In view of the relatively high freezing point of hydrazine (1.4^{o}C), in low temperature environments, it will freeze. It is necessary to prepare electrically heated temperature control systems. As a result, one increases the weight and complexity of the structure. Because of this, in the early 1970's, research was begun on low boiling point single component propellants. At the present time, test manufacture of such single component propellants as "Dantui-3", which has a freezing point of -30^{o}C. In conjunction with that, it has been tested and verified on the ground and in flight. This experimental verification demonstrated that the "Dantui-3" propellant's ignition is normal in a vacuum, that cold start up acceleration characteristics are good, that the specific impulse is approximately 20 m/s higher than hydrazine, and that maintanence and utilization are convenient. It is possible to acknowledge that taking

"Dantui-3" and applying it to auxilliary proulsion systems is practically feasible. Currently, test manufacture of several types of specifications for "Dantui-3" in attitude control is on-going. The thrust range is 24.5-1000 Newtons. In conjunction with this, a series will be gradually formed on this foundation.

Following along with the unceasing development of space flight technology, the higher and higher the requirements are for various types of spacecraft in terms of overall impulse and capabilities of auxilliary propulsion systems, the faster dual component propellant attitude engines will develop.

China began the test manufacture of dual component attitude control engines in the early 1970's. A choice was made of nitrooxide 9
agents and hydrazine. The thrust range was 19.6-1520. Among these, except for systems which opt for the use of pump pressure, the remainder are all constant pressure type extrusion systems. Among these, there are also 490 apogee engines and variable thrust engines. Liquid apogee engines as compared to solid fuel engines have clear advantages. Thrust and impulse deviations are relatively small. They can be operated multiple times. Precision of orbit entry is high.

The combination of dinitrogen tetroxide and monomethylhydrazine, due to the narrowness of the temperature range of the liquid state, good high altitude ignition characteristics, little wake pollution, relatively good performance, and stable combustion, as well as similar good points, is already widely used in various types of space engines. In conjunction with this, it has been successfully applied to integrated auxilliary propulsion systems composed of apogee engines and attitude control engines.

Besides this, there is also a type of combined single, dual component design which can supply an option, that is, it uses dinitrogen tetroxide/hydrazine dual component propellant to make apogee engines fly, but it uses single component hydrazine to effect attitude control and position maintenance.

One should point out that, following along with the development of liquid oxygen/hydrocarbon lifting rockets, liquid oxygen/hydrazine supplementary propulsion systems will also achieve acceptance.

IV CONCLUSIONS

1) In order to satisfy even better the requirements of the development of space flight technology, it is necessary to draw up a long range development plan for liquid fuel rocket propulsion technology and to have plans to gradually and greatly raise the level of liquid rocket engine technology.

2) In long range development projects for liquid fuel rocket propulsion technology, one should include the series of items below:

a. liquid oxygen/hydrocarbon large model booster engines

b. high performance liquid oxygen/liquid hydrogen engines

c. storable propellant orbital maneuver engines and upper stage engines

d. single component propellant (hydrazine and Dantui-3) and dual component propellent attitude control engines.

3) Massively begin development of key technological research. In conjunction with that, set up corresponding scientific research facilities.

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