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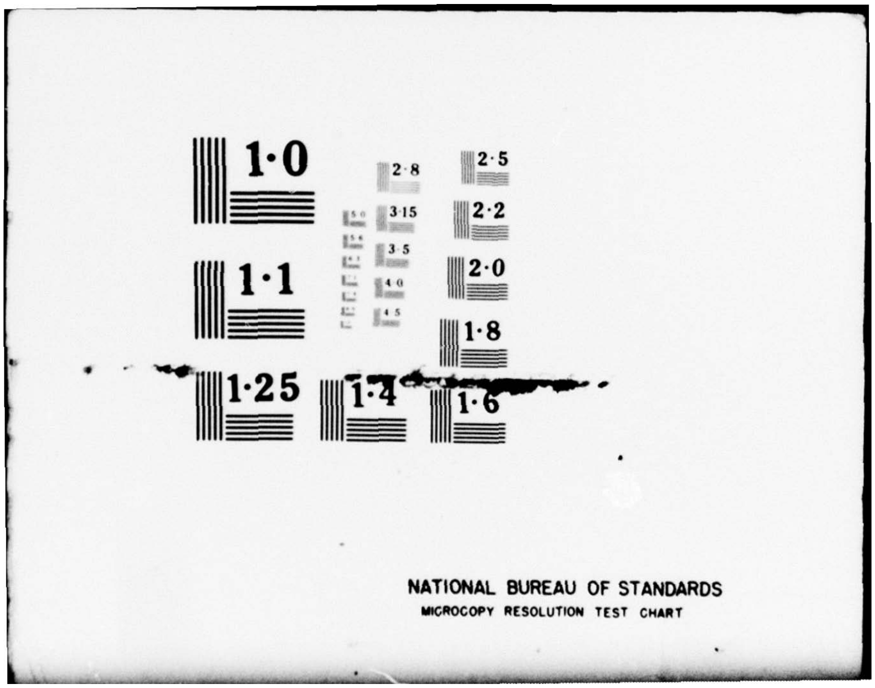
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FOREIGN TECHNOLOGY DIVISION

AIR FORCE SYSTEMS COMMAND

THE RETURN OF A SATELLITE AND SPACECRAFT

by

HAU Pao

EDITED TRANSLATION

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THE RETURN OF A SATELLITE AND SPACECRAFT

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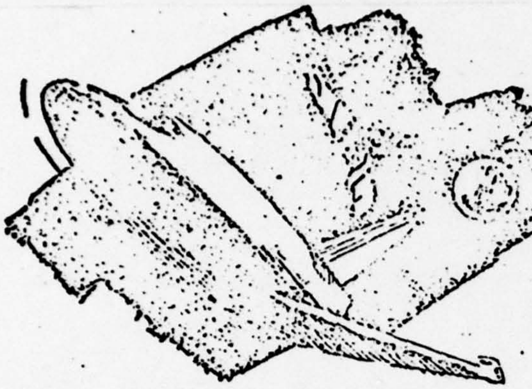


卫星和飞船的返回

THE RETURN OF A SATELLITE AND SPACECRAFT

by

HUA Pao

This article continues to introduce the aerodynamic heating, heat protection structure and its principle, landing process, and aircraft-shaped reentry vehicle of the satellite and spacecraft in the reentry process.

AERODYNAMIC HEATING AND HEAT PROTECTION STRUCTURE

When the sapcecraft starts to return from orbit, it possesses tremendous energy which includes kinetic energy (due to the velocity of the vehicle) and potential energy (due to the altitude of the vehicle above the earth). After the vehicle enters the atmospheric shell, the speed reduces rapidly due to the action of air drag. During the speed-reduction process, most of the tremendous energy of the vehicle at return is V = 7.73 km/sec. Then the kinetic energy possessed by 1 kg of mass is about 29,900,000 joules which can convert to 7,130 kilocalories of heat energy. Such large amounts of heat can heat 30 kg of steel (melting point 1,500°C) to 2,000°C. This means that if all the energy possessed by the vehicle were converted to heat energy at reentry and all the heat were transferred to the vehicle itself, then all that heat could turn the whole vehicle with the heat protection and cooling systems to ashes. However, a large portion of the heat that was converted from the energy of the vehicle dissipates into the surrounding space through the shock wave and the effect of radiation, and only a small portion is transmitted to the structure of the vehicle.

