

ROCKET ENGINE TEST FACILITY  
NASA Glenn Research Center  
Cleveland  
Cuyahoga County  
Ohio

HAER No. OH-124

PHOTOGRAPHS

WRITTEN HISTORICAL AND DESCRIPTIVE DATA

REDUCED COPIES OF MEASURED DRAWINGS

HISTORIC AMERICAN ENGINEERING RECORD

National Park Service  
Great Lakes Support Office  
1709 Jackson Street  
Omaha, Nebraska 68102

February 27, 2003

HISTORIC AMERICAN ENGINEERING RECORD  
ROCKET ENGINE TEST FACILITY

HAER No. OH-124

Location: NASA Glenn Research Center  
Cleveland  
Cuyahoga County  
Ohio

UTM Coordinates: GRC Building 202 – Rocket Engine Test Cell, UTM: 17.427520.4584000  
GRC Building 205 – Propellant Transfer and Storage,  
UTM: 17.427550.4584040  
GRC Building 206 – Cryogenic Vaporizer Facility,  
UTM: 17.427510.4584040  
GRC Building 100 – Rocket Operations Building, UTM: 17.427602.4584485  
GRC Observation Blockhouse, UTM: 17.427510.4584080  
Quadrangle: Lakewood, Ohio 1:24,000

Date of Construction: 1955-57

Engineers: H. K. Ferguson Company

Present Owner: National Aeronautics and Space Administration – Glenn Research Center

Present Use: Vacant/Not in use.

Significance: The Rocket Engine Test Facility Complex is a National Historic Landmark, and the listed buildings are included in the description of the complex on the National Historic Landmark nomination form. It is located at the south end of the NASA-Glenn Research Center at Lewis Field on a tributary of Abram Creek. This facility played a key role in the development of the technology for using hydrogen as a rocket fuel. The Rocket Engine Test Facility was also responsible for extraordinary work in developing lightweight, regeneratively cooled, hydrogen-fueled rocket engines. The successful development of the Centaur rocket and the upper stages of the Saturn V could be largely credited to the work carried out here. NASA personnel at this facility built or developed much of the equipment, technology, and methodology for testing rocket engines using ingenious solutions to resolve design and operational problems.

Project Information: This documentation was initiated on May 15, 2002, in accordance with a Memorandum of Agreement among the Federal Aviation Administration, National Aeronautics and Space Administration (NASA), The Ohio State Historic Preservation Officer, and the Advisory Council on Historic Preservation. The City of Cleveland plans to expand the Cleveland Hopkins International Airport. The NASA Glenn Research Center Rocket Engine Test Facility, located adjacent to the airport, must be removed before this expansion can be realized. To mitigate the removal of this registered National Historic Landmark, the National Park Service has stipulated that the Rocket Engine Test Facility be documented to Level I standards of the Historic American Engineering Record (HAER). This project was initiated to fulfill that requirement.

Historians: Robert C. Stewart      Historical Technologies, West Suffield, Connecticut  
Dr. Virginia P. Dawson      History Enterprises, Cleveland, Ohio  
Roy A. Hampton III      Hardlines Design Company, Columbus, Ohio

### **Historic Context – Planning and Development of Rocket Testing at Lewis Flight Propulsion Laboratories:**

Research into liquid-fueled rockets in the Cleveland area was conducted as early as 1933 under the aegis of the Cleveland Rocket Society. While the Society was a group of amateurs, a German engineer, Ernst Lobell, headed a team that successfully launched several liquid-fueled rockets starting in 1934. These rockets, however, were not destined for space, since Lobell envisioned using rocket vessels for speeding up intercontinental mail deliveries.<sup>1</sup> The costs and facilities necessary for advanced research were beyond the capability of individual researchers and amateur societies, and only the government or corporate sectors could therefore complete serious rocket research. The government and major corporations, however, were not developing rocket engines at the time. Instead, their efforts were focused on developing advanced piston-engine designs. The progression into jet and rocket engines by government and corporate laboratories was consistent with the advance of technology.

In the late 1930s research into advanced aircraft engine design was centered in governmental laboratories in Great Britain and Germany. Wright Aeronautical Corporation and Pratt & Whitney, the major American engine manufacturers, produced fine commercial engines but were reluctant to commit major funding to advanced engine development.

Several aeronautical engineering pioneers, including George W. Lewis, Director of Research for the National Advisory Committee on Aeronautics (NACA), saw a critical need for a government-funded laboratory devoted to engine development. He and others successfully

---

<sup>1</sup> Frank H. Winter, "Lighting the Fuse," *Timeline* (October-November 1986): 14-17.

managed to secure federal funding for an engine research laboratory. From 1930-40, the Cleveland Municipal Airport had expanded to more than 1,000 acres. During this period the airport hosted the National Air Races, and the western portion of the airport was used as a parking area during the races. In 1940 NACA decided to build its Aircraft Engine Research Laboratory in Cleveland on 200 acres of the municipal airport.

In April 1947 the Aircraft Engine Research Laboratory was renamed the Flight Propulsion Research Laboratory to reflect its role in propulsion research. The name was changed again the following year to the Lewis Flight Propulsion Laboratory (herein referred to as Lewis Laboratory), in honor of George William Lewis.<sup>2</sup>

In the late 1940s and early 1950s, the U.S. military was responsible for aggressive research in rocket propulsion.<sup>3</sup> As part of this development, portions of laboratories at Wright-Patterson Air Force Base that had tested jet propulsion technologies during World War II were converted into rocket engine test facilities from 1946-49.<sup>4</sup> Concerns about national security guaranteed that the Army, Navy, and Air Force received ample funding for propulsion research and development. In contrast, funding for propulsion development by NACA remained tight through the early 1950s.<sup>5</sup>

As part of its mission as a nationwide laboratory focused on aircraft engines, Lewis Flight Propulsion Laboratory began rocket propulsion research as early as 1944. There was strong interest in rocketry for U.S. military applications during the early Cold War years due to the success of the German V-2 rocket during World War II. A rocket propulsion section was established at Lewis Flight Propulsion Laboratory in 1945. Between 1945 and the early 1950s, a large amount of research at the Lewis Laboratory rocket lab focused on the improvement of existing turbojet technologies. Although NACA management during the late 1940s was uncomfortable with the organization taking a more aggressive role in rocket propulsion development, the Lewis Laboratory rocket lab completed some research on rocket fuel development during the late 1940s. Rocket propulsion research completed at Lewis Laboratory in the late 1940s was circulated to the Navy Bureau of Aeronautics, Air Force Materiel Command, and other U.S. military organizations.<sup>6</sup> In the late 1940s, researchers at Lewis Laboratory became interested in experimenting with hydrogen rocket technology.

---

<sup>2</sup> George W. Lewis (1882-1948) was a leading proponent for basic research at the National Advisory Committee on Aeronautics (NACA). He strongly believed that practical testing of concepts was the way to acquire useful knowledge, and he was an active participant in formulating research policy and NACA's early emphasis on engineering rather than basic aeronautical science.

<sup>3</sup> Virginia P. Dawson, *Engines and Innovation* (Washington, D.C.: National Aeronautics and Space Administration, 1991).

<sup>4</sup> Hardlines Design Company, "Historic Documentation of Buildings 79A-C and Building 95, Wright-Patterson Air Force Base," on file at Hardlines Design Company, (1998-99).

<sup>5</sup> Dawson, *Engines and Innovation*, 149.

<sup>6</sup> Virginia P. Dawson, "History of the Rocket Engine Test Facility at NASA-Glenn Research Center" (draft). On file at Hardlines Design Company (February 19, 2003), 4-10.

In 1951, Lewis Laboratory received its first formal funding appropriations for rocket research, possibly following intelligence reports of Soviet advances in rocket technology development. At that time, Lewis Laboratory had a series of cinder-block World War II-era rocket test cells, and four larger cells that had been built later using laboratory operation funds.<sup>7</sup> When the initial request for construction of the Rocket Engine Test Facility was made in 1952, much of the rocket research at Lewis Laboratory was related to military applications. This was still true in 1955 when construction began on the Rocket Engine Test Facility.<sup>8</sup> It was only after the successful launch of Sputnik by the Soviet Union in 1957 that the space travel potential of Rocket Engine Test Facility research was more strongly emphasized.<sup>9</sup>

Liquid hydrogen had been proposed as a rocket fuel as early as 1903, and Tsiolkovsky's *Treatise on Space Travel* advocated the material as an ideal fuel. The American rocket pioneer Robert Goddard recognized its potential. Goddard calculated that liquid hydrogen, even diluted 2:1 over that required for complete combustion, would increase the total rocket's mass by only 11 percent.<sup>10</sup>

As early as 1945, researchers at The Ohio State University produced a liquid-hydrogen-fueled rocket.<sup>11</sup> Unfortunately, there were no laboratories or pilot plants available immediately after World War II capable of doing research on liquid hydrogen as a rocket fuel, although experiments using liquid hydrogen and gaseous oxygen in rockets were completed at Ohio State from April 2, 1947, until May 29, 1950. Aerojet General Corporation was also running similar tests in California from 1945-49, as was the Jet Propulsion Laboratory from 1948-49.<sup>12</sup>

The U.S. Army carried out major programs of rocket research in the early to mid-1950s at Redstone Arsenal, near Huntsville, Alabama. This work focused on missile development. Two major new weapons resulted from research completed during World War II. The United States developed the atomic bomb, while the Germans developed the V-2, a liquid-fueled, medium-range, rocket-powered missile. In the late 1940s, the U.S. Army sought to make the atom bomb lighter and the V-2 engine more powerful, so that a missile capable of carrying an atomic warhead could be developed. By 1950, an American team of scientists, which included many of the Germans who had worked on the V-2, achieved this goal. The team reduced bomb weight to 6,900 pounds, and they developed a prototype rocket engine capable of producing 333

---

<sup>7</sup> Dawson, *Engines and Innovation*, 150-151.

<sup>8</sup> *Ibid.*, 12, 25.

<sup>9</sup> *Ibid.*, 30-32.

<sup>10</sup> Robert H. Goddard, *Rocket Development* (New York: Prentice-Hall, Inc., 1948), 102.

<sup>11</sup> Virginia P. Dawson, *Rocket Propulsion Research at Lewis Research Center* (Cambridge, Massachusetts: Lewis Research Center, July 1992), 1.

<sup>12</sup> John Sloop, *Liquid Hydrogen as a Propulsion Fuel, 1945-1959* (NASA Special Publication No. 4404, 1978), 2.

kilonewtons (75,000 pounds) of thrust. The Army continued to develop what was called the “Redstone” missile, and spent millions of dollars to improve guidance systems and rocket reliability. The Redstone was deployed to NATO troops in West Germany in 1959.

Post-design phase rocket engine development generally follows three stages: engine testing, static rocket testing, and experimental launches. The second stage requires that the rocket be securely anchored in a “static test stand” where its performance can be measured and evaluated. This requires a facility to house the stand, an infrastructure to supply reactants, and instrumentation to monitor rocket performance. In 1952, the Army realized that further development of the Redstone would require construction of a more sophisticated test stand than the primitive rigs in use during this period. A law passed by Congress, however, restricted the research and development funds that could be spent to build facilities. Rather than wait the usual four years required to appropriate funds to construct a facility, Redstone engineers designed and built an “interim test stand” for \$25,000. This amount was the maximum that could be spent without congressional approval. By 1957, a permanent test stand, the “Static Test Tower,” had been built, but the Army opted to continue operations at the interim test stand.<sup>13</sup> Part of the reluctance to fund additional rocket research through the military may have come from President Eisenhower’s inclination to create a new agency for space exploration, the National Aeronautics and Space Administration (NASA), out of NACA.

The Redstone and its supporting infrastructure were designed for the use of alcohol and liquid oxygen as propellants. The interim test stand was equipped with a steam-powered pump to force the reactants into the combustion chamber. Steam was generated for the pump by using potassium permanganate to cause hydrogen peroxide to decompose.<sup>14</sup> During the period when research on the Redstone was ongoing at Huntsville, scientists at NACA-Lewis Research Center were exploring the development of liquid hydrogen as a fuel.

Steady supplies of liquid hydrogen were unavailable during the post-war period. Consequently, early research focused on un-symmetrical dimethyl hydrazine as a fuel and oxidizers such as hydrogen peroxide, chlorine trifluoride, liquid oxygen, nitrogen tetroxide, and liquid fluorine.<sup>15</sup> These reactants were toxic and produced toxic by-products. Any facility using them required the implementation of methods for the safe handling and disposal of waste.

