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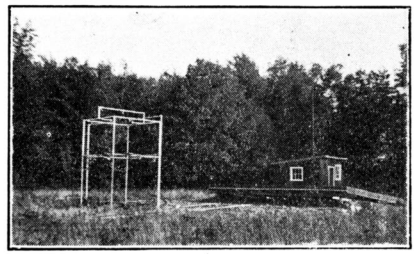
NEWS OF ROCKETRY

United States

At the ninety-seventh meeting of the American Association for the Advancement of Science, Dr. Robert H. Goddard presented, before a joint session of the Section on Astronomy and the American Meteorological Society, ocular demonstration of his progress in developing the liquid fuel rocket. A moving picture of one of his large rockets in flight near Roswell, New Mexico, was shown for the first time. Data concerning this apparatus was released as follows: weight, 80 pounds; weight of propellants, 60 pounds; fuel, gasoline; oxidizer, liquid oxygen; injection by means of nitrogen pressure; altitude reached, 7500 feet; stabilization by means of gyroscopic controls. Dr. Goddard has concentrated his attention on this problem of stabilization and has not attempted to make altitude flights uutil he feels it has been solved. As *Astronautics* goes to press the Smithsonian Institution announces that publication of a report of Dr. Goddard's work is scheduled for the 16th of March. Preliminary data released indicates that Dr. Goddard's motors have developed exhaust velocities of over 5000 feet per second, thrusts up to 289 pounds with burning periods of somewhat over 20 seconds. The next issue of *Astronautics* will contain further material on this.

The Cleveland Rocket Society is at present engaged in putting its proving field in shape for early spring motor tests. Ernst Loebell, the Society's chief research engineer, writes that motors of special design and construction are completed and ready for proving stand trials as soon as the operating trench is ready and electric current supplied.



Cleveland Rocket Society Field

Considerable interest has been aroused by the "rocket mail plane" flights at Greenwood Lake, New York, sponsored by Mr. F. W. Kessler, a New York philatelist. These flights were made by two aluminum airplanes of about fifteen foot wingspread whose aerodynamic form was worked out under the supervision of Dr. Klemin at the Guggenheim School of Aeronautics. They were powered by rocket motors built by Mr. Kessler's staff of designers. The motors burned alcohol and liquid oxygen and are understood to have developed a thrust of forty pounds for periods up to thirty-five seconds when tested on the proving stand. The flights, after some postponement due to trouble in charging the oxygen tanks, were run on February 23. The rocket motors showed themselves definitely able to lift the 120 pound planes from the ice after a run of about ten seconds, and propel them upwards at a steep angle of climb, but the short burning time (about thirty seconds) coupled with several mishaps, lowered the distance covered to about a thousand feet

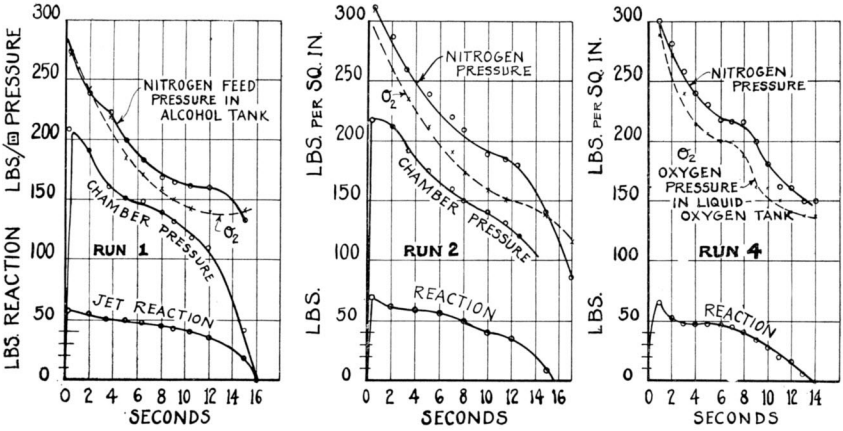
(continued on page 16)

REPORT ON THE ROCKET MOTOR TESTS OF AUGUST 25th

The third series of rocket motor tests was conducted by the Society's Experimental Committee at the Crestwood proving grounds on August 25th, 1935. The particular information sought was: (a) the effect of using alcohol diluted with varying proportions of water as the fuel, (b) the correct ratio of length of combustion chamber to its diameter, and (c) the performace of a special water jacketed motor made of spun aluminum

The three graphs below show the data obtained by photographing the five gages representing the chamber, fuel, and liquid-oxygen pressures, the jet reaction, and the time in seconds. The procedure of the tests was essentially the same as that described in the writer's report of the June 2nd tests in the October, 1935, issue of *Astronautics*. Briefly it consisted of (1) placing the alcohol in the fuel tank, then forcing in nitrogen gas to 300 lbs. per sq. in. pressure. (2) placing the correct amount of liquid oxygen required for combustion in the other tank of the Shesta proving stand and closing all valves; (3) allowing the gaseous oxygen above the liquid oxygen to build up to 300 lbs. per sq. in. pressure by heat absorption from the air; and (4) opening the quick release valves by pulling a cord attached to them from the safety of the barricade 50 ft. away, and at the same time completing an electrical circuit which fired a powder fuse inserted in the rocket nozzle; and finally (5) photographing the positions of the 5 dial indicators with a motion picture camera.

Table I shows the summarized data, with calculated values of the average jet velocity and efficiency of each run. Other data which applies to all of the 5 runs is as follows: alcohol fuel inlets, 1/8″ inside diameter, liquid oxygen inlet, 3/16″ I. D.; nichrome nozzle throat diameter, 1/2 inch, flaring to a 1-1/16″



PERFORMANCE CURVES FOR THREE OF THE 5 MOTORS TESTED ON AUG. 25, 1935.

mouth dianeter on a 12° cone, 3 inches long; initial feed pressures 300 lbs. per sq. in. in all but the fifth run, which was 450 lbs. per sq. in.; amount of alcohol, 1 quart; of liquid oxygen, 2 quarts, (of which ½ quart evaporated in cooling the tank to a low enough temperature to hold the remaining 1½ quarts); inside diameter of combustion chamber, 2 inches, length varied by insertion of additional sections. The motors tested in Runs 1, 2, 3, and 5 were designed by John Shesta; the water jacketed motor of spun aluminum tested in Run 4 was designed by Willy Ley.

Method of Calculating the Thermal Efficiency

For the purpose of making the significance of the results in Table I clear, all the calculations for Run 1b will be given. The same method was used for the calculations for Runs 2 and 4.

