

THE SPACE-AGE MAGAZINE

FUTURE SCIENCE FICTION

THE RACE INTO SPACE
definitive science article

by **THOMAS N. SCORTIA**

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**GIFT FROM
THE STARS**

by **KATE WILHELM**



FUTURE SCIENCE FICTION

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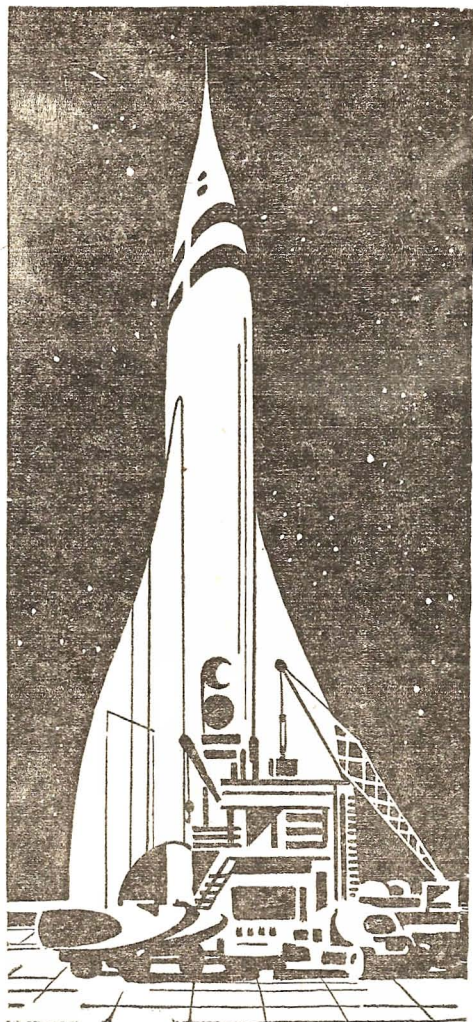
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Editor: ROBERT A. W. LOWNDES DOROTHY B. SEADOR, Asso. Ed.

COVER BY EMSH symbolizing a close finish in the "Race Into Space"

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***First
In
A
Series
Of
Definitive
Articles***

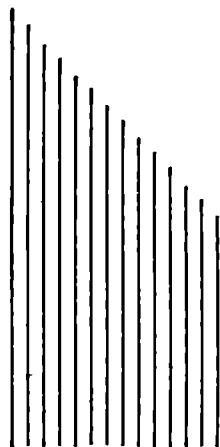


by Thomas N. Scortia

The Race Into Space

I. Operation Bootstrap

What's holding us back right now is the fuel problem. There are several possibilities, some of them in use, some still to be explored. Here's a breakdown on where we stand at the present time.



SOME MONTHS ago, a reporter asked Dr. S. Fred Singer, "Dr. Singer, when we finally land on the moon, what do you expect to find there?"

"Russians," Dr. Singer replied.

The race for the moon is on. No one will deny that now, nor will you find anyone foolish enough to argue that the Russians do not have a formidable lead. With satellite launchings an almost work-a-day accomplishment, the rocket programs of both the U. S. and the U.S.S.R. have turned to the problem of an unmanned shot to the moon or its vicinity.

The Russians have had a moonshot program for some time. They call it "Project Boomerang" and it's under the guidance of Professor G. A. Chebotarev, who is well known for a paper considering the best method of establishing a fifty to one hundred kilogram (110 to 220 pound) payload in an orbit around the moon. Sputnik III, launched just a week before these words are written, fully confirms the rumors of a monster Soviet rocket, capable of developing from 100 to 250 metric tons of thrust. Such a rocket, given a well designed guidance system, can easily land a significant payload on

the moon...say, a final stage carrying an H-Bomb marker.

IT IS MY personal belief that in the five months between writing these words and their actual appearance on the newsstands, the Soviet rocket men will have successfully landed a rocket on the moon, or established one in orbit around the moon. This doesn't take the talents of a Cassandra to predict. It has now been fairly well established that the Russians have tried a moonshot twice already. The March, 1958 *Missles and Rockets*, a respected professional magazine, announces that excellent sources of information have confirmed the first attempt. Other sources of information indicate this first try was on November 7, and that at least one subsequent unsuccessful attempt was made. The frustrating thing about all this is that we are not now even in the race. Our nearest competitor to the Russian monster is the Air Force's "Atlas", which probably won't be operational for from six months to a year at the least.

