N66-12166

TO WHOMSOEVER WILL READ IN ORDER TO BUILD /501

Yu. V. Kondratyuk

Above all, do not be frightened by the theme of this paper nor distracted from the realization, difficult as it might be to comprehend, that from the theoretical viewpoint rocket flight into outer space is nothing astonishing or improbable.

I will have frequent occasion to use phrases which are quite inadmissible in scientific writing, such as: "not too large," "sufficiently," etc., without indicating anything exactly. This is because I do not have on hand the materials for drawing the line between "sufficient" and "insufficient," in fact a good part of the materials needed for the construction of a rocket still have not been assembled.

On less frequent occasion, this is dictated simply by a disinclination to carry out the computations, which anyone can perform.

Allow me to say a word about terminology; in many instances, I have made up my own, in many others I have probably adulterated existing terminology, so that if such happens to be the case it should not be puzzled over, but probed for substance of meaning.

The realization of this undertaking will require tests, tests, and more tests on an ever-increasing scale. A gradual approach must be exercised particularly in flights with people. In such a new area, it is impossible to foresee everything, and in interplanetary space help is to be expected from nowhere.

General Theory

The first stipulation for flights from earth and back is that they do not risk the lives of the passengers.

The second stipulation is that they be maneuverable.

The first stipulation requires, first, that the mechanical accelerations imparted to a vehicle carrying passengers should not exceed a definite threshold, above which this acceleration could be harmful or fatal to humans; /502
second, that a vehicle with passengers on board must be hermetically sealed to prevent the escape of air, this air must be maintained fresh, and the temperature of the vehicle must be kept normal. All of the latter conditions are easily met, but the first requires some discussion; in order for the vehicle to be able to overcome the earth's gravitational pull, it must acquire a tremendous velocity (about 11 kilometers per second) (note 1, Commentary). In order to gain such a velocity without mortal consequences, acceleration must be imparted over a rather long period of time (in hours) and over a very long distance (hundreds) of kilometers). Any sort of cannon, in the conventional sense of the word,

besides the fact that it cannot communicate the necessary velocity to the vehicle with today's materials, is totally unsuitable for the additional reason that a man seated in the projectile would be mashed to a pulp at the bottom of the vehicle.

It is conceivable, of course, to construct an electric "cannon" several hundred kilometers in length, which would comfortably supply a velocity of 11 km/sec, but such an item would be very costly and would not solve the problem of the return trip to earth or of maneuverability.

Consequently, the cannon must be abandoned; this leaves the sling principle and reactive device. The sling is unsuited to the purpose at hand for the same reasons. It requires tremendously bulky equipment (so that the man will not be crushed) and does not solve the return-trip problem. The reactive device is left.

The second stipulation, maneuverability, eventually leads to the reactive device, since in the celestial void there is no point of support other than that which is taken with oneself.

The problem, then, is the following: Is it possible in general theoretically for a reactive device to develop a velocity of 11 km/sec and to recover it for the return trip, and does this require dimensions that are impracticable or very difficult to realize. We will consider the rocket as a reactive device, since any other type than comes into my mind is either unrealizable due to the enormous dimensions required, or the problem of realizing it calls for prior investigations which, at the moment, I am unprepared to carry out.

A Theoretical Formula for the Weight of the Rocket

Let us suppose that we have a substance (which we will henceforth call the "active" substance) or a composition which can perform p ergs of work per gram and that we can utilize all of this work to expel this (the usable amount) substance from the remaining body of the rocket.

Let the mass of the entire body of our rocket be equal to m grams, and let /503
us burn up (henceforth we will use this expression instead of "using energy," because this is in fact what happens) an infinitesimal quantity h grams of the active agent, using up the developed energy ph to expel the quantity h (which is precisely the substance that we have burned up) from the remaining body of the rocket. As the two bodies are pushed apart the energy (kinetic energy) relative to their common center of gravity is distributed between them in inverse proportion to their masses, hence the remaining body of the rocket (whose mass is m - h) acquires as its portion

$$hp \frac{h}{(m-h)+h} = \frac{h^2 \cdot p}{m} \text{ erg.}$$

We translate this work into velocity (continuing to regard the mass of the rocket as m, since the loss h is insignificant).

$$\frac{m\cdot V^2}{2} = \frac{h^2 p}{m};\quad V = \sqrt{\frac{2h^2 p}{m^2}} = \frac{h}{m}\sqrt{2p}\ \text{cm/sec}.$$

We see from the resultant expression $\frac{h}{m}\sqrt{2p}$ that, other than the properties of the active agent (p), the imparted acceleration depends only on its relative proportion, h/m, or, what amounts to the same thing, on the ratio of the total mass (m) to the passive part (m-h):

$$\frac{m}{m-h} = 1 + \frac{h}{m}\left(\text{since } h = \frac{1}{\infty}\right).$$

Consequently, every time that we burn up an amount of active agent in this proportion, the indicated acceleration will be obtained, and whatever the ratio of the required velocity V to the derived velocity $\frac{h}{m}\sqrt{2p}$, this is the amount of active agent that must be burned up in proportion to the ratio of the total mass to the passive part: $1+\frac{h}{m}$; i.e., to develop a velocity V it is necessary to burn an amount in the given ratio $\frac{Vm}{h\sqrt{2p}}$.

Therefore, the ratio of the starting mass of the rocket to that which remains will not be $1+\frac{h}{m}$, but $\left(1+\frac{h}{m}\right)^{\frac{V\cdot m}{h\cdot\sqrt{2p}}}$ We transform this expression, relying on the fact that $h = 1/\infty$.

$$(1+h)^{\frac{V\cdot m}{m\cdot h\cdot\sqrt{2p}}} = (1+h)^{\frac{1}{h}\frac{V}{\sqrt{2p}}} = e^{\frac{V}{\sqrt{2p}}}$$

Consequently, denoting the mass of the entire rocket by M, the mass of the passive load by m, we have the formula /504

$$M = me^{\frac{V}{\sqrt{2p}}}.$$

We conclude from the resultant formula that it is always possible to impart any velocity V to a given mass m, even if only a mildly active substance is involved (p), and its activity only affects the size of the rocket M, which of course increases very rapidly with decreasing p and could very quickly overstep the bounds of practicality.

Derivation of a Formula in Application to the Potential Energy of the Earth's Gravitation

The potential energy of the earth's gravitation is equal to rj, where r is the radius of the earth, j is the gravitational acceleration for any point outside the earth's surface. We transform rj to velocity:

$$rj \text{ ergs} = \frac{V^2}{2} \text{ cm/sec}^2 \quad \text{(note 2, Com.)}; \quad V = \sqrt{2rj} \text{ cm/sec (note 3).}$$

We substitute into the general equation

$$M = me^{\frac{\sqrt{2rj}}{\sqrt{2p}}} = me^{\sqrt{\frac{rj}{p}}},$$

This is the formula for flight away from the earth; in order for this velocity to be recovered for the return trip, it is necessary to have twice the same mass. We obtain

$$M = me^{2\sqrt{\frac{rj}{p}}}$$

$$\ln M = \ln m + 2\sqrt{\frac{rj}{p}}$$

A partial calculation, assuming p = 10/3 kcal/g (approximately the calorific value of $H_2 + O$), yields

$$M = me^{2\sqrt{\frac{600\,000\,000 \cdot 1000 \cdot 3}{42\,800\,000\,000 \cdot 10}}} = \text{approx. } me^4 =$$
$$= \text{approx. } 55!$$

The ratio 55 (even though it is a theoretical minimum and should perhaps in practice be set equal to 100, 200, 500, or 1000) is not an unreasonable figure; the rocket is entirely practicable!!!

(All of the symbols that I use are expressed in absolute units, and my calculations are in the same units.)

The Complication Introduced by the Limited Endurance of Man and Vehicle

/505

In deriving the above formulas, we did not include in our calculations the period in which acceleration would be imparted. These formulas are exactly applicable only for the case when the acceleration is imparted instantaneously, because as long as we are imparting acceleration to the vehicle away from earth, the earth's gravitational field imparts an acceleration toward the earth, and the longer the period of time in which we impart acceleration to our vehicle the greater will be the acceleration that can be imparted to it in the opposite direction by the earth's gravitation, and this acceleration must then be compensated by the active agent. (This argument becomes clear from the following: If we impart to the vehicle away from the earth an acceleration equal to the earth's gravitational acceleration, our vehicle would not go anywhere, but would hover in the air.) Consequently, from this point of view, the greater the acceleration that is imparted to the vehicle, acceleration per unit time until the required velocity is attained, the better. But, first of all, man cannot withstand an acceleration (imparted mechanically) greater than some definite maximum (the way to raise this level is discussed below). Furthermore, the vehicle must be made stronger in proportion to the amount of acceleration, i.e., the passive load must be increased. Therefore, we will not impart to the vehicle an acceleration greater than some given value q. We will call the ratio q/j (where j is the earth's gravitational acceleration) k. It is expected that k will be of the order 5 or 10.

First Method of Flight and its Formula

The first method of flight consists in imparting to the vehicle an acceleration directly away from the earth in a radial direction (or, if not radially, in one fixed direction), and for the return flight imparting the same acceleration in the reverse radial direction, toward the center of the earth. Let the ratio of the imparted acceleration to the gravitational acceleration be k. Although k will increase on ascending away from the earth due to diminution of the earth's gravitation, I will assume for the present calculation that it is constant (or that it does not vary too appreciably, especially when it is large (5-10) at the start), in order to avoid complicating the calculations unnecessarily. Thus, of the total acceleration imparted to the vehicle kj, $1 \cdot j$ will be used in overcoming the earth's gravitation, the remaining (K-1)j comprising the effective part, i.e., the activity of the substance in the sense of communicating velocity will be lowered by a factor of $\frac{k}{k-1} = 1 + \frac{1}{k-1}$. This factor of $1 + \frac{1}{k-1}$, therefore, must be substituted in the exponent of the mass formula:

$$M = me^{2\sqrt{\frac{rj}{p}}\left(1+\frac{1}{k-1}\right)}$$

Even if k = 5, the factor $1 + \frac{1}{k-1}$ in the exponent represents a very vexing quantity. /506

Second Method of Flight and its Formula

The second method of flight consists in imparting to the vehicle an actual acceleration in a direction perpendicular (roughly) to the radius vector and returning along a tangential direction with the reverse acceleration, again perpendicular to the radius (fig. 1).

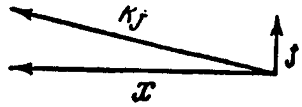


Figure 1

From the velocity parallelogram we find the actual acceleration, if to our vehicle we impart an acceleration such that when added to the gravitational acceleration it will give the actual acceleration perpendicular to the radius:

$$x = \sqrt{k^2 j^2 - j^2} = j\sqrt{k^2 - 1}.$$

With the communication of such an acceleration,the activity of the substance is lessened by a factor of $\frac{k}{\sqrt{k^2 - 1}}$, and this only at the very beginning. As velocity and centrifugal force are developed, this ratio will approach unity.

