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FOREIGN TECHNOLOGY DIVISION

AIR FORCE SYSTEMS COMMAND

AERONAUTICAL KNOWLEDGE
(SELECTED ARTICLES)

FOREIGN TECHNOLOGY DIVISION

EDITED TRANSLATION

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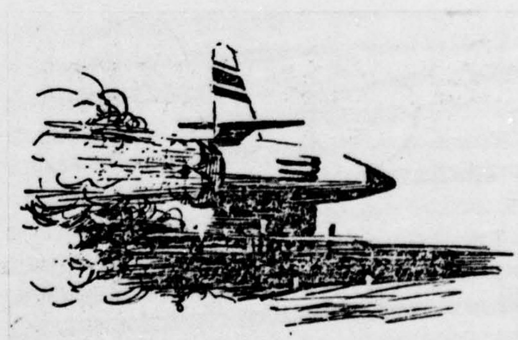
ROCKET VEHICLES

Meija

Rocket vehicles are new equipment which are powered by rocket engines to slide on specially built rails at high speed. They can be used in a large number of simulations for testing airplanes, guided missiles, and other space vehicles. This article introduces the principle, function, and testing equipment of rocket vehicles.



As scientific technology advances, the speed and acceleration of airplanes, guided missiles and other flying vehicles become increasingly high. Therefore, more technical problems are encountered which require more tests for new vehicles using simulations. A rocket vehicle is new test equipment developed with the help of new technology to satisfy this requirement.

Principle and Characteristics of Testing

A rocket vehicle is new equipment which is power by rocket engines to slide on specially built rails at high speed. It has all the appearance of a regular railway car. The rocket propulsion system is located at the rear of the vehicle. It advances by sliding blocks instead of by rolling wheels. During testing, the systems to be tested (such as guided missiles, airframes) are located at the front end of the vehicle. When the rocket engine starts, the vehicle will slide on specially built rails at high speed, powered by the huge **thrust** of the rocket engine as shown in Figure 1. At present the maximum speed that can be achieved by the rocket vehicle is in excess of Mach 5. Specially designed brake systems stop the vehicle and recover it. The vehicle is equipped with instruments for test data collection.

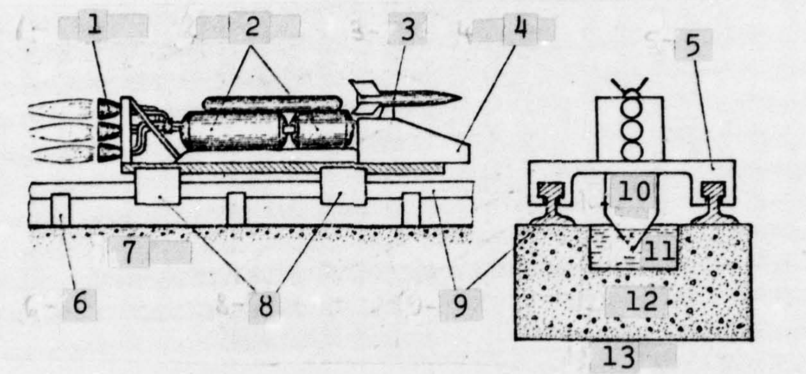


Figure 1. Schematic diagram for rocket vehicle structure

1 - rocket booster; 2 - propulsion fuel tank; 3 - tested part; 4 - test instruments; 5 - sliding block; 6 - blocking board; 7 - rail foundation; 8 - sliding blocks; 9 - **rails**; 10 - hydraulic equipment; 11 = water; 12 - rail foundation; 13 - rear cross section view

The main characteristics of rocket vehicle testing is that is provides a realistic environment for the tested flying systems, therefore it provides realistic data for testing. Because the test is done on the ground, it is advantageous for observation and data collection. Usually testing of rocket vehicles is done outdoors. The volume of the test system need not be limited and can be used to test large scale test bodies (such a full scale guided missiles, airplane parts, etc.), as well as small ones. It also has a large range for various speeds. Besides, rocket vehicles can be recovered after testing. After repair and adjustment they can be used for further tests, thus reducing expenses and labor, and shortening the schedule.

Main Parts

Due to different objects and objectives for testing, the shapes and sizes of the rocket vehicles are different. There are many different kinds of rocket vehicles, but they are all variations on a theme. The main parts are: vehicle body, power plant, brake system and sliding blocks (see Figure 1).

1. Vehicle body. The size and shape vary depending on the tested objects and objectives. Generally there are two kinds: unibody construction where the tested object and test equipment are put together into an instrumentation compartment. The other is the use of a mechanical link to connect the front and rear parts. The tested object and testing equipment is loated in the front and the power plant is at the rear (see Figure 1).

2. Power plant. Solid boosters, liquid boosters, or rocket engines are used which use either solid or liquid fuel as the power plant. It is more economical to use solid boosters for rocket vehicles which are used infrequently. They are easy to use and simple to store. However, the thrust of the solid booster is not easy to adjust and cannot function for a long period. These are its main deficiencies. Liquid boosters are used for rocket vehicles which have to perform a large number of experiments. The advantages are: less expensive, smooth acceleration, adjustable thrust, and long period of operation.

3. Braking. To reduce the speed and to stop the rocket vehicle, parachutes, frictional brakes, and hydraulic brakes can be installed. Reverse braking engines can also be used. For hydraulic brakes, water is stored in the tank between the rails. When the brake is applied, the brake hood undernearth the rocket vehicle (Figure 2 brakes the surface of the water tank. The water then will enter the hook and go through a bend and exit in the reverse direction. The main force of braking is created by the water stream at the bend and the angle of the bend. Usually a bend angle of 140° will give a maximum braking force.

4. Sliding block. The sliding block slides on the rails and holds the vehicle on the rails. It engages the rails tightly so that the vehicle will have no motion either toward left or right or upward. To make sure that the vehicle will slide along the rails smoothly at high speed, the requirement for the gap between the block and rails and the smoothness between the two surfaces is very strict. Otherwise the friction between the two will induce vibrations and pulses which influence the reliability of the test data. The calibration of the smoothness is usually done by optical methods.

