History of Rocketry and Astronautics

Proceedings of the Ninth, Tenth and Eleventh History Symposia of The International Academy of Astronautics

Lisbon, Portugal, 1975

Anaheim, California, U.S.A., 1976

Prague, Czechoslovakia, 1977

Frederick I. Ordway, III, Volume Editor

R. Cargill Hall, Series Editor

AAS History Series, Volume 9

A Supplement to Advances in the Astronautical Sciences

IAA History Symposia, Volume 4

AAS Publications Office
P.O. Box 28130
San Diego, California 92128

Affiliated with the American Association for the Advancement of Science
Member of the International Astronautical Federation

First Printing 1989

ISSN 0730-3564

ISBN 0-87703-309-9 (Hard Cover)
ISBN 0-87703-310-2 (Soft Cover)

Published for the American Astronautical Society
by Univelt, Inc., P.O. Box 28130, San Diego, California 92128

Printed and Bound in the U.S.A.

AAS 89-321

Chapter 22

HARRY BULL, AMERICAN ROCKET PIONEER*

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BACKGROUND

In the infancy of liquid propellant rocket technology, during the early 1930's, one technical problem perhaps stood out above all the rest. This was cooling. Rocket engines which could not be sufficiently cooled would simply burn through the chamber wall, sometimes explosively, shortly after ignition of the propellants. In brief, this heat barrier made them useless for long-duration applications. Hence, liquid rocket engines of the period were unsuitable for any practical uses despite the highly optimistic aims of the experimenters of the newly created American Interplanetary Society (1930), later more sedately called American Rocket Society (ARS). Their European counterparts, the members of the Verein für Raumschiffahrt (the VfR, founded 1927) in Germany and various Russian groups faced the same barrier and the same initial frustration. (The British Interplanetary Society (1933) was prohibited by law from experimenting.)

As early as 1923, the Rumanian-born astronautical pioneer Hermann Oberth in his *Die Rakete zu den Planetenräumen* proposed the earliest logical -- and probably inevitable -- technological solution to the cooling and combustion stability problem, a regenerative system in which one of the propellants circulates around the combustion chamber in a cooling jacket, thus cooling the motor and simultaneously preheating the fuel prior to its injection into the combustion chamber. Yet this concept does not appear to have been generally known in America even up to the 1930's. The very first modes of cooling adopted and in turn abandoned by the ARS and VfR were in fact water jackets and the like. Such methods were very inefficient.

Before reviewing these techniques, it suffices to say that it was not until the pioneering work of Harry Bull, a young engineering student of Syracuse University, that the United States' first partially regeneratively-cooled rocket motor was actually built and successfully fired. The results were subsequently published and disseminated through the ARS journal *Astronautics*.

* Presented at The Tenth IAA History of Astronautics Symposium, Anaheim, California, U.S.A., October 1976.

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Figure 1 Harry W. Bull (1909-1971), according to a portrait made a year or so before his death.

Bull went on to initiate other design ideas, though it was his partially regeneratively-cooled motor which is of special interest as it helped lead James Wyld, a later ARS member, to develop his own regenerative system. It in turn led to the stable, long-duration liquid propellant motors that would later power the Air Force Bell X-1 rocket aircraft, the Navy's Lark missile, and other significant early American rocket projects. Bull's story is all the more remarkable considering that he worked entirely independently, using his meager personal funds and the machine shops and laboratories of Syracuse University, and miles away from the heart of the American East Coast rocketry community which was then located in and around New York City. He was, nonetheless, a charter member of the ARS and also known to Robert H. Goddard, the American rocket pioneer of Worcester, Massachusetts, who at least distantly encouraged him.

Fortunately, through the generous donation of Bull's papers to the National Air and Space Museum of the Smithsonian Institution by his widow, Mrs. Bertha K.

Bull of Midland, Michigan, further details of his pioneering work and his life are now available.

Harry W. Bull was born 4 April 1909 in Syracuse, New York, the son of Horace P. Bull (who became the managing editor of the Syracuse *Post-Standard*) and Clara B. Bull. In 1928, Harry entered the L.C. Smith College of Applied Science at Syracuse University and graduated with a B.S. in mechanical engineering in 1932. In addition to mechanical engineering, he particularly excelled in chemistry and the other sciences. These abilities, coupled with his natural studiousness, resourcefulness, and energy, were to mold young Bull into an imaginative and productive rocket pioneer [1] (Figure 1).

In 1927, while still in high school, he penciled his earliest known thoughts on interplanetary travel. Although elementary by today's standards they demonstrate an early awareness of the possibilities of rocket-powered space travel and the direct influence of Dr. Robert H. Goddard. The youngster had also vaguely heard of the 1927 Exhibition of Interplanetary Machines in Moscow. Bull was compelled to write to Goddard to seek direction. Bull later recalled:

> My early interest in rockets was brought about by the vivid accounts of Dr. Goddard's experiments which newsmen claimed were aimed at sending a rocket to the Moon. My rocket goals were aimed entirely at developing a rocket that would climb to relatively high altitudes. Goddard was interested in reaching 100 miles (160 km) and I would have settled for 10 (16 km) [2].

In addition to this testimony, Bull received the first of several letters from Dr. Goddard himself on 19 March 1928. The professor, while cordial, was also characteristically noncommittal in revealing any details of his propellants to the enquiring youngster. Not to be discouraged, even by his new idol, Bull wrote:

> Prof. Goddard's great advancement in the art of rocket making need not stop me from experimenting [3].

The first experiment had been conducted in the fall of 1927 in what was then the outskirts of Syracuse. It was a very crude solid propellant rocket, 10 in. (25.4 cm), 2 in (5.08 cm) in diameter, and with a 0.38-in (9.5-mm) brass nozzle. Performance was equally modest: the rocket simply exploded after flying to a very low altitude. The novice experimenter recalled that this setback did not deter him "in the least" and that on the contrary, he embarked upon an exhaustive program, primarily static tests to determine the effectiveness of propellant combinations, both solid and liquid, as well as working towards the most efficacious rocket engine he could build. As a student of mechanical engineering at Syracuse University, his notes continue:

> I found that considerable equipment was available that would lend itself to research in the field of rocketry. During my college days and for two years after graduation I performed 829 tests. The great bulk of testing data has long since been thrown out but the little foldout insert included here and a small bundle of reports labeled 'Early Rocket Research' still remain which may be of casual interest to someone in the future [4].

Throughout these tests, which lasted from 1928 to 1933, Bull worked entirely alone. He financed his work as well as his collegiate career through a small stipend from home and through a part-time job as a photographer with the *Post-Standard* where his father also worked. Though he readily admitted that, "Not being mechanically inclined and also conservative by nature, my father was less than enthusiastic about my rocket experiments [5], nevertheless Bull persisted in his efforts.

Nonetheless, it was by means of the *Post-Standard* and its affiliated wire news services that Bull and his rockets were afforded national attention and that his dwindling financial resources required to continue his experiments were given a needed boost. Bull tersely summed up this giddy episode in his notes:

> My interest in rockets increased after I entered college. During my junior year, in the midst of the depression, money was scarce and everything I made went for tuition. To increase my earnings I decided to build a rocket sled. Money I planned [to earn] was to come from three sources: copyrighted news photos, talks to the many organizations in the city and a booklet telling how to build a sled [6].