When the vehicle attains the velocity at which the centrifugal force becomes greater than j, the vehicle will have a tendency to move about the earth in an ellipse. By imparting velocity to it in those parts of its flight path where it is most perpendicular to the radius, near the ends of the major axis, we will obtain an activity coefficient near unity. The return trip is by the same means. Inasmuch as I am not able to perform all of the computations, I will use in the formula the ratio $k/\sqrt{k^2 - 1}$, which is worse than any efficiency factor but which is still very good, incomparably better than k/k -1; even for small k the coefficient $k/\sqrt{k^2 - 1}$ is very near unity.

$$M = me^{(2)\sqrt{\frac{rj \cdot k^2}{p(k^2-1)}}} = (me^{2\sqrt{\frac{rj}{p}\left(1+\frac{1}{k^2-1}\right)}}$$

Here is an approximate drawing of the vehicle's path (fig. 2). /507

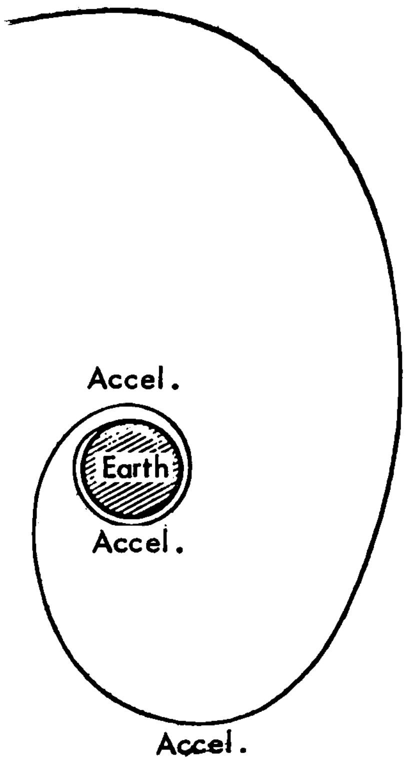


Figure 2

Thus, the second means is far more complex in the sense of control, but it requires considerably less active agent (if k is not particularly large, say 20).

Note: Subject to the influence of the force of gravity (which is appreciable), it will always be true in general that the more judiciously we utilize the active agent, the more perpendicular to the direction of gravity we will impart acceleration (but here, of course, it must be remembered that the more judicious acceleration is imparted parallel to the already existing velocity). The second means of flight is the application of this principle (note 4, Commentary).

On Techniques for Increasing the Endurance of the Human Body with Respect to Appreciable Mechanical Accelerations[1]

As we have seen, the limited endurance of man with respect to accelerations, especially in the first flight method, is a very detrimental factor in the rocket weight formula. We will now describe in general terms the reasons for nonendurability and how they might be coped with in some measure.

The reasons for lack of endurance are the limited strength of the body, the presence of fluid elements, and differences in the absolute density of the constituent parts of the organism. As we know, if a man falls from a great height his members will be broken, i.e., his body will not withstand the acceleration imparted to it by the ground surface. Then, of course, if a man spends a long period of time in a situation that is unfamiliar to him, for instance upside-down, or, better yet, spinning rapidly about some point, his blood, due to the acceleration of gravity in the former instance (centripetal acceleration) and centrifugal acceleration in the latter, will rush to certain parts of his body and drain from others. In magnified form, this effect terminates in rupture of the vessels in those portions of the body filled with blood.

The injurious effect of the third factor, differences in density of the constituent parts of the body, in normal living is not pronounced, but can be manifested upon acquiring appreciable acceleration. In the chest, where this difference is the greatest, a heavy organ - the heart - and the organic part of the lungs together with the blood contained in them are found side by side and in disordered fashion with air contained in the lung sacs. Excessively large acceleration can result in blood discharge in the lungs, collapsing of the lungs, and subsidence of the heart in the lungs.

This is how the harmful consequences of mechanical acceleration can be overcome (provided it is not excessively high, say 1000 m/sec^2 (note 5)), without sacrificing the latter: The man, completely nude, lies on his **back** in a form specially contoured to provide a snug overall fit to his figure. This form comes up to a little more than half the thickness of his body, as indicated by the heavy line in the figure (fig. 3).

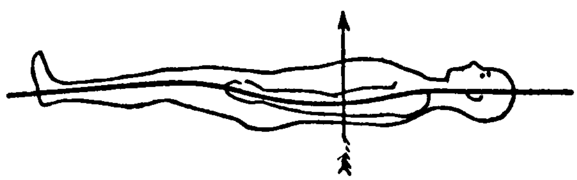


Figure 3

[1]By "mechanical" I mean acceleration that is imparted mechanically, i.e., by exerting pressure, for example. This is the only acceleration that can be detected, while acceleration imparted by gravity cannot be detected by any means on the body itself.

The direction of acceleration is indicated by the arrow. In this position, the pressure will be distributed uniformly over the entire backside of the body, and all of the harmful effects, except for the process in the chest, will be greatly mitigated. If the acceleration is not so large as to call for such measures but is still considerably larger than the acceleration of earth's /509 gravitation, it is recommended that the man lie on something, mainly being careful that the body does not extend anywhere too far in the direction of acceleration, so as not to obtain rushing of the blood in some places and draining in others; either is proportional to the height of the blood column, i.e., the extent of the body in the direction of acceleration. It is also possible that reliance on a contoured form would not be at all suitable, if below the acceleration for which this would be required any undesirable effects occur in the lungs (of course, this would not be affected by the form). Experiments relating to all of this are not difficult to set up with a man on a large centrifugal device employing centrifugal force.

Concerning Other Possible Reactive Devices

1. A mechanical reactive device consists of a wire coil whose center is connected to the passenger chamber. If we impart to the coil a sudden rotation (opposite to the sense in which the wire was coiled) and then release the end of the wire, it will fly along a tangent to the circle in one direction, while the coil with chamber will fly in the other direction (fig. 4).

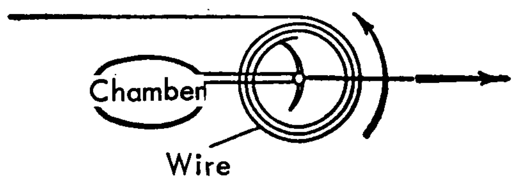


Figure 4

This kind of device is unsuitable for flights from the earth, because a wire coil made of even the best steel cannot possibly withstand rotation at a velocity (absolute, irrespective of the radius) greater than about 300 m/sec; above this the coil cannot withstand the centrifugal force and will break.

Because of the low attainable velocity, it would be necessary to build the device with enormous dimensions: approximately $M = m.55^{10}$ /510

2. Reaction from Material Emission. - Cathode rays represent particles with mass, which are charged and travel at velocities of 200 000 km/sec. Consequently, they yield a corresponding reaction, or recoil, and could be utilized, provided the necessary intensity were attained. Their drawback is the tremendous amount of energy required, and their velocity is greater than need be; the larger the velocity, the greater the amount of energy that we must expend to obtain the same reaction, and they are accompanied by a high electric charge of high potential that serves no purpose. It is possible, however, that any dissipation of energy could probably be eliminated by passing these rays

through an anode layer, wherein they could lose their surplus velocity and charge, and we could again utilize the heating of the anode. Even though right now a reactive device based on material emission seems very difficult and unlikely to me, it is nevertheless worth thinking about and working on; in the event that it succeeds, it promises to give as collossal a velocity as could be given to even the most gigantic rocket. It would perhaps be possible to test the theory of relativity. The energy for such an apparatus can only be taken from the rays of the sun, either our own or another (see the discussion of reflectors and solar energy) (note 6).

General Form of the Vehicle

The vehicle consists of a chamber to house the passengers, instruments, and, in compact form, the control mechanisms; tanks for the active agent; and tubes in which combustion and expansion of the active agent and its gases take place (as they expand, these gases press on the tube, imparting acceleration to the vehicle, while they themselves escape from the latter in the opposite direction). The tanks for the active substance must be several rather than just one, because one tank would weigh considerably even at the end of the flight when almost all of the active agent is spent, constituting a totally unnecessary mass, which might weigh down the vehicle severalfold and require a large quantity of active agent and could even render the whole undertaking unfeasible. For this reason, there must be several tanks of various dimensions. The substance is first used up from the large tanks, after which they are simply rejected, and the agent from the next tank begins to be used. The dimensions of the tanks should be calculated so that the weight of the spent tank (one empty tank) will amount to the same portion of the entire remaining rocket for all tanks (note 7). This portion needs to be worked out, first with acknowledgement for the requirement that this portion be as small as possible, second, for the fact that the number of tanks should not be too large, so as not to com- /511
plicate the construction of the vehicle excessively. Figure 5 gives a schematic representation of what I consider to be a suitable form for the vehicle; the chamber is approximately spherical, the tanks are in the form of conical layers (approximately congruent). They are made in the form of layers so that they will extend less in the direction of acceleration and so that large pressure will not be produced in them (high fluid column). It is not a good idea to make the cone too broad nor too long; in both cases the strength of the tanks should be increased with allowance for acceleration, and in the first case with allowance for pressure (the active agent consists of liquid gases, oxygen and carbon).

In order for it to be possible to make the bottom of the tanks flatter, without making them heavier, it might be more appropriate to run tie rods to them from the point of application of force a (gas pressure on the tube), to which all of the tanks are then connected by the rods and in which the tube is secured.

If for some reason liquid oxygen and hydrogen cannot be held together in the mixture, it will be necessary to provide each tank with two compartments (note 8), one above the other. In correspondence with the several tanks, the /512
tube should also be altered with the rejection of old tanks, either by

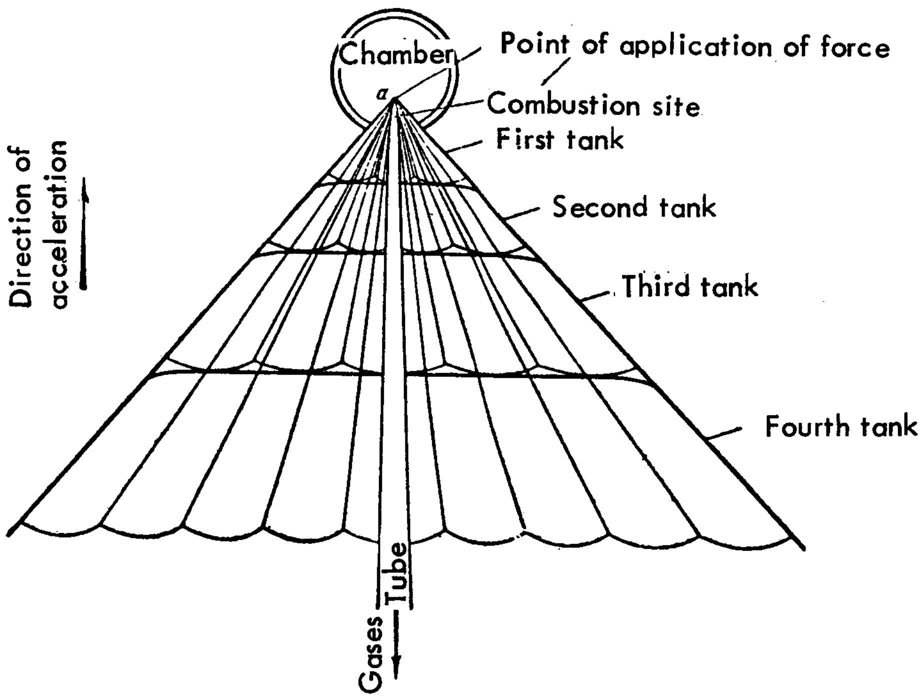


Figure 5. Schematic Section of the Vehicle

discarding the projecting member of the tube and shifting the combustion region or replacing the whole thing with a new one; the best approach will be determined by experiments. The chamber, of course, is airtight, well heated, with equipment for freshening the air.

It must be found out experimentally whether man can breathe an oxygen-hydrogen atmosphere; if so, things are greatly simplified.

Theory of the Tanks

Relative to expansibility ⟨of the contents⟩. - Let us assume the tanks contain an ideal gas. We will consider the ratio (advantage) of the weight of the tank to the weight of the amount of gas that it can just hold (the thickness of the walls are used nowhere in the calculation, only their strength (in shear).