In the early 1950s, the Lewis Laboratory acquired a hydrogen liquefier, and many tests were run in the Rocket Lab Test Facilities. Hydrogen/fluorine engines were tested in Cell 22, which was

---

<sup>13</sup> Historic American Engineering Record (HAER), National Park Service, U.S. Department of the Interior. “Marshall Space Flight Center, Test Stand.” HAER No. AL-129-A, Historic American Engineering Collection, Library of Congress, Washington, D.C., 1995, 5-10.

<sup>14</sup> *Ibid.*, 32.

<sup>15</sup> *Ibid.*

equipped with a scrubber.<sup>16</sup> However, rocket staff at Lewis Laboratories began to plan a large rocket engine test complex better suited to testing liquid hydrogen technologies. At first, they planned this propulsion laboratory for a remote location in the western United States, but they eventually decided to develop a smaller rocket test facility at Lewis Laboratory. Lewis Laboratory scientists requested authorization to construct a test facility for evaluating high-energy propellants and rocket engine designs. NACA approved this request in 1952. The test laboratory that resulted from this approval was Lewis Laboratory's Rocket Engine Test Facility.<sup>17</sup>

Construction drawings were produced for the Rocket Engine Test Facility from 1955-56, and construction was completed between 1955-57. The facility included a test cell and ancillary buildings dedicated to the testing of full-scale rocket engines, and researchers soon focused on the use of liquid hydrogen as a fuel. The complex was located on a ten-acre site within a forty-acre area at the southern end of NASA's Glenn Research Center, a location locally known as the "South 40." The facility was designed to permit up to three minutes of operation at a thrust of eighty-nine kilonewtons (20,000 pounds) of thrust. However, on rare occasions, tests were run at 311 kilonewtons (70,000 pounds) of thrust. In 1957, this facility was the largest high-energy test facility in the country capable of handling liquid hydrogen and other liquid fuels that could produce toxic exhaust. The construction of a large scrubber to remove pollutants was unique at the time.

The complex was finished in the fall of 1957 at a cost of \$2.5 million, and originally consisted of two major components: a control center housed in Building 100, and a test cell in Building 202. An observation blockhouse was also included in the original construction campaign. Support structures added subsequently included Building 205, a propellant transfer and storage facility built ca. 1962-65, and Building 206, which was built in 1968 to accommodate a cryogenic vaporizer and compressor. This facility was an integrated laboratory, designed and built to perform specific experimental functions. As such, it differed from the more developmental missile-oriented facility at Redstone and other similar developmentally oriented facilities operated by the military.<sup>18</sup>

---

<sup>16</sup> According to George Repas; cited in NASA-Glenn Research Center, "Comments on the Rocket Engine Test Facility Historic American Engineering Record Documentation" (January 24, 2003), 5.

<sup>17</sup> Dawson, *Engines and Innovation*, 151.

<sup>18</sup> [www.cr.nps.gov/history/online\\_books/butkowsky4/space8.htm](http://www.cr.nps.gov/history/online_books/butkowsky4/space8.htm). Other major centers of rocket propulsion development in the late 1940s and 1950s included White Sands Missile Range and Edwards Air Force Base. Rocket propulsion test stands built at White Sands in the late 1940s and 1950s included the "100K" and "5000K" Static Test Stands, both completed in 1946, and the "300K Test Stand" built in 1953. However, these stands accommodated static propulsion systems testing of full-scale missiles rather than testing of single engines, as was the case at the Rocket Engine Test Facility. As at Redstone Arsenal, these White Sands test stands were developmentally oriented, in contrast to the strong research orientation of the Rocket Engine Test Facility.

**Contemporary NASA Rocket Testing Facilities:**

The Rocket Engine Test Facility at the Glenn Research Center at Lewis Field was one center among several in NASA's facility inventory. At present the John C. Stennis Space Center in Hancock County, Mississippi, manages NASA's rocket propulsion testing programs. It oversees facilities at the Marshall Space Flight Center in Alabama, the White Sands Test Facility in New Mexico, and the Glenn Research Center's Plum Brook Station in Sandusky, Ohio. All main engines used on the Space Shuttle undergo acceptance testing at the Stennis facility. In addition to acceptance testing, Stennis is equipped to test developmental rocket engine components in a complex of seven separate test cells equipped with facilities for handling ultra-high-pressure gases and high-pressure cryogenic fluids.

The George C. Marshall Space Flight Center in Huntsville, Alabama, is currently NASA's primary center for developing space transportation and propulsion systems. Its facilities include a Combustion Research Facility, Component Test Facility, Solid Propellant Test Facility, Advanced Engine Test Facility, Hydrogen Cold Flow Facility, and Test Cells for evaluating scale model combustion devices and rocket engines.

NASA also operates the White Sands Test Facility near Las Cruces, New Mexico. White Sands tests and evaluates potentially hazardous materials, components, and rocket propulsion systems.<sup>19</sup> These facilities have continued much of the work formerly conducted at the NASA-Glenn Rocket Engine Test Facility.<sup>20</sup>

**Overview of Testing and Facility Development at the Rocket Engine Test Facility:***Test Stand A*

It must be emphasized that the Rocket Engine Test Facility was classified as a research facility. As such, the staff focused on a mission to test new designs and concepts, analyze successes and failures, and then re-design and re-evaluate. This environment fostered creative and innovative solutions in a field of study that was new and in which there were many unknown factors. While major aerospace companies were undertaking corporate research in rocket engine development, the Rocket Engine Test Facility was able to evaluate novel concepts and transfer viable ones to other research facilities for scale-up and possible production. The type of research carried out produced data cost-effectively by testing model and sub-scale engines. Sub-scale testing also produced useful design data with minimal use of expensive fuels and oxidizers. Typically these test engines had 4.8" chambers with 2.62" throats, or 10" chambers with 7.6" throats. Using

---

<sup>19</sup> Website <http://www.ssc.nasa.gov>.

<sup>20</sup> NASA-Glenn researchers demonstrated the capability for testing a hydrogen- and oxygen-burning rocket in a continuously operating altitude facility. This Rocket-Based Combined Cycle is designed to lower the cost of space transportation by combining both rocket and air-breathing propulsion systems. This work was reported in June 2002; *ibid*.

high-pressure reactant feeds, an engine with a 4.8" throat could produce thrusts of 75 kilonewtons (17,000 pounds).

In 1958 the name of Lewis Laboratory changed to Lewis Research Center to reflect its incorporation into the new National Aeronautics and Space Administration (NASA), formed around NACA as its core. During the 1950s and 1960s, the Rocket Engine Test Facility participated in several important research programs, most notably a program focusing on the development of liquid hydrogen as a rocket fuel. The facility also made important contributions to the development of the Pratt and Whitney RL-10 engine used in the Centaur rocket, and the J-2 engine used for the second stage of the Saturn V rocket.<sup>21</sup> The facility also accommodated important research on improving rocket engine combustion stability by reducing unwanted pressure oscillations during operation.<sup>22</sup>

The programs often used relatively inexpensive sub-scale engines made of carbon steel coated with a ceramic coating known to the trade as "Rockide." These engines could also be re-used after several cycles. When the Rockide coating became thin, the engines were recoated and put back into the test program.<sup>23</sup> Rockide was a cooperative development of Metco and the Norton Company. To coat a metal with this material, a rod of ceramic material was passed through a Metallizing<sup>24</sup> gun plasma flame where it melted and formed droplets that accumulated on the carbon steel rocket engine. Either alumina (Rockide "A," aluminum oxide) or zirconia (Rockide "Z," zirconium dioxide) could be coated on the test engine components. Instead of expensive water-cooled test components, the hardware designers found that they could obtain useful data with Rockide-coated steel engines and firing times as short as three seconds.

The Rocket Engine Test Facility was originally designed to handle engines using liquid oxygen (LOX) and rocket propellant (RP), which was a refined grade of kerosene. NASA researchers tested early experimental engines on the facility's vertical test stand (Stand A), which could support engines that exerted 20,000 pounds of thrust. Liquid oxygen was used as the oxidant. However, records indicate that engines using a hydrogen-fluorine combination were tested at the Rocket Engine Test Facility from 1957-59, including a 1959 test of a regeneratively cooled hydrogen-fluorine engine with a 480-pound thrust, the highest thrust attained by any chemical rocket up to that time.<sup>25</sup>

---

<sup>21</sup> Dawson, *Engines and Innovation*, 235.

<sup>22</sup> Robert Stewart, Tour of the Rocket Engine Test Facility with George Repas (former Rocket Engine Test Facility engineer), VHS videotape, 2002.

<sup>23</sup> Interview with George Repas (February 21, 2003).

<sup>24</sup> Metallizing is a process used to coat or build up metal substrates with a layer of another or similar metal. It is useful for building up worn areas on machinery or for coating an inexpensive substrate with a layer of another hard, wear-resistant metal. In operation, the coating metal, in the form of a rod or wire, is passed through a plasma torch. Miniscule molten droplets of the metal are formed and projected onto the substrate to be coated. The droplets fuse together and form a coating that may be machined to specified dimensions.

<sup>25</sup> Virginia P. Dawson, "History of the Rocket Engine Test Facility at NASA-Glenn Research Center," 30-31.

In the early 1960s, test runs were completed at the Rocket Engine Test Facility on a Centaur RL-10 engine, the world's first liquid hydrogen rocket engine. A number of technical problems with the RL-10 were investigated at the Rocket Engine Test Facility from 1959-61. The Centaur was first used in the second stage of an Atlas rocket that carried a robotic probe to the moon. The success of RL-10 tests at Lewis Research Center helped confirm the reliability of the RL-10 and contributed to growing confidence at NASA in the project management abilities of the Lewis Research Center staff. In October 1962, management of the Centaur Program was transferred from Marshall Space Flight Center in Huntsville, Alabama, to Lewis Research Center. The expertise of the Rocket Engine Test Facility staff was an important factor in this transfer, and the Centaur program continued to be managed by Lewis Research Center for the next thirty years.<sup>26</sup>

Research completed at the Rocket Engine Test Facility during this period also influenced the decision to use a liquid hydrogen engine for the upper stage of the Saturn rocket. It is now widely accepted that use of liquid hydrogen in the upper stages of the Saturn rocket gave the United States a decisive advantage in the race to complete a manned mission to the moon.<sup>27</sup> By the 1960s, reactants such as nitrogen tetroxide, un-symmetrical dimethyl hydrazine, and fluorine were increasingly used in tests at the Rocket Engine Test Facility, although all fluorine testing ended by 1966 because it was considered impractical as an oxidizer.<sup>28</sup> Use of these chemicals resulted in alterations to the Rocket Engine Test Facility. The facility's unique configuration with a massive scrubber/silencer was in large part dictated by the necessity to ensure that no toxic by-products were released into the environment. The scrubber also reduced the noise generated by the firing rocket engines.

There were a number of upgrades to the test facility during the 1960s. Over that decade, the original gas bottles of the Rocket Engine Test Facility were upgraded to test more powerful engines. Originally rated for 2,200 psi, they were filled to 1,500 psi. In 1972 the bottles were upgraded to 6,000 psi for helium and nitrogen, and 5,000 psi for liquid oxygen. The higher pressured allowed the facility to test sub-scale engines with thrusts equivalent to full-size or larger model engines. Modifications during the 1960s included construction of Building 205 ca. 1962-65 as a propellant transfer and storage area. Building 206, the cryogenic vaporizer facility, was built in 1968. Both buildings had vaporizers. Mobile Dewars could transport liquefied gases to these facilities, where the vaporizers converted the liquids into high-pressure gases. The exhaust scrubber stack at Building 202 was also extended in the late 1960s to guarantee thorough removal of toxic exhaust products related to the reactants in use at the facility. In addition, the

---

<sup>26</sup> Virginia P. Dawson, "Memo on Rocket Engine Test Facility," on file at Hardlines Design Company (February 15, 2002).

<sup>27</sup> *Ibid.*, 30-34.

<sup>28</sup> According to George Repas; cited in NASA-Glenn Research Center, "Comments on Rocket Engine Test Facility Historic American Engineering Record Documentation" (January 24, 2003), 5.

test facility control room in Building 100 was repeatedly upgraded during this period to keep pace with advances in instrumentation technologies.

