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Robert Goddard Exhibit

PROPOSAL FOR THE REUSE PLAN OF THE WORCESTER MEMORIAL AUDITORIUM

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Introduction

The Worcester Memorial Auditorium is a historic building in the city of Worcester. The building was originally erected as a monument for the over 9,000 residents of Worcester that served in the First World War. It contains approximately 125,000 square feet of space including a small theater-style venue and a larger, multi-purpose space. The small theater, known as the Little Theater, has seating for 675 audience members. The large space has been previously used for basketball games, and public gathers and also includes a large stage and balcony seating. The two stages are connected and can open up to join the two spaces. Besides these two spaces, numerous smaller rooms line the sides of the first and second floor of the auditorium.

The building was completed in 1932 and opened in 1933. It was designed by architects Lucius W. Briggs of Worcester and Frederick C. Hirons of New York. The architectural style is a mix of Classic Revival and Art Deco. The main building materials were granite and limestone. The entryway to the building contains three well preserved Leon Kroll oil-on-canvas murals that depict Worcester's wartime history. The largest painting took three years to complete and is 57 feet wide by 30 feet tall.

The Worcester Auditorium, on the corner between Grove and Highland Street, was built on what was originally a traffic circle. When the traffic circle was replaced with the current layout, some buildings in the area were moved, while others remained, bearing the influence of the rotary. The former vocational school bears a curved façade, and the Worcester World War I Memorial was erected as the center of the rotary. The displacement of buildings as a result of the traffic restructuring has reduced the focus on the area. Based on discussions with the architect whose idea this was, recreating the rotary would be beneficial to the area, but impossible due to part of the area it had originally occupied is now taken by a parking garage belonging to the School of

Pharmacy. Being that the auditorium is part of the historical district, it would be of great benefit to the area if the auditorium was able to attract more attention to the area.

Today the Worcester Memorial Auditorium is on the Preservation Worcester's Most Endangered Structures list for its architectural and historical significance. The building has not been used in roughly 15 years and the large space has been used most recently to store state court documents. In 2010, the Worcester City Council gave the city's administration the authority to sell the auditorium.

The auditorium is in a slightly dilapidated state today. The ceiling has quite a few holes and water damage is evident. All of the facilities are extremely outdated and a lot of wear and tear is apparent. The wood floor in the large auditorium has some large cracks and stress bulges. The ceiling throughout the Little Theater is cracked and deteriorating. The mural room and entryway are, however, in great condition; the room has been maintained very well and the murals are preserved excellently.

When we began work on this project, we found that little had been done, and we were not given much to start with. There was the Worcester Memorial Auditorium Study from 2008, but other than that we had little to work with. Based on this, our goal for the project became providing the background research for this exhibit, and determining what will need to be accomplished in order to make this museum proposal a reality. After some research, we determined that we should take a deep look into Goddard's life in order to extract some ideas for exhibits. In addition, we needed to do the necessary research to ensure the exhibit was relevant to middle school aged children. Doing so would allow us to develop an exhibit that will be fun and engaging to the target crowd. We would also need to compile a list of physical objects which it would be useful to obtain or replicate. As soon as we came to these conclusions, they became our goals for moving forward with this project.

This project was to be done with the help of the architect whose idea this museum was, Dan Benoit, and the Collings Foundation, which had offered to help with the acquisition of exhibit materials.

After viewing the current state of the Worcester Memorial Auditorium, it is obvious that renovation is necessary to convert the space into an exhibit. We propose leaving the World War I Memorial entryway exactly as is. That space is well maintained and should retain the same feel that it started with. For the main auditorium space, we propose replacing the degraded roof with a glass roof, with either a pyramid or dome top. This would bring a sense of modern architecture to an old building and could be compared to the glass dome roof that was constructed on the Reichstag in Berlin. Below the glass roof, we would level the balcony (2^{nd} floor) halfway over the main floor. This means that starting from the mural room and entering the main auditorium, there would be an open second floor that creates more space for exhibits but still allows for the size of the auditorium to be fully observed. The main auditorium space would also need new floors, along with a complete refinishing. The Little Theater would also require extensive renovation. In order to utilize the space to show a short film that sets the mood of the exhibit, the theater would have to be completely gutted. With a new stage installed, new seats, a new ceiling and new walls, the space would be ideal for our purposes. Both the first and second floors of the auditorium have side rooms that also need renovation. These fixes would be mainly cosmetic with new floors, walls, and ceilings. These spaces would be utilized for various purposes, such as classrooms for field trips, computer labs for the rocket simulator, demonstration rooms for experiments, as well as a number of administrative rooms. These rooms would also include the gift shop and the admissions ticket office. With the aforementioned renovations completed, the Worcester Memorial Auditorium would be well suited to hold this Robert Goddard themed exhibit.

On September 15th, Kyle Mercik, Nick Aleles and Zack Tripp visited the Worcester Regional Airport for the Collings Foundation's stop there on their Wings of Freedom Tour. Since the Collings Foundation is one of the sponsors on this project, we took the opportunity to introduce ourselves, and establish contact with them. The Collings Foundation brought with them a P-51 Mustang, B-24 Liberator, B-17 Flying Fortress, M16 Half-track, and an M4 Sherman tank. When we were there we took note that despite this being the third day of the showing, and the fact that there were only two aircraft which could actually be entered, there was a great interest, with a continuous crowd of a few hundred people throughout the day. We took a multitude of pictures while we were there, and a small collection of them can be found in Appendix D.

The Steven F. Udvar-Hazy Center is located in Chantilly, Virginia and is an annex for the Smithsonian National Air and Space Museum. Tripp was able to visit the museum over the summer before this project began. The museum showcases items such as the Space Shuttle Discovery, an SR-71 Blackbird, Concorde, and even the Enola Gay. Also on display, were numerous Goddard related items. There was a Goddard 1935 A-Series Rocket as well as random rocket parts created and used by Robert Goddard. These parts include a rocket motor, ion collector, propellant injector and spark plug igniter, control vane, propellant flow regulator and a liquid oxygen tank. Robert Goddard seems overshadowed in such a large and impressive museum because his work was mostly before the aerospace age, yet was vital to its existence. For this reason, the Udvar-Hazy Center indicates that a Robert Goddard centered exhibit is imperative in educating people about his contributions to aerospace. Seeing the attendance and interest in this Chantilly exhibit demonstrates the interest surrounding these topics and signifies that a Worcester exhibit that focuses on Goddard would be a popular and desirable attraction. Pictures of the mentioned displays can be found in Appendix E.

We consider both of the above instances to be very relevant to this exhibit proposal. The similar subject matter and high interest levels in these exhibits demonstrates the success such an exhibit could see, as well as provides a model for our own exhibit.

Local Curriculum

In order to determine how to make our exhibit interactive to the target audience of middle school aged kids, we needed to figure out what these kids were learning and when. For this, we analyzed the local curriculum. In second grade, they are introduced to the basics of the concept of forces, and how to recognize simple machines. In third grade, the students are introduced to the scientific method, referring to it as *skills of inquiry*. In addition, basics of energy transfers, electricity and magnetism, and simple and complex machines are covered. In fourth grade, simple machines are once again covered, along with the *skills of inquiry*. The *skills of inquiry* will be covered each year through the eighth grade. In seventh grade, the engineering design process is covered as well. This includes methods of properly representing solutions to a design problem, the purpose of a prototype, the appropriate materials, tools, and machines necessary to construct a prototype, design features and cost limitation that affect the construction of a prototype, and the five elements of a universal systems model. The students are taught to identify the appropriate materials (ceramics, metals, plastics, adhesives) for the various tasks necessary for building a prototype, along with the appropriate measuring and building tools. Properties of matter are also covered, and students should be able to differentiate between mass and weight, and recognize that weight is the amount of gravitational pull on an object. Students should also have a complete understanding of gravity. In addition, the students are to learn about transportation technology, including land, air, water and space travel. They also must learn to identify the different subsystems of transportation vehicles, such as structural, propulsion, guidance, suspension and control components. Finally, that should be able to identify and explain the lift, drag, friction, thrust, and gravitational forces on a vehicle.

Based on the standardized test scores of the school systems in the area, only one third of the students coming through the exhibit should be considered to fully understand the concepts that the public school system has been teaching them. Another third has some comprehension, but could really use some work. The final third of the students should be considered to have no real understanding of the above concepts. We must take this into careful consideration when creating this exhibit.

We could use this curriculum as the basis for the different displays, and so that the exhibit can be extension of what these kids are learning. The exhibit should definitely be interactive when possible, so that they get to see some of Goddard's ideas in action, as well as get the opportunity to view some of the forces that rockets experience.

We must also strive to make the exhibit relevant to other nearby school districts as well. Nearby districts most likely have similar curricula, so this should come naturally. The success of this project requires the exhibit be a success and consistently used throughout the school year, and become a destination for families in the area looking for fun, learning and entertainment.

We have an opportunity for a pre-planned lesson for teachers to use while bringing students through the exhibit, in the form of the design process of Robert Goddard in the Development of the first liquid propelled rocket. A basic idea for such a lesson would start with helping the students identify the design constraints and requirements, or in other words what was expected of the rocket, and thus what it must be capable of doing in order to succeed in its desired task. Next, the students should be asked to identify and understand why each component of the rocket is necessary to meet the previously determined design constraints. The students could also be asked to identify the materials Goddard chose for each structural component, and why he would choose such a material. Afterwards, it should be pointed out how Goddard learned from each of his prototypes, and the changes that he made in order to avoid the problems that he learned from previous iterations. The above would probably be best done in a class type setting, with a large images available on the walls, with a piece of sheet metal behind the images. The most important and significant of the parts are cut out separately, with magnets on the back, so that they can be applied to the magnetic image. The purpose of a part is presented to the students, after which they must correctly identify the part and place it on the magnetized image. The below link provides a similar design, albeit in electronic form, for the design of the V2 rocket.

http://www.pbs.org/wgbh/nova/tech/build-rocket.html

Another suggestion incorporates what they should be learning about methods of transportation. With visual explanations of how planes, cars, and rockets work, the students are asked to create a vehicle for use on the Moon. The students should be reminded of how the conditions on the Moon defer from those on Earth, and then leave them to their creativity. This will force them to think independently, and think about how different methods of travel work. While what they will be making might be a picture, a drawing or a model of some sort, they are expected to be able to explain how it is expected to work. After they have come up with individual solutions, a few premade options are presented, each of them quite unique from one another. In these premade ideas, the ideas of both solar sail power movement and regolith (aluminum oxide) powered rockets should be offered. After this, the group of students can be left to produce a concept as a group.

The third and final suggestion we have to present involves a computer game called Kerbal Space Program. This game is in very earlier stages of development at this point, but it is progressing quickly, and an education specific version is in the works. The game is a full-fledged rocket simulator, and is known to be a favorite amongst NASA scientists. A great deal can be learned about rocket science from playing this game, in the spirit of reaching nearby moons and to the other planets within the fictional solar system of the game.

The game starts the player on the fictional planet Kerbin, which is inhabited by only a race of green men referred to as Kerbals, whose primary goal is reaching all parts of their solar system. The surface gravity and atmosphere are similar to those conditions found on Earth, except both properties are scaled down in terms of longevity, in order to make launching successful rockets easier, and make the scale for the rockets smaller and easier to manage and control. There is an easy to use vehicle assembly building, with a large variety of rocket parts available to use to build a rocket however the player desires. Putting the students through the basic tutorial for construction, and then putting them in charge of building their own rockets should be quite engaging, as well as forcing them to really think about the physics in involved in the launching of a rocket. The wide variety of parts available and the virtual aspect will allow students to create an immense variety of rocket crafts, and explore the different possible ways to successfully achieve suborbital flight, and possibly even orbital flight.

Both NASA and TeacherGaming LLC have announced plans to create their own mods for the game. The TeacherGaming LLC version is at this point known as KerbalEdu (can be found at www.kerbaledu.com), and is the version that we suggest the proposed exhibit use. The NASA mod will be a mission pack that includes the player saving Kerbin from an asteroid that is on a collision course with the planet.

A mission pack should be put together using KerbalEdu, in which the students are presented with a limited supply of parts, specifically parts that would be more useful for building a first rocket rather than parts that would be used for building planes, space planes, space stations, or landing modules. The students will have missions to accomplish, such as reaching the upper atmosphere, achieving a first suborbital trajectory, and finally achieving orbit. In order to achieve the goals, the students will need to be introduced to the differences between solid and liquid fueled rocket propellants, and they should each be used for maximum efficiency. They will also need to be shown stage separation, both inline and radial. These are concepts that will need to be introduced to them in order to achieve a suborbital trajectory, but in order to get into orbit they will need to learn which direction to burn to get into orbit efficiently, and this will be an opportunity to introduce the apoapsis and periapsis of an orbit (apogee and perigee when concerning orbit about Earth). If we are able to do this, we will have successfully taught the kids basic rocket science and orbital mechanics. The students might also have the opportunity to notice that their orbital velocity will be lowest at apoapsis and greatest at periapsis, and that achieving a higher orbit means forcing the craft's average velocity to be greater.

Relevant Patents

Besides calling for physical model displays and their respective abstracts, we also recommend that various patents published by Robert Goddard be placed throughout the museum. We do not wish to have all 211 of Robert's patents to be displayed but only the significant ones that can relate more easily to the general public. In order to further simplify the method of reading the patents, descriptions should be added alongside each patent. At the same time they should be placed across from a smaller scale physical model/depiction of the patent in order that the person reading the patent can refer to the model design. The most significant patent collection that should be included depicts the components of a V-2 rocket, which was also considered to be included. Other patents that influenced the technology of propulsion were also considered.

The following patents are recommended documents to be included within our proposal, along with brief descriptions included. The first two patents will be given longer explanations and outlines of each the labeled parts and their functionalities.

- No. 1102653, July 7 1914: Rocket apparatus (rocket chamber with nozzle; also step-rocket)
- No. 1103503, July 14, 1914: Rocket apparatus (rocket chamber supplied by pumps; power plant for driving pumps; tanks containing a liquid fuel and a liquid oxidizer; explosive head)
- No. 1879186, September 27, 1932: Apparatus for igniting liquid fuel (combustion chamber with outside jacket for cooling the wall; holes in wall introducing liquids so as to have a hot flame in the center of the chamber, spaced from the walls)
- No. 1879187, September 27, 1932: Mechanism for directing flight (pilot gyro; control of directing vanes in blast; and also directing vanes in air stream)
- No. 2127865, August 23, 1938: Seal for centrifugal pumps (pump suitable for pumping liquid oxygen)

- No. 2217,649, October 8, 1940: Combustion chamber for Rocket apparatus (cooling of a combustion chamber wall by sprays through holes in the chamber wall)
- No. 1159209, November 2, 1915: Method of and apparatus for producing electrical impulses or oscillations
- No. 1980266, November 12, 1934: Propulsion apparatus (applies to V-1 rocket)
- No. 2158180, May 16, 1939: Gyroscopic steering apparatus

Further information, along with diagrams for the patents, can be found in Appendix F.

Liquid fueled rocket: 1st experiment & influences

On March 16th, 1926, Robert Goddard launched the first liquid-fuelled rocket, the first of its kind that would officially start the space age. Despite obstacles delaying his construction and testing of the rocket, Goddard was successful in proving a new concept that was superior in some aspects over that of the conventional solid-fuelled rocket technology.

When the rocket was launched, it rose to an overall height of 184 ft. At that point, the lower half of the nozzle had burned off its fuel reserves. The rocket weighed 6 lbs empty, 10.45 lbs fuelled, and was powered by liquid oxygen and gasoline. In order for the rocket to launch, the propellants were forced into the combustion chamber by pressurized tanks rather than by pumps. The following passage is an extract of Robert's Diary describing the reflection of the experiment:

> March 17, 1926. The first flight with a rocket using liquid propellants was made yesterday at Aunt Effie's farm in Auburn.
>
> The day was clear and comparatively quiet. The anemometer on the Physics lab was turning leisurely when Mr. Sachs and I left in the morning, and was turning as leisurely when we returned at 5.30 pm
>
> Even though the release was pulled, the rocket did not rise at first, but the flame came out, and there was a steady roar. After a number of seconds it rose, slowly until it cleared the frame, and then at express train speed, curving over to the left, and striking the ice and snow, still going at a rapid rate.
>
> It looked almost magical as it rose, without any appreciably greater noise or flame, as if it said "I've been here long enough; I think I'll be going somewhere else, if you don't mind."
>
> Esther said that it looked like a fairy or an esthetic dancer, as it started off.
>
> The sky was clear, for the most part, with large shadowy white clouds, but late in the afternoon there was a large pink cloud in the west, over which the sun shone.
>
> One of the surprising things was the absence of smoke, the lack of very loud roar, and the smallness of the flame.

Goddard continued to make improvements on his rocket following the March launch. On April 3, Goddard ran an additional test on a rocket that was given a four-tube bracing. At the conclusion of the flight, it had landed about 50ft away and it had incurred a 4.2 sec flight time. The next month, on May 5, Goddard reported his successful test flights to the Smithsonian, but only wanted his feats to be revealed to a select few. His extensive desire for privacy was a big factor for his rationale. In general, he feared that his work would fall into unworthy hands and be developed for wrongful purposes. Goddard's experiments were later implemented into conventional warheads developed by the Nazis in WWII.

Personal papers/documents

Alongside scientific documents, the consideration of putting up significant material of Robert Goddard's life was analyzed. Goddard's personal words provided an accurate sketch of how he developed his interest in rocketry. Throughout his life, Goddard had been documenting a lot of his activities and thoughts, either about conducting various experiments or making observations of his surroundings. When he started his collection of journal entries, Goddard's style of writing was very simple yet straightforward. The fact that Goddard maintained a vast diary collection reflected that he had a drive of wanting to know what he was doing. He would use his notes to keep track of his progress in order that he can move forward in a smooth manner. As he grew older, his observations and diary entries became more detailed, but at the same time were kept concise just as his earlier entries were. In order that the exhibit items are given more historical background, Goddard's personal papers were considered as an addition to the exhibit.

Clark University and Worcester Polytechnic Institute each hold archival collections of Robert Goddard's work and papers. Currently, they are viewable at the online database within Clark's library website, the Dr. Robert Hutchings Goddard Digital Collection, where countless papers are downloadable. In addition, Clark still has the physical papers in the Goddard archives. WPI also has a small Robert Goddard exhibit within its library displaying small-scale models as well as volumes of his papers that can borrowed from the library. These papers were written by Goddard and were later published by his wife. Today, many primary documents are not seen or accessed by the public; it has become an irony that Robert Goddard, the most prominent figure of scientific history in Worcester, has become lesser known within the community. As a way to resurrect his history, his prominent entries should be loaned out by Clark to be used in the exhibit, which would not only shed more light into Goddard’s life and experiments, but would increase the education experience of the relevance behind Robert Goddard.

The papers that are included in the proposal are to be placed in chronological order throughout the museum. They would be placed in areas that correspond to the items of the time period.

Biographical Content

Goddard’s work on rocket development is only understood at a limited level by the general public; its connection to today’s rockets is known even less. In order to optimize the learning experience and relevance of the Robert Goddard exhibit, his documented scientific experiments and personal life notes should be implemented into displays. We analyzed Goddard’s background and how it influenced the craftsmanship of his experiments that would lead to what today’s aerospace technology is. Therefore, a brief biography of Goddard and his early work leading up to his development of the liquid fueled rocket should be included in the exhibit to provide more detail behind the exhibit.

The beginning of the rocket concept dates back to 13th century China, when the solid rockets were invented as a weapon tool against the Mongols. Overtime, the technology was adopted by others in Asia and later by the Europeans, but it wasn’t until the 18th and 19th centuries when these solid-fueled rockets would be deemed standard; a new technology revolution was needed to succeed the solid-fueled rocket. In 19th century New England, the Industrial Revolution was thriving and inventions were replacing traditional items. Worcester, being the heart of the Revolution was a great breeding ground for new ideas to be born. The people of Worcester generally embraced on the cultural norm of preserving its traditional customs by blocking out influences from outside areas like Boston. At the same time, they were willing to show pride on the development of new ideas, since Worcester was a big industrial center at the time. Robert Goddard, a bright individual born from a Yankee family in 1882 would propel the Industrial Revolution further into territory that most people were hesitant to follow. To develop an innovation was very costly and it was hard to raise funds or receive donations from public organizations like the Smithsonian. For example, the Smithsonian would only lend out funds if the potential recipient were to produce a legitimate invention proposal. Despite this, Goddard was able to develop the first liquid-fueled rocket and with later improvements, it would lead to what rockets are today.

