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How It Started

The dear Queen had finally gone to her reward, and King Edward VII was enjoying himself immensely as he reigned over the Empire upon which the sun never set. Kaiser Wilhelm II in Germany was building battleships and making indiscreet remarks, and in the United States President Theodore Roosevelt was making indiscreet remarks and building battleships. The year was 1903, and before its end the Wright brothers' first airplane was to stagger briefly into the air. And in his city of St. Petersburg, in the realm of the Czar of All the Russias, a journal whose name can be translated as "Scientific Review" published an article which attracted no attention whatsoever from anybody.

Its impressive but not very informative title was "Exploration of Space with Reactive Devices," and its author was one Konstantin Eduardovitch Tsiolkovsky, an obscure schoolteacher in the equally obscure town of Borovsk in Kaluga Province.

The substance of the article can be summarized in five simple statements.

1. Space travel is possible.
2. This can be accomplished by means of, and *only* by means of, rocket propulsion, since a rocket is the only known propulsive device which will work in empty space.
3. Gunpowder rockets cannot be used, since gunpowder (or smokeless powder either, for that matter) simply does not have enough energy to do the job.
4. Certain liquids *do* possess the necessary energy.

5. Liquid hydrogen would be a good fuel and liquid oxygen a good oxidizer, and the pair would make a nearly ideal propellant combination.

The first four of these statements might have been expected to raise a few eyebrows if anybody had been listening, but nobody was, and they were received with a deafening silence. The fifth statement was of another sort entirely, and a few years earlier would have been not merely surprising, but utterly meaningless. For liquid hydrogen and liquid oxygen were new things in the world.

Starting with Michael Faraday in 1823, scientists all over Europe had been trying to convert the various common gases to liquids—cooling them, compressing them, and combining the two processes. Chlorine was the first to succumb, followed by ammonia, carbon dioxide, and many others, and by the seventies only a few recalcitrants still stubbornly resisted liquefaction. These included oxygen, hydrogen and nitrogen (fluorine had not yet been isolated and the rare gases hadn't even been discovered), and the holdouts were pessimistically called the "permanent gases."

Until 1883. In April of that year, Z. F. Wroblewski, of the University of Krakow, in Austrian Poland, announced to the French Academy that he and his colleague K. S. Olszewski had succeeded in their efforts to liquefy oxygen. Liquid nitrogen came a few days later, and liquid air within two years. By 1891 liquid oxygen was available in experimental quantities, and by 1895 Linde had developed a practical, large-scale process for making liquid air, from which liquid oxygen (and liquid nitrogen) could be obtained, simply by fractional distillation.

James Dewar (later Sir James, and the inventor of the Dewar flask and hence of the thermos bottle), of the Royal Institute in London, in 1897 liquefied fluorine, which had been isolated by Moisson only eleven years before, and reported that the density of the liquid was 1.108. This wildly (and inexplicably) erroneous value (the actual density is 1.50) was duly embalmed in the literature, and remained there, unquestioned, for almost sixty years, to the confusion of practically everybody.

The last major holdout—hydrogen—finally succumbed to his efforts, and was liquefied in May of 1898. And, as he triumphantly reported, "on the thirteenth of June, 1901, five liters of it (liquid hydrogen) were successfully conveyed through the streets of London from the laboratory of the Royal Institution to the chambers of the Royal Society!"

And only *then* could Tsiolkovsky write of space travel in a rocket propelled by liquid hydrogen and liquid oxygen. Without Wroblewski and Dewar, Tsiolkovsky would have had nothing to talk about.

In later articles, Tsiolkovsky discussed other possible rocket fuels — methane, ethylene, benzene, methyl and ethyl alcohols, turpentine, gasoline, kerosene — practically everything that would pour and burn, but he apparently never considered any oxidizer other than liquid oxygen. And although he wrote incessantly until the day of his death (1935) his rockets remained on paper. He never *did* anything about them. The man who did was Robert H. Goddard.