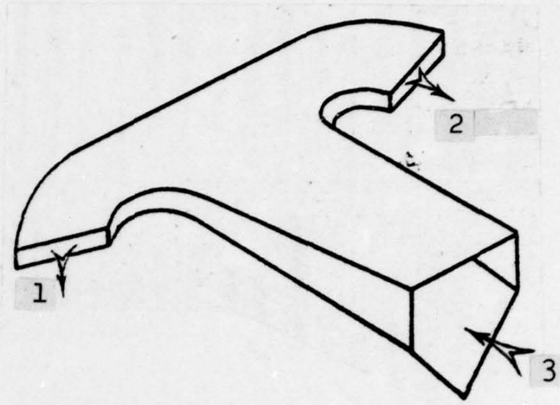


Figure 2. Outline of hydraulic brake equipment

1,2 - water exit; 3 - water entrance

Types of Tests

Since rocket vehicle tests can be run in a realistic environment (including sudden change of acceleration, sustaining acceleration, vibration, etc.) under full scale conditions and can be used repeatedly, it is a very cost-effective and is widely used in aeronautical engineering. The types of tests generally run are:

1. Structure, instruments, and parts of guided missiles.

During the ignition and launch period, the shock wave generated could reach 50 g (g is gravitational acceleration). Inside the missile, the moving parts, engine noise, and other mechanical vibrations could reach 40 g. This complex dynamic environment seriously affects the normal functions of missile structure, instrument, and parts. From tests conducted on rocket vehicles, weak links in structure, instruments, and parts should be detected and corrected.

2. Guidance and control system test

In actual flight, the high rate of change of acceleration will damage the guidance and control system and cause malfunctions. As an example, the system which will function properly at a load of 30 g and a rate of acceleration change of 2000 g/sec will be damaged at a load of 20 g and a rate of acceleration change of 10,000 g/sec. Rocket vehicle tests will solve the reliability problem of guidance systems on the ground.

3. Fuel pumping system test

At high velocities and high pressure, the pumping of fuel inside the rocket engine is very difficult to control accurately. If mixing is improper, fuel in the tank might be consumed prematurely or other malfunctions may occur. The rocket vehicle could be used to test the engine for accurate design parameters.

4. Aerodynamic test

Rocket vehicles are known as "outdoor wind tunnels". They can be used for subsonic, sonic, and supersonic speed aerodynamic tests to avoid the restrictions intrinsic to wind tunnels. Full-scale models could be tested to obtain data more accurately than from tests done in wind tunnels. The aerodynamic tests which could be done on rocket vehicles are:

(i) Vibration tests for full-scale guided missiles and airplane parts. The main purpose of the test is to check the parts which are susceptible to vibration (such as the surfaces of wings and rudders) for possible defects to insure flight safety. For full-scale tests, actual parts could be used and no scale models need be built. In wind tunnel tests, scale models are used. They could simulate some parameters (such as length, speed, air density, etc.) but not parameters such as discontinuities, nonlinearities, resistance and drag of the structure.

(ii) Aerodynamic characteristics test. To test the lift force drag force, twisting force and twisting moment. Figure 3 is a schematic diagram for aerodynamic tests of a missile.

(iii) Test for structure soundness under aerodynamic influence.

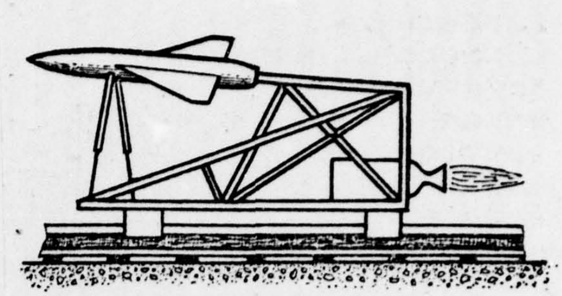


Figure 3. Schematic diagram of guided missile undergoing aerodynamic characteristics test

(iv) Test of ejected parts from missile in motion. In this test, tested parts such as ejection seat and bombs could be ejected from the rocket vehicle.

(v) Dynamic tests of warheads and fuzes. Using rocket vehicles, the functioning of fuzes, penetration force, and warehead fragments could be tested at high speed.

(vi) Tests for separation mechanism of multistage missiles.

(vii) Other tests. Rain erosion, airplane drag parachute, and biological effect in space tests (study of physiological effect on human beings under high g, see Figure 4).

Test Equipment

To accomplish the previously stated tests, we need test fields for the rails and rocket vehicle, test equipment and buildings. High precision instruments are indispensable. They are used to conduct tests; collect, transmit, receive, record, and analyze data. The major instruments are:

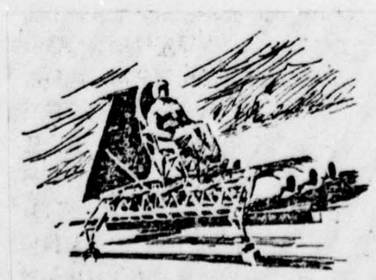


Figure 4. Pilot loading test using rocket vehicle

1. Velocity measurement instruments

They are used to measure accurately the velocity of the rocket vehicle. They consist of photoelectricmeter, transmitter, ground receiver, pulse counter, and blocking boards. Blocking boards are installed alongside the rails at certain intervals. When the vehicle passes the block boards, the light to the photoelectric meter is suddenly cut off. This induces a pulse which is transmitted to the ground receiver. Using pulse counters, the time between every blocking board can be accurately calculated. Using computers, the velocity and acceleration of the vehicle can be determined.

2. Remote sensing equipment

Different remote sensing devices could be used to run different tests.

3. Photographic equipment

Cameras could be installed on the vehicle to record various phenomena during the test. Some cameras could be installed along the way to be used as auxiliary equipment for speed measurement.

So far, we have introduced some simple facts about rocket vehicles. Compared to wind-tunnel and scale-model test flights, the use of rocket vehicles to test parts of a system has its advantages. However, some disadvantages exist as well. Examples are: the length of the rails is limited; the short duration of the test; more complicated flight environment due to ground effect; long lead time for preparation. Therefore, rocket vehicles can be used only as a supplement to wind tunnels, vibration test equipment, centrifuges, etc., but not as a replacement. They can be used only in conjunction with other test equipment. As rocket vehicle technology advances, the disadvantages mentioned could be overcome. We can expect rocket vehicles to have a definite impact on the design of flying vehicles.