THE ROCKET SLED

This clever, though hardly scientific scheme, had been inspired by the rocket sled, car, and plane experiments undertaken in Germany from 1928 to 1930 by the experimenter Max Valier in union with Fritz von Opel, the publicity-seeking automobile magnate. While spurned for his "stunts" by the VfR, Valier's object was dramatically to arouse public interest in the potential of the rocket. By so doing, he hoped to advance the cause of rocketry and astronautics in the long run by not only demonstrating the power of rockets, but also by attracting potential patrons who could financially help to speed the advance of the state of the art. In America, like the VfR, Dr. Goddard was also diametrically opposed to what he considered were entirely frivolous devices and always took a more sober, strictly scientific approach. He advised Bull in a letter of 16 May 1932 -- after Bull had already conducted his famous sled ride -- that:

> To begin with my most definite advice first, I frankly believe the department store 'stunt' would not advance your knowledge of rockets particularly, and would not add to your standing in the eyes of reputable scientists [7].

Goddard's rational, fatherly advice, Bull heeded, though at that point the sled stunt was already behind him. It had begun late in 1930.

About that time, following a series of unsuccessful trials with solid propellant rockets of his own manufacture, Bull visited the Rochester Fireworks Company. There, he was given a tour of the factory and some technical literature as well as powder and rocket samples by the Superintendent, Edward Klein. An attempt was then made to duplicate the Rochester rockets. Spindles and different sized rammers were lathed and welded in Syracuse University's Machinery Hall during Bull's spare time. Great difficulty was met, however, in reconstructing a rocket press such as used by the Rochester Company and which was capable of ramming in the propellant under a maximum pressure of 9 tons/in^2 (18,000 psi, or 1,265 kg/cu cm). Violent explosions often occurred, one of which ruined the young experimenter's test stand set up in the university's Hydraulics Laboratory.

Because of the stability of the firework company's ready-made rockets and the obvious inherent dangers and costs involved in constructing his own rockets for his anticipated man-carrying sled, Bull seems to have eventually opted for the commercially made units but constructed the sled himself. His mother and sister, Jane Bull, sewed the fabric. The rockets themselves appear to have been 6 lb (2.7 kg) caliber black powder skyrockets manufactured by the Rochester Fireworks Company. Without stars and sticks, the rockets were 3 in (7.62 cm) in diameter, approximately 18 in (45.72 cm) long, and produced approximately 15 lb (6.8 kg) thrust for 3 sec. Thirty-six rockets in all, eighteen on each side, powered the finished sled. Theoretically, they would produce at least 540 lb (245 kg) thrust for 3 sec if ignited simultaneously [8]. (It is noted that Max Valier similarly relied upon large commercial pyrotechnic rockets for his own sled.)

Designated the BR-1 (Bull Rocket 1), Bull's sled was an elongated streamlined teardrop-shaped fuselage, 14 ft (4.3 m) long, tapering to a point at the rear. The maximum diameter at the front, which resembled a dirigible, was about 3 ft (0.9 m) and the whole was mounted upon three steel runners, two up front and a single one in the rear. The two front runners were about 10 ft (3 m) apart and fixed, while the one at the rear was movable and connected to the single vertical rudder. Both rear rudder and runner were steered by a rudder bar in the pilot's cockpit.

The cockpit had a regulation airplane windshield and headrest that were dismountable in order to enable the pilot to get in and out. The sled thus resembled a small wingless aircraft, minus its horizontal tail surfaces. The interior framework was of white pine and spruce wood slats, band iron trussed with wire also serving as reinforcements. Over the frame was stretched glider cloth which was clear nitrate-doped and painted with aluminum (aluminum dust and dope), further adding a sleek, airplane appearance to the little craft.

The rockets were strapped by steel braces mounted on top of both of the front runners. In contrast to such Valier's rocket sleds as the Bob Rak 1, the Bull Rocket 1 was pulled rather than pushed. Bull made his own hit-wire fuses operated by three 1.5 v dry cells and activated by a six-point rheostat panel in the cockpit. The first contact on the rheostat or "control board" fired ten rockets; the second, six; the third, eight; the fourth, eight; while the remaining two were for reserve. Simultaneous ignition was therefore not contemplated and Bull estimated then an initial discharge of 18 rockets would be sufficient to get the craft under way with another ten rockets fired shortly after maximum speed had been attained. Following that, a few seconds later, the remaining eight rockets were to be ignited to enable the "boat" to complete its ride to a distance of 1,500 ft (457 m) at 20 ft/sec (6.1 m/sec). Total cost of this project was $22, of which $15 went for the rockets (some of the steel was donated by Syracuse University and Bull's helmet and goggles were loaned by a friend) [9].

An ordinary heavy ice sled served as the first test bed for the system, two of the large Rochester rockets being lashed to it and ignited in a trial on a deserted skating rink. Bull simply reported that "The sled shot across the ice for some 150 ft (45.7 m) in a straight line" and that "Photographs were taken of the trial." The BR-1 itself was then taken one night to a small lake in a cemetery for ignition tests and a week later, on 9 March 1931, the final run was made in front of the Syracuse Yacht and Country Club at South Bay on Lake Oneida [10].

The sled was to have gone on 7 March but a short circuit prevented ignition. Bull had then to re-wire the boat far into the night in readiness for another attempt on the 8th, only to face another day's postponement due to a gale. Finally, at 3:30 p.m. on 9 March, before a crowd of from 500 to 1,000 spectators, including Fox Movietone, Paramount "talking" newsreel men and other press representatives, Bull rode his BR-1 in a short but thrilling ride over mushy ice to 50 ft (15.2 m) in 2/5 sec, or 75 mph (120 km/hr) from standstill.

Slush had clogged the runners and the little sled had swerved almost as soon as the flames of the ten boosting rockets had shot out. This was despite the fact that fellow students, including Charles F. Chatfield and Andrew Pauceck, had done their best to clear the still mushy ground. As it was, they had been compelled to help push the sled prior to ignition and had not cleared back in time so that their overcoats and trousers became scorched and their eyebrows and hair singed. (Bull's sister says her brother later bought a new coat to replace one of the burnt ones.) A third helper, Henry Levine, who had clocked the run with a stopwatch and a measuring tape afterwards, confirmed the distance. Bull was elated, but not as much as he had hoped. Fifteen minutes later, he attempted another ride and then a third. Both were similar to the first run. Though all of the runs were still considered successes and seemed to prove that with clear-ice conditions the BR-1 was entirely capable of far greater distances and speeds of up to 90 or more mph (145 km /hr) [11] (Figure 2).

