The Rocket Experiments of Robert H. Goddard, 1911 to 1930

By Brian R. Page

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Robert H. Goddard is properly regarded as one of the founders of rocket theory. He articulated the physics of rocketry with a long series of careful experiments. In 1926, he launched the first liquid-fuel rocket. Nevertheless, much of Goddard's contribution to rocketry is still controversial. His exacting research standards can be contrasted with his jealous protection of experimental results and his xenophobic attitude toward European researchers. Goddard actively sought acknowledgment from his financial supporters as the chief architect of modern rocket theory. Yet he failed to publish his experimental results in a timely fashion—an omission that compromises his contribution in the eyes of history.

Robert Goddard was born in 1882 in Worcester, Massachusetts. He attended Clark University in his home state, earning his M.A. in 1911 and his Ph.D. in 1912. Both degrees were in physics. After a short term as a research associate at Princeton University, Goddard returned to Clark, eventually rising to full professor.

Rocketry

Goddard's initial interest in rocketry developed while he was in high school. The interest stayed with him through his graduate days at Clark. Seeking to undertake serious rocket research, Goddard accepted a position at Princeton in May of 1912 that included only "incidental teaching responsibilities."[1] He began by working out the theoretical aspects of rocket propulsion. Illness cut short his research at Princeton, and by the time his health permitted resumption of experiments, he had obtained a position at Clark University. From 1914 to 1916, Goddard was "concerned with the measurement of efficiency of common rockets, and of steel rockets provided with nozzles, the latter experiments being repeated in part, *in vacuo*."[2]

In formulating the mathematical physics of rocketry, Goddard had to overcome popular misconceptions of Newton's third law—to every action there is always opposed an equal reaction. It was widely imagined that a rocket engine operating in a vacuum would not be able to deliver propulsive force. According to this misconception, the rocket exhaust would, in effect, be sucked out of the engine into the near perfect vacuum of space. Reactive force would be cancelled by the vacuum. The two bodies involved in the reaction were imagined to be the rocket and the vacuum rather than the rocket and its exhaust. With his vacuum-chamber experiments, Goddard conclusively demonstrated the ability of an engine to deliver propulsion in a vacuum (Fig. 1).

Fig. 1. Robert H. Goddard in 1916 with his circular vacuum chamber. The device was used to demonstrate that the efficiency of a rocket fired in a vacuum was greater than when fired in air. In use, the rocket nozzle was positioned at the top of the vertical tube. The circular portion reduced the rebound of exhaust gases. Photograph courtesy of Goddard Collection, Clark University.

By 1916, Goddard was convinced of the theoretical possibility of developing a rocket capable of carrying a useful payload to unprecedented altitude. Also, since by that time he had exhausted some $800 of his own money on these experiments, he was convinced that outside financial support was essential for further work. So in September 1916 Goddard sent a letter to the "president" of the Smithsonian Institution. The letter opened meekly: "For a number of years I have been at work upon a method of raising recording apparatus to altitudes exceeding the limit for sounding balloons."[3] For more than a page Goddard delayed stating that his device was a rocket. Finally, anticipating the objection that a rocket could not deliver propulsion in a vacuum, Goddard took the offensive: "All of the experiments *in vacuo* showed that the recoil was practically the same as that at atmospheric pressure, down to a pressure of 0.5 mm. The recoil was therefore the result of an actual jet of gas, and was not due to reaction against the air."[4] The recipient of the letter, Charles D. Walcott, turned to Charles G. Abbot, director of the Smithsonian Astrophysical Observatory, for a technical evaluation. Abbot reviewed the proposal and concluded that the theory was "probably sound."[5] Walcott then requested that Goddard submit a more detailed proposal along with cost estimates. The paper Goddard submitted was substantially the same as an unpublished paper he had written in 1914. To this earlier paper, Goddard added the tests of the rocket motors in the vacuum chamber. He also requested $5000.