The specific gravity of the commercially pure alcohol used was about .79, and the specific gravity of liquid oxygen, about 1.14, so that one quart of the alcohol weighed 58 (cu. in. in a quart) times .036 (lbs. in a cu. in. of water) times .79 or 1.65 lbs. One and one-half quarts of liquid oxygen weigh 1.5 times 58 times .036 times 1.14, or 3.58 lbs. The total weight of liquids injected (and consequently of gases ejected since there was practically no excess of either liquid after combustion ceased) was 5.23 lbs. for all runs. This figure divided by the duration of the runs, 16, 15, and 14 seconds, gives the average jet flow, or .33, .35, and .37 lbs. per sec., respectively. The actual jet flow at any instant of course varied with the chamber pressure, but for the purpose of obtaining some simple index of the relative performance of the different motors, using the average jet flow is sufficiently accurate.

The average jet velocity is calculated by substituting the average jet reaction and flow in the fundamental relation, *the jet reaction, "R" lbs., is equal to the mass flow of the gases per second, "m", times the jet velocity, "c" ft. per second.*

$$\text{Thus, } R = mc, \text{ or } c = \frac{R}{m} = \frac{Rg}{w}$$

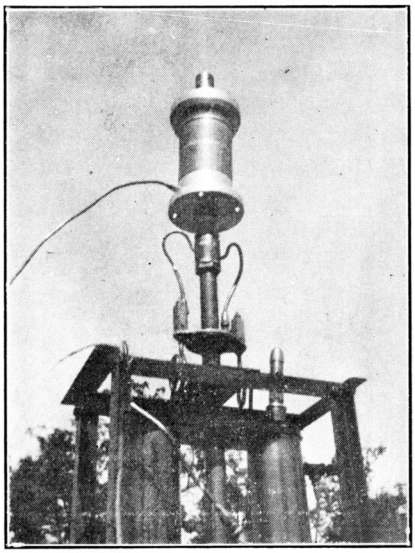
$$= \frac{42 \times 32}{.33} = 4100 \text{ ft. per sec.}$$

Since *the kinetic energy of a moving body is one-half its mass times its velocity squared,* the output per second during this run was:

$$\text{K.E.} = \frac{mc^2}{2} = \frac{wc^2}{2g} = \frac{.33 \times (4100)^2}{2 \times 32}$$

$$= 87{,}000 \text{ ft. lbs. per sec.}$$

The fuel input per second was 1.65



Proving stand showing motor that gave 4350 feet per second exhaust velocity.

Table I **Summarized Data**

Run No.	1b	2	3	4
(1) Length of combustion chamber, inches	7	5	3	3
(2) Ratio, length to diameter	3.5	2.5	1.5	1.5
(3) Maximum jet reaction, lbs	57	73	56	64
(4) Average " " "	42	47½	45	36
(5) Duration of reaction, seconds	16	15	14½	14
(6) Impulse, = (4) × (5), lb. secs	670	712	652	500
(7) Average jet flow, w, lbs. per sec.	.33	.35	.36	.37
(8) " " velocity, c, ft. per sec.	4100	4350	4000	3100
(9) " fuel input, ft lb. per sec., thousands	1030	1100	1130	1180
(10) " thermal efficiency	.085	.094	.079	.047

lbs. of alcohol times its calorific energy content, 12,800 B.T.U. per lb. times the work equivalent, 778 ft. lbs. per B.T.U., all divided by 16 seconds, or 1,030,000 ft. lbs. per sec. Finally, calling the ratio of the kinetic energy output of the jet to the heat energy input of the alcohol the "thermal efficiency", this is found to be:

$$E_{th} = \frac{87,000}{1,030,000} = .085$$

It should be noted again that this efficiency of 8½%, simply tells what proportion of the heat energy of the fuel is converted into the kinetic energy of the jet. The availability of this "output" for propulsion of the rocket depends upon the velocity of the rocket. If the rocket reached a forward velocity equal to the jet velocity, this velocity-ratio efficiency* would be 100%, and all of the kinetic energy of the jet would be utilized in propulsion.

It is interesting to note that at this velocity the useful output of the 5 lb. motor would be 158 H.P., or about 32 H.P. per lb., while the average of the best airplane motors is only about one H.P. per lb.

* See October, 1935, ASTRONAUTICS.

Conclusions:

(a) The dilution of the alcohol with 50% of water prevented its ignition in Run 1a, and therefore no records were obtained. While such a mixture can no doubt be ignited at atmospheric pressure, the high pressure of the test and resulting high inlet velocity make the problem of proper atomization very difficult.

(b) Table I shows that the ratio of combustion chamber length to diameter 2.5 in Run 2 gave the best performance of the 3 recorded runs. The thermal efficiency of this run, 9.4%, is the highest obtained in all of our tests so far, and is very encouraging since it has been calculated that a 7½ mile rocket shot to the stratosphere can be made with an efficiency of only 6.7%.

(c) The open water jacket failed to prevent melting of the aluminum nozzle in Run 4. All of the water either flashed into steam or was drawn up into the vacuum around the jet in the first few seconds of firing and the entire nozzle melted or was burned off. In order to produce an appreciable cooling effect, it is evident that more

(concluded on page 20)

ROCKET FUELS

In general, there are two types of rockets, namely powder rockets and liquid fuel rockets. The fuel of a powder rocket consists of some form of explosive suitably packed into the firing chamber. The most commonly used mixture is an explosive of the nitrate type, such as ordinary gunpowder, or some modification thereof. Explosives of the chlorate type have also been used, sometimes with disastrous results. Mixtures containing potassium chlorate are now considered too unsafe to be of value. A number of German experimenters have been killed by an explosion of a chlorate powder.

Of fuels suitable for use in liquid fuel rockets we can consider both liquefied gases and substances liquid at ordinary temperatures. These include alcohols, liquid hydrogen, various hydrocarbons, and certain other organic compounds. It is an interesting fact that only two chemical elements are of any importance as fuel constituents, namely, carbon and hydrogen. As a general rule, hydrocarbons comprise the most important group of liquid fuels. Other organic compounds contain inert ingredients from the point of view of combustion, and therefore have a lower calorific power. Fuels are commonly rated on the basis of B. T. U. per pound, this being a measure of the energy content of the fuel. In rocket work it is more convenient to compare fuels on a somewhat different basis.

