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PREVIEWING THE AEROLOGICAL ROCKET

It is generally conceded that one of the first useful fields of application for the liquid fuel rocket when it is adequately developed will be as an apparatus for carrying meteorological instruments into the upper atmosphere. It is therefor of interest to note what requirements it must meet to serve satisfactorily in this capacity, and what advantages over other techniques now in use it may offer.

Although studies of the upper atmosphere have been carried on since the beginning of the last century and even earlier, it is only since the advent of extensive aerial navigation and the modern principles of air-mass analysis that systematic soundings have been maintained. "Air-mass analysis", which is the study of weather formation by determining the characteristics and interactions of large horizontally homogenous sectors of the atmosphere emanating from various "source regions", requires a complete knowledge of the vertical properties of the atmosphere over many points on the earth's surface — a knowledge which now falls in the province of meteorology called "aerology". This information, consisting primarily of temperature, pressure, water-vapor content, and wind directions and velocities is now obtained in the United States by daily pilot balloon observations at 77 stations, and by daily airplane flights from about 25 stations. The airplane observations, which include visual reports of cloud forms, precipitation, etc., are made to an altitude of 16,500 feet when practicable; the pilot balloon observations, which consist of wind directions and velocities, and cloud formations determined by theodolite measurements of the drift of small free balloons, are made to whatever altitudes the balloons remain visible and occasionally reach the stratosphere. "Sounding balloon" observations — that is, data determined by automatic recording or transmitting instruments sent up in small unmanned balloons to great heights — are not at present used in regular weather forecasting, but only in special meteorological research, as during international months when upper air soundings are made simultaneously by all weather bureaus represented in the International Commission for the Exploration of the Upper Air.

Precisely how the perfected liquid fuel rocket will fit into this program it is of course impossible to foresee, due in part to evolution in the science of meteorology itself, and in part to the unpredictable operating characteristics of such rockets. However, some general conclusions may be drawn, based on reasonable assumptions and present information.

Even if we assume that no radical change takes place in the science of meteorology, making it more dependent on knowledge of phenomena in the high stratosphere such as rockets are in theory especially qualified to deliver, still the rocket could well be employed in extending the range, effectiveness, and precision of aerological soundings of the sort now executed by other devices — provided, of course, that it attains a certain standard of reliable and inexpensive performance. In other words, if rocket experimenters and designers find it possible to develop a comparatively small and inexpensive machine that is simple to operate, it could be used to good advantage by weather bureaus to take over various functions now discharged by pilot balloons, airplanes, and sounding balloons.

A very general description of the necessary operating charcteristics of such a standard "troposphere sounding" or aerological rocket may be attempted. First, it should be able to ascend vertically from five to ten miles and then descend by parachute at a predetermined rate. It should be able to repeat this performance regularly and with the minimum of upkeep, adjustment, and propellant consumption. Its rate of acceleration should not exceed two or three gravities, or whatever figure is arrived at as reasonable for the preservation of recording instruments. It should be capable of carrying a meteorograph for recording temperature, pressure, and humidity and weighing one or two pounds.

Assuming that such a rocket uses a motor that operates on a gasoline-loxygen propellant charge at a thermal efficiency of 20%, that it weighs 22 pounds loaded and carries ten pounds of propellant (giving an energetic efficiency of about 40%) that it accelerates at an average of 3 gravities (hence a dynamic efficiency of 75%), that its "air resistance efficiency" is about 40%, then such a rocket would operate at an over-all efficiency of over 2%, and its charge of propellants containing about 33,000,000 foot-pounds of energy would be able to drive it to an altitude of about eight miles. The duration of the shot would be about a minute or a minute and a half.

The meteorograph carried by a rocket of this type could be substantially the same as those employed in present sounding balloons except that it might need to be somewhat heavier and more rugged. Meteorographs now in use having bimetallic temperature element, hair hygrometer and aneroid cell, together with clockwork recording drum, weigh 175 grams or less. The instrument would be held in a locked position during the vertical flight and would be set in motion by the same device that actuates the parachute release at the apex of the shot, so that it would record on the way down instead of on the way up as with sounding balloons. The speed of descent could be easily regulated by the size of the parachute, and velocities as great or greater than the highest reached by sounding balloons (about 1500 feet per minute) could be easily attained.

The advantages of such a system of aerological soundings are as follows: 1. A substantial reduction of the time required for the process, due to the rocket's high speed and the rapidity of descent. Airplane soundings often require several hours, and balloon soundings not much less, while the rocket could ascend to the substratosphere and return in ten or fifteen minutes. 2. By the same token, a far more nearly vertical cross-section of the atmosphere would be obtained, which is very desirable. 3. The horizontal drift would be reduced to a minimum. This is a serious factor in the operation of sounding balloons, which often drift tens or even hundreds of miles before landing, and not infrequently are either lost or are found only after a long period. 4. Vertical soundings to an altitude two or three times greater than with airplanes could be obtained regularly, independently of weather conditions. 5. The drift of the descending rocket and parachute could be measured by theodolites from the earth and upper winds charted without the use of pilot balloons.