Walcott next asked Abbot and Edgar Buckingham, a physicist with the Bureau of Standards, for another evaluation. Abbot reported:

> I believe the theory is sound, and the experimental work both sound and ingenious. It seems to me that the character of Mr. Goddard's work is so high that he can well be trusted to carry it on to practical operation in any way that seems best to him. I regard the scheme as worth promoting.[6]

Buckingham's conclusion was similar. Both men recommended that Goddard be granted the $5000. Walcott concurred and appointed Abbot and Buckingham as a committee to which Goddard should report, "yearly, or oftener if notable progress is made."[7]

In building hardware, Goddard's approach was, first, to increase the exhaust gas velocity as much as possible. He did this by adjusting the size of the combustion chamber to the proportion of fuel being consumed and by using a nozzle to extract propulsive force from the expanding gases once they had left the combustion chamber. Second, he sought to increase the mass of fuel relative to the total rocket mass. To accomplish this, Goddard used a chamber for combustion that was separate from the fuel chamber. Thus, the fuel container could be made extremely light, not having to withstand the pressure of combustion.[8] Third, Goddard wanted to permit rapid combustion by feeding propellants to the chamber as quickly as possible. To satisfy these design objectives, he envisioned a rocket that used powder cartridges supplied to a combustion chamber by a mechanism similar to a machine gun. Goddard's 1917 experiments exploited the principles he had patented in 1914. In this patent, he laid claim to the notion of feeding fuel to a separate chamber. The patent itself was broad in concept, covering both discontinuous feed (the machine gun) and continuous feed (liquid fuels). In 1916, Goddard still believed that a working high-altitude rocket could be developed more quickly through the use of successively fed powder charges (Fig. 2). Although liquid fuels contained more chemical energy than powder fuels and continuous feed provided greater thrust than intermittent feed, Goddard believed the difficulties in handling extremely cold fuels, such as liquid oxygen, were practically insurmountable. As a result, the majority of the first Smithsonian grant was spent developing a mechanism to deliver powder cartridges to the combustion chamber.

By 1919, three years after the Smithsonian had originally endorsed his project, Goddard had completed work that was scientifically significant. Yet he had published nothing. Goddard was finally coerced into publication by a threat from Dr.

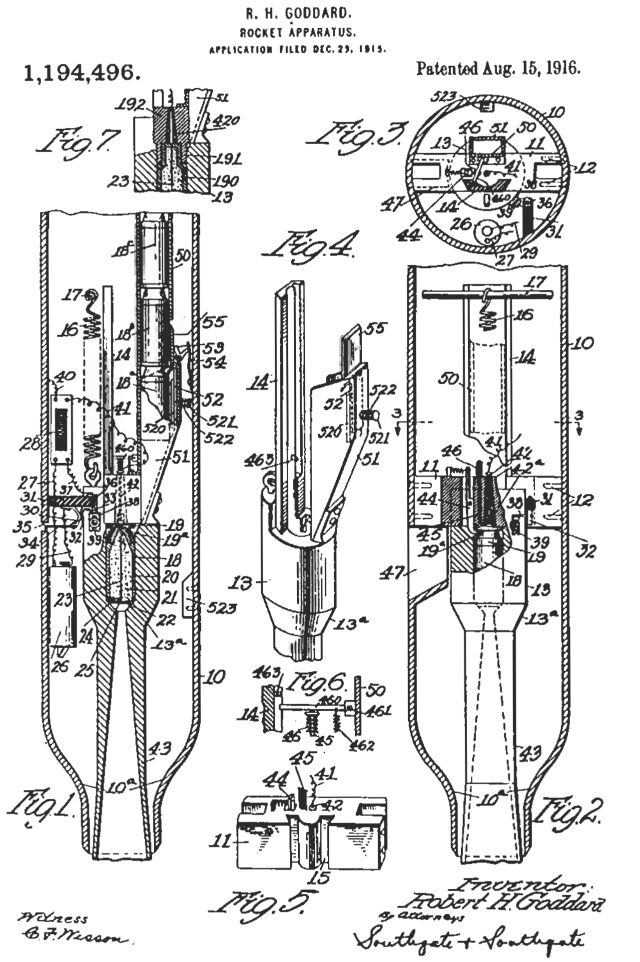

Fig. 2. Patent illustration from 1916 clearly showing the powder cartridges and loading mechanism Goddard envisioned would power his rocket. Illustration courtesy of Goddard Collection, Clark University.