Simple computations show that the advantage of such tanks does not depend at all on their dimensions, and for the same gas at the same temperature it never depends on the expansibility; that the most advantageous tanks are a hollow sphere and a long (infinite) cylinder (tube), the cylinder turning out to have a slightly higher advantage than the sphere (π for the cylinder, 3 for the sphere) (note 9).

Relative to acceleration. - We will now investigate a tank filled with a ponderable liquid, to which some ("mechanical") acceleration is imparted. The force producing the acceleration is applied to the tank.

Simple computations show that for such tanks the advantage is inversely proportional to the lengthwise dimensions (larger tanks are less advantageous); that the advantage is always inversely proportional to the magnitude of the acceleration; that the advantage is inversely proportional to the cube root of the absolute density of the liquid <for the same given amount>; that for a cylinder whose axis is parallel to the direction of acceleration, if its bottom is not included in the computation, the advantage does not vary with the radius and is inversely proportional to the height; that the most advantageous shape for the tank is one bounded above (assuming downward acceleration) by a plane; that this shape is something like a hemisphere; that the most advantageous shape has only one flat surface, the one bounding it from above; that the advantage of the tank is increased with more uniform application of the force to the bottom of the tank, in which case it becomes more advantageous to make the tank wider and flatter (the same rule applies to an assemblage of interconnected tanks). On the basis of all the above, it becomes fairly evident why I have chosen for my vehicle tanks in the form of conical layers tied by rods to the vertex.

Construction of the Vehicle; Control and Stability /513

In order for us to be able to control the vehicle properly, we must be able to turn it in space in all directions, i.e., to rotate, together with rotation of the vehicle-tube, the direction of the emerging gases, i.e., the direction in which acceleration is transmitted, and we must be able to hold to a given direction at will, so that the vehicle will not go astray in space due to an unavoidable but large irregularity of the load (its center of gravity not being on a line with the applied force), tracing out a spiral or circular path. A predetermined course can be held by using a biaxial astatic gyroscope (note 10) (see the section entitled "The Biaxial Astatic Gyroscope"), and its direction can be altered by means of a thrust attachment at the end of the tube (fig. 6).

If we work with thrusts, then a short tube attached to the end of the tube by means of Cardan joints, being narrow enough not to interfere with the normal gas glow, deflects the pressure of the stream when rotated slightly, thus imparting to the entire vehicle the rotational moment needed for changing direction. If possible, it may not be necessary to construct this entire accessory, but to create thrusts directly at the end of the tube so that they will tend to turn it slightly in a desired direction. Here we have a lever arm to which all four thrusts will be imparted (fig. 7).

The point of rotation a of the lever should be in the same plane as all four of the pulleys B. Then the action in one direction will not detract altogether from the others. We note that this single lever system for controlling turning in all directions can also be used in other situations, for example aeroplanes, where the rudders and elevators are combined in one control device as, for example, a cylindrical surface, with control by means of a single stick.

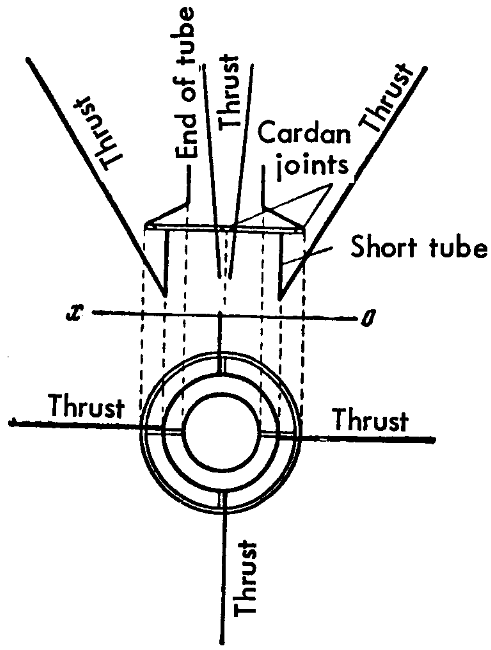


Figure 6

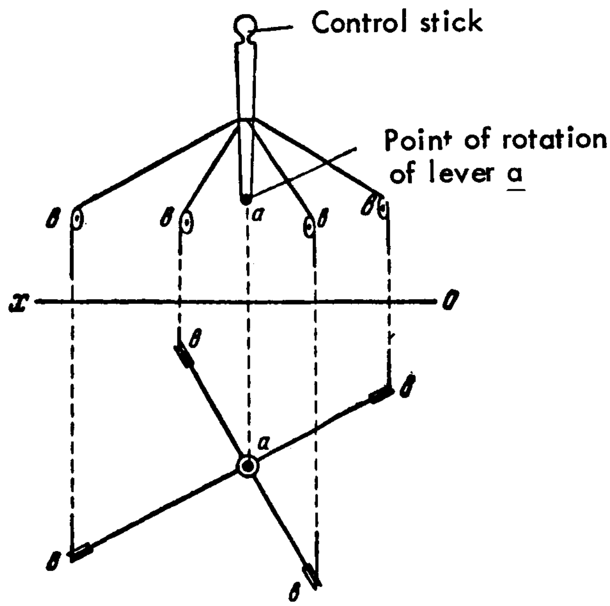


Figure 7

Control is accomplished in the following manner. The gyroscope (its frame) is housed in a yoke, which is rigidly secured to the body of the rocket. This yoke, when we need to hold a given course, is clamped; hence the body of the rocket is rigidly attached to the gyroscope, and it will in general remain stationary. When we need to execute a turn we release the yoke and make the turn freely, since the gyroscope is disengaged; we then clamp the yoke in place again. That's all there is to it. /514

The Biaxial Astatic Gyroscope (note 11)

The biaxial system consists of two gyroscopes in a single frame, their axes not parallel (perpendicular). The ordinary uniaxial gyroscope is countered by the rotation of the frame in all directions except that in which it spins itself, so that it does not always provide reliable support. If we build the gyroscope in biaxial form (see above), the total frame for both components of the gyroscope will be protected against rotation in all possible directions; wherever one of the gyroscopes is not countered the other will be completely countered. To make the frame of the biaxial gyroscope with approximately the same stability in all directions, it is necessary to make both gyroscope components of equal resistance (to rotation of their axes). For convenience, we /515
will make both gyroscopes in the form of hollow bodies of rotation and insert one within the other (fig. 8).

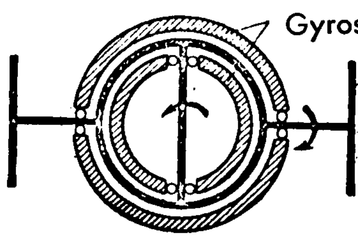


Figure 8

I use the term astatic to describe a gyroscope that reacts identically to rotation of its axis in a given direction as in the exact opposite sense, i.e., a gyroscope that is not given to any sort of nutation, precession, etc. The ordinary gyroscope will thus be unsuitable for the vehicle, for although it may rotate the vehicle in one desired direction it may not do the same in the direction perpendicular to that one. In order to build an astatic gyroscope it is necessary to combine two gyroscopes of the same resistance to rotation in a single frame, such that their axes coincide, while the directions of rotation are opposite (fig. 9).

The two gyroscopes so joined will tend to oppose all nutations, etc. with an equal and opposite force and, in this sense, nothing will happen, which is the required result.

The term "biaxial astatic" refers to a biaxial gyroscope, both components of which are astatic. Here is a schematic drawing (fig. 10).

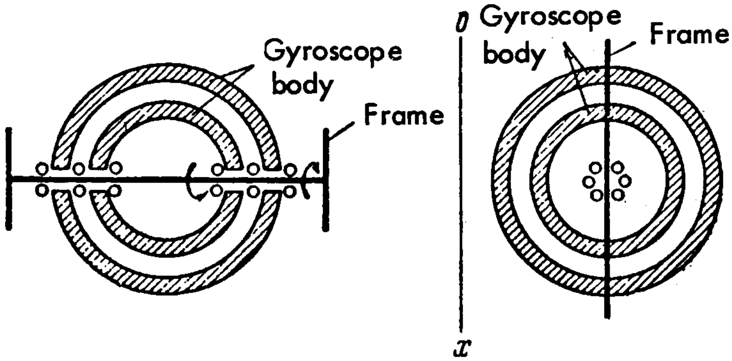


Figure 9

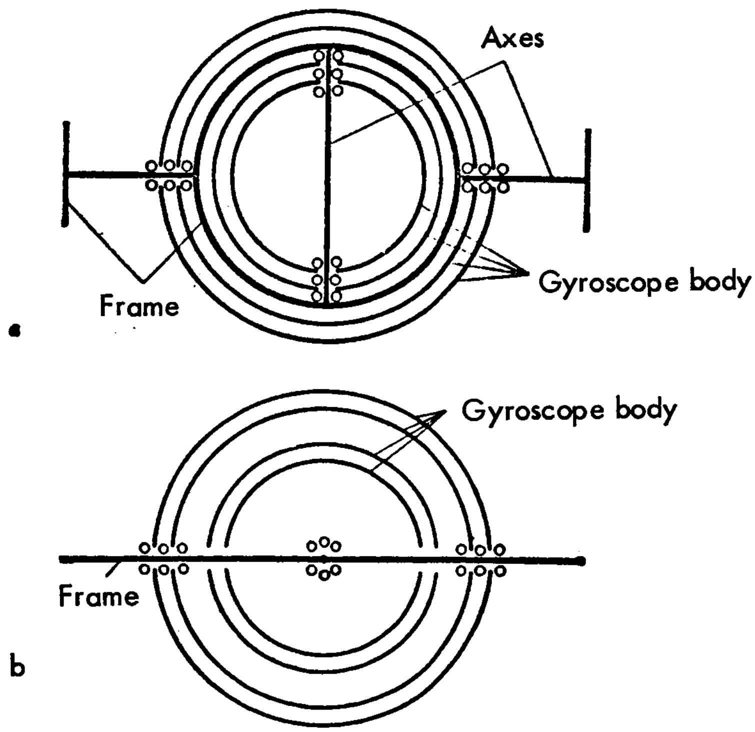


Figure 10

a) Schematic section in the plane of both axes; b) schematic section parallel to one axis (outer), perpendicular to the other (inner).

The frame of our gyroscope is hermetically sealed inside a hollow sphere, which is then inserted in the spring-clamped yoke. The appropriate rotation of all four bodies of the gyroscope does not impose particular difficulties. It is transmitted mechanically in sequence from the external to the internal /516
system and is driven by some kind of very small (electric) motor. As the weight of the entire rocket decreases due to combustion, the gyroscope can be replaced by smaller ones and the large ones rejected.

The Chamber

The chamber should have a window for observation purposes and an opening, closed off by airtight doors, for the discharge of refuse.

In order to discharge anything, we open the upper door, deposit the waste matter on the lower door, close the upper, then open the lower one; the refuse is ejected and we once again close the lower door (note 12).

For control of the vehicle it is necessary to have communication between the interior of the chamber, i.e., the passenger quarters, and the external part of the rocket. This can be done by passing electrical wiring or pneu- /517
matic lines or simply connecting links through the walls of the chamber. There are no problems in the first two methods, but they are complicated, whereas the last method is simple but must be installed so that air will not excape from the chamber. This is how it is done: The connecting link (in the form of a tube, for thickness) runs through the wall via an opening of approximately the same size; the link is enclosed in a rubber tube, which fits it hermetically; this tube is twisted and hermetically fitted to the wall of the chamber so as to surround the opening for the connecting link. In this way, it enables the link to be moved in and out in that part of the rubber which is fitted to the opening; some kind of lubricant must be used between it and the link so that the rubber will not be squeezed under small pressure.