We are still, I hope, in the

race to land the first manned rocket on Luna, however.

Yet, with all of this talk of moonshots, rockets, ion drives, photon drives and the like turning the front pages into something resembling the contents page of *Science Fiction* January, 1941, you still run across the celebrated innocent who asks with wide-eyed wonder, "Yes, but how can a rocket work in space when there's no air for it to push upon?"

THIS GENTLEMAN is perfectly at home with such esoteric matters as ion drives, anti-gravity, photon drives, because they obviously can't work in an atmosphere, but a rocket now...well...

So, you and I—we're going to talk about space drives. Not just rockets, although rockets will obviously occupy a great deal of our time together. We're going to dig into some of the meat of present-day rocket science, talk about thrusts, specific impulses, heats of reaction, nozzle theory, all the stuff that gives a rocket engineer grey hairs. Only, I hope we won't get grey hairs doing it. Actually, the concepts

themselves are easy, easy as addition and subtraction (though, in my time, I've run across math that floored me completely, even though I could spot an occasional plus or minus sign in it.)

Basically, every space drive so far elaborated in theory is a reaction engine. There are no exceptions, unless you count anti-gravity—which hasn't been elaborated in theory—and Verne's space gun—which others have debunked far better than I can in this small space. Such books as Willy Ley's wonderful "*Rockets, Missiles, and Space Travel*" and Oberth's exciting "*Man Into Space*" (Cf. Bibliography at the end of this series.) discuss the principles of the reaction motor in more detail than I think appropriate here.

For our purposes, we can say that a reaction motor depends on Newton's third law of motion which says that for every action there is an *equal and opposite* reaction. Translated into rocketry, this means that if a rocket throws out a mass with a certain momentum, the rocket will assume an equal momentum in the opposite di-

rection. Since momentum is defined as the product of mass times velocity, you get a sort of lever or see-saw effect in the balance. A ship, weighing 1000 pounds, throws out a pound of gas, moving at 1000 mph; and as a result, the ship moves forward one mile per hour. That is, the velocity of the ship times the mass of the ship equals the velocity of the gas times its mass or $(1 \text{ mph}) \times (1000 \text{ pounds}) = (1000 \text{ mph}) \times (1 \text{ pound.})$

IN ACTUAL practice, of course, the ship does not throw out a reaction mass in a single chunk, but rather as a continuous stream, which means that the ship is constantly getting lighter and constantly increasing its speed. To get around this, we apply calculus to get a formula with which we can work. However, the basic principle remains the same. (For the math bugs in the audience, figure 1 gives the derivation of the basic reaction equations.)

Since the rocket is strictly a reaction engine, it will work anywhere. As a matter of fact,

rocket motors are now being used underwater. Actually, a given rocket design will develop more force or thrust as the outside pressure goes down, its thrust sometimes increasing as much as thirty per cent in go-

ing from sea level to outer space. The V-2 motor, for instance, developed 56,000 pounds of thrust at sea level but nearly 66,000 pounds at 100,000 feet. The rocket engineer may treat this pressure

FIGURE I

DERIVATION OF THE BASIC ROCKET EQUATION

Since the change of momentum of the ship at any instant is the same as the change of momentum of the exhaust gases at the same instant, we may write:

$$m \frac{dv}{dt} = \frac{d(MV)}{dt} \quad (1)$$

where m and M are the masses of the gas stream and the ship respectively, and v and V are the velocities of the gas and ship respectively. (Note that the effects of air resistance and gravity are ignored in this development.)

But since the change of momentum of the ship, $\frac{d(MV)}{dt}$,

may also be written as $-c \frac{dm}{dt}$, the expression for the momentum change of the gas stream (both momentum changes being, by definition equal), in which $-c$ is the velocity of the exhaust gas (negative because of its direction with respect to the motion of the ship), (1) becomes:

$$m \frac{dv}{dt} = -c \frac{dm}{dt}$$

or, as a differential equation:

$$m dv = -c dm$$

or:

$$dv = -c \frac{dm}{m} \quad (2)$$

Integrating (2):

$$\int_{v_0}^{v_t} dv = \int_{M_0}^{M_t} \frac{dm}{m}$$

Thus

$$v_t - v_0 = -c \ln \frac{M_t}{M_0} + K \quad (3)$$

or, evaluating (3) for the boundary conditions:

$$v_t - v_0 = -c \ln \frac{M_0}{M_t} \quad (4)$$

Equation (4) will then treat the mass and velocity ratios of a rocket between any two points in its flight.

thrust effect with the following equation:

$$F = \left(\frac{W}{g} \right) v_2 + (P_2 - P_3) A_2$$

where F is the thrust or actual pull of the rocket in pounds, W is the propellant mass flow rate in pounds of propellant per second, g the gravitational constant, 32.2 ft/sec/sec, V_2 the velocity of the exhaust gases, P_3 the outside pressure, 15 pounds per square inch at sea level and zero in space, P_2 is the pressure of the exhaust gases and A_2 the cross-sectional area of the exhaust as it leaves the rocket nozzle.