Since a rocket must carry not only its fuel, but also the oxygen necessary for the combustion, as well as pressure tanks, which comprise a large part of the total weight, the calorific power of

TABLE A

Heats Of Combustion Of Various Fuels By Weight

Substance	B.T.U. per lb.	Lbs. Ox. required	Lbs. total weight	B.T.U. per lb. of total wt.
Hydrogen H_2	51900	8.00	9.00	5760
Acetylene C_2H_2	20700	3.08	4.08	5060
Ethylene C_2H_4	20000	3.43	4.43	4520
Benzol C_6H_6	17300	3.08	4.08	4330
Methane CH_4	21400	4.00	5.00	4280
Ethane C_2H_6	20200	3.73	4.73	4260
Pentane C_5H_{12}	19300	3.56	4.56	4240
Hexane C_6H_{14}	19200	3.54	4.54	4230
Heptane C_7H_{16}	19100	3.52	4.52	4220
Dodecane $C_{12}H_{26}$	18700	3.48	4.48	4170
Ethyl Alc. C_2H_5OH	12100	2.44	3.44	3520
Methyl Alc. CH_3OH	9100	2.00	3.00	3030
Smokeless powder	1870	0.00	1.00	1870
Black powder	1000	0.00	1.00	1000

fuels based on total volume becomes just as important, as that based on total weight. To illustrate this, two tables have been compiled. Table A gives calorific powers of fuels based on weight, while table B gives heats of combustion based on the unit volume of one pint. The theoretically necessary quantity of oxygen has been calculated from molecular weights and included in evaluating the total amount of active ingredients in each case.

Gasoline and kerosene are not definite chemical compounds, but rather mixtures of various hydrocarbons, and for that reason they have not been included in the tables as such. For practical purposes it is sufficiently accurate to consider gasoline as equivalent to either heptane or hexane, depending on the specific gravity of the sample, while dodecane is fairly representative of average kerosene.

It is interesting to note that there is not so much difference between liquid fuels as might be expected. Hydrogen is the best fuel on the weight basis, but this fact is only due to the phenomenally low specific gravity of liquid hydrogen. Liquid hydrogen is not made commercially. It is much more difficult to handle than liquid oxygen. Liquid acetylene shows up very favorably, but due to its unstable nature, is a rather dangerous substance, decomposing with great violence under some conditions. Benzol appears to be the best available fuel, but its relatively high freezing point of $+42^0$F. makes it difficult to keep feed lines open when in proximity to liquid oxygen.

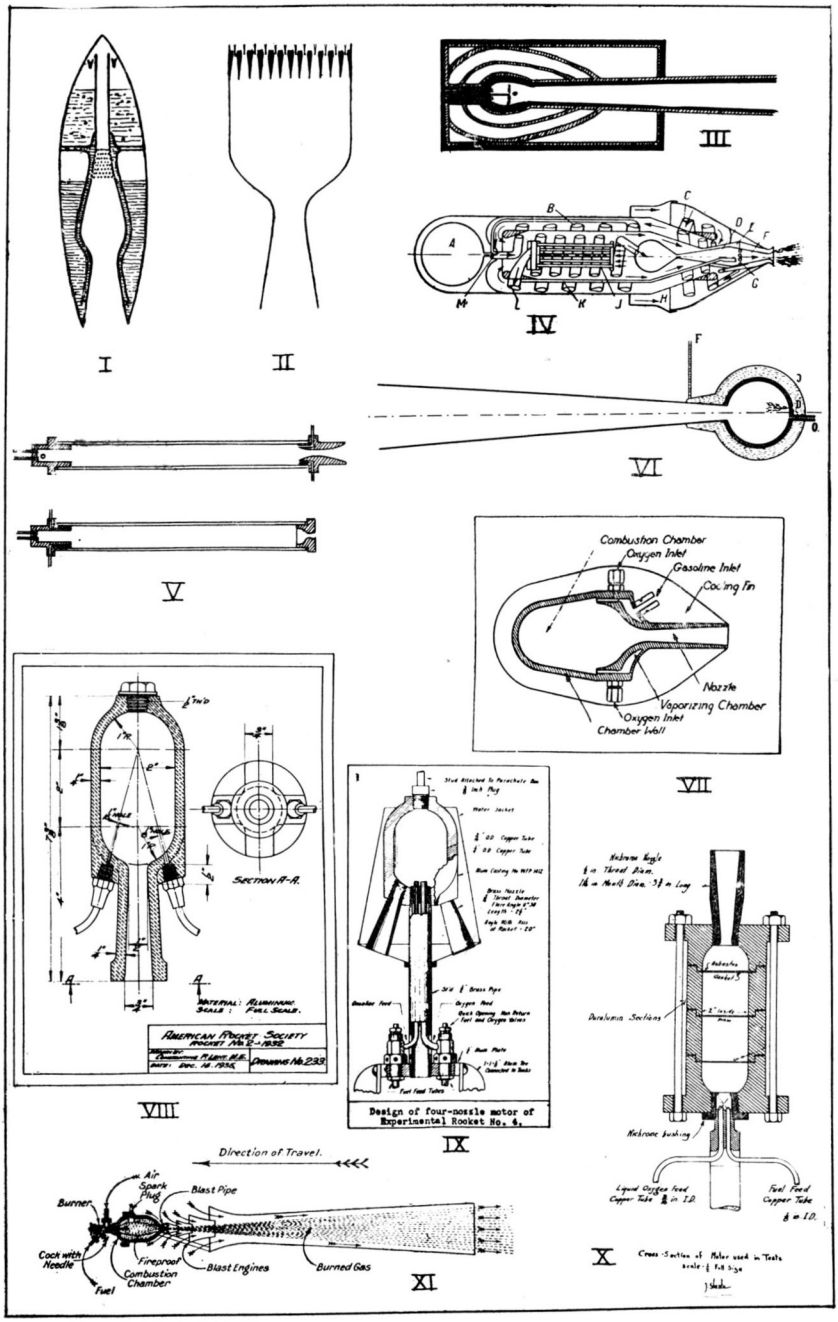
It should also be noted that in order to realize the greatest amount of the available potential energy of the fuel, the shape of the combustion chamber, and the arrangement of the fuel inlets should be adapted to the particular fuel

(concluded on page 20)

TABLE B

Heats Of Combustion Of Various Fuels By Volume

Substance	sp. grav. water = 1	B.T.U. per pint	Pints Ox. required	Pints total	B.T.U. per pint total	Boiling pt. F^0
Benzol	.879	15860	2.36	3.36	4730	+176
Acetylene	.520	11200	1.39	2.39	4700	−121
Dodecane	.770	15000	2.33	3.33	4510	+417
Heptane	.690	13750	2.11	3.11	4420	+210
Hexane	.660	13200	2.03	3.03	4360	+156
Pentane	.634	12750	1.96	2.96	4310	+ 99
Methane	.466	10400	1.62	2.62	3970	−243
Ethane	.466	9820	1.51	2.51	3910	−123
Ethylene	.411	8560	1.22	2.22	3860	−152
Eth. Alc.	.789	9960	1.68	2.68	3740	+172
Meth. Alc.	.800	7600	1.39	2.39	3180	+151
Hydrogen	.071	3850	.49	1.49	2580	−423
Oxygen	1.150	——	—	——	——	−297


