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Chapter 14

THE CONSTRUCTION OF A REPLICA OF ROBERT H. GODDARD'S FIRST SUCCESSFUL LIQUID-PROPELLANT ROCKET*

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In 1985, following the Science Museum's decision to prepare a major new gallery dealing with the exploration of space, a number of items of hardware were selected for modeling or full-size replication. Among the initial requirements was a full-size replica of Robert Goddard's first successful liquid propellant rocket as launched on March 16th 1926 at Auburn, Massachusetts.

The Science Museum is not entirely self reliant for the manufacture of replicas or models, and much excellent work has been provided from external sources. Nevertheless some curators have a marked preference for key items to be manufactured in the museum's own workshops, and in this case, as it appeared that a reasonable amount of support information had already been assembled early on in the project, in house manufacture was decided upon. The museum's facilities must be among the finest available for this sort of work, and the technicians employed enjoy a deserved reputation for superlative skills and dedication.

RESEARCH FOR REPLICAS

There is usually quite a difference between normal museum research and that for replica construction purposes. Irrespective of the significance of the individual components of a replica, all visible parts are required to look as authentic as possible to achieve a convincing effect. There is also the responsibility to the viewing public, who, reasonably enough, tend to accept as the literal truth all that is presented to them. It is this requirement for infinitesimal detail which can be difficult to satisfy, and in the eleven years the author has been involved in this type of work, there have been many occasions when the information provided has been inadequate and, more unfortunately, difficult to amplify or extend. This, surprisingly, holds good with respect to items from recent history, as well as those of many years ago.

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As far as the history of Space Technology is concerned, this sort of problem was first brought home to the author when the Museum was preparing its "Exploration" exhibition in 1975. For this project a range of finely detailed models of items of space technology such as Surveyor, Ranger, Mariner, and Pioneer, and replicas of *Apollo 11*'s experimental lunar surface packages, were required. During the gathering of the technical data for that program, it seemed to be almost as difficult to find out, for example, what was on the reverse side of Surveyor's solar panels, as it had once been to discover the appearance of the other side of the Moon!

INITIAL BRIEFING

Three items of information were provided by the commissioning curator and were as follows:

1. The frequently published photograph, Figure 1, of Dr. Goddard standing alongside his rocket in its launching frame, amid the snows of New England.
2. "How it worked," a two-page leaflet published by the Goddard Space Flight Center, which deals with the basic principles of the rocket and the launch procedure.
3. A one-sheet drawing, marked as produced for the Smithsonian Institution, giving dimensions and other details of the rocket and launch frame. This was drawn by Kenneth B. Seamon of Worcester, Massachusetts, and dated June 1966.

Figure 1 "Rocket ready for test."

We were also aware that the National Air and Space Museum (NASM), Washington, D.C., along with other American museums and institutions, had full-size replicas of the rocket on display to the public. By a fortunate coincidence a Science Museum colleague, Alan Morton, was currently working on a research project in Washington, and he was asked to take photographs and note some particular constructional details of this NASM replica.

Another source of information readily available was the three-volume set of "The Papers of Robert Goddard," a publication co-edited by Edward Pendray and Goddard's widow, Esther. These volumes cover in broad detail much of Goddard's work and contain a number of brief extracts from his diary. A copy of the transcript of this diary, as typed out by Mrs. Goddard, and which covered the period from January 1st, 1925 to April 11th, 1926 was requested from Frank Winter of NASM, who later was very helpful in dealing with a number of our more detailed questions.

OUTLINE DESCRIPTION OF THE ROCKET

The first successful liquid propellant rocket was a frail yet functional craft incorporating three main units supported in line by interconnecting pipework and tensioning wire. The following description covers the rocket as we understood it to be at the start of our project.

The Rocket Motor

Unusually by today's conventions the motor was the leading unit and comprised a cylindrical combustion chamber with a domed cap and a tapered exhaust nozzle. The match head/black powder ignition system (activated by a blow-lamp on a pole) and the two fuel input lines, complete with their associated flow-rate control valves, were individually mounted to the cap.