Between 1962 and the early 1970s, the Rocket Engine Test Facility investigated the problem of combustion instability, also sometimes referred to as “screech.” This instability was caused by pressure changes in the engine combustion chamber during firing, and could lead to melting of the chamber wall and, ultimately, engine failure. The F-1 engine used for the first stage of the Saturn launch vehicle experienced serious combustion instability problems. Rocket Engine Test Facility investigations of various combustion chamber and injector designs may have contributed to a 1965 re-design of the F-1 engine’s injector. This re-design successfully solved the F-1 engine’s combustion instability problems.<sup>29</sup>

From 1962-66, Rocket Engine Test Facility research focused on combustion instability in the M-1 engine. The M-1 was developed as an upper-stage hydrogen engine for the Nova rocket, which was to be more powerful than the Saturn rocket. Tests at the facility determined that the inclusion of baffles in the M-1 combustion chamber sufficiently reduced instability. However, a decision to use a lunar orbit rendezvous approach for the moon rather than a direct ascent approach meant that the more powerful Nova would not be needed for the moon project. The M-1 program was cancelled in 1966, but the Nova rocket was kept on the drawing board for future missions beyond the moon.<sup>30</sup>

After the end of research for the Apollo Program, a number of research programs were undertaken at the Rocket Engine Test Facility in the 1970s and 1980s. In 1974, a proposal was written to use the facility to research development of a reusable upper stage for the space shuttle. The focus of this proposal was the development of an engine capable of completing up to fifty missions.<sup>31</sup> In the late 1970s and 1980s, Rocket Engine Test Facility engineers tested the first liquid-oxygen-cooled engines built by NASA and explored the problems of using this unique cooling concept. Another important program involved testing a research engine known as the Plug Engine, which was tested in the interest of developing re-usable engines. Each Plug Engine featured an hourglass-shaped, ceramic-coated, cooled plug in the injector. These engines were often fired and shut off eighty-five times in a row until the facility’s hydrogen supply tank was nearly empty. In some cases an engine was fired more than 300 times in one evening. Testing stopped when the engine began to leak. These tests were conducted to determine the low thermal cycle fatigue characteristics of the engines. These engines, commonly known as spool pieces, were constructed of various metal alloys and featured a number of different cooling passage designs. This testing program was conducted on Test Stand A from 1972 through the 1980s.<sup>32</sup> Testing at the Rocket Engine Test Facility during the 1970s and 1980s greatly

---

<sup>29</sup> Dawson, “Memo,” 6.

<sup>30</sup> *Ibid.*

<sup>31</sup> *Ibid.*, 7.

<sup>32</sup> George Repas, “South 40 Hardware Identification,” on file at Hardlines Design Company (July 5, 2002).

contributed to the development of propulsion systems for the Space Shuttle and other important NASA programs.

The Rocket Engine Test Facility was significantly upgraded in the 1980s. Building 206A, a liquid hydrogen vaporizer facility, was added to the Rocket Engine Test Facility in 1982. This structure was built on a site east of the rocket test facility's 500,000-gallon water tank. A second test stand ("Stand B") was also added to Building 202 in the 1980s. The Rocket Engine Test Facility continued to play an important role in propulsion technology development during the 1980s and the first half of the 1990s. For example, hydrogen-oxygen engines used in the Space Shuttle were tested at the Rocket Engine Test Facility.

### *Test Stand B*

Until 1984, all engines tested at the Rocket Engine Test Facility were evaluated in the ambient atmospheric conditions found at the earth's surface. Since most rocket engines are designed to operate in outer space, a test stand that could simulate the conditions found there would provide a practical means of obtaining data in a terrestrial laboratory. In 1984 a second test stand, known as Stand B, was added to Building 202.<sup>33</sup> Stand B introduced the capability of evaluating rocket nozzles with ratios of up to 1,000:1 on small low-thrust engines. The new Stand B could also simulate the vacuum of space. The new stand consisted of a cylindrical chamber in which a rocket engine could be mounted horizontally. The forward end of the chamber was a shallow dome that supported a test stand for mounting the rocket engine. Sealed feed-through openings provided a means for supplying reactants as well as control and sensory wiring. The back end of the chamber was a cylinder mounted on wheels that could be connected to the vacuum system. After the engine had been mounted and connected to supply, sensor, and control systems, the wheeled cylinder was rolled into position against the shallow dome, sealing the engine in the chamber. The exhaust port of the chamber was then connected to the vacuum system. The engine exhaust was directed through a water-cooled diffuser that was supplied from the 500,000-gallon scrubber/silencer reservoir. The exhaust then passed through an inter-cooler and into the scrubber/silencer. The vacuum was maintained during the test period by two gas ejectors powered by the facility's nitrogen supplies. The ejectors evacuated a vacuum reservoir chamber that measured 28' long and 10' in diameter, and that was coupled to the test chamber.<sup>34</sup> Normally this type of ejector was steam-powered, but the availability of a high-pressure nitrogen supply on the site made the use of this gas cost-effective.<sup>35</sup>

---

<sup>33</sup> *Ibid.*

<sup>34</sup> Drawing CF 100873 – 6/1/83.

<sup>35</sup> Ejectors use the venturi effect to create a vacuum. An ejector is a simple form of vacuum pump that has no moving parts. It consists of a gas nozzle that discharges a high-velocity jet of nitrogen across a suction chamber connected to the vacuum chamber. The gas to be evacuated is entrained by the nitrogen and carried into a venturi-shaped diffuser that converts the velocity energy of the nitrogen into pressure energy. Ejectors normally used high-pressure steam to provide the energy necessary to create a vacuum. Since the Rocket Engine Test Facility had access to ample supplies of pressurized nitrogen, it was cost-effective to use this gas rather than steam.

*Test Stand C, Later Programs, and Decommissioning*

In 1991 another test stand, known as Stand C, was added to the Building 202 complex. The new test stand was a freestanding structure located approximately 40' north of the test cell that accommodated Stands A and B. The new Test Stand C was used to test seal materials and designs for liquid oxygen pumps and other components. The initial test program tested seals on a turbo pump rig. A small pole barn was also built for storage on the southern portion of the site in the early 1990s.

In the 1990s, three separate testing programs were run for TRW, Inc., at the Rocket Engine Test Facility under an agreement between NASA and the contractor. Under this contract, TRW provided the engine and NASA provided the hardware, piping, instrumentation, computers, software, and operations personnel to complete the testing and to provide data to TRW. An engine fueled by liquid hydrogen and liquid oxygen and capable of exerting 16,000 pounds of thrust was tested, along with a liquid-hydrogen-fueled engine capable of exerting 40,000 pounds of thrust. An engine fueled by kerosene and liquid oxygen and capable of exerting 13,000 pounds of thrust was also tested.<sup>36</sup> This research was related to development of a low-cost rocket engine.<sup>37</sup>

NASA developed plans in the 1990s to rehabilitate the Rocket Engine Test Facility. The agency proposed a "Construction of Facility Modification" contract for \$12.5 million to upgrade and substantially rehabilitate the facility. The purpose of this rehabilitation was the restoration and enhancement of productivity. The project included a "Distributed Control System," a "Rehabilitation of Building 100," and a "Rehabilitation of Miscellaneous Systems." Substantial repairs to the facility's exhaust scrubber/silencer that would cost \$880,000 were also part of this project.<sup>38</sup> This rehabilitation was to include the replacement of corroded steel water spray bars in the facility's exhaust scrubber with new stainless steel bars. Maintenance of the spray bars had been an ongoing concern, since scrubber effluent had corroded the bars and caused major physical damage to the spray system. Plans called for the Rocket Engine Test Facility to close temporarily for these repairs, and some new corrosion-resistant, stainless steel spray bar components were ordered and delivered to the site. These new spray bars were never installed.

The City of Cleveland announced plans to expand Hopkins International Airport through the construction of an extended runway. This expansion would require demolition of the Rocket Engine Test Facility, including Building 202. In addition, NASA's Space Propulsion Technology Division had no planned NASA or reimbursable programs that required the Rocket Engine Test Facility, and no future program funds were anticipated that could offset operational costs at the

---

<sup>36</sup> See note 18.

<sup>37</sup> Dawson, "Memo," 39.

<sup>38</sup> Aerospace Technology Facilities Division, *RETF CoF Status*. Record of overhead slides prepared for meeting (Cleveland, LeRC), undated but probably 1994. Archives: NASA-Glenn Research Center, Cleveland, Ohio.

facility. Awareness of plans to expand the airport runway and demolish the Rocket Engine Test Facility led NASA management in the first half of 1995 to decide against further investment in the test facility. NASA therefore canceled the “Construction of Facility Modification” project, and announced that the Rocket Engine Test Facility would close permanently. The last tests were completed at the facility during the first half of 1995, and the official shutdown date was July 1, 1995. Since closing, the Rocket Engine Test Facility has remained vacant and in “Inactive-Mothballed” status.<sup>39</sup>

The Rocket Engine Test Facility was listed on the National Register of Historic Places in 1984-85 for its role in the development of lightweight, regeneratively cooled hydrogen engines and for its role in facilitating the overall progress of propulsion technology used in NASA missions and programs.<sup>40</sup> The National Park Service also designated the facility a National Historic Landmark. The entire Rocket Engine Test Facility site in the South 40 area is currently slated for demolition to accommodate the expansion of the adjacent Cleveland Hopkins International Airport. Because of the facility’s National Register and National Historic Landmark status, this Historic American Engineering Record documentation project is required to mitigate the demolition.

### **Overview of Major Rocket Engine Test Facility Buildings:**

#### *Building 202 – Rocket Engine Test Cell*

Building 202 was part of the original 1955-57 construction phase for the Rocket Engine Test Facility, but this building has been substantially altered throughout the history of the facility. Building 202 originally housed a test cell, a propellant supply system, and a distinctive scrubber system that removed combustion waste products from the exhaust stream. The scrubber system also muted the noise of rocket firing. Gasoline was the test fuel originally used at the facility, before liquid hydrogen was readily available.

Adjacent to the test cell was a small shop where NASA personnel assembled engines and installed instrumentation, and a tank farm of high-pressure helium bottles. Storage areas for fuels, liquid oxygen, and water for the scrubber were located on the hillside east of Building 202. Water for the scrubber was fed by gravity through a pipe measuring 55" in diameter from the 500,000-gallon tank located 26.7' above the test cell floor. The center of the feeders to the spray nozzle assembly is about 16' below the test cell floor, giving a total water head of approximately 47.7' plus the depth of water in the 500,000-gallon reservoir tank. Water pressure at the spray manifold was generally 80 psi. A valve at the reservoir could shut off the water entering the pipe. A second valve at the base of the pipe could not be fully closed and stayed about 10 percent open. This allowed the pipe to drain and prevented water in the pipe from freezing. Liquid

---

<sup>39</sup> Larry A. Diehl, 5300/Chief, Space Propulsion Technology Division, Cleveland, to 7000/Acting Director of Technical Services, January 31, 1996. Archives: NASA-Glenn Research Center, Cleveland, Ohio.

<sup>40</sup> Harry Butowsky, “Rocket Engine Test Facility, National Register of Historic Places Nomination” (Washington, D.C.: United States Department of the Interior, National Park Service, 1984).

reactants were transferred to tanks in the fuel and oxidant pits using the pressure of vaporized and re-pressurized inert gas.<sup>41</sup>

Critical to a successful test run was the availability of an adequate fuel and oxidizer supply that could be forced into the test engine at a controlled rate. Hazardous reactants also had to be kept isolated before being pumped into the rocket engine. These conditions were met by the construction of a fuel pit and an oxidant pit for storing fuels adjacent to the test cell.

The termination or observation room in Building 202 was located adjacent to the test cell. This space was designed to protect observers and electronic data transmission equipment during the unpredictable tests of experimental engine designs. The room housed termination hardware that allowed connection between wiring from the test engine to the relatively long-distance communications lines that carried data to the control room in Building 100. A periscope-like mirror system allowed the observer to watch a test directly from a safe location. The engineer in the observation room could also immediately terminate a test by pressing an “abort” button related to a programmable logic controller.

The Test Cell.<sup>42</sup> The test cell was a lightly built but solidly framed structure sheathed in asbestos cement Transite panels. In later years fiberglass sheets replaced these panels. Explosions blew these sheets free of the frame and relieved pressure inside the cell.<sup>43</sup> The panels were then easily replaced.

