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# FOREIGN TECHNOLOGY DIVISION

ROCKETS AND MATERIALS

by

Wu Yun-shu

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# ROCKETS AND MATERIALS

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The primitive rockets invented by the Chinese a few hundred years ago were constructed from bamboo and wooden objects.

During the more than twenty years since fascist Germany created the "V-2" ballistic liquid rocket during World War II, modern rocket technology has made rapid development and has promulgated all kinds of rockets. In the area of fuels we can divide rockets into two major categories — liquid-propellant rockets and solid-propellant rockets, calling them simply liquid rockets and solid rockets.

## Material Problems of Liquid Rockets

Just as in airplanes, the chief demand concerning the materials of any kind of rocket is to have the highest possible specific intensity* and at the same time to have a certain flexibility of form. In order to explain the material problems of liquid rockets, a structural outline of liquid rockets is given below.

*Specific Intensity — When material is destroyed, the ratio of the specific gravity of the material to the load withstood on the area of the unit is called specific intensity.

1. Warhead Materials

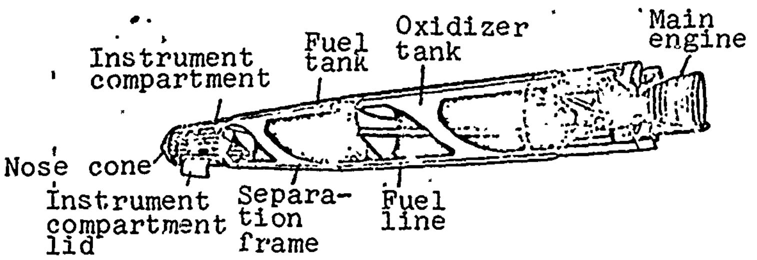
During the take-off of a multistage rocket, as the first stage rocket engine begins to work, the rocket's ascent speed increases commensurate with the increase in the thrust of the engine, and the flight speed also increases, but the air becomes thinner. At this time, the temperature of the outer surface of the rocket does not rise to a very high level. After the fuel of the first stage is completely exhausted, the first stage is jettisoned, followed by the second and third stages, which are also jettisoned. All that remains until the time of re-entry into the atmosphere is the warhead. After the warhead enters the atmosphere, it meets with air friction, causing its surface temperature to surpass 5000°C. At this time any normal metal would be melted, just as a meteorite is burnt up when it falls into the atmosphere.

If we want the warhead to accurately hit its target, we must prevent it from burning up at extremely high temperatures. There are two main methods to solve this problem. The first is to create a type of porous ceramic material and to store within the pores a medium which has a capacity to absorb a great amount of heat. When encountering high temperatures, the medium absorbs the heat and burns, preventing the warhead from overheating. The second method is to use a multi-layered heat shield which, on encountering high temperatures, is able to burn off one layer or a few layers at a time, leaving the interior completely undamaged. Naturally, a type of material that can absorb a great quantity of heat, such as beryllium, etc., may also be used; warheads of this type are called heat-sink type warheads. However, this kind of warhead is very heavy and is rarely used at present.

2. Materials of Propellant Tanks

The weight of the propellant tanks in liquid rockets occupies an extremely large portion of the total weight of the rocket structure. The materials used in propellant tanks are dependent upon the type of propellant. If alcohol combined with fuming nitric acid is used as a propellant, all of the materials used must be able to endure the corrosion of the nitric acid. Examples are stainless steel, titanium alloys, and some aluminum alloys, which all can be used as materials that can endure acid. If propellants containing fluorine are used in rockets in the future, the corrosion problems will be even more serious, for the corrosiveness of those fuels is the same as that of commonly known hydrofluoric acid, which can corrode even glass. At that time, propellant tanks will have to be made of some type of high-intensity antifluorine plastic material in order to be satisfactory. If liquid hydrogen and liquid oxygen are used as propellant components, because their boiling points are very low (liquid oxygen is -183°C and liquid hydrogen is -252°C), most materials at these low temperatures would become as brittle as glass and absolutely could not be used. It is necessary under the aforementioned low-temperature conditions to have a good pliable material, such as austenitic stainless steel, bronze containing beryllium, titanium alloys, aluminum alloys, certain nickel-based alloys, etc.