The Oxygen Unit

This unit was centrally positioned, some three feet below the nozzle to minimize the effects of the exhaust and was made up of a pressure tight cylindrical chamber enclosing an open ended liquid oxygen container. All control valves and pipe terminations, together with a spring-loaded mechanism controlling an inner needle valve, were mounted on the top of the cylinder and protected by an asbestos covered conical blast deflector and a short aluminum sleeve. The needle valve, which seated on a hole in the base of the inner container, was released immediately before launch, thereby permitting drops of liquid oxygen to fall on the base of the outer cylinder, which was externally heated by a small alcohol burner. This vaporization feature was devised to assist in the generation of internal pressure necessary for the in-flight fuel feed system.

The Petrol Tank

This cylindrical pressure tight unit, somewhat smaller than the oxygen unit, was situated at the tail of the rocket. Pressurized oxygen was piped to the top of the tank, the fuel outlet being at the bottom. A float sealed the outlet when all the petrol had been expelled. A filler entry with screw cap was located at the top of the tank.

The Structure

There was no framework as such, the interconnecting pipework also serving this purpose. The oxygen pressure line, its free end terminated by a one-way valve, ran from a point just below to a point just above the petrol tank where it branched. One line entered the tank, the other continued and entered the top of the oxygen unit. Pressurized petrol and liquid oxygen were fed from their respective tanks to the domed head of the combustion chamber by diametrically opposed pipes. These pipes were tied together by two tubular cross members, the upper one of which gave additional central support to the exhaust nozzle. Where the pipes were exposed to the effects of the exhaust, they were lagged with asbestos tape held in place with wire binding. At the rocket base a tensioned bracing wire was provided, diametrically opposite to the pressure line, with one anchor point at the base of the petrol tank and the other at the base of the oxygen unit. Apart from the conical deflector and short tubular sleeve there was no cladding.

Launch Stand

For launch purposes the rocket assembly was supported in a free standing, demountable tubular frame. The pre-launch fuel feed pressure was supplied at 90 psi from a separate oxygen cylinder through a heavy duty flexible hose connected to the one way valve at the base of the rocket. This hose also did duty as a tether during the build up of thrust. The needle valve and hose releases were operated one after the other by means of cords attached to a vertical rod, which was attached and pivoted at the base of the stand and pulled away immediately before launch by means of a rope. There was also a free-standing blast deflector/shelter to one side of the frame, part of which can be seen to the right hand side of Figure 2.

SECONDARY RESEARCH

The eagerly awaited diary transcript, construction details and photographs of the NASM replica were less helpful than anticipated, and more seriously made it clear that there were significant differences between our sources of information. To summarize:

We were now reasonably sure that the photograph, Figure 1, of Goddard beside the rocket, was taken a few days before the launch, probably on March 6th, and was a posed shot with the rocket inexplicably wrongly positioned in the launch frame. It is shown 180° axially out of position, which would have prevented it from being launched by the method described in the "How it worked" leaflet.

The replica at NASM was similarly wrongly positioned.

Some details of the launch shown in Figure 1, differed from the NASM replica.

The replica had short cylindrical components in the fuel feed lines between the needle valves and the combustion chamber, which were not shown on the Seamon drawing. The photograph was too indistinct in this area to be of help.

The nozzle was shown on the Seamon drawing, and could be seen on the replica as being made of aluminum. The diary did not mention the nozzle material, but did refer, on February 15th, 1926, to the welding of a steel ring to the end of the nozzle. We couldn't see the reason for the ring, nor how steel could be welded to aluminum.

The replica did not feature the alcohol burner, and it was only shown in outline on the drawing, again the photograph was of no help.

Many dimensions were missing from the drawing, in particular the overall length was not given, nor was it possible to calculate it from other dimensions. It could be scaled, but not very reliably.