Most of Goddard's early years consisted of illness and disabilities that impacted his ability to attend school often, and as a result, his character of being an independent-minded individual had developed. In order to catch up on his studies, he taught himself on principles such as mathematics and physics, and that he applied the concepts by conducting various lab experiments in his Worcester home attic. Concepts such as electricity, transportation, physics, and chemistry were applied to his simple tests of existing scientific theories, such as creating static by rubbing a carpet or attempting to create diamond. One particular experiment Goddard conducted involved using zinc from Leclanche batteries on gravel to propel himself over a low fence at succeeding heights. Overtime, his family had become very intrigued in Goddard's activities. His father, Nahum was a handy-man, developing interesting tools such as a machine knife that was used for cutting rabbit fur. As a result of his reputation, he was referred as "The Goddard Welder". When taken into perspective, Nahum was a man of innovation who looked to pass his knowledge to his young son. With Goddard's early exposure to his father's technological activities, Goddard pushed himself to expedite his curiosity of his surroundings and looked to make sense of them, fueling his dreams of being an innovator. His mother, Fannie, who was a more realistic parent than Nahum saw what Goddard wanted to accomplish and when she witnessed him conducting the zinc experiment, she warned him not to become too dreamy: *"sometime it might work, and then you'll go sailing away and might not be able to come back".* There had been many instances that Goddard was brought back to earth from his world of thought, but thanks to his more optimistic father, his curiosity in science grew stronger. On

October 19 1899, Goddard went outside in his backyard and climbed a cherry tree to cut off dead tree limbs. While maintaining the tree, Goddard became very mesmerized at the sky; it would be that moment when Goddard's dream of reaching space and the moon had begun to take hold. The idea of climbing the cherry tree implied that Goddard yearned to reach greater heights, setting the bar high for accomplishing his goals. Anytime that Goddard would be in doubt, the cherry tree event of October 19 would return to his mind and put him back on track, thus not letting any issue distract him. His own words describing the event reflect how much of a passion he developed on flight: '*On this day I climbed a tall cherry tree at the back of the barn … and as I looked toward the fields at the east, I imagined how wonderful it would be to make some device which had even the possibility of ascending to Mars, and how it would look on a small scale, if sent up from the meadow at my feet. I have several photographs of the tree, taken since, with the little ladder I made to climb it, leaning against it.'*

Other major influences on Goddard's pursuit of space travel were written works such as H.G. Well's "War of the Worlds", a sci-fi novel depicting extraterrestrial aliens from space that invade earth. Goddard was influenced by this so much that he wrote a personal letter to the author, thanking H.G. Wells for enlightening him on the science of space. In 1904, Goddard graduated from South High School as the class president with a valedictorian title; many noted him to be a very bright individual that despite his looks, he had a strong character and was actually quite sharp-edged. At his graduation ceremony, Goddard delivered a speech titled "On Taking Things For Granted": '*Just as in the sciences we have learned that we are too ignorant to safely pronounce anything impossible, so for the individual, since we cannot know just what are his limitations, we can hardly say with certainty that anything is necessarily within or beyond his grasp. Each must remember that no one can predict to what heights of wealth, fame, or* *usefulness he may rise until he has honestly endeavored, and he should derive courage from the fact that all sciences have been, at some time, in the same condition as he, and that it has often proved true that the dream of yesterday is the hope of today and the reality of tomorrow'.*

Following his years in high school, he attended Worcester Polytechnic Institute, formerly known as the Worcester County Free Institute of Industrial Science, where he obtained his Bachelor of Science in physics in 1908. Once again, he attracted a lot of attention from his peers as well as a few of the professors. Professor Duff, the head of the physics department, was a vital proponent of Goddard's scientific breakthroughs; when Duff took Goddard under his wing as a laboratory assistant, Goddard accelerated his learning progress of science. During his years at WPI, Goddard experimented with the electromagnetic theory and then used his findings to figure out how it can be applied as being a source of propulsion. Following his WPI years, he went to graduate school at Clark, where he quickly became prominent for conducting endless amounts of experiments that were geared to the construction of the rocket. After some years spent at Clark, Goddard obtained a research position at Princeton. However, he did not spend a lot of time there because a few months later he contracted tuberculosis. The disease had crippled Goddard substantially and his doctors did not have expectations for him to survive. Goddard's dreams of spaceflight however helped him endure the sickness and fuel his will to live. In order to stay fit, he spent time outside in the fresh air, walking for exercise. When he spent his time inside, he worked on applying his mathematical theories that he composed at Princeton to develop his vision of a rocket. Eventually, his work would lead to the publication of his first patent, No. 1,102,653 on July 7 1914, which depicts a rocket having multiple stages that activate in sequence after ignition. One week later, Goddard published his second patent, Patent No. 1,103,503, which represents what would be known as a liquid-fuelled rocket, a rocket fuelled by gasoline and liquid nitrous oxide.

When he returned to Clark to become a full-fledged professor of physics, Goddard took up a teaching position. An irony that can pointed out is that while Goddard yearned to teach his material, he devoted most of his time to his experiments, which took up a lot of Goddard's time. With little funds, he shifted his focus to understanding solid-fuelled rockets in order to be prepared to take on new rocketry concepts. During the years of 1914-1916, Goddard was concerned with the measurement of efficiency of common rockets and with steel rockets that were provided with nozzles. After conducting repetitive experiments with them, he concluded that solid-fuelled rockets were very unreliable and despite his modifications of installing more nozzles and combustion chambers, they could not work. In formulating the mathematical physics of rocketry, Goddard had to overcome popular misunderstandings of Newton's Third Law: 'TO EVERY ACTION THERE IS ALWAYS OPPOSED AN EQUAL REACTION'. However, he would get confused on how the scientific law can be applied into the propulsion mechanics of rockets. It was widely thought that a rocket engine operating in a vacuum would not be able to deliver propulsive force; the rocket exhaust would be sucked out of the engine into the near perfect vacuum of space. Thus, the reactive force would be cancelled by the vacuum. The two bodies involved in the reaction were depicted to be the rocket and the vacuum rather than the rocket and its exhaust. With his vacuum-chamber experiments, Goddard finally concluded about the practicality of an engine to deliver propulsion in a vacuum. With much supporting evidence, Goddard was able gain enough confidence in contacting the Smithsonian, informing them of his progress on developing a working rocket: *"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".*

Robert Goddard’s early experiments would eventually attract attention from higher figures in science and receive decent feedback. Charles Abbot, director of the Astrophysical Observatory at the Smithsonian and his companion, Charles Walcott, reviewed Goddard’s written statement and provided positive feedback of it, noting it as “probably sound”. Goddard’s statement was interesting, but it was typical since the Smithsonian constantly received those kinds of proposals; Goddard had to submit a more detailed proposal along with a budget plan of the rocket development to provide more legitimacy. Therefore, Goddard made additions to his paper by providing his documented tests of the rocket motors in the vacuum chamber, as well as a request of $5000. Goddard was able to secure the funds, but in return he had to report to the Smithsonian staff every year to portray progress. In the confines of the WPI Skull Tomb, with little to no assistance, Goddard pressed on to pursue his ambitions of rocketry; his next approach was to increase the exhaust gas velocity in order that propulsion would be more effective.

In order to achieve this, he adjusted the size of the combustion chamber to the proportion of fuel being consumed. Goddard also used a nozzle to extract the propulsive force from the expanding gases that would leave the combustion chamber. The mass of fuel relative to the total rocket mass was also increased; Goddard used a chamber for combustion that was separate from the fuel chamber, enabling the fuel container to be much lighter. This would mean that the container would not have to withstand the pressure of combustion. Furthermore, the rate of combustion had to be amplified, which was to be done by feeding propellant elements to the chamber as quickly as possible. Continuing his research, Goddard looked into the military technology of machine guns, which was still quite new in the trenches of the WWI period. He also analyzed his earlier patent of the rocket apparatus, which used the notion of feeding fuel to a separate chamber. In order to satisfy the design objectives of increasing the rate of combustion, Goddard brainstormed a rocket that used powder cartridges that would be supplied to a combustion chamber by a mechanism similar to that of the machine gun. The general difference between the machine gun and Goddard's envisioned rocket though is that the machine gun was based on a discontinuous feed system while the rocket was based on a continuous feed system. In Patent No. 1,194,496, which was released in August 15 1916, the implementation of this rapid continuous feed concept was broadly portrayed to be a working model of Goddard's updated rocket. To summarize his research on solid and liquid fuel fundamentals, Goddard analyzed the liquid fuel rocket concept and compared it side by side with the solid fuelled rocket. He concluded that the continuous feed concept would provide more thrust than the intermittent feed approach. However he noted that while liquid fuels contained more chemical energy than powder fuel, handling extremely cold liquid fuels such as liquid oxygen would be overwhelming. Therefore, Goddard decided to use most of his $5000 grant into the development of the mechanism of delivering powder cartridges to the combustion chamber.

By 1919, 3 years after Goddard began his liquid-fuelled rocket experiments, Goddard's accomplishments were considered scientifically significant. However, Goddard did not produce published versions of his work. Groups such as the Army's Signal Corps continuously requested information from Goddard, which had become a mere annoyance. Out of concern for his privacy, Goddard thereafter made continuous train trips across the country in hopes of not being found by them. In addition, he was avoiding the demands of his mentors at Clark who were pressuring him to publish his work. Nevertheless, Dr. Webster, director of Clark University's Physical Laboratory forced Goddard to publish his research by threatening to publish the work for him and take the credit. In response, Goddard later published his famous work "A Method of

Reaching Extreme Altitudes”. The paper was only a repetition of Goddard’s project proposal of 1916, except that it included a few footnotes.

This substantial work set forth the more basic physics of rocketry and Goddard concisely described the problems of these concepts 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 stated that “it is the 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.” In March 1920, Goddard then wrote a report outlining his vision of a manned interplanetary mission that included an optional landing on a celestial body. He also discussed the practical use of liquid oxygen and liquid nitrogen; these fuels, he noted, had the advantages of being cheaper. From 1921-1924, Goddard experimented with liquid fuels and then developed the first crude operating liquid-fuel rocket motor. As Goddard made progress towards developing the rocket, the Smithsonian periodically gave him $500 funds. In March 1926, Goddard successfully launched the first liquid fuel rocket outside of his aunt’s barn. When he reported his success to the Smithsonian, the institute was very pleased with the results. Therefore, it continued to grant funds to Goddard, enabling him to conduct more successful flights. In July 1929, another rocket, measuring 11 feet and 6 inches long was launched. The rocket had reached a height of 90 feet. The noise of the rocket plus its exhaust flame attracted unwanted attention from the media; 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.” After the Fire Marshall of

Worcester declared the rocket “a fire hazard”, Goddard had to leave Worcester and head to a more remote area to continue with his rocket tests. Goddard moved to New Mexico, where he set up a machine shop in the desert and constructed another rocket, which was launched successfully to a height of 2000 feet. Charles Lindbergh was very intrigued by Goddard’s rocket; therefore, he vowed to give Goddard continuous support. Lindbergh was able to convince Daniel Guggenheim, an American industrialist in aviation to grant Goddard $50,000, which was a much more satisfactory amount that Goddard needed. It would be that contribution that brought Goddard and Lindbergh together as close friends.

In the following years up to his death in 1945, Goddard continued to pave the way for rocket development and enabled others to put his inventions to practical use. Despite many false assumptions of Goddard’s work, the rocket had proved to be a very useful tool for enabling transportation via air and space. Goddard had developed a bazooka as well, which was tested and presented as a prototype during WWI. Later on, it was put into use during WWII as a conventional weapon. Goddard’s work and designs allowed Wernher Von Braun to improve the liquid fuelled rocket by increasing the amount of delta-v the rocket launched with, in order to greatly improve the flight time and range. The updated rocket would become the V-2 ballistic missile. Eventually other rockets were later developed for the United States Army and NASA. Today, aerospace technology is continuing to grow, but without Goddard’s development of the liquid-fueled rocket, aerospace technology would not be where it is today.

Based on the information that was gathered and summarized, we strongly considered that various items in connection with Goddard’s background be included in our exhibit proposal. A cherry tree similar to the one Goddard climbed was thought to be placed outside of the Worcester Auditorium to portray his rise to success despite early life struggles. Specifically, the reason behind this proposal is that Robert's outdoor adventures helped him formulate his scientific ideas and free his mind while taking breaks from his demanding experiments. The public would also make a stronger connection to what was in Goddard's mind when he climbed the tree outside in his backyard and looked up towards the sky. Goddard's first two patents of July 1914 were also suggested to be included in the exhibit in conjunction with the V-2 rocket display that was proposed to be in the center of the auditorium. Today, these two patents are viewed as a standing point to Goddard's upcoming patents. They have also become a reference for the development of the German V-2 rocket developed in World War II. The patents also eventually lead to the advancement of modern aircraft and rockets that occurred in the middle of the 20th century. Goddard's experiments were seen to be very important in the field of rocketry, therefore we recommend that Goddard's most prominent rocket experiments be applied into visual representations within the proposed experiments rooms of the auditorium.

Proposed Materials to Exhibit

The below items and ideas are recommended for the exhibit. We recommend these items because they demonstrate Goddard's influence on rocketry as well as give perspective on what else was being developed at the time. All of the items are not directly related to Goddard but they are still vital and relevant in understanding the period in which Goddard was working. The items include a mix of rockets and aircraft as well as miscellaneous exhibits that, when presented chronologically, will give visitors a new angle on each revolutionary invention. The broad array of topics and items also greatly increases the interest for our target audience, the local students.

Aircraft Exhibits

These are aircraft to be included in the exhibit. What is included could be a partial scale model, the actual aircraft or even just a graphical display. Images of all aircraft can be found in Appendix B.

Zeppelin:

The zeppelin illustrates the first practical ideas toward flight. It was a type rigid airship, unlike a balloon. These aircraft were used as the first airline. They were first outlined in 1874 and the first commercial use began in 1910, in Germany. The zeppelin is a great aircraft to include in the exhibit because it shows what flight was seen as when Goddard was a child. This was all Robert Goddard had to reference when it came to a rigid body flying in the sky. (See Appendix B1)

Wright Flyer

The Wright Flyer was the first successful powered aircraft. The Smithsonian describes it as, "the first powered, heavier-than-air machine to achieve controlled, sustained flight with a pilot abroad." The significance of this is obvious but also worth mentioning is that Goddard was in high school at this time (1903). High school is a time when students make the decision on what they really want to devote their life to. The timing of this with the first powered aircraft flights by the Wright Brothers is an undeniable motivator for Goddard. (See Appendix B2)

Bristol F.2 Fighter

The Bristol F.2 Fighter was one of the most popular biplanes of the First World War. It was an extremely agile, two seat British biplane. Its main roles in the war were aerial fighting and reconnaissance. The solid design kept the Bristol Fighter in service until the 1930s. The plane shows the progress made since the Wright Brothers. It also gives an idea of how much of an impact war had on the development of aircraft. (See Appendix B3)

B-17 Flying Fortress

The B-17 Flying Fortress was developed in the 1930's as a four engine heavy bomber. It was responsible for dropping more bombs in WWII than any other United States aircraft. It was a durable design with heavy defenses and a higher service ceiling than any other Allied aircraft. This plane shows the advancements in large multi-engine planes. (See Appendix B4)

Bell X-1

The X-1 was the first of the X-series of experimental rocket powered planes. The X-1 reached a speed of roughly 1000 mph in a test in 1948. . Chuck Yeager piloted the first test to break the sound barrier, making it the first airplane to exceed the speed of sound in level flight. Since it was rocket powered, the X-1 relates directly to Goddard's work. (See Appendix B5)

B-29 Superfortress

Another in the B-series of bombers, the B-29 saw action toward the end of the Second World War. The B-29 was a very advanced high altitude strategic bomber. It featured a pressurized cabin, electronic fire-control system, as well as remote controlled machine gun turrets. The B-29 also holds the distinction of being the first nuclear capable bomber. It was the plane chosen to drop the atomic bombs on Hiroshima and Nagasaki within days of the death of Robert Goddard. (See Appendix B6)

Boeing 707

The Boeing 707 is the first jet Airliner developed by Boeing. It could carry 189 passengers up to 5750 nautical miles. This was the first commercially successful airliner and resulted in Boeing continuing the line of 7X7 aircraft. The jet powered aircraft was also new at the time and relates very closely to rocketry. (See Appendix B7)

Cessna 172 Skyhawk

The Cessna 172 Skyhawk is the most built aircraft in history. It is a basic four-seat, single engine, high wing, fixed wing aircraft. It first flew in 1955 and is still widely popular today with amateur pilots. (See Appendix B8)

U-2 Dragon Lady

The U-2 “Dragon Lady” is a high altitude spy plane flown by the USAF as well as the CIA. It first flew in 1955 and can fly at 70,000 feet to gather intelligence in any weather conditions. It was built by Lockheed Skunk Works and is still in service today, even though it is not used frequently. The U-2 was one of the first successful high altitude spy planes that would pave the way for the future of intelligence gathering. (See Appendix B9)

Boeing B-52 Stratofortress

The B-52 is very important historical aircraft. It is a long range, subsonic, jet powered Strategic bomber. It is capable of carrying a payload up to 70,000 lbs, which high even today. It is powered by *eight* turbojet engines. It was built as a nuclear-capable strategic bombing deterrent plane. The plane saw extensive use during the Cold War as it was the go to plane for an attack on the Soviet Union. It is still in service today, after entering service in 1955. (See Appendix B10)

North American X-15

The North American X-15 was another of the X-series experimental rocket powered aircraft. The aircraft flew mainly in the 1960s and was used as tests for future rockets and spacecraft. It was dropped from the bottom of a B-52 Bomber. The highest altitude achieved was 67 miles and the highest speed was 4519 mph. That top speed was set in 1967 and is still the highest top speed achieved by a manned aircraft. Neil Armstrong made seven test flights in an X-15. (See Appendix B11)

Hawker Siddeley Harrier

The Hawker Siddeley Harrier was the first generation of Harrier aircraft with vertical/short takeoff and landing capability. It was capable of being used as operational close-support and reconnaissance fighter aircraft. The Harrier was the first successful V/STOL aircraft of the time (late 1960s) and rapidly accelerated this age of aircraft. (See Appendix B12)

Concorde

The Concorde is a supersonic turbojet passenger aircraft. Only 20 were ever built, however they flew regularly for 27 years. The most common route was from Paris to New York. This flight could be completed in 3.5 hours at an average speed of 1334 mph and an altitude of 60,000 ft. The Concorde was retired after lack of interest and high maintenance costs but it still remains an amazing aircraft with a significant impact on aerospace. (See Appendix B13)

Boeing 747

The Boeing 747 is arguably the world's most recognized aircraft. It is a four engine passenger aircraft that first rolled out in 1970 and is still widely used today. A distinguishing feature of the

747 is the hump in the front of the plane. This was designed as second deck first class lounge or extra seating. (See Appendix B14)

SR-71 Blackbird

The SR-71 was a long range strategic reconnaissance aircraft developed by Lockheed Skunk Works. The plane was capable of consistently flying at M3+ and could outrun missiles. It has been the fastest air-breathing manned aircraft since 1976 and still holds numerous speed records. The Blackbird saw service from 1966 to 1998 and resulted in amazing advances in stealth, materials, and propulsion. (See Appendix B15)

F-16 Fighting Falcon

The General Dynamics F-16 Fighting Falcon is a multirole fighter aircraft. Over 4,500 of these aircraft have been built since 1976. Innovations in its design include a frameless bubble canopy, side-mounted control stick, a 30 degree reclined seat (which reduces g-forces), as well as a relaxed static stability/fly-by-wire flight control system. It is still a very popular air superiority fighter today. (See Appendix B16)

Lockheed C-5 Galaxy

The C-5 Galaxy is a military transport aircraft. It is among the largest military aircraft in the world. It is capable of carrying a payload of 270,000 lbs. This aircraft boasts really impressive numbers from its size and carrying capabilities. (See Appendix B17)

Lockheed F-117 Nighthawk

The F-117 Nighthawk is a stealth ground attack aircraft. It first flew in 1981 and saw action in the Persian Gulf War. The Nighthawk uses sharp angles with flat surfaces to deflect radar signals and resulted in a dramatic increase in radar stealth technology. The plane’s looks make it very intimidating and it is one of the more unique looks to aircraft. (See Appendix B18)

F/A-18 Hornet

The McDonnell Douglas F/A-18 Hornet was introduced in 1978 as a supersonic, all-weather combat jet. It was capable of Mach 1.8 and was known for its proven versatility and reliability. For this reason it is still widely used today. It was upgraded in various redesigns since its introduction but is still in service by the US Navy and Marine Corps. The F/A-18 Hornet is really the quintessential fighter jet today. (See Appendix B19)

B-2 Spirit

The Northrop Grumman B-2 Spirit showcases the futuristic flying-wing design. Known as the Stealth Bomber, the B-2 featured extremely low observability and the ability to carry up to 80 conventional guided bombs or 16 nuclear weapons. It could attack with deadly precision from altitudes of 50,000 feet and had an unrefueled range of 6,000 miles. Only 21 were built due to high cost with budget cuts and the end of the Cold War. The B-2 Spirit first saw service in 1997 and is only flown by the United States Air Force. (See Appendix B20)

C-17 Globemaster III

The Boeing C-17 Globemaster III is a very large military transport aircraft. It is the primary cargo transport aircraft for the United States and has unique engines with the ability to reverse thrust, allowing the plane to descend faster and even go in reverse on the runway. It is capable of transporting a 69-ton M1 Abrams battle tank as well as other armored vehicles. It was designed to be able to take off from short and rough runways, making it an ideal combat transport plane. The C-17 Globemaster III entered service for the USAF in 1995. (See Appendix B21)

MQ-1 Predator

The General Atomics MQ-1 Predator is a great example of where aircraft are today. This unmanned aerial vehicle (UAV) was first introduced in 1995 and has seen only increased use since. It was originally only a reconnaissance and observation aircraft but was later equipped with hellfire missiles. In Afghanistan, it was the primary unmanned aircraft used by the CIA and USAF. The MQ-1 Predator was the first successful UAV, initiating the push toward unmanned aircraft that we are in the midst of today. (See Appendix B22)

Boeing V-22 Osprey

The Bell Boeing V-22 Osprey is the most known tilt-rotor aircraft. It is capable of vertical take-off and vertical landing but tilting its rotors forward and up. The idea is to combine the functionality of a helicopter with the long range and higher cruising speed of a turboprop aircraft. (See Appendix B23)

MQ-9 Reaper

The General Atomics MQ-9 Reaper is a larger, heavier and more capable version of the MQ-1 Predator. The Reaper entered service with the USAF in 2007 and shows the progress made in UAVs since the Predator. The Reaper can carry 15 times the payload of the Predator and can fly at three times the speed. (See Appendix B24)

F-22 Raptor

The Lockheed Martin F-22 Raptor is the latest in manned fighter jet technology. It was introduced in 2005 as part of the fifth generation fighter. The Raptor is currently the most advanced fighter aircraft in the world. Its combination of stealth, speed, agility and precision are unmatched. A major advancement shown by the F-22 is thrust vectoring. The ability to vector the thrust of the twin engines of the aircraft give the Raptor superior maneuverability in aerial warfare. (See Appendix B25)

F-35 Lightning II

The Lockheed Martin F-35 Lightning II is still in its testing phases. It is similar to the F-22, although smaller. What differentiate the F-35 from the F-22 are its different models in development. They comprise a short take-off and vertical-landing model, a conventional take-off model and a carrier based model. The vertical-landing model builds on the Harrier, while greatly increasing its effectiveness. (See Appendix B26)

Rocket Exhibits

Rockets to include in some form in the museum. Corresponding images can be found in Appendix C.