From the aspect of manufacturing technology, almost all large propellant tanks are welded together from metal plates in an atmosphere of a protective gas. But not all alloys, such as the hard aluminum type high-intensity aluminum alloys in present use on aircraft, can be welded. Because of poor welding properties, there is more use of riveting in assembly. From this we can see that large propellant tanks require materials that have a high specific intensity, are readily weldable, are able to resist either corrosion or low temperature, and other characteristics.




Structural schematic of an intermediate-range liquid fuel rocket.

### 3. Materials of Liquid Rocket Engine Combustion Chambers

The temperature inside the combustion chamber of a liquid rocket engine is over 2000°C. At temperatures this high it is difficult to demand a material that will still be able to maintain a certain intensity. For example, steel can melt at temperatures above 1500°C. In order to reduce the temperature of the internal walls of the combustion chamber, we perhaps would need to use many pipes welded securely onto the engine housing and, moreover, to flow the propellant through these pipes, preventing the temperature of the interior walls from becoming overly high. Or we might use two layers of steel plating welded firmly onto the engine casing and then flow the propellant between the layers, causing cooling of the interior walls. Thus, aside from the fact that the material should possess a certain intensity, it still also must have a good ability to conduct heat, be easy to form, be easy to weld, as well as having other special characteristics. Because of this, a great many engines presently are welded together with low-carbon steel tubing, but they possess a disadvantage in that their intensity is relatively low.

## Material Problems of Solid Rockets

The construction of a solid rocket must be much simpler than that of a liquid rocket, the casing being its most important part. The casing is the propellant tank, and it is also the combustion chamber of the engine. In addition, there is still an ignition system and a thrust-direction guidance unit.

### 1. Casing Materials

The material demands of solid rockets are greater than those of liquid rockets. Because solid propellants can produce high temperatures and high-pressure gases in the combustion process, casings, even though they can be coated with a heat-resistant material, still cannot help but be affected by the high temperature. At temperatures above 300-500°C the intensity of most materials declines significantly. In order to maintain a certain intensity, the shell of the casing must be made very thick. In this way the weight of the rocket would increase, affecting the capabilities of the rocket. This is one important reason for the faster development of liquid rockets than of solid rockets.

Advancements with solid fuels in recent years have been rapid. There have also been improvements made on the construction, form, and design of solid chemical charges. Usually a hole is bored into the center of the chemical charge so that it burns outward from within until the fuel is burnt up, during which time the heat is transferred to the interior walls of the combustion chamber and the task of the rocket body is also completed. This measure will prevent the casing from overheating. It is only necessary that the materials used be prepared for the demands of high specific intensity. Most of the high intensity structured steel or iron alloys, even lightweight alloys or plastics, are useable as casing materials. This is one reason for the rapid development of solid rockets in recent years. But we cannot just give attention to raising the intensity of the materials and ignore their pliability. Otherwise we would have the potential danger of explosion, as in the occasions of trouble that have already occurred in the United States. Particularly in large type casings, most must be welded together to be formed. The brittleness of the welded seams must be given a great deal of attention.

2. Exhaust Nozzle Materials

The second difficulty of solid rockets is the problem of cooling the exhaust nozzle, since it must directly withstand temperatures above 2000°C. It is necessary that materials under these high temperatures not allow any significant oxidation (otherwise the diameter change of the throat section will influence the capabilities of the rocket), and at the same time they must not be allowed to crack because of subjection to quick-cool quick-heat operations. Aside from this, they also must be able to withstand the flush of high temperatures and high-speed gas flow. Finding a material that can meet all of these demands at the same time is very difficult. Thus, exhaust nozzle materials have limited development in the direction of large solid rockets for a long time.