I
II
III
IV
V
VI
Combustion Chamber
Oxygen Inlet
Gasoline Inlet
Cooling Fin
Nozzle
Vaporizing Chamber
Oxygen Inlet
Chamber Wall
VII
Section A-A.
Material: Aluminum
Scale: Full Scale.
American Rocket Society
Rocket No. 2 - 1932
Drawing No. 233
VIII
Design of four-nozzle motor of Experimental Rocket No. 4.
IX
Direction of Travel.
Air
Spark Plug
Blast Pipe
Burner
Cock with Needle
Fuel
Fireproof Combustion Chamber
Blast Engines
Burned Gas
XI
Pyrolusite Sections
Nickrome bushing
Liquid Oxygen Feed Copper Tube
Fuel Feed Copper Tube
X
Cross-Section of Motor used in Tests

THE ROCKET MOTOR

A Brief Survey of Ideas Concerning its Design and Construction

Extreme simplicity in one sense marks the rocket motor as the ideal prime mover; yet this very simplicity creates certain knotty technical problems whose final solution is still to be found. In proportion to the amount of energy which a motor of this type liberates and transforms, its mass is so slight that exceedingly high temperatures are developed. The design of a light and compact apparatus to withstand this immense heat of combustion, and to deliver the maximum kinetic energy to its exhaust gases, is not easy. The one favorable factor is the short time such an engine must operate; a few minutes of continuous firing is the most that need be required of it.

Oberth, in his book *Wege zur Raumschiffahrt*, works out forms for liquid fuel rocket motors based on purely theoretical considerations. Figure I represents his concept of a small apparatus for a sounding rocket two or three meters long. The motor is set along the axis of the rocket and its lower part is surrounded by the fuel tank, the upper part by the loxygen tank. Heat is applied to the loxygen (possibly by the injection and burning of small quantities of fuel) and a strong current of hot gaseous oxygen is thrown off and passes downward through the vertical tube, meeting at the beginning of the combustion chamber a spray of the fuel forced by gas pressure through a series of fine perforations or "pores". Oberth suggests that this "diffuser tube" might be of silver to resist oxidation and because of its high heat conductivity. For larger sized rockets he works out the diagrammatic design of Figure II. Oxygen is forced into the combustion chamber through a honeycomb of small expansion nozzles at the head of the motor. Each expansion nozzle has a small "needle jet" at its throat where the fuel is sprayed in. Both of these designs were evolved when very little practical work had been done.

Another early theoretically deduced design is that of Ziolkowsky, the Russian patriarch of rocketry. (Figure III) This motor consists of a small, massive combustion chamber giving into a long expansion nozzle. The chamber is surrounded by two concentric jackets; through the inner the fuel is circulated before being pumped into the motor, through the outer passes the loxygen. The two propellants are then pumped into the head of the combustion chamber where they vaporize but are separated until they strike a screen or grill of vanes which throw them against each other. A "glow point" on the nozzle side of the screen ignites them. The combustion chamber and nozzle are to be of iron or possibly tungsten, electroplated externally with copper in order to improve the heat conductivity.

Several very complicated schemes appear in Federick Zander's book *Flight Problems and the Development of the Reaction Motor* (Russian). Figure IV is a reproduction of one of these. It appears to be a regenerative reaction motor burning atmospheric air, in

which the products of combustion (from the point of combustion, M) are passed through a heat transfer coil to warm the incoming air before it is burned with the fuel. It is difficult to find if any of these ideas have been put into practise.

Johannes Winkler, president of the former Verein fur Ramschiffahrt, in the November-December, 1929, issue of *Die Rakete*, gives theoretical proofs based on rates of heat absorption and speed of flow of propellants that "throat feed" greatly increases the capacity of a given rocket motor. He also seems to favor long and slender combustion chambers. Two illustrations from his paper are reproduced (Figure V). Presumably such a motor was built and installed in the large rocket which he shot in East Prussia.

The absence of thoroughgoing data seems to be the rule in the field of experimental rocketry. The rocket motors of Oberth and the Verein fur Raumschiffahrt appear to have graduated from the form of a simple cone to the round or egg-shaped combustion chamber, in which throat injection of the propellants was used (Injection from ports near the nozzle throat in a direction opposite to the flow of exhaust gases). The construction was of pressed pure aluminum surrounded by a water jacket. Firing periods up to 90 seconds were claimed for them. In this connection it should be noted that a motor of this type was tested on August 25th, 1935, by the American Rocket Society, and burned out four or five seconds after ignition. A circulatory pressure system of water cooling might have prolonged its life. A ceramic lined copper motor was tried by Oberth, but the ceramic appears to have disintegrated.

Sanger, in his book *Raketenflugtechnik* gives some results of tests with a motor cooled by its fuel (Figure VI). This motor had a spherical combustion chamber about 2½ inches in diameter, and a long expansion nozzle. The fuel (light oil) circulated through a jacket and entered through a port at the head of the motor. Gaseous oxygen was pumped in at an adjacent port. The propellants were injected at the high pressure of 150 atmospheres provided by a Bosch fuel pump of a type used on Diesel engines. Sanger reports the remarkable velocity of ejection of 3000 meters per second for this motor, a burning time of 20 minutes and thrust of 25 kilograms, but does not give fuel consumption and constructional details. It would of course be very difficult to duplicate the high feed pressures in a practicable rocket.

Harry Bull's exhaustive studies of small rocket motors burning gaseous oxygen led to some interesting results, and Figure VII (reproduced from *Astronautics* No. 21) shows the design which he arrived at as most efficient. A motor of this type made of tool steel burned for 56 seconds on gasoline and gaseous oxygen, giving a thrust of two pounds, a velocity of ejection of about 5400 feet per second, and an efficiency of about 12½%. A thrust augmentor was found to double the burning time on the same amount of fuel yielding the same thrust.

A longitudinal-section of the first motor built by the American Rocket Society is shown at Figure VIII. This motor was of cast aluminum, and while exact proving stand records of its performance are not available, it delivered

a thrust of approximately 60 pounds for 15 seconds, burning 1½ pints of gasoline. It was fired three times and stood up quite well.