Fireworks:

The first place to look when examining the history of the rocket is fireworks. Fireworks date back to the 7th century in China. These fireworks were propelled by the simplest of gunpowder rockets. Essentially, this is what Robert Goddard started with when making his first rocket designs. He theorized that this method of propulsion could get a craft to the moon. (See Appendix C1)

Goddard Solid Fuel Rocket

This was Goddard's first rocket idea. Drawing from how a firework operates, he thought that a series of gunpowder explosions could periodically accelerate a rocket into the sky and even to the moon. After many failed tests, the idea was abandoned for this type of rocket to reach very high into the atmosphere. The idea was not completely scratched however, as some uses for solid fuel rockets did arise. (See Appendix C2)

Bazooka design

The Bazooka was the idea of Robert Goddard during the First World War. It was a rocket-powered recoilless weapon that could be used against enemy personnel, tanks and armored positions. Goddard worked on this project while working at both Clark University and in WPI's magnetics lab. During this time, he developed the tube-fired rocket for the United States military. On November 6, 1918, the bazooka was successfully demonstrated to the US Army. However, the First World War ended only five days later and the project was discontinued. (See Appendix C3)

Goddard Liquid Fuel Rocket

The first liquid fueled rocket took flight in 1926. This flight made Goddard known as "the father of modern rocketry." On a farm in Auburn, Massachusetts, Goddard's first liquid fuel rocket to take flight launched 41 feet into the air. Although the first launch only rose 41 feet, the same technology used there took man to the moon only 43 years later. This revolution in propulsion was the beginning of the space age. (See Appendix C4)

V-2

The V-2 rocket was the first long range ballistic missile. They were used heavily by Nazi Germany to attack London toward the end of the Second World War. It is also the first manmade object to enter outer space. The V-2 rocket was very advanced and its design actually ties back to Robert Goddard. Goddard offered his help to German scientists who asked for help with rocket designs before the United States entered the war. Little did Goddard know until after the war ended, the V-2 was almost exactly his own design. The V-2 is really the last direct relation between Goddard and rocketry because he died at the end of WWII. (See Appendix C5)

Mercury Redstone

The Mercury Redstone launch vehicle was the first American manned spacecraft. During the year of 1960, six suborbital launches were made. Shortly after, the Mercury Redstone launched the first and second Americans into space. The launch vehicle was designed from the Redstone ballistic missile but also included more safety features and a modified structure. (See Appendix C6)

Gemini Titan II

The Titan II Gemini Launch Vehicle was responsible for ten manned missions to space. It was a two stage liquid fueled rocket designed from the Titan II missile. This launch system featured a malfunction detection system that could inform the crew of emergencies. Another added safety feature was system redundancy, which meant a greatly reduced occurrence of launch failure. It also featured hypergolically fueled engines which use far less components than the previous engines. The Titan II flew 12 missions from 1964 to 1966. (See Appendix C7)

Saturn V

The Saturn V is the rocket that first brought man to the moon. It was used by the NASA Apollo and Skylab programs. The Saturn V is still the tallest, heaviest, and most powerful rocket ever built. It is the only launch vehicle to transport Americans beyond low Earth orbit, and transported 24 astronauts to the moon over a four year span. The Saturn V is still the most powerful machine ever built by mankind based on its power output. The scale of the rocket is truly something that everyone that visits this exhibit should understand. (See Appendix C8)

Space Shuttle

The Space Shuttle first launched in 1981, twenty years after the first man was put in space. It was the first partially reusable launch system, designed to fly back to Earth like a giant glider and land on a runway. The Shuttle program launched over 130 missions over a span of 30 years. It is also the only launch system that was manned on its first ever launch. Four operational orbiters were originally built, Columbia, Challenger, Discovery, and Atlantis. The Challenger accident in 1986, in which seven astronauts were killed, led to the creation of the orbiter Endeavour. Another disaster in 2003 with the Columbia orbiter left seven more fatalities. (See Appendix C9)

SpaceX Grasshopper

The Space Exploration Technologies Grasshopper design is for a completely reusable rocket. Unlike the Space Shuttle, every stage of this design is reusable. The product is currently well into testing and significant progress had been made this year alone. The idea is to land each stage vertically on a launch pad with the use of its thrusters. If successful, these rockets could reduce the cost of a rocket launch from about $50 million to simply the cost of fuel, which is a mere $50,000. Such a milestone would surely relight the Space Age that has faded since the end of the Cold War. (See Appendix C10)

Space Launch System

The Space Launch System, or SLS, is the new project from NASA. It is due to be the replacement to the Space Shuttle which is now retired. The SLS is a heavy launch system that will be able to be upgraded over time. The second planned version will be capable of a higher payload than the Saturn V, at 130 metric tons. It is also planned to be able to take astronauts beyond low Earth orbit to destinations such as the Moon, Mars and asteroids. The first flight is scheduled to take place at the end of 2017. (See Appendix C11)

Miscellaneous Items and Ideas

The following are a variety of items and ideas which do not quite fit in with the preceding subsections, but are worthy of noting.

Quote over Writings

"*It is difficult to say what is impossible, for the dream of yesterday is the hope of today and the reality of tomorrow." –Robert Goddard, High School Oration Speech*

The above quote was said by Robert Goddard in his high school Graduation speech. The quote is very powerful and really shows the motivation and mindset of Goddard even from a young age. As an important theme to the exhibit, this quote could be placed on a wall of the museum in large font that is raised out of the wall. Behind the quote on the wall would be hundreds of pages of Goddard's lab notes and writings. The papers would be normal sized and people would be able to walk up to the wall and actually be able to read some of Goddard's work. This would provide an understanding of how much Goddard did during his life in order to progress the field of rocketry.

Image Comparing Altitudes

This image would be a cross section of the atmosphere. On the bottom would be the surface of Earth and on the top would be a low earth orbit. On this image, a small picture of each air and spacecraft mentioned in the exhibit will be placed at the service ceiling for that aircraft. For airplanes this will simple show the plane flying horizontally with a small text saying the altitude at which it flies. For the rockets and spacecraft, a basic trajectory could be drawn showing the path they take to their target. The International Space Station could be the furthest point on the map as a comparison for the rest of the vehicles. Of course, this image would be created to scale so that guests can appreciate the size of the atmosphere as well as how we have concurred it since Goddard's time of birth.

Room on Goddard's forward thinking ideas:

This idea is for a side exhibit in a room on one of the wings of the museum. In the room, we would display how Goddard was thinking into the future. One of his ideas to display would be a vacuum tube transportation system. Goddard wrote about this in a 1905 paper which focused on travel in the year 1950. He talked about traveling in a train-like vehicle inside a vacuum tube at very high speeds. Recently, entrepreneur Elon Musk revealed plans for a similar system called the Hyperloop. This system is very similar to Goddard's and it is crucial to compare the two when discussing Goddard's ability to visualize what will be engineered in the future. As a hands-on demonstration of this idea, a simple tube and vacuum vehicle could weave around the room. This would be similar to the tubes used at a bank drive-thru. Goddard also made a point in his writings to discuss survival in space. He theorized that some form of pressurized space suit would be needed in order for a human to survive this could tie into the David Clark Company space suit exhibit. Another item that could be included in this room would be the NY Times article that slams Goddard's idea for space travel. The article goes to show how outlandish the idea of space travel was at the time and that Goddard faced constant disbelief in his work.

David Clark Company Exhibit

The David Clark Company is based in Worcester and specializes in pressurized suits for pilots and astronauts. The company has voiced that it would be ready and willing to assist this exhibit in creating high fidelity replicas of some of their suits for the exhibit. This side exhibit could be all about survival in space and the challenges that the space environment creates. The David Clark Company created the suits worn by Space Shuttle Astronauts as well as a few of the experimental planes under the aircraft section of the museum. The company also suggested that some employees may volunteer to give lectures or presentations on survival in space.

Local Map

A map of the local area with significant places from Goddard's past would also suite this museum. The map could be located at the end of the desired path so that people will be already exposed to the locations mentioned throughout the exhibit. Locations to include on this map are WPI, Clark University, the location of Goddard's childhood home and the farm where he first tested his rockets. Other relevant locations could also be included.

Sci-fi Influence

A display that explains the influence of science fiction writings on Robert Goddard would also be a good asset to the museum. Goddard wrote about his interest in reading books from Jules Verne and H.G. Wells. These authors were very popular at the time and their futuristic themes surely had an influence on Goddard that is worth mentioning in the exhibit. To sell some of their hit books in the museum store is also a good idea.

Narrative

We jumped into A term by determining how we wanted to conduct each meeting. We set up a meeting each week, in which one person would lead the group meeting, while another group member would be responsible for taking meeting minutes. Our intention was to have the leader of the meeting and the person taking minutes to change each time. We determined that there were a few people we needed to get into contact with, especially Mott Linn at the Clark archives, Dan Benoit, the architect on the project, and Hunter Chaney from the Collings Foundation. We met Hunter Chaney while the Collings Foundation made a stop in Worcester on their Wings of Freedom tour. This was a nice introduction, but a later tour of the Collings Foundation facility would be necessary. After a tour of the Worcester Auditorium, we met with Dan Benoit to get his thoughts on the project, since this museum was originally his idea. We had difficulty in getting into contact with Mott Linn, and later discovered it was because we needed to get into contact with Fordyce Williams instead. The next step we took was learning about the local curriculum, since the primary purpose of this museum was to add and enrich the history and science curriculum of schools in the area. This is something that we will get into later. Overall, Mercik determined the 7th grade curriculum would be potentially the easiest to tie in with our exhibit. In addition, we need to take into account the standardized testing scores of the kids in the local districts, since while a third are demonstrating complete understanding, another third demonstrates a complete lack of understanding, while the remaining third is somewhere in the middle.

Mercik, Aleles and Tripp met Hunter Chaney at the Collings Foundation's Worcester stop on their Wings of Freedom tour on September 15th. We established contact with the Collings Foundation, and gained their contact information. We also got to view the parts of their collection that they brought along, and get an idea of how they would be able to help us. At the exhibit they had a P-51, B-24, B-17, M16 Half Track and a Sherman tank. While these aircraft may not be one's that we would be interested in using the Goddard exhibit, the Collings Foundation should be able to help us determine how we would be able to acquire the aircraft and rockets that we are interested in.

Aleles discovered that Clark has an archive dedicated to Robert Goddard, with notes, lab materials, diaries, and news clippings, which we intended to draw upon and utilize within the exhibit. There are also some materials available in the WPI archives. At this point in the project we were brainstorming and developing basic ideas behind how we could present the layout of this exhibit. Some of the ideas we had included a wall of notes from his diaries and lab materials, and using the Little Theater to present a Goddard themed film of early flight and rocketry.

On the 23rd of September we took a tour of the Auditorium that we would be utilizing for this exhibit. It appeared as if the ceiling of the auditorium will require replacement, and so we intend on including that in our proposal, since this allows us the opportunity to make the auditorium more noticeable from afar, and attract more attention. There were side rooms that could be repurposed and converted into classrooms that could be used for demonstration of experiments, lectures or presentations, in order to make the exhibit school friendly. An idea that came up at this time was a small rocket demonstration. We also came up with the idea of leveling the balcony, and adding another floor to the exhibit. If we did so, we would need to rethink where we would be putting large objects and exhibits, like rockets and airplanes. We also concluded that the Little Theatre should be refurbished before we use it.

In addition, it was discussed at this time tying the first floor in with what will be going in on the floors below, the Lunar and Mars bases. An educational session in which kids consider transportation across the surface of the Moon could a potential way of doing this.

Moving on, the next step was doing in depth research. This started in the WPI Archives with *The Man Behind the Rocket*, by Leonard M Fanning. Most notable from this research was a paper Goddard wrote as a freshman, detailing how he imagined travel in the 1950s: a train that ran in a vacuum rather than on tracks, which would move very quickly, potentially able to travel from Boston to New York in 10 minutes.

At this time Tripp had attempted to contact Dan Benoit, but was unsuccessful. He was also trying to contact Hunter Chaney to make arrangements to meet them for the World War II reenactment that the Collings Foundation was to be putting on at their location in Stores.

When we met next we looked back at what we had gotten done during the term, and set some goals for the next two terms of the project. We set our goal for B term to have a floor plan for the auditorium, so that C term could be spent writing our project narrative. In addition, we planned on having an inventory list of things that we could display, along with methods to make the exhibit interactive with the students.

In November, we met twice a week to keep progressing through the project. We continued looking for the small details of Goddard's life that would give a visitor to the exhibit as much information about the life of Goddard as possible. *This High Man* was the perfect place to find these details. At the beginning of November, we also contacted the developer of Kerbal Space Program to find out about using the program as an interactive exhibit on tours. We also began working on the three-dimensional renderings of the exhibit. We continued to struggle with contacting Hunter Chaney. During this time, we also discussed the possibility of creating a space travel exhibit based on Goddard's talks about survival during space travel and suspended animation.

Also in early November, we decided that it would best if we split up the main topics of the project. This meant Tripp would focus on the items for the exhibit and the building itself. Mercik would focus on the curriculum aspect, while Aleles would focus on the specific aspects of Goddard's life that could be included in the exhibit. At this time, a basic flight simulator, Kerbal Space Program, was proposed as a means to engage kids in the material. We decided that we should try to contact the developers of Kerbal Space Program to see if educational versions of the simulator exist. We also continued to try to contact Paula Proctor, from the WPS system, as well as Hunter Chaney from the Collings Foundation.

In mid-November we made good progress on the project. Aleles gathered ideas from the book, "This High Man." We tossed around the idea of bringing a cherry tree into the exhibit since it is said that Goddard's transforming moment was when, as a child, he sat high in a cherry tree and stared at the moon. We also contemplated what we could show for a film In the Little Theater. We decided that the best option would be a short documentary, of perhaps 20 minutes, that detailed the advancements of flight during Goddard's lifetime. At this time, we also began discussing some items that could be included in the museum, such as a large map that displays the altitudes that certain air and spacecraft fly at. The image would give perspective as to how far away the moon is and how high some planes can fly. The David Clark Company was also mentioned. The David Clark Company designs and manufactures space suits of all kinds and is located right here in Worcester. We decided to try to contact them to see if they would be willing to contribute to this exhibit if it were to happen. Another idea that was mentioned was creating a section on how some of Goddard's ideas appear in the future. An example of this was when in 1905 he talked about a vacuum tube transportation system much like the Hyperloop that was theorized recently.

Toward the end of November, we heard some valuable information from other organizations we were in contact with. Aleles made it to the Clark University Archives to look at their Goddard Collection. Tripp made contact with the David Clark Company who was extremely helpful. If the exhibit was to be built, they expressed interest in providing a gallery on space suits and space environments. They also then put us in contact with Mr. William Wallace of the Worcester Historical Museum. They also mentioned the possibility for providing occasional lectures on protecting the human body in space. Mercik heard back from the developers of Kerbal Space Program and found out that an educational version was in the makings and could be purchased for a discounted price for use in our exhibit.

Coming into December, we started compiling our work thus far and seeing what else needed to get done. We took some time to create a list of what our final deliverables would include at the end of C term. Tripp started compiling his list of aircraft and spacecraft to include in the exhibit. Bacon showed continued to work on the 3-D model of the auditorium as well as looking into relevant patents from Robert Goddard. Mercik also looked more into the Kerbal Space Program simulator and found a download or a V-2 Rocket. This could be used in the computer simulation room to demonstrate how the V-2 worked, which was created from Goddard's designs.

With only a few weeks left in B term, we continued along with our parts for the project. We discussed together the layout for the exhibit and how we wanted people to move through it. We decided that a chronological flow seemed to make the most sense. We all also created flow diagrams so that we could see which layout worked best for moving through the auditorium.

The idea for having an area or room devoted to patents was also discussed and seemed like a good idea.

At our last meeting in B term, we talked about our progress with writing our parts of the project. Mercik and Tripp were making good progress with the writing. Aleles talked about his ideas for the film to be shown in the Little Theater and how we should decide what will be included in the video if it were to be made. We also shared our frustrations with contacting people such as Hunter Chaney of the Collings Foundation and the architect, Dan Benoit. At this time we also discussed which floor plan would be best for the flow of the exhibit based on the designs that we each came up with. We ended the term with checking what still needed to get done and discussing our progress through A and B term.

Conclusion & Recommendations

The Robert Goddard Aerospace Exhibit project has made substantial progress toward the goal of creating a museum dedicated to the "Father of Modern Rocketry." The project underwent numerous successes as well its fair share of complications. Overall, we have a strong vision of where the exhibit should go moving forward. This vision was shaped by our triumphs and realizations.

The project experienced many achievements throughout the duration. Early on, we were able to visit the Wings of Freedom Tour that the Collings Foundation runs, as well as visit the Worcester Memorial Auditorium. The Wings of Freedom Tour gave us a glimpse into what the Collings Foundation had to offer as well as allowed initial contact with Hunter Chaney. The group had a great time at the event and seeing the interest levels in the sizeable crowd was very encouraging. Our visit to the auditorium was also a high point in the project. We were able to see what we were dealing with, and in a sense view the empty canvas with which we were to work. A meeting with local architect Dan Benoit was also organized early in the project. This meeting was very interesting because we got to hear from the man who first proposed this project about his ideas for altering the auditorium itself. We enjoyed his ideas and decided to incorporate many of them in our plan for renovating the building. We also had much success with finding interesting items for the exhibit. Some great sources, such as the book, "This High Man," as well as the Clark Archives were very helpful in digging into Goddard's past. Some documents at the Clark Archives were too specific for our purpose of finding exhibit items, so we found it wise to avoid reading endless diary pages. The rocket simulator, Kerbal Space Program, was a great find for our exhibit. It was great to find a simulator that is student friendly but still has the science to back it up. When it came to physical items to put in the exhibit, our greatest success came from The David Clark Company. This Worcester company was fully supportive of our project and expressed interest in helping with a space environments exhibit involving their work as a company. Their eagerness to help really motivated the group and reminded us of the importance of this exhibit.

While the project went well overall, we did experience troubles along the way. One of these troubles came in the way of communication with people outside of the group. While we were able to make first contact with both Dan Benoit and Hunter Chaney, it was difficult to maintain contact with them. Both were unresponsive to our attempts at communication after our initial meetings with them. This was very unfortunate because we would have benefited from exchanging ideas back and forth with them. Also, the Collings Foundation was initially interested in displaying some of the aircraft shells they possess as well as helping us find replicas of other aircraft. It was disappointing to have communication cut off with our main leads at such an early point in the project.