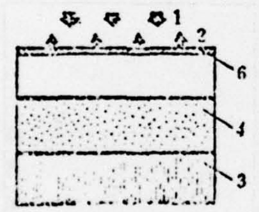
The heat dissipation due to the action of the shock wave is the result of the interaction of the air molecules surrounding the vehicle. After entering the atmosphere, the velocity of the vehicle is very high. It is more than 10 to 20 times the velocity of sound at an altitude of 40 to 50 kilometers. In such a hypersonic air stream the vehicle constantly and forcefully compress the air in front of it. The density of the compressed air increases by more than 10 times, the temperature increases to 6,000°C - 8,000°C, and a strong shock wave is formed in front of the vehicle. The air molecules hit the surface of the vehicle and bounce off. Many of the bounced molecules impinge on the new incoming molecules which are scattered in the air stream and unable to contact the surface of the vehicle, thus preventing the new incoming air molecules from transmitting energy to the vehicle. Consequently, a large amount of heat is dumped in the space between the shock wave and the surface of the vehicle. The shock wave extends outward and backward for a long way from the vehicle and forms a big trail. This trail is formed of heated air which includes the largest portion of the heat generated by the reentry capsule when it reenters the atmosphere. The heat in the trail gradually dissipates in the atmophere. The dissipated heat is proportional to the intensity of the shock wave. The higher the intensity of the shock wave, the more the heat can be dissipated, and the less the heat transmitted to the vehicle. For the vehicle to generate a strong shock wave, the nose of the vehicle must be blunt. Therefore, the reentry capsule of the space ship or satellite chooses a blunt nose, unlike the long streamline of the supersonic airplane.

A reasonably selected aerodynamic contour of the vehicle could dissipate 98% of the heat generated from the reentry of the vehicle into the atmosphere; only about 2% of the heat passes through the boundary layer to the structure of the vehicle. Though the proportion of heat is small, it is serious for the vehicle: on the intensely heated portion of the nose, the maximum heat stream could be several hundred kilocalories per second per square meter and the total heat on each square meter could reach at several tens of thousands of kilocalories. Therefore, the vehicle must take reliable heat protection measures; otherwise it will burn up in atmosphere like the meteorites.

The heat protection structure has a higher specific gravity on the reentry capsule. The weight of the heat protection structure is about 10% of the total weight of the reentry capsule of the vehicle which reenters from near-earth orbit. It is about 14% of the weight of the vehicle that returns from the moon. Therefore, selection of a heat protection method according the degree of heating from the process of reentry with various reentry modes of the vehicle to reduce the structural weight and to warrant a safe return is very important. There are three heat protection methods commonly used in foreign countries (Fig. 6):

Heat Sink Method

Radiation Method



Ablation Method

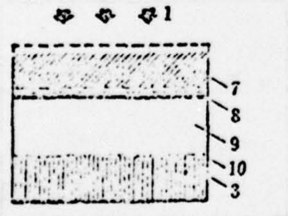


Fig. 6 Diagrams showing the principles of three heat protection methods

Key to Fig. 6: 1. heat from the air stream, 2. heat radiates from shield, 3. supporting structure, 4. insulltion, 5. shield of large heat capacity, 6. shield, 7. carbonized layer, 8. decomposed layer, 9. non-ablated material, 10. adhesive layers.

1. Heat Sink Method: The shield of the heat protection structure for the heat sink method is rather thick. It uses a high specific heat ratio, good heat conductivity, and high-melting metals, such as beryllium, copper, etc. Thus, the shield has a larger heat capacity. The aerodynamic heat is absorbed by the shield when transmitted to the structure and stored in the shield as a dam stores water that flows down from the upper course of the river. suppose that the shield is at 0°C at the time of return. Beryllium can hold 830 kcal/kg before its surface starts to melt, and copper can hold about 150 kcal/kg. If the reentry capsule gains a large amount of aerodynamic heat at reentry, the weight of the heat protection structure must be made very heavy. Consequently, the heat protection ability of the heat sink method is limited; it is only suitable for a small portion of the reentry vehicle. For example, when the "Mercury" spacecraft reenters the atmosphere, the base (big head) is in the front, the cylindrical portion of the rear end is located behind the wake area, heating is not too intense, and a heat sink type heat protection is used. The shield is beryllium plate, and its maximum thickness is 5.6 mm.