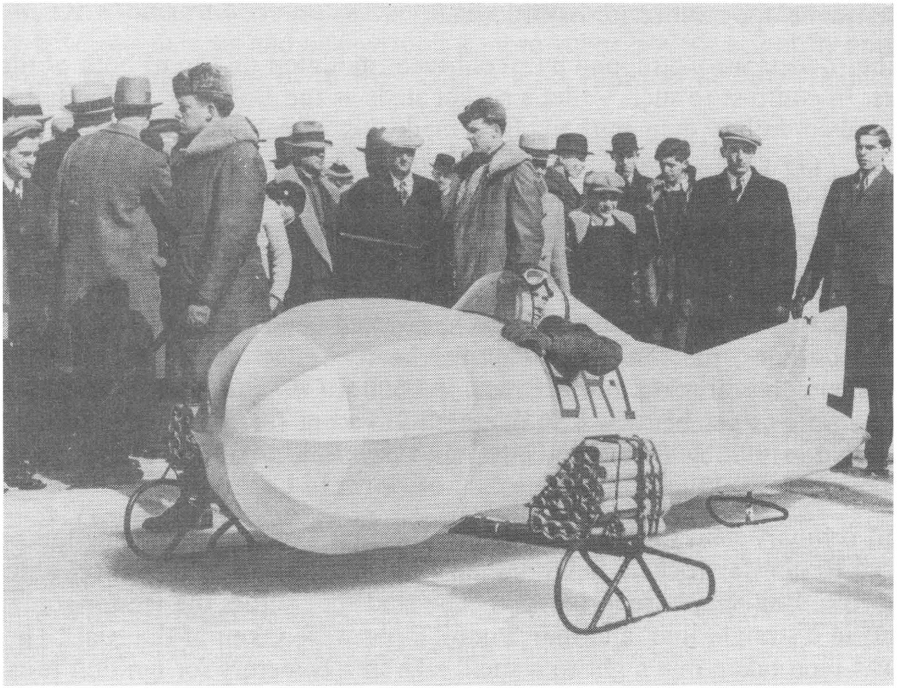

Figure 2 Bull's BR-1 rocket sled prior to test run on Lake Oneida, Syracuse, New York, on 9 March 1931.

Through the press witnesses gathered on frozen Lake Oneida that afternoon, an enormous amount of publicity on the experiment was generated around the country. Bull's notes show that he collected some 1,500 news stories, the majority of which he was later forced to discard. Generally, the BR-1 was hailed as "this country's first rocket sled" and Bull did not lose the opportunity to announce that it could lead to far profounder developments. "The ultimate aim of these experiments," he afterwards wrote in some by-lined articles, "is the development of a motor suitable to propel airplanes capable of flying in the stratosphere" and that "If, in future tests with liquid propellants, I meet with success, I will apply this new type of rocket to a small plane or glider." The promises were reminiscent of Valier's, following his own successful and similarly highly publicized rocket sled and automobile runs. Almost exactly two years previously Valier had written that, "My final aim is not the automobile, but an airship with a rocket impulse powerful enough to pierce the atmospheric armor of our globe." In both instances, the German and the American envisioned the eventual emergence of the spaceship [12].

In both cases also, these pledges were hardly braggadocio but said in full earnestness by two very dedicated pioneers. Two people who knew Bull, John W. Herrick, a fellow student at Syracuse and afterwards an engineer with Aerojet-General, and William J. Sauber, a chemical engineer who worked closely with Bull at the Dow Chemical Corporation in the 1960's, both attest to his innate modesty and absolute dedication. Herrick recalled that Bull persisted with his experiments, even after being chided by some of his classmates for setting his sights on the Moon. Sauber remembered Bull as above reproach and an exceptionally modest and highly capable man who rarely spoke much. Similarities in character might be suggested of Bull and Goddard, although insofar as the rocket work was concerned the latter was both an advanced and brilliant physicist who had considerably more resources at his disposal as well as a chosen lifetime of work [13].

AFTERMATH AND FIRST LIQUID EXPERIMENTS

Bull's originally stated goals of the sled ride were met. In addition to receiving plaudits from the public, a letter of congratulations from the Chancellor of Syracuse University, Dr. Charles W. Flint, and an average of 18 to 20 other letters daily (most of them containing bids for his services in one form or another). Bull was also able to raise needed money for his schooling and experimentation by selling copyrighted photos (though not as much if the professional news photographers had not been there, the newsmen having been called by Bull's father). One particular offer of note came from William G. Swan, a stunt pilot representing the Million-Dollar Pier in Atlantic City, New Jersey. Swan offered Bull $30 a day for 100 days if he would exhibit a rocket glider that he had proposed building. Bull was through with stunts and considered his serious experiments and university work of primary importance.

Interestingly, Swan did complete his rocket plane and on 4 June 1931, three months after Bull's rocket sled debut, apparently became the first American to fly a rocket-powered aircraft. Earlier, in May, Bull took time out to construct a miniature space rocketship model and deliver an accompanying lecture at an air show at

Luna Park, New York City. Also important to his goals -- or rather, dreams -- he began delivering lectures on rocketry and space flight to the Syracuse Technology Club and similar groups. While in New York City, he also conferred with fellow members of the American Interplanetary Society and, probably in January of 1931 met with the great French astronautical pioneer Robert Esnault-Pelterie.

Curiously, Bull also became known to the Russians. Fulfilling his plan to sell an instructional booklet on how to build the sled, Bull wrote and copyrighted a detailed and well drawn 10-page leaflet in 1933 entitled *How to Build & Run a Rocket Ship* (copyrighted by the Thermo-Reaction Company, which was in fact situated at Bull's home address). He sold 528 copies, including one to Professor Nikolai Rynin of Leningrad, the eminent Soviet space and rocket encyclopedist. Unfortunately, Bull's brochure was received after publication of Rynin's famous nine-volume *Mezhplanetnye soobshcheniya (Interplanetary Flight and Communication)*; otherwise, it doubtless would have been included therein. The booklet was also sold in Mexico, Canada, and Germany (one purchaser being Willy Ley the renowned popularizer of rockets and space) [14].

The few monies derived from the sales of the booklet and the pictures were sagaciously spent not on developing a rocket airplane immediately -- as the public had been led to believe -- but upon a more cautious path: a systematic program of seeking the most efficient fuel combination and a reliable form of rocket engine. As phrased by one contemporary newspaper some months after the sled run:

> The 22-year-old inventor, who gained national prominence through his sensational series of tests with a rocket-propelled ice boat last March on Oneida Lake, has been confining all his spare time for several months to experiments of a 'static' nature in his open air laboratory near Syracuse. Aware of the fact that several men have lost their lives in attempting to make discoveries with the rocket motor, Harry is putting emphasis on the stationary method of approach. In other words, he is forgetting the possibilities of the motor's application to fields of transportation until he has satisfied himself that the motor itself can be perfected to the best of modern scientific knowledge [15].

The paper then went on to describe his new test stand for determining the thrust of liquid fuel motors, operating temperatures, pressure differences, and the velocity of the escaping gases. While the liquid stand was his first, and indeed one of the earliest in this country*, Bull had actually conducted some crude static experiments with compressed air and gasoline when he first entered college in 1930. These comprised tests 17-34 in his series of 829. He apparently recorded the pressures of the incoming vaporized gasoline and air besides the recoil or thrust. A simple spring scale measured the latter parameter and was found to be quite small because of the low air pressure (30 psi or 2.1 kg/sq cm). Even earlier, in his high school days, perhaps in 1927, he had noted that an:

> ... apparatus for testing the recoil of different combinations of gases was constructed. Rolls of paper which were moved by clockwork recorded the duration and strength of the recoil. An electrical clutch permitted the apparatus to be operated from the next floor [16].