The deciding factor in such a program would be the cost of building and operating such rockets, and at this stage of development this is difficult to foresee. However, it is safe to say that once a successful type of rocket motor and rocket is achieved, fabrication costs will not be high, as one of the principle characteristics of this engine is its extreme simplicity compared to other prime movers. A small standardized rocket weighing under fifteen pounds empty should certainly be built for a few hundred dollars, and the instruments it would carry should cost no more than those necessary in any other method of aerological sounding. Propellant consumption, amounting roughly to a quart of gasoline and a gallon of loxygen, should amount to not more than two or three dollars per shot. This is less than the cost of one of the rubber balloons used in a sounding balloon ascension. Interest on the original cost of the rocket plus its upkeep would probably be more than made up for by the "mortality rate" of meteorographs sent up in sounding balloons (11% of all meteorographs sent up in sounding balloons from 1904 to 1926 in the United States were lost permanently) and by the investment necessary in reserve meteorographs for use with sounding balloons while those in the field were being found and returned. As compared to the cost of sounding by means of airplanes, the expense of employing a small machine such as the aerological rocket should be far less than that of employing a large and costly machine such as an airplane, which must be piloted by a licensed transport pilot.

Some writers have suggested that meteorological rockets should be so constructed that the instruments and the empty rocket shell descend on separate parachutes, presumably with the idea that the light instruments could be allowed to descend more slowly. However, since provision must be made for the safe descent of the rocket anyway, and since this plan makes necessary the tracing of two obects instead of one, it seems hardly advantageous. To facilitate location of the rockets, a small radio tone emitter (which can be built weighing only an ounce or two) could probably be included in their equipment, and a scout car provided with a loop aerial to follow them. Even in strong winds, such rockets would never drift more than ten miles from the launching station, because of their free fall. Even if quick recovery proved not always feasible, radiometeorographs as used in the latest sounding balloons could be used instead of ordinary recording meteorographs, so that the data would be received instantly. Such radiometeorographs can at present be built weighing one pound and with a transmitting range of 100 miles or more.

As the altitudes to be explored increase, the superiority of the rocket becomes more clearly marked. If at a future date a program of stratosphere sounding as intensive as present-day troposphere sounding is achieved by weather bureaus, the rocket will be the machine par excellence for the purpose. For this task we must envisage a more powerful projectile than the aerological rocket of the preceding discussion, which was conceived as simple as possible so that its use might be economically feasible in all upper-air stations which now employ airplanes or pilot balloons. A high-altitude rocket such as this might weigh in the neighborhood of forty or forty-five pounds (including six or eight pounds of instruments) and carry 40 pounds of propellants. Because of its larger size and power, such an apparatus would have better performance characteristics than the troposphere rocket. Air resistance efficiency would mount substantially, since the major portion of the trajectory would lie in very rarified atmosphere. The thermal efficiency of the motor would also be higher, because of its larger size and more refined design, and it could burn a somewhat more powerful fuel such as benzol, since the operation conditions would make its use practicable. Assuming an air resistance efficiency of 70%, motor efficiency of 25%, acceleration at 3 gravities (dynamic efficiency of 75%)and with an energetic efficiency of about 40% determined by the propellant to dead-weight ratio of about one to one, the resulting over-all efficiency becomes better than 5% which enables the forty pound benzol-loxygen propellant charge to lift it to an altitude of about 20 miles. The time of ascent would be 2 or 3 minutes.

The meteorograph carried by a rocket of this type would have to be of a radically different design from those in use at present, because of the conditions under which it would have to operate. Since the upper two-thirds of the trajectory passes through air too rarified to operate a parachute (parachutes attached to instruments dropped from manned stratosphere balloons do not even open at heights of ten miles or more) the recording instruments would have to be designed to function at very high speeds — in fact, during upward flight. The barograph, for instance, would probably record the dynamic pressure due to the airflow through some sort of a Pitot tube arrangement, since reading the static air pressure at such speeds would be most difficult. (This factor must be taken into account to some extent with Friez-type aerometeorographs when mounted on airplanes). In like fashion the temperature recording instrument—possibly a modification of present resistance thermometers—would have to be corrected for the dynamic effect of the airstream. Probably the most difficult problem would be the design of a hygrometer capable of reacting rapidly and accurately enough for use at such high velocities. All instruments would probably be calibrated for use in a small variable-density wind tunnel.

To coordinate their readings with the altitude and velocity of the rocket, a simple accelerometer could be made to trace its curve on the same recording drum. From this could be calculated the velocity and altitude for all points along the trajectory, so that the proper correcting factors could be applied to the readings of the other instruments. This last operation might even be done mechanically.

A sounding rocket so equipped would secure a complete record from ground level to 20 miles height of the three major characteristics of the atmosphere necessary for air-mass analysis and the study of dynamic meteorology. It is even possible that it might be equipped to record the direction and intensity of horizontal winds at various levels, by means of two sensitive recording accelerometers acting at right angles to the horizontal plane, and with their orientation maintained by gyroscopes. At the apex of the flight, all instruments would be locked and the projectile would begin its fall back to earth. A strongly constructed parachute of small diameter would allow it to drop at very high speed to within a mile or two of the surface, when a larger parachute would open allowing it to drift the rest of the way. The whole process would be over in a few minutes, and the horizontal drift would be negligible.