There were a welter of comments in the diary which required study and interpretation. Dr. Goddard was conducting his work on the rocket simultaneously with student supervision duties at Clarke University, and the most notable aspects of this work were recorded in the diary, a small pocket one, together with items of domestic interest. The following entry for June 26th, 1925 is a typically mixed one:

> S finished pump. Made drawing on article in a.m. Had nozzle (5-1/4 lbs) welded on chamber (4-3/4 lbs) and made a bird bath in p.m. Sat on piazza in eve. S worked on lower pump valve in eve.

Figure 2 "The empty frame."

We had an illustration, Figure 2., of Goddard standing by the empty launch frame gazing skywards (Pendray and Goddard, 1970, page 590). This picture is captioned "The empty frame" and is described as an enlargement from a frame of a film taken by Mrs. Goddard. Apparently the film ran out at the critical moment of launch. What was interesting about this photograph, apart from the fact that the launch frame differed in some minor details from the other photograph, Figure 1, was the appearance of two triangular shaped pieces at the very top of the frame. A copy of this film was requested from NASM and the meaning of the diary entry of March 15th, 1926, ". . . had sheet metal braces fitted," was speculated on.

THE SEAMON DRAWING

For construction purposes this drawing should of course have been our most useful source of information, but its promise had been short lived. In the first place it did not even attempt to record any of the internal details, and furthermore, significant dimensions were missing. What was worse, as our information accumulated it was seen to be deficient in many of the external details and dimensions, as well as being extremely misleading on the matter of the materials of construction.

Nevertheless it represented our most detailed source, and it seemed worth while to find out more about its background. Although nothing definite could be established, our contact at NASM reported that another set of drawings had been heard of, but attempts to track them down had failed. Fortunately at this juncture, Dr. Becklake, the curator of the Museum's Space Technology collection was about to visit the U.S.A. and was requested to obtain a set if at all possible. He also undertook to see if any more helpful information might be available.

CERAMIC LINING

During early examination of the diary transcript, it had been noted that there were several references to a material described as Alundum. Being advised initially that it was an alloy of aluminum, we let the matter rest, while more urgent enquiries were being pursued. Now that we had some time free, while the above research was being carried out, we started a more thorough enquiry into the nature of this material.

There were several diary entries which made it clear that Alundum was being used for its heat resistant properties, and that it was being obtained in plate- and tube-form from a local company referred to as Nortons. We discovered them to be one of the world's leading manufacturers of industrial abrasive products, and that Alundum was the registered name for one of the main materials used in the manufacture of grinding wheels.

The Norton Grinding Wheel Company, fortuitously for Goddard, was based at Worcester, Massachusetts., the seat of his employer, Clarke University. His connection with Norton's went back at least as far as 1918, when he had a lathe on loan from them (Pendray and Goddard, 1970, page 215), and it may well be that it was this connection that enabled him to appreciate the other properties of their product appropriate to his research.

At the turn of the century, Norton's, like others in their industry, had been seeking alternatives to their main abrasive material, Corundum, a naturally occurring mineral whose deposits were almost worked out. Experiments in smelting Bauxite, using electric furnace technology, began to interest them as a possible source of artificial Corundum. When samples of material produced by this process and named Alundum by its developer, The General Electro Chemical Company, were submitted to Norton's, they lost no time in securing an exclusive license (Cheape, 1985, page77). This was effective from August 1900, and by the time Goddard's requirements were determined, the manufacturing process was well established.

It is not clear when Goddard started to use Alundum for its heat resistant properties, but it was certainly in use by September 1921 during the first static firings using liquid propellants, liquid oxygen and ether (Pendray and Goddard, 1970, page 499). By 1925, however, he was encountering some difficulties, evidenced by a number of diary entries for May, which report a series of tests of alternative materials. Mrs. Goddard, in a diary footnote for June, commented that "bad luck" with these materials was forcing her husband into thoughts of "curtain cooling" of combustion chambers. Despite these problems, and notwithstanding failures of Alundum as late as March 6th, 1926, he persisted with its use.