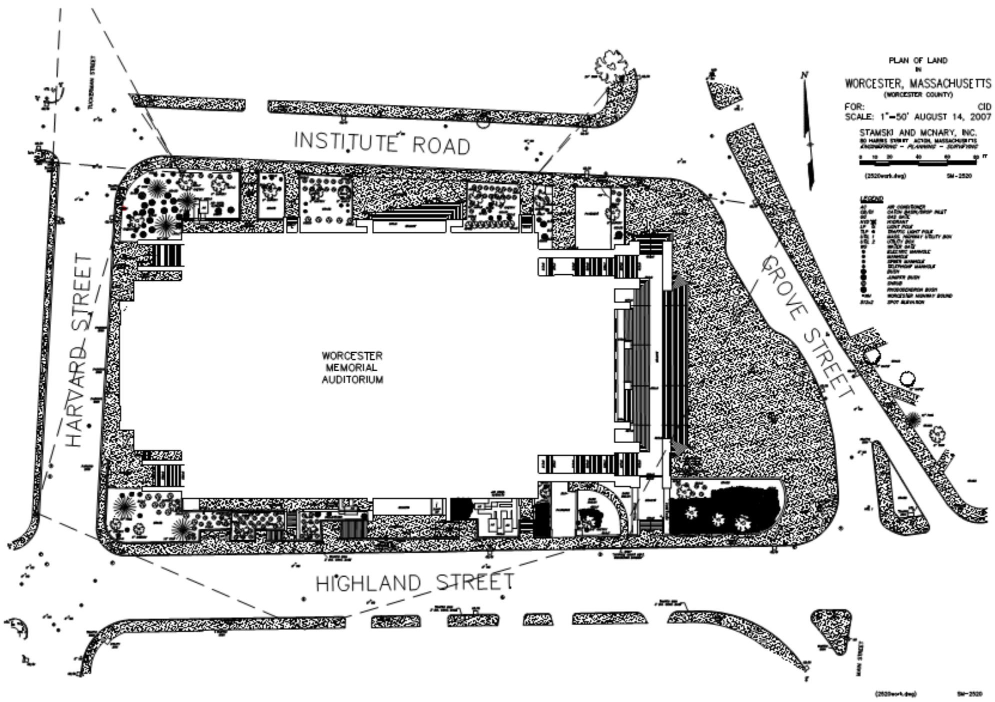
Our project was able to focus on key areas of the proposal for this exhibit. We gathered a list of aircraft, rockets, and other Goddard related items to go into the exhibit. We also studied the local curriculum of the Worcester Public School system to make sure our exhibit was relevant to our target audience, as well as studied the history of Goddard and his experiments. With this information, our exhibit ideas give the audience the perspective of travelling through the lifetime of Goddard and beyond. We also examined what modifications would need to be done to the auditorium to be used for this purpose while still maintaining the stature and significance that the auditorium has. Moving forward, there is more to be done to complete the exhibit proposal. With more time and resources, we would like to have created three dimensional renderings of what the exhibit would look like inside the auditorium. In order to do this, a complete layout throughout the space would need to be created. This would identify where all models of aircraft and spacecraft would go, as well as designate flow of visitors through the auditorium. We decided upon a chronological flow that moved through the space by decade, but were not able to finalize any plans. Another area that we did not cover in depth was the short film to be played in the Little Theater. The idea is to create a short (15-25 minute) film that is shown to visitors before they go through the exhibit. What to include in this video could be anything from a documentary about Robert Goddard or simply about the advancements made in aeronautics during his lifetime.

Having accomplished and learned so much, we now have a great idea of the feasibility of this project. Even though we have struggled with communication with some people and were not able to achieve everything that we wanted to in this project, we recommend that the project be continued by future groups. With a scope as wide as this project, we predict that a couple more projects could be created from this. One project could organize the flow and layout of the auditorium and work on three dimensional renderings. Another project could focus solely on the film to be showed in the Little Theater. The amount of interest in creating an exhibit dedicated to Robert Goddard and aerospace in Worcester is much higher than we anticipated. Goddard does not have his own dedicated exhibit anywhere in the world, so there is no better place than where it all began: right here in Worcester. With this information, we strongly recommend that additional work be completed on this topic and that a finalized proposal be completed that can be presented to the City of Worcester.

The Appendix

Appendix A: Existing Conditions of Worcester Memorial Auditorium

The following images were provided by the Worcester Memorial Auditorium Adaptive Re-use Study. These images demonstrate the current floor plans of the auditorium, and are intended for reference purposes.



EXISTING CONDITIONS - SITE PLAN

Worcester Memorial Auditorium Restoration and Renovation Study

LAMOUREUX PAGANO ASSOCIATES.ARCHITECTS

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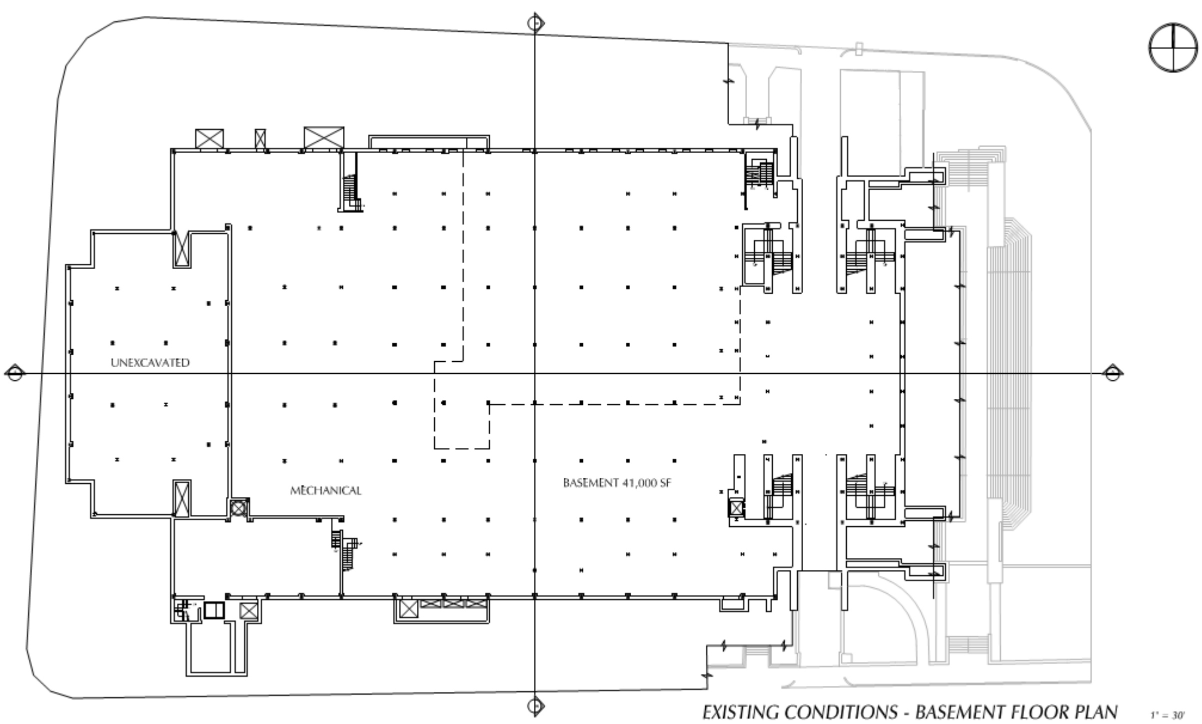

EXISTING CONDITIONS - BASEMENT FLOOR PLAN 1" = 30'

Worcester Memorial Auditorium Adaptive Re-Use Report

LAMOUREUX PAGANO ASSOCIATES.ARCHITECTS

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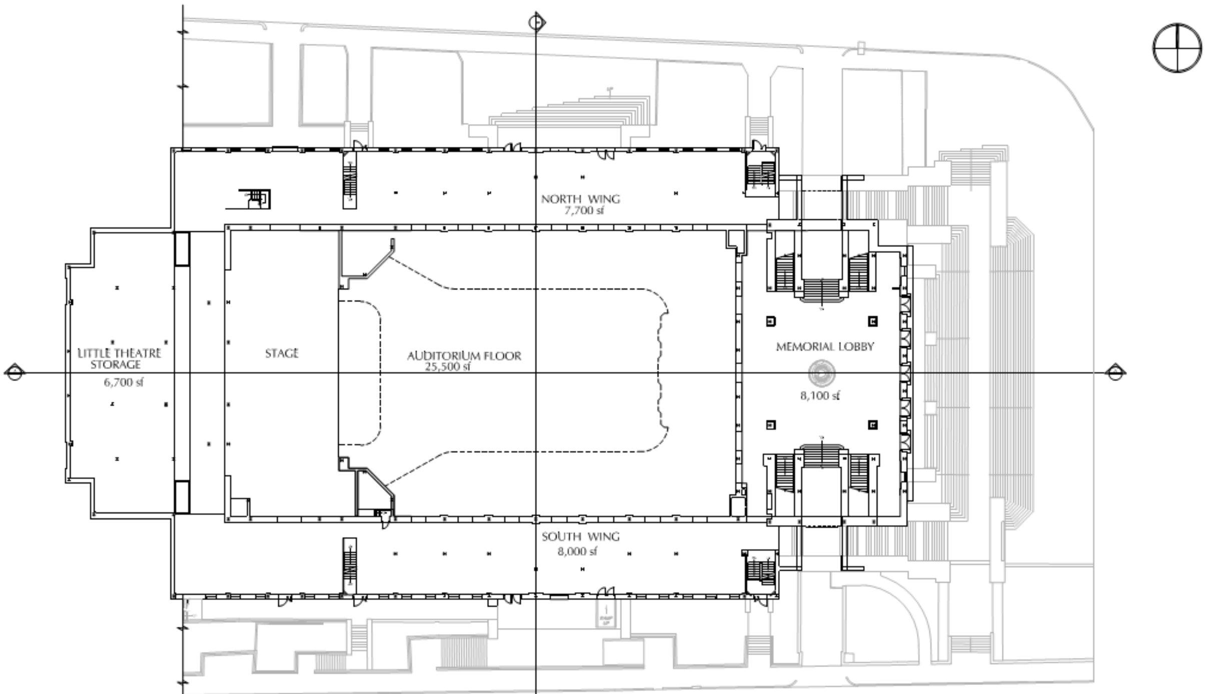

EXISTING CONDITIONS - FIRST FLOOR PLAN 1" = 30'

LAMOUREUX·PAGANO ASSOCIATES.ARCHITECTS

Worcester Memorial Auditorium Adaptive Re-Use Report

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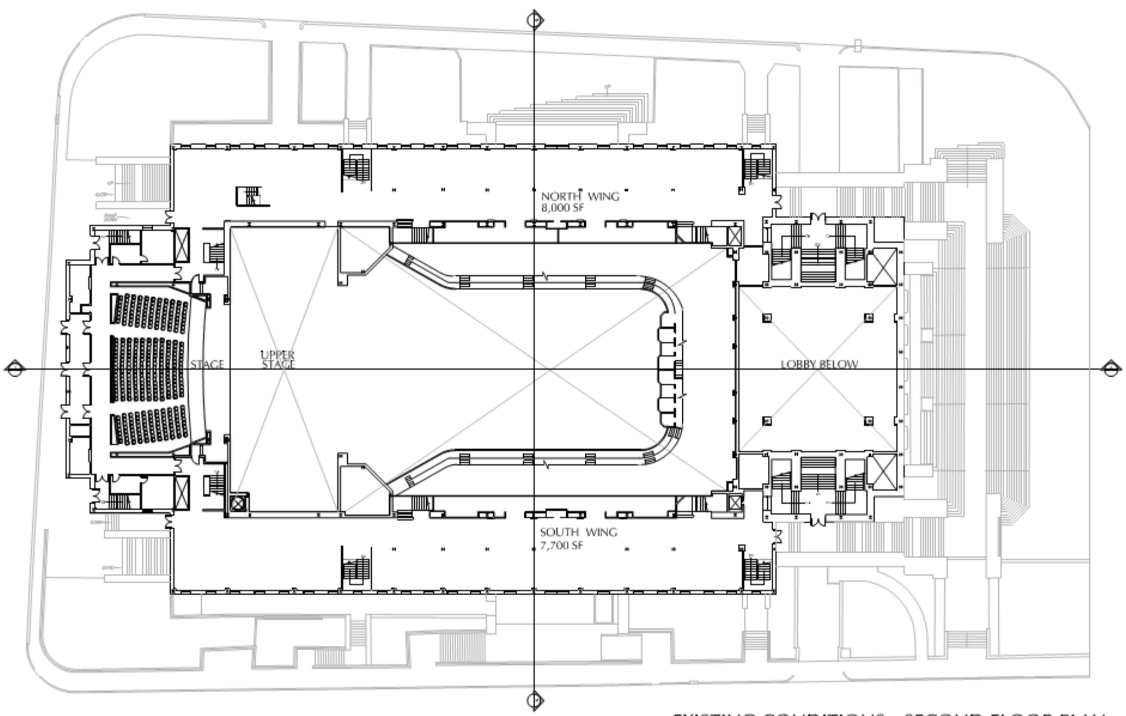
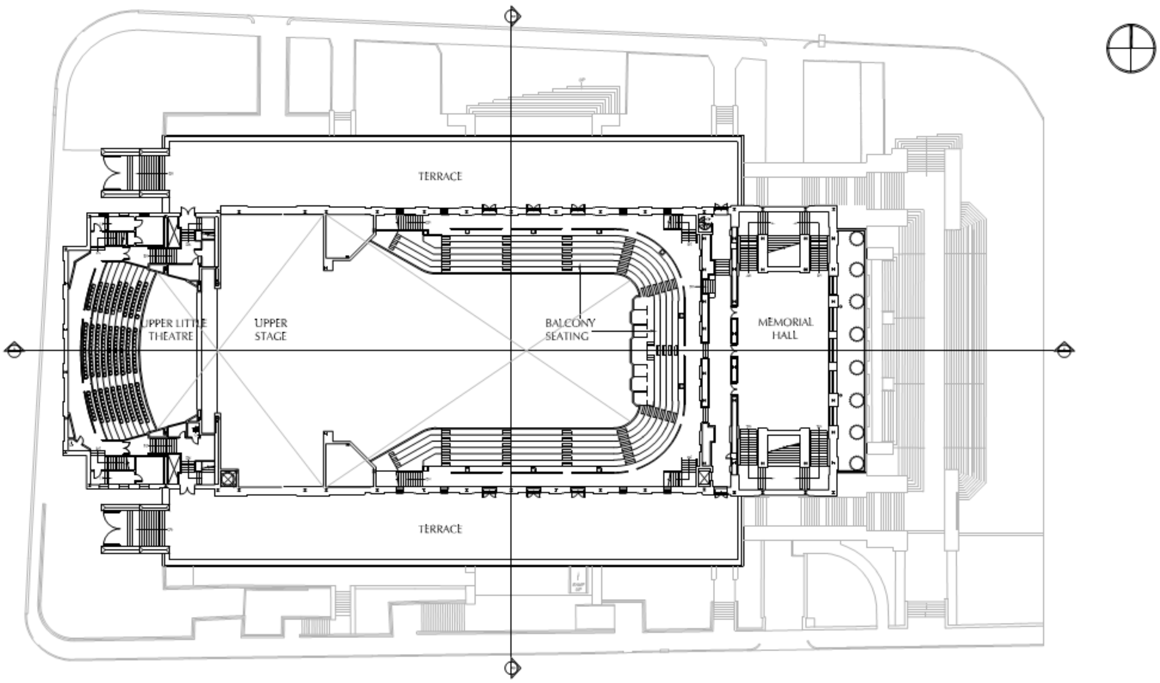


EXISTING CONDITIONS - SECOND FLOOR PLAN 1" = 30'

LAMOUREUX·PAGANO ASSOCIATES.ARCHITECTS

Worcester Memorial Auditorium Adaptive Re-Use Report

Page 14



EXISTING CONDITIONS - THIRD FLOOR PLAN 1" = 30'

LAMOUREUX PAGANO ASSOCIATES.ARCHITECTS

Worcester Memorial Auditorium Adaptive Re-Use Report

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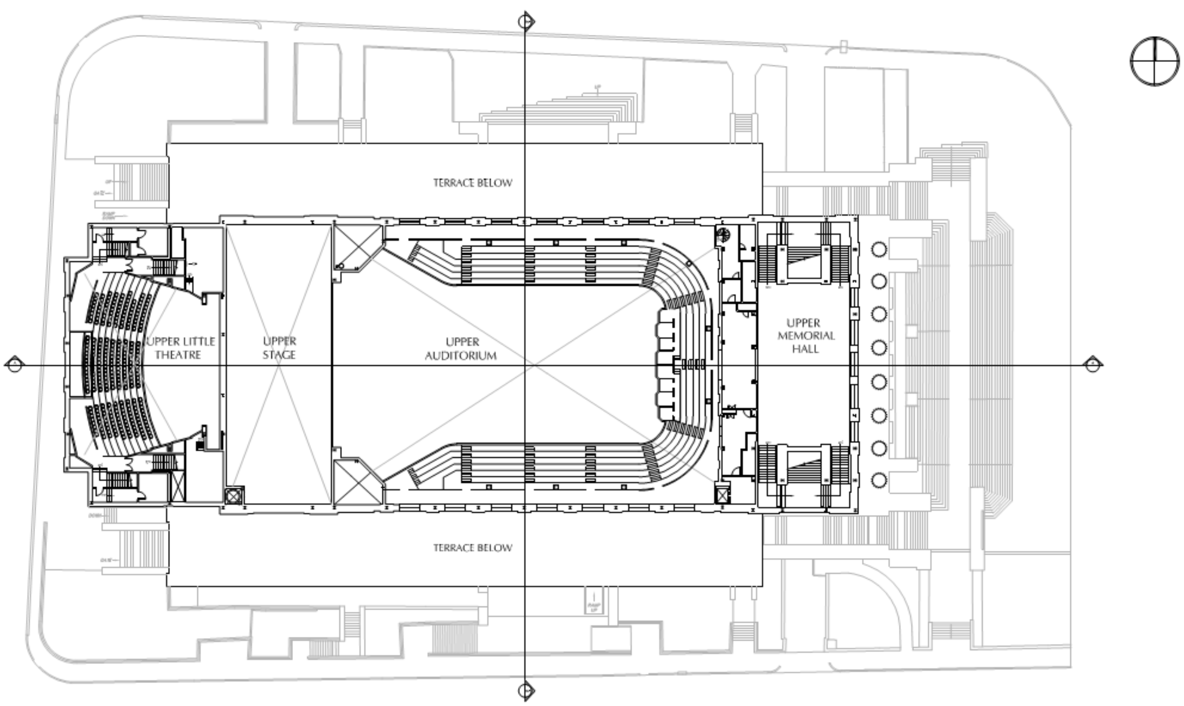

EXISTING CONDITIONS - PROJECTION BOOTH FLOOR PLAN 1" = 30'

