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AERONAUTICAL KNOWLEDGE (SELECTED ARTICLES).(U)

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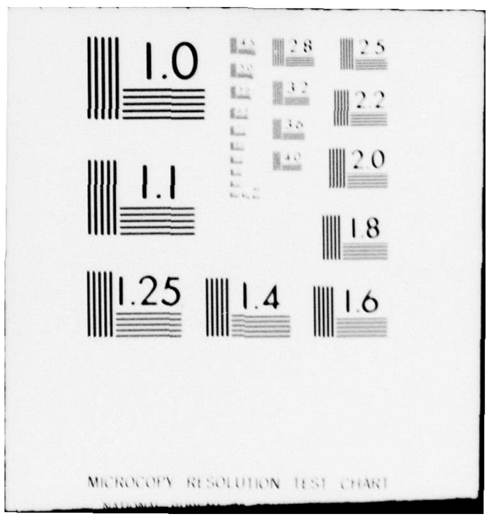
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FOREIGN TECHNOLOGY DIVISION

AIR FORCE SYSTEMS COMMAND

AERONAUTICAL KNOWLEDGE
(SELECTED ARTICLES)

FOREIGN TECHNOLOGY DIVISION

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Table of Contents

A Discussion of The Orbit of Man-made Satellite

--The movement of a satellite in the orbit--

Wu Ling-yao

There is a definite orbit for man-made satellite to fly in space. This article attempts to make a brief introduction of the magnitude, shape, inclination and characteristics of the orbit. Because this article is rather long, it will be published in two consective issues of this journal. In this issue, it gives an account of the movement of a satellite in the orbit, and in the next issue, it will describe the movement of the satellite orbit.

Since man-made satellite appeared in space, the concept of first space speed has gradually beomce known. This means that an object that has a speed of 9km. per second can move around the earth cycle after cycle without stopping. So,by such a speed a satellite can circle the earth once in about 84 minutes and the journey is about 40,000km.long. But, in fact, the orbiting period of a man-made satellite is often more than 84 minutes. Taking China's first and second man-made satellites for example, they took 114 and 106 minutes respectively. This is because that the satellite is not flying closely along the surface of the earth, but it flies at several hundred kilomtres or even higher above the earth. The journey of circling the earth once is more than 40,000km., so the orbiting period is longer. The reasonable explanation of this fact would be that the flight of a satellite becomes slower as its altitude increases. The speed required for circling the earth we call orbiting speed, and it constitutes an inversed ratio with the square root of distance from the satellite to the center of the aerth. The so-called "first space speed" means the speed of an object which moves closely along the surface of the earth (altitude is zero). The higher the object goes, the smaller orbiting speed it requires. For instance, the orbiting speed at altitude of 500km. is 7.6km per second, and at 5,000km. it will be 5.9km. per second (see Figure 1). On the orbit, when the orbiting period is same as the rotation period of the earth, the orbiting speed is only 3km. per second.

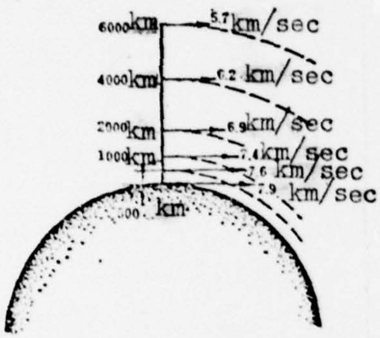

Figure 1

The following table gives the orbiting speed and orbiting period of a man-made satellite at different altitudes.

Orbit altitude (km)	Orbiting speed (km/sec)	hr.	m.	sec.
0	7.912	1	24	25
200	7.791	1	28	25
300	7.732	1	30	27
400	7.675	1	32	29
500	7.619	1	34	32
1000	7.356	1	45	2
2000	6.903	2	7	9
4000	6.203	2	55	17
6000	5.679	3	48	18
35810	3.076	23	56	:

Since the higher altitude of a satellite, the smaller orbiting speed it requires, isn't it that to launch a high orbit satellite is easier than to launch a low orbit one? The answer to this question is "No." In order to send a satellite high above in space, you must try to overcome the gravitation and air resistance. So the higher the satellite goes, the more energy is consumed. The energy used in launching is always much more than that saved when the orbiting speed becomes lower.