Arthur G. Webster, director of Clark University's physical laboratory. Webster threatened to publish Goddard's results for him! In response, Goddard presented "A Method of Reaching Extreme Altitudes" in the *Smithsonian Miscellaneous Collections*. This article, which appeared in January 1920, was, with the exception of twenty-four footnotes, the same as that presented as a project proposal in 1916. That document, it will be remembered, was itself a revision of another prepared in 1914.

"A Method of Reaching Extreme Altitudes" set forth the basic physics of rocketry. Goddard concisely described the problems likely to be encountered and their theoretical solutions. On the practical side, Goddard was still convinced that successively fed powder charges provided the quickest method to obtain flight. Near the end of the paper, in a speculation on the future of high-altitude rocketry, he added:

> It is of interest to speculate upon the possibility of proving that such extreme altitudes had been reached.... The only reliable procedure would be to send the smallest mass of flash powder possible to the dark surface of the moon when in conjunction.... The light would then be visible in a powerful telescope.[9]

This passage brought to the attention of the press what would have otherwise been an obscure scientific document.

By the time Goddard published his views on the theoretical basis of rocketry, based on solid fuels, he was reconsidering liquid fuels. He had two reasons for the switch. First, after several years of development, his loading mechanism for the powder charges was not at all close to perfection. Second, the difficulties of obtaining and using cryogenic fuels had diminished.

In March 1920, in an unpublished "Report to Smithsonian Institution Concerning Further Developments of the Rocket Method of Investigating Space," Goddard outlined a manned interplanetary mission with an optional landing on a celestial body. In this paper, he discussed at length for the first time the use of liquid oxygen and liquid hydrogen. These liquid fuels, he noted, had the advantages of being cheaper than powder fuels and providing more energy per unit. From 1921 until 1924, Goddard experimented with liquid fuels. During this period, he achieved the first crude operating liquid-fuel rocket motor.

By 1924, the Smithsonian Institution had been associated with Goddard's research for more than eight years. Goddard still had not produced a flying rocket. Nor had he published anything beyond a slight revision of a 1914 paper. Beginning in January 1924, Charles Abbot began to pressure Goddard to make something that worked:

> ...the Institution is able to make a grant of $500 at this time, with the understanding that it is to be used for approaching a trial in the open in the most expeditious manner. In other words, the Institution feels that the chances of getting support will be excellent if a fairly successful trial in the open can be had, but that a further delay to try out some new scheme, even though it should promise to be a better scheme than that now in effect, would be apt to have a bad moral effect. If this grant makes satisfactory progress, it is not unlikely that we shall be able to give you some further support from the same source.[10]

But technical obstacles remained. In research financed by Clark University, Goddard had isolated the problems of using cold liquid fuels. He found that the combustion chamber would easily overheat from the higher energy content and the sustained combustion of liquids. Also, delivery of the fuel into the combustion chamber required more than simple pressurized tanks. Pumps had to be developed.

In March 1924, Abbot visited Goddard. He learned that the major obstacles blocking the construction of a flight-worthy rocket had been overcome. Abbot reported to Secretary Walcott that the combustion chamber was complete, ignition system reliable, and pumps working. All that remained for development were systems to drive the pumps and to control fuel flow. "There is every reason to believe," Abbot wrote, "that a successful trial of the rocket might be expected, as Dr. Goddard hopes, within the present calendar year."[11] One month after Abbot's visit, Goddard was granted another $500. The solution of the two remaining problems took longer, however, than either Goddard or Abbot expected. It was not until the end of 1925 that a rocket engine worked

Fig. 3. Robert H. Goddard posing with the first successful liquid-fuel rocket prior to its secret launch on March 16, 1926. Goddard did not notify his financial backers of the successful flight until May 5, 1926. For this rocket, fuel was delivered to the nozzle (positioned at the top) via pressurized tanks. No pumps were used. Photograph courtesy of Goddard Collection, Clark University.

successfully using the systems developed in 1924. This engine, though tested in a frame, lifted its own weight for the last ten seconds of its twenty-four second "burn."