LAMOUREUX PAGANO ASSOCIATES.ARCHITECTS

Worcester Memorial Auditorium Adaptive Re-Use Report

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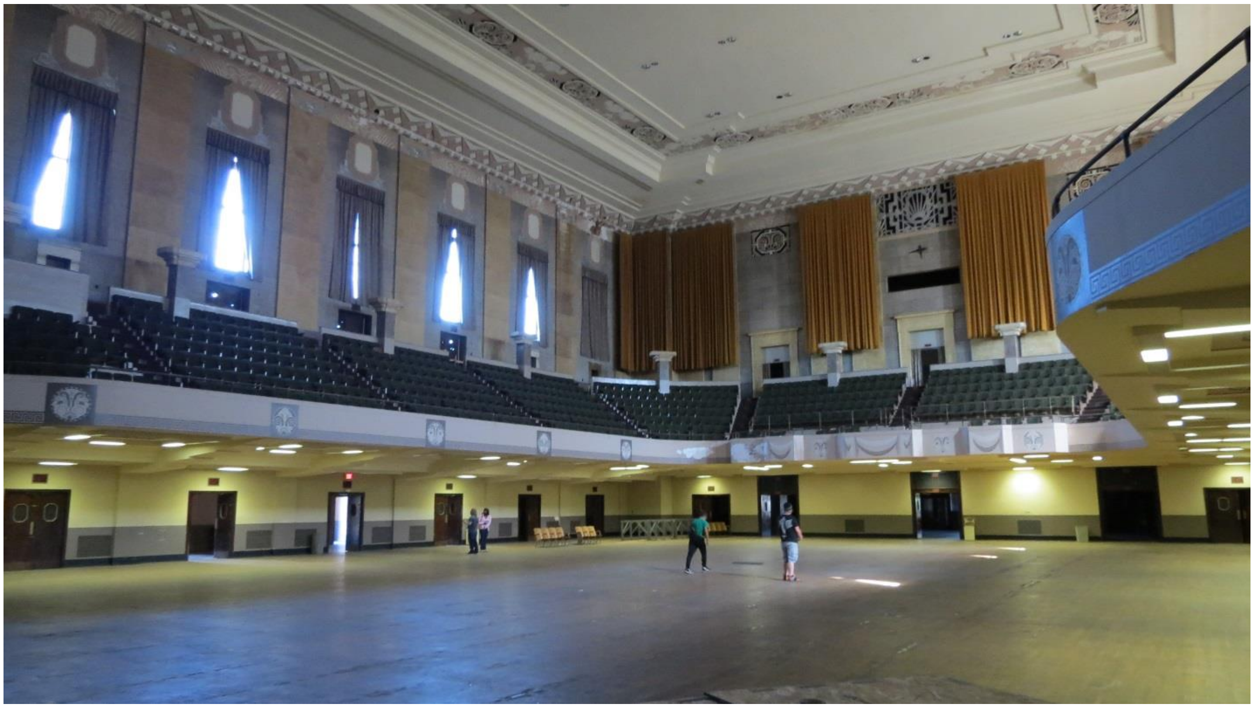
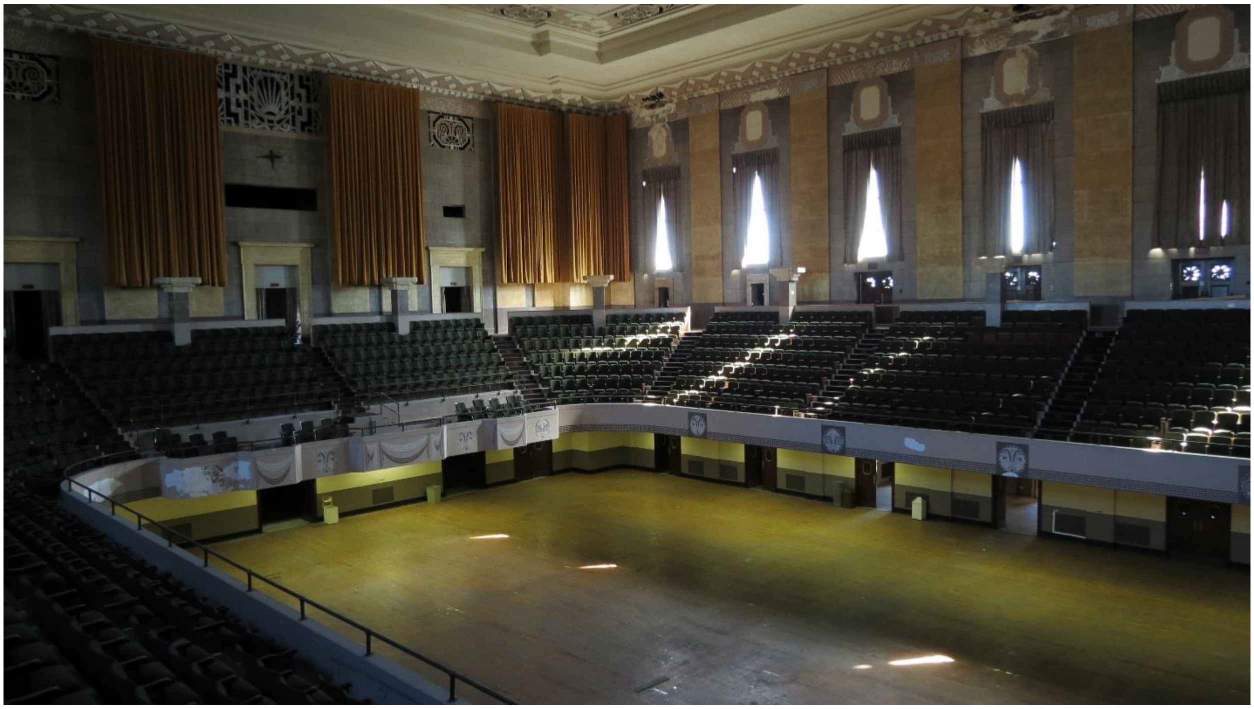
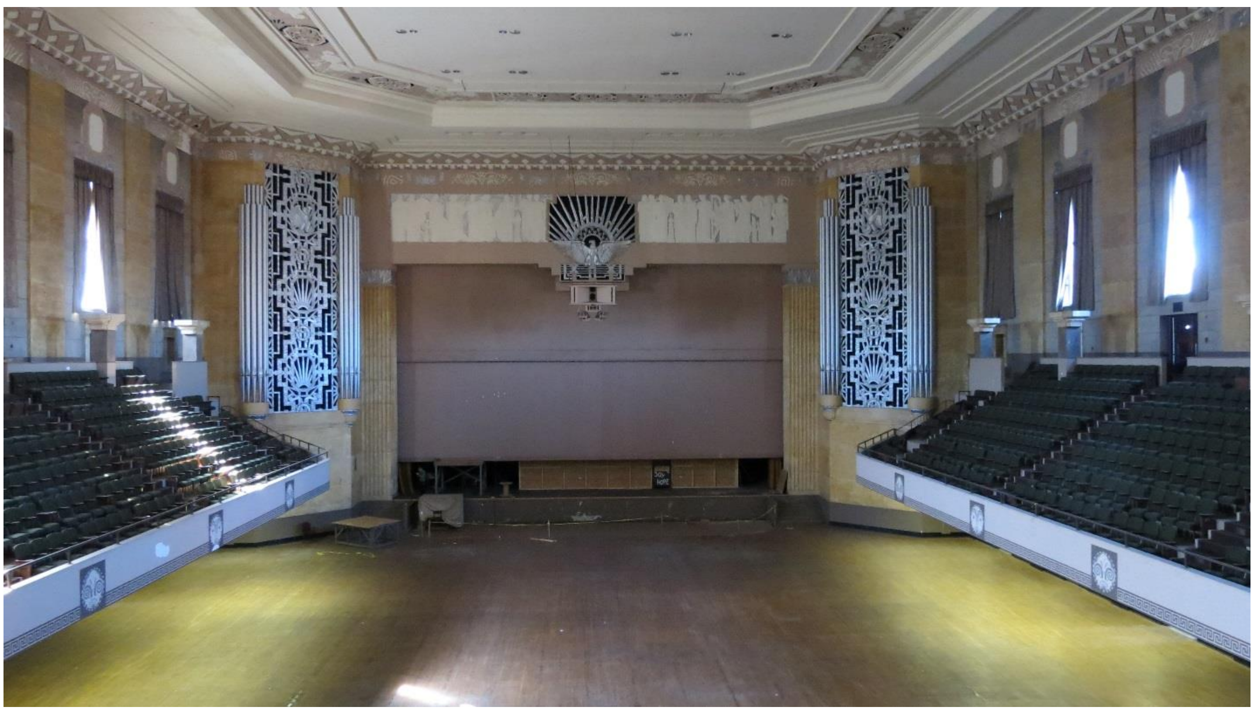
This second half of Appendix A consists of pictures that were taken by Tripp during our visit to the auditorium. They show the current state of the auditorium, and demonstrate the amount of repair that will be necessary.








PAX
VENTURED
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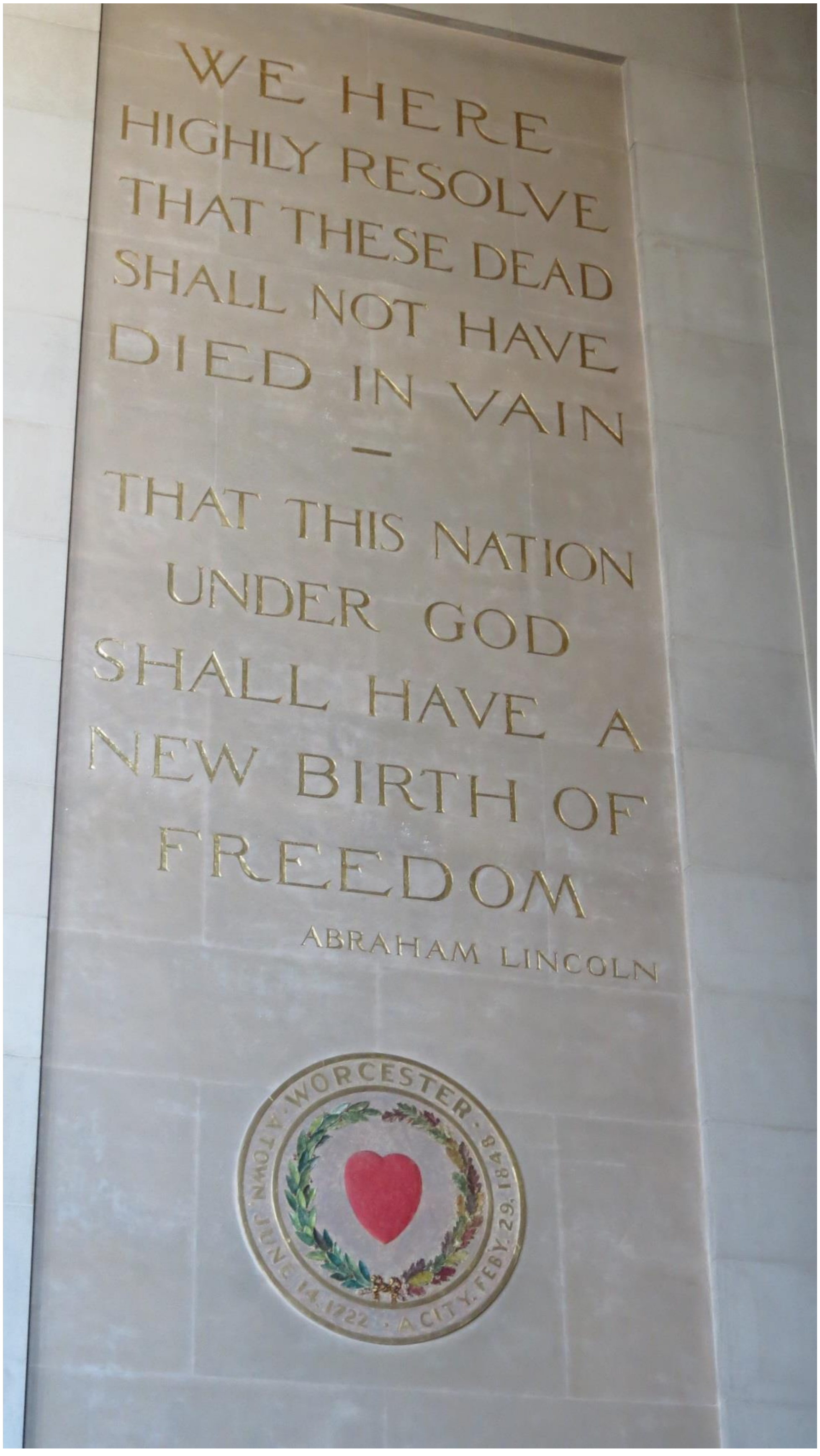
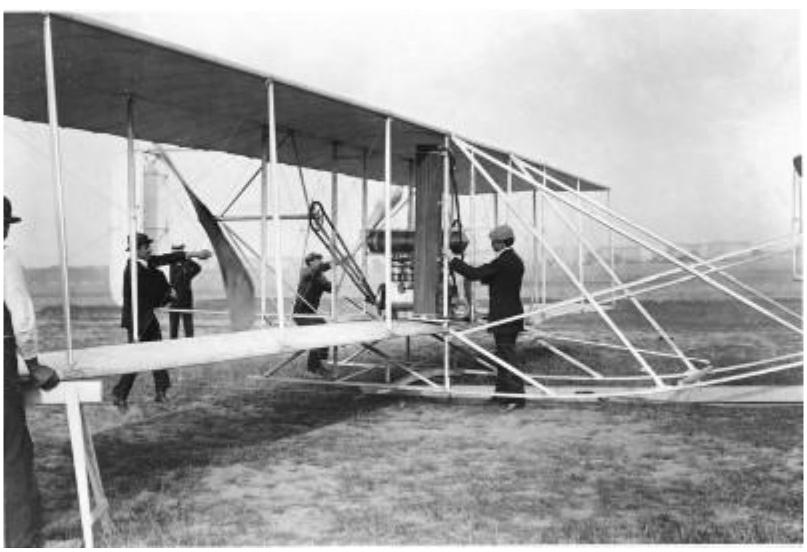

WE HERE
HIGHLY RESOLVE
THAT THESE DEAD
SHALL NOT HAVE
DIED IN VAIN
—
THAT THIS NATION
UNDER GOD
SHALL HAVE A
NEW BIRTH OF
FREEDOM
ABRAHAM LINCOLN
WORCESTER
A TOWN JUNE 14, 1722 · A CITY FEBY. 29, 1848

Appendix B: Aircraft Images

B1: Zeppelin:

B2: Wright Flyer:



B3: Bristol F.2 Fighter:

B4: B-17 Flying Fortress:

B5: Bell X-1:

B6: B-29 Superfortress:

B7: Boeing 707:

B8: Cessna 172:

B9: U-2:

B10: B-52 Stratofortress:

B11: X-15:

B12: Harrier:

B13: Concorde:

B14: Boeing 747:

B15: SR-71:

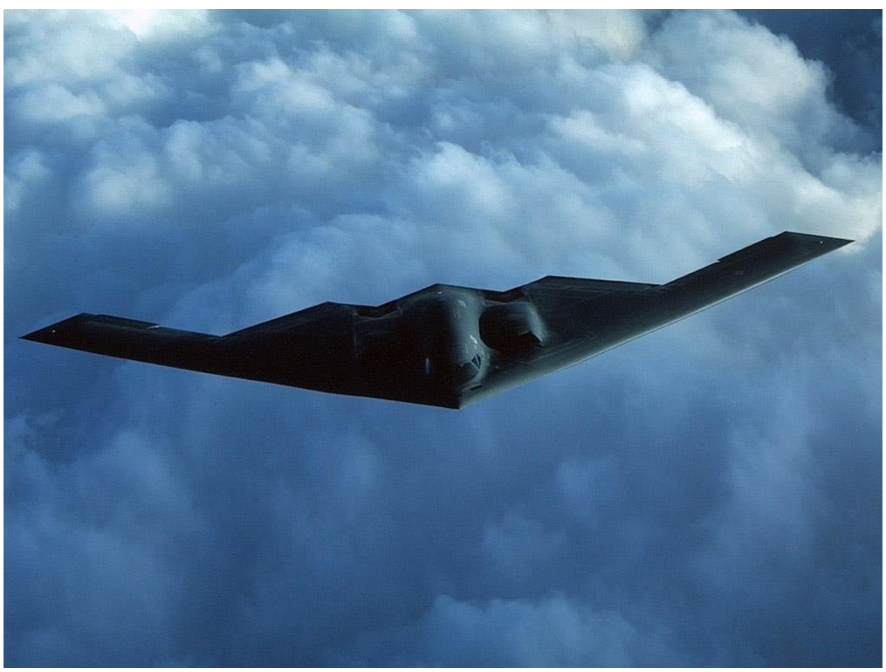
B16: F-16 Fighting Falcon:

B17: C-5 Galaxy:

B18: F-117:

B19: F/A-18 Hornet:

B20: B-2 Spirit:



B21: C-17:

B22: MQ-1 Predator:

B23: V-22 Osprey:

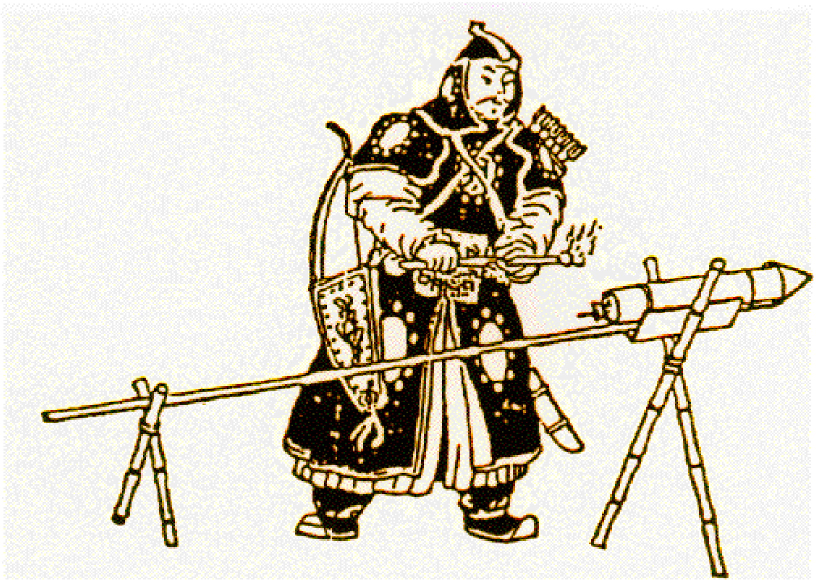
B24: MQ-9 Reaper:

B25: F-22 Raptor:

B26: F-35 Lightning II:

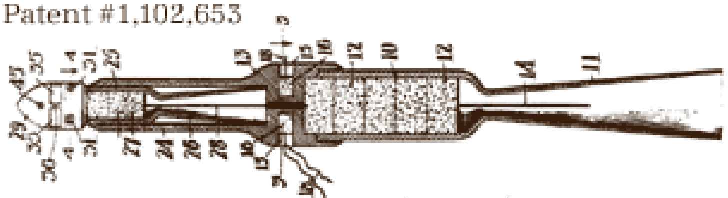
Appendix C: Rocket Images

C1: Fireworks:

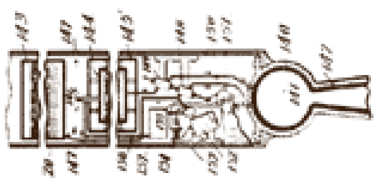


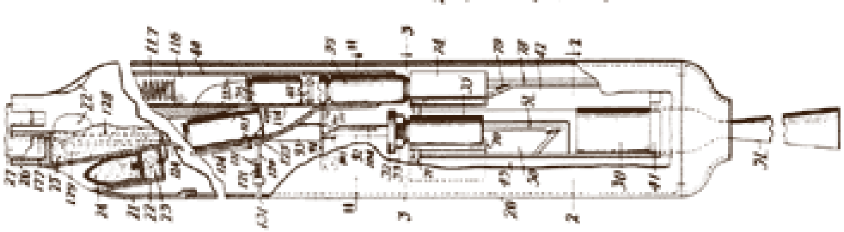
C2: Goddard Solid Fuel Rocket:

Patent #1,102,653

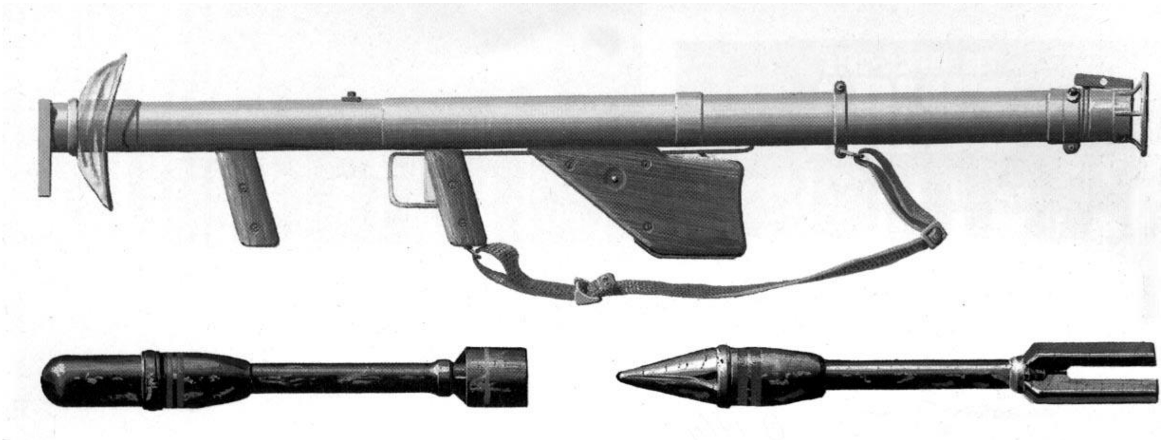


Patent #1,103,503



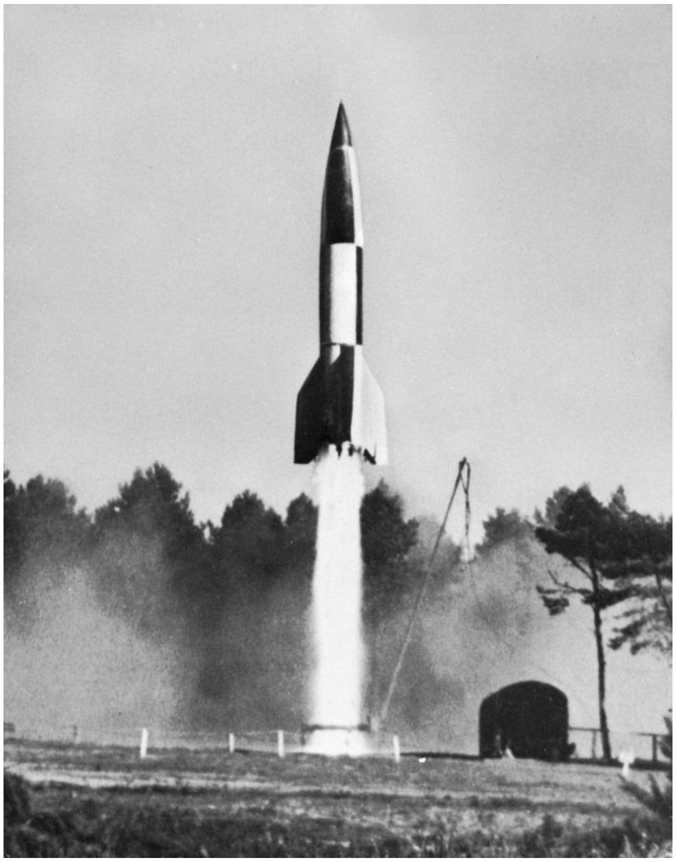


C3: Bazooka design:



C4: Goddard Liquid Fuel Rocket:

C5: V-2:



C6: Mercury Redstone:

C7: Gemini Titan II:

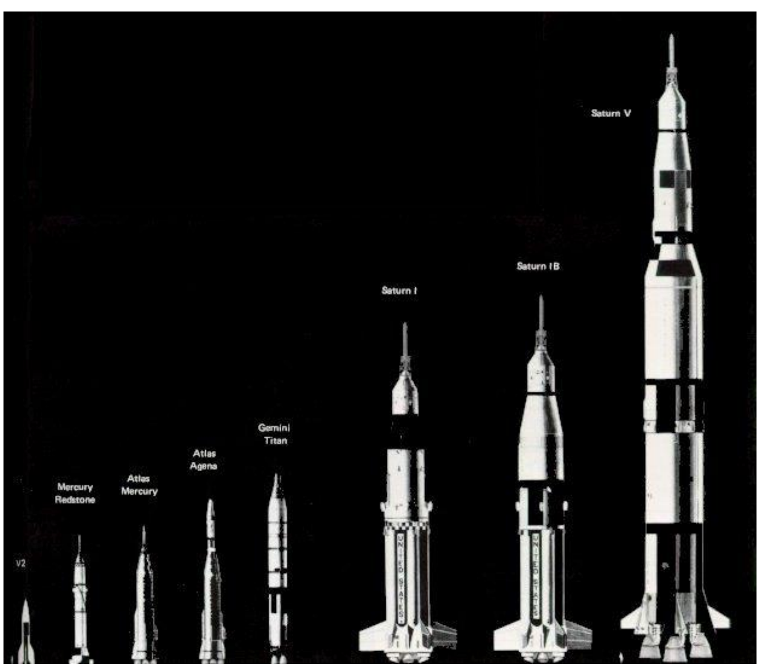
C8: Saturn V:

C9: Space Shuttle:

C10: SpaceX Grasshopper:

C11: Space Launch System:

C12: Comparison: V-2 is all the way to the left and Saturn V on the right



Appendix D: Wings of Freedom, Collings Foundation

Below are the images that were taken of the Collings Foundations Wings of Freedom Tour.


252534


Witchcraft


CM


massport
WORCESTER AIRPORT


252534
M


A
231909
R


PLANE SPONSORS


NINE
O
NINE


CM
Betty Jane

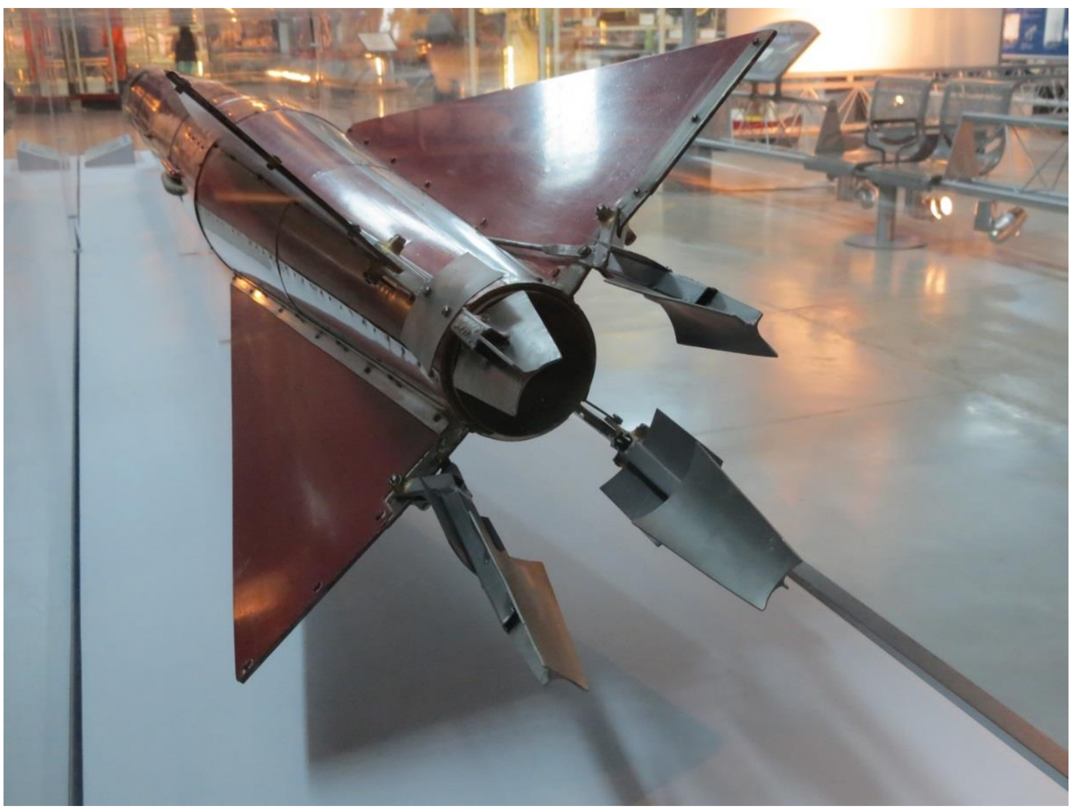

1

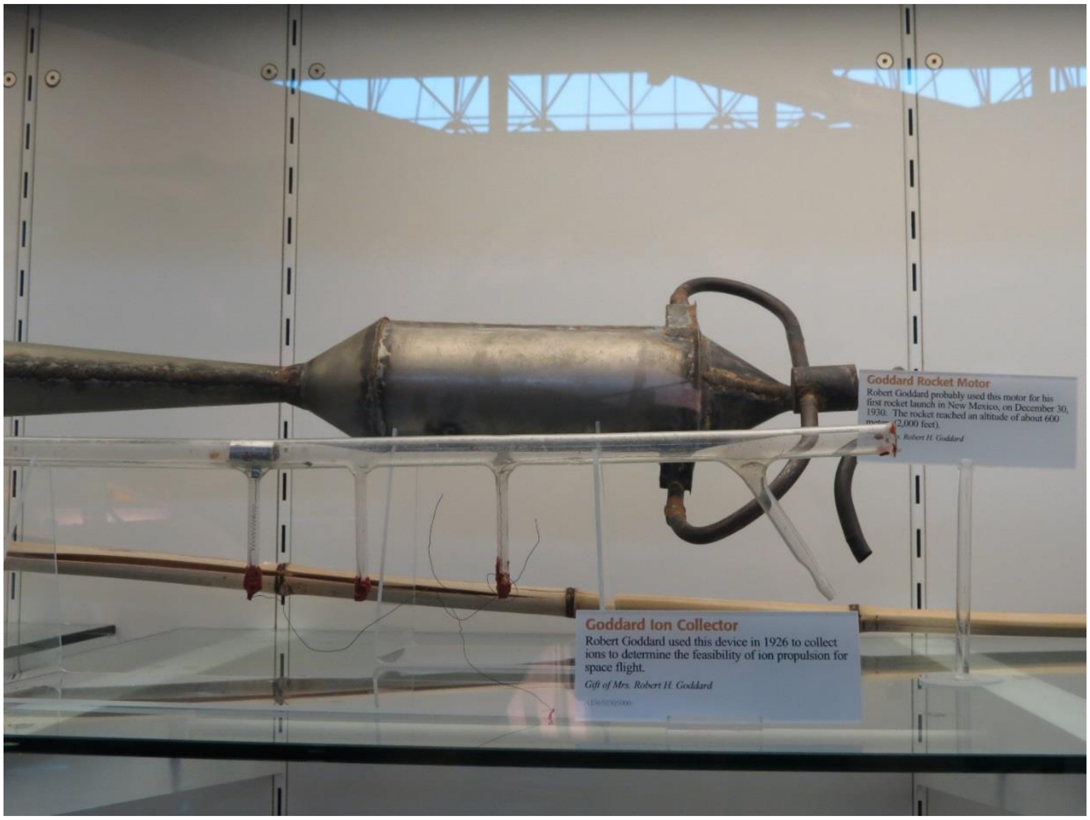

Betty Jane
CM

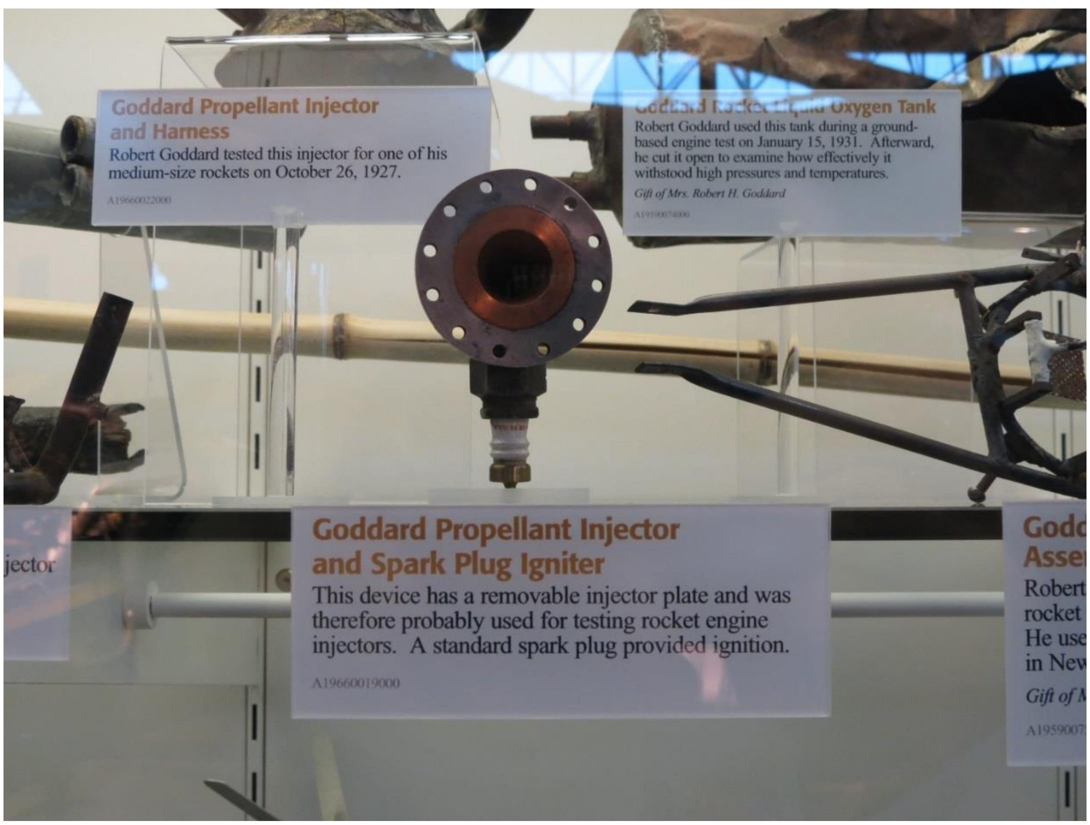

M
252534
Witchcraft

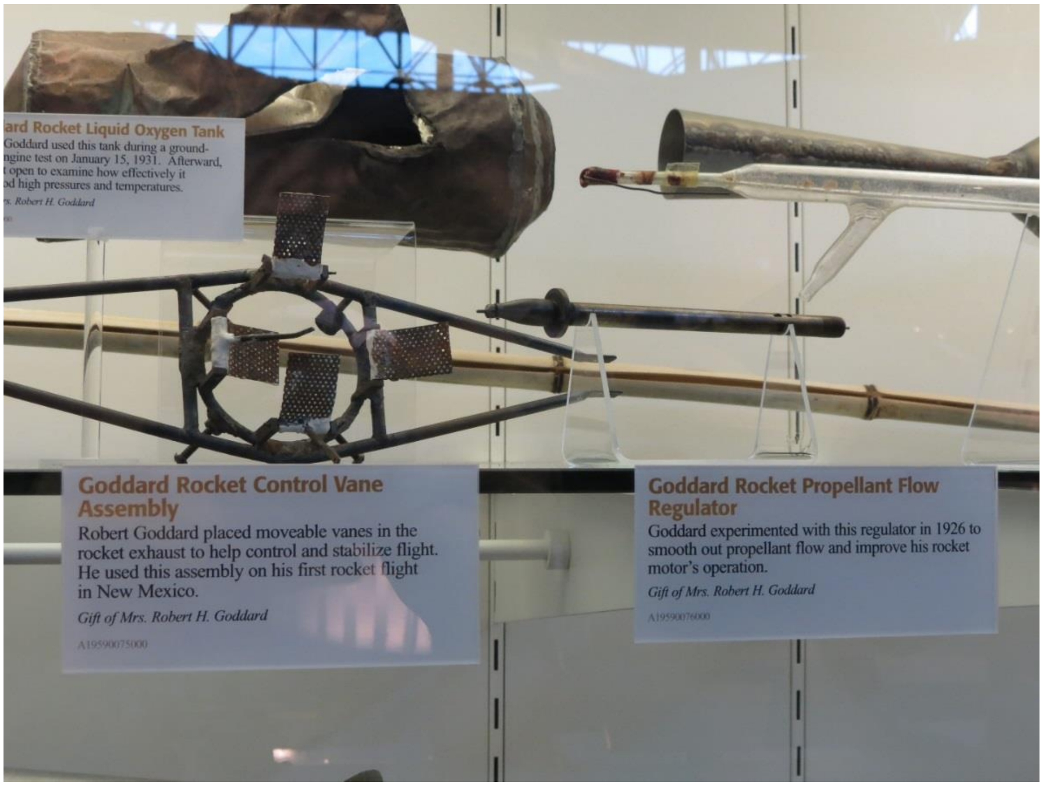
Appendix E: Smithsonian Pictures

The following images were taken during Tripp's visit to the Udvar-Hazy Center

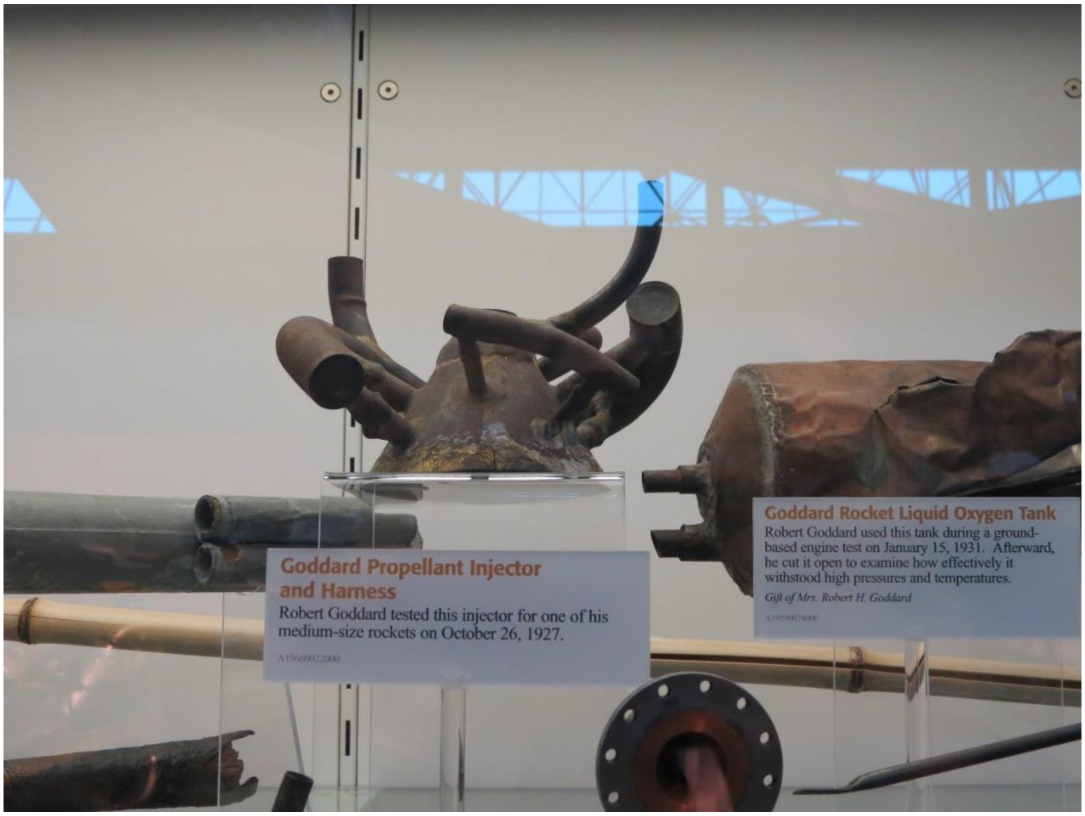



Goddard Rocket Motor
Robert Goddard probably used this motor for his first rocket launch in New Mexico, on December 30, 1930. The rocket reached an altitude of about 600
(2,000 feet).
Robert H. Goddard
Goddard Ion Collector
Robert Goddard used this device in 1926 to collect ions to determine the feasibility of ion propulsion for space flight.
Gift of Mrs. Robert H. Goddard


Goddard Propellant Injector and Harness
Robert Goddard tested this injector for one of his medium-size rockets on October 26, 1927.
Oxygen Tank
Robert Goddard used this tank during a ground-based engine test on January 15, 1931. Afterward, he cut it open to examine how effectively it withstood high pressures and temperatures.
Gift of Mrs. Robert H. Goddard
Goddard Propellant Injector and Spark Plug Igniter
This device has a removable injector plate and was therefore probably used for testing rocket engine injectors. A standard spark plug provided ignition.
A19660019000


rd Rocket Liquid Oxygen Tank
Goddard Rocket Control Vane Assembly
Robert Goddard placed moveable vanes in the rocket exhaust to help control and stabilize flight. He used this assembly on his first rocket flight in New Mexico.
Gift of Mrs. Robert H. Goddard
Goddard Rocket Propellant Flow Regulator
Goddard experimented with this regulator in 1926 to smooth out propellant flow and improve his rocket motor's operation.
Gift of Mrs. Robert H. Goddard


Goddard Rocket Liquid Oxygen Tank
Robert Goddard used this tank during a ground-based engine test on January 15, 1931. Afterward, he cut it open to examine how effectively it withstood high pressures and temperatures.
Gift of Mrs. Robert H. Goddard


Goddard Propellant Injector and Harness
Robert Goddard tested this injector for one of his medium-size rockets on October 26, 1927.
Goddard Rocket Liquid Oxygen Tank
Robert Goddard used this tank during a ground-based engine test on January 15, 1931. Afterward, he cut it open to examine how effectively it withstood high pressures and temperatures.
Gift of Mrs. Robert H. Goddard