As early as 1909 Dr. Goddard was thinking of liquid rockets, and came to the same conclusions as had his Russian predecessor (of whom he had never heard); that liquid hydrogen and liquid oxygen would be a near-ideal combination. In 1922, when he was Professor of Physics at Clark University, he started actual experimental work on liquid rockets and their components. Liquid hydrogen at that time was practically impossible to come by, so he worked with gasoline and liquid oxygen, a combination which he used in all of his subsequent experimental work. By November 1923 he had fired a rocket motor on the test stand, and on March 16, 1926, he achieved the first flight of a liquid-propelled rocket. It flew 184 feet in 2.5 seconds. (Exactly forty years later, to the day, Armstrong and Scott were struggling desperately to bring the wildly rolling Gemini 8 under control.)

One odd aspect of Goddard's early work with gasoline and oxygen is the very low oxidizer-to-fuel ratio that he employed. For every pound of gasoline he burned, he burned about 1.3 or 1.4 pounds of oxygen, when three pounds of oxygen would have been closer to the optimum. As a result, his motors performed very poorly, and seldom achieved a specific impulse of more than 170 seconds. (The specific impulse is a measure of performance of a rocket and its propellants. It is obtained by dividing the thrust of the rocket in pounds, say, by the consumption of propellants in pounds per second. For instance, if the thrust is 200 pounds and the propellant consumption is one pound per second, the specific impulse is 200 seconds.) It seems probable that he worked off-ratio to reduce the combustion temperature and prolong the life of his hardware — that is, simply to keep his motor from burning up.

The impetus for the next generation of experimenters came in 1923, from a book by a completely unknown Transylvanian German, one Herman Oberth. The title was *Die Rakete zu den Planetenraumen*, or *The Rocket into Planetary Space*, and it became, surprisingly, something of a minor best seller. People started thinking about rockets —

practically nobody had heard of Goddard, who worked in exaggerated and unnecessary secrecy—and some of the people who thought about rockets decided to do something about them. First, they organized societies. The Verein fur Raumschiffart, or Society for Space Travel, generally known as the VfR, was the first, in June 1927. The American Interplanetary Society was founded early in 1930, the British Interplanetary Society in 1933, and two Russian groups, one in Leningrad and one in Moscow, in 1929. Then, they lectured and wrote books about rockets and interplanetary travel. Probably the most important of these was Robert Esnault-Pelterie's immensely detailed *L'Astronautique,* in 1930. And Fritz Lang made a movie about space travel—*Frau in Mond,* or *The Woman on the Moon,* and hired Oberth as technical adviser. And it was agreed that Lang and the film company (UFA) would put up the money necessary for Oberth to design and build a liquid-fueled rocket which would be fired, as a publicity stunt, on the day of the premiere of the movie.

The adventures of Oberth with the movie industry—and vice versa—are a notable contribution to the theater of the absurd (they have been described elsewhere, in hilarious detail), but they led to one interesting, if abortive, contribution to propellant technology. Foiled in his efforts to get a gasoline–oxygen rocket flying in time for the premiere of the movie (the time available was ridiculously short) Oberth designed a rocket which, he hoped, could be developed in a hurry. It consisted of a long vertical aluminum tube with several rods of carbon in the center, surrounded by liquid oxygen. The idea was that the carbon rods were to burn down from the top at the same rate as the oxygen was to be consumed, while the combustion gases were ejected through a set of nozzles at the top (forward) end of the rocket. He was never able to get it going, which was probably just as well, as it would infallibly have exploded. But—it was the first recorded design of a hybrid rocket—one with a solid fuel and a liquid oxidizer. (A "reverse" hybrid uses a solid oxidizer and a liquid fuel.)

At any rate, the premiere came off on October 15, 1929 (without rocket ascent), and the VfR (after paying a few bills) fell heir to Oberth's equipment, and could start work on their own in early 1930.