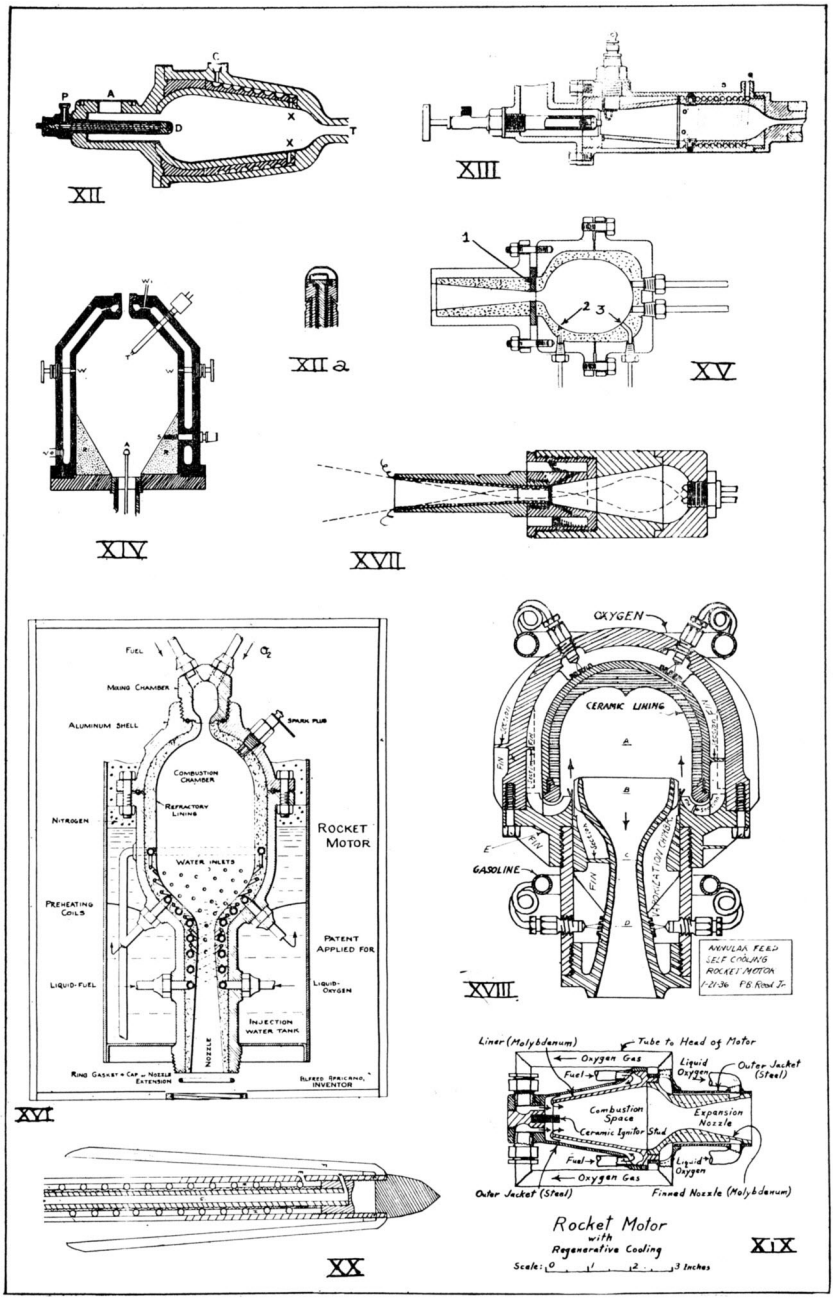
The four-nozzled motor used in rocket number 4, built by John Shesta, is shown in Figure IX. This motor behaved well thermodynamically and drove the rocket in September, 1934, to a height of 400 feet, but burned out one nozzle at this point. The water jacket method of cooling proved inadequate, probably due to steam-cushion effect.

In Figure X is shown the type of motor studied by the Society in its 1935 proving stand tests. Detailed reports of the performance of this motor and its modifications are to be found in this and the two preceding issues of *Astronautics*. This is, so far as is known, the most complete and accurately reported information on a type of liquid-fuel rocket motor.

An interesting series of tests were made during the war by Melot at the French Laboratoire du Conservatoire des Arts et Metiers. This inventor's object was to develop a satisfactory method of jet-propulsion for aircraft, by the use of thrust-augmentors. Figure XI is a diagram of his apparatus, reproduced from *Aeronautics*. This jet-propulsor is not a true liquid fuel rocket motor since it burns atmospheric air, but Melot's handling of the problem should be of interest to rocket designers The combustion chamber was lined with refractory cement, and the engine burned for long periods (from the point of view of rocketry) developing 45 kilograms thrust at an efficiency which was claimed to be greater than that of aviation engines and propellors of the time.

Technical problems strikingly similar to those presented by the rocket motor were met and studied at some length by various experimenters with the gas turbine. Combustion chambers for the Armengaude-Lemale machine built in 1909 are shown in Figures XII and XIII. The chamber was lined with carborundum backed by elastic asbestos, and the nozzle was also of carborundum. Water was circulated around the chamber and injected at x (or O in the second design) to cool the burned gases. Temperature in the combustion chamber averaged 1800 C, and the velocity of ejection was 4000 feet per second. Hourly consumption was 330 kg. air, 179 kg. water, and 17.4 kg. gasoline. The carborundum lining disintegrated after a period of continuous operation. Figure XIIa is a section of the fuel injector and ignitor rod. Gasoline was sprayed against the incoming blast of air out of side orifices, and a platinum wire served for initial ignition. A later patent calls for a platinum ignition wire stretched along the axis of the chamber. "Combustion chamber efficiency" for this type of apparatus is given by Davey at from 90 to 95%.