Perhaps it will be possible simply to polish and seat the link in the opening such that air leakage will be a factor of safe magnitude; this would be best of all. (We always have oxygen and hydrogen in tanks.) Special plugs will have to be used for the openings of those links that are discarded during flight (which includes the majority of them, since as the tubes and tanks are rejected their appurtenant control links must also go).

If the chamber is so arranged that a full-circle field of view is possible, it will be necessary to furnish it with optical devices permitting vision in a full circle.

The Active Agent and its Combustion

The active agent is a fulminating gas. It is best stored in solid form (note 13) so that the pressure of the gases inside the tanks will be minimized, since too much pressure will load them excessively. For proper combustion the hydrogen and oxygen should be stored separately (each one in such a state, i.e., at such temperature, that the pressure of the saturated gases will be a minimum). So that uniform pressure and uniform issuance of the gases will exist in the tanks, we must supply the tanks with an amount of heat necessary for vaporization or sublimation. This heat will be delivered by the circulation of the hot hydrogen in the tube via tubes (heaters) running through the tanks (more on this arrangement below).

The gases will emerge from the tanks into pumps, which raise their expansibility to the point where it can exit from the combustion region and heaters into the tube (also more on the construction of the pumps below).

The actual combustion can be produced by three means; either the already hot mixture will ignite, the gases will not be mixed until the instant of ignition, or they will be only partially mixed just prior to this instant. /518
Experience will tell which of the three methods should be used (note 14).

The first method is nice in that complete union of the hydrogen and oxygen is guaranteed, without remnants of the unmixed gases.

A shortcoming of the method is the hazard of an explosion penetrating through the gas to the point where it begins to mix. This situation can perhaps be avoided by passing the fulminating gas ahead of the actual ignition zone through a layer of mechanical wire gauze (Davy lamp principle) where they would normally be mixed, or through some kind of porous materials, or perhaps by yet another means. If at all realizable, the first method should be used.

If the danger of explosion can only be circumvented by incomplete mixing, i.e., by delivering the oxygen separately to the ignition region but with more or less of a hydrogen admixture, and hydrogen with an admixture of oxygen, then the combustion must be accomplished by this method. Partial mixing can be accomplished by passing the gases through two tubes, one of which is more or less porous or even perforated. But even if with incomplete mixing we are not able to obviate the danger of explosion, the gases must be delivered to the combustion region separately (it is quite certain, however, that safety will be achieved with incomplete mixing). With either partial mixing or no mixing at all, the final mixing will therefore take place freely in the tube itself; experience will reveal just how profitable this will be.

To make it easier for the gases to mix in the tube, they should be injected by branching the oxygen and hydrogen tubes into a large number of very small ones, with the same, square cross section. These tubes are then intermingled so that their ends form a checkerboard pattern (note 15):

Oxygen	Hydrogen	Oxygen
Hydrogen	Oxygen	Hydrogen
Oxygen	Hydrogen	Oxygen

With this method, even though the gases are not mixed at the ignition site, they will still be rather finely stratified. It goes without saying that the heater (oven) must be made of suitable materials so that it will not set fire to the fulminating gas.

Scheme of the Heating System, Pumps, and Regulator 519

The pumps - or what amount to pumps in their general proportions - and all of their associated lines must be solidly built, especially for large tanks, because from them will be consumed an enormous volume of gas every second. This solidity requirement even makes it desirable to do without them if possible (note 16).

But, again, this is unsuitable, because sufficient pressure is required in the tank to enable the gases to emerge into the tube, where the pressure is never very low. The pumps are of the single-cycle type, one for the hydrogen, one for the oxygen.

From the pumps, part of the gases go for combustion, the other part for heating. Both must be regulated. The heating gas is clearly pumped as a surplus quantity. It is delivered along the tubes to absorption heaters (where it is heated) contained within the tube, whence it passes along the small tubes into the heating ovens, which are contained in the tanks. From the heating ovens it is simply ejected back into the tank. The heating regulator is located near the injection orifice and consists of a baffle, which moves at right angles to the tube and its opening to make it wider or narrower. This baffle operates on pressure; should the pressure become ever so slightly greater than normal the baffle will close off the opening, and the inadmission of heat, instead of causing vaporization, will lower the temperature and pressure. The same is true in reverse; if the pressure is low, the heating is stepped up, elevating the temperature and pressure. The position of the baffle can be regulated as a function pressure in the tank by constructing its wall like the aneroid barometer. This, in any event, presents no difficulties. I feel only that installing a mixture regulator in the rocket is a good idea, but right now I find that it complicates the vehicle unnecessarily; in the actual tuning, everything should be adjusted and experimentally tested to the extent that extensive regulation will not be necessary. And if everything is in proper balance, misfortune will not result. The residual unused agent is simply vaporized. The pumps are driven by an engine (internal combustion or, better yet, a turbine, again with appropriate materials), which also operates with the fulminating gas. The accelerator of this engine will also include all necessary combustion-acceleration control.[2]

---

[2] The exhaust pipe of this engine should open into the tube where the pressure of the gases in the tube is such that the exhaust gases can emerge from the engine.

The Tubes

The most appropriate type of tube is shown (fig. 11) (approximately a parabaloid of revolution, except that the parabolas are not quadratic but one degree higher; in the following discussion, however, we will go over to a simple cylinder for convenience).

Its surface should be as highly polished as possible, in order to minimize drag on the escaping gases. Theory shows that with a proportionate overall decrease or increase in cross sectional area, if the gases are fed in at the same temperature and in the same quantity, only the density of the gases is varied throughout (increasing by the same factor), while all the rest - velocity, temperature, efficiency - remain unchanged.

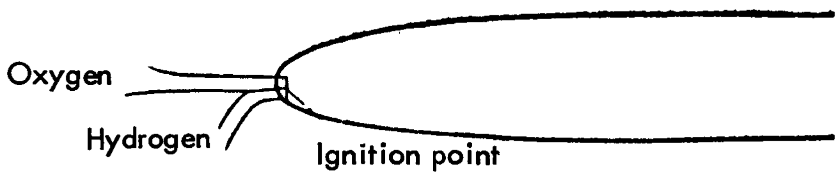


Figure 11

However, particularly narrow tubes ought not to be used, because the /520
pumps would become quite overloaded trying to feed the gases at a proportionately increased pressure.

Right now, we are not able to estimate the dimensions of the tube, even approximately. Tests will be needed with tubes, and it will be necessary to develop a theory to describe the flow of gases from one volume to another (has this perhaps already been done in the theory of ideal gases?) (note 17). Inasmuch as the cross sections of the tubes need to be made roughly proportional to the amount of substance expended, each tank will have to be equipped with its own tube; for large tanks they would have to be very large. If considerable length is demanded of the tubes, they could be made from several bends, the small bends of the large tubes could serve then as large bends for the smaller tubes.

Note: In order for the liquid (or solid) gases to occupy the proper state at all times in the tanks, for it always to be possible to set the vehicle in operation without special accessories, and for the necessary temperature to be maintained in different parts of the vehicle, it is essential that the operation of the vehicle ⟨i.e., the acceleration⟩ not be stopped at any time during flight; instead, when this operation is not needed, it should be reduced to a minimum without being shut off altogether. The accelerator of the engine, therefore, should never be completely closed.

Instrument for Orientation

In addition to optical devices (periscopes and telescopes), permitting a full-circle field of view, it will also be necessary to carry along instruments that will indicate certain standard directions for expeditious orientation, so that we will know in which direction to transmit accleration to the /521 vehicle (which way to turn it). These directions are the axis of the earth and the perpendicular to the earth's eccliptic, and perhaps other directions, depending on how we execute the flight. We can fix these axes in the form of astatic gyroscopes, secured so as to render it fully possible to freely turn in all directions, i.e., more correctly, to remain stationary relative to turning of the vehicle. This could be done, for example, by allowing them to float freely in a fluid. They could be rotated by electric motors.

Acceleration Indicator (Mechanical Type)

The acceleration indicator is simply a tightly stretched spring balance on which a weight is hung. The spring balance will then indicate the weight of this load relative to the vehicle, i.e., the magnitude of the mechanical acceleration of the vehicle (there is no possible way of determining the gravitational acceleration inside the vehicle). After looking at this spring balance, we can then operate the accelerator of the engine accordingly. If to the spring indicator we attach a pencil and place under this pencil a moving paper tape, on the latter we will obtain a curve (actually the area bounded by it) which will serve as an indication of the total mechanical acceleration imparted to the vehicle (i.e., the sum of all imparted accelerations), or, equivalently, a record of the spent and remaining active agent (note 18).

The Complications Introduced by Atmosphere

Above all, the atmosphere will hold back the vehicle during escape and at sufficiently high velocity will heat it (see the section entitled "Temperature of a Moving Gas Relative to a Stationary Body"). In order to preclude either effect, should they become excessive, it might be possible to fit the entire vehicle within a jacket specially adapted for flight in air.

A second problem is that atmospheric pressure raises the pressure and density of the gases at the exit opening (and they cannot be exhausted so easily), which means a reduction in velocity of the emerging gases and a reduction in the efficiency. To cope with this circumstance it will be obligatory to compress the gases at the exit sufficiently that they will never be affected by atmospheric pressure, i.e., to compress the gases somewhat higher than would otherwise be necessary. To do this, however, without losing efficiency, i.e., without raising the temperature of the gases at the exit, it will be necessary to decrease the area of the exit cross section, in other words, for flight in the atmosphere to fit the exit opening with a constricting nozzle or to a function in general with a specially designed, narrower tube, which is subse- /522 quently rejected. Since the pressure in the beginning of the tube is correspondingly increased, this means that the pumps must be built to transport larger quantities of gas, to work harder in other words. In this case, the pumps must be reinforced by special bracings, which are subsequently discarded.

Eureka! But then, during flight in the atmosphere the pressure must also be raised inside the tanks so that they will not be crushed by the atmosphere. This is accomplished automatically, since the heating regulator is regulated according to the difference between the inside and outside pressures; it must be constructed so that the velocity of the vehicle will not affect the air pressure on the regulator. On returning to earth, the same must be repeated.

Just from what has been said so far (concerning atmospheric resistance, heating, complication of the tube), it is apparent that the sooner the escape from the atmosphere, the better. The main factor here is the first few tens of kilometers of the atmospheric thickness, since beyond this limit its density becomes negligible. Therefore, even the second method of flight must begin approximately as the first, almost perpendicular to the earth's surface, with the acceleration directed along a tangential course from the moment of takeoff.

Utilization of the Atmosphere

Over and above the harmful complications occurring in departure, namely heating of the tube, there are useful effects on the return trip, particularly in the second method of flight and in the third method of return (which will be discussed presently), namely the resistance of the atmosphere, which is helpful in this case. For the first method it plays a minor role, while for the others it may play a very large role.

Suppose that we return by the second method. We will begin describing a circle around the earth, not outside the atmosphere as had to be done in departure and as might be done on the return trip, but inside it. Then the atmosphere can be used to absorb the velocity of the vehicle, so that we do not have to expend active substance for this purpose (except, of course, that which is used to bring the vehicle into its circular path). The applicable formula, then, is the following:

$$M = me^{\left[1+\left(1-\frac{1}{\sqrt{2}}\right)\right]\sqrt{\frac{rj}{p}}\left(1+\frac{1}{k-1}\right)} = me^{\left(2-\frac{1}{\sqrt{2}}\right)\sqrt{\frac{rj}{p}}\left(1+\frac{1}{k-1}\right)} \text{(note 19)}$$

and the economy of active agent is substantial indeed.