The rocket engine being tested exhausted directly into the scrubber/silencer. Seven burners on top of the scrubber ignited any hydrogen or other fuel not consumed by the engine, and prevented this explosive, unburned fuel from accumulating inside the scrubber.<sup>44</sup> Instrumentation measured engine thrust, chamber pressure, and other parameters. This instrumentation included strain gauges, load cells, pressure sensors, thermocouples, platinum resistance temperature detectors, and accelerometers, which were mounted on the various supporting frames and near the rocket engine. These data were sent to the adjacent observation room for transmission to the control room in Building 100.

The Scrubber/Silencer. The rocket exhaust was treated inside the scrubber/silencer, where the hot gas passed through a heavy spray of water. The scrubber/silencer consisted of several

---

<sup>41</sup> Drawing No. CE-159887 – 3/5/92.

<sup>42</sup> The descriptive material on the test cell and its operation was obtained during a videotaped tour of the facility conducted by George Repas, who was employed as a hardware design engineer at the Rocket Engine Test Facility throughout most of its years of operation.

<sup>43</sup> According to Mr. Repas, an explosion blew away all of the fiberglass panels on only one occasion. All other explosions blew away only a few panels.

<sup>44</sup> This was a technological change from the procedure used in Rocket Lab Test Cell 22, where carbon dioxide was injected into the exhaust stream to suppress explosions; NASA-Glenn Research Center, Comments on Rocket Engine Test Facility Historic American Engineering Record Documentation (January 24, 2003).

sections. The test engine was supported on a thrust stand over the inlet end. This conical section was attached to a horizontal tank measuring 25' in diameter and approximately 60' long. The scrubber was equipped with multiple water spray nozzles that cooled the exhaust stream, dissolved soluble matter, and captured solids.

Exhaust gases produced by the rocket exited at velocities of 9,000-12,000 feet per second and temperatures up to 6,000°F. The transition of the exhaust stream from a rocket nozzle measuring a few square inches in surface area to a horizontal scrubber/silencer tank with a cross section of more than 490 square feet slowed the exhaust to a velocity of approximately twenty-five feet per second. The cooled exhaust, clear of soluble compounds, entered an elbow-shaped transition to a vertical section of the scrubber/silencer. Exhaust emerged from this opening at a temperature below 160°F, and at a velocity of around twenty feet per second.

Additional water treatment equipment was located north of the scrubber/silencer. Water, condensed steam, and combustion by-products trapped by the scrubber drained into a detention tank with a capacity of 20,000 gallons. Wastewater remained in this tank until the end of the day's test program, when it was pumped into a neutralizing tank. Chemical technicians analyzed the wastewater and determined the quantity and type of additive needed to neutralize acidity or alkalinity. After treatment, the water was retested and then pumped to a holding tank. The treated water was then pumped to the municipal wastewater treatment plant, and solid wastes were sent to a stable landfill.<sup>45</sup> Solid wastes are essentially insoluble in water. For example, the waste generated by fluorine reactant treated with calcium hydroxide would be calcium fluoride, a compound with a solubility of 0.0016 parts per 100 parts by weight of water. The resulting compound is chemically the same as fluorite, a mineral found in nature.

#### *Building No. 205 – Propellant Transfer and Storage Area*

Building 205 was constructed ca. 1962-65 approximately 170' north-northeast of the Rocket Engine Test Cell in Building 202. The building is a lightly constructed shed that covers an area of about 1,710 square feet. The original equipment has been removed from this building, and some cladding is missing from the east elevation, but the shell of the original building remains.

The Rocket Engine Test Facility did not use conventional electrically driven centrifugal pumps to deliver liquid oxygen to the test cell. When the Rocket Engine Test Facility complex was built from 1955-57, commercially available mechanical pumps for handling cryogenic fluids were not ideally designed for forcing liquid oxygen at high flow rates into test engines. To overcome the problems inherent in directly pumping liquid oxygen, the designers developed an indirect pumping system. The system used pressurized gaseous helium to transfer the pumping energy of

---

<sup>45</sup> A stable landfill is defined as one that presents no threat of polluting the environment, has no evidence of concentration gradient of pollutants between the landfill and the surrounding area, and that complies with legislative mandates. The actual technical requirements and extensive material on developing a stable landfill are detailed in United States Environmental Protection Agency, *Solid Waste Disposal-Facility Criteria – A Technical Manual EPA530-R-93-017* (Washington, D.C.: U.S. Environmental Protection Agency, November 1993), Chapter 4, section D.

electrically driven compressors to the liquid oxygen supply system. Building 205 housed the compressor and automated control system that pressurized helium gas to 6,000 psi. This pressurized helium was then used to force liquid oxygen through the piping system.

The helium that was pressurized by the compressor in Building 205 was then piped to the liquid oxygen tank in the oxidant pit at Building 202. Control valves admitted pressurized helium into the liquid oxygen tank. The pressurized helium pushed the liquid oxygen into the outlet pipe and out to the test rig at the rate necessary to obtain the engine's maximum thrust.<sup>46</sup>

#### *Building 206 – Cryogenic Vaporizer Facility*

Building 206 was constructed in 1968 and has undergone little alteration.<sup>47</sup> This structure was part of the gas distribution system for the Rocket Engine Test Facility. Building 206 housed a liquid nitrogen vaporizer and a nitrogen gas compressor. It may have been designed to handle other gases, since the building was equipped with explosion-proof lighting and telephones. Inert, non-flammable nitrogen gas was used at the Rocket Engine Test Facility to power pneumatic actuators that opened and closed valves. Electrically operated solenoid valves in turn controlled the pressurized nitrogen supply to the actuators. Hydraulic fluid pressurized the engines' fire control systems while the fire suppression system was pressurized with inert, non-flammable nitrogen gas.

The most cost-effective method of transporting nitrogen, however, was to maintain it in liquid form. Large mobile Dewars could transport the nitrogen, and maintain it below its boiling point of  $-195.8^{\circ}\text{C}$ , with limited loss through evaporation. The liquid nitrogen had to be vaporized for use in the facility. A nitrogen vaporizer is basically a heat exchanger.<sup>48</sup> Liquid nitrogen was first fed through a pump/compressor, pressurized to 6,000 psi. The highly pressurized liquid then flowed through a network of pipes to the vaporizer. Fans pulled ambient air across the exterior surface of the pipes. The liquid nitrogen in the pipes warmed and boiled, forming high-pressure nitrogen gas. This gas was then piped throughout the Rocket Engine Test Facility for use.

The use of pressurized air to actuate remote valves was common practice in the 1950s. Textbooks of the period describe devices called "pneumatic diaphragm motors," which were used at the Rocket Engine Test Facility to open sliding stem control valves, dampers, rotary plug valves, and other remotely controlled devices.<sup>49</sup> The use of inert, compressed nitrogen to operate pneumatic actuators yielded an extra margin of safety in controlling reactive fuels and oxidants.

---

<sup>46</sup> Drawing No. CE-101632 – 8/16/55.

<sup>47</sup> Building 206 is sometimes referred to in NASA records as "Building 206B" in an effort to distinguish it from Building 206A, which is a different building that was constructed later. In this report, Building 206B is always referred to as Building 206.

<sup>48</sup> John H. Perry Ph.D., ed., *Chemical Engineers' Handbook* (New York: McGraw-Hill Book Company, 1950), 1733.

<sup>49</sup> Perry, 1328.

Nitrogen also powered the ejectors that simulated the vacuum of space in Test Stand B, which was added to the facility in 1985.

### *Building 100 – The Control Room*

Building 100 was built in 1955-57 during the original Rocket Engine Test Facility construction phase. The northernmost wing of Building 100 housed the central control room where engineers ran and monitored rocket engine tests. Its location 1,600' north of the actual test stand provided a safe location where engineers could run the tests. The transfer and pressurizing of the fuels and oxidizers used during the engine tests were also controlled from the control room. Equipment in this space also detected, monitored, and recorded engine performance during tests. A remote control facility enhanced the safety of testing new rocket engine designs using hazardous fuels, and test engineers could therefore collect and store data in an area that was unlikely to be damaged in case of catastrophic engine failure.

The design of the control room followed standard practice of the time. The main control and instrument consoles were centrally located and surrounded by model or control boards that showed the operating status of the major valves, pumps, motors, and actuators. The control console and model boards were schematic representations of the system, with colored lines that represented the pipes carrying reactants to the engine being evaluated.<sup>50</sup>

Test engine operations were complex and short, rarely lasting more than a few minutes. During that brief time, transient events could occur that were significant to longer-term performance, but human reaction time was insufficient for manual operation of a test. In addition, real-time direct observations by engineers did not yield much useful data. Consequently, the operation, sensing, and recording of engine tests were mostly done using electro-mechanical devices or computers.

In the late 1970s, programmable controllers (PCs) were developed. With the development of the personal computer, these devices were re-designated as programmable logic controllers, or "PLCs." At the Rocket Engine Test Facility, programmable logic controllers made by the Modicon Corporation replaced the earlier electro-mechanical devices used in the control system. A programmer calibrated the PLC to operate the valves and actuators controlling the fuel, oxidant, and ignition sequence according to a predetermined time schedule. The engine test runs were nominally controlled by the PLC, but they could be manually overridden by a "panic button" located on the main control panel.

Originally, the performance data of a run were recorded on magnetic tape, thermal paper linear recorders, multicolor pen recorders, or "Visicorders," devices manufactured by Honeywell that recorded several events simultaneously. In the 1980s, personnel at the Rocket Engine Test Facility reduced raw data using TRADAR or CADDE programs that were written by Lewis Research Center personnel specifically for rocket engine testing. These data were then fed by direct digital data link to the Research Analysis Center (RAC) in Building 142, where IBM 3033

---

<sup>50</sup> Drawing No. CD-101455 – 5/17/56.

TSS and Cray 1-S computers, as well as DEC VAX clusters, further processed data before transmitting it to the control room for analysis.<sup>51</sup> This system provided on-line data processing facilities to the control room, hard copy terminals, and monitors located in the rocket operations building control room.

The control room has undergone several re-configurations since 1957. Changing technology and the addition of a high-altitude rocket test stand and a turbo pump test stand required the addition of new control and recording equipment. In 1991, Test Stand C was added to Building 202. This stand was used to test seal materials and designs for liquid oxygen pumps and other components. The controls for Test Stand C were located in instrument racks on the southeast side of the control room.

### *Observation Blockhouse*

The observation blockhouse was also built during the original Rocket Engine Test Facility construction phase of 1955-57. During the early years of operation at the Rocket Engine Test Facility, technicians and engineers relied on direct human observation of engine firings to supplement instrument readings. Some of these observations were made by engineers and technicians stationed in a small blockhouse located approximately 294' north of the test stands in Building 202.<sup>52</sup> The blockhouse protected these observers from flying debris in case of catastrophic engine failure.

The blockhouse was equipped with an intercom system, emergency communications, and a telephone system to allow two-way contact between observers and test engineers. Positioned below the observation window was a "panic button" similar to the one in the Building 100 control room. The observer could activate this button to initiate an automatic test shutdown under programmable logic control, in case of an emergency.<sup>53</sup> As sensors, instrumentation, and computerized data reduction became more sophisticated, the information that could be provided by observers in a protected area was less significant and the blockhouse fell into increasing disuse. In 1972 the staff installed a closed-circuit television system with a camera on top of the blockhouse.<sup>54</sup> The test cell in Building 202 and the surrounding area were also equipped with additional lighting, which enabled technicians and engineers in the Building 100 control room to observe tests on closed-circuit television. This further enhanced safety and reduced the need for observers stationed in the blockhouse.

---

<sup>51</sup> Email letter from Kevin P. Coleman, Records and Electronic Forms Manager, History Office Liaison, NASA, John H. Glenn Research Center at Lewis Field, Cleveland, Ohio.

<sup>52</sup> Drawing CF101580 – 7/3/86.

<sup>53</sup> See HAER No. OH-124-D – GRC Building 100 – Rocket Operations Building.

<sup>54</sup> Interview with George Repas 10/24/02.

