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# PRACTICAL MECHANICS

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# Rocket Propulsion

## The American Rocket Society : Rocket Motors on Test

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(*Continued from page 224, April issue*)

AFTER the trials of the A.R.S. Experimental Rocket No. 4, no further liquid-fuelled types were constructed for free flight, that is, not until 1939.

The Experimental Rocket No. 3 was never actually fired because of charging difficulties. Similarly, Experimental Rocket No. 5 was not prepared for test, due in this particular case to the results of earlier proving trials which had brought out severe failings in the design.

Since the building of these types, only ground trials of liquid-fuelled rocket propulsion units have been made, although complete powder rockets have been developed for stability trials and tests of alighting mechanism, for the purpose of which, free-flight firings are obviously essential.

The more current experimentation of the American Rocket Society comprises what is undoubtedly the most exhaustive technical development yet conducted outside the secrecy of the Government laboratories.

In view of the technical significance of this work, it is perhaps desirable to go into the various designs and test procedures a little more fully than in the previous discussions.

### The Truax Rocket Motor

Among the most successful types developed by the Society to date is the water/fuel-cooled constant-volume motor (Fig. 22), designed by R. C. Truax.

The motor, designed to employ liquid oxygen, with petrol as fuel, was built almost entirely of nickel steel. Its chief attribute is in the unique cooling system, which combines a fuel circulation in a double walled nozzle " throat," with direct water injection into the efflux stream. This latter process is effected through an annular slot formed into the inside of the nozzle " throat." The fuel is introduced at high pressure, and has its inlet through the nozzle coolant jacket. From this, a fuel feeder line connects the nozzle jacket to a small pre-mixing chamber at the motor " head "; the fuel entering at the side. Just prior to injection, the fuel is " atomised " by its forced passage through a small centrifugal whirl fitted within the feed line. The oxygen, which enters the same pre-mixing chamber directly from the motor " head," is thus homogeneously mixed with the fuel prior to entering the combustion chamber. Both the fuel and water are forced to the motor under air pressure; and at the commencement of operation each is supplied under fully 700 lb. per sq. in. This pressure is subsequently regulated, at full operation, to 200 lb. per sq. in., and 160 lb. per sq. in., for the fuel and water respectively.

### The Truax Motor on Test

The complete unit, which was first tested at Annapolis, Md., in December, 1937, had, for recording, simply a beam balance. Because of the necessity of having the operator within some 15ft. of the combustion unit—for reason of safety—the complete set-up was given a hydrostatic test up to 1,000 lb. per sq. in. The motor and testing scale on the one side, and the fuel tank, water tank, air compressor with containing tank (oxygen was not employed during the initial trials), ignition gear, etc., and operator on the other, were divided by a steel sheet.

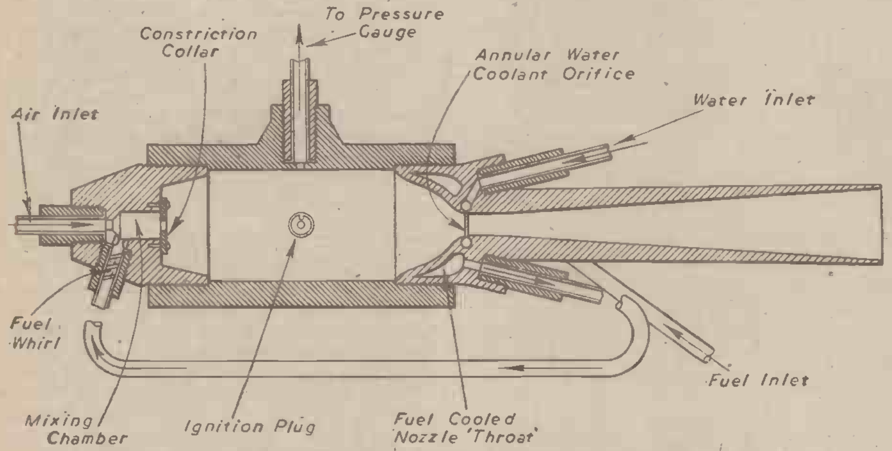


*Fig. 22.—Sectional diagram of the Truax fuel and water-cooled motor* (1937).

The testing sequence was as follows: Air is first supplied to the feeding lines, the ignition circuit cut in, and with the fuel and water tanks fully pressurised at 700 lb., the inlet valves operated. Air for combustion was then introduced at a slowly developing pressure; but unfortunately, in the initial test, the motor refused entirely to respond.

A second attempt was immediately made, using the same functioning sequence, the sole difference being that the motor and fuel supply lines were first raised in temperature to red heat by oxy-acetylene flames. The fuel system was again pressurised and air supplied in slowly increasing quantity until the attainment of the required combustion proportion. On this occasion, the motor did fire, but in no way so effectively as had been hoped; its sound emanated a motor-cycle engine—a loud continuous popping. However, with slight adjustment of the supply valves, the motor was at length made to function with a steady roar, but only for a few seconds before reverting to its previous irregularity.