On March 5, 1926, Goddard received from Alexander Wetmore, acting secretary of the Smithsonian Institution, a request "to keep us in constant touch with developments from now on so that we may have several preparatory stories in anticipation of the test flight and a big story on the flight itself."[12] Wetmore's desire for publicity was motivated by a Smithsonian fund-raising campaign. A few days after receiving this letter, on March 16, 1926, Goddard secretly launched the first liquid-fuel rocket. "It rose 41 ft, and went 184 ft, in 2.5 sec, after the lower half of the nozzle had burned off."[13] This rocket weighed 6 lbs empty, 10.45 lbs fueled, and was powered by liquid oxygen and gasoline. The propellants were forced into the combustion chamber by pressurized tanks, not by pumps (Fig. 3).

On April 3, again in secret, Goddard "ran a test with a rocket having four-tube bracing. It rose after some time and landed about 50 ft away, occupying 4 1/5 sec in the air."[14] The next month, on May 5, Goddard finally made a report of the flights to Abbot. He wished to keep information about the flights confidential, offering a somewhat bizarre explanation for the secrecy:

> My reason is that this rocket work is being made almost a national issue in Germany, a novel having been written, playing upon race feeling, in which Germany is urged to support the development of a German liquid-propelled rocket, which the readers are given to understand, is a German idea.[15]

By June 1926, the Smithsonian had invested $7500 in Goddard's work. Another $2500 would be made available, Abbot informed Goddard, if a successful high-altitude flight could be assured. Abbot did not mince words when informing Goddard of the terms:

> Hitherto, for the past two or three years, we have been supplying additional sums of $500 at a time with the expectation that each in succession would bring the matter to a climax. That is just what we do not wish to do any longer, but to go about the matter with a well-grounded assurance that it is going to bring it to a fruition, or else drop it right here.[16]

Goddard accepted the grant and began construction of a rocket twenty times larger than his successful preliminary vehicle. Having complained for months of the difficulties in building a small rocket (to suit his budget) he found himself unable to achieve success with a larger model. Near the end of his grant, Goddard scrapped the large rocket and assembled one only four times as large as his original model. He then appealed once again to the Smithsonian for help:

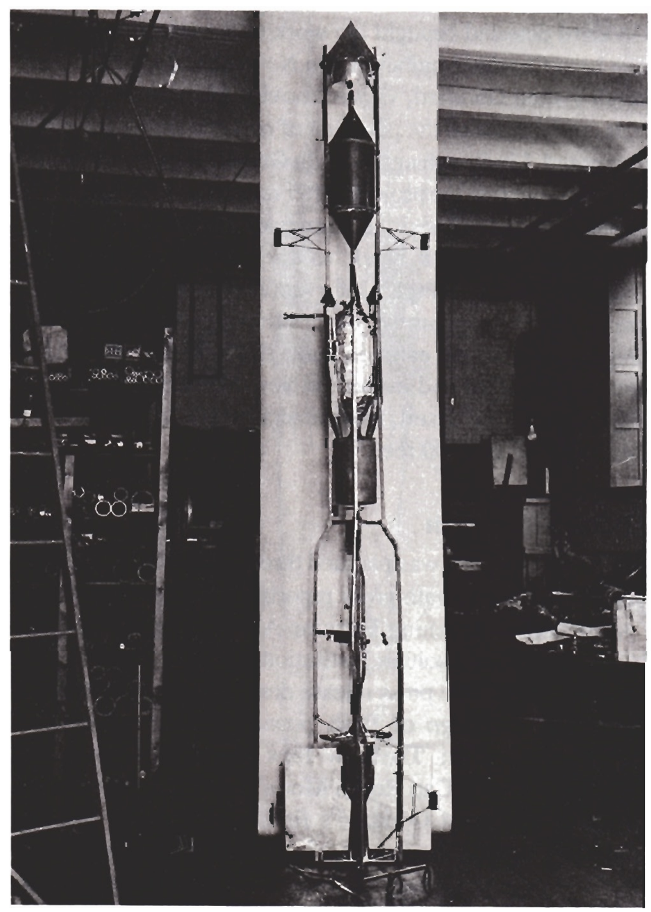

Fig. 4. Goddard's work went largely unnoticed until this rocket, launched in July 1929, attracted the attention of the newspapers. Among those to read of his work was Charles Lindbergh, who secured increased funding for Goddard. Photograph courtesy of Goddard Collection, Clark University.