**Conclusion:**

The Rocket Engine Test Facility was an outstanding example of a research and development operation that made major contributions to several space programs. It was instrumental in developing liquid-hydrogen-fueled rocket engines. Its staff, engineers, and technicians exhibited creativity and ingenuity in developing effective solutions to complex engineering problems. The facility was designed with sufficient foresight and flexibility to allow the expansion and use of new technologies that were developed during its working period. Researchers at NASA's Glenn Research Center continue to do outstanding work in rocket research, and their recent efforts have focused on rocket-based combined-cycle engines. These engines combine both rocket and air-breathing propulsion systems to reduce the cost of on-board oxygen by using atmospheric air for a portion of the burn.<sup>55</sup>

---

<sup>55</sup> Jeff Hass, "Ground Testing," *Aerospace America* (December 2002): 77.

Sources of Information/Bibliography

A. Engineering Drawings:

NASA Lewis Research Center – Cleveland, Ohio 44135  
Rocket Engine Test Facility  
Observation Post  
Drawing No. CF 101540 – 6/29/55

National Advisory Committee for Aeronautics – Lewis Flight Propulsion Laboratory –  
Cleveland, Ohio  
Rocket Engine Research Facility – Test Cell Building  
Foundation Plan  
Drawing No. CE-101310 – 6/29/55

National Advisory Committee for Aeronautics – Lewis Flight Propulsion Laboratory –  
Cleveland, Ohio  
Rocket Engine Research Facility – Exhaust Duct and Detention Tank – Demister Support Details  
General Plan and Miscellaneous Details  
Drawing No. CE-101261 – 7/18/55

National Advisory Committee for Aeronautics – Lewis Flight Propulsion Laboratory –  
Cleveland, Ohio  
Rocket Engine Research Facility – Exhaust Duct and Detention Tank  
Exhaust Duct Elevations and Sections  
Drawing No. CE-101263 – 7/18/55

National Advisory Committee for Aeronautics – Lewis Flight Propulsion Laboratory –  
Cleveland, Ohio  
Rocket Engine Research Facility – Exhaust Duct and Detention Tank  
Exhaust Duct Wash Down Spray System  
Drawing No. CE-101276 – 7/18/55

NASA Lewis Research Center – Cleveland, Ohio 44135  
Rocket Engine Test Facility  
Oxidant Tank Details  
Drawing No. CF-101632 – 8/16/55

National Advisory Committee for Aeronautics – Lewis Flight Propulsion Laboratory –  
Cleveland, Ohio  
Rocket Engine Research Facility – Fuel Tank General Assembly  
Drawing No. CE-101634 – 9/27/55

NASA Lewis Research Center – Cleveland, Ohio 44135  
High Pressure Propellant System for Rocket Engine Test Facility  
Oxygen System Schematic Diagram  
Drawing No. CF-101233 – 12/14/55

NASA Lewis Research Center – Cleveland, Ohio 44135  
Facility Plan and Equipment Layout  
RETF Area Master Plan S-40 – Drawing No. CF 101539 – 2/3/84

NASA Lewis Research Center – Cleveland, Ohio 44135  
Rocket Engine Test Facility – Building No. 202 – Pilot Plan Equipment Location  
Drawing No. CF-101580 – 7/9/86

National Aeronautics and Space Administration – Lewis Research Center – Cleveland, Ohio  
Gaseous Nitrogen System–Turbo Machinery Test Facility Building 202  
3000 PSIG Gaseous Nitrogen Supply Test Stand C  
Drawing CE-183172 – 9/3/92

NASA Lewis Research Center – Cleveland, Ohio 44135  
Rocket Engine Test Facility –Gaseous Nitrogen System  
South 40 – Building No. 202  
3000 psig Gaseous Nitrogen Supply System Schematic  
Drawing No. CF-183170 – 9/3/92

NASA Lewis Research Center – Cleveland, Ohio 44135  
Rocket Engine Test Facility – Gaseous Nitrogen System  
South 40 – Building No. 202  
6000/4000 psig Gaseous Nitrogen Supply System Schematic  
Drawing No. CF-101541 – 9/3/92

NASA Lewis Research Center – Cleveland, Ohio 44135  
Rocket Engine Test Facility for Altitude Testing (202)  
Piping Section  
Drawing No. CF-100873 – 6/1/83

B. Interviews:

Repas, George, Hardware Design Engineer  
Interview by the author, 28 May 2002  
Cleveland, Video recording, Hardlines Design Company, Columbus, Ohio

Repas, George, Hardware Design Engineer  
Interview by the author, 24 October 2002  
West Suffield, Connecticut, Telephone interview, Hardlines Design Company,  
Columbus, Ohio

Repas, George, Hardware Design Engineer  
Interview by the author, 15 November 2002  
West Suffield, Connecticut, Telephone interview, Hardlines Design Company,  
Columbus, Ohio

C. Letters:

Diehl, Larry A. Cleveland, 5300/Chief, Space Propulsion Technology Division,  
Cleveland, to 7000/Acting Director of Technical Services. January 31, 1996.  
Archives: NASA – Glenn Research Center, Cleveland, Ohio.

D. Slide Presentation:

Aerospace Technology Facilities Division. *RETF CoF Status*. Record of overhead slides  
prepared for meeting. (Cleveland, LeRC) Undated but probably 1994. Archives:  
NASA-Glenn Research Center, Cleveland, Ohio.

E. Websites:

HABS-HAER website <http://memory.loc.gov/ammem/hhquery.html>

NASA website <http://www.ssc.nasa.gov>

National Park Service website [www.cr.nps.gov/history/online\\_books/butkowsky4](http://www.cr.nps.gov/history/online_books/butkowsky4)

F. Secondary Sources:

Butowsky, Harry. "Rocket Engine Test Facility, National Register of Historic Places  
Nomination." Washington, D.C.: United States Department of the Interior,  
National Park Service, 1984.

Dawson, Virginia P. *Engines and Innovation*. Washington, D.C.: National Aeronautics  
and Space Administration, Scientific and Technical Information Division, 1991.

\_\_\_\_\_. "History of the Rocket Engine Test Facility at NASA-Glenn  
Research Center" (draft). On file at Hardlines Design Company, Columbus,  
Ohio. February 19, 2003.

\_\_\_\_\_. "Memo on Rocket Engine Test Facility." On file at Hardlines Design Company, Columbus, Ohio. February 15, 2002

\_\_\_\_\_. "Rocket Propulsion Research at Lewis Research Center," 28<sup>th</sup> Joint Propulsion Conference AIAA/SAE/ASME/ASEE, July 6-8, 1992, AIAA-92-31230. NASA Contractor Report 189187.

Goddard, Robert H. *Rocket Development*. New York: Prentice-Hall, Inc., 1948.

Haas, Jeff. "Ground Testing." *Aerospace America* (December 2002): 77.

Hardlines Design Company. "Historic Documentation of Buildings 79A-C and Building 95, Wright-Patterson Air Force Base." 1998-1999. On file at Hardlines Design Company.

Harris, Cyril M. *Dictionary of Architecture and Construction*. New York: McGraw-Hill Book Company, 1993.

Historic American Engineering Record (HAER), National Park Service, U.S. Department of the Interior. "Marshall Space Flight Center, Test Stand." HAER No. AL-129-A, Historic American Engineering Collection, Library of Congress, Washington, D.C., 1995.

Mulready, Dick. *Advanced Engine Development at Pratt and Whitney*. Warrendale, Pennsylvania: Society of Automotive Engineers, Inc., 2001.

National Aeronautics and Space Administration. *Lands of the Lewis Research Center*. Cleveland: National Aeronautics and Space Administration, 1978.

Perry, John H., Ph.D., ed. *Chemical Engineers' Handbook*. New York: McGraw-Hill Book Company, 1950.

Sloop, John. *Liquid Hydrogen as a Propulsion Fuel*. Washington, D.C.: NASA Special Publication No. 4404, 1978.

Thomas, Wayne. *Description of the Rocket Engine Test Facility*. Cleveland: Lewis Research Center, 1984.

United States Environmental Protection Agency. *Solid Waste Disposal – Facility Criteria – A Technical Manual EPA530-R-93-017*. Washington, D.C.: U.S. Environmental Protection Agency, November 1993.



# HISTORIC AMERICAN ENGINEERING RECORD

## INDEX TO PHOTOGRAPHS

ROCKET ENGINE TEST FACILITY (RETF)  
NASA Glenn Research Center  
Cleveland  
Cuyahoga County  
Ohio

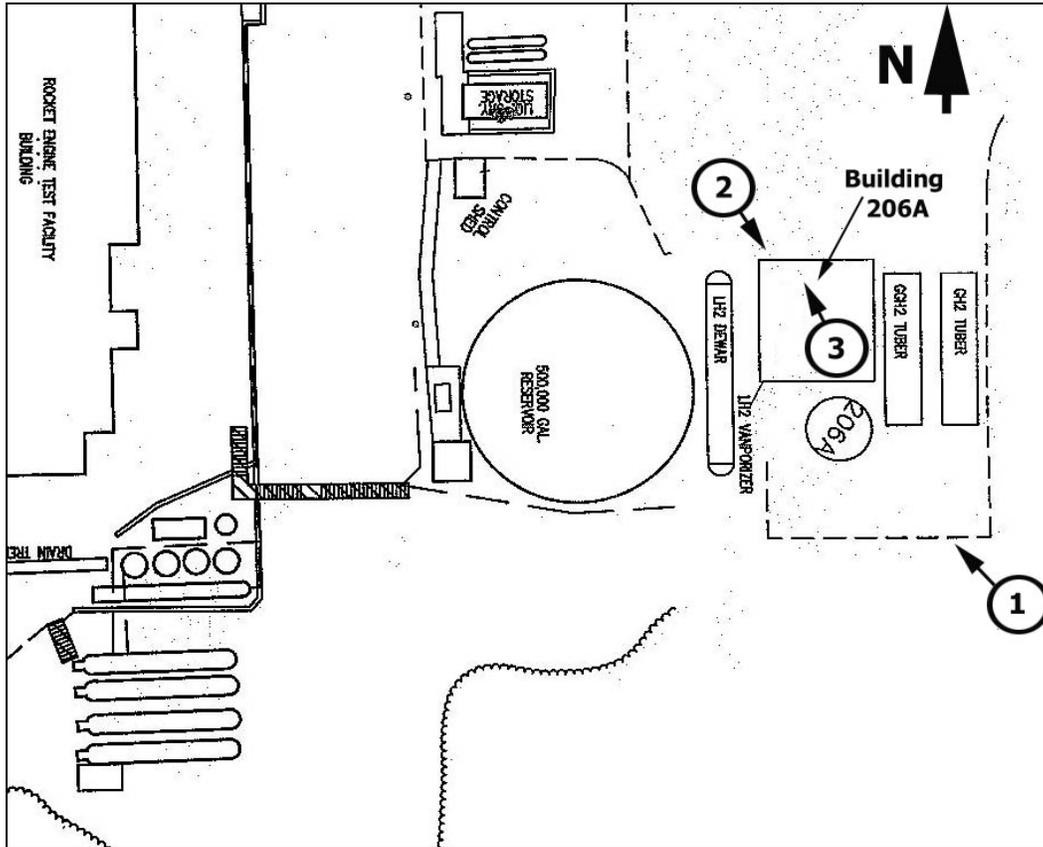
HAER No. OH-124

Jeff Bates, Hardlines Design Company, Field Photographer, May 2002

NASA Information Technology Center (ITC), Copywork Photographer, November 2002

- OH-124-1      CONTEXT VIEW OF BUILDING 206A, LOOKING NORTHWEST, SHOWING SOUTHEAST CORNER, WITH WATER TANK IN BACKGROUND.
  
- OH-124-2      PERSPECTIVE VIEW OF NORTHWEST CORNER OF BUILDING 206A, LOOKING SOUTHEAST.
  
- OH-124-3      INTERIOR OF BUILDING 206A, LOOKING NORTHWEST.
  
- OH-124-4      HISTORIC PHOTO OF FUEL AND OXIDANT TANKS IN HILLTOP AREA OF ROCKET ENGINE TEST FACILITY. 1956. ON FILE AT NASA PLUMBROOK RESEARCH CENTER, SANDUSKY, OHIO. NASA GRC PHOTO NUMBER C-1956-160D.
  
- OH-124-5      HISTORIC PHOTO OF SCALE MODEL OF ROCKET ENGINE TEST FACILITY, JUNE 18, 1957. ON FILE AT NASA PLUMBROOK RESEARCH CENTER, SANDUSKY, OHIO. NASA GRC PHOTO NUMBER C-45264.
  