The third method of return to earth consists in approaching earth tangentially without consuming any of the active agent but utilizing the atmosphere to reduce the velocity and overcome the excess centrifugal force which would otherwise hurl the vehicle back from earth into empty space. The remainder of the operation is executed as in the second method.

The formula for the third method is now /523

$$M = me^{\sqrt{\frac{rj}{p_s}}\left(1+\frac{1}{k-1}\right)}$$

The radical with no longer any coefficient is the square of the material economy.

As we will see presently, both the second (in the atmosphere) and third method of return yield very large fuel economy, i.e., we can accomplish the same flight with incomparably less expenditure of material, or with the same expenditure we can realize much longer flights (see the section entitled "Flights Inside and Outside the Solar System").

Both of these methods, however, are far from simple to realize. We will show why later (note 20).

Temperature of a Moving Gas Relative to a Stationary Body

The temperature of the gas is a function of the (mean) velocity of its molecules relative to the body we use for measurement. Consequently, if the body used to measure the temperature is moving relative to the gas it will exhibit a higher temperature than if it were at rest (relatively). It is said, for example, that meteors burn up from the "friction" of the air. They burn up because the mean velocity of the air molecules (due to the tremendous velocity of the meteor relative to earth) relative to the meteor is enormous, hence the air temperature relative to the meteor is enormous.

For this reason, it becomes hot and burns up. When the issue concerns the motion of a gas relative to a polished surface, then, since smoothness prevents us from being able to determine the motion parallel to a surface, and since the (ideally) polished surface does not resist the motion of a gas parallel to it, it must be supposed that the more highly polished the surface the more its temperature relative to the moving gas will become a function solely of the velocity component of the gas normal to the surface. In other words, if a polished surface moves at an angle through the atmosphere with respect to the direction of motion, then the smaller the angle of attack the less this surface will be heated in flight (fig. 12).

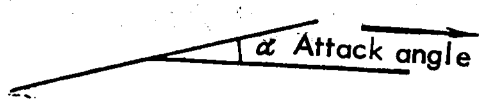


Figure 12

All this, of course, needs to be investigated experimentally from the quantitative aspect (note 21).

Heating associated with rapid motion through the air is the first complication in the second means of descent with the help of the atmosphere, as well as the third method. The second complication of these methods is the risk attending even the slightest error in control.

Form of the Vehicle for Atmospheric-Assisted Descent and Control During Such Descent

/524

For the reasons enumerated above, the vehicle (that part of it which remains at the time descent commences) must be placed in a sheath, which (if it proves feasible not to burn up like a meteor) should preferably resemble a very elongated projectile, rather than an aircraft. All of its forward-facing surface angles should be small with respect to the direction of motion. This is not required for surfaces facing backwards, because a void is formed at the rear; however, this sheath (or, perhaps, not a sheath but the vehicle itself will be constructed in this form) will have to be constructed so that there will not be the slightest propensity for it to fly through the air other than nose first. Here is my conception of the vehicle cross section in highly simplified form (fig. 13). If the vehicle itself is built in this form (which would be better), the chamber and remnant active agent will occupy the entire volume.

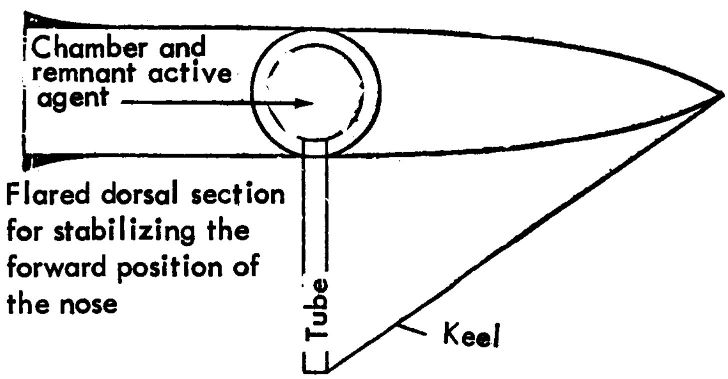


Figure 13

Almost all of the velocity loss must be completed in the very upper layers of the atmosphere, where its density is insignificant, the resistance then being correspondingly less, and where the hydrogen content will be less likely to heat the surface of the vehicle (in the theoretical analysis of the feasibility of not burning up in the atmosphere, the hydrogen composition of the upper layers must be taken into account) (note 22), since the hydrogen molecule is extremely light and the same velocity with respect to it will produce a correspondingly lower temperature. As long as possible, i.e., until almost all of the velocity has been absorbed, control should be maintained such that the vehicle is kept in the upper layers of the atmosphere, desisting from descent into the denser regions until the velocity has been reduced. Using the third method of descent, the angle of attack must first be negative in order for the centrifugal force not to hurl the vehicle away from the earth. The control must be very precise. /525

The slightest error in the angle of attack and the vehicle will plunge into the dense layers of the atmosphere, where neither will the vehicle be able to withstand the drag force nor the passengers be able to tolerate the deceleration, or it will simply hurtle into earth. Or it might fly upward from the atmosphere into empty space and then fall to earth at such an angle that it will be impossible to forestall catastrophe; after all, for velocities reckoned in tens of kilometers per second, the atmospheric layer is not so thick that maneuvers can be performed in it. Finally, even with an insignificant increase in the angle of attack, the vehicle will fail at once to withstand the increased drag. For descent by the second method, it is recommended that from the very beginning the angle of attack be chosen such that it will be safely larger than necessary, but without forgetting that a large angle of attack means greater heating. If we approach the highest layers exactly tangentially, such an angle of attack will not cause the vehicle to descend much below the "surface" of the atmosphere until its velocity is safely reduced.

Control is executed by means of an elevator control device. The vehicle must be constructed so that other control foils or fins will not be needed; it should be self-stabilizing. Furthermore, the vehicle itself will contain a bulwark of stability, the gyroscope. But the latter will not be able to cope with turns that are excessively abrupt. The gyroscope must therefore be clamped at all times during descent; at no time should it be disengaged. The elevator, of course, must be constructed so that the largest rotations of which it will be capable are small.

In readying the vehicle for the atmospheric-assisted return trip, it should be contrived in some way, so as not to allow the vehicle to incandesce excessively, to cool it, making it in the form of several, sequentially ejectable casings, or to change only the penetrating portions of the nose section as they wear out, to make the surface of the vehicle of the most highly polished, yet high-melting material (quartz), or to make only the nose section of such material, and even to make of such material something akin to the forward buttresses used in bridges. In general, it seems to me, this problem is rather difficult. And experiments must be carried out in large numbers on the problem, gradually approaching velocities of 22 (for the second method) and 35 (for the third method) kilometers per second (note 23). If it is possible to eliminate burnup only at velocities which are smaller but all the same rather appreciable (say, 10 kilometers per second), then a hybrid method of descent might be used; some of the velocity is lost outside the atmosphere, and only the remaining part is liquidated by means of the atmosphere.

The Best Thermal Nonconductor; Heaters /526

As is known, the currently best known nonconductors of heat are empty layers between two very highly reflective polished surfaces. Heat conduction cannot take place through such a layer, and the transmission of thermal radiation is weak due to the inability of the surface bounding the vacuum layer to radiate and absorb radiant heat. The thickness of the empty layer in this case, obviously, does not play any role, since we are concerned here with radiation. This means that the very existence of the empty layer between two polished surfaces presents a substantial obstruction for the transmission of radiant heat. If, however, we insert into this empty layer between two surfaces, parallel to it, a certain number of thin polished plates, we obtain as a result several, rather than one, such empty layers. Consequently, we can acquire in a small thickness a layer that represents a tremendous obstruction to heat. The use of such an arrangement on my vehicle is all the more suitable in that it can prove to be exceedingly light (the plates can be made as thin as we like, as long as they do not become transparent), and the void between is extremely easy to construct, because its size amounts to next to nothing.

Thermal nonconductors are needed throughout my rocket: to heat the passenger chamber; to separate the hydrogen and oxygen, which will be at very different temperatures; to heat (or to prevent from heating), in general, to insulate all tanks from the temperature effects of interplanetary space and solar radiation. Heaters will also be needed on the tube, so that it will not dissipate heat into space as the hot gases move through it. In general, thermal conconductors will be required in many places, because such disparate temperatures must exist throughout the vehicle: in the oxygen and hydrogen tanks, chamber, gases in the tube, and the outside interplanetary temperature. Moreover, heaters will have to be used as part of the equipment for absorbing solar energy (more on this below).

A Device for Utilizing Solar Energy (For the Decomposition of Water)

The construction of the device is evident from a schematic cross section (fig. 14). A parabolic reflector is aimed with its axis toward the sun. The sun's rays are reflected and converge at the focus, where they pass through an aperture into the heater (see the section entitled "The Best Thermal Nonconductor"), which is placed so as to prevent the receptacle located within it from dissipating the heat nonproductively.

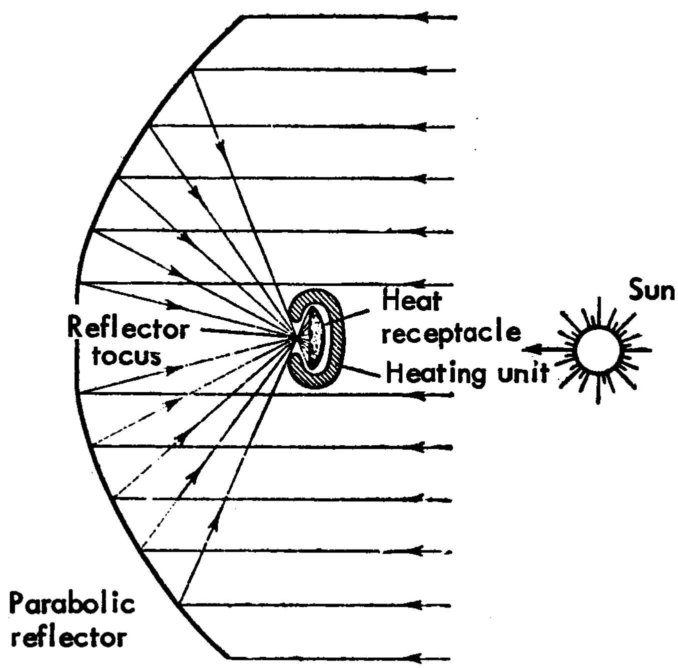


Figure 14

This is a very suitable arrangement for any device to utilize solar radiation for the development of high temperatures, which we can achieve in the receptacle by means of concentrated solar illumination, without the nonpro- /527 ductive loss of heat. Now, we have two possible arrangements of receptacles for the decomposition of water: In the first case, we require a very hot mixture of hydrogen and oxygen; then the receptacle is simply a high-melting, gas-impermeable tube, whose temperature, maintained by concentrated solar radiation, is such that the water is decomposed and we obtained the required products; in the second case, we wish to obtain hydrogen and oxygen separately in the cold state. Here is a diagram of the appropriate arrangement (fig. 15).