Presently there are about four types of materials that can be used to make exhaust nozzles. They are metal, porcelain, graphite, and bakelite.

In the area of metallic materials, only molybdenum (m.p. 2160°C), tantalum (m.p. 2996 ± 50°), rhenium (m.p. 3180 ± 20°), tungsten (m.p. 3410°), and a few other metals can withstand temperatures above 2000°C. Their advantages are that they can endure flush and resist heat vibration; disadvantages are that they oxidize easily in the poisonous air of high-temperature oxidation and moreover their specific gravities are very great. If vaporization of the fuel is in progress or just beginning, resistance to oxidation is not important. As to the uses of pure tungsten, molybdenum, rhenium, tantalum, and other materials when making exhaust nozzles, a method for overcoming the excessive weight of these kinds of nozzles is to coat the interior surface of a nozzle made of copper or steel with a layer of tungsten, molybdenum, rhenium, or tantalum, which possibly is a plan for manufacturing exhaust nozzles.

The second type is porcelain materials, which are some oxidized substances (such as oxidized aluminum, oxidized magnesium, etc.), carbonized substances, boronized or nitrogenized substances, etc., which undergo pressure, baking, and other processes to make an exhaust nozzle. The disadvantages of this type of material are that their resistance to heat vibration is relatively low and they crack open easily under quick-cooling quick-heating operations. But it is possible to add some powdered metal that does not melt easily to powdered porcelain and again press and bake it, thus improving its resistance to heat vibration.

The third type of material is graphite. We know that most graphite (like that in pencil lead) is very soft, and we cannot use it to make exhaust nozzles. What we are talking about is a kind of so-called fixed direction graphite which possesses a crystallized structure, a specific gravity of approximately 1.6-2.1, when at 3000°C it still has a comparatively high intensity (30 kg/mm$^2$), it resists flush, it has a relatively small sensitivity to breaks – that is, if an acute angle scratch is bored into the material, it still does not crack easily, and it is a rather ideal material for use as an exhaust nozzle and as an internal rudder for control of the rocket direction.

The fourth type of material is high-temperature resistant bakelite. But even though it is high-temperature resistant, at temperatures above 2000°C there is still the possibility of burn damage. Also during the fuel combustion process the diameter of the throat section of the exhaust nozzle will continuously expand. If this is not first considered in the design, then it will have serious effects on the special characteristics of the rocket.

After all that was mentioned above, materials used for exhaust nozzles should certainly be at least as good as graphite. This is the reason for the great and earnest entry into research by all countries of the world in recent years.

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13. ABSTRACT

Material problems of liquid and solid propellant rockets, such as specific intensity, pliability, resistance to heat, and materials that can be used successfully are discussed. Uses of layers of heat resistant material or layers that will burn off to prevent heat transfer are mentioned as methods to prevent burning of a warhead upon re-entry into the atmosphere. Materials used in propellant tanks are dependent upon the types of fuels used, and the author gives examples of alcohol and fuming nitric acid, fluorine fuels, and liquid hydrogen and oxygen. High-intensity plastics, austenitic stainless steel, bronze containing beryllium, titanium alloys, aluminum alloys, some nickel-based alloys, etc. are suggested as usable. Methods of cooling engine combustion chambers are mentioned. The author discusses the use of metals (with high melting points), porcelain, graphite, and bakelite as rocket exhaust nozzle materials, and goes into detail concerning the advantages and characteristics of graphite, which he feels is the best of the four types of material.

| 14. KEY WORDS | LINK A | | LINK B | | LINK C | |
|---|---|---|---|---|---|---|
| | ROLE | WT | ROLE | WT | ROLE | WT |
| Solid Rocket Propellant System | | | | | | |
| Liquid Rocket Propellant System | | | | | | |
| Rocket Structure | | | | | | |
| Rocket Material | | | | | | |