- OH-124-6      HISTORIC PHOTO OF ROCKET ENGINE TEST FACILITY BUILDING 202 COMPLEX IN OPERATION AT NIGHT, SEPTEMBER 12, 1957. ON FILE AT NASA PLUMBROOK RESEARCH CENTER, SANDUSKY, OHIO. NASA GRC PHOTO NUMBER C-45924.
  
- OH-124-7      HISTORIC AERIAL PHOTO OF ROCKET ENGINE TEST FACILITY COMPLEX, JUNE 1962. ON FILE AT NASA PLUMBROOK RESEARCH CENTER, SANDUSKY, OHIO. NASA GRC PHOTO NUMBER C-60674.
  
- OH-124-8      HISTORIC AERIAL PHOTO OF ROCKET ENGINE TEST FACILITY COMPLEX, JUNE 11, 1965. ON FILE AT NASA PLUMBROOK RESEARCH CENTER, SANDUSKY, OHIO. NASA GRC PHOTO NUMBER C-65-1271.
  
- OH-124-9      HISTORIC AERIAL PHOTO OF ROCKET ENGINE TEST FACILITY COMPLEX, JUNE 11, 1965. ON FILE AT NASA PLUMBROOK RESEARCH CENTER, SANDUSKY, OHIO. NASA GRC PHOTO NUMBER C-65-1270.

- OH-124-10 HISTORIC PHOTO OF RENDERING OF ROCKET ENGINE TEST FACILITY COMPLEX, APRIL 28, 1964. ON FILE AT NASA PLUMBROOK RESEARCH CENTER, SANDUSKY, OHIO. NASA GRC PHOTO NUMBER C-69472.
- OH-124-11 HISTORIC PHOTO OF CUTAWAY RENDERING OF ROCKET ENGINE TEST FACILITY COMPLEX, JUNE 11, 1965. ON FILE AT NASA PLUMBROOK RESEARCH CENTER, SANDUSKY, OHIO. NASA GRC PHOTO NUMBER C-74433.
- OH-124-12 HISTORIC PLOT PLAN AND DRAWINGS INDEX FOR ROCKET ENGINE TEST FACILITY, JUNE 28, 1956. NASA GRC DRAWING NUMBER CE-101810. ON FILE AT NASA GLENN RESEARCH CENTER.
- OH-124-13 HISTORIC DRAWING OF ROCKET ENGINE TEST FACILITY LAYOUT, INCLUDING BUILDINGS 202, 205, 206, AND 206A, FEBRUARY 3, 1984. NASA GRC DRAWING NUMBER CF-101539. ON FILE AT NASA GLENN RESEARCH CENTER.
- OH-124-14 HISTORIC ELEVATION DRAWING OF BUILDING 206A, SEPTEMBER 8, 1982. NASA GRC DRAWING NUMBER CF-100863. ON FILE AT NASA GLENN RESEARCH CENTER.



Key to Context Photos

# ROCKET ENGINE TEST FACILITY

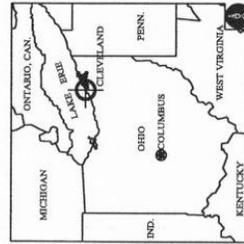
## NATIONAL AERONAUTICS AND SPACE ADMINISTRATION LEWIS RESEARCH CENTER, CLEVELAND, OHIO

The National Aeronautics and Space Administration (NASA) began construction of the Rocket Engine Test Facility (RETF) in 1955 on land that was formerly part of the Cleveland Municipal Airport. In 1940, the National Advisory Committee on Aeronautics (NACA) selected 200 acres of the airport site for the construction of an Aircraft Engine Research Laboratory. The site of this original lab and the RETF is the present NASA John H. Glenn Research Center at Lewis Field.

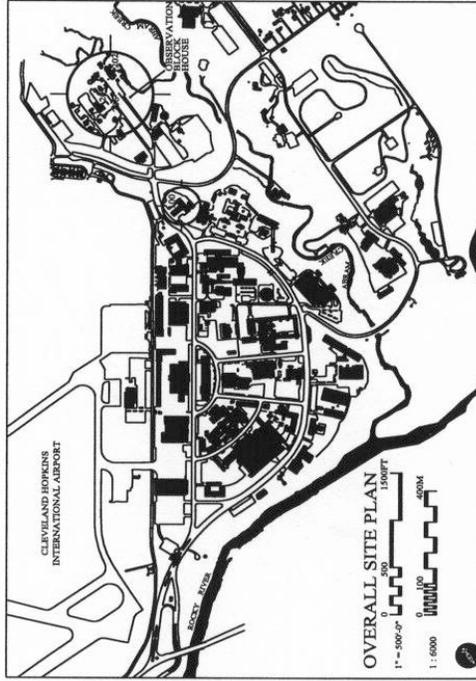
The construction of RETF was related to post-war missile development, which required the construction of facilities designed for the testing and testing of rocket engines and auxiliary equipment. RETF was built in 1955 and 1957 to test rocket engines and to collect the resulting test data. The main rocket engine test stand was located in Building 202, while the control room and data recording equipment were housed in Building 100. Equipment that vaporized and compressed liquid gases and oxidants before they were supplied to the test stand was accommodated in ancillary Buildings 205, 206, and 206A. Photographs taken in 1957 show observers in the Building 100 control room using closed-circuit television to monitor tests. In addition, an observation blockhouse provided a safe location for operators to monitor rocket engine tests during the early years of testing at RETF. In 1972 the installation of a closed-circuit television camera on the roof of the blockhouse reduced the need for observers to eyewitness testing from inside the blockhouse.

The terrain of the site was suited to its function. Building 202 stands in a remote location, on the east side of a deep Creek, Building 100, which houses the observers' facilities, and the test stands constructed on flat ground 1,600 feet north of the test stands in Building 202.

These tests run in RETF involved the use of hazardous fuels in experimental engine designs, and performance could be unpredictable and dangerous. Test engineers were therefore housed in the protected control room in Building 100, where they could run their rocket engine test at a safe distance. The



STATE MAP 1" = 70 mi. 1:441,100

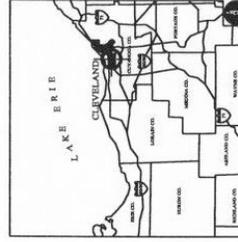


OVERALL SITE PLAN  
1" = 500 ft. 1:6000

engineering design information collected at this facility made a significant contribution to developing the technology to use liquid hydrogen as a rocket fuel. The RETF was also instrumental in the development of the Centaur and Saturn rocket engines used in the Apollo space program as well as the engines for the Space Shuttle vehicle.

The testing procedures used at RETF changed regularly to keep pace with the rapid technological advances in the aerospace industry during the facility's active use from 1957 to 1995. Developments in computer technology required frequent upgrades to the control and data acquisition systems used at RETF. Changing technology and the addition of a high-altitude rocket test stand in 1985 required the addition of new control and recording equipment. In addition, the high-altitude test stand required the vacuum chamber to be evacuated to simulate the vacuum of outer space. Equipment maintained the vacuum during the test period. Advanced methods for handling cryogenic materials were also incorporated into the test procedures, and in 1991 a test stand was built for the evaluation of cryogenic turbo pump components. RETF personnel designed many of these innovative controls and systems, using technology developed at RETF.

This documentation was initiated on May 15, 2002 in accordance with a Memorandum of Agreement among the Federal Aviation Administration, The National Aeronautics and Space Administration, The Ohio State Historic Preservation Office, and the Advisory Council on Historic Preservation. These drawings are based on Hardlines Design Company's field inspection, field measurement, and interpretation/integration of personal interviews, historic photographs, and as-built construction drawings retained by NASA, Glenn Research Center, Cleveland, Ohio. The drawings were prepared by Stan Ciprovic, AICP (Principal Architect), Wang, AIA (Project Architect), Vivian Maljeyvi (Architectural Designer), in Sudartha (Interior Designer), Feliciano Rahardjo (Interior Architect), Roy A. Hampton III (Architectural Historian), and Amy D. Case (Editor), of Hardlines Design Company, in Columbus, Ohio. Mr. Robert Stewart of Historical Technologies, West Suffield, Connecticut, provided technical assistance and wrote the historical texts.



REGIONAL MAP 1" = 16 mi. 1:1100

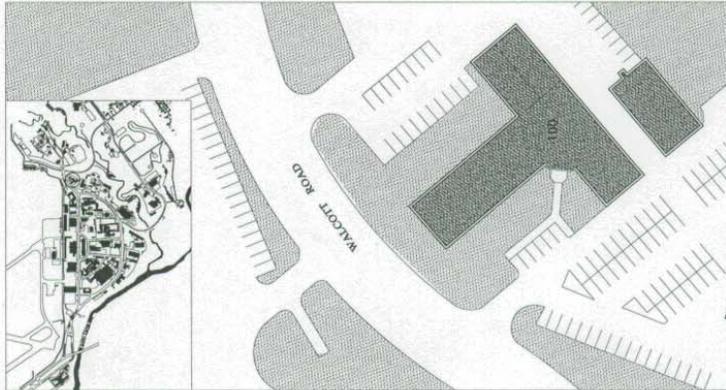
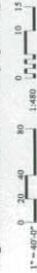
NASA KSC ENGINEERING PROJECT  
 ROCKET ENGINE TEST FACILITY  
 NATIONAL AERONAUTICS AND SPACE ADMINISTRATION  
 LEWIS RESEARCH CENTER  
 CLEVELAND, OHIO  
 1:12  
 OH 124-D

The National Advisory Committee for Aeronautics (NACA) Lewis Flight Propulsion Laboratory began research on liquid rocket propellants shortly after World War II. The small-scale test facilities and laboratory experiments gave engineers and scientists at the research center the necessary experience to develop larger liquid-propelled rockets. Experimental data indicated that a combination of liquid hydrogen and liquid oxygen was the most effective means of powering high-performance upper stage rockets. This conclusion helped justify construction of a full-scale test facility for liquid fuels and oxidizers. The new Rocket Engine Test Facility (RETF) was operational one year after NACA became the National Aeronautics and Space Administration (NASA) in 1958.

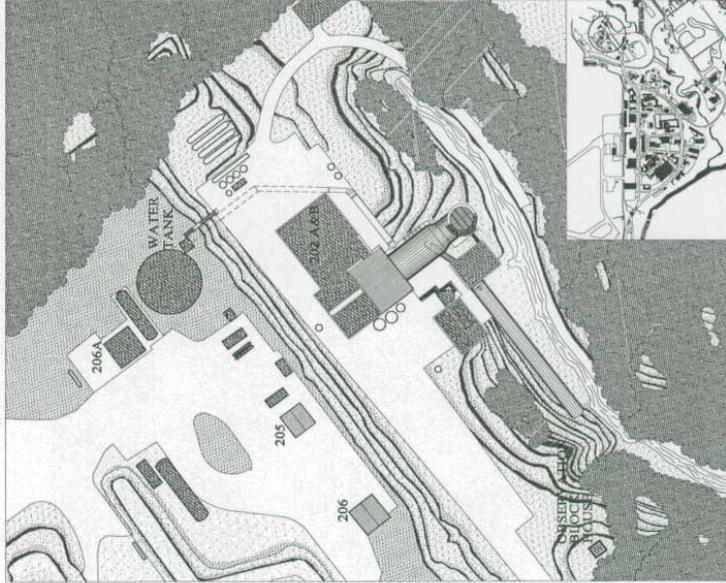
The original RETF Building 202 (A) housed a single test cell and rocket exhaust scrubber/silencer. Gas storage facilities and a shop area adjacent to the stand supported tests, and a large reservoir stored water for the scrubber operation and for fire suppression. Integrated carbon dioxide and water deluge nozzles mounted on the test stand ceiling enabled the emergency fire suppression system in Building 202. Buildings 205, 206, and 206A were located on a nearby hillside and housed pumps, a helium compressor, and a liquid hydrogen pump-vaporizer. An observation blockhouse completed the test stand complex.