THE PART of equation (1) to the left of the plus sign merely restates the relationship of force, mass, and acceleration which you learned in high school physics. The most interesting part of the equation for this discussion is that to the right of the plus sign. This tells us that as P_3 , the atmospheric pressure goes down, the right hand term becomes bigger and hence the thrust becomes great-

er, just as we expected. (Actually, for the most efficient use of the energy in a particular fuel, the engineer tries to design a rocket nozzle which will deliver exhaust gases at a pressure equal to the outside pressure, that is, so that P_2 equals P_3 and the right hand term becomes zero.)

We said earlier that all space drives were reaction motors, that they were devices to impart energy of motion to a mass, and throw that mass to the rear at a high velocity. Right at the moment, our sole workable reaction engine for space flight is the chemical rocket. The important thing to remember about a chemical rocket is that it is nothing but an overgrown heat producer and exchanger. It takes a high energy fuel and tries to burn that fuel as efficiently as possible, to milk it of as much energy as it can; then it tries to convert as much of that heat energy into motion within the gases that result from the burning, and throws them through a nozzle. This nozzle, incidently, is a device to expand the issuing gases as much as possible

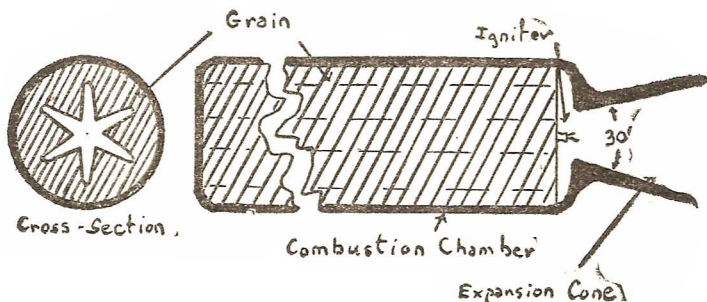
since, if the gas stream is properly directed, this is the best way to get the most velocity out of the gas. (There'll be more on nozzles later.)

A ROCKET is completely self-contained. It needs no air as does the jet, since it carries its own oxidizers with it. This oxidizer is usually oxygen which may be present in pure form—in the form of high oxygen inorganic compounds which yield oxygen on heating, or feed the oxygen directly into the burning reaction—or the oxygen may be built directly into the fuel. Whenever a bond is formed between two atoms in a compound, that bond may give off heat or take up heat. The chemical reactions in a fuel system between oxygen and other materials causes bonds to break and to re-form between other atoms. The extra heat from these bond exchanges is the heat we want for our rocket and, as we shall see later in this series, the nature of these shifts in bonding put a definite limit on the amount of energy we can ever expect to get from chemical fuels.

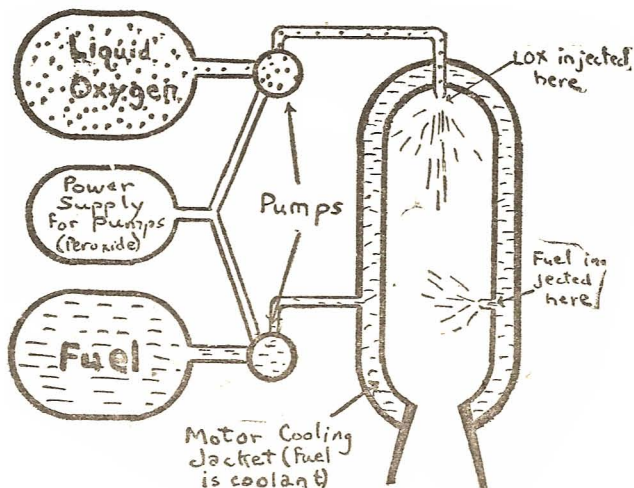
THERE ARE presently two general types of chemical rockets, the liquid fuel rockets and the solid fuel rockets. (Figure 2 gives a general schematic of each type.) The trend in military rockets is increasingly to the solid fuel rocket, in spite of the lower energy content of solid fuels as contrasted with liquid fuels. The main reasons for the trend lay in the stability and storeability of the solid propellant and in the ease of preparing and launching a solid fuel rocket.