2. Radiation method: The shield of a radiation type heat protection structure uses a very thin high-temperature alloy such as the alloy of nickel, niobium, etc. Under the influence of the heat stream of aerodynamic heating, the temperature of the shield increases continuously and the heat radiated from the surface of the shield increases according to the fourth power of the shielding temperature. When the temperature is raised to a certain de-

gree, the heat stream transmitted from the air stream to the shield is equal to the heat stream radiated from the shield surface and the shield temperature will not raise nay further. This temperature is called equilibrium temperature. Theoretically speaking, the radiation method has nothing to do with the heating time and the accumulated total heat; it is only related to the maximum heat flow which is related to the heat transmitted from the air flow in a unit time to a unit area. The larger the maximum heat flow, the higher the equilibrium temperature of the shield; however, the latter is limited by the mechanical and physical properties of the material under the high temperature. According to the properties of high heat-resisting metal, the radiation method is suitable for the condition that the maximum heat flow is not more than 100 kcal /sec/sq m. For instance, the cone of the "Mercury" spacecraft is in the wake area during reentry, the heat flow is not great, and radiation-type heat protection is used. The shield is a 0.4-mm nickel alloy plate, with blue-black high radiation coefficient glaze painted on the surface, and the maximum temperature during reentry is about 900°C.

3. Ablation method: When solid material, generally high molecule material, is under a strong heat condition, the surface of the material starts to melt, evaporate or sublimate, or decompose and vaporize. This phenomenon that absorbs heat during those processes is called ablation. Ablation-type heat protection is a kind of "sacrifice the pawn to save the castle" method, that is, let the structural surface material burn out on purpose to take

away the heat and save the main structure.

There are many kinds of ablative material. The carbonized ablative material is a common one. Glass cloth reinforced phenolplast and nylon reinforced phenolplast are the so-called glass steel. Under the influence of heat flow, the temperature of the structural surface rises. When the temperature has reached the decomposing temperature, the polymer of glass steel, such as phenolic resin, starts to decompose to gas and carbon residue. During this process tremendous heat is absorbed. Gradually the decomposed area extends inwardly due to the continuous heat, the decomposed gas gradually escapes to the surface of the structure, dissipates to the air flow, and forms a carbonized layer on top of the decomposed are. The exhaled gas, thickening the boundary and forming a protective gas layer on the surface of the vehicle, prevents the heat flow into the structure to some degree. The carbonized layer, which is a perforated structure, is also good air insulation. At the same time the incandescent surface can also radiate part of the heat.

The ablation type heat protection is generally applied to the reentry heat protection of the long-range missile and is also the main heat protection method for the reentry heat protection of the spacecraft at present. Presently, foreign satellites and spacecraft use this type of heat potection method at the most intense reentry heated portion. However, in comparison with the satellite the spacecraft has longer heating time, smaller heat stream, lower air flow pressure and, therefore, the selection of ablative material is also quite different. For example, the base of the "Mercury" spacecraft is in the front during the reentry process, it is heated intensely, the maximum heat stream is 180 kcal/sec/sq m, the heat is 24,000 kcal/sq m, and the base ablative heat protective layer is a 16.5-mm glass steel layer (40% phenolic resin, 60% glass cloth). When the spacecraft descends to an altitude of 46 km, the surface temperature is the highest - about 1,650°C.

LANDING

After the vehicle enters the atmosphere, the speed is reduced rapidly due to air drag. It is reduced to subsonic speed at an altitude of 15 km. Descending further, the speed of the vehicle gradually approaches the equilibrium descent velocity. At this moment, if the speed is not further reduced, the vehicle will crash on the ground with a velocity of more than 100 m/s. The impact is equivalent to that of an aircraft that crashes into mountain with a velocity of nearly 500 km/hr. In order to assure the vehicle's landing at a certain safe speed, it is necessary to further reduce the speed before landing. Most foreign returnable spacecraft use a parachute as a means of reducing landing speed.

The area of the parachute is inversely proportional to the square of the equilibrium descent velocity of the "object-parachute system". Therefore, if the landing speed is made too low, the area of the parachute must be very large. Generally the landing velocity (vertical component) of a manned vehicle must be no higher than 6 m/s on land, 10 m/s on the surface of the sea, and for an unmanned vehicle it can be 15 m/s.