Systematic high-altitude soundings carried on by such a device would be incalculably valuable to the meteorologist, since they would yield detailed information as to the structure of the upper atmosphere and its fluxions, laws of circulation, relation to phenomena in the troposphere, climatological cycles, etc., etc. With regard to the importance of research of this kind, a statement of Dr. J. Bjerknes is particularly apposite: "...much further investigation of the mutual interaction of the stratosphere and troposphere in the genesis and development of our weather phenomena will be necessary before we can hope to really understand these processes and to forecast the weather with complete accuracy." Improved balloons and radiometeorographs to facilitate this study are now being developed by meteorologists in various centers (as the Blue Hill Observatory, U. S. Bureau of Standards, California Institute of Technology) but once rocket experimenters have developed their devices to an adequate point, there is little doubt that they will be adopted for such purposes.

Rockets of the more powerful type discussed would of course be too expensive and would require too specialized handling to use except at central stations, but even so it is doubtful that they would represent any

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ON THE AERODYNAMIC PRINCIPLES OF THE GREENWOOD LAKE ROCKET AEROPLANE

On February 23, 1936, at Greenwood Lake, N. Y., test flights of two rocket-propelled pilotless airplanes were made under the auspices of the Rocket Airplane Corporation of America, of which Mr. F. W. Kessler is the president. A concise report of the flights appeared in the March issue of Astronautics, and Dr. Klemin has kindly agreed to furnish an outline of his calculations for the aerodynamics of these machines. As actually constructed by an independent concern employed by Mr. Kessler the two planes did not exactly follow these specifications, but were somewhat heavier, and in addition, a different type of catapult was used; however the following calculations are of great interest and value. — Editor.

When in November, 1935, Messrs. Kessler and Ley asked me to make the aerodynamic calculations for the rocket airplane to be tested at Greenwood Lake, New York, I gladly agreed to cooperate because the problems involved were novel and very interesting.

The general scheme of the flight as outlined by Mr. Ley was as follows: A rocket motor was to propel a miniature airplane carrying 20 pounds of mail and ten pounds of fuels over a distance of about 1½ miles. In order to obtain a long flight under full consideration of all the peculiarities of rocket propulsion, the 'plane was to climb under power at an angle of approximately thirty degrees. It was slightly tail heavy as long as loaded with fuel. When the fuel was exhausted the balance of the plane would shift in such a way as to insure a long glide. The burning time of the rocket motor was to be thirty seconds, the thrust during this time approximately 35 pounds. In order to use this limited power to the best advantage the model was to be launched from a catapult so that the rocket motor would not be required to furnish the power necessary to bring the model up to flying speed. The catapult, at the same time, was to give the proper climbing angle to the model.

It was decided to design and build a monoplane without a landing gear. In landing the airplane would land on the bottom of the fuselage. The rocket motor was placed in the extreme tail end and the payload in the nose of the fuselage, with the fuel tanks and fuel in the center. As the fuel was consumed, the center of gravity of the small airplane would shift slightly forward.

In order to find the most efficient performance the following cases were calculated:

Case I. Initial velocity 84 ft/sec.
Trimmed for 2° power on, 10° off.
Length of flight X_t — 15,040 feet — 2.85 miles.
Vertical velocity in glide 3.28 ft/sec.
Speed in glide 46 ft/sec.
Case II. Initial velocity 64.8 ft/sec.
Trimmed for 4° and 10°.
X_t — 11,990 feet — 2.26 miles.
Vertical velocity 3.28 ft/sec.
Case III. Initial velocity 55 ft/sec.
Trimmed for 10° under all conditions
X_t — 10, 470 feet — 1.98 miles.

Case III appeared to be the simplest condition and was used as the basis for further calculations. The method of obtaining proper balance, using Case III, was:

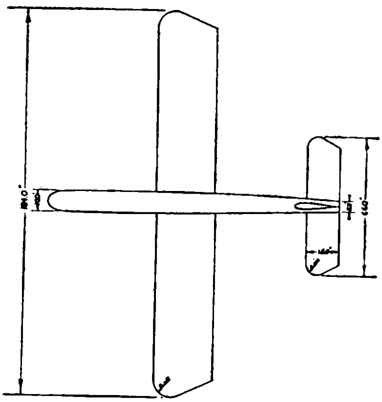
1. To balance the ship for no fuel at 24% chord of wing.
2. To have the thrust of the rocket motor go through the center of gravity. The consumption of fuel would result in a change of trim of the airplane of approximately 2.6 degrees. If an average trim of ten degrees is desired during the fuel burning period the ship should be trimmed at about eight degrees. This required a tail setting of —5°.

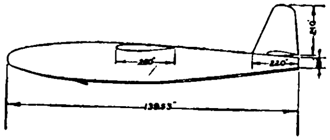
The conclusions eventually obtained were:

a. Gross weight = 77.5 ℔s.
b.Ship trimmed for no fuel at 24% c.
3. Center of gravity movement of fully loaded plane and empty.
d. Rocket motor fires on line thru c.g.
e. Tail is set at —5° to wing chord.
f. Catapult angle must be 23° giving a speed of 55 ft/sec.