CHIMPANZEE ABOARD ROCKET VEHICLE

Wang Fong-tze

Aviation and chimpanzees seem to be two totally unrelated subjects. However, chimpanzees make special contributions to certain areas of aviation. This article describes a simulation test of ejection seat using animals and introduces some related knowledge to the reader.

On the steppe there is a shining railway extending beyond sight. This is not a transportation route, but a test range. The test is going to start immediately. The green signal is given and a rocket vehicle advances at high speed. Suddenly there was a black spot ejected from the vehicle. It has a fire ball on its tail. Suddenly the black spot turned into two orange-colored parachutes. Excited people ran toward the direction where the parachute landed. All this happened so fast that some people had trouble keeping up. Even more surprising was that, standing beside the colorful parachutes, there was a chimp in a flight suit looking at the people who surrounded him. He appeared in good spirits, but his left arm was hanging loosely.

The test station was not very big, but the arrangement was compact and simple with a lot of antennas. The work crews in the command post were busily turning and adjusting knobs to record various test parameters or to process data. The command squad kept on communicating with various posts or exercising remote control. Display lights were flashing different colors to indicate that the work was still going on. The test just finished was conducted by this command post.

Figure 1. The chimp landed in flight suit

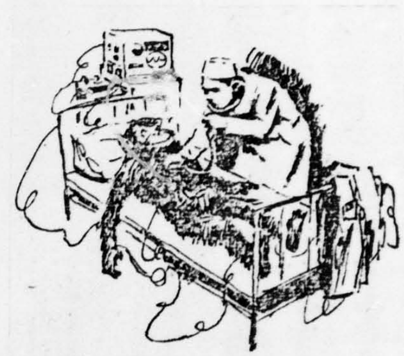


Figure 2. The doctor is checking the chimp thoroughly

The passenger of the rocket vehicle, the chimp, was quickly escorted away in a car. Moments later he was lying on a bed inside a diagnostic room. People were busy taking off his clothes. There were transmitters inside his pockets. Taking off the helmet and the suit revealed that there were electric sensors inside the helmet, on his breast, back, arms, and legs. These sensors reported the physiological reactions of the chimp during the flight. The doctors gave the chimp a thorough checkup and found that he suffered a shoulder dislocation. The doctors fixed up his shoulder, took an x-ray of his total bone structure, and let him rest.

The darkroom had already processed the high-speed film. The films were taken at several thousand frames per second to record the test. The two-to-three-minute test now became a two-hour movie. The rapid actions which could hardly be followed by the eyes were clearly visible like a slow motion sports event. You could see on the screen that when the rocket vehicle ejected the seat and when the seat was about to roll, a parachute suddenly opened from the back of the seat to stabilize it. Then the seat belt which held the chimp in place untied automatically. The chimp was now separated from the seat and the two parachutes opened to carry the chimp and seat safely to the ground. In this test, the left arm of the chimp was deliberately unprotected. The air flow from the back caused the shoulder dislocation.

The test was called an ejection seat animal simulation test. The purpose of it was to test the safety and dependability of the ejection seat. The test was conducted on the ground in a rocket vehicle instead of in the air in order to film the event. Rocket vehicles were discussed in another article of this issue. Some reader might ask, "Why the chimp?"

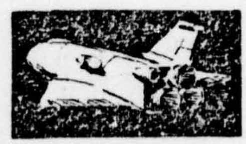
The chimpanzee is a highly developed animal. The chimps in the zoo amuse children. The chimps in circuses can even ride bicycles. But the fact that chimps in scientific research have made their special contribution is not a well-known fact. They are ideal substitutes for **humans** for some hazardous, premature aviation and military scientific tests. The chimps play the role of "adventurer" to collect test data and check out equipment for us to improve the functioning of equipment.

The safety and dependability of an ejection seat is achieved through thousands of "unsafe" animal simulation tests. The chimps ride on the supersonic rocket vehicles time and again. They are thrown into the air by an acceleration which is twenty times that of gravitational acceleration. There are subjected to all adverse conditions unprotected. As an example, their arms and legs are not tied down or protected or they tumble in the air. They are subjected to impulsive forces caused by the air stream. This time, the left arm of the chimp was deliberately not tied down or protected. The test showed that he suffered a shoulder dislocation. This proved that a protective device must be installed on the high speed ejection seat. Repeated tests will improve the equipment which will be safe for our pilots' use. When they are in dangerous situations, they can use ejection seats to leave the airplane and return safely to the ground.

ABLATIVE MATERIALS FOR ROCKETS AND GUIDED MISSILES

Chung Wen

Since a lot of people are interested in the materials used in rockets and guided missiles we plan to publish a series of articles on this subject and discuss it with our readers. When people talk about space vehicles (such as satellites and space ships) and nose cones of the re-entry ICBMs they usually have questions about how the problem of high temperature materials is handled. The present article briefly introduces this topic.



At night when the sky is full of stars, we sometimes see shooting stars flying through the sky. Occasionally they come down to Earth. What is left are pieces of burnt stones known as meteorites. In ancient times, men could not explain the phenomenon based on science, so some people even thought the burn patterns on the stone were "revelations of God". Since the advance of science, this mythology no longer exists. Science has a perfect explanation for it. Usually we do not come in contact with meteorites, because when a star is falling through the atmosphere the heat generated between the star and air due to friction is enough to burn the star into ashes. ICBMs, space ships, and satellites also are surrounded by a ball of fire when re-entry through the atmosphere occurs.

ICBMs start with the thrust of the first stage rocket. The velocity increases gradually. The surface temperature of the missile is not very high. When the first stage is burnt out it is ejected, and then the second and the third stages go through the same process. Finally, due to gravity of the Earth, it changes its direction and re-enters the atmosphere with only the warhead left. When the warhead enters the atmosphere, its velocity increases due to gravitational acceleration and can reach Mach numbers of 20 (Mach number M = speed of flight/speed of sound). The friction between the warhead and the air could generate a temperature of over 8000° C on the surface of the missile. At this temperature, any metal will melt just like a meteorite passing through the atmosphere. In order to ensure that the warhead will hit the target, necessary steps must be taken to prevent it from being burnt up.

When space ships (see Figure 1) re-enter the atmosphere, the surface temperature increases drastically and eventually the heat is conducted to the inside, which seriously endangers the safety of the crew and the normal functioning of instruments. For a 5-ton space ship, if ten percent of its kinetic energy is converted into heat, that amount of heat which is capable of raising the temperature of 50 tons of water to the boiling point or a rise of the local temperature of the space ship to 8000° C! Consequently, heat resistance is very important.