Only when the speed of a man-made satellite is exactly same as its orbiting speed in space, it is possible for it to orbit around the earth, otherwise, the orbit of the satellite will become elliptical.

The Rules of the Movement of a Satellite

When a man-made satellite against the earth gravity moves around the earth, it is the same as the earth against the sun gravity moves around the sun. (to be continued)

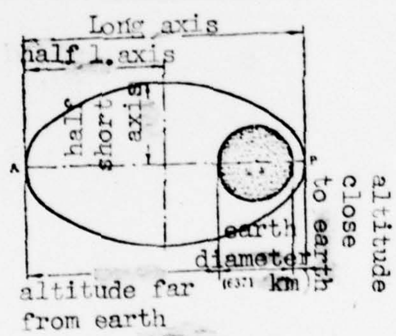

Figure 2

The Development of Air-to-Air Missile Engine

Chien Chin

Air-to- air missile is an air weapon that was created in the late 1940's. The engine,which is a power installation of an air-to-air missile, is in constant improvement and development. This article tries to make an account of how the continuous improvement and development have been going.

After World War II, in order to deal with the bombers which are equipped with powerful self-defence weapons and carry large atomic bombs, as well as to enable interceptors to destroy the bombers outside the attack range of their self-defence weapons, several countries have sucessfully manufactured the first generation air-to-air missiles.

Over the past 30 years, air-to-air missiles have undergone a period of development from short attack range, low velocity and small maneuverability to a longer attack range, higher velocity and greater maneuverability, and from a low hitting rate and small power to a high hitting rate and stronger power. At the same time, the pwoer equipment of an air-to-air missile has been correspondingly magnified in its impulse, and also some significant technical changes have taken place, such as liquid engine is replaced by solid engine.

The power equipment of an air-to-air missile is a rocket engine. Based on the physical condition of using propellant, the rocket engine can be classified into three different kinds: solid, liquid and solid-liquid combination.

Compared with liquid rocket engine, a solid rocket engine has the following advantages: 1. Structure is simple. Because the propellant can be set in the combustor, it need not have any complicated delivery system and storage equipment, nor any cooling system. 2. It is easy to manufacture and the cost is low. 3. Operation and maintenance are all easy. 4. Working reliability is high and it is almost hundred percent. 5. In a very short period of time, it can be in the working condtion as required. This is very important for an air-to-air missile to attack its target. 6. The specific gravity of solid propellant is great and its volume is small. The size of the engine is therefore small and its negative weight is small, too.

Because a solid rocket engine has such advantages, only a few of the first generation air-to-air missiles, such as FX-1400, X-4, "Fire Bird" and "Matra"R04, manufactured in the late 1940's and early 1950's, uses liquid rocket engine. But such missiles as "Sparrow" I, II, "Falcon"AIM-4, 4A, 4B, 4C, "Sidewinder"AIM-9B, K-5 (illustrated by Figure 1), "Fireflash", "Fire Streak, and "Matra" R.510 and R.511, use one-stage propelling solid rocket engine.

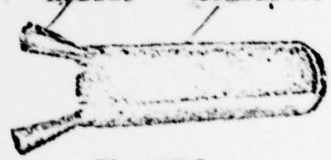

Figure 1

The velocity of these missiles is 1.8-2.5 times of sound speed, attack range is about 8km. and practical altitude is about 15,000m.. In order to improve velocity and attack range, the missile changes to use high energy engine and propellant which can burn completely under low pressure. Because of the increase of combustion heat of the propellant, the effective exhausting speed increases, thus the maximum velocity of the missile is increased. Besides, as the propellant has been burned completely under low pressure, pressure in the combustor becomes low, then the walls