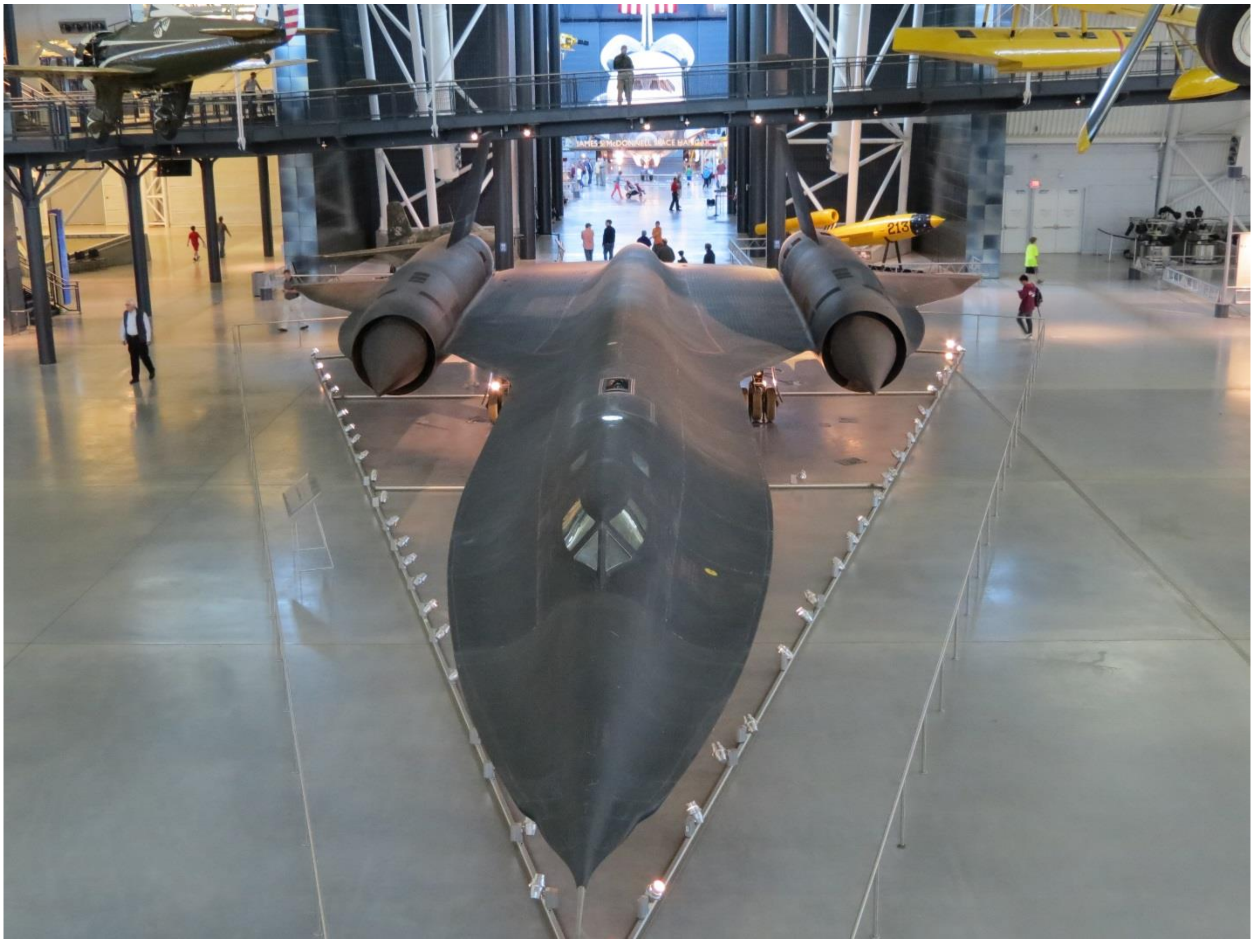

UNITED STATES
U S ARMY


Saturn 1B
NASA's Saturn 1B launched Apollo 7 into Earth orbit in 1968. It was also used later in the Skylab and Apollo-Soyuz Test Project programs
Transferred from NASA Marshall Space Flight Center
SATURN 1B
S-IVB/V
UNITED STATES
USA
FIRST STAGE
Saturn V
The most powerful operational rocket ever, the Saturn V was a three-stage, liquid-fuel vehicle that launched Apollo 8 into lunar orbit in 1968 and eight subsequent Apollo missions to the Moon.
Transferred from NASA Marshall Space Flight Center
Skylab I Commemorative Medal
The first Skylab crew (astronauts Pete Conrad, Joseph Kerwin, and Paul Weitz) deployed a sunshade to insulate Skylab, America's first space station.
Gift of the National Commemorative Society, U.S.A.


JAMES S. McDONNELL SPACE HANGAR


United States
Discovery


AIR FRANCE


213

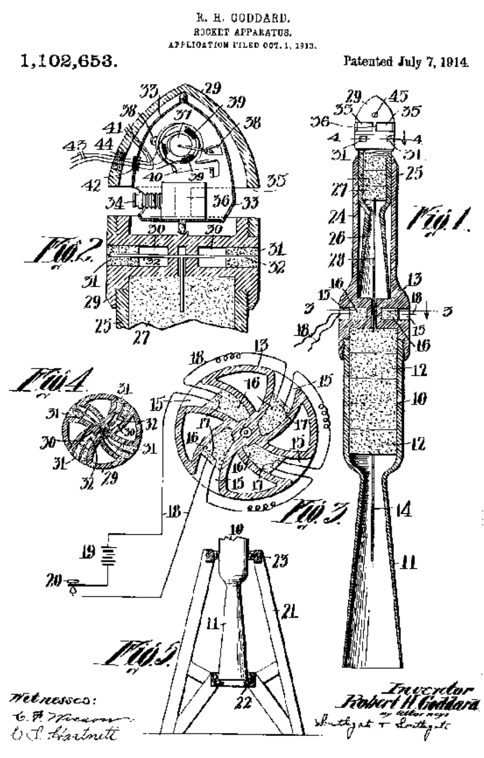
Appendix F: Patents

<u>Patent No. 1102653</u>: This invention depicts a rocket apparatus that would have transporting capabilities of reaching extreme heights. The patent describes the functions of the rocket apparatus and its parts through ignition and operations during flight (functions and guidance wise). Also, a parachute system was implemented to prevent damage upon entry. This patent would provide the base of what would become the V-2 rocket that would follow approximately 30 years later. The apparatus diagram is displayed in longitudinal view.

<u>Specifics:</u> Figs. 1 and 2 are an enlarged longitudinal sectional view of the head of the apparatus. Figs. 3 and 4 are enlarged transverse sectional views taken along the lines 3-3 and 4-4 respectively. Fig. 5 is a vertical elevation of a frame work from which the apparatus maybe fired, drawn to a reduce scale.

The rocket apparatus comprises of a primary rocket containing a combustion chamber (10); the explosive material is indicated as a plurality of disks (12) secured within the chamber 10 by a casting (13). The disks (12) are formed of a series of materials having progressively increasing rates of combustion so that as each disk is ignited it burns with increased rapidity and would therefore keep the pressure in the chamber (10) constant, for under which a specific pressure the tapered tube (11) is designed. To provide for igniting the several charges (16) simultaneously, the outer surface of each charge is a heating element (17), with these filaments being all connected in series by wires (18), with a battery (19), and a key (20). The closing of the key (20) sends a current through the wires. The wires (18), which instantaneously raises the temperature of the filaments (17) simultaneously ignites the several charges (16). The explosive force of the gases from the material (16) forces the filaments (17) and the wires (18) out of the tubes (15) so that they cannot interfere with the rotation of the apparatus. In order that this preliminary rotation may be produced, the vertical framework (21) shown in Fig. 5 is designed in which the rocket is supported upon ball bearings (22, 23). After the charges (16) have been ignited and the desired speed of rotation has been attained, the fuse (14) may be lighted and the flight of the rocket would then commence.

When the apparatus as a whole is projected to a considerable height and that the propelling charge (12) has been substantially exhausted, the fuse (28) would be ignited which in turn will ignite the charge (27), resulting in the firing of the auxiliary rocket from the tube (24). When the charge (27) is partially consumed, the explosive material (31) in the tubes will be ignited to increase the speed of rotation of the auxiliary rocket. While the rocket as a whole and the auxiliary rocket revolve at a high speed of rotation, the effect of the gyroscope is to maintain the support (33) in the same relative position in which it commenced so that the camera (34) may be directed before the flight in any desired direction and retain it throughout the flight.



Patent No. 1103503: This invention relates to a rocket apparatus, particularly adapted for carrying explosive signals, cameras, recording instruments or other devices to unusually high altitudes. A combustion chamber would be provided, within which the propelling charge is ignited and consumed. As this charge is explosive in nature, the walls of the chamber are necessarily thick and heavy and by their weight reduce the efficiency and limit the range of the apparatus. Furthermore, any increase in the propelling charge in a rocket of the ordinary type results in an increase in the size of the combustion chamber and a corresponding increase in the weight. The objective that Goddard was trying to achieve was to somehow optimize the amount of propelling agent in the rocket while reducing the weight of the apparatus. The main feature of the apparatus is a relatively small combustion chamber that is mounted within a light outer casing containing a reserve supply of propelling material and devices. The functionality behind the part was for renewing the charge in the combustion chamber. The rocket was also designed to reduce its in-flight rotation.

Specifics: Figure 1 is a longitudinal elevation partly in section of the improved device; Fig. 2 and 3 are transverse sectional views, taken along the lines 2-2 and 33 of Fig. 1; Fig. 4 is an elevation partly in section of the combustion chamber and certain parts movable; Fig. 5 is a bottom plan view of the breech block; Fig. 6 is a longitudinal sectional view of one of the cartridges used in the preferred form of the device; Fig. 7 is a detail view showing the mechanism for retaining certain of the cartridges within the magazine tube during the loading operation. Fig. 8 is a detail view of the mechanism for opening a full magazine tube when the tube in use becomes exhausted; Fig. 9 is a detail view of the means forth in the secondary rocket when the last magazine tube is exhausted; Fig. 10 is a view of a cap which may be used in place of the secondary rocket; Fig. 11 is a partial sectional view taken along the line 11-11 in Fig. 1; Figs. 12

and 3 are detail views of the devices for firing the charge in the combustion chamber; Fig. 14 is an elevation, partially broken away, of the cam which controls the breech block; Fig. 15 is an enlarged detail of a portion of the cam shown in Fig. 14; Fig. 16 is an enlarged detail of the device for separating the breech block from the combustion chamber as the chamber moves backwards in the casing; Fig. 17 is a sectional elevation of the firing devices taken substantially along the line 17--17 of Fig. 12; Fig. 18 is an elevation a part of the cam which controls the ejector, and Fig. 19 is a longitudinal sectional view showing a modified form of the invention.

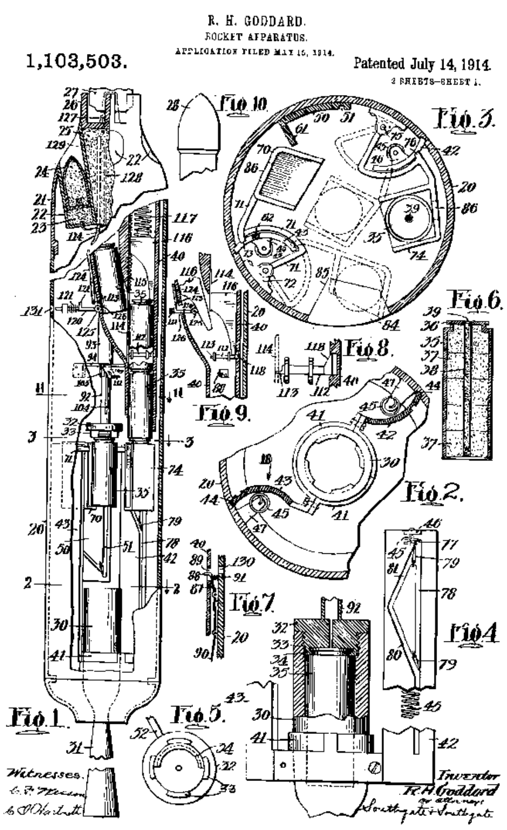
The invention is shown as enclosed within a thin light casing (20) to which is screwed a detachable head (21). This head may contain one or more firing tubes (22), each containing a charge (23) and a projectile (24) of any desired character. The head (21) may also contain a charge of high explosive indicated at (25) and may be provided at its upper end with extensions (26) for supporting a second rocket (27). This secondary rocket may be similar in all respects to the primary rocket or may be of any other desired character. Instead of the secondary rocket (27), the head (21) may be provided with the cap (28) shown in Fig. 10; the cap may carry the recording apparatus, signaling devices, explosives, or any other similar devices. The casing (20) encloses at its lower end of a combustion chamber (30--Figs. 1, 2 and 4) which may be provided with the rearward extension of the tapered tube (31) through which the products of combustion are discharged. At its upper end the combustion chamber carries a breech block (32), which is normally locked within the chamber by sectional screw-threads (33). At its lower end, the breech block carries an inwardly projecting flange (34--Figs. 4 and 5), which extends half way around the breech block and provides means for supporting a cartridge (35--Figs. 4 and (i)) in position beneath the breech block. The cartridge (35) is provided with a flanged projection (36) which is adapted to cooperate with the flange (34). The propelling material in the cartridge (35) may be in the form of disks (37) having successively increasing rates of combustion. A small tube (38) extends longitudinally through the cartridge and it contains a rapidly burning material adapted to be ignited by the firing of a primer (39) mounted at the upper end of the tube (38). The primer would ignite the lowest-disk (37) in the cartridge (35) and the combustion of the charge thereafter proceeds toward the upper end of' the cartridge. The cartridges (35) are placed in one or more magazine tubes (40--Fig.1) within the casing (20). The combustion chamber (30) is not fixed within the casing (20) but is instead mounted for longitudinal movement.

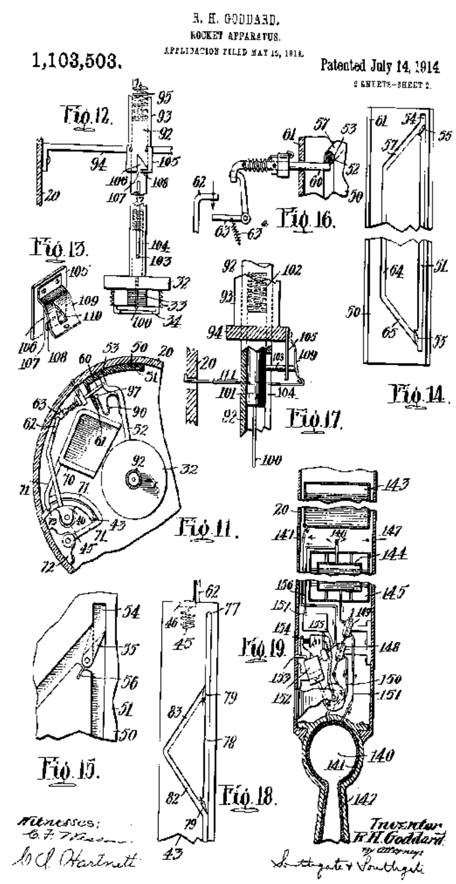
Figs. 2 and 4: The lower end of the chamber (30) is secured between a pair of clamping bars (41), with these bars being integral at their outer aids with cam plates (42, 43), whose edges slide in the grooves (44--Fig. 2) in the casing (20). Spiral springs (45) have their upper ends secured to lugs (46) upon the cam plates (42, 43) and at their lower ends are secured to lugs (47) upon the casing (20). As the cartridge (35) within the chamber (30) is ignited, the reaction of the propelling charge forces the combustion chamber together with the cams (42, 43) and the breech block (32) upward into the casing 20 against the yielding resistance of the springs (45). A cam plate (50--Figs. 11 and 14) is secured to the side of the casing (20), the cam (50) having formed in any convenient manner. The breech block (32) carries a laterally extending arm (52--Fig. 11) which may be provided with a roll (53) upon its outer end located within the cam groove (51). As the combustion chamber and breech block travel upward relatively to the casing, the roll (53) follows the straight vertical portion of the cam groove (51) shown to the right in Fig. 14. The breech block is thereby prevented from turning and is locked in the combustion chamber during its entire upward travel relatively to the casing and to the cam (50). The cam groove (51) has a short extension (54) at its upper end within which the roll (53) will be confined as the combustion chamber reaches its extreme upward limit. A switch-mock (55--Figs. 14 and 15) is held by a spring (56) in the position shown in Fig. 15. As the roller (53) passes upward, the switch block is moved to the position shown in dotted lines in Fig. 15 but immediately resumes the position shown in full lines. Similar switch blocks are used as indicated at different places in the several cam plates. As the charge in the combustion chamber becomes exhausted the reaction of the expelled gases decreases until the chamber itself is eventually forced rearward by the springs (45). On its rearward movement, the roll (53) is constrained by the switch block (55) to follow the inclined portion (57) of the cam plate (50). The combustion chamber, being clamped to the cams (42, 43) is prevented from turning but the breech block is partially rotated relatively by the portion (57) as it approaches its lower or normal position.

Figs. 3 and 11: An ejector is shown, supported upon a curved arm (71) to be pivotally mounted upon a bracket (72) secured to the casing (20). The arm (71) is shaped to the extent that it partially encircles the cam plate (43) which is longitudinally movable in the combustion chamber. The arm (71) is provided with a projection (73) to which it will follow the cam groove in the outer face of the cam (43---Fig.18). A substantially similar device (74--Fig. 3) is a pivot-ally (75) mounted upon the casing (20) and that it has a projection (76) banding with the cam groove in the outer face of the cam plate (42--Fig. 1). The normal position of the projections (73, 76) is at the extreme upper end of the cam grooves at the point (77) in Figs. 4 and 18. As the cam plates move upwardly with the combustion chamber, the projections (73, 76) move downward relatively to the cams along the vertical point. As the combustion chamber ignites the projections return along the grooves (78) until they encounter the switch blocks (79). The projections are thereby shifted to the inclined portions of the cam grooves. The cam plates (42, 43) are substantially similar in character with the exception that the cam (43) provides a greater lateral throw and that the inclined portions (82, 83) are nearer the lower end of the cam plate than the portions (80, 81) of the plate (42). As the cam plates move downwardly, the projection (78) encounters the inclined groove (82) and the ejector (70) is thus moved from the full line position in Fig. 3 to the dotted line position; in its passage from one position to the other, it moves under the suspended breech block and it removes the exhausted cartridge shell, the shell being finally opening (84) in the casing (20). An inwardly projecting lip (85) prevents the shell from falling backwardly into the casing. As the ejector is returning to its normal position, the projection (76) upon the loading device encounters the inclined portions (80, 81) of the cam groove in the plate (42) and is thus swung forward to the dotted line position shown in Fig. 3. The loading device having been previously supplied with a fresh cartridge is inserted beneath the breech block and is held suspended by the flange (34). Perforations (86) in the rear wall of the ejecting and loading devices prevent the cartridges from being retained by suction within the devices.

Fig. 7: A retaining mechanism that would prevent the cartridges from moving down in the magazine tube (40) while a loading device is inserting a cartridge in the breech block. It comprises of a latch (87) pivoted upon the casing (20) and having a projection (88) at its upper end adapted to extend through a perforation (89) in the side of the magazine tube (40). The projection (88) is located longitudinally to a point that it will engage the cartridge above the loading device beneath its flange (36) and would prevent the cartridge from moving downward in the magazine tube. As the loading device returns to its normal position it engages the lower end of a pivoted lever (90--Fig. 7) at its upper end, engaging the lower end of the latch (87) and acting to withdraw the latch from the magazine tube. A coil spring (01) moves ejected through a latch into an operative position whenever it projects upward from the breech block and it slides freely within a sleeve (93) which is mounted upon a support (91) secured at its opposite ends to the casing (20). A compression spring (95) is contained within the sleeve (03) and exerts a downward pressure upon the upper end of the tubular force; a spring arm (96--Fig. 11) therefore is mounted upon the arm (52), having a roll (97) upon its free end, adapted to contact with the flange (51) of the cam plate (50). As the arm (52) moves to the left, in descending along the portion (57) of the cam plate (50), the tension of the spring arm (96) will be increased, thus affording a reserve force which is available during the passage of the roll along the portion (65) of the cam groove to supplement the decreasing pressure of the spring (95).

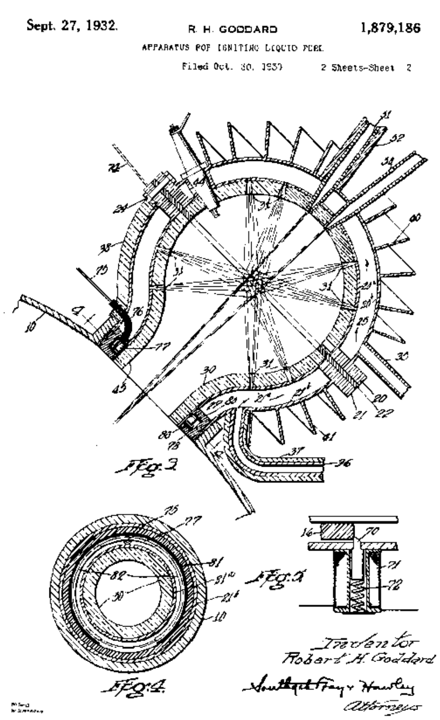
Fig 19: A modification in which the combustion is continuous rather than intermittent; a combustion chamber (140) has a refractory lining (141) and a rearward-extending tapered tube (142). Within the rocket casing contains two tanks (143, 144), which contain materials which when ignited will produce an exceedingly rapid combustion. This result may be attained by filling the tank (143) with gasoline; the substance is a liquid, which only at low temperatures it is necessary that it is used to fill the tank should immediately before the discharge of the apparatus. In order to retain the low temperature of the liquid oxide, the tank (144) is enclosed within a second tank (145). The space between the tanks may be filled with a suitable non-conductor or may constitute a cellular vacuum casing as shown in the drawing. In order to prevent a rapid rise of pressure in the tank from the resulting evaporation, a safety valve (146) is provided; the discharge gases passes to the atmosphere through openings (147) in the casing (20). Force pumps (148,149) are connected respectively to the tanks (143,144) by the system of pipes shown in the drawings. On their discharge sides, these pumps of any form are connected by the pipes (150,151) to the combustion chamber (140). The pumps are piston-operated by a single sliding rod connected to a crank pin upon a rotating disk driven by a small gasoline engine (152). This engine is provided with the usual exhaust pipe (153) and ignition apparatus (154). Gasoline is supplied to the engine from the tank (143) through a branch pipe (155) and in place of air, nitrous-oxide of gasoline and nitrous-oxide will be at all times fed to the combustion chamber (140). In this form of the apparatus the combustion is continuous and the propelling force is constant.