Upgrades to the RETF kept pace with technological development and increased testing capability at the facility. In 1967, a cone and stack were added to the exhaust scrubber/silencer to accommodate extensive testing of nitrogen tetroxide-hydrazine engines. The additional cone and stack contained gas flow and gannimed sensors for the test cell. In 1972, the test cell was expanded to include a larger shop and office area (B). Dramatic developments in computerized control and recording technology from 1960 to 1995 required regular modification of the control room in Building 100. In the late 1970s, programmable logic controllers, or "PLCs" replaced the earlier electro-mechanical devices. The PLCs controlled fuel, oxidant, and ignition sequences according to a predetermined time schedule. Other improvements included the addition in 1972 of new oxygen and fuel tanks to the existing pits. To minimize evaporative loss, the liquid oxygen storage tank and associated piping were enveloped in a liquid nitrogen jacket. Later upgrades involved the replacement of the hydrogen bottle farm with a liquid hydrogen storage facility, and the addition in the early 1980s of liquid oxygen engine cooling capability.

NASA built a new test stand, "Stand B," at the RETF in 1984. This new test stand replaced the "Stand A" test stand during tests. Engines were horizontally mounted on the inside of the cylindrical chamber. Nitrogen-powered ejectors removed exhaust from the chamber and maintained the vacuum. In 1991 NASA added a free-standing test stand, "Stand C," immediately north of Building 202A. Stand C tested seal materials, liquid oxygen pump designs, and other components. The control and monitoring equipment for Stand C were located in Building 100. The RETF made remarkable contributions to the development of lightweight, regeneratively cooled, hydrogen-fueled engines. This facility was instrumental to the development of engines that powered the upper-stage launch vehicles used in early space exploration.



BUILDING 100



BUILDING 202, 205, 206 AND OBSERVATION BLOCK HOUSE

A request authorizing construction of a Rocket Engine Test Facility (RETF) to test high-energy propellants and rocket engine designs was approved in 1952. The facility was designed to allow up to three minutes of operation at a thrust of 89 kilonewtons. RETF was completed in 1957 at a cost of \$2.5 million. At that time, it was the largest high-energy rocket engine test facility in the country.

The complex originally consisted of two major components: a control center housed in Building 100, and a test cell in Building 202. Auxiliary components included an observation blockhouse and equipment located in Buildings 205, 206 and 206A that vaporized propellants and pumped them into Building 202 for the test procedure.

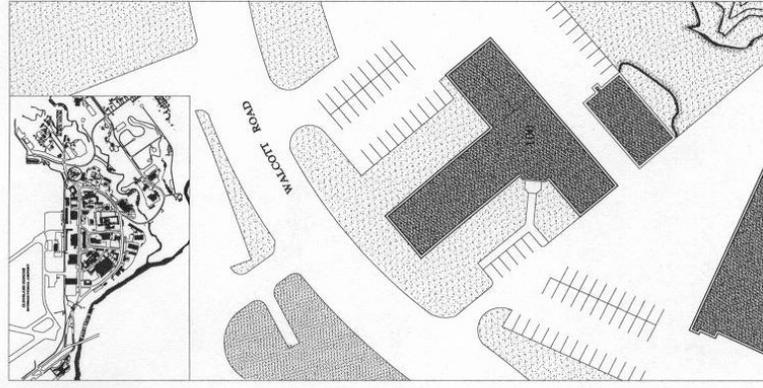
Engineers monitored rocket engines from a control room in Building 100, which is located 1,600 feet north of the rocket engine test cells in Building 202. The engine designs that were tested in Building 202 were experimental, and the test procedure involved the use of hazardous fuels. Performance was therefore unpredictable and potentially volatile. A control room housed in a separate building allowed engineers to monitor rocket engine tests from a protected location. Test controls during the early years of RETF consisted of a combination of manual controls and sequenced test procedures. The control room contained monitoring instrumentation, data acquisition devices, and valve controls. Cut-off switches in the control room and in the test cell allowed the engineer to abort a test in case of emergency. Safety monitoring was also centralized in the control room. Observers in an external blockhouse and in an observation room next to the test cell provided additional information on engine performance. During the early years of operation at RETF, collected test data were prepared for analysis using rules and manual computation. Observers in an external blockhouse and in an observation room next to the test cell provided additional information on engine performance.

Building 202 housed a test cell, a propellant supply system, and a distinctive system for scrubbing exhaust gases to remove the waste products produced by combustion. In addition, the scrubbing system muted the noise of rocket firing. Engines could be assembled in a small shop adjacent to the test cell. Also adjoining the test cell was a tank farm of high-pressure helium bottles. Storage areas for some fuels, liquid oxygen, and water for the scrubber was also supplied by the gravity feed system from a 500,000-gallon tank.

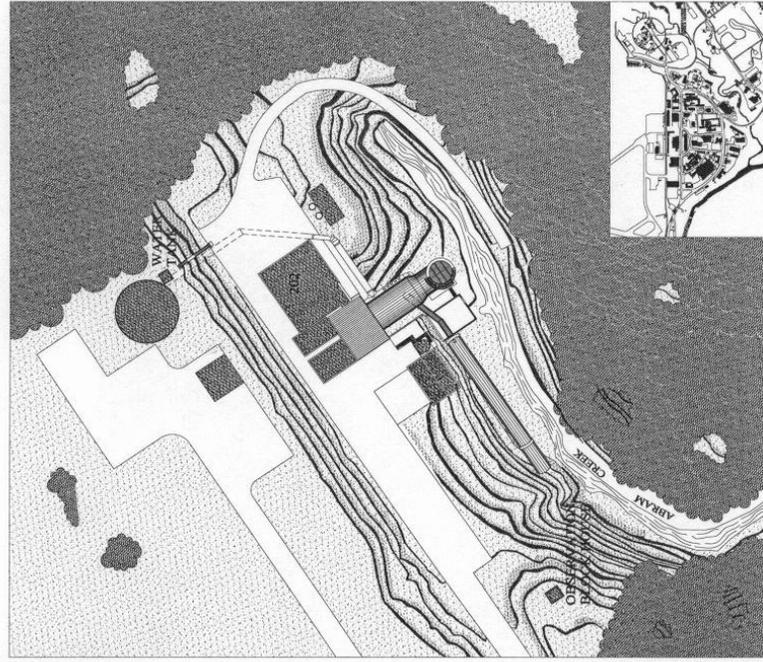
This facility was instrumental in developing the technology for liquid propulsion systems for the Saturn V. Research and testing completed at RETF contributed to the successful development of the Centaur rocket and the upper stages of the Saturn V.



1" = 40'-0" 0 20 40 80 FT 1:400 0 10 15 M



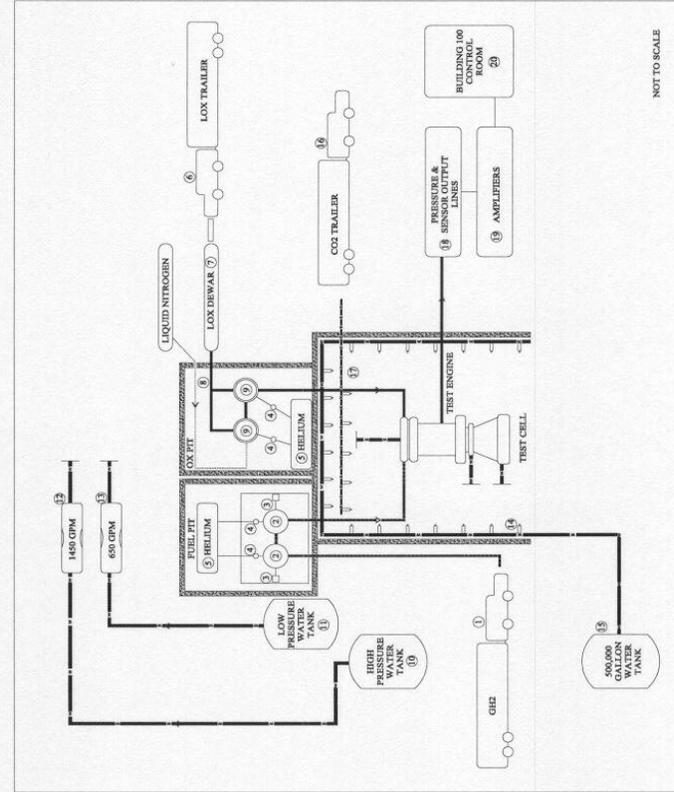
BUILDING 100



BUILDING 202, 205, 206 AND OBSERVATION BLOCKHOUSE

DESIGNED BY: Hardlines Design Company, 2003

# ROCKET REACTANT FLOW CHART



By the late 1950s research engineers and scientists working at Lewis Flight Propulsion Laboratory believed that hydrogen was the optimum fuel, and oxygen the ideal oxidizer, for upper-stage rockets. However, before NASA researchers could achieve the theoretical advantages of hydrogen/oxygen propulsion, they had to develop practical solutions for the engineering problems involved in devising such a propulsion system. These problems included the development of a powerful fuel that must be handled carefully to minimize the risk of explosion. In addition, large quantities of hydrogen were not available during the early years of the rocket research program.

From a practical standpoint, many rocket engineering design problems could be resolved using other, readily available fuels. In addition, the testing and operation of prototypical rocket engines would be useful regardless of which reactants were used. Consequently, the first experimental engines tested at the Rocket Engine Test Facility were gasoline-fueled and run on the 89-Kilonewton (20,000-lb.) high-thrust vertical test stand.

Researchers followed standard operating procedures to prepare an engine test. Gasoline was pumped from a mobile tanker-trailer (1) into cylindrical tanks (2) housed in the fuel pit. These tanks were mounted in a framework that contained load cells (3) in the suspension. The load cells weighed both empty and full tanks. Weight was measured while fuel was being drawn from the tank. By comparing the weight of a full tank with the weight of the tank after fuel was used in a test, researchers could accurately determine the amount of fuel burned during the test. They could then calculate the rate of fuel use by plotting the weight of the tanks against time. The pressure of inert helium gas (4) flowing into the fuel tanks. The pressure of this gas forced fuel from the tanks and into the rocket engine being tested.

Liquid oxygen was transferred from a mobile tanker-trailer (5) into a double-walled, vacuum-insulated tank called a "Dewar" (6).

which was located on the hill west of Building 202. Oxygen flowed through a pipe, which was jacketed with a liquid nitrogen bath (8), into liquid oxygen tanks (9) in the oxidizer pit. These tanks were encased inside outer tanks (10) that contained a liquid nitrogen bath.

These liquid nitrogen baths around the piping and tanks caused the oxygen to remain liquid. Helium gas (4) under pressure forced the liquid oxygen from the tanks and into the engine being tested.

Either a high- (1) or low-pressure tank (2) supplied water that cooled the rocket engine under test. This water was transported using a 1,450- (3) or a 650- (4) gallon-per-minute pump.

There was always some risk that an engine would explode during a test. The test stand itself was constructed with blast doors and louvers that remained open during tests. In addition, the frame of Building 202 was covered with "Transite" asbestos cement panels, and later with fiberglass panels, that would blow away in case of an explosion, and there were two fire suppression systems inside the test cell. A water pipe (5) with several nozzles was installed on three sides of the cell, and this pipe was connected to the 500,000-gallon water reservoir (6) located east of Building 202. In case of fire, water could quickly flood the test cell. The second fire suppression system was carbon dioxide, which (7) supplied a similar piping system (8) inside the test cell. Carbon dioxide could be released to extinguish any fires that started during a test.

The primary cooling, hydrocarbon fuel, and liquid oxygen systems were rated at 5,000 psi working pressure. On-site storage systems for liquid nitrogen could hold 28,000 gallons, while the capacity of liquid oxygen storage was 2,000 gallons. After 1959, 18,000 gallons of liquid hydrogen could be stored on site. The pumping facilities could supply gaseous helium at 6,000 psi and gaseous nitrogen at 3,000 psi for the gas pressurization systems.

The rocket engine being tested would be instrumented with load cells, strain gages, thermocouples, and pressure gages. These sensors (9) were connected by wires (pressure and sensor output lines) to terminal blocks and amplifiers (10) in the terminal room. The magnitude of some electrical signals would be small, and signal losses would exceed allowable limits. Consequently, electrical signals would need to be amplified before transmission to the control room (2) located 1600 feet away. The sensors would be transmitted over data transmission cables to the control room recording and readout devices (Building 100 data recording).