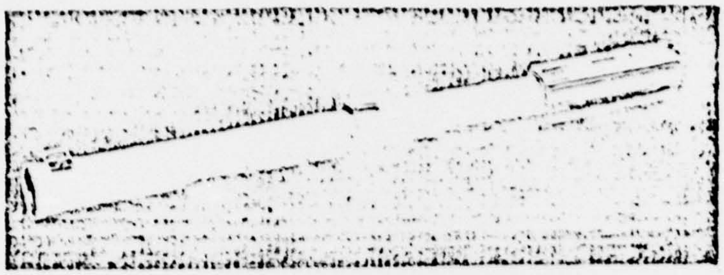

Figure 2

of the combustor can be not so thick, and the negative weight is therefore decreased. As a result, the velocity and attack range of the missile is improved. In addition, the engine must be made of heat-resistant material which has high degree of strength and small specific gravity, and the structure of powder charges should also be improved.

According to the requirements mentioned above, most charges of the first generation air-to-air missile engine use double-based powder made of nitrocellulos and nitrocotton. The quantity of heat of this combination is 800-1,200k-cal/kg., and the combustion temperature is about 1,800-2,500°C., and the practical epecific impulse is 180-200sec.. The shape of the charge is tubular free pouring powder. The shell of the engine is a round tube made of low alloy plate. For reducing the heat on the shell, it is painted with a layer of heat-insulating material. The nozzle is made of low carbon-steel and the ignition device is a box-shaped ignitor which is made of electirc fuse and black powder.

In order to minimize the negative weight and to promote attack range and velocity of the missile, the engine has changed to use center star-like hollowed combusting powder in place of tubular powder which can burn on both inner and outer sides. By using this kind of powder, the combustor walls can be protected by the powder that has not yet been burning, and

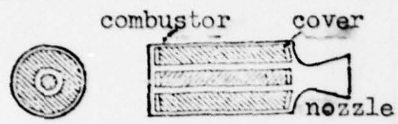

Figure 3 Enveloped tubular charge

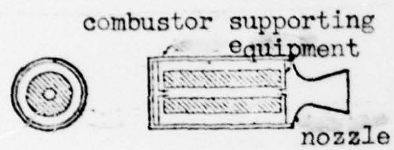

Figure 4 Tubular free pouring charge

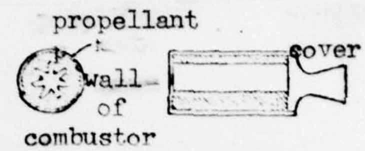

Figure 5 Center star-like hollowed pouring along the wall charge

they are therefore isolated from the high temperature combusting air. Thus the working temperature of the combustor walls maintains relatively low, and the walls can have highest strength. Often high strength aluminium alloy is used to be the main structure of a combustoras illustrated by Figure 2.

Some air-to-air missiles, such as "Falcon"AIM-4, 4A, 4B, 4C, use solid rocket engine, of which the feeding of combined powder is made along the walls.

Due to the technical changes mentioned above, the quality-quantity ratio of the engine can reach 0.5 and above, and its weight specific impulse is about 100sec..

From 1955 through 1966, there are medium range supersonic bombers, such as B-58, Chart-22, "Phantom" III, and the practical climbing ceiling is all above 18,000m., and there is also B-25, which carries many electronic counter equipment. Since the traditional boundary of an interceptor and a bomber has changed, most of tactical planes can be used as both an interceptor and a bomber, and they can also carry out nuclear bombing missions. Air-to-air missiles are therefore in need of new tactics, so they begin to have characteristics of the second generation air-to-air missiles. They can attack at every direction and under every kind of weather. The second generation air-to-air missiles include "Sparrow" IIIAIM-7C, 7D,7E, "Falcon" AIM-4E, "Super Falcon"AIM-4F, 4G, "Nuclear Falcon"AIM-26A, "Sidewinder"AIM-9C, 9D, "Red Top", "Matra" R.530, K-13. The velocity of these missiles is 2-3 times of sound speed, attack range is 8-22km. and practical altitude is 15,000-25,000m.. Most of the power equipment of the second generation air-to-air missiles use one stage propelling solid rocket engine and some, such as "Matra" R.530, uses double-stage propelling solid rocket engine.