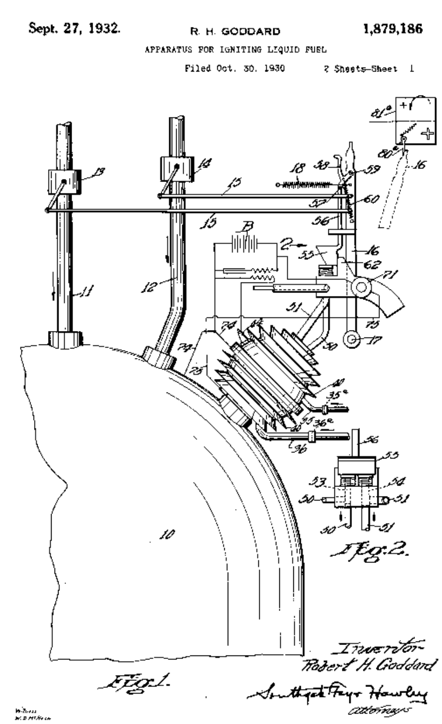




Patent No. 1879186: This invention relates to a combustion apparatus in which liquid fuel is used and more particularly to an apparatus in which a liquid oxidizing agent such as liquid air or oxygen is also used. Ignition is provided in the form of a flame directed into the combustion chamber which contains the mixture of fuel and an oxidizing agent. A further object is to provide improved means for maintaining an idle flame or hot point for lighting the igniting flame whenever desired. Safety parts are also included to reduce risk of explosive fallout.

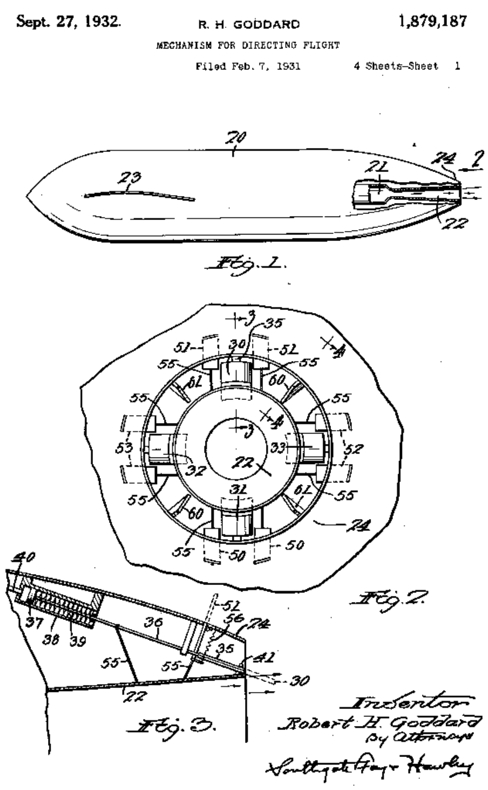
Specifics: Fig. 1 is a side elevation of a portion of a combustion chamber having improvements applied; Fig. 2 is a detail view, looking in the direction of the arrow 2 in Fig. 1; Fig. 3 is an enlarged sectional view of the ignition chamber.

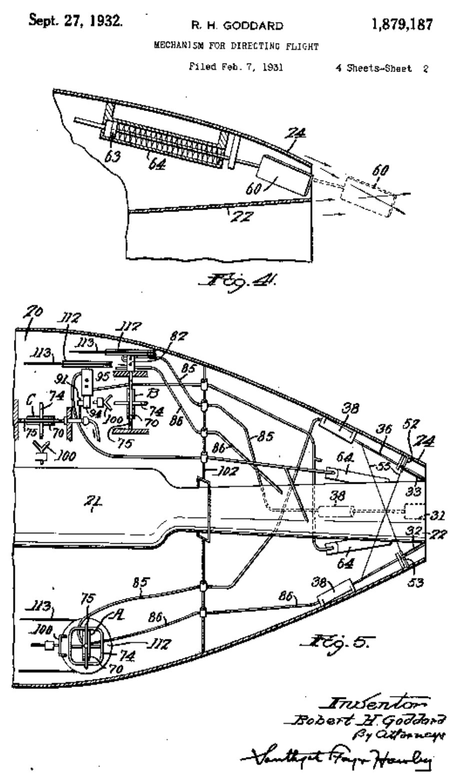




Patent No. 1879187: This invention relates to aircraft of the rocket type in which propulsion is ejected by the discharge of combustion gases through a rearward-directed nozzle or passage. A mechanism would enable the craft to preserve its direction of flight and its orientation under very low air pressure conditions without manual supervision. More specifically, the invention relates to the provision of directing vanes, controlled in position by a plurality of gyroscopes, and adapted to be projected into the atmosphere surrounding the aircraft or into the path of the discharge gases.

Specifics: Fig. 1 is a side elevation of a type of aircraft adapted to receive the improved direction mechanism; Fig. 2 is an enlarged rear elevation of the scope control valves; Figs. 3 and 4 are detail sectional elevations, taken along the lines 3-3 and 4-4 in Fig. 2; Fig. 5 is a partial sectional plan view of the rear portion of the craft, with the directing mechanism embodied within; Fig. 6 is a side elevation of one of the gyroscopes; Fig. 7 is a side elevation of the movable valve member; Figs. 8 and 9 are sectional end elevations, taken along the lines 8-8 and 9-9 in Fig. 6; Fig. 10 is a bottom view of the valve mechanism looking in the direction of the arrow 10 in Fig. 6; Fig. 11 is a perspective view of one of the gyroscopes; Fig. 12 is a partial sectional elevation of the rotating member of the gyroscope; Fig. 13 is a partial sectional plan view, taken along the line 13-13 in Fig.12 and showing the functionalities for rotating the gyroscope; Fig. 14 is a detail view showing the operative connections between the orienting gyroscope and its valve mechanism; Figs. 15 and 16 are detail sectional views, taken along the line 15-15 in Fig. 14 and showing the valve member in different positions; Fig. 17 is a detail perspective view of certain automatic directing apparatus; . Fig. 18 is a detail sectional plan view, taken along the line 18-18 in Fig. 11; Fig. 19 is a detail sectional elevation, taken along the line 19-19 in Fig. 18.





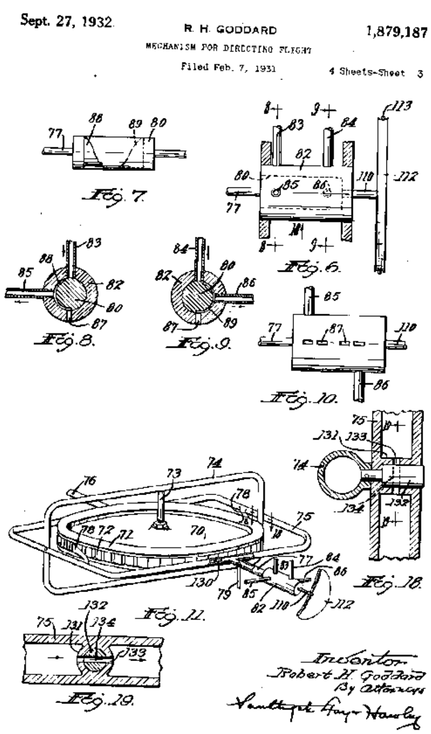
Patent No. 2127865: This invention relates to centrifugal pumps designed for handling low temperature liquids, such as liquid air at or near their boiling points.

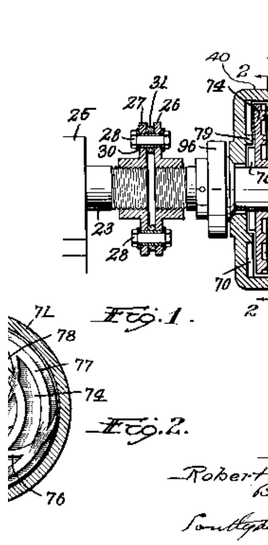
Specifics: Fig. 1 is an enlarged sectional front elevation of a portion of a centrifugal pump embodying improvements; Fig. 2 is a sectional end elevation, taken along the line 2--2 in Fig. 1.

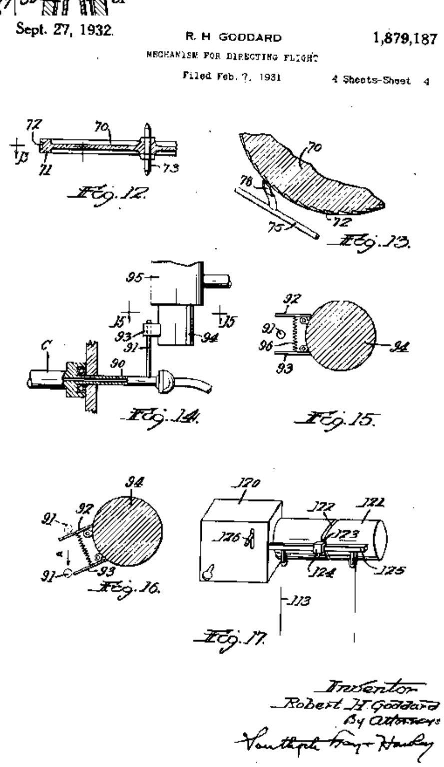
Aug. 23, 1938. R. H. GODDARD 2,127,865

SEAL FOR CENTRIFUGAL PUMPS

Filed Aug. 31, 1934







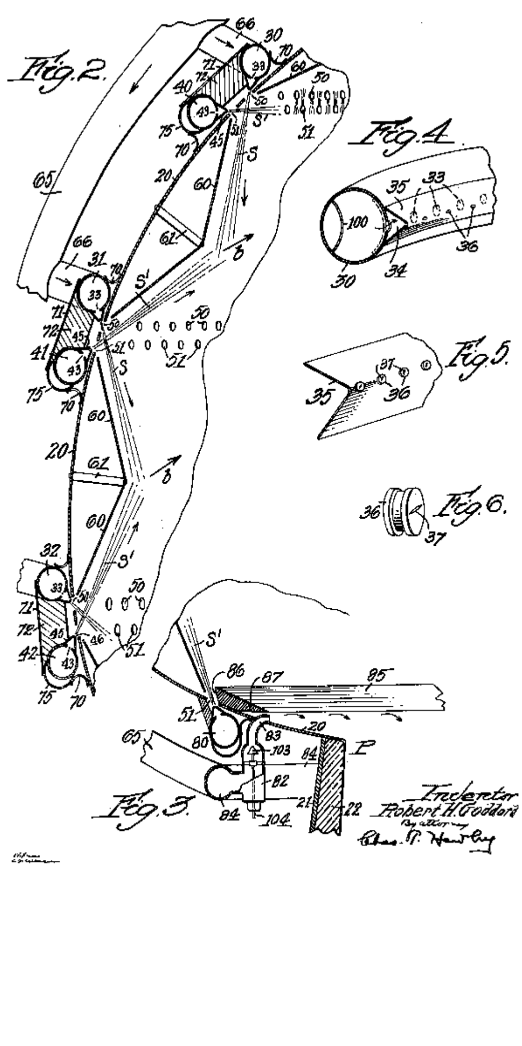
Patent No. 2217649: This invention is a modification to the rocket apparatus designed and patented by Goddard which provides the purpose of cooling the walls of the chamber without the use of jackets or cooling vanes. The walls would therefore be protected from overheating. A construction is also implemented in which sprays of a liquid fuel and a liquid oxidizing agent are directed toward each other along sharply intersecting paths and with no substantial contact with deflecting surfaces that might reduce the velocities of the liquid sprays.

Specifics: Fig. 1 is a longitudinal section of the improved combustion chamber and nozzle; Fig. 2 is an enlarged sectional view of certain parts shown in Fig. 1; Fig. 3 is an enlarged sectional view of additional parts shown in Fig. 1; Fig. 4 is a partial perspective view, partly in section, of a gasoline feeding device; Fig. 5 is a partial perspective view, partly in section, of a nozzle-supporting plate; Fig. 6 is a perspective view of a nozzle; Fig. 7 is a front elevation, partly in section, of a gasoline feeding device; Fig. 8 is a detail longitudinal section through one of the liquid feeding devices; Fig. 9 is a partial perspective view of a deflecting member; Fig. 10 is a partial perspective view of a gasoline shut-off plate and operating devices; Fig. 11 is a partial perspective view of a gasoline feeding tube and associated parts; Fig. 12 is a diagrammatic view of the feeding tube and parts

Oct. 8, 1940. R. H. GODDARD 2,217,649

COMBUSTION CHAMBER FOR ROCKET APPARATUS

Filed June 5, 1939 2 Sheets-Sheet 2



Oct. 8, 1940. R. H. GODDARD 2,217,649

COMBUSTION CHAMBER FOR ROCKET APPARATUS

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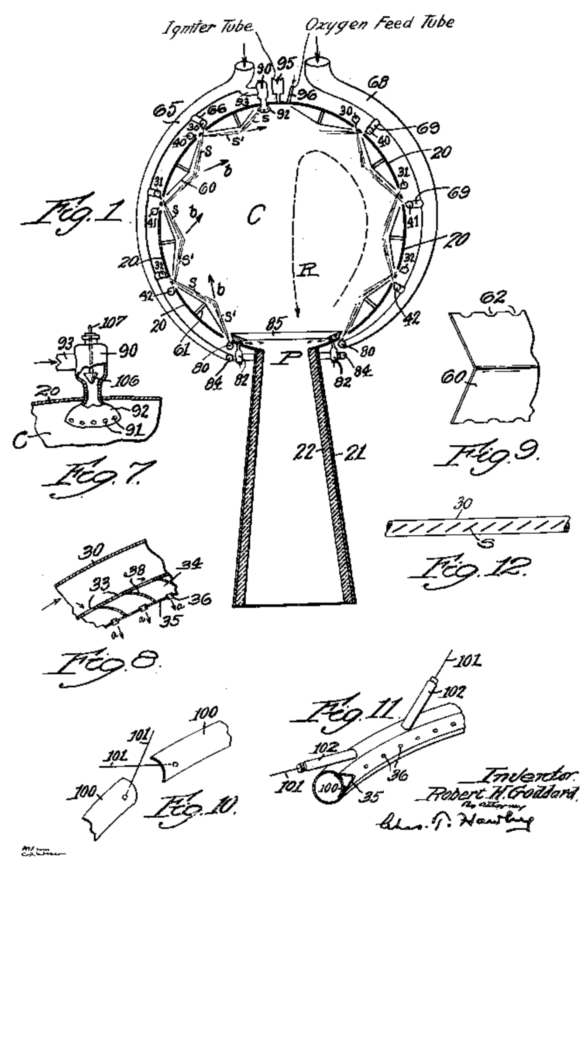


Patent No. 1159209:

R. H. GODDARD.

METHOD OF AND APPARATUS FOR PRODUCING ELECTRICAL IMPULSES OR OSCILLATIONS.

APPLICATION FILED AUG. 1, 1912.

1,159,209. Patented Nov. 2, 1915.

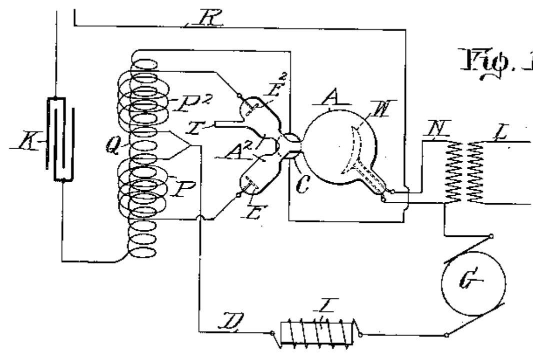
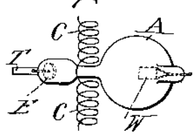


Fig. 2.



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Inventor:
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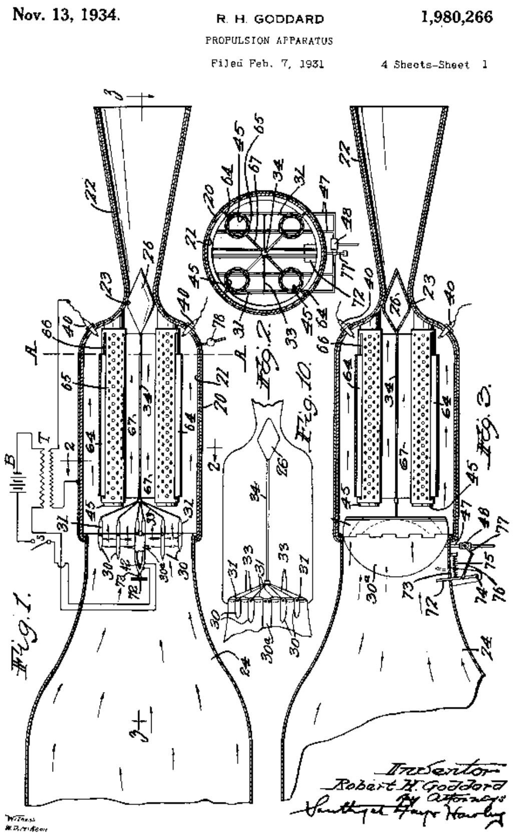
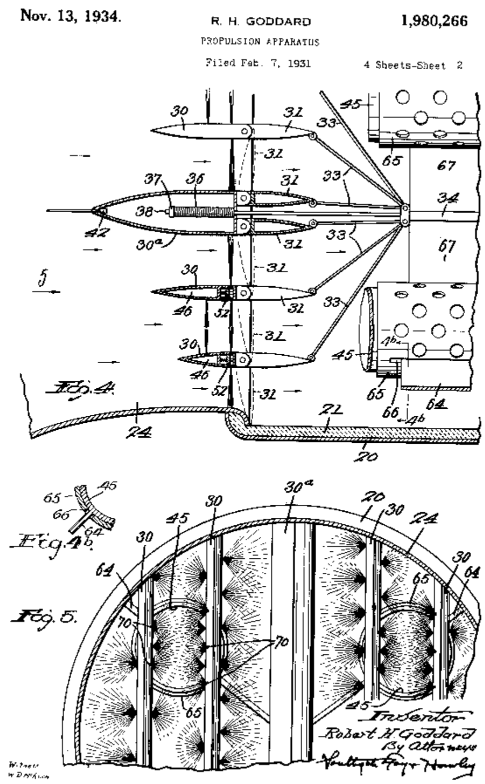
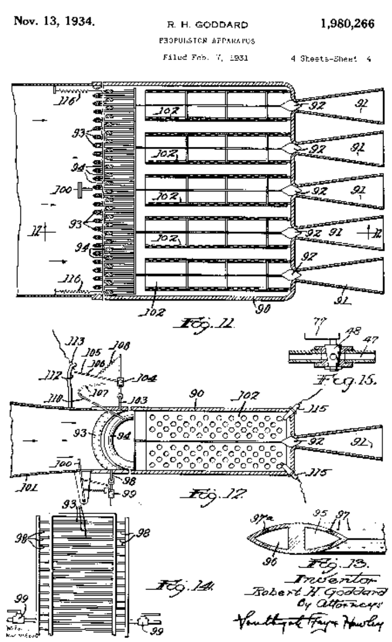
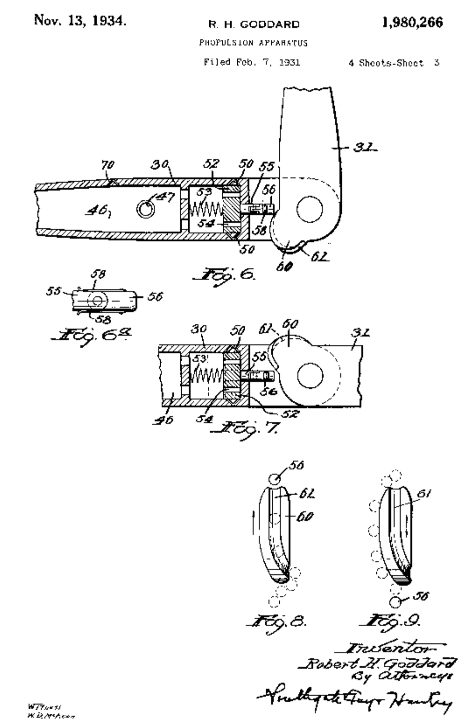
Patent No. 1980266:









Patent No. 2158180