With these conditions fulfilled the range of the rocket airplane model would be about two miles and the model should be stable satisfactorily under all conditions.

If the thrust of the rocket motor should exceed 35 pounds the climb of the model would become somewhat steeper, thereby losing distance and gaining altitude which would result in a longer glide. It was found that the total range would not noticeably change if the thrust were between 35 pounds and 50 pounds while a still higher thrust would lead to a slight shortening of the total range.





The material for the airplane model was aluminum. The general characteristics of the completed model were:

Wings	Total span	194 inches
	Chord	28 inches
Fuselage	Length	139.53 inches
	Width	10 inches
	Greatest Height	17.43 inches
	Rectangular Cross-Section	
Vertical Tail Surface		22 in. at base
Vertical Tail Surface		24 in. height
Horizontal Tail Surface		Rectangular Panform
Horizontal Tail Surface		Span 66 in.
Horizontal Tail Surface		Chord 15 in.

The construction of a catapult powerful enough to accelerate an airplane model of 77½ pounds gross weight to a velocity of 55 feet per second is not difficult. It had, however, to be considered that the size of

THE BUILD-UP PRESSURE OF ENCLOSED LIQUID OXYGEN

As Determined by Field Tests with the A. R. S. Proving Stand

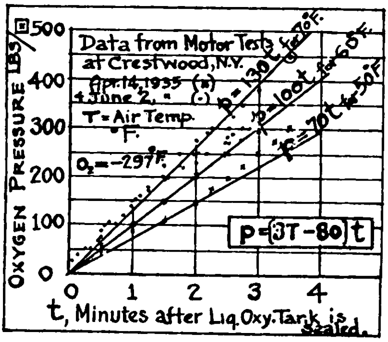
The graph shows the actual relation between the pressure in the liquid oxygen tank (read at intervals thru field glasses by Mr. Shesta) and the corresponding time after the oxygen-inlet valve had been closed. The purpose of this operation was to build up a feed-pressure back of the liquid oxygen equal to the nitrogen presure placed back of the gasoline.

The empirical formula

$$p = (3T - 80)\ t$$

where p is the oxygen pressure in lbs. per sq. in. gage, T is the atmospheric temperature, degrees Fahr., and t is the number of minutes after the liquid oxygen tank is completely sealed, is useful in estimating the time that will elapse before the rocket is ready to fire. It applies only to the Society's liquid oxygen tank in the proving stand. This is cylindrical copper tubing 3 in. outside diameter, 1/16 in. thick, and 21½ in. long. The theoretical pressure is a complicated problem in heat transmission involving a shape factor, and variable conductivity and surface transmission coefficients. Its solution will be undertaken at some future time.

— **Alfred Africano**



On the Aerodynamic Principles of the Greenwood Lake Rocket Airplane

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the catapult had to be limited while the acceleration had to be low. The solution was found in a catapult with 20 feet effective runway powered by rubber strands. Such a catapult would furnish the necessary flying speed without exceeding an acceleration four times that of gravity.

That these models did not fulfill the expectations may have been due to one or all of the following reasons.

1. That the catapult did not furnish the necessary power.
2. That the models were heavier than calculated.
3. That the wings were poorly built.

The test did show, however, that the models were satisfactorily stable and that rocket propulsion for airplanes under special conditions and for specialized purposes is possible.

— **Alexander Klemin**
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Aeronautics, N. Y. University

CONCERNING VELOCITY-RATIO EFFICIENCY

Further Discussion of an Interesting Problem

The three possible methods of calculating velocity-ratio efficiency have already been discussed by Alfred Africano in *Astronautics*. One of the methods, the third of the three, is obviously wrong, and this he shows. The first method, however, is approved by a number of workers in this field and when studied in more detail seems to be the most desirable of the three.

The difficulty is that in defining the output, you also automatically define the input, and vice-versa. You must therefore make your definitions in pairs; and, while the one alternative has one unusual definition, the other alternative has a definitely undesirable definition. The problem is not to choose the "right" definition, but the best, and most convenient, of two alternatives.

The alternatives, with the reasoning behind each, are as follows.

1. The power of a rocket, or its output, is considered as the product of the reactive force developed, as shown by the test stand, and the velocity of the rocket, which is the velocity at which the force acts.

$$\text{Output} = R\ V$$

The Input is defined as the fraction of the heat energy usefully transformed into kinetic energy *plus* the instantaneous kinetic energy of the fuel being used. This is defining a total energy quite comparable in form to that in the well-known Bernoulli equation.

$$\text{Input} = E_{\text{thermal}}\ m\ Q + \frac{m\ V^2}{2}$$

$$= \frac{m\ c^2}{2} + \frac{m\ V^2}{2}$$

Elementary physics seems to demand the first definition. The second definition is unusual, but the study of rocketry with its tremendous speeds should be expected to lead to new situations. It is certainly not an impossible definition; the absolute velocity with respect to the earth is already customarily used to find the final, or wasted, energy. Why not include it in the initial value? To do so does not involve giving the fuel extra energy "gratis", for the energy has already been charged to the previously burned fuel which was responsible for its development.