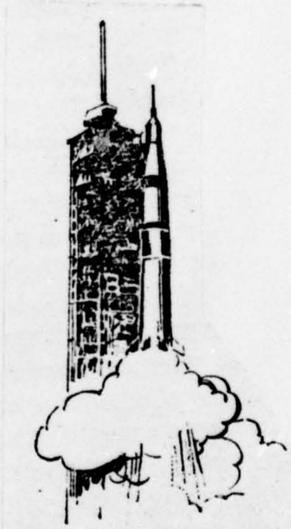


Figure 1. Space ship is launched

For guided missiles, in the past, some of the methods of heat resistance and thermal insulation proved to be defective. As an example, a transpiration cooling method was studied. This method uses ceramic material with holes on the surface. Inside those tiny holes there are heat-absorbing dielectrics. As the temperature rises, the dielectrics absorb the heat and evaporate to keep the temperature of the missile warhead down. This heat resistant method has a lot of defects:

1. The tiny holes are likely to be plugged;
2. Ceramic is very sensitive to heat shock and is easily broken. So far, this method has never been used.

During early development, the heat sink method was used for high temperature missile nose cones. A thick layer with a high heat capacity material, such as copper or beryllium, is used on the outside of the nose cone. Utilizing the heat capacity of the material to absorb heat, it reduces the temperature inside. However, these materials are too heavy. Their heat capacity is still limited and cannot be used for objects which spend a long time in the atmosphere. Then there is a new thermal insulation method — the ablation method.

Ablation and Ablative Materials

Ablation is a method where a protective coating is applied to the surface of missile warheads or space ships. The coating is allowed to be burnt away deliberately to carry away heat. This is a method of sacrificing some parts in order to protect the entire body.

Common ablative materials are non-metallic high polymers, such as teflon, fiber glass, and other inorganic and organic synthetic fibers and resins, composite materials. After being heated, the surface temperature of these materials rise. Heat is absorbed through melting, vaporization, and decomposition. They absorb a large amount of heat by reducing their own weight by means of a reaction. Here, we consider the silicon dioxide fiber and phenol-formaldehyde resin composite material as an example. The silicon dioxide fiber and phenol-formaldehyde resin composite material has a low heat conductivity. When the temperature of the nose cone surface rises, phenol-formaldehyde resin starts to decompose and releases a large amount of complex low-molecular-weight gas such as hydrogen, carbon monoxide and carbon dioxide, and a layer of carbon is created. At the same time, the silicon dioxide fiber also dissipates a large amount of heat through melting and vaporization. After the decomposition of the resin, the carbon layer reacts with oxygen and is washed away by the high velocity air stream and is consumed and deformed. This is the general outline of the ablation process (Figure 2).

In general, ablative materials must satisfy the following requirements:

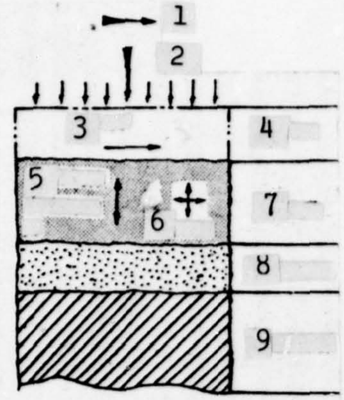


Figure 2. Schematic diagram showing the principle of ablation:

1 - convection heat flow; 2 - external pressure; 3 - shearing force; 4 - dissipated layer; 5 - stress due to vaporization; 6 - tensile stress; 7 - carbonized layer 8 - thermal decomposition; 9 - untouched layer

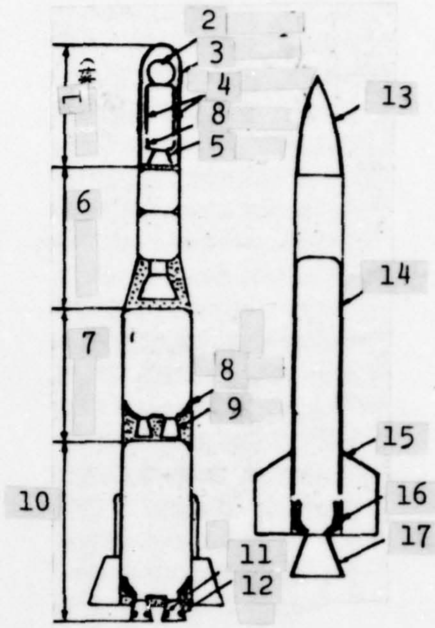


Figure 3. Applications of ablative materials. Rocket booster for launching satellites

1 - fourth stage (solid fuel); 2 - satellite air flow deflector; 3 - inner wall of combustion chamber; 4 - thermal insulation; 5 - exhaust nozzle; 6 - third stage (liquid booster); 7 - second stage (solid booster); 8 - thermal insulation; 9 - exhaust nozzle; 10 - first stage (solid booster); 11 - burner; 12 - exhaust nozzle; 13 - nose cone; 14 - combustion chamber inner wall; 15 - stabilizer; 16 - thermal insulation; 17 - exhaust nozzle

(1) Effective heat ablation. This means that the heat dissipated per unit of ablative material is large.

(2) Low heat conductivity and large specific heat.

(3) Under high temperature, the fiber material in the material has a high fusion point and vaporization temperature.

(4) The resin can be composed into a large quantity of low molecular weight gases and from a strong layer of carbon.

Applications and Development

Presently ablative materials are used on some parts of rockets and guided missiles such as nose cones, leading edges of stabilizer, exhaust nozzles of rocket engines and burners, space ship re-entry capsules, and satellite modules. Figure 3 shows the locations where ablative materials are applied. Now let us turn our attention to how it is applied on various parts of the vehicles.

Nose Cones and Stabilizer Leading Edges

Due to the high temperature generated at the nose cone and the leading edge of stabilizers in flight, heat absorbing materials such as copper and beryllium are used. Later, more effective materials such as inorganic fibers and phenol-formaldehyde resin are used. It is reported that the U.S. Lockheed Polaris intermediate-range guided missile and Boeing minuteman ICBM use silicon dioxide fiber and resin composite material in their nose cones. Convair Atlas ICBM uses silicon dioxide fiber and nylon fiber resin composite materials in the nose cones.