> I had hoped and expected to see it completed before this, and am greatly disappointed because it has not been possible to do so. I would deeply appreciate any suggestion you may care to make in this matter, and in case the Institution does not wish to do anything further with the work, I would be grateful for a suggestion as to what body or individual would be likely to make a demonstration possible.[17]

Abbot sent Goddard another $500.

Charles Abbot became Secretary of the Smithsonian Institution, succeeding Charles Walcott, in February 1928. The Smithsonian continued its support of Goddard through 1929 and was rewarded with several more flights. The most important flight, though certainly not considered so at the time, was that which took place in July 1929. The rocket, which was 11 ft, 6 in long, reached an altitude of about 90 ft (Fig. 4). The noise of the rocket plus its 20-ft exhaust flame attracted considerable attention. The *New York Times* reported that "the noise was such that scores of residents called Police Headquarters, saying that an airplane was shooting along afire. Two police ambulances scoured the section looking for victims...."[18]

Goddard did not welcome the publicity. "I planned to make no statement whatever, but when I learned that all the reports featured solely a rocket to the moon exploding in midair, I issued a short statement."[19] The publicity that Goddard detested brought his work to the attention of aviation hero Charles Lindbergh. On November 23, 1929, Lindbergh visited Goddard, viewed movies of some of the flight tests, and discussed the potential of rockets. Being favorably impressed, Lindbergh agreed with Goddard that more money should be put into the project. After unsuccessfully approaching Henry du Pont and the Carnegie Institution, Lindbergh brought Goddard's work to the attention of Daniel Guggenheim. Lindbergh's intervention resulted in a $50,000 grant plus the promise of continuing support.[20] The Guggenheim award came in June 1930. By the end of December, Goddard had moved to New Mexico, set up a machine shop in the desert, fabricated a rocket, and launched it to an altitude of 2000 feet.

Public Reception

Robert Goddard was plagued throughout his life by exaggerated and inaccurate press reports about his work. When "A Method of Reaching Extreme Altitudes" was published in 1920, the Smithsonian Institution released a short public announcement. The press release described the possibility of detonating a charge of flash powder on the moon. This created a sensation. The *New York Times*, in a story titled "Believes Rocket Can Reach Moon" correctly related most of the essentials of Goddard's findings. The story did not, however, include the results of the vacuum-chamber tests. The next day, on January 13, 1920, a *Times* editorial, reflecting a common misunderstanding of Newton's third law, delivered a stinging criticism of Goddard:

> That Professor Goddard, with his "chair" in Clark College and the countenancing of the Smithsonian Institution, does not know the relation of action to reaction, and of the need to have something better than a vacuum against which to react—to say that would be absurd. Of course he only seems to lack the knowledge ladled out daily in high schools.[21]

In May 1924, the *New York Times* printed a half-page interview with Goddard, around which the writer built an adventure story:

> ...let us take a mental glimpse.... The men get aboard, shake hands all around, enclose their glass cabin a last time and wave farewells. The rocket is touched off, perhaps by concussion, perhaps by some other method, such as we use in starting an automobile. Then comes the critical moment—away, up rises the rocket.

The writer did admit that "conjecture about the car and the men is far from Goddard's thoughts at this moment, of course."[22] After nearly every newspaper article, the Smithsonian Institution and Goddard himself received letters from persons volunteering to go to the moon.

The publicity was not limited, of course, to the *New York Times*. The London *Times* printed a small story that correctly presented, for example, the importance of increasing the exhaust gas velocity for a successful rocket. The story also included Goddard's estimate of rocket motors reaching an efficiency of sixty-four percent.[23] Goddard received letters from volunteer astronauts as far away as Italy and the Philippines, who wrote that they had seen stories in their local newspapers. Publicity was certainly widespread, if not entirely accurate.