2. The power, or *output,* is defined as

$$R\ V \left\{ 1 - \frac{r}{2} \right\}$$

(r is the velocity ratio, V/c)

and the *input* is the same fraction of heat energy as before.

$$E_{\text{thermal}}\ m\ Q \text{ or } \tfrac{1}{2}\ m\ c^2$$

The second definition could be used if desired, for it does represent one way of thinking about input; except that in accepting it you must also accept the first. And the first contradicts the laws of physics, gives no mental picture of its meaning, and is contrary to everyday usage. A rocket developing a force of 50 pounds and traveling at 3000 feet per second should be credited with a power output of 150,000 ft. lb. per second, not something around 75,000.

But in addition to the reasoning outlined in the two alternatives, which should be sufficient, there are two additional reasons why the first alternative should be adopted.

1. Because only in the first does a rocket which is actually doing positive work, overcoming inertial or frictional forces, always have a positive efficiency. A definition leading to a possible negative efficiency under such circumstances should be avoided if possible.

2. Because efficiency as defined in the first is a measure of the excellence of a rocket's work at a given moment, while in the second it is something which can only be called "instantaneous efficiency considering the trip as as whole". The former is the only one directly comparable to such commonly used efficiencies as that of the engine-propellor combination, and is therefore the one in which the engineer is most interested.

Considering the relative merits of the two alternatives, as well as the two additional arguments, it would appear that the velocity ratio efficiency is best defined as

$$E_{vr} = \frac{2r}{1 + r^2}$$

The total efficiency which follows from this is defined as

$$E_{total} = \frac{2r}{\frac{1}{E_{th}} + r^2}$$

In no case is the total efficiency the *product* of the velocity ratio and thermal efficiencies, although at low velocities the error in considering it so is small.

— **Robert Uddenberg**
Mass. Institute of Technology

Appendix

The two alternatives can not, of course, be split up. To take the output defined in the first and the input of the second is to have Mr. Africano's third alternative.

In this case

$$\text{Output} = R\ V$$

$$\text{Input} = \frac{mc^2}{2}$$

But it is agreed that the losses are

$$\frac{m}{2}(V - c)^2$$

and certainly

$$\text{Input} = \text{Output} + \text{Losses}$$

Substituting in the latter equation

$$\frac{m\,c^2}{2} = R\,V + \frac{m}{2}(V - c)^2$$

which leads to a reductio ad absurdum.

$$\frac{m\,c^2}{2} = m\,c\,V + \frac{m\,V^2}{2}$$

$$- m\,c\,V + \frac{m\,c^2}{2}$$

FUNDAMENTAL EQUATIONS OF ROCKET MOTION

Part II — Air Resistance and the Advantageous Velocity

Having obtained some insight into the motion of a rocket in airless space, we may now take up the more difficult problem of its motion in air. The additional force which we must now take into account, the air resistance, is composed of two distinct parts, the ***skin friction,*** caused by the rubbing of the air on the surface of the rocket and the ***head resistance*** caused by the pressure of the air on the nose of the rocket as it pushes through the atmosphere, and also by the suction of the low-pressure area around the rocket's tail. The exact value of these quantities at the high velocities attained by rockets is still rather doubtful, but sufficient data exists to give an approximate idea of the forces involved.

The skin friction on projectiles has not been investigated for high velocities, which is unfortunate, since calculations indicate that it is responsible for over half the total air resistance of a well-designed rocket. Experiments tend to show that at moderate speeds it varies according to the law

$$R_s = C_s \frac{d}{2} S V^2$$

where R_s = skin friction (pounds), $\frac{d}{2}$ = half the air density (slugs per cubic foot), S is the area of the "rubbing surface" exposed to the air (sq. ft.), V is the velocity (feet per sec.), and C_s is a coefficient dependent on the *Reynolds Number,* $\frac{V L d}{v}$ where L is the length of the rubbing surface in feet and v is the viscosity of the air, which varies with the temperature (for 60 F. and 1 atmosphere pressure, $\frac{v}{d} = 6350$.) (See Fig. 1). For constant air conditions (constant d and v) R_s varies as $V^{1.80}$, since C_s varies as $(\text{Reynolds Number})^{-.20}$, very nearly.

The head resistance varies according to an even more complicated law, and experimental data is scarce, especially for streamline bodies such as rockets. From experiments on artillery shells, the resistance is found to vary according to the equation

$$R_h = C_h d^2 V^2 \text{ (D. R.)}$$

where R_h = head resistance (lbs.), d = diameter of projectile (inches), V = velocity (feet per sec.), D.R. = ratio of air density to standard sea level air density, and C_h is a coefficient dependent on shape and velocity of the shell. (See Fig.2). The abrupt increase in C_h at the speed of sound (1130 feet per sec) is owing to the formation of air-waves ahead of the projectile which "pile up" on the nose and create a high-pressure area there.

An alternative equation proposed by Mayevski involves replacing V^2 in the previous formula by V^n, and dividing the air-resistance curve up

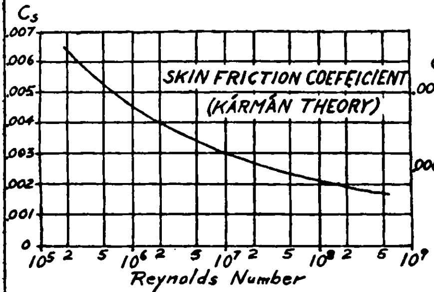


FIG. 1.