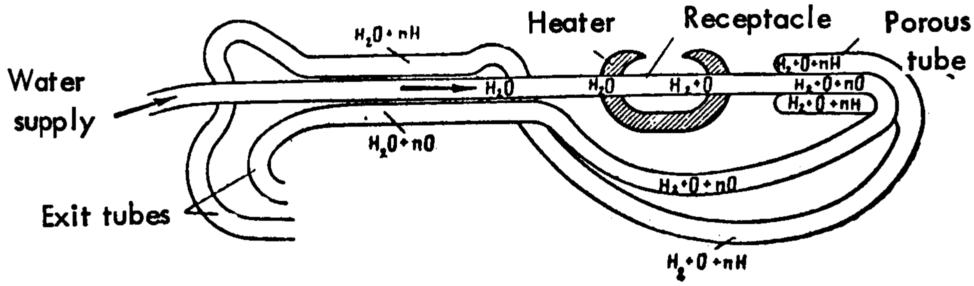


Figure 15

Decomposition is initiated the same as in the first case in the very hot receptacle-tube system.

The further (incomplete or partial) separation of oxygen from hydrogen takes place by the familiar technique based on the different diffusion rates of oxygen and hydrogen. From the receptacle the gasses pass into a tube with porous walls, which is encased in another tube (without porous walls). The gases diffuse through the walls of the porous tube and, because of the different diffusion rates, an excess of oxygen is obtained in the inner tube, of hydrogen /528 in the outer tube; also, the contents of both tubes flow countercurrent to the water feeding into the receptacle, imparting to the water all of their heat above normal (this is possible because the specific heat of H_2O is higher than that of $H_2 + O$). In the exit tubes, as a result, we obtain water, which is recirculated, plus oxygen in one and hydrogen in the other. The fulminating /529 gas extracted by decomposition can be used in an internal combustion engine. The power of solar radiation - about three horsepower per square meter of cross section - promotes the very profitable application of this machinery.

The entire system of tubes in these devices must, of course, be very painstakingly fitted with heaters (see "The Best Thermal Nonconductor").

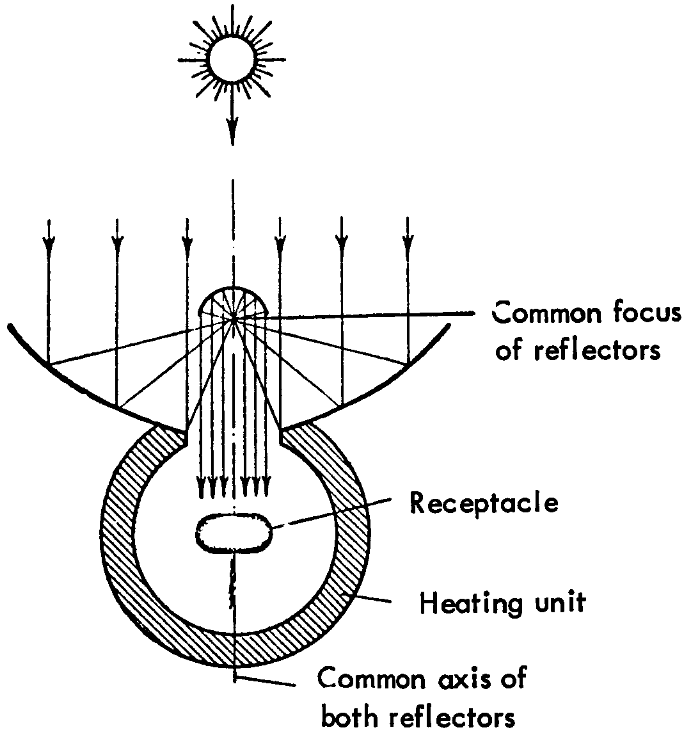


Figure 16. An Alternate Arrangement of Reflector and Heat Receptacle

Reflectors

The parabolic reflector can be of two types: a parabaloid of revolution (fig. 17) or the surface of a right cylinder, the basic cross section of which is a parabola (fig. 18).

Figure 17

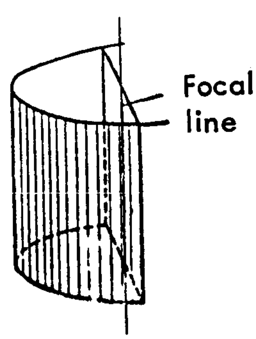


Figure 18

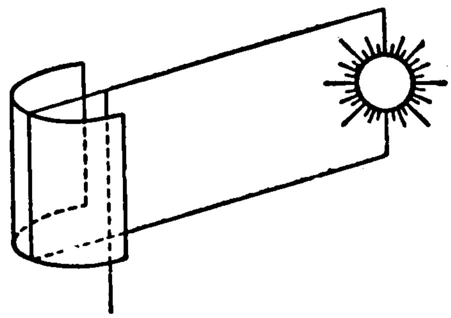


Figure 19

In the first instance, the focus of the reflector is a point, in the second it is a line parallel to the generatrices.

The one outstanding advantage or the first type of reflector is its greater concentration of rays (square-law) over the second type of reflector (linear). It has the following drawbacks:

1. Its surface is not expandable, so that it is very difficult to fabricate and is not readily portable, since it is poorly and imperfectly put together and stored, whereas the cylindrical surface can be folded up as much as we like.

2. (With reference to use on a rocket) in order to tolerate any acceleration imparted by the application of force to any part of it, the reflector must be made strong enough; the greater the potential acceleration the stronger it must be, i.e., it will have to be correspondingly heavy, whereas if an acceleration is imparted to the second type of reflector by a thrust parallel to its (focal) axis, then no matter how thin and light it is, it will sustain the /530
same acceleration as a wire of the same material, the same length, stretched in the same direction.

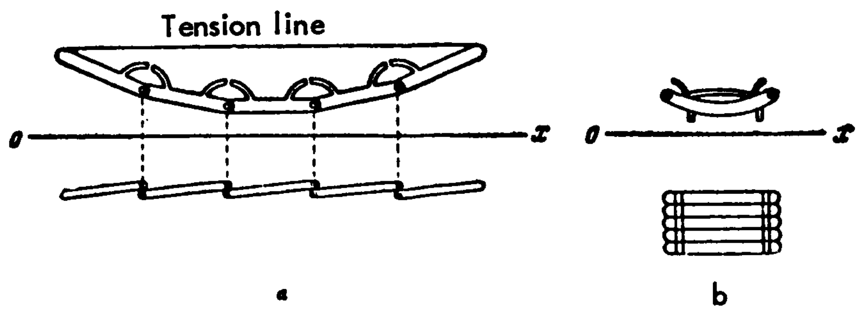


Figure 20. Collapsible Frame for the Second Type of Reflector:
a) in expanded form; b) in collapsed form

3. (Also important with reference to rockets) the first type of reflector, in order for the rays to intersect at its focus, must be accurately positioned in a certain direction relative to the sun. For the second type of reflector

fluctuations in one plane are permissible, namely so that the sun will be somewhere in its axial plane.

With these same limitations, only the amount of energy trapped by the reflector is affected by its rotation; on the vehicle, then, the second type of reflector, even though its axis must always be parallel to that of the vehicle so that it can be fairly delicate and still withstand acceleration, can always be used (only when the axis of the vehicle is pointed directly at the sun will their effectiveness fall to zero).

The one shortcoming of the second type of reflector (see above) does not play a major role, because temperatures higher than any material can withstand are not likely to be reached, and with reflectors of the second type we can strive for extremely high temperatures.

The thickness of the reflector itself has not been included here in my analysis, since for a vehicle the reflectors will be made very thin.

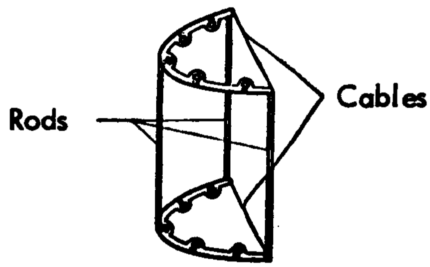


Figure 21. General View of the Overall Frame

Utilization of Solar Radiation in the Vehicle

In the vehicle (rocket), we can utilize solar radiation for preheating the oxygen and hydrogen prior to their delivery to the main tube. This will impart to them greater injection velocities, hence greater efficiency. To make use of solar radiation on the rocket, it will be necessary for the reflectors to encompass very large areas. These reflectors (second type, with collapsible frame) should be made of ultrathin sheets of some metal (nickel, for instance), which will reflect the largest possible percentage of the available power from /531
the sun's radiation. Inasmuch as the reflectors themselves will be very light, their frames can be correspondingly light. I am not able, due to unavailability of the necessary data, to estimate the lightweight characteristics of these reflectors, so I cannot evaluate their applicability on the rocket. Probably, their application will be advantageous only where considerable acceleration is not demanded, i.e., for example, in the second phase of flights from earth by the second method, in the first phase of the return trip by the second method, or in flights within the solar system by the second method (see "Theory of Flights"). If we succeed in building a reactive vehicle that operates from the emission of cathode rays, then only from the sun can it derive a sufficient quantity of energy and convert it from thermal into electrical energy.

Potential Uses of Reflectors

Let us suppose that we have been able to manufacture delicate and light-weight portable (plane) reflectors! We will make the reflectors very large and in large quantities (I am sure that a dessiatine (Russian unit of land measure equal to 2.7 acres) of reflector will not weigh more than a few dozen poods (36 pounds; hence an order of magnitude areal density of 10^{-3} lb/ft^2)). We send them up with rockets and put them in the state of earth satellites. There we expand them. We combine them in ever larger frames (note 24). We seek to control them (change their direction) in same way, for example, by placing small reactive devices at the nodes of their frames, actuating these devices by means of electricity from the central chamber.

If these reflectors are reckoned in dessiatines, a series of them could be used to illuminate a metropolis. But if we were to spend enormous sums on this project, producing the reflectors in tremendous quantities, and positioning them around the earth so that they (almost) always are accessible to solar radiation, they could be used to heat part of the earth's surface, warming the wastelands and rendering them fruitful. It may even happen that, by using the enormous quantities of heat and energy that the reflectors develop, they could be used to make other planets habitable for man, eliminating hazardous elements, permitting the growth of essential nutrients, and providing heat. The same reflectors, used as shields, could be used for cooling where necessary, by shielding from the sun. Finally, by concentrating solar radiation on a certain portion of the earth from several times the area, that region could be incinerated. In general, with the kind of enormous energies that reflectors can provide, our most fantastic dreams could become reality. For flight in /532 particular, they may have the added value that by aiming a broad beam of light at the vehicle, we can communicate to it a larger amount of energy than could be obtained from the sun. Similarly, we could also sound a signal in the solar system.

(Reflectors could also be used to reflect waves from wireless telegraph stations to send them wherever necessary.)

Theory of Flights

To make a stopover at some other planet, the ratio M/m for flight and return to earth must be multiplied by the same ratio for this planet. It would be more advantageous, therefore, not to land the entire vehicle on the planet but to send a satellite ⟨around the planet⟩, in fact just that part of the vehicle that will be needed for landing on the planet and returning to the vehicle. In order for the main vehicle to remain visible from large distances, it will have to be equipped with extremely large plates (of paper), exposed in different directions, so that they will be visible from any side; their surface should have a dull luster and they should have no weight, since no particular durability will be required of them (note 25).

Regardless of how the flight from earth is made, it will be advantageous to have bases with low gravitational potentials, for example, on man-made satellites of the moon or on the moon itself. On moon bases, if water exists there, solar radiation could be used to produce the active agent. On man-made satellite bases it would be necessary to store reserves of active agent, instruments, equipment, food supplies.

Bases, in general, could provide incomparably greater freedom of operation (note 26). Emergence from the chamber of the vehicle, of course (except on planets whose atmosphere can be breathed), can be made in outfits more or less resembling diver's suits, with a stored air supply. All bases will have to be made in the form of a chamber if we wish to take off the diver's suits (note 27).