In addition to providing Alundum in tube and plate form, Norton's were also making special lining components, some of them supplied in the "green" state so that Goddard could modify them more precisely to his requirements before the process of firing. An instance of this is recorded on January 19th, 1926, with Mr. Sachs working on an Alundum entrance plug for the petrol inlet to the combustion chamber, presumably putting in the four 0.040" diameter entrance holes. An entry on 9th July 1925 notes, ". . . worked on wooden taper form for Nortons," and the following day, "Took wooden form to Norton Co." There are several entries similar to that of May 27th. "Took green parts to Norton Co. for high temp firing."

As the ceramic lining to the exhaust nozzle would be clearly visible, an Alundum or similar liner would have to be provided on our replica. The details of this liner also cleared up the mystery of the ring welded to the end of the exhaust nozzle, it was there to retain this lining.

Contact was made with a subsidiary of Norton's in the U.K., and through their kiln furniture operation at Stoke on Trent a line of communication was established with the parent company at Worcester, U.S.A. This company has searched its archives for any relevant information, to no avail, but they also generously offered to provide whatever parts we might require, to the correct grade of Alundum (RA 98) as they supplied to Dr. Goddard some 60 years ago.

RESEARCH IN AMERICA

Dr. Becklake, meanwhile, was having some success through the contribution of a friend of long standing, Mr. Fred Durant, III, now retired but formerly of course, Assistant Director, Astronautics at NASM. Mr. Durant, a Goddard scholar in his own right, was greatly interested in our project and was delighted to be of help. He knew of the other set of drawings, prepared he told us, by the company of Atkins and Merrill of Sudbury, Massachusetts, in 1962, and went about finding a set for us with great enthusiasm.

The benefit of having skilled researchers, with access to primary source material, soon became apparent. Mr. Durant located and obtained a set of drawings for us from Seattle, and Dr. Becklake, with the kind assistance of the staff at NASM, obtained from their records a document of vital importance. This was a set of papers entitled "The development of liquid propelled rocket." We had earlier noted a reference to this report (Pendray and Goddard, 1970, page xiv), and had been in touch with the Robert Hutchings Goddard Library at Clarke. They were not, unfortunately, able to locate it at that time, but did produce it later.

This report contains much detailed information supported by photographs of excellent quality and cast an illuminating light on many of the problems we had been wrestling with.

On the other hand, the Atkins Merrill drawings were a considerable disappointment, and it is a mystery to us how such poor quality drawings could have been prepared, bearing in mind that the references on the drawings show that the draughstman must have had access to Goddard's photographs and, therefore, probably the report. These drawings had clearly been produced for the construction of models or replicas showing external details only. The needle valves, for instance, are drawn as solid with no bore or moving parts. There are many unnecessary errors made in the specification of materials, as well as some serious omission of detail and dimension. On the question of materials, the igniter is a typical, and seriously misleading, example as the material for the whole unit, (and the combustion chamber) is specified as aluminum throughout. From Goddard's report we can see that the igniter consisted of a vertical steel tube, welded to the steel top of the combustion chamber and with a short angled side tube made of copper. (This latter was designed to hold match heads, which, when heated with the blow lamp, would ignite and, in turn, light the black powder in the vertical tube, which finally lit the petrol/oxygen mixture in the combustion chamber.)

"REPORT ON THE DEVELOPMENT OF LIQUID FUELED ROCKET"

The notes in this report by Goddard are dated August 1929 and are arranged in two parts, the first sub-divided into five sections embracing the period July 1921 to August 1927, and Part Two, divided into four sections dealing with the period from September 1927 to July 1929. We worked from sections two and three of Part One covering the period September 1924 to May 1926. There are no drawings with these papers, but they are profusely illustrated with good quality photographs, on some of which parts have been numbered and cross referred to the text of the report, see Figure 3.

These photographs made it quite easy to establish that our assumptions about our original picture, Figure 1, showing the rocket the wrong way round, were correct. The caption for Figure 1, as it appeared in the report, was "Rocket ready for test." Another photograph in the report, Figure 4, was similarly captioned, but added at the end, "March 16th.," and it could be seen that the rocket was the other way round, with the slot, shown in close up at Figure 5, toward the pivoted rod, as necessitated by the launch procedure. The triangular guides can also be seen, replacing the earlier 3/8" diameter rods.