Most of our military liquid fuel rockets use LOX, liquid oxygen, as their oxidizer. LOX has a boiling point of -183°C (-297.4°F .) which makes it pretty cold stuff. You can't store it in a rocket for any length of time without arranging to replace the LOX that continually boils away. Because of its low temperature, it may cause valves to freeze, relays to stick, pumps to jam, and missile men to jump off tall buildings. It has a further disadvantage which is obvious if you've seen the first Vanguard failure. When a solid propellant rocket blows up, it

FIGURE 2

TYPICAL SOLID FUEL ROCKET

(Note that the grain is case-bonded to the motor wall and is pierced by a star. This design maintains a fairly even burning surface and hence fairly even pressure.)

TYPICAL LIQUID ROCKET

(Power for pumps may be furnished by decomposing hydrogen peroxide, gas generators, etc.)

generally stops burning. LOX-liquid fuels keep right on burning and making it hot for anyone in the area. This is the only argument that the Navy needed for going to solid propellant missiles, for obvious reasons.

There are other liquid fuels, of course, some of which have a very convenient property of spontaneously igniting when they are brought together in a rocket motor. Aniline and fuming red nitric acid, which are used in the Navy's *Aerobee*, is such a combination. Others are unsymmetrical dimethyl hydrazine and fuming nitric acid and hydrazine and concentrated hydrogen peroxide. However, both aniline and hydrazine are poisonous, the latter extremely so and both are absorbed by the skin. Suffice it to say that fuming red nitric acid isn't the safest material in the world itself. It exhibits an appetite for all metals on dilution and for all organic materials—flesh included—that makes you wonder if it isn't a working model for the universal solvent.

months and years without appreciable change in their ballistic properties. The solid fuel rocket is easier to construct, too, since it dispenses with the complicated plumbing, and pressurizing systems of the liquid rocket, and substitutes a single piece of oxygen-rich fuel (called a grain, regardless of its size), surrounded by a pressure-resistant combustion chamber opening to the expansion nozzle.

One obvious advantage the liquid fuel rocket has over the solid fuel rocket is in inert weight. The liquid motor need be only large enough to handle the amount of fuel being injected into it, while the solid motor must be big enough to enclose the entire fuel supply. Of course, the weight of pumps, storage vessels, and plumbing in the liquid rocket partly offsets this advantage, while the use of case-bonding techniques in the solid rocket that allow the fuel to add its strength to the walls of the combustion chamber helps to lower the solid rocket's weight.

SOLID PROPELLANT rockets can be stored for

ONE OF THE big headaches with solid propellant grains

stems from expansion and contraction, both in the curing process and afterwards, when the grain is subjected to wide ranges of field temperatures. During the curing process, the solid grain goes through a chemical or physical process that hardens the grain and gives it greater mechanical strength. The changes that occur within the grain may cause it to swell or contract, resulting in cracks, flaws, and imperfections in the case-bonding. Such a crack or imperfection will increase the burning surface—and consequently the combustion pressure—above that for which the motor was designed, often resulting in an explosion. These problems are magnified with large grains. The Aerojet General Corp., for instance, has developed an elaborate testing and quality control program to screen out any flawed "Polaris" grains. The "Polaris" is designed to be fired from a submerged submarine and an underwater "Polaris" explosion would have the effect of several direct hits by depth charges.

While the solid propellant rocket has quite a number of

advantages over the liquid fuel rocket in military applications, the reverse is true in the area of space flight. Liquid fuels inherently are able to develop more energy per pound than solid fuels. This, coupled with the weight advantage in hardware, more than compensates for the other disadvantages of liquid fuels. Moreover, liquid systems have another major advantage over solid systems in that they can be more easily controlled.

THE LIQUID motor can be cut off simply by closing the fuel valves, stopping the fuel flow—and consequently, the thrust of the motor can, though somewhat inefficiently, be controlled in the same way. Solid fuel rockets, on the other hand, have a burning rate characteristic of the fuel itself and the internal combustion pressure, while the thrust for a given nozzle design is determined by the interior geometry of the grain—that is, by the amount of surface exposed to the flame. It is possible to control these factors within narrow ranges by variable nozzles and pressure vents, but the

resulting motor is clumsy and inefficient. A solid motor can be stopped under certain circumstances, before its fuel is exhausted, by venting the combustion chamber suddenly.