* Cleve Shaffer in San Francisco seems to have built an earlier though much more rudimentary test stand. For its part, the American Rocket Society did not construct any until at least 1932. Goddard, of course, predated the others.

In 1929, possibly using the same or a similar apparatus, he sought a double reaction formula:

> It seemed possible to explode two gases in two separate chambers and then permit the two exhausts to mingle and explode again. Possibilities were:
>
> $3H_2 + N_2 = 2NH_3$
>
> then combine again
>
> $O_2 + 2N_2 = 2N_2O$
>
> Simpler combinations were give[n] which included such elements as hydrogen and chlorine, hydrogen and nitrogen, oxygen and chlorine and nitrogen. Difficulty was found in igniting some of the mixtures, others exploded readily, but so little of the gases were to be had that nothing new was found out [17].

Static tests were made also on a pendulum arc stand with solid propellants including Dupont Superfine FF powder. Recoils were produced of up to 26 lb (11.8 kg). These experiments, which were to determine the most efficient relation between chamber volume and nozzle length, were reportedly "carried out very smoothly." But, it was not until 1931, after the sled run, that Bull carried out a long-term static test program of liquid research. He likewise investigated gaseous combinations, steam propulsion and other means. According to his abstracted notes:

> [A] most complete and accurate apparatus for testing rockets was next built. Valves were carefully made, steel containers turned on the lathe, pressure and recoil indicators installed, and a composite combustion chamber made which moved on roller bearings [18].

A local newspaper paraphrasing Bull's fuller report on the stand paints a more graphic description:

> All these experiments are taking place on the rocket testing stand he has built and from which he records his findings. It has the appearance of a large tube, mounted on three legs. The tube acts as a safety enclosure for the rocket combustion chamber which it surrounds. In case the chamber being tested should become overheated and explode, the tube will protect those near the stand. Bolted to the inside of the protecting tube are two rods on which the rocket chamber is free to slide. The distance the chamber moves is recorded by a pointer to which a spring is attached so that the power the motor is developing can be read from a scale above the apparatus. (3.2 mm) of the rocket chamber will cause the pointer to move three inches (7.6 cm) on the scale. In this manner the power of the different combustion chambers (and fuel combinations) can easily be measured. Mounted on the left side of the protecting tube are the fuel tanks which supply the rocket being tested. These are made of tool steel and are capable of withstanding a pressure of more than 40,000 pounds per square in (2,812 kg/sq cm) or a total pressure of 500 tons. The tank containing the liquefied oxygen is fitted with a special relief valve which maintains the fuel at any desired pressure. This is accomplished by varying the force which holds the valve down and for this purpose a tank of water is used. The oxygen is lined with glass to prevent the intensely cold fuel (actually, the oxidizer) from coming into contact with the sides of the tank. Directly below the fuel tanks are valves controlling the flow of the fuel into the combustion chamber. The valves are equipped with dials which may be read from a distance when remote control is used [19] (Figure 3).

The individual combustion chambers themselves were machined from solid blocks of 2-in. (5.1 cm) steel stock and were composed of four heavily gasketed and bolted sections. That is, they were segmented so that any of the sections could rapidly be removed without the necessity of construction an entirely new chamber. Damaged or flawed parts could easily be inspected, a microscope being used for this purpose, and modifications, replacements, or improvements could be facilitated. Bull's "composite combustion chamber" also kept experimentation expenses down. The fuel inlets were drilled in the rear, semi-spherical section, or in the forward center section, while the forward section was reamed to serve as the nozzle. It was by this modest but effective system that the inventor was able to conduct a wide and evolutionary series of combustion chamber tests that were eventually summarized by Bull at the request of the American Interplanetary Society and published in the July 1932 issue of the Society's journal *Astronautics*. Even earlier, progress of Bull's work was cited in the predecessor of *Astronautics*, the *Bulletin of the American Interplanetary Society*, for March 1932.

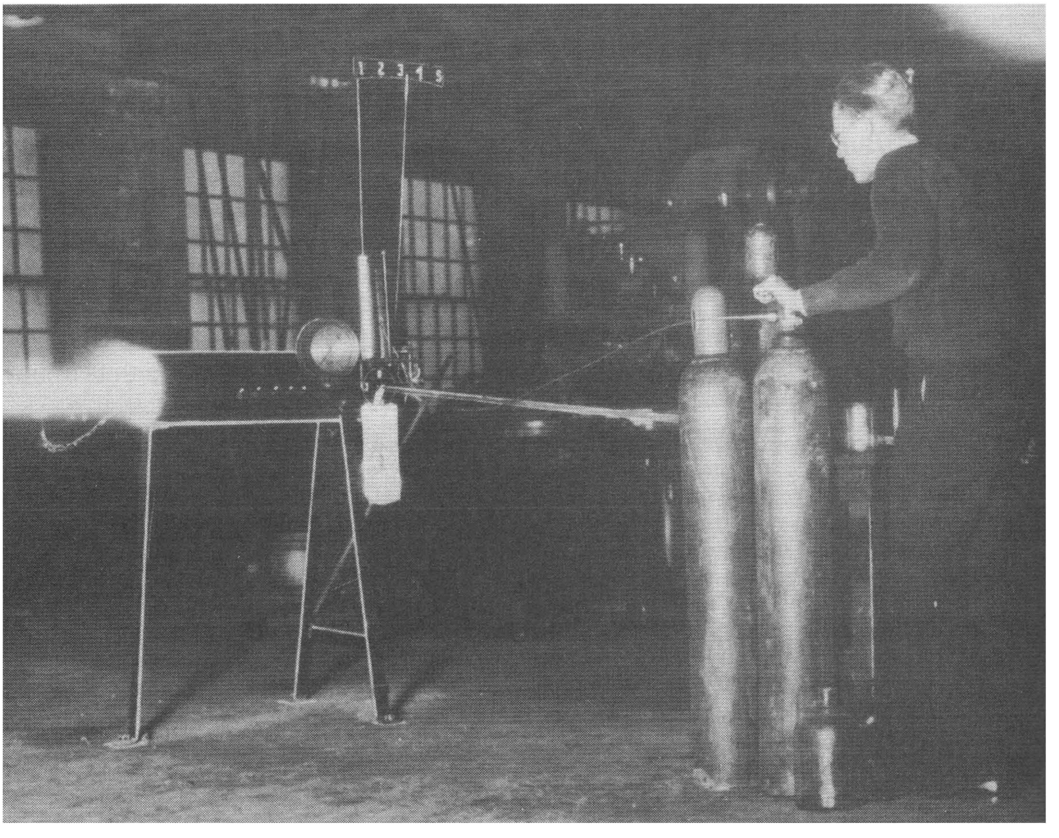

Figure 3 Bull testing liquid-propellant rocket engines on test stand bolted to the floor of the Chemistry Laboratory at Syracuse University in 1932.