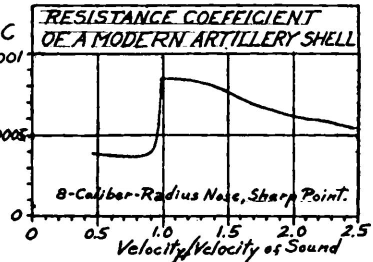
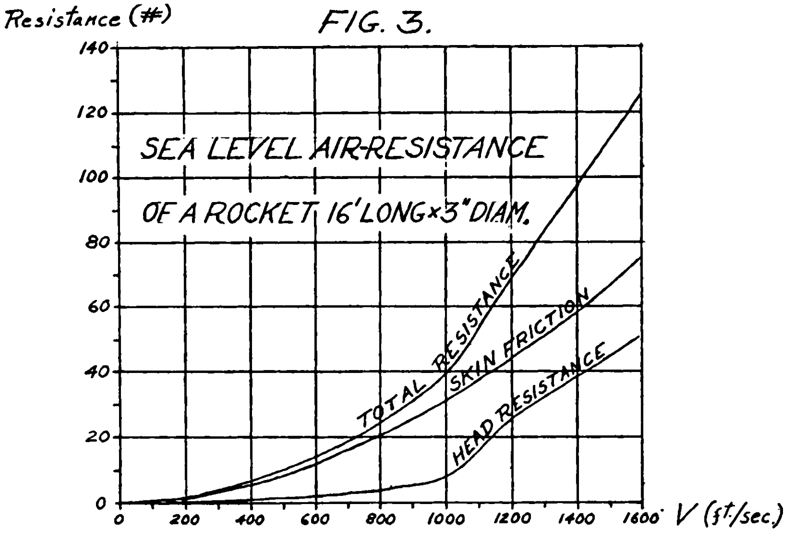


FIG. 2.

FIG. 3.



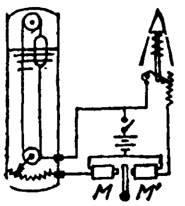


FIG. 4.

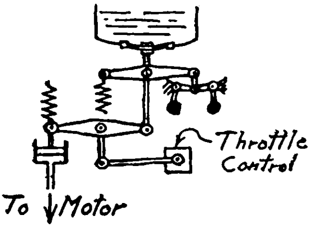


FIG. 5.

into six or more "velocity zones", for each of which constant values of n and C_h are used. This avoids the continuous variation in C_h of the "square-law" equation and is preferable for certain theoretical work. The values of n vary from 2 to 5, the latter value being reached in the "zone" near the speed of sound, where R_h rapidly increases.

The flow-patterns, wave-effects, and other phenomena of air-resistance must be passed over here for lack of space, though it is hoped that these may be discussed in some future article.

The forces on a rocket owing to air-resistance are very considerable, amounting to as much as forty or fifty pounds on a fair-sized rocket of good streamline form (see Fig. 3), and calculations show that the altitude attained in air may be less than half that theoretically obtainable in vacuo. How can this great loss be lessened? First of all, by the utmost attention to streamlining, dispensing with all unnecessary projections such as pipes, valves, bolts, etc., and fairing all parts into a smooth shell with streamline nose and tail. Obviously, the "tail-drive" rocket is best suited to this purpose. The rocket should be long and slender, with a length about thirty times its diameter, according to the author's calculations. Also, dynamic stabilization by means of gyros or other such devices working small movable rudders or "gas-fins" is better than the use of large fixed fins, from the standpoint of air-resistance, aside from that of stability. The rocket should be as large as possible, too, since the weight and carrying capacity of a rocket vary as the cube of its dimensions while the air resistance varies only as the square of its dimensions. Indeed, Oberth maintains that an efficient rocket cannot be built smaller than about sixteen feet long; a smaller rocket, no matter how light and efficient in fuel consumption it is, will have its flight "killed off" by air resistance to such an extent that it cannot go up more than fifteen or twenty miles at most. The fuels used should have a high density—a strong point against liquid hydrogen, so often proposed for rocket work — and the clearance spaces for gas in the tanks should not be too large. If possible, the rocket should be launched from a considerable elevation such as a high mountain, or even an airplane or balloon as Oberth suggests, thus relieving the rocket of the hard work of boring up through the thicker layers of the earth's atmosphere, besides giving it a good head start in the matter of altitude. Finally, the rocket ought to be adjusted to operate at all times as nearly as possible at its *advantageous velocity* — that is, the speed at which the two evils of low acceleration and of high air resistance are best balanced against one another.

The proper value for the advantageous velocity can be obtained as follows: Suppose that the thrust T of the rocket is split up into two components, P being the thrust employed in accelerating the rocket and R being the thrust wasted in lifting the rocket against its own weight and air resistance. Suppose the rocket traverses a thin stratum of air of thickness dh and air density d, with a given acceleration a. Let m_p be the fuel consumption in pounds per second required to produce thrust P and m_r be that required for thrust R, and assume a constant exhaust velocity c.