For minimizing the structural weight and promoting attack range and velocity, the charge in the missile uses high energy combined powder, which is made of crystal oxidant(such as potassium perchlorate, ammonium perchlorate, and ammonium nitrate) and some kind of polymer as adhesive agent (such as polysulfide rubber, plastomer, polyvinyl chloride and polybutadiene). The quantity of heat of this kind of combined powder is 1,100-1,400k-cal/kg., the combustion temperature is 2,500-3,000°C or above and the specific impulse is 210-240 sec. or above. Their shapes have enveloped tubular charge (as illustrated by Figure 3), tubular free pouring charge (as illustrated by Figure 4) and center star-like hollowed pouring along the wall charge (as illustrated by Figure 5).

Because of the use of center star-like hollowed combined powder poured along the walls, the propellant can combust normally under lower pressure. The combustor is a complete structure using low alloy steel pressed into its shape. The structural weight of the combustor is small, reparing period becomes short and the cost is low, but the capability of the missile is increased. Since the energy charge is improved, the combustion temperature evidently goes up. For this reason, the nozzle made of ordinary materials can no longer satisfy the requirement, so a nozzle which is made of high strength

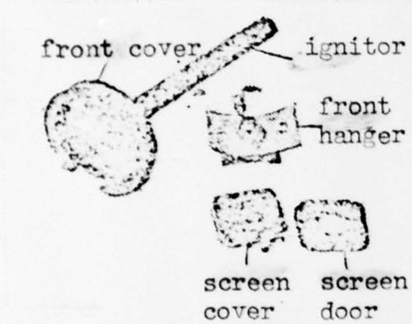

Figure 6 Ignition system

Figure 7 Ignitor and high energy tubular igniting charge

whole carbon and a compound nozzle which is made of high temperature resistant and worn-off proof combined material have been manufactured. The ignition device is made of powders of various shapes and the shape of the ignitor is also multiform as illustrated in Figure 6 and 7.

As the engine of the second generation air-to-air missile uses high energy combined powder, the quality-quantity ratio of the engine goes about 0.7, and the weight specific impulse can reach 140 sec. or so. Consequently the capability of the missile is greatly improved. Figure 8 and Figure 9 are illustrations of the solid rocket engine of the second generation air-to-air missiles.

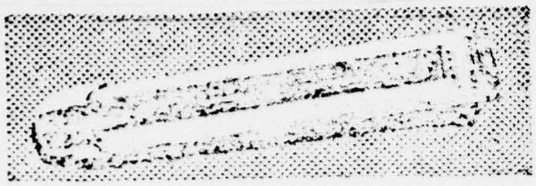

Figure 8

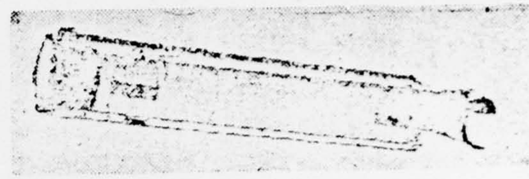

Figure 9

Since the middle and late 1960's, the tendency of the development of air-to-air missiles has been double-headed. For dealing with the bombers which can make attack at long range and low altitude, several countries have successfully manufactured air-to-air missiles which can make attack long range attack at target coming from any altitude. This is the so called third generation air-to-air missile, such as "Falcon"AIM-47A, "Immotal Bird"AIM-54A, and "Matra" super R.530, AA-6. The velocity of these missiles is 3-6 times of sound speed, attack range is 35-185km., and the practical altitude is 15,000-29,000m..

From the experience of using medium range missiles in Vietnam, Middle East and India-Pakistan wars, it has proved that today available missiles cannot meet the requirement for planes which can engage in dog-fight. So many countries have begun to manufacture the so-called hand-to-hand fight missiles, such as "Agile", "Matra" R.550, SRAAM and AA-8. The velocity of these missiles is 2-3 times of sound speed, attack range is 200-2,000m. and the practical altitude is 15,000m.. The power equipment of the third generation air-to-air missiles uses double-stage propelling solid rocket engine.

The engine that is commonly used now is of a single combustor and double-stage propelling force. Its main structural parts include a combustor, boosting charge, flight-sustaining charge, nozzle and ignitor as illustrated by Figure 10.