Solid Rocket Booster Exhaust Nozzle

Inside the exhaust nozzle, the surface is impacted by high-speed high-temperature air flow which can reach temperatures as high as 2000° C to 3000° C. The speed at the throat can reach one Mach, and the pressure reaches 20 - 80 kg/cm^2. The inner wall of the nozzle must be heat resistant, corrosion resistant, and pressure resistant. In foreign countries, it is presently made of graphite, fiber glass, and other composite materials. Figure 4 is a schematic diagram of the nozzle made of composite material.

Re-entry Vehicles

Presently, most ablative materials used in re-entry vehicles are nonmetallic composite materials. When a satellite leaves the atmosphere to return to the Earth on an elliptical orbit, its speed reaches 8 km/second. For moon-landing space ships the re-entry speed is even higher; about 11.2 km/sec. Since 1957, the U.S. and the Soviet Union have been furiously competing in space for military purposes. The Soviet Union and the U.S. sent manned space ships into orbit in April 1961 and February 1962, respectively. Since then, the two superpowers have competed in manned space flight. The first generation of the U.S. manned space ships was the Mercury. Its sealed capsule used the ablative method for heat resistance on the bottom and the radiation cooling method on the sides. The second generation Gemini basically had the same radiative cooling structure as Mercury, but with an improved ablative material on the bottom. It used a fiberglass honeycomb structure composite material. The inside of the honeycomb was filled with silicon rubber ablative substance. After this improvement, during the re-entry while the surface tempberature is about 2800° C, the temperature at the inner surface of the heat shield is kept below 60° C. The U.S. third generation space ship Apollo which landed on the Moon has a command module which is constructed from three layers of honeycomb structures. The inner aluminum honeycomb structure is for loading. The middle honeycomb structure made of stainless steel is used as a support structure. The outer honeycomb is made of fiber glass and filled with phenol-formaldehyde resin for thermal protection. Fiber glass honeycomb and stainless steel honeycomb are connected to form a heat shield. They are linked with the aluminum honeycomb structure by a mechanical connection. Figure 6 is a schematic diagram of the Apollo thermal protection system structure. Since it is equipped with a deceleration rocket, its re-entry speed is much lower than that of a missile warhead. Its surface temperature is about 2000 - 3000° C and re-entry lasts about several minutes. Figure 7 shows a manned space vehicle thermal

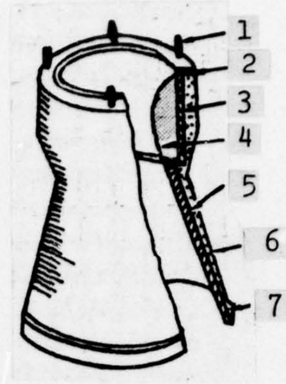


Figure 4. Schematic diagram of a composite-material exhaust nozzle

1 - fastening screw; 2 - high temperature panel; 3 - exhaust nozzle inner wall; 4 - throat of nozzle; 5 - skirt inner wall; 6 - nozzle body; 7 - installation ring

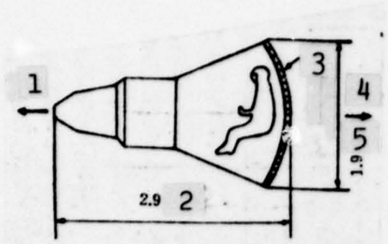


Figure 5. Location of thermal insulation panel in "Mercury" sealed module:

1 - rocket thrust vector; 2 - meters; 3 - insulation panel; 4 - re-entry direction; 5 - meters

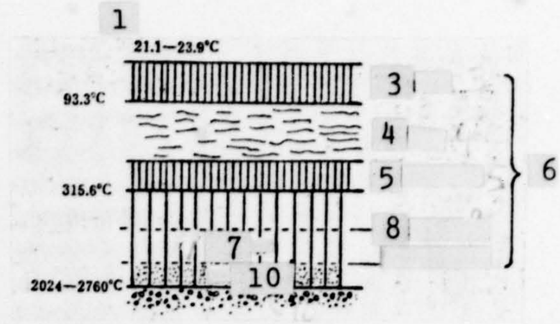


Figure 6. Schematic diagram of the thermal insulation structure of the Apollo command module

1 - temperature; 3 - aluminum honeycomb structure; 4 - insulation material; 5 - stainless steel honeycomb structure; 6 - thermal insulation structure; 7 - decomposed part; 8 - ablative material (phenol-formaldehyde); 10 - carbonized part

protection system. It slides into the atmosphere with the help of rocket lift to reduce speed. Most parts of the surface are coated with an ablative substance.

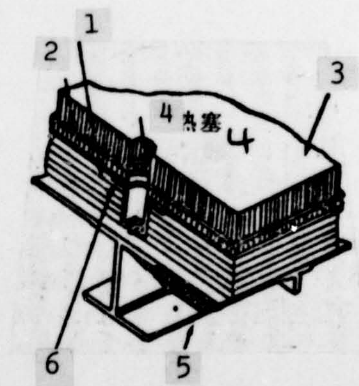


Figure 7. Structure material of re-entry vehicles

1 - quartz fiber multi-layer thermal insulation; 2 - honeycomb middle layer structure; 3 - ablative material; 4 - thermal insulation plug; 5 - aluminum alloy; 6 - phenol-formaldehyde resin fiber glass protective layer

The advance of using composite materials as ablative substances has been going on rapidly in recent years. Composite material usually consists of two parts: base material and strengthening fiber. The strengthening fiber must have high strength and must be easy to work with to form different shapes. Besides, it must be heat resistant and have a high fusion point. Therefore, commonly used fibers are inorganic ones such as fiber glass, silicon dioxide, carbon fiber, boron fiber, and asbestos fiber. The bases of composite materials are synthetic resins such as phenol-formaldehyde and other high polymers. Phenol-formaldehyde has good ablative properties, and is commonly used as a base. However, as missile technology advances, missiles and other space craft enter into a hyperenvironment and the requirement on thermal protection systems becomes more strict. The ablation characteristics of the nose cone will to a large degree determine its accuracy. Therefore, the requirement for thermal protection is not to burn away any part of the surface or to burn smoothly away very little to retain its shape. Low purity ablation material such as silicon dioxide or carbon-phenol-formaldehyde is no longer suitable for this purpose. In recent years, foreign laboratories have been doing research work on carbon-carbon composite material. It uses chemically decomposed carbon deposited on carbon fiber. It is reported that this carbon-carbon composite material is high in heat dissipation and has a high strength at high temperatures, a low ablation rate, and low thermal stress. It is expected that it will become the leading ablative material for missile application.