Reporting on the activities of the VfR, G. Edward Pendray next turned his attention to the United States. (It is to be borne in mind that these were the days before the first ARS experiments which, at the time of writing, were only in their embryonic planning stages.) "In the meantime," wrote Pendray, "Americans have not been idle. Besides Dr. Goddard there is Harry W. Bull, of Syracuse, New York, and Cleve Shaffer, of San Francisco. Both of these men are members of the American Interplanetary Society. The results of their experiments are being made available to other members, so that there need to be no duplication." Pendray then briefly discussed the experiments of Shaffer (he conspicuously lacked data on Goddard's researches, which were unpublished) before returning to Harry Bull:

> More important still are the experiments of Mr. Bull, at Syracuse ... While the German experimenters have also made proving stand tests, those now being made by Mr. Bull will probably be the most complete ever undertaken, and when they are finished the Society will have available an extremely fine set of results upon which specifications for future rocket motors can be confidently based [20].

Bull's engine tests were based upon the American Interplanetary Society's "primary unit" (a water-cooled motor designed by the society and included chambers: (1) with different lengths and diameters, (2) with sloping and parallel walls, (3) with opposed rear fuel injection, (4) with forward spray fuel injection, (5) "chambers water and air cooled," (6) designed for vaporizing fuel, (7) with different nozzle diameters, (8) with different fuel inlet diameters, (9) using different fuels, and (10) provided with "auxiliary air cones" (i.e. thrust augmenter tubes).

In order to gauge his advancements, Bull similarly utilized the Society's "primary unit" as a standard. The usual fuel was gasoline and liquid oxygen, generally operating on a capacity of 100 cc of gasoline. The average thrust was 2 lb (0.9 kg), a very small value, but the duration of combustion was variable. "That is," wrote Bull, "the chamber which will operate for the greatest length of time on 100 cc of gasoline, while giving a recoil of two pounds, is the more efficient chamber." To illustrate this principle, he pointed out that the final chamber design produced approximately the same thrust and consumed the same quantity of fuel as the first or primary unit, but that it ran over seven times as long. Under normal conditions the first configured chamber, with water cooling, forward fuel injection and parallel chamber walls, burned for 15 sec. The final design, with four gasoline and eight oxygen injectors, and cooling fins welded to the inside and around the nozzle, lasted for some 110 sec, or almost 2 min. Thus, while Harry Bull's engine was tiny, his partially-regenerative cooling system was a significant breakthrough and showed that prolonged and safe rocket operation was now practicable [21] (Figure 4).

Though Bull concluded that this was "undoubtedly far from the ultimate goal," he recognized that "to my knowledge, it surpasses any of the rocket power units of today." It certainly was the longest duration rocket then ever fired in the U.S. and, perhaps, a link towards America's first fully regeneratively-cooled motor that was to appear just half-a-dozen years later, in 1938. James H. Wyld, the originator of this engine and one of the four founders of Reaction Motors, Inc., which later utilized the principle in the Bell X-1's 6000C4 rocket, did not fail to acknowledge Bull's contribution. Wyld rightly credited Hermann Oberth with proposing the regenerative principle in 1923 and suggested that Max Valier was close to actually testing such a system in a rocket automobile before his death in 1930.

However, two other sources conclusively proved that the regeneratively-cooled motor could work in practice, as based on experimental results. One was the article "Der Verbrennungs Raketenmotor" ("A Rocket Combustion Motor") by the Austrian rocket pioneer Eugen Sänger that appeared in the Swiss periodical *Schweizer Bauzeitung* in January 1936. In it, Sänger presented an account of a series of experiments undertaken in 1933 with small regeneratively-cooled motors burning light oil and gaseous oxygen. (Sänger's work is detailed in the paper "The Development of Regeneratively Cooled Liquid Rocket Engines in Austria and Germany, 1926-42" by Dr. Irene Sänger-Bredt and Rolf Engel.)

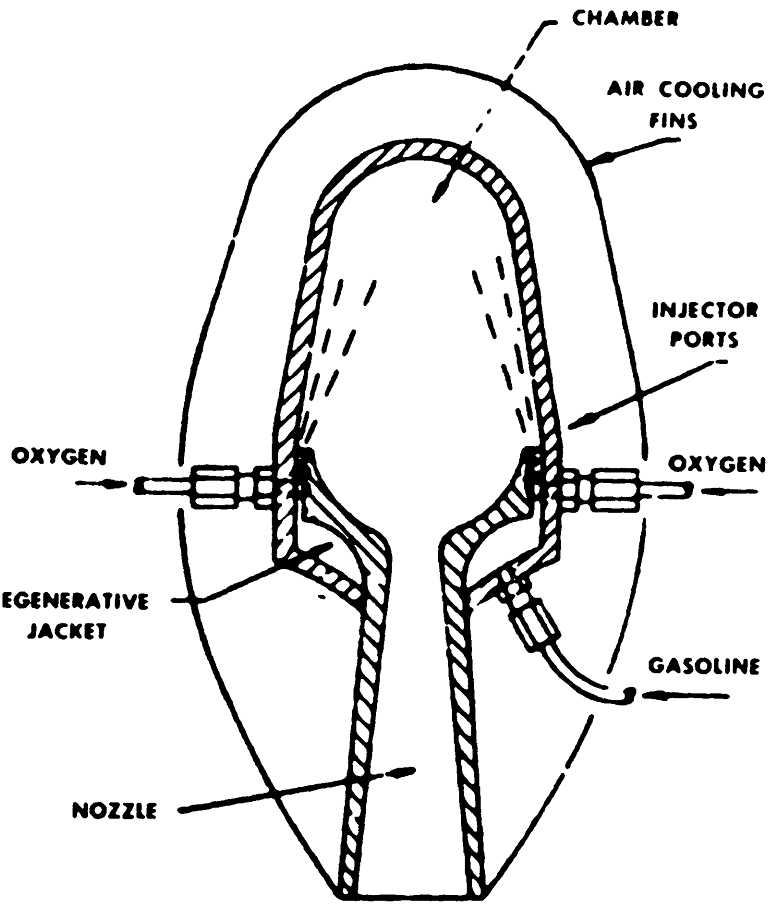

Figure 4 Diagram of partially regeneratively cooled rocket motor prepared by Harry W. Bull in 1932.

Sänger sent the article to ARS member Peter van Dresser who may have given it to Wyld, who is known to have been able to read German. In any event, the Sänger article was translated into English and appeared in *Astronautics* in October 1936 and almost certainly would have been seen by Wyld. Furthermore, Sänger's experiments also appeared in his *Raketenflugtechnik*, or *Rocket Technology*, published in 1933, which apparently was available in the U.S. by 1936 since van Dresser alludes to it in his survey article "The Rocket Motor" in the March 1936 issue of *Astronautics*. The other sources available to Wyld were various accounts of Bull's experiments made the same year Sänger undertook his work. (Van Dresser described both the Sänger and Bull experiments in his survey article.)

A year later, Wyld wrote:

The regenerative cooling jacket made its first appearance in practice (in the U.S.) in a small motor constructed in 1933 [1932] by Harry W. Bull of Syracuse, N.Y., a member of the American Rocket Society. Bull's motor was fired on gasoline and oxygen gas, and gave very promising results [22] (See Figure 5).