Then the work done in accelerating the rocket through dh is P dh = $\frac{Wa}{g}$dh, where W is the weight of the rocket in pounds. Since W, a, g, and dh are all independent of the velocity, P is also independent and as P = m_p c, m_p is also independent. Thus the assumption of various values for V will affect R only. Now, R = m_rc, and the total fuel expended in producing R throughout the interval dh is $m_r\,d\,t = \frac{m_r\,d\,h}{V} = \frac{R\,d\,h}{c\,V}$

For minimum fuel consumption,

$$\frac{d\,(m_r\,d\,t)}{d\,V} = 0 = \frac{d}{d\,V}\frac{(R\,d\,h)}{c\,V}$$

and so $\frac{d}{d\,V}\left\{\frac{R}{V}\right\} = 0$, dh, and c being constants.

Now R = W + D, where W = rocket's weight and D = total air resistance = $C_0\,V^n$, assuming Mayevski's formula, C_0 being a constant depending on the size and shape of the rocket and the air density in stratum d h.

$$\frac{R}{v} = \frac{W}{v} + C_0\,V^{n-1}$$

$$\frac{d}{dV}\frac{R}{V} = 0 = -W\,V^{-2} + (n-1)\,C_0\,V^{n-2}$$

Therefore W = (n—1) D for the *advantageous velocity*, at which the fuel consumption is the least. If we assume n = 2, which is nearly true for speeds up to that of sound and also for supersonic velocities, we obtain the very simple relationship

$$W = D = \frac{R}{2}$$

which is known as *Oberth's Law*, having been first derived (by a somewhat different method than the present one) by Prof. Hermann Oberth, the famous German rocket experimenter.

Another useful equation can be derived from Oberth's Law as follows: At the advantageous velocity,

$$T = P + R = \frac{Wa}{g} + 2W$$

$$= \left\{\frac{a}{g} + 2\right\} W$$

Many very interesting conclusions can be drawn from Oberth's Law. Evidently as long as D is less than W the rocket is running below its advantageous velocity and its acceleration can be high as we like; so during the first part of the flight (which may be termed the "speed-up") the acceleration ought to be large (say 3 or 4g). As soon as the advantageous velocity is reached, when the air resistance and weight are equal, the acceleration ought to be slacked off, and a period ensues during which the rocket bores upward against gravity and air resistance, at nearly constant or even decreasing velocity (depending on whether the rocket weight decreases less rapidly or more rapidly than the air density). Obviously the advantageous velocity during the bore should be as high as possible, both from the standpoint of velocity-ratio efficiency and from the desirability of building up high kinetic energy for the 'coast' after powered flight is completed. There is thus a double reward for cutting the air resistance to tthe lowest possible figure.

The mechanical problem of maintaining the advantageous velocity throughout the flight is a rather knotty one. The method suggested by Oberth (Fig. 4) is as follows: The weight of the rocket is approximately proportional to the fuel level, which can be obtained by a float gage in the tank. This gage operates a rheostat which controls the current in magnet M. A pressure-plate on the nose of the rocket is pressed in against a spring by the air-resistance, and actuates another rheostat which controls magnet M'. An armature between the magnets controls throttle valves in the feed lines. Evidently if the balance of the armature is upset by the rocket weight's falling behind the air resistance, or vice versa, the fuel feed will be decreased or increased till balance is restored.

Another device, due to the present author, makes use of the equation

$$T = \left\{ \frac{g}{a} + 2 \right\} W$$

(See Fig. 5). The bottom of one fuel tank has an inserted flexible diaphragm acting against a spring and a pendulum weight, on opposite ends of a "floating lever". The deflection of the diaphragm can thus be made proportional to $\frac{Wa}{g} + 2W$, if the mechanism is correctly adjusted. The diaphragm motion controls a second floating lever, whose other end is acted on by a spring-loaded piston moved by combustion chamber pressure, which is a measure of T, the thrust. The central pivot of this lever controls the throttle arm shown, which in turn controls the fuel valves through a suitable servo device. Evidently as long as the thrust is correctly balanced against the other components, the floating lever will simply tip back and forth, but any lack of balance will cause the throttle arm to move till the thrust is readjusted to the correct value.

The above devices, while correct in theory, are complicated in practice. Where the trajectory of the rocket can be calculated in advance, they may be replaced by a simple timer controlling the fuel throttles by a cam or the like. An even simpler expedient is to use a small clearance space in the tanks but utilize a high initial tank pressure. The acceleration will then be high to start with but will rapidly drop off. After the pressure has fallen to a certain point, a pressure-regulator begins to feed gas at constant pressure from a high-pressure tank, maintaining a constant reaction for the "bore".

So much for the bugaboo of air-resistance and our present means of combatting it. It is hoped that the previous discussion, incomplete as it is, has thrown some new light on this complicated question. Those who seek further material will find much of interest in the works listed in the bibliography following this article — Oberth's "Wege Zur Raumschiffahrt"

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NOTES AND NEWS

The Society's program of meetings is now well under way. At the first winter meeting Mr. Shesta discussed the future plans of the Society, which include the completion of the new proving stand and a series of motor tests by various Society members, probably sometime this Spring. The construction of a new experimental rocket, for the purpose of studying stability in flight and trying out gyro controls and other instruments under actual flying conditions, is also under consideration, and we hope to present some definite news on this subject in our next issue. The work on the proving stand has been greatly hampered by various constructional difficulties and many changes have had to be made in its details. For this reason, it has seemed preferable to postpone a description of the stand till the work is further along.