Flights Inside and Outside the Solar System

The potential energy of the sun's gravity on earth corresponds to approximately 40 km/sec (note 28). But we already have 27 km/sec in the earth's velocity in its orbit; we only need an additional 13 km/sec to acquire the velocity needed for the flight and return to earth (35 km/sec), in order to be able not only to fly away from earth and back again, but also to move freely /533
inside the solar system and even to fly away from it altogether. The ratio M/m for this only needs to be raised to the power (13 + 35)/35, which is about 4/3. This is not too frightening. In order to move about in the solar system from one place to another, two methods of flight are also possible, by complete analogy with the arguments relative to flight from the earth (straight or spiral trajectories). The second method has the advantage here that, after flying away from earth, we are already in the second phase; we are no longer confronted with its shortcoming, namely the considerable difficulty in maintaining control in the flight from earth, when it is necessary to operate quickly and with precision; on the other hand, the second method requires much more time (note 29). Consequently, I believe that if the vehicle is to function solely on the active agent, the first method will be more suitable, but if reflectors are used and they cannot provide considerable acceleration in comparison with the sun, it will be necessary to fly by the second method.

But there is a happy combination of both: to wait until the earth moves around the sun to a point nearest the prospective destination, then to head there.

In all flights, of course, the method and direction of flight will have to be such that the motion of the vehicle relative to the sun will be in the same direction as the motion of the earth (or base), just as the flight from earth was made in the direction of its rotation about its own axis. This means that solar gravitation will only have to be slightly reckoned with.

Utilization of the Relative Motion of Celestial Bodies

Use of a satellite for flight in the solar system when it is required to gather velocity, and the return from this flight when it is required to absorb velocity.- Figure 22 shows a line of flight equally suitable for flight from a planet and for return (under the conditions specified in the heading). Consid- /534
ering the relative size of the satellite and its distance, this method can provide or take away velocity in an amount equal to as much as twice its velocity.

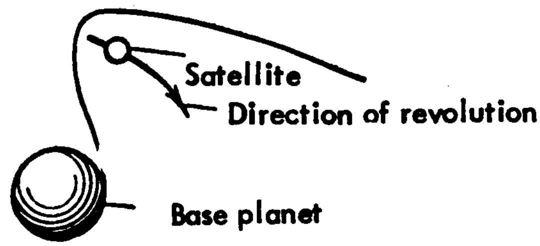


Figure 22

Utilization of Bodies Moving Toward or Away from One Another. - It is readily perceived that if we describe a curve about two bodies approaching one another (fig. 23), the velocity of the vehicle will be increased until we are able to force it to break away into outer space, even flying near their surface. If the two heavenly bodies are moving apart, on the other hand, the velocity will be decreased.

Figure 23

The Electric Gun

If, for some reason, the convenience afforded by motion in interplanetary space can justify the very large cost, it will be necessary to build an electric gun, the only device that will provide the necessary velocity, and if not all that is needed for escape, at least part of it. Here is its construction (fig. 24).

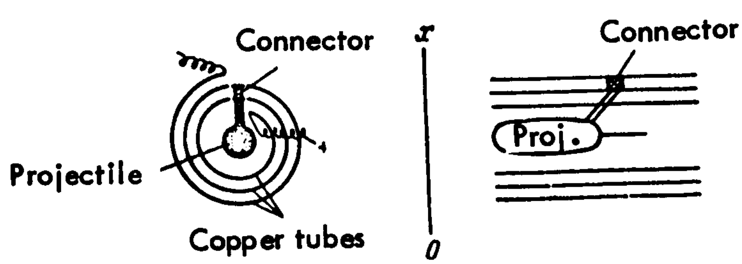


Figure 24

The body of the gun consists of several (many) copper tubes, one inside the other and mutually insulated, with a slit running their entire length. The innermost is connected with one terminal of the electrical source, the outermost with the other terminal; a projectile of soft iron moves inside the gun. /535 The projectile is joined to a connector, which makes the section of these tubes into a helix, along which current can pass. Since the connector is situated somewhat ahead of the projectile, the current in the helix attracts the projectile and compels it to move, the connector along with it, the projectile never overtaking the latter. That's all there is to it. It must be borne in mind that at the tremendous velocities and distances required, no contacts (connector) will withstand friction. This means that the passage of current must be realized without contacts, instead indirectly, by means of high-voltage arcs. In order for these arcs not to damage the connector in a short time, a lower voltage will be required, and to cause less trouble in general, the guns must be evacuated of their atmosphere, but to just that degree of rarefaction that the arcs - today a Giessler tube, perhaps later cathode rays - will be exactly what is required. This can probably be effected by proper alignment and design of the insulators, not permitting the arcs or rays any accessible opening other than necessary. Evacuation of the atmosphere is still necessary to permit freer motion of the projectile; at the enormous velocities developed, this is extremely important. And, in addition to contact between the connector and gun, it will be necessary to find and eliminate any contact between moving and stationary parts in general, for the same reasons. If the projectile tends to remain in the midline of the channel of its own accord, the arrangement will be self-adjusting. If, however, this is not the case, it must be aligned by some electromagnetic means (note 30).

If the projectile is the vehicle itself, carrying passengers, then the whole affair will require a great many years and a tremendous amount of energy. A more practicable arrangement of the gun is shown in sectional view (fig. 25).

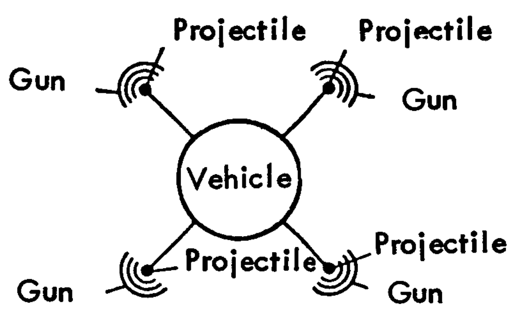


Figure 25

The vehicle is joined with the projectiles of several guns through slits in the latter. Each projectile in this case consists of several projectiles in series, which are connected in a unit form (fig. 26) by some nonmagnetic /536 material, so as to reduce drag from unavoidable residues of atmosphere.

Figure 26

If the projectiles themselves are not inclined to follow the midline of the channel, but press toward the walls, then their position can be regulated by regulating the position of the vehicle, which, it seems to me, is not difficult to cope with by electromagnetic means. It goes without saying that the entire gun must have perfect precision. How best to construct it, I do not have the data to say; either it should be built on the flatlands or allowed to float on the ocean.

Such a gun, no matter how it is realized, by imparting a considerable initial velocity to the vehicle, will relieve much of the concern about... (note 31) ... the amount of active agent consumed. It must be remembered, however, that every <unneeded> meter per second does not increase the active agent additively, it multiplies it.

So, if we could fly out there by means of a gun and return with the aid of the atmosphere, then, without carrying particularly large amounts of active agent on board the vehicle, we could carve our initials in the universe.

COMMENTARY

/657

Yu. V. Kondratyuk first became concerned with the problems of interplanetary communication, according to his own attestation, in 1916 (see the author's preface to his book, Conquest of Interplanetary Space (Kondratyuk, ref. 2; also page 57 of the present collection)). Clearly, by the beginning of 1917 he had written the first version of the manuscript, in which he treated such problems as the derivation of an equation for rocket flight, construction of the spaceship, conditions for flight within the solar system, the creation of interplanetary transfer bases, the effects of atmosphere on the flight of a cosmic flying machine, the utiliazation of solar energy, and others.

This version was in the form of rough copy and was not intended for publication. Later on, continuing to work on the manuscript, Kondratyuk somewhat expanded and augmented it. Besides purely editorial modifications, he wrote new sections to it, such as "On Techniques for Increasing the Endurance of the Human Body with Respect to Appreciable Mechanical Accelerations." "Utilization of the Relative Motion of Celestial Bodies," etc.

The outcome of this was the second version of the manuscript, which in the author's opinion was ready to stand trial before the reading public, as evinced by the rather enigmatic title which Kondratyuk appended to it: "To Whomsoever Will Read in Order to Build." In 1938, when he sent his scientific archives to B. N. Vorob'ev, Kondratyuk dated this manuscript 1918-1919, but this date is in need of refinement. This version of the manuscript is also the one included in the present collection.

The pages of the manuscript contain later additions and corrections, obviously made at different times. The latest additions incorporated by Kondratyuk directly into the text of the manuscript are enclosed in angle brackets. The remaining changes and additions are given below.

Note 1, page 15. The author originally had written at this point: "about 35 kilometers per second." However, he later added the following in the margins of the manuscript: "Whence this figure was obtained, I myself fail to understand, for now I would say 11, rather than 35, of course it is 11." Accordingly, we have corrected the figure in this phrase and throughout the rest of the /658 text. It is important to note that the precise value of the second escape velocity is equal to 11.189 km/sec.

Note 2, page 18. The dimensions are not correct; they should be cm^2/sec^2 (or erg/g).

Note 3, page 18. In this and subsequent equations, the author implies by r the incremented radius of the earth, and the acceleration in the field of gravity j = const.

Note 4, page 21. Kondratyuk later made one additional remark: "In flight by the second method, it should be executed in line with the earth's rotation (as should the landing), in order to utilize, rather than to incur harm by the considerable velocity of the earth's rotation."

Note 5, page 22. This is apparently a misprint in the manuscript; it should be 100, rather than 1000, m/sec^2.

Note 6, page 24. Kondratyuk later added another conceivable principle for the construction of reactive devices:

"3. Reaction from the repulsion by electrical discharges of material particles of nonmolecular dimensions, for example, graphite powder or a finely pulverized conducting fluid. - It is readily calculated that the velocity of such particles with a large (but fully practicable) potential difference could be made exceedingly high - greater than the molecular velocity of an intensely heated gas (figure 1).

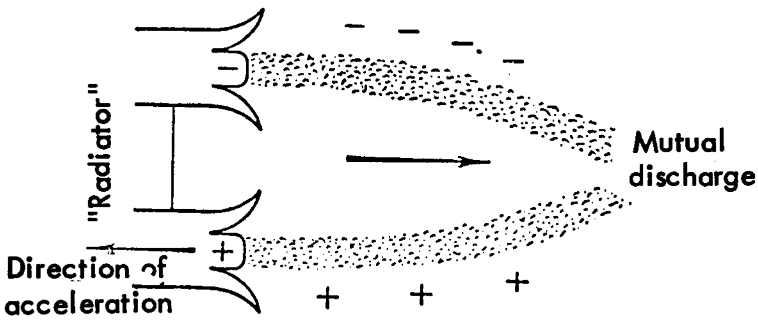


Figure 1

"Very concerted attention should be devoted to such a method. It would not be suitable, of course, until the vehicle reached atmosphere-free space."

"A second variant: A positively charged particle tends from plus to minus and, coming in contact with the latter, loses its charge, continuing on in its flight" (figure 2).

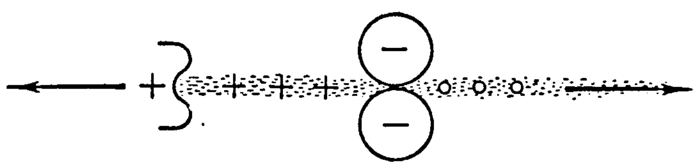


Figure 2

Note 7, page 24. Here the author indicates the need, first of all, to have a series of several expendable containers of different sizes for the fuels, second, to use up the fuel at first from the larger tanks, changing over gradually to smaller tanks, third, to recognize the fact that the proportion by weight of the tanks should be constant with respect to the weight, essentially, of the last state of the rocket, because after the tanks are exhausted, they /659 are aborted. These were unquestionably extremely advanced concepts for the time, on the part of the author.