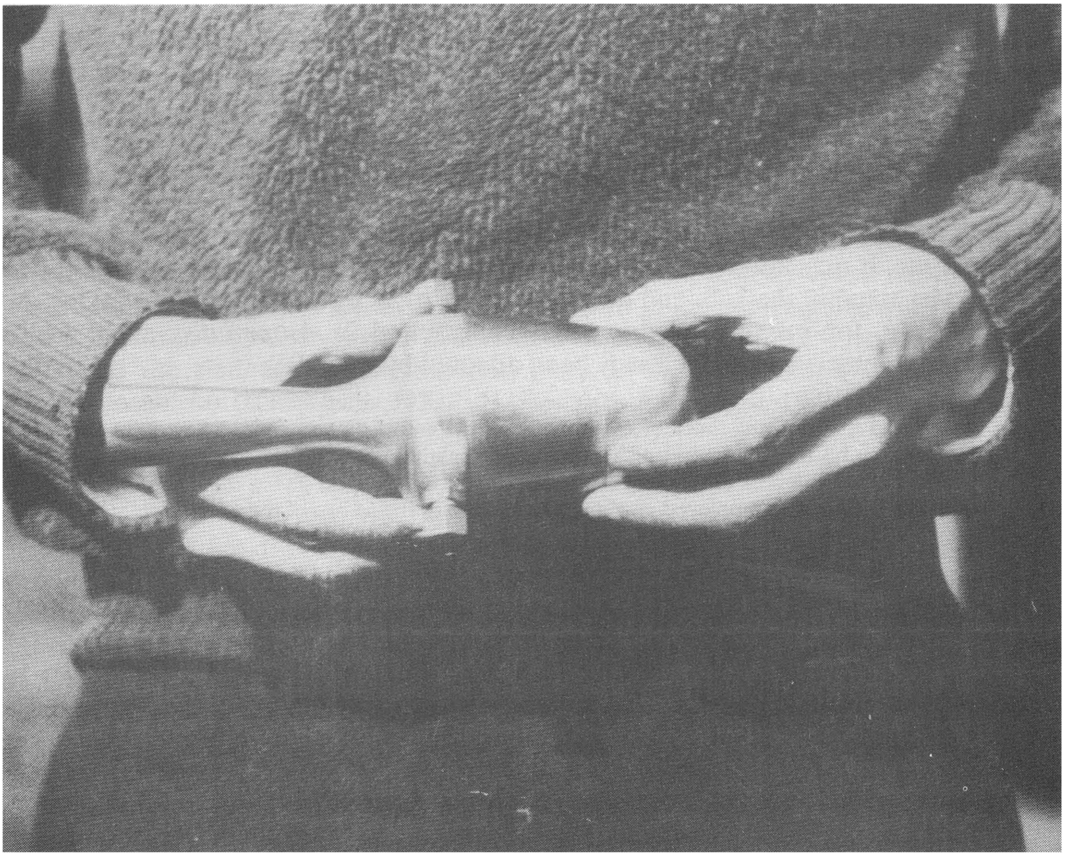

Figure 5 Bull holding partially regeneratively cooled rocket motor, 1933-34. This motor developed approximately 2 lb of thrust for up to 2 min, burning liquid oxygen and gasoline.

A search through Wyld's extant papers at the National Air and Space Museum further shows that soon after he joined the American Rocket Society in 1935, he made a thorough study of all the literature, including back issues of the society's journals, and that he was particularly struck by Bull's approach to the problem of cooling rocket motors. His own design, however, grew out of his overall survey and original thinking. He knew that some form of regenerative cooling was necessary to replace the inadequate water-jacket, refractive-lining, aluminum block and ceramic nozzle methods that were tried*. Wyld also realized, as noted in a letter of 27 April 1935 (and continued on 5 June) to G. Edward Pendray, that the main drawback of Bull's system was that it was a ground test and that "probably large tanks were used to provide gas pressure to force in the gasoline; hence the fall in pressure during the run was insignificant and was insufficient to cause an oversupply of oxygen [23]."

The only German (or Austrian) rocket designs with which Bull himself within this period was familiar were the essentially water-cooled early (1931-1932) Mirak and Repulsor types of the VfR reported in the pages of the *Bulletin of the American Interplanetary Society* and in *Astronautics*. But Bull's regeneratively-cooled configuration was distinctly different from the German and Austrian designs. In short, the American developmental story of the regeneratively-cooled rocket motor was wholly independent from that of Europe. Moreover, Harry Bull must still be accorded credit for arriving at the first workable partially-regenerative system in the U.S. as well as establishing the longest-duration running American rocket known up to that time. It may also be said that except for Goddard, he built the first complete rocket test stand in the U.S. and devised several other technological innovations. As late as 1944, for instance, Cedric Giles commented in *Astronautics* about Bull's thrust augmentor which had already been adopted by the ARS:

> After a series of combustion chamber tests, H. Bull reported in 1932 the increase in power and longer firing times of chambers having Venturi-shaped cones 15 in. [38.1 cm] in length and 3 in [7.62 cm] in diameter placed slightly in front of the nozzle. In tests of two identical chambers each using the same amount of fuel and giving the same average reaction, the Venturi employed chamber ran 110 sec to the 56 sec of the other [24].

LATER WORK -- SEARCH FOR PROPELLANTS

Other innovations followed. After his composite chamber tests in a search for a more efficient motor, Bull next concentrated on propellants. His object was to find an inexpensive liquid fuel that was likewise of maximum efficiency. This phase of his research, lasting until 1933 and comprising more than 700 individual tests, appears to have been the most exhaustive program of rocket propellant study to date (some of his tests, however, were repetitive in order to verify results). Unfortunately, Bull lacked both adequate testing apparatus and technical literature to produce any appreciable results. Nevertheless he was possibly the first to experiment with nitric acid as a rocket propellant and one of the first to try hydrogen peroxide, as well as hybrid combinations and monopropellants. This research was very broadly outlined in *Astronautics* (September 1934) and also communicated to leading chemists of the day.

In his quest for fuels, Bull posted a sort of "wanted" notice on the bulletin board of the Syracuse University Chemistry Laboratory and he corresponded with as many interested and knowledgeable individuals upon the subject as he could. For example, to Charles G. Philip, member of the British Interplanetary Society and author of one of the first popular English-language books on space flight, *Stratosphere and Rocket Flight* (1935), he wrote to enquire of the characteristics of liquid

* FY – (Goddard's film "curtain" cooling, tested in 1929, and patented in 1935 – his first cooling patent – was generally now known.)

acetylene. Bull also consulted his chemistry professors and scrutinized all the chemistry books he could find for usable data on explosives and propellants. There is also a curious note appearing in *Astronautics* for October 1932 seemingly indicating that Bull similarly exchanged his engine and propellant ideas with other universities. The essentials of this report, however, have since been found to have been misleading. According to *Astronautics*:

> A new group of rocket experimenters has been formed at Tri-State College, Agnola (Angola), Indiana. Mr. [later, Professor Walter E.] Burnham, aeronautical instructor; Professor [Raymond T.] Rousch, dean of the Mechanical Department; and John W. Herrick, aeronautical engineer are members of the group. They have already begun work on a spherical combustion chamber with a nozzle of circular section; and will try out the reaction of various hydrocarbons and nitroglycerin. The group has been in close communication with member Harry W. Bull, formerly of Syracuse University [and] have followed closely Bull's experimental experience [25].