The parachute system starts to function at an altitude of 15-km or lower. Usually there are two stages in reducing the speed, first, a small parachute opens at an altitude of 12 to 7 km; this will reduce speed some what. Then the main parachute opens at an altitude of 7 to 3 km to ensure the reentry capsule a safe landing. The operation of a parachute system should be very reliable; otherwise the entire flight mission could be ruined. On April 24, 1967, The USSR "Soyuz 1" failed in landing due to fouled parachutes (mainly the shroud lines were tangled), the spacecraft crashed, and cosmonaut V. Komarov was killed. On 7th August 1971, U.S. "Apollo 15" had one of the three parachutes malfunction. Fortunately, the other two main parachutes each of which has an area of 510 square meters opened normally and it was not destroyed. The spacecraft had a velocity of 9.8 m/s when it hit the water, the landing impact overload was over 16 g's. When three main parachute open normally, the landing speed is 8.5 m/s, and the impact overload is from 8 to 10 g's. (Fig. 7)

In order to be recovered by the ground recovery team in time after landing, a marker is installed on the reentry capsule. For example, there were no recovery beacon and sea-water dye on the "Discoverer". The recovery beacon sends radio beacon signals before landing, and from a locator the recovery team can determine the location of the reentry capsule. When the reentry capsule drops in the sea, the water at the landing point is turned into a bright yellowish green by the dye and it will be easy for an airplane in the air to discover the capsule. On 19th August 1959,

Fig. 7 One of the three main parachutes of "Apollo 15" is broken, only two main parachutes are working normally.

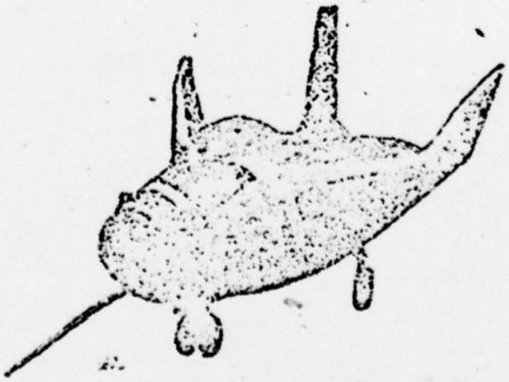


Fig. 8 A lift body type vehicle.

"Discoverer 6" descended on the sea. Judging from the remote signals, every link of operation was normal during the reentry, but the radio beacon had some trouble and did not send out signals; the recovery team was never able to recover this reentry capsule. Later, for better discovery chances, two items were added. One is a blinking light for the convenience of the recovery people at night. Another is the chaff. Thousands of very fine metal wires (zink wires or copper wire) are put in a small box which is tied to the rigging line of the parachute. When the parachute opens, the chaff is cast out and forms a metal cloud for the ground radar to find.

AIRCRAFT-TYPE REENTRY VEHICLE

The ballistic reentry vehicle has been introduced as above because of the aerodynamic shape and heat protection structure's simplicity. A number of advantages include the fact that it is practical from an engineering standpoint and, therefore, all foreign returnable satellite and spacecraft use this type. However, there still exist many defects in the ballistic reentry vehicle. For instance, it doew not have a mechanical flying capability (ballistic type) or limited flying capability (semi-ballistic type); it can land vertically only by parachute, thus requiring a large recovery area and a big recovery team; its heat protection structure is badly burned and cannot be reused, etc.

For many years, the Soviet Union and United States, two super countries which are based on the reactionary characters of their imperialism, have consistently put a great effort into airplane-type reentry vehicle research work. The main characteristic of this type of vehicle is that it produces a reasonable lift during the reentry. Thus, it can glide, circle, and fly mechnically for several thousands miles in the atmosphere. It may land on a predtermined runway using a landing gear and can be reused many times.

The airplane-type can be divided into two categories, the lift body and vehicle with wing. The lift body (Fig.8) has no wings. The lower body of the fuselage is rather flat. It can produce a certain amount of lift and the lift-drag ratio is in the range of about 0.5 to 1.3. The winged vehicle is also called sailing sky airplane*; it looks like a high speed airplane and the lift-drag ratio can reach 2 (please see Sept. 1974 issue). These two types of vehicle have been studied in foreign countries for many years, but there are still a number of key technical problems that remain unsolved. They are still under study and will not be introduced here in detail.

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