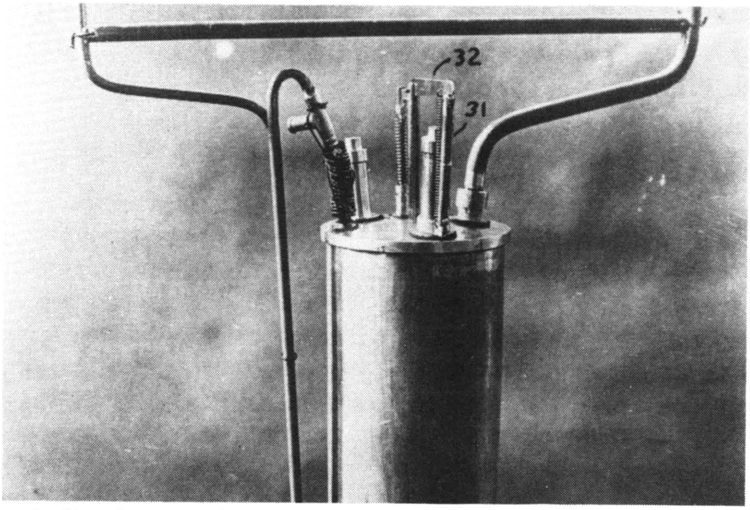

Figure 3 Top of oxygen unit.

Figure 4 "Rocket ready for test, March 16th."

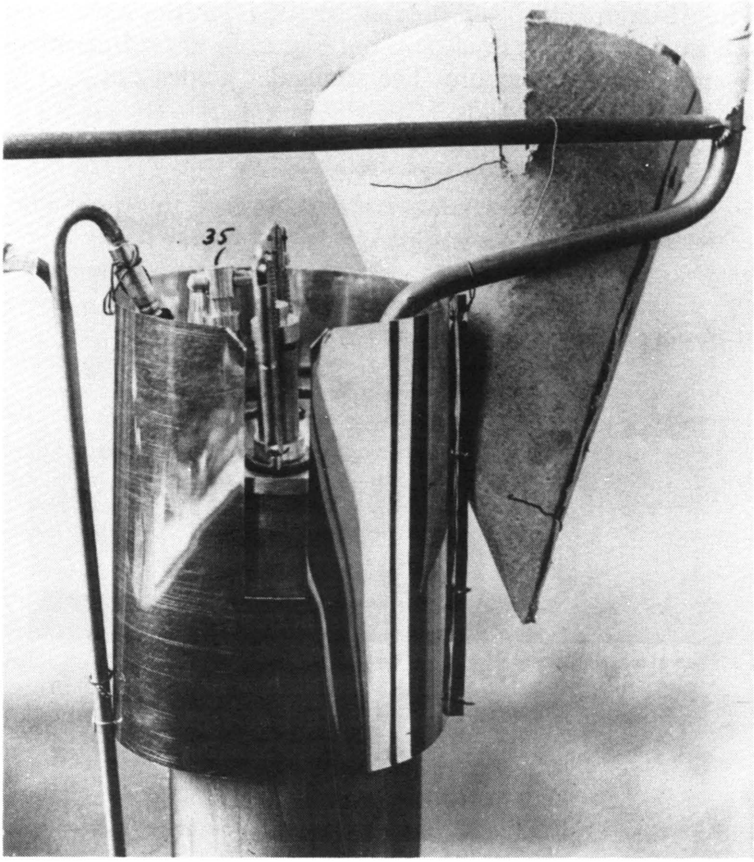

Figure 5 Clearance slot for needle valve release cord.

The report gives many of the important dimensions, although extracting them can involve a great deal of back tracking. This can be well illustrated by taking the question of the adjustable fuel choking or needle valves, the crucial details from an operational point of view being their nominal bore diameters and the number of turns for the needle settings.