Note 8, page 24. Of course, it is impossible to store liquid oxygen and liquid hydrogen in one tank.

Note 9, page 25. Later, Kondratyuk wrote: "(This is erroneous. For the sphere it turns out to be 2/3, for the cylinder 1/2)."

Note 10, page 26. After the words "astatic gyroscope," Kondratyuk later made the following footnote: "The biaxial astatic gyroscope definitely cannot perform the functions that I have ascribed to it herein; a nonastatic gyroscope may be suitable, or it may be necessary to replace the gyroscope altogether with other accessories (for example, to navigate by the sun. Its illuminating power could provide a tool for automation)."

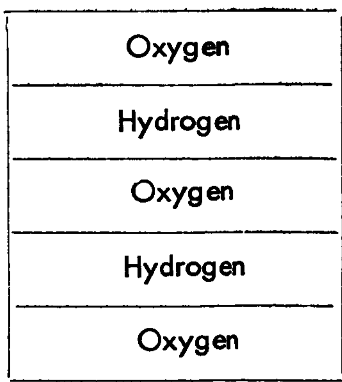
Note 11, page 28. After the heading "The Biaxial Astatic Gyroscope," Kondratyuk wrote: "(please forgive the title)." Later on, he placed this entire section, right up to the section entitled "The Chamber," in doubt. The following footnote was added to the manuscript: "See the note on page 43a" (note 10, above).

Note 12, page 30. This concept, judging from the American literature, is realized in the Apollo Project.

Note 13, page 30. The idea of keeping the fulminating gas in the tanks in solid form is without physical basis, since even if the fulminating gas could be instantly ignited and solidified, it would be impossible to be certain of a homogeneous system corresponding to the composition of the fulminating gas.

Note 14, page 31. The only possible approach is to feed the heated hydrogen and oxygen fuel components into the combustion chamber separately; the other two methods of combustion indicated by the author would not guarantee the explosion-free safety of the system.

Note 15, page 31. Kondratyuk subsequently proposed still another variant of the tube arrangement. After the words "form a checkerboard pattern," he appended a footnote: "Or, better and simpler, in tiers:"



Note 16, page 32. Kondratyuk later made the following addition here: "The pumps can also be made piston-free, by the following scheme: Liquid oxygen (Hydrogen) is forced by the pressure of the gases from the tank into a chamber of smaller dimensions but of sturdier construction, which is then disconnected from the tank, and from there the pressure of the gases again, but this time more strongly, forces the liquid oxygen into the combustion region."

Note 17, page 33. It is important to note that, at the time the article was written, analytical methods had already been developed in application to the Laval nozzle.

Note 18, page 34. Later, after the words "active agent," Kondratyuk added: "Another indicator of acceleration might be the following: A fluid is allowed to flow under its own inertia from one vessel into another via a narrow tube (so that the inertial resistance of the fluid will be very small in comparison with the friction resistance). The flow velocity will be an indicator of the mechanical acceleration magnitude, the amount of fluid that runs out will correspond to the quantity of spent active agent." /660

Note 19, page 35. From this point on in the manuscript, apparently, the expression in parantheses in the exponent written previously, $\left(1 + \frac{1}{k - 1}\right)$, is not written, in the interest of brevity. We have rendered the equations complete.

Note 20, page 36. Kondratyuk was subsequently inclined to doubt the feasibility of utilizing the atmosphere as a cushion for the velocity of the vehicle. After the words "We will show why later," he wrote: "It looks as if they are altogether impossible, in that the vehicle represents a falling star."

Note 21, page 36. Later, Kondratyuk appended the following to this sentence: "It turns out that, as far as molecules are concerned, there is no such thing as a polished surface."

Note 22, page 37. The author's supposition as to the hydrogen content of the upper atmospheric layers has not been borne out by present-day research, although recently a thin hydrogen cloud has been discovered at an extreme altitude.

Note 23, page 38. The cited numerical values are incorrect, inasmuch as Kondratyuk began with much too high a value for the second escape velocity (see note 1, above).

Note 24, page 44. Later, after the words "larger frames," Kondratyuk entered the footnote: "Most likely, the best frames are made of thin-walled tubes filled with a gas with a certain expansibility."

Note 25, page 44. Kondratyuk later proposed still another method for enhancing the visibility of the satellite vehicle; after the phrase "required of them," he made the addition: "Or, more simply, a large bubble of some light, silky material, the shape of which is maintained by a flexible wire-mesh skeleton; the bubble, of course, is collapsible."

Note 26, page 45. Kondratyuk later gives here a calculation of the amount of active agent necessary for flight: "Here is a calculation of the amount of active agent that is necessary for flight from the earth and back again (by the first method), if bases are employed.

"In order to go from the satellite (base) state to the state of zero motion in the return to earth by the first method, it will be necessary to absorb a velocity of about 7.5 km/sec, for which the amount of active agent required is about $\sqrt[3]{55} - 1$ (see page 13) (page 18 of the present collection), since all that is needed for going and returning is 22 km/sec = approx. 3 x 7.5 = approx. 3.8 - 1 = 2.8 m. This quantity, then, must be available on the base. In order to go from the earth satellite state to the state of a free planetoid and back, it will be necessary to develop and reabsorb 3 km/sec, or a total of about 6 km/sec, for which about 3m - 1m = 2 m active agent will be needed. Consequently, a total of about 2 + 2.8 + 1 = 5.8 m will be necessary to arrive at the state of an earth satellite, for which is required a vehicle weighing 5.8 m x 3.8 = a total of about 22 m, instead of 55, which is a considerable amelioration."

Note 27, page 45. Later, after this paragraph, the author added the following:

"It is advisable to proceed as follows: first, to send out from earth a base with supplies but without personnel, such that it will automatically be made into an earth satellite, then to send up a vehicle with people; after flying to the base, they will pick up any necessities and continue the flight, the base continuing to circle the earth. On the return flight, provisions are again picked up on the base and the return to earth completed. Such a method is appropriate in that, by sending ahead the main bulk of the load without people, we are not held back by limited acceleration and could even utilize the cannon principle.

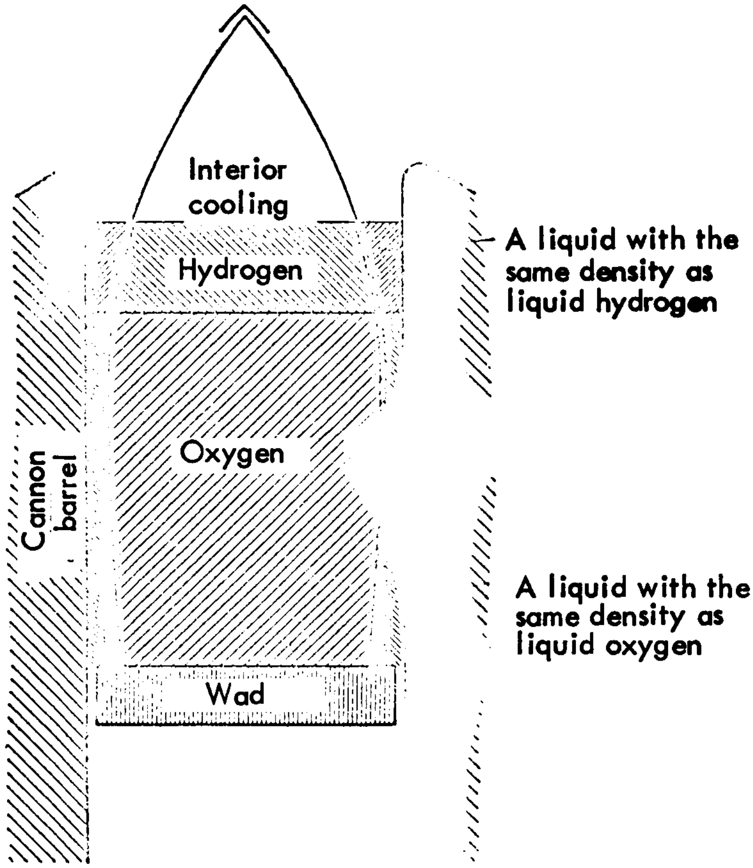


Figure 3. Construction of the Active Agent Transport Vehicle. /661

"With such a construction (the vehicle is just slightly narrower than the bore and the space between is filled with fluids), the walls of the vehicle need extra strength only to the extent that they will not be crumpled from their own weight when fired. The hydraulic pressure will not be destructive. Here we have a cross section of the vehicle (fig. 4).

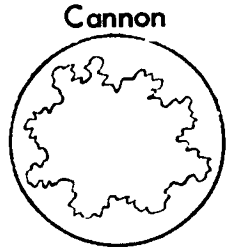


Figure 4

In order for the walls not to be crumpled during firing, the vehicle chamber should not break communication (break continuity) with the space between the walls during its motion in the bore of the cannon, or the walls of the vehicle should be made so they are capable of changing its volume.

"In order not to have to build an unreasonably large cannon, it would be better not to transport active agent in one vehicle, but in machine-gun fashion from several or even many vehicles, interconnected by cable (quartz). The cable should have a checking mechanism, so as to provide a certain tension (absorb energy), but without permitting it to spring back. In the head of each vehicle should be an attachment for automatically steering it in the direction of maximum illuminating power. The transport should be sent up at sunrise at an inclination with respect to the east; on escaping the atmosphere, the vehicle automatically turns toward the sun, i.e., aligns its axis parallel to the /662 earth's surface (eastward) and, like a rocket, having attained sufficient velocity in this direction, enters into the satellite phase. Some of the vehicles should contain active agent, while another, smaller group should be for recognition signals that will be visible from afar. Besides large surfaces or paper and silk balloons, the signal could be made in the form of a large electric lamp or other powerful source of illumination (a special device capable of withstanding the acceleration sustained in firing), which would derive its energy from the sun through the medium of mirrors. Its advantage would be its ability to shine at night, provided the daylight energy could be stored up automatically.

"It would be best to place the cannon in water so that it would float. This would greatly diminish the ancillary equipment needed for the cannon, would simplify the cannon itself since it would not need to bear its own weight, and would facilitate direction-control of the cannon. Furthermore, the water pressure at considerable depths would reduce the need for strength on the part of the cannon, because it would be acting in a direction opposite to the gas pressure. Note: If the breaking strength is considered equal to $100\ kg/mm^2$, then a cannon whose wall thickness was equal to the radius of the bore could sustain a pressure of 10,000 atm; it would be more sensible, in terms of quantity of material, not to permit a pressure of more than 2500 atm.

"When the completed base is equipped to utilize solar energy, it would be better not to send the active agent there in the form of separate oxygen and hydrogen, but simply as water, decomposing it when it arrives there."

Note 28, page 45. The numerical values quoted by the author here and below are inaccurate. Moreover, it should be realized in the present instance that Kondratyuk started with much too high a value for the second escape velocity (see note 1, above).

Note 29, page 45. Later, after the words "requires much more time," Kondratyuk wrote: "the same as the first; I did not include the dimensions of the solar system in the calculation; here acceleration only needs to be applied once."

Note 30, page 47. After the words "electromagnetic means," Kondratyuk later made the following annotation:

"P.S. All of this (i.e., an electric gun that would be capable of supplying a velocity of 10 versts/sec (approx. km/sec)) now seems impracticable to me."

Note 31, page 48. Here, after the words "will relieve much of the concern about," which came at the end of a page in the manuscript, one or two lines are missing.