But here the story starts to get complicated. Unknown to the VfR—or to anybody else—at least three other groups were hard at work. F. A. Tsander, in Moscow, headed one of these. He was an aeronautical engineer who had written extensively—and imaginatively—on rockets and space travel, and in one of his publications had suggested that an astronaut might stretch his fuel supply by imitating Phileas Fogg. When a fuel tank was emptied, the astronaut could simply grind it up and add the powdered aluminum thus obtaining to the remaining fuel, whose heating value would be correspondingly enhanced! This updated emulation of the hero of *Around the World in Eighty Days,* who, when he ran out of coal, burned up part of his ship in order to keep the rest of it moving, not unnaturally remained on paper, and Tsander's experimental work was in a less imaginative vein. He started work in 1929, first with gasoline and gaseous air, and then, in 1931, with gasoline and liquid oxygen.

Another group was in Italy, headed by Luigi Crocco, and financed, reluctantly, by the Italian General Staff.*

Crocco started to work on liquid rockets in 1929, and by the early part of 1930 was ready for test firings. His work is notable not only for the surprising sophistication of his motor design, but above all for his propellants. He used gasoline for his fuel, which is not surprising, but for his oxidizer he broke away from oxygen, and used nitrogen tetroxide, N_2O_4. This was a big step—nitrogen tetroxide, unlike oxygen, can be stored indefinitely at room temperature—but nobody outside of his own small group heard of the work for twenty-four years! †

V. P. Glushko, another aeronautical engineer, headed the rocket group in Leningrad. He had suggested suspensions of powdered beryllium in oil or gasoline as fuels, but in his first firings in 1930, he used straight toluene. And he took the same step—independently—as had Crocco. He used nitrogen tetroxide for his oxidizer.

The VfR was completely unaware of all of this when they started work. Oberth had originally wanted to use methane as fuel, but as it was hard to come by in Berlin, their first work was with gasoline and

* The fact that the whole project was headed by a General G. A. Crocco is no coincidence. He was Luigi's father, and an Italian father is comparable to a Jewish mother.

† In a letter to *El Comercio,* of Lima, Peru, 7 October, 1927, one Pedro A. Paulet, a Peruvian chemical engineer, claimed to have experimented—in 1895–97 (!)—with a rocket motor burning gasoline and nitrogen tetroxide. If this claim has any foundation in fact, Paulet anticipated not only Goddard but even Tsiolkovsky.

However, consider these facts. Paulet claimed that his motor produced a thrust of 200 pounds, and that it fired intermittently, 300 times a minute, instead of continuously as conventional rocket motors do.

He also claimed that he did his experimental work *in* Paris.

Now, I know how much noise a 200-pound motor makes. And I know that if one were fired three hundred times a minute—the rate at which a watch ticks—it would sound like a whole battery of fully automatic 75 millimeter antiaircraft guns. Such a racket would have convinced the Parisians that the Commune had returned to take its vengeance on the Republic, and would certainly be remembered by *somebody* beside Paulet! But only Paulet remembered.

In my book, Paulet's claims are completely false, and his alleged firings never took place.

oxygen. Johannes Winkler, however, picked up the idea, and working independently of the VfR, was able to fire a liquid oxygen–liquid methane motor before the end of 1930. This work led nowhere in particular, since, as methane has a performance only slightly superior to that of gasoline, and is much harder to handle, nobody could see any point to following it up.

Much more important were the experiments of Friedrich Wilhelm Sander, a pyrotechnician by trade (he made commercial gunpowder rockets) who fired a motor early in March 1931. He was somewhat coy about his fuel, calling it merely a "carbon carrier," but Willy Ley has suggested that it may well have been a light fuel oil, or benzene, into which had been stirred considerable quantities of powdered carbon or lampblack. As a pyrotechnician, Sander would naturally think of carbon as *the* fuel, and one Hermann Noordung (the pseudonym of Captain Potocnik of the old Imperial Austrian army), the year before, had suggested a suspension of carbon in benzene as a fuel. (The idea was to increase the density of the fuel, so that smaller tanks might be used.) The important thing about Sander's work is that he introduced another oxidizer, red fuming nitric acid. (This is nitric acid containing considerable quantities—5 to 20 or so percent—of dissolved nitrogen tetroxide.) His experiments were the start of one of the main lines of propellant development.