An informative series of tests on gas turbine combustion chambers was run in 1921 at the University of Wisconsin, by G. P. Warren. Figure XIV shows the most successful apparatus used. Very comprehensive reports are given in the October and November issues of *The Wisconsin Engineer*. The combustion chamber was of cast iron, water jacketed, and was lined at its lower end with a mixture of Hi-temp-ite cement and fireclay (R) backed by elastic as-


XII
XIII
XIII a
XIV
XV
XVI
XVII
XVIII
XIX
XX
Fuel
Mixing Chamber
Aluminum Shell
Spark Plug
Combustion Chamber
Refractory Lining
Nitrogen
Water Inlets
Preheating Coils
Liquid-Fuel
Liquid-Oxygen
Injection Water Tank
Nozzle
Ring Gasket + Cap — Nozzle Extension
Alfred Spiegano, Inventor
Rocket Motor
Patent Applied For
Oxygen
Ceramic Lining
Gasoline
Annular Feed Self Cooling Rocket Motor
1-21-36 F.B. Read Jr.
Liner (Molybdenum)
Tube to Head of Motor
Oxygen Gas
Fuel
Liquid Oxygen
Outer Jacket (Steel)
Combustion Space
Expansion Nozzle
Ceramic Igniter Stud
Finned Nozzle (Molybdenum)
Rocket Motor
with
Regenerative Cooling
Scale: 0 1 2 3 Inches

bestos. Cooling water was introduced near the nozzle at Wi (which proved a mistake as the chilling caused cracking) and was circulated through the jacket and into the chamber at W. Fuel was sprayed into the incoming air-blast by an atomizer A. Internal temperature was measured by a platinum-platinum 10% rhodium thermocouple T. This apparatus ran for periods up to 45 minutes, giving exhaust velocities up to 3790 feet per second, reactions up to 38 pounds, temperatures to 2072° F, and overall efficiencies to 43.4% (This being 96% of the theoretical thermal efficiency possible for the cycle used). Compressed air was introduced at about 100 lbs. per square inch, the combustion chamber pressure was about half this, and the expansion ratio of the nozzle was 1:7. From 0.01 to 0.015 lbs. of gasoline was burned per second, and from three to five times as much water was injected.

Some recent ideas as to motor construction, developed by members of the Society from theoretical and practical considerations, are reproduced. Figure XV is a motor designed by Noel Deisch for proving stand work, so that the refractory lining may be varied as may also that of the nozzle. Provision is made for a plate of resistant metal (1) inserted at the throat to withstand the erosive effect of the gases, and for taps (2, 3) to note combustion chamber pressure.

Figure XVI is a design by Alfred Africano. It embodies a mixing chamber where the propellants enter in semi-liquid form and are thrown together to form a vortex. They are then injected into the combustion chamber which is lined with refractory cement. Cooling coils are provided in the lining, and orifices from which water passes into the chamber and nozzle. Provision is also made for fuel and loxygen preheating coils embedded in the refractory lining. The designer plans to build and test motors of this type this spring. He calculates that the efficiency will be superior to that of the motors heretofore tested, because of the pre-mixing of fuels and the water injection.

Figure XVII is a diagrammatic design by Constantine Lent, in which water is drawn by venturi effect into the throat from a reservoir around the base of the nozzle. It vaporizes and forms a protective steam jacket for the nozzle lining. Mr. Lent lays stress on the destructive effect of reflected streams of high velocity gases, and provides a cylindrical section at the nozzle throat to bring the gases into true axial movement. The correct proportioning of combustion chamber length to nozzle length also must be studied, according to this investigator, so that the lines of flow of gases will pass into the nozzle without destructive impact and reflection.

Motors in which the propellants are vaporized completely before burning are felt by some to be the best solution of the problems of combustion within a reasonable sized combustion chamber, and the good results obtained by Sanger and Bull with gaseous oxygen support this idea. There are also advantages in this type due to a cooling, also a recuperative effect. Figure XVIII is a rather elaborated design for such a motor by Prentiss Reed, Jr. The com-

[concluded on page 18]

MATERIALS FOR ROCKET CONSTRUCTION - II

This instalment completes the able report of Mr. Smith on the properties of available metals and other materials for rocket construction, undertaken at the request of the Society's Experimental Committee. The first section of the report was published in ASTRONAUTICS No. 31.

As we have seen, the problem before the rocket designer in choosing materials resolves itself into two sections:

1. Materials for the blast chamber
2. Materials for the fuel tanks

In the first part of this report I presented the properties and characteristics of some materials available for motor construction.

The *fuel tank* materials should have these properties:

(1) High sp. ten. strength at low temp.
(2) Low thermal conductivity
(3) Practical fabrication possibilities

Fuel tanks made of beryllium-copper, stainless steel, duralumin, and dow-metal, with the same strength and capacity would be about equal in weight, provided they were used to operate at ordinary temperatures. But at the temperature of liquid oxygen (-186^0 C) only aluminum copper and lead alloys appear to remain applicable.

Magnesium and Lithium alloys have not yet been investigated. Lithium (not satisfactorily alloyed as yet) if it follows lead in this respect as it does in other physical ones, may be superior to all in tensile strength at low temperatues.

Aluminum and copper alloys are the most workable. Aluminum, however, has this advantage, in that the safe working tolerances on parts made from it are 3 times greater than for copper, due to that much increase in the thickness of members.

The process of gas welding the new strong Duralumin alloys and Beryllium-copper remains to be perfected, but welding in an induced atmosphere of hydrogen is possible in both cases and if a welding rod having the composition of the original alloy is used little strength will be lost at the welds after heat treatment.

Two other branches of substances must be given consideration in a discussion of rocket materials: *refractories* and *plastics*.

Table II **Fuel Tank Metals**

Metal	Sp. Gr.	Ten. Strength lbs/in^2	Sp. Ten. strength	Thermal conductivity	Mech. Properties at -186^0 C.
Dow metal	1.8	40,000	22,200	20	Not known
Duralumin	2.8	65,000	23,200	30	T. S. improved
Cro-Mo-Steel	7.8	175,000	22,100	5	becomes brittle
Ber.-Copper	8.2	193,000	23,500	40	T.S. probably "

Other Possibilities

Metal	Sp. Gr.	ten. strength lbs/in^2	Thermal conductivity	Mechanical properties at low temperatures
Lead	11.34	1,500	10	TS becomes greatly increased
Lithium	.53		20	May behave like lead

Table III **Refractories**

	Crushing Strength 1000°C	1500°C	M.P.°C	Density
Alumina	9,800 lbs/in^2	200 lbs/in^2	2050	2.6
Carborundum	7,500 lbs/in^2	1,000 lbs/in^2	2200	2.5
Magnesia	3,000 lbs/in^2	450 lbs/in^2	2800	2.5
Quartz	10,000 lbs/in^2	1,500 lbs/in^2	1700	1.8
Zirconna	5,000 lbs/in^2	150 lbs/in^2	2950	4.0
Graphite	T. S. equals	2,500 lbs/in^2	3500	2.2-2.3

The only refractory higher in melting point than Tungsten is graphite. Those, other than graphite, that exceed Molybdenum do not do so by any great margin. All are poor conductors of heat, the best, Graphite, having a resistance 800 times greater than copper. All are either brittle or poor in tensile strength at high temperatures with graphite again coming out highest. A transparent fused quartz motor also remains as a possibility and would be exceedingly useful in studying gas flow and combustion not too high in temperature.