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*Translator's note. Two paragraphs of political information are omitted here.

HOW DO MEN LIFE ABOARD A SPACE SHIP?

Chia Szu-Kuang

The advance of modern technology provides the necessary material basis for launching human beings into space. Presently astronauts can live normally in space above the ground. Nevertheless, there is a distinct difference between space and Earth. The life style has to change according to the environment. This article introduces some aspects about living in space and safety.

The earth is surrounded by a thick layer of atmosphere. The atmosphere protects all living things on the Earth. At sea level, the density of the air is greatest and has a pressure of 760 mm Hg, called the pressure of one atmosphere. After a long period of evolution, human beings have adjusted to the atmospheric surroundings and its pressure, composition, temperature, and humidity.

Space Environment

Present-day manned spacecraft travel in an orbit which is about 200 kilometers above the Earth in the lower part of the ionosphere where only a small number of air molecules, electrons, and ions move freely. The mean free path among them is very large and the collision probability is very small. Therefore, atmospheric pressure no longer exists at this height. It is very close to a vacuum. The pressure here is about 1/100,000 to 1/1,000,000 mm Hg. Since there is very little air, the concept of the temperature in the air is no longer valid. It is obvious that human beings cannot live in such a hyperenvironment. What damage could it do to human beings?

1. The first threat is the so-called "explosive lack of oxygen". When man is exposed to such a hyperenvironment, the pressure inside the body is hundreds of times higher than that outside. Not only can he not obtain life-supporting oxygen from outside (actually there is none), but whatever oxygen he has inside the body will escape. After a few seconds his brain which is most sensitive to oxygen will lose its consciousness. No meaningful function is possible. It is extremely dangerous and there are only several seconds available for survival. Obviously, this is the most important problem which has to be solved.

2. The next is "air-inflated man". The human body contains a large amount of water (over 60%) and gas (approximately five liters). Its state is closely related to pressure and temperature. On the ground, this water and gas exist in a state which is compatible with one atmospheric pressure and 37° C. They contribute to the physiological functions of man and are benevolent in nature. When man is suddenly exposed to space, the environment changes and they become adverse instead of benevolent. First, the gas expands and stretches the organs, which is painful, and some weak organs such as the lungs and stomach might even rupture. This phenomenon is similar to a balloon rising to a certain height and exploding in the air. The only difference is that is expands fast and packs more power.

The air in the liquid also expands as the outside pressure reduces to vacuum. Saturation occurs and the air is "liberated" from its solution and forms a large amount of bubbles which float around. It travels with the blood to the vital organs, such as the heart, and causes serious damage and death. Even more dangerous is the fact that there is a large amount of water in vapor form in the human body. The boiling point of water depends on pressure and temperature. The boiling point is lowered when the pressure is low. The boiling point of water on the ground under one atmosphere pressure is 100° C. Under vacuum, the boiling point is much lower than the body temperature. Hence the water quickly starts to boil. It reaches the boiling point within a minute. This induces the collapse of the lungs and produces a large amount of air bubbles in the blood stream and seriously hinders blood circulation. Steam starts to form around the eyeballs and obscures vision. Large amounts of steam form under the skin and makes man become a "balloon" man. The evaporation of body fluids causes body damage less quickly than an "explosive lack of oxygen". If the man is rescued within a minute and moved to a higher pressure environment where the boiling point of water is higher than the body temperature, then water will be converted from the gaseious state to body fluid and normal functioning resumes.

3. Extreme temperature makes life impossible. There are two extremes which exist in space: one is extremely low temperature. Some people believe that a true-vacuum space has a temperature of absolute zero (-273° C). The other is that the temperature of moving electrons and ions at 200-kilometer altitude is about 400° C to 800° C. Our reader might ask then, will human beings be burned by these particles in space? The answer is "no", since the density of the particles is very low and the probability that they will collide with people is very low. Even if they do collide, the thermal effect is next to zero since their mass is so small compared to the human body. Besides, when man is exposed in space, the part which is toward the sun will be burned and damaged by the solar radiation; the part which is in shadow loses its body heat to a heat sink and freezes. The phenomenon that a man is half burned and half frozen cannot be observed in daily life. Nevertheless, in the winter, if one sits in front of a fire outdoors, he feels warm in the front but cold in the back. This is a similar siutation. The difference is that the temperature difference is much greater in space.

4. Cosmic ray and meteorite danger. Cosmic rays are highly penetrating and damaging particles and will cause radiation damage in human bodies. There is a strong radiation belt around the Earth. Fortunately, present spacecraft fly at altitudes below 300 kilometers which is lower than the radiation belt. However, there is still some less intense radiation there. The spacecraft shields human beings to reduce the possible damage.

High-speed meteorities have even more damaging capacity. At the altitude where spacecraft operate, micrometeorites are encountered which have a mass of one hundredth to one several thousandth of a gram. These flying micrometeorites, of which there are millions above the Earth, could cause a large number of dents on the spacecraft surface and possible damage to its occupants. Again, the density is low and the probability of collision is low, even though a meteorite of a few grams could penetrate the spacecraft wall. A meteorite of several tons could smash the whole space ship. According the statistics, it will happen only once in 100 years of flying and consequently need not be taken into account.

Sealed Cabin (Space Ship Main Module)

From what has been said it is not difficult for the reader to conclude that the best way to prevent crews from being threatened by various dangers in space is to seal the cabin and completely isolate the crews from this hyperenvironment. Sealed cabins originated from this idea. A simple space ship consists of a main module and an auxiliary module. The crews live in the main module which provides life support systems and equipment (see space ship simple diagram).