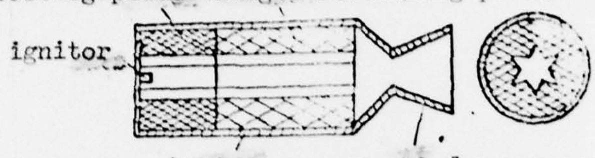

Figure 10 Single combustor and double-stage thrust engine

The single combustor and double-stage thrust engine has two different internal hollows, in which the charges are made of powders of same burning speed and solid fuel of different burning speed (fast-burning and slow-burning). Thus they form a two-stage propelling force.

The ignitor ignites the boosting charge and the flight-sustaining charge at the same time, so the missile soon has its required velocity. As the burning speed of the boosting charge is fast (or it is very thin), the powder can be burned up very fast, but the flight-sustaining charge can continue to produce propelling power to overcome the air resistance and to maintain the acquired velocity (or a small acceleration). Thus the missile can fly forward to its target.

The advantage of this kind of two-stage thrust engine is that the missile can have a greater final velocity, good maneuverability. And in the whole flight, the velocity change is stable, and this is good to change the propelling direction and to control the missile.

Compared with the previous two generations, the propelling force device of the third generation air-to-air missile, in addition to high energy powder and light structure, has a construction of thrust vector quantity control in the short range hand-to-hand fight missile. "Agile", for example, except for a small stable tailwing, is wingless, and the direction control is performed by the revolving of the nozzle. Simply because it has a vector quantity control, its maneuverability is better than others.

The short range fight air-to-air missile SRAAM-75, based on the principle of thrust vector quantity control, on the tail of its engine set four modulating blades to modulate the combustion air flow, thus it can change the propelling direction in order to control the missile direction.

Before the appearance of these newly made short range missiles, in several countries, they have tranformed some of the avialble models. That is the so-called "trnsitional" short range missile, such as "Falcon"AIM-4D, 4H, "Sparrow"AIM-7E2, 7F, 7G, and "Sidewinder"AIM-9L.

The velocity of these transitional missiles is 2-3 times of sound speed, attack range is 9-26km., and the practical altitude is 15,000-18,000m..

The power equipment of these missiles is a one-stage propelling rocket engine. The charge is made of center star-like hollowed combined powder poured along the wall as illustrated by Figure 11.

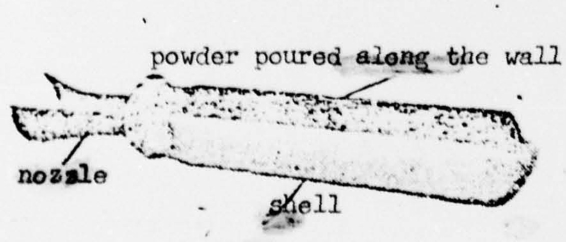

Figure 11

The cover of the engine is made of alloy steel rolled into its shape. The nozzle and the ignition equipment are the same as those of the second generation missiles.

The third generation air-to-air missiles not only have longer attack range and greater velocity and their maneuverability is excellent as well. This is because that they use high energy powder charge, single combustor and double-stage propelling force engine, and they are also equipped with revolving nozzle, modulationg blades and adjustable nozzle. Moreover, the new techniques of direction control and the new materials and new technology all have their contributions to these superiorities of the new missiles.

In short, over the past 30 years, the attack range of air-to-air missiles has increased from from 4km. to 185km., it has been promoted 46 times more. The velocity has been increased 3.5 times greater by improving it from 1.8 to 6 times of sound speed. The practical altitude has been changed from 15,000m. to 29,000m., it is almost doubled. The weight of the missile has been changed from 50kg. to 400kg., it is more than 7 times heavier. All these advancements are certainly connected with the continuous development of the engine.

As a result of the advancement of aviation technology, there come out new bombers and new interceptors. For satisfying the requirements for making the air-to-air missile of new generation have higher ability, many countries are now being engaged in developing solid-liquid rocket engine by combining solid and liquid propellants. This effor will certainly lead the power of rocket engine to reach a new level and its theoretical impulsion can become 350 seconds.