Question of Priority

The matter of priority in the development of rocket theory has been a subject of continued debate. While Goddard was working in the United States, several German engineers were attempting to build rockets. Willy Ley, a noted German author and experimenter, has stated that Goddard's first Smithsonian publication "remained virtually unknown" in Europe.[24] Ley neglects to consider that a number of European newspapers printed stories about Goddard. Also, the leading British science magazine, *Nature*, published an abstract, complete with photographs, of "A Method of Reaching Extreme Altitudes."[25] In addition, copies of the original publication were deposited in European libraries.

The most controversial bit of evidence involves Rumanian mathematics and physics student Hermann Oberth. Writing from Germany, Oberth requested a copy of the Smithsonian publication directly from Goddard. In a letter dated June 8, 1922, Oberth acknowledged that Goddard's publication had been received and that the work would be mentioned in an appendix to a book that Oberth himself was about to publish.[26] Also, prior to Oberth's communication with Goddard, a Frenchman, Robert Esnault-Pelterie, asked and received Goddard's permission to present descriptions of the experiments and theory in a lecture before the Société Astronomique de France. Both Oberth and Esnault-Pelterie published works that Goddard thought "followed rather closely" his "A Method of Reaching Extreme Altitudes."[27]

When Oberth published *Die Rakete Zu Den Planetenraumen* in 1923, Goddard wrote to Charles Walcott that he was not surprised that Germany had awakened "to the importance and the development possibilities" of rockets.[28] He described Oberth's book as a

> ...well written and comprehensive paper, which sets forth the general method as his own (as he claims to have been working independently), and which supposedly demonstrates that what I have been working upon cannot be developed for the ultimate uses for which his device can be applied.[29]

What Oberth questioned was the ability of a machine-gun apparatus to deliver a regular flow of fuel to the combustion chamber. As promised, Oberth summarized Goddard's work in an appendix. He acknowledged Goddard's experimental results but noted "certainly Goddard's principle [the machine-gun rocket] has no development possibilities...." Later, Oberth added: "That I have proceeded completely independently of Goddard everyone will immediately understand who has compared both of these works."[30]

With the appearance of Oberth's book, Goddard sought to establish his own claim to priority. The claim was based on two documents: the 1914 patent covering the successive feeding of propellants to a separate combustion chamber and a footnote to "A Method of Reaching Extreme Altitudes." Goddard stated his position in reports to the trustees of Clark University. The 1914 patent called the plan of supplying several cartridges to a combustion chamber a "multiple-charge" system. "It should be particularly understood," Goddard wrote to the trustees, "that the successive portions may be liquid oxidizing agent and liquid combustible, as well as solid explosive."[31] Applying a liberal interpretation, he went on to explain that liquid fuels could be used "to illustrate the general so-called 'multiple-charge' rocket principle."[32]

Goddard claimed that Oberth had adopted the fundamental concepts of rocketry from reading "A Method of Reaching Extreme Altitudes." In that publication, liquid fuels had indeed been discussed, but only in a single footnote. Goddard had stated:

> Attention is called to the fact that hydrogen and oxygen, combining in atomic proportions, afford the greatest heat per unit mass of all chemical transformations.... Incidentally, except for difficulties of application, the use of hydrogen and oxygen would have several other advantages.[33]

Goddard's main problem was that he had priority over Oberth in fact but not in spirit. Goddard had indeed considered the use of liquid fuels as early as 1909; but he considered them only in passing. The three sentences in the footnote are just barely enough to claim priority. Oberth, on the other hand, concentrated solely upon the application of liquid fuels. His *Die Rakete Zu Den Planetenraumen* is an essentially complete and modern theoretical evaluation of rocketry