Most solid propellant rockets operate with combustion chambers in the range of 500 to 2000 pounds per square inch. If the internal pressure drops, burning rate decreases. If the pressure is dropped to outside pressures suddenly, the flame front may be torn from the grain and the burning extinguished. Personally, I have a feeling that the man who is willing to ride a solid propellant rocket controlled by any of these devices is braver by far than he is smart.

IF IT COMES to a chicken-or-the-egg contest, we'll have to agree that solid propellants were known before liquid fuels, unless you want to count Heron's aeoliphile, but the water in that one was probably converted to steam by a solid fuel. The first rockets, then, were the crude black powder rockets of the Chinese. Wm. Congreve, whose gadgets contributed "the rocket's red

glare" to the lyrics of "*The Star-Spangled Banner*", improved on the hardware of rocketry quite a bit; but his propellants were still basically the black-powder formulations . . . sulfur, salpetre, willow charcoal . . . that the fireworks manufacturers had been using for years. The really important high-energy solid propellants were developed during World War II and after. There was the JPN formulation . . . nitrocellulose, nitroglycerine, etc. . . which was used in the bazooka and larger rockets, the GALCIT series developed as JATO fuels for the Navy by the Jet Propulsion Laboratories of the Gugenheim Aeronautical Laboratory of the California Institute of Technology (Guess where they got the name GALCIT.) and many others.

ALL OF THE propellants developed during the war and up to the present fall into four broad categories: (1) single base fuels composed of nitrocellulose with various solvents and stabilizers (2) POL powders composed of nitrocellulose and DEGN, diethylene glycol dinitrate, with a plas-

ticizer (3) double base grains, patterned after Alfred Nobel's double base powders (e. g. Cordite) and composed of desensitized nitroglycerine and nitrocellulose with solvents and stabilizers (to take up acid decomposition products) or plasticizers, depending on how the grain was to be formed and (4) composite grains, composed of some solid oxygen-rich compound, usually inorganic, and a fuel binder that released a large amount of energy on burning.

The single base propellants and the POL powders are no longer of major importance because of their low energies. Until recently, when new casting methods appeared, the double base propellants (which included JPN) were being used less frequently because most of these were extruded under pressure which made it difficult to manufacture large grains.

The composite propellants are presently the most widely used of the propellants in large military grains. The GALCIT series was one of the earliest examples of a composite propellant. The fuel was nothing

more than asphalt mixed with potassium perchlorate with plasticizing oils added. The potassium perchlorate, on heating, released about 46% of its weight as pure oxygen, which in turn combined with the asphalt, producing heat and some formidable clouds of white smoke. Since the GALCIT's, the roster of composite propellants has grown enormously.

THE DEVELOPMENT of composite propellants has been essentially a history of plastic and resin chemistry. Since the fuels used in composite grains do not contain their own oxygen, as does the nitrocellulose and nitroglycerine in the double base propellants, a solid oxidizer is needed to supply the oxygen; and the choice of these is severely limited. The oxidizer must have a rather large percentage of its weight available as oxygen; it must not absorb an undue amount of moisture from the air; the molecules it feeds into the exhaust gases must be fairly light in molecular weight, and preferably gaseous rather than solid; and it should be reasonably cheap. (Actually, the last

requirement is becoming less important each day, as we try to crowd more energy out of a propellant. Propellant chemicals may often cost as much as a hundred dollars a pound in experimental quantities (these days.)

THE PRINCIPLE oxidizers now in use are Ammonium Perchlorate (oxygen: 34%); Ammonium Nitrate (oxygen: 20%); Potassium Perchlorate (oxygen: 46%); Potassium Nitrate (oxygen: 40%), and Sodium Nitrate: (oxygen: 47%). Of these, ammonium perchlorate comes the closest to filling the bill. A whole class of ammonium nitrate propellants has been developed, but ammonium nitrate has three major disadvantages: Its oxygen content is low; it goes through two distinct volume changes at higher temperatures before melting; and it absorbs moisture rapidly from the air if the relative humidity is much above 41%. The picrates have been used to some extent, but the first two compounds, ammonium perchlorate and ammonium nitrate are still the most popular for high energy composite propellants. (The

potassium and sodium salts mentioned have a disadvantage in that their combustion products are partly solids of comparatively high molecular weight. Later we will discuss the quantity called "specific impulse", by which the propellant chemist compares the thrust that a given weight of propellant burned over a given time will produce; and we will find that, as the molecular weights of the materials in the exhaust go up, the specific impulse goes down.)