One part of the propellant of a solid-liquid engine is solid and the other is liquid. The oxidant is liquid and the fuel is solid. When the liquid oxidant is sprayed on the solid powder charge, it begins to burn. The fundamental structure of the engine is that it consists of a combustor which contains solid powder, a case of liquid oxidant and a combusting air producer producing compressed air, by which the oxidant is sent into the combustor. The structure is illustarted by Figure 12.

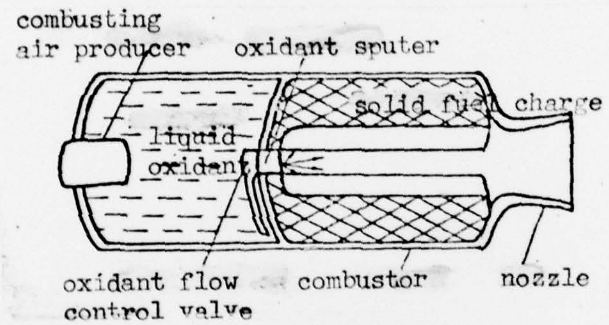

Figure 12 Diagram of a solid-liquid rocket engine

Solid-liquid rocket engine absorbs the good points of the solid and the liquid engines and eliminates their shortcomings. It is a good combination of the two. A solid-liquid rocket engine has the following strong points:

1. It has high specific impulse and broadens the range of propellant selection.

Generally speaking, the theoretical impulsion of a solid-liquid combined propellant is higher than solid propellant and liquid propellant which can be stored. But it is slightly lower than low temperature liquid propellant, of which the specific impulse range is between 250 and 400 seconds. Compared with the specific impulse range of 200 to 310 seconds, it is a great promotion.

2. It has the thrust which can be changed and the power which can restart the engine.

Like a liquid engine, the solid-liquid engine has the thrust which can be changed, and in a flight, it can stop burning but it can be ignited again. It is hardly possible for a solid engine to do so.

3. The structure is simple.

Obviously the structure of a solid-liquid engine is more complicated than a solid engine, but it is much simpler than a liquid engine because it leaves off a number of supporting systems. Compared with the solid engine, the liquid oxidant of a solid-liquid engine can be cooled off, so it excludes the weight of the cooling part. Thus it greatly increases the possibility of having more working hours.

4. It is easy to manufacture and to transport. It is safe to handle it and it has good durability.

Unlike the solid propellant, the oxidant and the fuel of a solid-liquid combined propellant are separate. So it is not like the solid propellant which must be under various limitations.

5. The cost is low.

In addition to high ability, the main characteristics of a solid-liquid engine are high maneuverability, safe to operate and simple to use. Above all, it can achieve high propelling force at low cost. Therefore, the solid-liquid engine represents an important development of chemical rocket. It has caught attention in many countries. Solid-liquid engine is now at its flight testing stage.

(Drawings by Chang Chen-yeh)

****

New Terms

Quality-quantity ratio. The quality-quantity ratio of a solid rocket engine is the rate of the powder charge weight in the engine and the total weight of the engine (the powder charge weight plus the structural weight of the engine). The larger the value is, the greater the velocity of the missile is.

Total impulse. That the thrust of the engine times working hours is the total impulse of a rocket engine. Its unit is "kg.sec".

Specific impulse. It is the thrust produced by the engine by using 1kg propellant per second. Its unit is kg.s/kg, and it can be simplified as sec. When the weight of the powder charge is fixed, the larger the specific impulse is, the greater the total impulse of the engine is, and when the load is fixed, the farther the attack range of the missile is.

Weight specific impulse. It refers to the ratio of the total impulse and the total weight of the engine, namely the impulse produced by 1kg of the engine.

Volume specific impulse. It refers to the impulse produced by one unit of the volume of the engine. It indicates the degree of using space by the engine.

Negative weight. In a rocket engine, the structural weight excluding the propellant is called negative weight. Under a fixed load, the smaller the negative weight is, the farther the missile flies.

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