Plastics like Bakelite have this advantage over metals in making tanks: being in fact thermal and electrical insulators, they can reduce considerably the amount of losses sustained in filling them with liquid oxygen or other fuels with low boiling points. Up to the present time, where the use of metals for tanks has been exclusive, this factor has been a source of great annoyance and danger.

The subject of plastics has scarcely been scratched. Their properties at extremely low temperatures are not fully known.

Manufacturing them to suitable forms is usually easier than with most other substances.

Taking all in consideration, Molybdenum copper of Aluminum for the motor and Duralumin or Ber-Copper for the tanks would be our best choice at the present time.

As is customary in articlees of this sort, costs of materials and production have been ignored. To mention them would be equivalent to eliminating some of our best prospects.

— **Bernard Smith**

Table IV **Plastics**

	Tensile Strength	Density	M.P. °C
Pyroxylin (Celluloid)	8,500 lbs/in^2	1.35	85
Phenol Resins (Bakelite)	25,000 lbs/in^2	1.32	200

Through special arrangements with the publishers, the Society will be able to supply its members with the American edition of Mr. P. E. Cleator's book, "Rockets through Space" at 10% off list price, postage prepaid, in the U.S.A. The book will appear in April, and the list price has been tentatively set at $2.50, making the price to members $2.25. Non-members may purchase through the Society, at list price.

News of Rocketry

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(inclusive of distance traveled on the ice). A blow-out occurred in one side of the combustion chamber of the first plane, producing a side thrust which destroyed its stability, and the wings of the second plane collapsed while in flight at about the fifteenth second of firing This is probably the first time that the liquid fuel rocket has been applied to airplane propulsion, perhaps because workers in this field have not only to contend with the difficulties of building an effective rocket motor but also with that of making such a motor operate efficiently at the comparatively low speeds which even the fastest aircraft attain.

France

The term "astronautics" originated in this country (attributed to the writer, J. H. Rosney) as did also the first and only international award for furthering this science It was gratifying to learn that the REP-Hirsch award, which ran for three years — 1928, 29, 30 — has been revived by its originators, Robert Esnault-Pelterie and Andre Hirsch. The prize of 5000 francs is offered to the author of "the best original scientific work, either theoretical or experimental, which tends to improve the solution of the problem of interplanetary navigation or of any one of the branches of science which are included in 'Astronautics'." The closing date for the contest was the first of this year, and the jury will render its decision this June. A special "Committee for Astronautics" has been formed by the French Astronomical Society to handle the contest. It is headed by M. E. Fichot, Member of the Academie des Sciences, and is made up of eighteen scientists, astronomers, and engineers. A summary of the work of the American Rocket Society, prepared by a committee appointed by Mr. Pendray, has been submitted as the A.R.S. official entry in the contest.

The French Astronomical Society is also considering a proposal by Mr. Alexandre Ananoff for the establishment of a permanent astronautical center under its auspices. Mr. Ananoff, who has been working at the project, for some time proposes that this center acquire a library of the literature of astronautics and rocketry, as well as the services of a staff of translators.

A very thorough experimental study of the characteristics of large powder rockets has been carried on at the Aeronautical Institute of St. Cyr by M. Louis Damblanc. The tests were made by means of a proving stand which recorded the thrust on a revolving drum and also on high-speed motion picture camera film. The rockets tested were standard signal, coast guard, and "anti-hail" types. M. Damblanc works out expressions for the value of the exhaust velocity at various points along the thrust curves, also general formulas for the altitude of a given powder rocket in terms of the size, shape and composition of its charge and case, together with its air resistance as determined in wind-tunnel tests. The largest rocket tested was a 70 mm. calibre two-step life-saving one which carried 1.85 kg and 1.165 kg of powder in its two stages and developed a peak thrust of almost 100 kg. Its thrust curve and a drawing

of its construction are appended here. M. Damblanc calculates its maximum exhaust velocity at 536 meters per second, but with a smaller anti-hail rocket loaded with blasting powder and made by the Ecole de Pyrotechnique de Bourges the remarkable exhaust velocity of 1,320 meters was reached. The theoretical altitude attainable by the coast guard rocket was 1100 meters, that of the anti-hail rocket 3000 meters. M. Damblanc plans to develop the powder rocket for meteorological, military and other purposes. He believes that its performance can be improved by (1) fabricating powders maintaining peak effort during most of the combustion time (2) raising the maximum thrust without increasing the speed of combustion (3) utilizing shells of lightweight metals (4) using the multi-step principle.

Though not strictly within the field of rocketry, renewal of experiments with the Melot "propulseur a trompe" is of interest. This apparatus is essentially a jet propulsor for aircraft, in which atmospheric air is burned with liquid fuel and the efficiency increased by means of thrust augmentors or series of cones which draw air into the exhaust jet so as to decrease its velocity and increase its mass flow. A method has been devised for overcoming one of the chief drawbacks of the original system—the difficulty of supplying the compressed air for combustion. Instead of a mechanical compressor, it is proposed to provide the plane with an "air-scoop" in the form of a converging nozzle. In the throat of the nozzle is a steam jet which injects the incoming air into a pressure tank after the manner of a steam injector. The steam then condenses out and is returned to the boiler, and the compressed air fed to the combustion chambers of the reaction motors where it burns with the fuel. It is calculated that this method of propulsion would reach its maximum efficiency at an altitude of 30,000 meters and a speed of 1000 km. per hour. Great simplicity and the ability to burn cheap fuel oils are also claimed for it.

Germany

An international bureau of information on rocketry has been proposed by Werner Brugel, German writer on astronautical subjects. The "I.R.K.A." (Internationale Raketenfahrt-Kartei) would contain indexed material covering rocket history, rocket experiments, rocket experimenters and all published data pertaining to this field, according to Herr Brugel's plans.

Russia

Stories of rocket research in Russia are frequent, but it is difficult to get any authoritative reports. The accompanying photograph, supplied through the courtesy of Science Service, shows a Russian rocket which is said to have

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The Rocket Motor

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bustion chamber is lined with carborundum or other refractory material in small segments. This segmented lining, properly designed, will provide good heat-insulation, and prevent shattering. This lining is carried in a hemispherical shell of chromium. On it fins are provided which serve as support as well as cooling members. These fins have a slight twist giving oxygen gas rotation counter to that provided for gasoline by fins around throat. The annular lip at the convergence of the oxygen and gasoline is slotted and "set" much as the teeth in a saw, to provide rapid mixing.