In actuality, according to his recollections, Herrick, had simply written a letter of general inquiry to Bull soon after he had transferred from Syracuse University to Tri-State. He had been a fellow student with Bull in engineering classes. Although at the time more concerned with gliders than with rockets, Herrick had nonetheless witnessed the sled experiment and had been an early member (No. 13) of the American Rocket Society. In 1932, he wished to know how Bull was progressing and to inform him that he was then interested in forming a rocket group at Tri-State. Lack of money prevented the group from coming about, however, and no experiments were conducted [26].

When the progress of Bull's overall propellant studies eventually were made public, through his *Astronautics* survey article of September 1934, a real "mystery" did present itself. This was created by Bull's reticence in identifying his newly found ideal fuel which he called "Atalene." In his *The Coming Age of Rocket Power*, written in 1945, G. Edward Pendray sums up Bull's survey and how, after a long series of tests, he was led to discover the mysterious Atalene:

> ... Harry W. Bull, a rocket experimenter at Syracuse, New York, made one of the most elaborate series of tests on possible fuel substances ever reported. He tried high-pressure steam; then a series of liquids with low boiling points [for "vapor," or gaseous propellant rockets], including carbon disulfide, alcohol, ether, carbon tetrachloride, methyl sulfide and chlorine [as well as nitrogen tri-oxide, nitrite, ethylene oxide, methyl tetramethylene, pentane, ethyl bromide and methyl sulfide, and other substances]. 'After many explosions -- I ceased experimenting along these lines,' Bull reported in *Astronautics*. He next tried a rocket motor using solidified carbon dioxide. He found it difficult to liberate the gas rapidly enough. Next he experimented with a powder and paraffin mixture, intended to give a low exhaust temperature, but after several tests decided it was impractical. He followed this with a motor burning magnesium metal, and next developed a powder rocket having the powder arranged in sections or tubes of small diameter to prevent too rapid burning. Experiments then followed with these fuel combinations: nitroglycerin; alcohol and 30 percent hydrogen peroxide; turpentine and nitric acid; gasoline and various nitrates. Concluding his tests by developing a special monopropellant of his own (composition not revealed) which he called 'Atalene,' ... It was, as he described it, 'cheap, colorless, leaves no residue on burning, can be stored for months, [is] safe to handle and will not backfire.' For ignition, however, it required to be heated to 400 degrees Fahrenheit (204C), and this he reported to the American Rocket Society. 'Five months were spent building new designs ... Many types of fuel heaters were tried before the final plan of spraying the fuel into a magnesium flame was perfected.' 'Perfected' however was the wrong word. Shortly thereafter one of the experimental motors exploded violently, driving

a jagged section of one-inch [2.54 cm] pipe into the experimenter's leg. Fortunately it left no permanent injury [27] (See Figure 6).

Figure 6 Bull loading propellant at his rocket test stand on the outskirts of Syracuse, New York in 1933.

Admittedly, many of Bull's fuels were somewhat strange and generally low-yielding, particularly the low-boiling point liquids and the 30 percent hydrogen peroxide (the highest strength then available according to Clark). However, James Wyld could still appreciate the value of the monopropellant Atalene from the engineering point of view:

> Bull also appears to have been the first to experiment with a monopropellant liquid-fuel motor, on which full details have unfortunately never appeared. In this type of motor, which was later extensively developed in Germany for glide-bomb propulsion and jet-assisted take-offs, the fuel and oxidizer are combined in a single propellant, which is so

> arranged as to burn only in the motor combustion chamber. The obvious nature in this plan is the likelihood of a flashback from the motor to the main fuel tank. The dangerous nature of monopropellants was brought home to Bull when he was seriously injured in an explosion of his motor, and he soon afterwards dropped his experiments. The scheme has been widely worked on by others in later years but has not yet (1947) attained as high a degree of safety, efficiency, or reliability as the bipropellant type, in spite of the attractive simplicity of the idea [28].

John D. Clark, in his history of liquid rocket propellants, also acknowledges Bull as an early monopropellant investigator but credits the Italian rocketry pioneer Luigi Crocco as perhaps being the first to experiment with this form (in 1932). (Crocco's experiences along these lines are told in his own words in *Smithsonian Annals of Flight*, No. 10, pp. 44-48.) Bull would thus appear to have been the second but certainly the first in the U.S. When high strength (80 percent) hydrogen peroxide became available in Germany, Helmuth Walter at the Chemical State Institute in Berlin secretly pioneered in 1934-1935 a monopropellant system using it with potassium permanganate as a catalyst. Afterwards, his firm in Kiel successfully adapted the fuel to JATO (jet assisted take-off), the Me-163 powerplant, and other projects alluded to by Wyld.

In America, since Wyld made his statement, monopropellant technology has advanced considerably and small motors utilizing such fuels as hydrazine (usually with an iridium catalyst) have proved highly reliable, inexpensive, and lightweight thrusters for satellites and space probes. Bull's own monopropellant, the hitherto cryptic "Atalene," can now be at least partly identified from his retrieved notes. It was a solution of 60 percent perchloric acid and 40 percent hydrocarbon (carbon disulfide and ether are given as two considerations though another substance may also have been chosen for the final formula). Rather than a catalyst, Bull resorted to the magnesium flame ignition system described above. It was while in the latter stages of testing the overall system, on Sunday, 18 June 1933 (as has also been briefly related), Bull encountered a serious explosion. It was a disaster that virtually ended his rocketry career. Paradoxically, he felt so confident about the fuel that he had special stationery printed reading, "Harry W. Bull -- Atalene Explosives [sic] -- Reactions Motors -- Gravity Releases." Bertha Bull says nothing came out of this "venture" [29].

Like Goddard, Bull preferred to undertake his work undisturbed and away from the general public, on a rather wooded lot adjacent to a farm on the outskirts of Syracuse. However, the explosion had again thrust Bull into public attention. According to the Syracuse *Post-Standard* the following Monday:

> Harry W. Bull of 326 Hickock Avenue who built and demonstrated the first rocket ice boat, escaped serious injury early yesterday afternoon when a small rocket motor he was testing in a field at the end of Lancaster Avenue exploded prematurely and hurled a piece of steel into the calf of his left leg. He was taken to Crouse-Irving Hospital in a private automobile. Several stitches were taken in the wound. The young inventor went to the large field a short distance east of East Colvin Street to test the motor of a new rocket he designed and constructed in his laboratory at home. He attached a long electrical wire to the motor and then began to warm up the small power plant with a mixture of chemicals. As he started toward the switch, 100 ft [30.5 m] away, to set off the rocket, there was a loud report. A piece of steel from the tubes, the part of the cylindrical motor that ex-

ploded, imbedded itself in the calf of his leg and he fell to the ground. He was only a few feet away from the motor when the explosion occurred [30].