Esnault-Pelterie, an aviation pioneer and aeronautical engineer, during 1931, worked first with gasoline and oxygen, and then with benzene and nitrogen tetroxide, being the third experimenter to come up, independently, with this oxidizer. But that was to be a repeating pattern in propellant research—half a dozen experimenters generally surface simultaneously with identical bones in their teeth! His use of benzene (as Glushko's of toluene) as a fuel is rather odd. Neither of them is any improvement on gasoline as far as performance goes, and they are both much more expensive. And then Esnault-Pelterie tried to use tetranitromethane, $C(NO_2)_4$ for his oxidizer, and promptly blew off four fingers. (This event was to prove typical of TNM work.)

Glushko in Leningrad took up where Sander had left off, and from 1932 to 1937 worked with nitric acid and kerosene, with great success. The combination is still used in the USSR. And in 1937, in spite of Esnault-Pelterie's experience, which was widely known, he successfully fired kerosene and tetranitromethane. This work, however, was not followed up.

Late in 1931 Klaus Riedel of the VfR designed a motor for a new combination, and it was fired early in 1932. It used liquid oxygen, as usual, but the fuel, conceived by Riedel and Willy Ley, was a 60–40 mixture of ethyl alchol and water. The performance was somewhat below that of gasoline, but the flame temperature was much lower, cooling was simpler, and the hardware lasted longer. This was the VfR's major contribution to propellant technology, leading in a straight line to the A-4 (or V-2) and it was its last. Wernher von Braun started work on his PhD thesis on rocket combustion phenomena at Kummersdorf-West in November 1932 under Army sponsorship, the Gestapo moved in on the rest of the VfR, and the society was dead by the end of 1933.

Dr. Eugen Sänger, at the University of Vienna, made a long series of firings during 1931 and 1932. His propellants were conventional enough—liquid (or sometimes gaseous) oxygen and a light fuel oil—but he introduced an ingenious chemical wrinkle to get his motor firing. He filled the part of his fuel line next to the motor with diethyl zinc, to act as what we now call a "hypergolic starting slug." When this was injected into the motor and hit the oxygen it ignited spontaneously, so that when the fuel oil arrived the fire was already burning nicely. He also compiled a long list, the first of many, of possible fuels, ranging from hydrogen to pure carbon, and calculated the performance of each with oxygen and with N_2O_5. (The latter, being not only unstable, but a solid to boot, has naturally never been used.) Unfortunately, in his calculations he somewhat naively assumed 100 percent thermal efficiency, which would involve either (a) an infinite chamber pressure, or (b) a zero exhaust pressure firing into a perfect vacuum, and in either case would require an infinitely long nozzle, which might involve some difficulties in fabrication. (Thermal efficiencies in a rocket usually run around 50 or 60 percent.) He also suggested that ozone might be used as an oxidizer, and as had Tsander, that powdered aluminum might be added to the fuel.

Then Luigi Crocco, in Italy, had another idea, and was able to talk the Ministry of Aviation into putting up a bit of money to try it out. The idea was that of a monopropellant. A monopropellant is a liquid which contains in itself both the fuel and the oxidizer, either as a single molecule such as methyl nitrate, CH_3NO_3 in which the oxygens can burn the carbon and the hydrogens, or as a mixture of a fuel and an oxidizer, such as a solution of benzene in N_2O_4. On paper, the idea looks attractive. You have only one fluid to inject into the chamber, which simplifies your plumbing, your mixture ratio is built in and stays where you want it, you don't have to worry about building an injector which will mix the fuel and the oxidizer properly, and things are simpler all around. *But!* Any intimate mixture of a fuel and an oxidizer is a potential explosive, and a molecule with one reducing (fuel) end and one oxidizing end, separated by a pair of firmly crossed fingers, is an invitation to disaster.