1. Atmospheric surroundings. The auxiliary module carries enough air and air pressure is maintained at one atmosphere in the main module by the automatic control system. Pressure, air composition, temperature, and humidity are maintained at specified levels. The composition of the air depends on the pressure inside the module. If one atmosphere is selected, then the composition should be the same as on the ground. If a quarter of one atmosphere is selected, the gas should be all oxygen to provide enough oxygen for the crews. The ideal pressure system is to provide enough oxygen for consumption and safety at the lowest possible pressure. When the pressure inside is too low, then the pressure difference between the inside and outside is small and consequently the leakage is small, and the quantity of gas which has to be carried aboard is reduced. This in turn reduces the required thrust of the engine. It takes about 400 tons of fuel to launch a 4-ton spacecraft into orbit. This is a

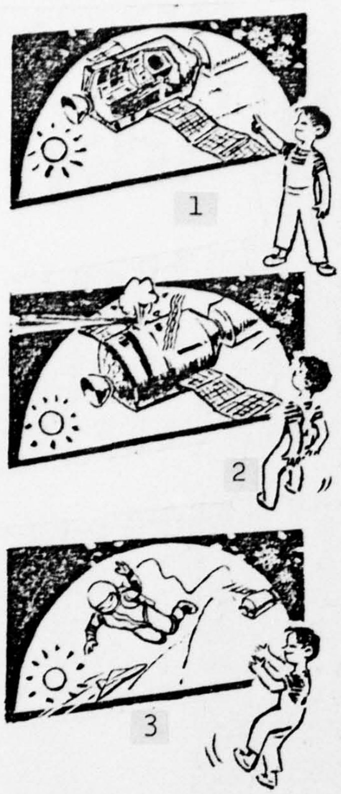

Figure 1. Safety is ensured

1 - sealed cabin, first protective measure; 2 - meteorite once in 100 years of flight; 3 - space suit, second protective measure

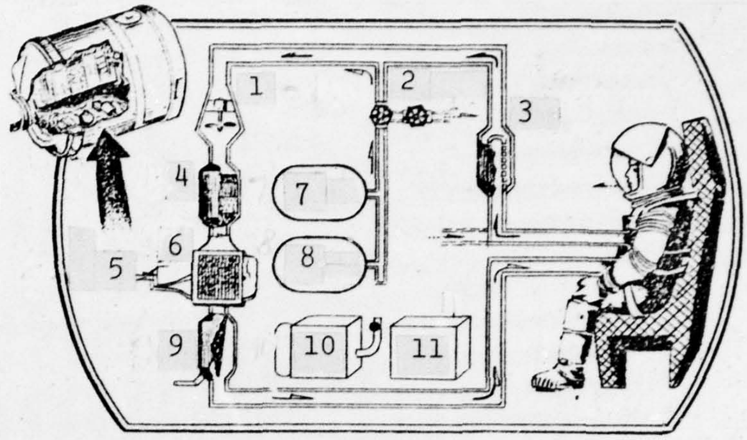

Figure 2. Schematic diagram of life-support system aboard a space ship

1 - fan; 2 - adjustment control; 3 - filter; 4 - purification device; 5 - to air conditioning system; 6 - heat exchange; 7, 8 - supplement oxygen; 9 - water separator; 10 - water; 11 - food

huge fuel consumption. Therefore, special attention must be paid to the weight of the spaceship. If one atmosphere is selected, the wall thickness and the quantity of air carried aboard have to be increased and represent a waste of thrust power.

Neither the U.S. nor the Soviet Union used an ideal pressure. The Soviet Union chose one atmosphere. The U.S. used 1/3 atmosphere. The system contains almost pure oxygen. Both have their defects. The first Apollo space ship of the U.S. had a fire on the ground and three astronauts were burned to death.

2. Complete air purification system. Human beings, instruments and equipment aboard release waste gases which are harmful to the human body and pollute the air. This pollution is diluted by air ventilation and washed away by water when it is produced on the ground. However, in a sealed environment, the harmful gas could

accumulate to reach a dangerous level and have to be eliminated. For a short space flight, the following methods could be used:

(i) Carrying pressurized and liquid oxygen aboard for fresh oxygen supply to replace the oxygen lost through leakage. It could also dilute the pollution. The U.S. spacecraft use this approach.

(ii) Using alkaline peroxide (Na_2O_2 or KO_2, etc.) to eliminate carbon dioxide released by humans, and also generate oxygen for human consumption. They could be used singly or in mixtures. In a mixture, the chemical reaction is:

$$(KO_2/Na_2O_2) + CO_2 \rightarrow (K_2CO_3/Na_2CO_3) + 1.2O_2$$

There peroxide compounds are in solid form and could absorb some moisture, **harmful** gases and virus. USSR spacecraft used this approach for recycling and purification of air.

(iii) Using oxygen supply. Eliminating CO_2 with LiOh, the chemical reaction is:

$$CO_2 + 2LiOH \rightarrow Li_2CO_3 + H_2O + \triangle H$$

It is very effective. The U.S. spacecraft used this approach and it proved to be safe and effective.

(iv) Using active carbon to eliminate harmful gases. This is a popular, effective approach and is indispensable no matter which purification approach is adopted.

3. Air circulation system.

Both astronauts and instruments generate heat. People also generate moisture. On the other hand, heat is conducted into the inside from the surface of the spacecraft. When the spacecraft completes on orbit around the Earth, 70% of the time it is exposed to the Sun. The surface temperature could reach 130° C. The balance of the time is spent in the shadow where the surface temperature is

-10° C. On balance, it absorbs more heat than it releases. There must be an apparatus to reduce the temperature and humidity inside the cabin to maintain 20° C and 50% humidity. Under weightless conditions, air molecules no longer follow the diffusion law which is valid on the ground. There is no concept of heavy and light. Hot air will not rise and cold air will not descend. All the air molecules are in free motion. Harmful gases could float near man's breathing organs. Blowers have to be installed to circulate the air. Waste gas from the cabin and space suit must be circulated through a purification system to be converted to fresh air for consumption.

The sealed cabin is truly a specially designed house in the sky. It has windows. Astronauts can look through the windows to observe space, stars, and the ground. It opens a new frontier for scientific exploration for human beings. One will not feel lonely inside since there are several crew members there. On the contrary, one feels tense due to the busy assignments of manning the spacecraft. When passing over his homeland, the astronaut has to report to ground stations and receive instructions. The fruitful and colorful life of an astronaut is hard for us to imagine on the ground. The only disadvantage is that the cabin is too small to allow for extended movement. Particularly the early craft were so small that the crews were tied down to their seats and could not even stretch their legs.