In view of these failings, the motor was stripped down in a search for possible fault. Consideration showed that it might be the case that the fuel supply had been affected by the momentary pressure built up during the intermittent explosion periods, and the constriction collar in the mixing chamber was replaced by a smaller one, the intention being to cause a greater pressure prior to ignition. When put to further test, however, the motor did not even function.

In the next test, the restriction collar was removed entirely. The motor was again set up, and, after pre-heating the chamber, the fuel and air supply were once more cut in. Within a few seconds of adjustment, the motor finally burst into life, but first only with the same popping noise as had resulted earlier. Slowly the supply pressure was modulated, and then, suddenly, at a certain minute adjustment, there came at last a loud, smooth roar; the sound indicative of continuous combustion. Almost immediately it became necessary to operate the nozzle coolant system because of the rapid rise of temperature which accompanied proper combustion. The water coolant device proved highly effective, cooling the motor instantly, and in subsequent trials the inlet was left slightly open.

### Test Results

At the commencement of proper function, the combustion pressure rose to 50 lb., and by effecting a gradual increase of the input pressure—at the same time due care being taken to maintain the correct propellant ratio—a pressure of 150 lb. per sq. in. was finally achieved.

Had oxygen been employed instead of air as the " supporting " medium, it was considered that the motor would quite easily have reached the designed chamber pressure of 300 lb. per sq. in. As it was, the inlet ports were too small to allow the air to build up sufficiently.

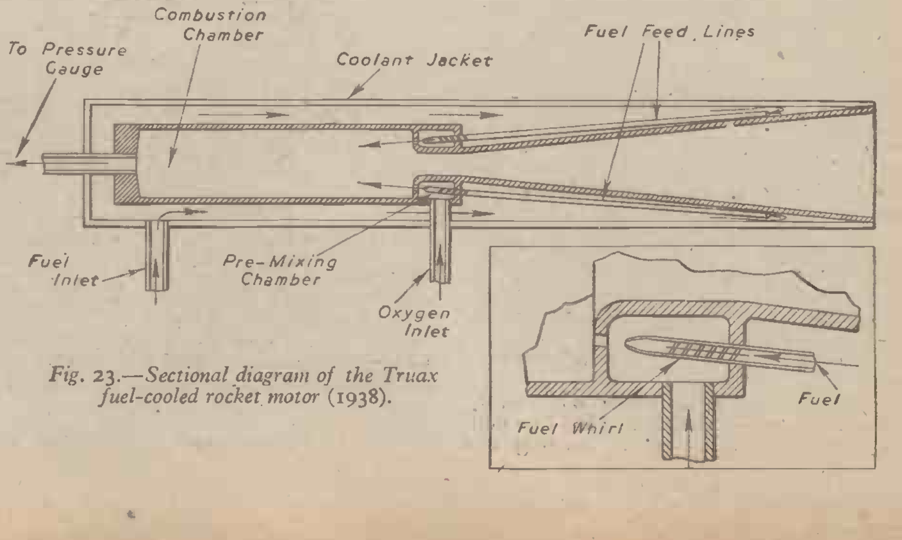


*Fig. 23.—Sectional diagram of the Truax fuel-cooled rocket motor* (1938).

Several further firing runs were made later in which, by an interchange of valves, even greater steadiness of control and burning was achieved. It is indeed unfortunate that the testing apparatus employed in these particular experiments was not more elaborate. There were, for instance, no facilities for determining such necessary characteristics as the constant thrust factor or the amount of fuel consumed, and, therefore, the thermal efficiency. However, R. C. Truax—who conducted the tests—reporting in *Astronautics*, April, 1938, pp. 9-11, made the following general observations, which, for our purposes, are in many ways as conclusive as the recorded figure: "The matter of determining the proper fuel mixture caused no concern; the motor would not run on an improper mixture. While the rocket motor was in full operation without water, there was neither smoke nor flame issuing from the nozzle mouth. This probably indicates excellent combustion and complete expansion. In fact, with the jet at full power an observer put his hand about a foot and a half from the nozzle, and so little heat remained unconverted that he was able to hold it there (though with considerable effort) without injury."

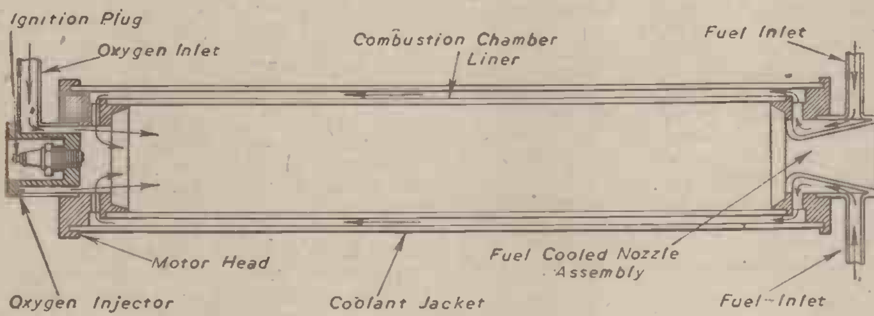


*Fig. 24.—Sectional diagram of the Wyld self-cooled tubular regenerative motor* (1938).