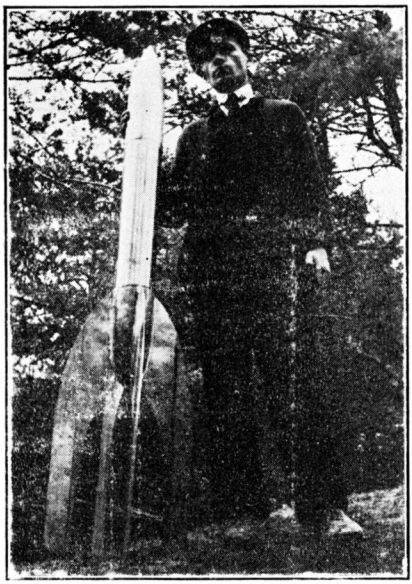
"It is significant that liquid oxygen is normally *at* boiling temperature, necessitating carefullest insulation. Not shown but suggested is sub-cooling of the oxygen by liquid helium if possible and also asbestos packing of all oxygen pipes, including tank. No practicable check valve for the gases seems possible and babbitt blow-out plugs in the exterior walls of both vaporization chambers may be judicious. The fuels cannot absorb sufficient heat by vaporizing to do all the necessary cooling, but they may possibly be induced to carry away heat to the exterior cooling fins nearest the annular inlet." This motor design is too extreme a step from present practise for any estimate of its performance and it offers considerable constructional difficulties, but it may foreshadow a type of motor that will be developed.

Figure XIX is a design by James H. Wyld. "The fuel and oxygen are passed through vaporizing jackets, keeping motor cool, also vaporizing and preheating the combustibles, which then impinge on one another from the annular ports at the motor head and are ignited by the red-hot ignitor stud. The use of this ignitor, together with preheating and high turbulence, makes for rapid and complete combustion and a small, compact motor. Molybdenum is suggested as liner material for the motor, but aluminum alloy probably would serve, provided care was taken against excess of oxygen. Oxygen-resisting films (e.g. "calorization" or else vitreous enamel) might be applied to interior of motor and of the oxygen vaporizer spaces."

Some investigators hold that the use of the combustion chamber is unnecessary, and that a satisfactory reaction will be developed by a process of continuous combustion along a nozzle of special design. Figure XX is a design by Franklin Pierce and Nathan Carver (*Astronautics* No. 27) for a reaction motor of this type. Fuel and oxygen are injected from ports around the core of a conical nozzle. While this principle may prove sound, it is at present an unknown factor, as studies of the subject have been based on the idea of burned gases from a combustion chamber passing through an orifice into an expansion nozzle. Combustion in the nozzle, with its consequent turbulence and irregularities, is to be avoided in this classical system.

— **Peter van Dresser**

[Editor's Note: Readers of *Astronautics* are invited to submit rocket motor designs for publication in the next symposium on the subject.]



Russian Experimental Rocket
- Courtesy Science Service

News of Rocketry

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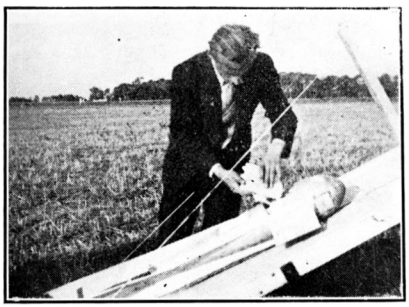
reached 19,000 feet. Information released is as follows: time of ascent, one minute; descent by parachute; altitude calculated from temperature and pressure recorded by a meteorograph. No further data is available.



A Dutch Dry-Powder Mail Rocket

Holland

The *Nederlandse Rakettenbouw* has been carrying on a series of mail flights with powder rockets over distances reported up to 900 meters. The shot which newspapers said was to be attempted from Calais to Dover, and which was prohibited by the French authorities, was actually to have been from Calais to Sangatte. The Society plans to begin experiments with liquid fuels.

India

Successful transportation of two live birds by rocket across the Damodar River is reported as having been achieved by Stephen H. Smithof the Indian Air Mail Society. The range of the rocket was increased by the use of wing-like fins which enable it to glide some distance.

Notice From The Librarian

The supply of past issues of *Astronautics* has become depleted and after April 15th, the price of issues for 1934 and 1935 must be placed at one dollar per copy. For older issues consult the librarian.

Arrangements are being made with the British Interplanetary Society for exchange of official publications. In the future, members of the American Rocket Society will receive with each copy of *Astronautics* the most recent issue of the *Journal* of the British Society.

Report on the Rocket Motor Tests of August 25th

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effective methods must be used, such as rapid circulation of water around the chamber and nozzle, or injection into the chamber itself.

Run No. 5 was a high pressure run, at 450 lbs. per sq. in. initial feed pressures for the alcohol and liquid oxygen. Burning out of an asbestos gasket on the side wall of the combustion chamber permitted gases to escape, and the resulting horizontal reaction overturned the proving stand.

— **Alfred Africano, M.E.**
Technical Secretary

[Editor's Note: Empirical rocket design formulas derived from the data of the four series of motor tests conducted by the Society in 1935 will be presented in a paper by Mr. Africano to appear in the next issue of *Astronautics.*]

Rocket Fuels

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being used. The flame characteristics and speeds of combustion differ with various fuels. Unfortunately sufficient experimental data is lacking on this important subject, at present, to enable one to design the most efficient rocket motors. Only a small percentage of the heat energy is utilized, but as the development work goes on, greater efficiencies will be attained.

In the proving stand tests of the American Rocket Society during the summer of 1935, three different fuels were tried, namely Pentane, Heptane, and Ethyl Alcohol. The best results were obtained with Ethyl Alcohol. This, in spite of the lower calorific power of Alcohol, as compared to either Pentane or Heptane, is believed to be due to the fact that the rocket motor, because of its shape, was able to utilize the fuel with greater efficiency in the case of Alcohol. Furthermore, Alcohol contains less Carbon than the two other fuels tried

In general, it appears that a large percentage of carbon in a fuel will decrease the speed of combustion and make for a longer flame, while a large percentage of hydrogen produces the opposite effect.

The ratio of the heat energy of fuel to the weight of rocket is of interest. A "2 pound" powder rocket was examined some time ago. This was found to contain a driving charge of 23 gm. of black powder, with a total weight of 242 gm., which is equivalent to 95 B.T.U. per pound overall.

A rocket recently built by the American Rocket Society weighed 20 lbs. and carried 5 pints of gasoline. This corresponds to an available energy content of 1320 B.T.U. per pound overall, which is nearly 14 times that of the powder rocket.

This illustrates the great advantage of liquid fuel over powder rockets. However imperfect they may be at present, liquid fuel rockets have potentialities which, for any distance flights, leave the powder rockets out of consideration.

— **John Shesta, C.E.**

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