Space Suit

Sealed cabins provide good protection. But malfunctions do occur. The additional protection is provided by space suits. The space suit is a multi-layer multi-purpose suit. It has a sealed layer and a constraint layer — equivalent to the inner and outer tubes of a tire — to ensure that there is no air leak and that it does not crack under pressure. It has a thermal insulation layer to reduce the influence of outside temperature. It also has a ventilation structure to ensure the circulation and ventilation for the whole body. There is a special helmet to isolate the head from the surroundings. Since it is heavy and awkward to wear, the crew member usually takes it off once the craft is launched into orbit. If the situation does not permit it to be taken off, one can open the face plate or just take off the helmet to carry out intricate assignments. The space suit is connected to life support systems through tubes and forms a complete cycle to carry fresh air for consumption and waste gas for elimination (see Figure 2).

When the cabin suddenly loses pressure and an emergency condition exists, the astronauts immediately put on space suits, or close the face plates, and put on gloves to seal themselves off completely. The life support system continues to supply oxygen, ventilates and purifies the air to provide safety for the astronauts. If the astronauts want to do space walks, they can wear special suits with life support systems on their backs to venture outside the space craft. Hence the space suit is an integral part of the whole system.

Life under Weightlessness Conditions

Living on the ground, human beings are always under the influence of gravitational force. Body structure and functions are adjusted to it. Once the space craft is in orbit, weightlessness conditions occur and everything inside the cabin is now "liberated" to float freely in space. This creates new problems for man. Old habits formed on the ground can no longer handle the situation. New adjustments are called for.

The concept of "up" and "down" is no longer valid. For example, if one wants to put a cup on a desk, bottom up or bottom down, it will not say on the desk. Once it is released from the hand, it will leave the desk and float around. It is impossible to drink water from a cup. When water leaves the faucet, it will not follow the wall of the cup and go to the bottom. It forms different sizes of water balls on the wall which float around. However, once the rules for weightlessness are understood, it no longer presents a problem. Just by applying an external force, drinking water or juice is now easy. For example, in the weightless condition, juice powder and water are separated. Just press water into the plastic tube with the power inside and squeeze. The powder will mix with water and you have juice, which in turn is squeezed into your mouth. Diluted rice and noodles can be served the same way. How about steamed rice? So long as they are glued together and stick to the pot you can scoop it up with a spoon and eat it. Steam bread presents a problem simply because it has crumbs which might fly all over the cabin and disrupt the functions of life support systems. For solid food, it is best to make it in small pieces and eat it piece by piece with a closed mouth to prevent it from escaping.

Figure 3. Don't jump around

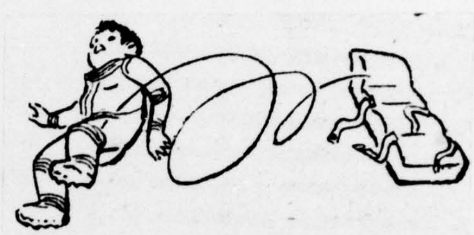

Figure 4. Be careful about turning while in bed

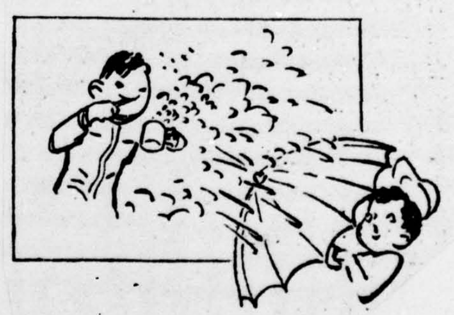

Figure 5. Brushing teeth can cause trouble

When the space ship functions normally, the space suite need not be airtight and eating is convenient. During an emergency sealed situation, this presents a problem. One has to eat through a small tube attached to the helmet. To eat solid food now is impossible. One can only eat liquid or semi-liquid food which is stored in toothpaste-like tubes and can be squeezed into the mouth. Fortunately, emergencies do not occur very often and normally do not last long. Semi-liquid high protein food will serve the purpose.

The nutritional value of the food is similar to food on the ground. It should be tasty, easy to digest, less waste to reduce human waste. Living in a narrow environment, busy brain activities, limited physical activities and insufficient sleep all contribute to loss of appetite. Early spacecraft imposed a strict restriction on the weight and volume of payloads. Food had to be dehydrated and was not very tasty. The U.S. astronauts reported that eating in spacecraft was a problem.

Sleeping is another problem. Semiconsciousness and the inability to sleep very deeply is very hard on the crews. The main reasons for this are:

(i) Even though weightlessness does not create too big a problem for short flights, it affects the physiological and mental functions of the crews nevertheless, particularly for sensitive people.

(ii) Sleeping at night and working in the daytime is a strong habit of human beings. There is no distinction of day and night aboard the space ship. The surroundings are always the same. There are lights inside the cabin all the time and only stars in the dark background outside the cabin. Working and sleeping are regulated by an artificial schedule which is hard to get used to.

(iii) In a narrow cabin, one can only lie down half way and in a fixed position. One mis-coordination and you will turn upside down. Fortunately, the astronaut is tied down on the seat; otherwise he could not even lie down. Besides, one has to sleep with the space suit on. How could one have a sound sleep under this circumstance? The only solution seems to be tranquilizers.

Physical movement is even more difficult. In the weightless condition, all reflex and balance functions become inoperative. Before one gets used to it, he cannot stand or sit in a stable position. Each misstep could tip the balance of the whole body. One can only move slowly and gradually adjust himself to reestablish his muscle coordination and body balance. Inside the cabin, the space is limited and adjustment is comparatively easy. To venture outside, movement is even more difficult. The space suit makes any bending movement a difficult and tiring task.

The standard of personal hygiene has to be lowered. Washing the face with water is now impossible. A wet towel is the best one can do. To brush teeth is another problem. The critical point here is that of handling the waste water. Otherwise the water will escape from the mouth and wander around inside the cabin to create a rain. Human waste also has to be handled with care. Bowel movement habits have to be adjusted to the new environment. To simplify matters, the food usually contains very little waste to reduce the number and quantity of bowel movements.

From this short introduction, readers can understand that life in spacecraft is a unique, new experience, even though the way of life can be adjusted to. However, with present day technology, life in space is limited only to a selected trained few for a short duration. For longer duration, we still have to wait for research and development.

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