There are about 14 references to these valves in Part One, Section Three, ranging in date from December 27th, 1925 to January 2nd, 1926. Working backwards through the notes, the last entry gives the final setting of the valves, the seventh entry specifies the bore size of the petrol valve (0.136"), the sixth entry states the bore of the oxygen valve, (0.199") and the third entry specifies for each valve the number of turns to the fully open position. It should be borne in mind that all these entries refer to static firings of an earlier prototype. There are no specific references to the settings on the successful rocket.

It should also be mentioned as a caution that Dr. Goddard does not seem to be as reliable in his notes as one might like. For instance, whilst he writes at entry 3 of the above sequence of the "needles or screws" being fully open at 14 turns for oxygen and 7 for petrol, with the very next entry he refers to the same number of "half turns" for the fully open positions. Furthermore, from entry 8 onwards he writes of the petrol settings as fractions of 14 turns and the oxygen settings as fractions of 16 turns. We have also noted that he used the incorrect photograph, (Figure 1) in two of his own publications (Goddard 1936a, page 78 and 1936b, page 11), so it is hardly surprising that the alignment mistakes have been made, and that many other authors have used the same picture. He is also credited with producing a schematic drawing of the rocket (Pendray 1945, page 98), which leaves out essential features. This drawing has also been reproduced in a number of publications.

THE SCIENCE MUSEUM REPLICA

Using Dr. Goddard's notes and photographs, cross checking with diary references and only in the last resort referring to the Atkins Merrill or the Seamon drawings, we have been able to prepare a build specification, which we believe to be as faithful as possible under the circumstances. A few weeks study of his notebooks in the collection of his papers at the Robert Hutchings Goddard Library might have filled in the unknown details, but that was not possible at the time.

Manufacture had commenced before the arrival of all the information, and the rocket motor assembly had been completed by the time the painful facts became known to us. As we had to start again, and as we had obtained so much good quality information, the decision was made to construct as exact a replica as possible, producing internal, as well as external, detail.

We have had to make assumptions where gaps in our knowledge exist, and these areas of doubt are set out in some detail below.

The Launch Stand

The only dimensioned information we have is recorded in sketch-like detail on the Seamon drawing, where it occupies a small space in a corner. The fittings used on the replica for joining the tubular members of the framework together differ from those on the record photographs, and a cross member is wrongly positioned on drawing and replica. We have followed the photographs as closely as possible. The replica uses supports fashioned from rods to support the upper part of the rocket, similar to those which can be seen in Figure 1. However, in Goddard's own words:

> Another difference was the use of two guides of galvanized sheet iron shown in the figures, at the top of the testing frame, to replace the 3/8" iron rods, first used to support the rocket. These sheet iron guides were movable outwardly, so that the rocket could not bind, or catch as it emerged from the frame.

Unfortunately there are no dimensions given for this design amendment. We feel that the motive for fitting these guides at the last minute resulted from the wish to avoid any repetition of the damage caused on the test of March 6th, 1926. (The report has the test on March 8th, but the diary, written at the time, gives the date as the 6th, and says he had a nap on the 8th!) It would seem that on this test the combustion chamber had burned through, ". . . and the recoil from the nozzle . . . jerked the remainder of the chamber upwards and bent the supply pipe."

It is easy to envisage the possibility of the asbestos and wire binding catching on the rod guides on launch, hence this switch to the smoother surfaced and hinged guides.

Liquid Oxygen Container

Because the liquid oxygen container has to be spaced a small distance from the base of the outer casing in order to give room for the vaporization of the released drops of liquid oxygen, there must have been a distance piece or some other positioning device. This part would also have been required to hold the seating on the base of the container against the needle valve prior to its release during the launch sequence. There is, however, no reference to such an item, and we have had to improvise.