While work is still being done on the GALCIT type of propellant, most of the binders now used draw from the more exotic areas of plastic and resin chemistry for their structure. One of the most important solid propellant companies, Thiokol Chemical Corp., has developed a whole series of polysulfide rubbers as binders while both natural and synthetic rubbers have also been used as binders in composite propellants. Besides these, the propellant chemist has developed propellants based on plastics and resins such as the polystyrenes, polyurethanes, the polyvinyls, par-

ticularly the polyvinyl acetate and polyvinyl chloride resins, and so forth.

ALL OF THESE resins and plastics have two things in common: when they combine with oxygen, they release a great deal of energy and their formulations before curing are sufficiently fluid to cast into molds. All of these materials are what the chemist calls "high polymers"—that is, long molecules made of very simple building blocks that repeat and repeats like beads on a string. These high polymers may be long chains—as in the case of the polyvinyl resins—or they be long chains cross-linked down their length as in the polyurethanes. When the binder material is mixed with the oxidizer and cast into a mold, the chains and the degree of crosslinking are both low or non-existent. The process, called curing, increases the length of the chain and/or the degree of cross-linking which in turn causes a comparatively fluid material in the mold to become more and more solid. The resulting propellant material may vary in physical appearance from a stiff rubber or

rough gel to a hard, brick-like material.

There are other types of binders being investigated at present, but most of this work is classified.

Besides the oxidizer and the plastic or resin binder, the composite propellant grain may contain a variety of materials to modify the burning rate of the propellant, its flame temperature and other such ballistic properties as well as to modify its physical strength, and elasticity. Carbon black may be added, for instance, to modify burning rate and to make the grain opaque. (A translucent grain may develop internal hotspots from infrared radiation penetrating the grain from the burning surface.)

HIGH ENERGY additives such as powdered zinc, powdered aluminum, boron, and a borane may be added to increase the propellants burning rate and to increase its energy. Powdered magnesium has also been investigated, but has not proved attractive at present—in spite of its favorable effect on the specific impulse

—because of its reactivity with moisture trapped within the grain. The boron hydride, decaborane ($B_{10}H_{14}$), has proved of interest in solid propellants. Decaborane is the only presently-available borane that is solid and the current classified literature suggests that it might prove of value. The disadvantages of adding metals such as aluminum to the composite or double-base propellant lie in the nature of their combustion products. Aluminum yields a solid material, aluminum oxide, which has a fairly high molecular weight and, more important, has pronounced abrasive properties. In the same way the chromates yield a abrasive chromic oxide. These abrasive materials tend to erode a rocket nozzle, and over longer operating periods, the properties of the rocket motor itself will change in an unpredictable fashion.

THE DOUBLE-BASE propellants have recently gained a new hold on life with the advent of manufacturing techniques which do not require expensive extrusion tech-

niques and which do not require the use of clumsy casting powder techniques in which a casting powder composed of nitrocellulose and various modifiers is placed in a mold and a nitroglycerine casting solvent drawn up through the mold dissolves, gels, and finally solidifies the casting powder. (Needless to say, the solvent-casting method has another disadvantage. The casting solvent may often contain as much as 75% nitroglycerine and, though a desensitizer is present, the process still is not the sort of thing to guarantee a long life-span to the operator.)

One of the main attraction of the double-base powders is that the oxidizer is built right into the nitrocellulose and nitroglycerine molecules. As a result a double base grain is more homogeneous physically and contains less inert, non-energy-producing weight. The newer double-bases seem to have better physical properties and, in spite of the release of acidic decomposition products, better storeability.

IN SECTION two of "The Race Into Space", we're going to discuss liquid fuels, some

of the methods of evaluating chemical fuels, and the future possibilities and limitations of the chemical fuel in space flight. Along with this, we're going to explore two of the more esoteric fields of chemistry to talk about both solid and liquid fuels based upon what the chemist calls free radicals and upon what the

physicist calls meta-stable excited states. And after that, in part three, we'll talk about atomic fusion and fission drives, ion-drives, plasma drives, solarpower drives including the resurrected concept of the clipper ship of space, photon drives, and anything else that sound faintly possible. Bring your slipsticks.