There is no doubt in the success of the cooling system. The amount of water consumed during the testing was about half that of the fuel, but a reduced quantity would undoubtedly serve to cool the nozzle with little effect on the operating effciency.

As already mentioned, the fuel consumption was not directly recorded, but it has been estimated that a total of about 10 gallons was used to run the motor, intermittently and at varying powers, for six or seven hours of testing.

## The Truax Fuel-cooled Rocket Motor

A further Truax motor (Fig. 23), developed early in 1938, featured a fuel-cooled combustion chamber and nozzle, with reverse fuel injection.

As can be seen from the diagram, the component layout is extremely simple and no elaborate "contouring" of the chamber and nozzle firing faces is involved. Distinctions in the design are complete fuel cooling, and the provision of a propellant premixing system at the nozzle "throat."

The design is such that the fuel enters from the side, near the motor "head," circulating through the coolant jacket down to the nozzle "mouth" prior to entering the pre-mixing chamber at the nozzle "throat" through feed lines. Small centrifugal whirls fitted in the lines "atomise" the fuel prior to its injection. The oxygen enters the pre-mixer from the side, where both propellant components are well mixed, prior to their injection into the combustion chamber—towards the motor "head"—through small bore holes. A small ignition plug, fitted in the chamber wall, serves to initiate combustion.

The fuel-cooled Truax motor was shown in England when the designer visited London and delivered a lecture to an assembly of the British Interplanetary Society in July, 1938.

## The Wyld Rocket Motor

As with the motors previously described, the point of significance in the Wyld regenerative motor (Fig. 24) is its unique cooling system. Again, petrol is used, with oxygen, as propellant.

With reference to the diagram: the fuel enters the motor at the double-walled nozzle, flowing round the combustion chamber, through the jacket "manifold," and is introduced, for combustion, at the motor "head." The oxygen is fed from a radial injector and enters from just above the fuel inlets, which inject from radial holes at the sides. By this arrangement, the fuel acts to cool both the nozzle and chamber, and, conversely, to vaporise the fuel by pre-heating, with a resultant improvement in combustive efficiency. The complete motor weighs only 2lb.

## The Wyld Motor Under Test

The motor was tested on December 10th 1938, the recording apparatus being the American Rocket Society Proving Stand No. 2.

Fuses, along with gunpowder loosely packed into the nozzle, were used for ignition. When fired, the gunpowder caused the exhaust to appear first as a large yellow flame, which immediately shortened into a "spear" of blue as the liquid propellant caught. At the same time, the reactive thrust rose to 90 lb., which figure remained steady on the recording dial for 13.5 seconds, until the liquid oxygen became exhausted in the supply tank.

Upon examination the motor showed no sign of defect, apart from slight melting and erosion at the chamber "head" and liner, which had occurred about an inch from the injector ports.

## Empirical Performance Data

The performance figures of the Wyld regenerative motor, derived from proving stand test, as from the period of efficient combustion, are as follow: Maximum reaction, 91lb.; alcohol feed, 0.084lb./sec.; oxygen feed, 0.34lb./sec.; tank pressure, 250lb./sq. in.; chamber pressure, 230lb./sq. in.; maximum exhaust velocity, 6,870ft./sec.; maximum thermal efficiency, approximately 40 per cent.; and jet energy, 310,000ft./lb. sec.; or 565 h.p.

Further trials of the same motor were made in August, 1941, when the American Rocket Society experimental committee conducted three exacting firings at their Midvale, N.J., proving grounds.

In the first firing, the motor functioned for 21½ seconds, consuming during that time about 12lb. of propellant. The jet appeared as a violet flame approximately 3ft. in length; the motor operating with a deep roar interspersed by sharp detonations which occurred at intervals of about five seconds. These regular explosions caused considerable vibrations, which, as well as shaking the proving stand, were actually felt by those taking part in the test. The phenomena which were in attendance throughout the three testing runs, caused no hurt to the motor.

The second test was concluded with similar results as the first, though the firing duration was bettered at 23 seconds.

The final firing was by far the most satisfactory, lasting for a period of 45 seconds, and, despite the use of a leaner propellant mixture, the motor recorded a maximum thrust of 135lb.

The average thrust for the three firings was approximately 125lb., while the tank and combustion chamber pressures were 250lbs.

One further point of interest arising from the trials was that, due to a misfire in the initiation of one of the firings, unignited propellant ejecting from the nozzle developed a thrust of almost 50lb. on its own account.

These figures are among the most favourable ever recorded by the American Rocket Society. Coupled with the fact that the motor functioned almost without damage, this data shows clearly the increased reliability obtainable in the development of liquid-cooled rocket propulsion units. A similar, though admittedly less ambitious motor, it will be remembered, was produced a number of years earlier by the German engineer, Dr. Eugen Sänger.

*A Mosquito of Coastal Command being loaded up with rockets while final adjustments are made to the machine preparatory to taking off.*