Bull's future wife, Bertha, who was present at the time, concludes with her own account:

I was with Harry when this accident happened. I could not drive a car at this time and so I started to run for help down the road. By the time I found someone Harry had dragged himself to the car, gotten in and was driving towards me. The man I located got in and drove us to the Crouse-Irving Hospital where Harry spent several days. He was on crutches later and had a very painful recovery but he was determined to exercise his leg, as much as it hurt, and soon was able to walk without crutches. This episode made him think that it would take a great deal of equipment and a huge sum of money to get anywhere in the rocket field. After much persuasion by me and his parents he decided to give up the dangerous pastime [31].

Harry Bull's researches and interest in rocketry, and especially his dream of flight in space, did not end as abruptly as all that. He wisely ceased experimenting, but continued to design and theorize. He was also fervent enough that he still entertained the hope of actually working with or getting assistance from Goddard, always his idol. As late as 15 October 1935, Goddard had written to Bull from Roswell, New Mexico:

I arrived in Roswell about the middle of September for another year's work [under a Florence Guggenheim Foundation grant] on the research. Although it is not on quite the scale of the previous work, it is a good opportunity, considering the present state of affairs. Sometime, when I am in the East, it may be possible to arrange matters so that I can see you, and explain the conditions under which I am working more fully [32].

Earlier, soon after he graduated from the University of Syracuse with his B.S. degree in Mechanical Engineering on 6 June 1932, Bull had inquired several times about the possibility of a teaching or laboratory assistant position with Goddard at Clark University. Goddard's responses were always cordial and expressed an interest in Bull's experiments, but could only be noncommittal on the question of employment. Following graduation, Bull did obtain a job in the field of chemistry, though far removed from rocketry. He joined Church and Dwight Co., a chemical processing concern at Solvay, New York, close to Syracuse. He remained with them for two years until the spring of 1935, when he became associated with the Tennessee Valley Authority in Chattanooga, Tennessee. There, he was engaged in aerial and topographical drafting and compilation. In 1935 also, he was married (18 May).

Bertha K. Bull recalled that prior to the move to Chattanooga, "all the rocket motors and other hardware were disposed of." Presumably this included the bulk of Harry's notes as well. While many of the details are thus unfortunately lost, a few of his latter ideas are known in a general way. During his final experimental days, for example, he contemplated hybrid rocket propulsion and appears to have conducted some preliminary tests. There was also a rather dubious "kinetic repulsor," or "entirely new reaction method" which was briefly covered in his rocket fuel survey article in the September 1934 issue of *Astronautics* as well as in *Popular Science* for January 1935. Cedric Giles, in his article "Elevators and Levitators" in the *Journal of the American Rocket Society* (December 1946), briefly sums it up as electromagnetic-powered and consisting of:

... two reciprocating weighted disks mounted on a shaft in a cylinder .. When the discs were suddenly thrown apart, by explosive or other means (electromagnetic force), the one striking a flat steel plate would give a weak force, derived from the impact, while the other disc thrown against a spring actuated a strong impulsive force. The difference in the efficacy of the two forces was about three times more force by impulse than by impact, which caused the cylinder to move forcibly in the direction of the spring [33].

A.V. Cleaver, writing in the *Journal of the British Interplanetary Society* in June 1947, properly characterizes Bull's electromagnetic-mechanical levitator as "fallacious," though the search that led him to it was undoubtedly borne out of a long-term frustration in seeking cheap and alternative fuels and propulsion means for his envisioned rocket aircraft. More valid was his well executed design of a 10 mi (16 km) sounding rocket which was to be powered with a full-scale version of his partially regeneratively-cooled rocket engine [34].

As was the fashion with many rockets of the early 1930's, such as the first ARS models and first VfR Miraks, Bull's plan placed the motor in the nose and forced in the liquid oxygen/unspecified hydrocarbon fuel into the combustion chamber by compressed nitrogen. Bull's configuration, however, had a more streamlined, aluminum body, but its unique features consisted of the partially regeneratively-cooled engine, the centrally-located payload section, the rear-mounted parachute release, and the pendulum-activated guiding rudders. Though the design was not publicized, it appears to have been communicated to the Society as James Wyld commented upon the rudder system in his letter to G. Edward Pendray of 5 June 1935: "Harry Bull has proposed stabilizing a rocket by fins operated by servo solenoids, controlled by a pendulum. This seems unnecessarily complex; servo air cylinders would be better, but I think the pendulum itself would do the trick directly." Pendray also alluded to this plan in his article "Men of Space," appearing under the pseudonym Ugo Andres in *New Outlook* for October 1934: "The injury [to Bull] was not serious ... and he is now out of the hospital, determined to continue. He has drawn plans for several types of control apparatus to guide a rocket in flight which will soon be tested out ..." The tests, of course, were never made.

Interestingly, and perhaps unknown to Bull, Goddard was thinking of a similar pendulum stabilizer about the same time and successfully proved the technique in a flight of 8 March of the same year. Though he afterwards preferred the gyroscope. Goddard was likewise testing a rear-mounted parachute arrangement, his release mechanism being more sophisticated than that of Bull's which worked by an explosive activator. Bull's remaining fragmentary notes on the sounding rocket also show that he had considered dual combustion chambers (that he felt were actually easier to cool) as well as spin-stabilization. High-pressure rotary valves and a high-pressure feed pump are also roughly sketched, as are some of the approximate dimensions of the proposed rocket: diameter, 5 in. (12.7 cm); height, 5 ft (1.52 m); fin span 16 in. (40.6 cm); and fin height, 2 ft (0.61 m). Bull's summary notes further reveal that he was on the verge of constructing this rocket as he actually built a 10-ft-high (3.04-m) launch tower of steel wire, brass tubing and aluminum turnbuckles. The stand, however, was never to be used. The accident had cut short all future testing plans [35].

With the cessation of the experiments and more especially his move to Chatanooga and the beginning of an entirely new phase in his life, Bull's active rocketry career also ceased. He stayed with the Tennessee Valley Authority until January 1937, when he joined the Dow Chemical Company at its headquarters in Midland, Michigan, the same firm he had written to four years previously for potential ingredients for his rocket propellants. Beginning as a design engineer and eventually, in 1962, becoming Director of Packaging for Dow, Bull pioneered in another field, chemical packaging. He developed equipment for the spinning of synthetic fibers, paper coating, product packaging and film coating. As such, he has been credited with a number of processes and machine patents and was the author of many technical papers on the subject.

In October 1968, Bull retired due to cancer. During his last years he again returned to his remaining rocketry notes, putting them in order, as he had said, for the interest of "someone in the future". However, according to Bertha K. Bull, even after his experiments "his interest in rockets never lessened and he followed the progress of such experiments through books, magazine articles, etc. until his death." Harry Bull died in Midland on 1 July 1971 [36].

In retrospect, Bull's studies and test work suffered from lack of funds, adequate technical direction and professional assistance as well as being remotely situated from the heart of the American rocketry community. Nevertheless, there is no question that he was naturally gifted and that the impact of his research was recognized by his peers. Provided with adequate resources and able assistants close at hand, his accomplishments would have been all the more durable.

ACKNOWLEDGEMENT

The assistance of Mrs. Bertha K. Bull of Midland, Michigan is gratefully acknowledged. All illustrations were provided by her and are published with her courtesy.

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