Securing the Nozzle to the Combustion Chamber

The precise way in which this was carried out is now known to us. The nozzle, which failed on the test, was made of aluminum and welded to the end of the chamber. Goddard admits to the unsatisfactory nature of this weld, and he tells of sealing the pin holes in the weld with asphalt varnish. For the successful version he opted to have a steel nozzle, which was welded to a 1/16" thick steel disc and secured to the base of the combustion chamber with a screwed rim. No indication is given whether or not the rim was separate or integral with the steel plate. We have assumed that it was separate and made of aluminum for lightness, as the notes usually refer to welding whenever it occurs.

One Way or Flap Valves

The short cylindrical components between the needle valves and the combustion chamber referred to earlier turned out to be one way valves provided so that "any sudden pressure in the chamber would not force liquids back into the supply pipes, and hence produce a pulsating effect" (Goddard, 1929, Part One, Section 3, page 65). We have no information on the design or internal dimensions of these valves, but as their design is not especially significant, we have derived our own version, (tested to 100 psi) retaining the same external appearance.

Needle or Choking Valves

There is a similar problem with these items, although we do have some idea, if a little confused, of their bore sizes and needle settings. We have used the Atkins Merrill external dimensions.

Pressure Inlet Pipe

At the test of March 6th, the pipe at the base of the rocket, through which the external oxygen pressure was fed to the petrol and liquid oxygen unit, was bent through a right angle and fitted with a flap valve. The hose from the remote cylinder was connected to this pipe, and Goddard notes that on flight day this hose, ". . . was attached directly to the vertical 1/4" aluminum alloy pipe, instead of having this pipe bent through a right angle as before." We are not sure how this would affect the release arrangements, but this presumably was another consequence of the test failure and resulting damage.

Alcohol Burner

The photographs are too indistinct to be of any help. Mr. Durant recalled a conversation with Mrs. Goddard, when she thought it was a small baking tin with holes. The Seamon drawing shows a small tin. Dr. Goddard's notes say, ". . . made of a thin piece of sheet aluminum, cupped out to hold alcohol soaked cotton." This latter description is the approach we have adopted.

Size of Igniter

There are a number of doubts on the length and construction of the igniter. The details of the igniter at launch are dismissed in the report as "previously described," and the only reference giving any useful information is dated February 5th 1925. After describing the formula for the black powder, he describes it as "being pressed, one inch at a time into a 5/16" diameter steel tube with a 1/64" wall . . . burning in the air at the rate of 90 seconds for a 16-3/4" length." Page 50 describes a modification to the copper side tube, making it 2-1/2" long with a "layer of asbestos cord, 1/4" in length along the closed end." This is the only information about the external dimension.

The Seamon drawing shows the overall length to be 10-1/2" for the steel tube, but as Figure 4 gives the impression that it was much shorter, we have scaled from the photograph a dimension of 6."

Neither the drawings nor Goddard's notes give any indication of how the igniter was re-charged, but we feel that it is reasonable to assume that it would be undesirable and awkward to strip the rocket down for re-charging, so we have assumed that their outer ends would be fitted with screw caps. As there is a later reference to the igniter being lined with Alundum, we have assumed that this lining would be located by a projection on the copper side tube mating with a cross hole in the Alundum liner.

CONCLUSION

Our replica is as faithful to the original as can be reasonably expected, but as the saying goes, "The proof of the pudding is in the eating." Perhaps, when our exhibition closes, we will be allowed to put our replica through its paces. We will know that if it reaches a height of 41 feet and travels a distance of 184 feet in 2.5 seconds our efforts will not have been in vain!

ACKNOWLEDGEMENT

In addition to thanking those people mentioned in the text, I also wish to acknowledge the help given by the following. Ian Watson, who not only made our replica, but contributed in the analysis of the research, Dorothy Mosakowski of the Robert Hutchings Goddard Library, Derek Herrell, Technical Director of Norton Industrial Ceramics and Dr. Ault of the Norton Company, Worcester, Massachusetts., and Mr. Peter Turvey of The Science Museum for his valuable help with the research. I am also indebted to the National Air and Space Museum, Washington, D.C., for all the help given by their staff, and for the use of all the illustrations used in this paper.

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