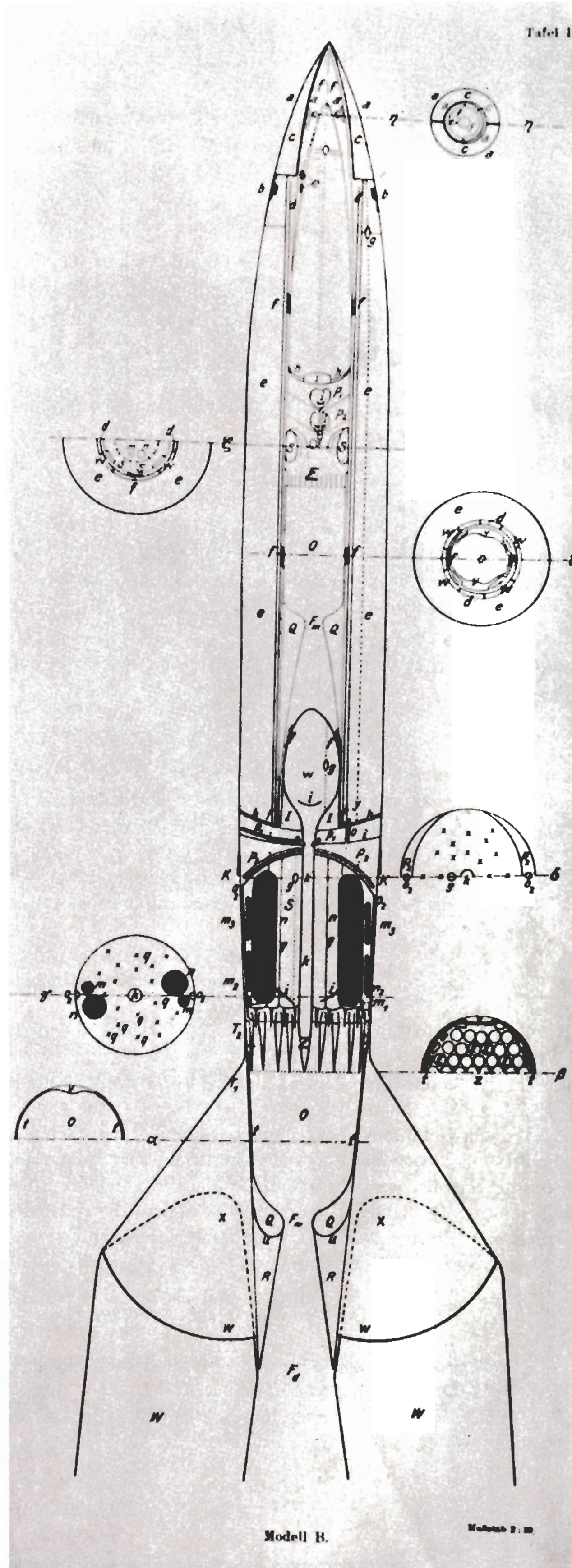

Fig. 5. (At right) Illustration from Hermann Oberth's 1923 publication showing his *modell B* liquid-fuel rocket. Contrast this with Goddard's 1916 patent illustration.

(Fig. 5). This fact is what Goddard resented. Even in 1923, after working for two years with liquid fuels, Goddard's only published account essentially described the powder technology of 1914.

Had Goddard regularly published information about his current state of research, there would be little question of priority. Almost from the beginning of the work supported by the Smithsonian, his technological development vastly exceeded his published account. Goddard's compulsion for secrecy deprived him not only of the full acclaim usually bestowed on a discoverer but also of something more historically important: lasting personal influence on the development of rocket technology. In biological terms, his work might be termed an evolutionary dead end. For even though Goddard set a high benchmark in both theory and experimentation, the more open and collaborative approach of Hermann Oberth nurtured the line of development that eventually resulted in modern rocketry. Oberth collaborated with the young Wernher von Braun, who later led development of the Nazi V2 ballistic missile. Following World War II, von Braun's team developed rockets for the United States Army and, later, the National Aeronautics and Space Administration (NASA). In doing so, the immigrants continued Oberth's intellectual heritage, not that of Goddard, in their adopted country.