At the same meeting, Mr. James Wyld described a new rocket design embodying a number of new features, such as a fuel-cooled motor, a pressure-equalizing system in the tanks, and gyro steering. The plan aroused much interest and discussion, and will probably be described in an early issue of *Astronautics.*

Mr. Alfred Africano was the speaker at the next meeting, and presented an ingenious analysis of the heat losses in a rocket motor, which tended to show that present rocket motors attain an efficiency much closer to the theoretically possible one than has hitherto been supposed. A summary of Mr. Africano's interesting discussion will appear in our next issue.

The first public meeting of the year, at the Museum of Natural History, was the occasion of a talk by Mr. Pendray on "Six Years of Rocket Research", which was embellished with a large array of lantern slides showing rocket work both here and abroad and an equally large array of witticisms... The meeting was well attended and resulted in much interest — and a few new members for the Society!

Previewing the Aerological Rocket (continued from page 6)

greater investment either of money or of skill than the airplanes now used for aerological soundings, which are elaborately equipped with many instruments such as directional gyro, radio transmitter, artificial horizon, etc., and which are piloted by highly trained men. In addition to securing almost instantaneous records of atmo- impossible for any heavier than air spheric conditions to heights utterly craft, such rockets could at the same time be used in programs of geophysical and astrophysical research which would vastly extend their usefulness. Special instruments could be installed for this purpose, such as electroscopes, air samplers, cameras, etc.

However, such considerations lead into other fields of application too extensive for discussion in this paper, restricted as it is to the aerological rocket, which from the point of view of the rocket experimenter is only the first useful application of an engine of almost infinite potentialities.

In the foregoing discussion the performance characteristics of the hypothetical sounding rockets are of course only rough approximations, though they are based on the known laws of rocket motion and such experiments and calculations as are available. The figures for the "air resistance efficiency" of the troposphere rocket are of the order of such efficiencies derived by Alfred Africano and J. H. Wyld in studies by the method of numerical integration using standard ballistic formulas. The motor efficiencies are assumed greater than any so far attained with rocket motors burning fuel and liquid oxygen (12%, by Professor Goddard) but are substantially less than those of other types of rocket motor that have been built and tested (45 to 70%, by Sanger of Vienna).

— Peter van Dresser

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Fundamental Equations of Rocket Motion (continued from page 16)

contains a particularly exhaustive and scholarly study, especially of the advantageous velocity and its mathematical implications. But the whole subject is in a very rudimentary state, and until test data is available on the behavior of high-velocity streamline bodies the elaborate and ingenious mathematics which has been so plentifully lavished on the theory of rocket flight is of very questionable practical value. And even theoretical investigations are greatly hampered by the tedious and cumbersome methods of numerical integration which are employed at present in the study of rocket trajectories. The proper correlation of existing data, intensive experimentation in wind tunnel and flight tests, development of improved methods of calculation, the use of new graphical and mechanical analysers, and a fuller knowledge of the possibilities of improved thermal efficiency and

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ROCKET EFFECT IN STANDARD AIRPLANE PERFORMANCE

In an article in the *Journal of the Aeronautical Sciences* for August, Manfred Rauscher of M. I. T., points out that the exhaust blast of a regulation airplane engine is in effect a rocket jet and is capable of contributing perceptibly to the total thrust delivered by the engine and propellor. He calculates that a speed of 300 m. p.h. and with an unmuffled exhaust speed of 1000 ft. per second (corresponding to the jet velocity of a rocket motor) "there is a difference of 6% between the total thrust furnished by an engine whose stacks point straight backwards and the thrust of an engine with stacks pointing straight sideways." As in the case of rocket performance, when the speed of the airplane increases, the energy delivered by these exhaust gases also increases.

However, the effect is complicated by the fact that energy is expended by the engine in drawing in air for combustion from the surrounding atmosphere. Momentum must be given to this air in proportion to the square of the airplane velocity through it, so that this loss of power mounts rapidly with airspeed, and soon overbalances the gain in power from the exhaust jet reaction. This phenomena is an exact parallel to the "velocity-ratio efficiency" of a rocket in motion, since the communication of momentum to the intake air of the airplane engine corresponds to the increment of kinetic energy of the propellants carried by an accelerating rocket. Mr. Rauscher works out curves combining intake power loss and exhaust power gain for various exhaust velocities and airspeeds, showing that above 400 m.p.h. the loss overpowers the gain and at very high speeds becomes in fact a serious hindrance to the functioning of a standard-type power plant.

Fundamental Equations of Rocket Motion (continued from page 18)

weight reduction will all be necessary before rocket theory ceases to be a heterogeneous mess of abstruse calculation, inadequate data, half-baked guesswork, and hopeful figure-juggling, and becomes instead a practical, exact, and usable science.

— J. H. Wyld

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