All of which Crocco knew. But with a species of courage which can be distinguished only with difficulty from certifiable lunacy, he started in 1932 on a long series of test firings with nitroglycerine (no less!) only sightly tranquilized by the addition of 30 percent of methyl alchohol. By some miracle he managed to avoid killing himself, and he extended the work to the somewhat less sensitive nitromethane, CH_3NO_2. His results were promising, but the money ran out in 1935, and nothing much came of the investigation.

Another early monopropellant investigator was Harry W. Bull, who worked on his own at the University of Syracuse. By the middle of 1932 he had used gaseous oxygen to burn gasoline, ether, kerosene, fuel oil, and alcohol. Later he tried, without success, to burn alcohol with 30 percent hydrogen peroxide (the highest strength available in the U.S. at the time), and to burn turpentine with (probably 70 percent) nitric acid. Then, in 1934 he tried a monopropellant of his own invention, which he called "Atalene," but did not otherwise identify. It exploded and put him in the hospital. Dead end.

And Helmuth Walter, at the Chemical State Institute in Berlin, in 1934 and 1935 developed a monopropellant motor which fired 80 percent hydrogen peroxide, which had only lately become available. When suitably catalyzed, or when heated, hydrogen peroxide decomposes into oxygen and superheated steam, and thus can be used as a monopropellant. This work was not made public—the Luftwaffe could see uses for it—but it was continued and led to many things in the next few years.

The last strictly prewar work that should be considered is that of Frank Malina's group at GALCIT. (Guggenheim Aeronautical Laboratories, California Institute of Technology.) In February of 1936 he planned his PhD thesis project, which was to be the development of a liquid-fueled sounding rocket. The group that was to do the job was gradually assembled, and was complete by the summer of 1937: six people, included Malina himself, John W. Parsons, the chemist of the group, Weld Arnold, who put up a little money, and Hsu Shen Tsien, who, thirty years later, was to win fame as the creator of Communist China's ballistic missiles. The benign eye of Theodore von Kármán watched over the whole.

The first thing to do was to learn how to run a liquid rocket motor, and experimental firings, with that object in view, started in October 1936. Methanol and gaseous oxygen were the propellants. But other propellants were considered, and by June 1937, Parsons had compiled lists, and calculated the performances (assuming, as had Sänger, 100 percent efficiency) of dozens of propellant combinations. In addition to Sänger's fuels, he listed various alcohols and saturated and unsaturated hydrocarbons, and such exotic items as lithium methoxide, dekaborane, lithium hydride, and aluminum triemethyl. He listed oxygen, red fuming nitric acid, and nitrogen tetroxide as oxidizers.

The next combination that the group tried then, was nitrogen tetroxide and methanol. Tests began in August 1937. But Malina, instead of working outdoors, as any sane man would have done, was so ill advised as to conduct his tests in the Mechanical Engineering building, which, on the occasion of a misfire, was filled with a mixture of methanol and N_2O_4 fumes. The latter, reacting with the oxygen and the moisture in the air, cleverly converted itself to nitric acid, which settled corrosively on all the expensive machinery in the building. Malina's popularity with the establishment suffered a vertiginous drop, he and his apparatus and his accomplices were summarily thrown out of the building, and he was thereafter known as the head of the "suicide squad." Pioneers are seldom appreciated.

But the group continued work, until July 1, 1939, when, at the instigation of General Hap Arnold, the Army Air Corps sponsored a project to develop a JATO – a rocket unit to help heavily laden planes take off from short runways.

From now on, rocket research was to be paid for by the military, and was to be classified. GALCIT had lost her virginity with Malina's first explosion. Now she had lost her amateur standing.