References

1. "W.F. Magie to R.H. Goddard," June 8, 1912, in *The Papers of Robert H. Goddard*, Vol. I, edited by Esther C. Goddard and G. Edward Pendray (McGraw-Hill, New York, 1970), p. 111. Hereafter cited as *Goddard Papers*.
2. "Material for an Autobiography," *Goddard Papers,* **I**:22.
3. "R.H. Goddard to President, Smithsonian Institution," Sept. 27, 1916, *Goddard Papers,* **I**:170.
4. *Ibid.*, p. 174.
5. "C.G. Abbot to C.D. Walcott, Secretary, Smithsonian Institution," Oct. 2, 1916, *Goddard Papers,* **I**:175.
6. "C.G. Abbot to C.D. Walcott," Dec. 18, 1916, *Goddard Papers,* **I**:181.
7. "C.D. Walcott to R.H. Goddard," Jan. 5, 1917, *Goddard Papers,* **I**:190.
8. In contrast, traditional rockets, such as fireworks, burn their fuel in its storage container. As the fuel burns, the size of the combustion chamber increases, while the surface area of burning fuel increases only slightly. The net result is a decrease in chamber pressure with a resultant drop in the velocity of exhaust gas.
9. "A Method of Reaching Extreme Altitudes," *Goddard Papers,* **I**:393.
10. "C.G. Abbot to R.H. Goddard," Jan. 21, 1924, *Goddard Papers,* **I**:524-525.
11. "Summary of the Present State of the Goddard Rocket by C.G. Abbot," Mar. 25, 1924, *Goddard Papers,* **I**:542.
12. "A. Wetmore, Acting Secretary, Smithsonian Institution to R.H. Goddard," Mar. 5, 1926, *Goddard Papers,* **II**:578-579.
13. "Diary," Mar. 16, 1926, *Goddard Papers,* **II**:580.
14. "Diary," April 3, 1926, *Goddard Papers,* **II**:584.
15. "R.H. Goddard to C.G. Abbot," May 5, 1926, *Goddard Papers,* **II**: 590.
16. "C.G. Abbot to R.H. Goddard," June 24, 1926, *Goddard Papers,* **II**:596.
17. "R.H. Goddard to C.G. Abbot," Dec. 7, 1927, *Goddard Papers,* **II**:628.
18. "Meteor-Like Rocket Startles Worcester," *New York Times*, July 18, 1929, p. 2:4.
19. "Description of Flight of July 17, 1929," *Goddard Papers,* **II**:671.
20. "Daniel Guggenheim to Wallace W. Atwood," June 12, 1930, *Goddard Papers,* **II**:744.
21. "A Severe Strain on Credulity," *New York Times*, Jan. 13, 1920, p. 12:5.
22. "Hopes to Reach Moon with a Giant Rocket," *New York Times*, May 25, 1924, p. XX, 4:1.
23. "A Rocket to the Moon," *Times* (London), Jan. 13, 1920, p. 11b.
24. Willy Ley, *Rockets, Missiles, and Men in Space* (Viking, New York, 1968), p. 100.
25. Robert H. Goddard, "A method of reaching extreme altitudes," *Nature,* **105** (2652), 809 (Aug. 26, 1920).
26. The debate over priority between Oberth and Goddard is a relative affair. Both men were preceded by the Russian, Konstantin Tsiolkovsky, who published a strictly theoretical work on rocketry in 1903. However, since Tsiolkovsky's work was unknown at the time and had little impact on the subsequent development of technology, the debate continues.
27. "Material for an Autobiography," *Goddard Papers,* **I**:24.
28. "R.H. Goddard to Secretary, Smithsonian Institution," Aug. 1, 1923, *Goddard Papers,* **I**:498.
29. *Ibid.*, p. 497.
30. Hermann Oberth, *Die Rakete Zu Den Planetenraumen* (R. Oldenbourg, Munchen, 1923), pp. 90-92.
31. "Report to the Trustees, Clark University, on the Principles and Possibilities of the Rocket Developed by R.H. Goddard," Aug. 1, 1923, *Goddard Papers,* **I**:509.
32. "Supplementary Report to the Trustees, Clark University, on Work Performed July 1921 to August 1923," Aug. 1, 1923, *Goddard Papers,* **I**:498.
33. "A Method of Reaching Extreme Altitudes," *Goddard Papers,* **I**:404.

Additional Reading

Milton Lehman. *This High Man: The Life of Robert H. Goddard.* New York: Farrar, Straus, 1963.

Frederick I. Ordway III and Mitchel R. Sharpe. *The Rocket Team.* New York: Thomas Y. Crowell, 1979.

The Papers of Robert H. Goddard. Edited by Esther C. Goddard and G. Edward Pendray. New York: McGraw-Hill, 1970.

Wernher von Braun and F.I. Ordway III. *History of Rocketry and Space Travel.* New York: Thomas Y. Crowell, 1975.