HISTORIC AMERICAN ENGINEERING RECORD  
SEE INDEX TO PHOTOGRAPHS FOR CAPTION

HAER No. OH-124-1



HISTORIC AMERICAN ENGINEERING RECORD  
SEE INDEX TO PHOTOGRAPHS FOR CAPTION

HAER No. OH-124-2



HISTORIC AMERICAN ENGINEERING RECORD  
SEE INDEX TO PHOTOGRAPHS FOR CAPTION

HAER No. OH-124-3

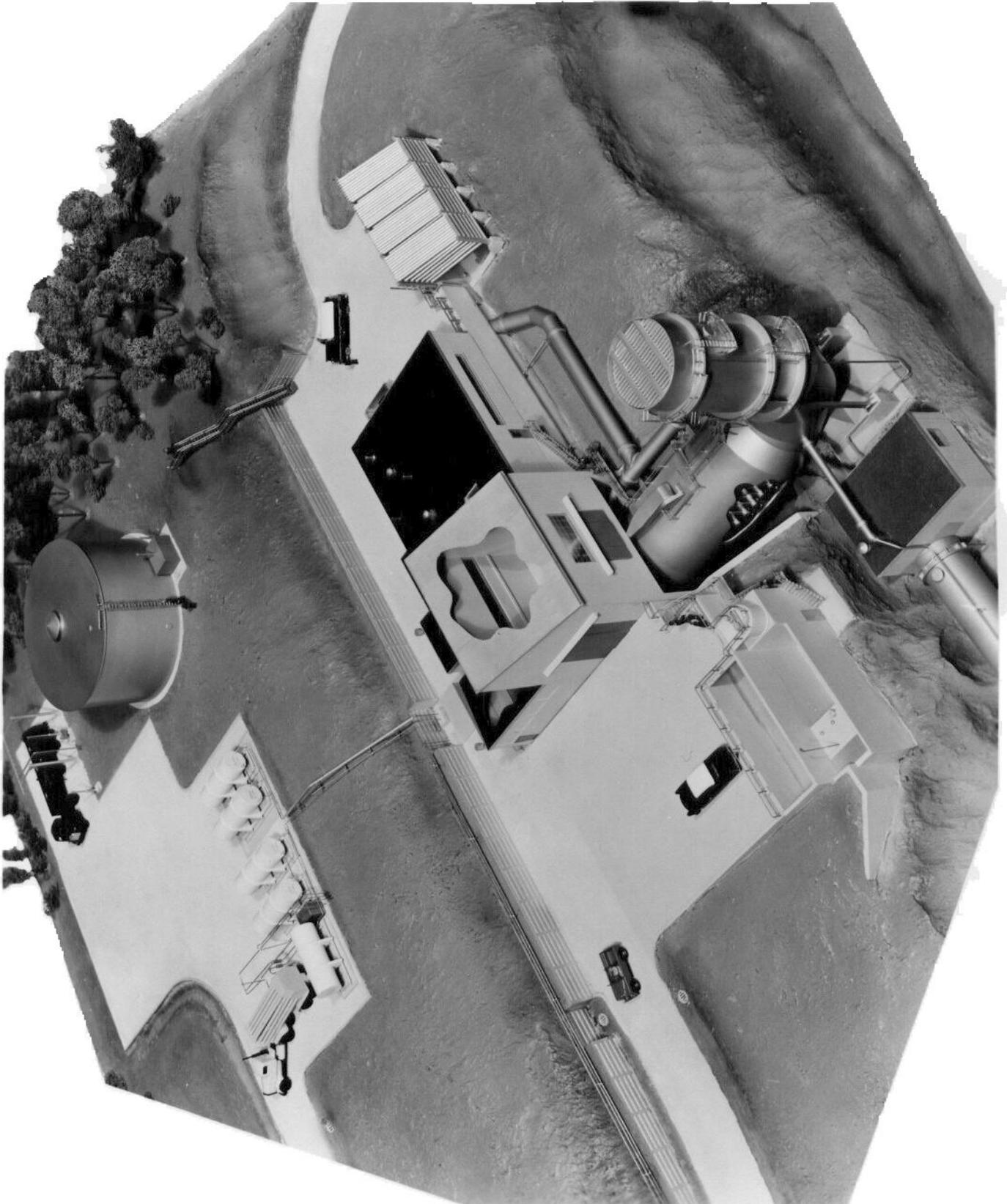




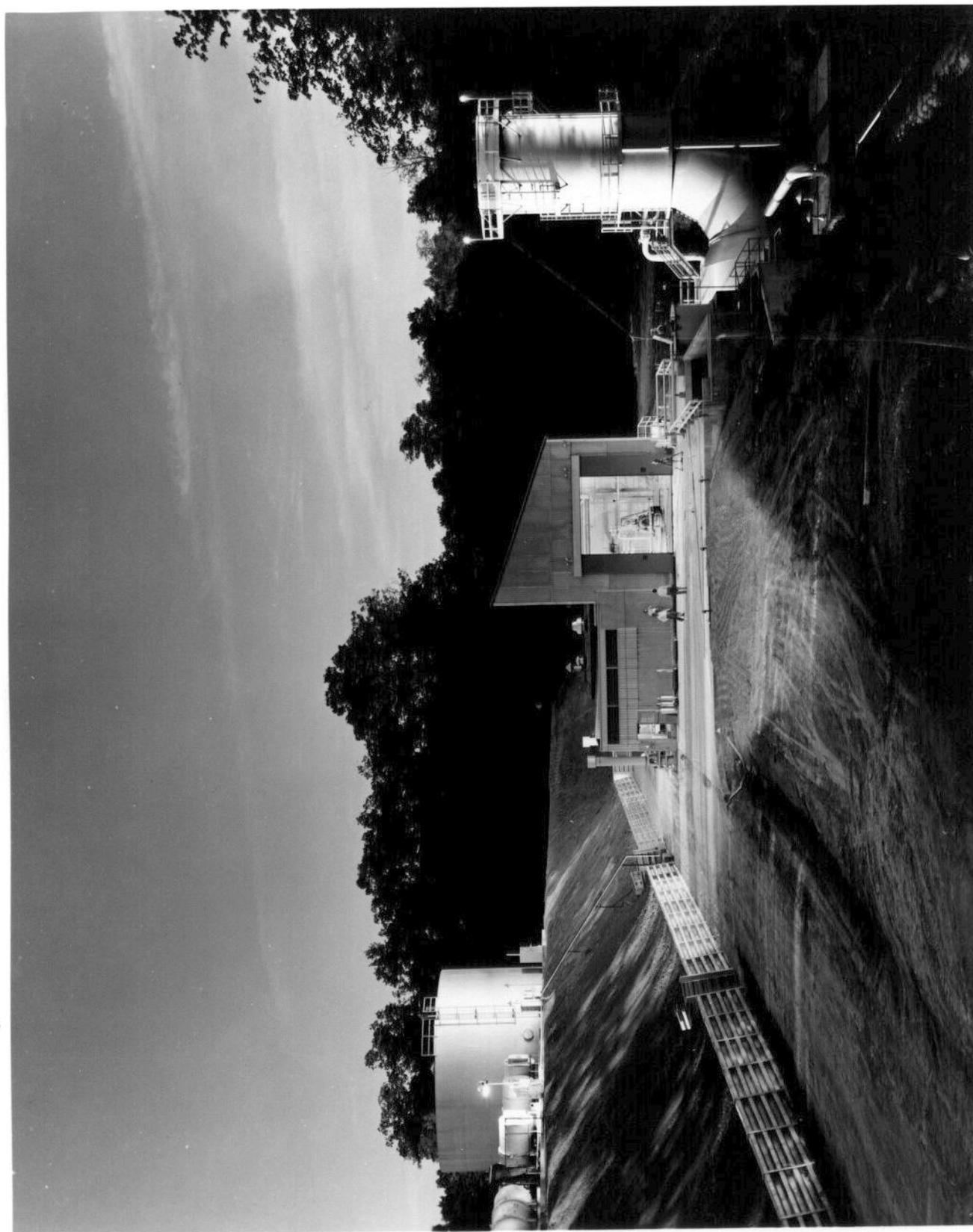
C160D-1956

HISTORIC AMERICAN ENGINEERING RECORD  
SEE INDEX TO PHOTOGRAPHS FOR CAPTION

HAER No. OH-124-5



HAER No. OH-124-6



NACA  
C-45924

16 X 20

HISTORIC AMERICAN ENGINEERING RECORD  
SEE INDEX TO PHOTOGRAPHS FOR CAPTION

HAER No. OH-124-7



NASA  
C-60674

**HISTORIC AMERICAN ENGINEERING RECORD  
SEE INDEX TO PHOTOGRAPHS FOR CAPTION**

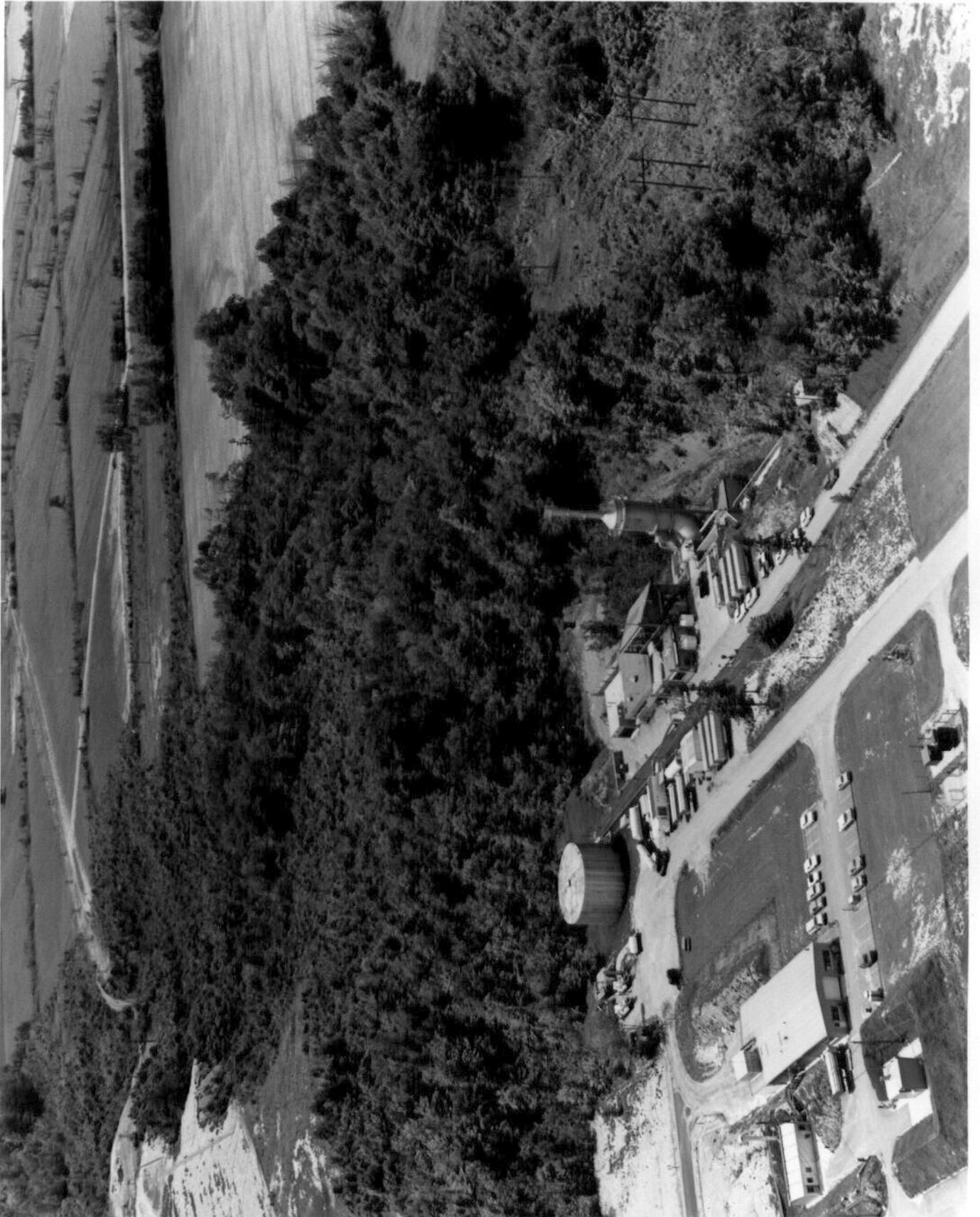
HAER No. OH-124-8



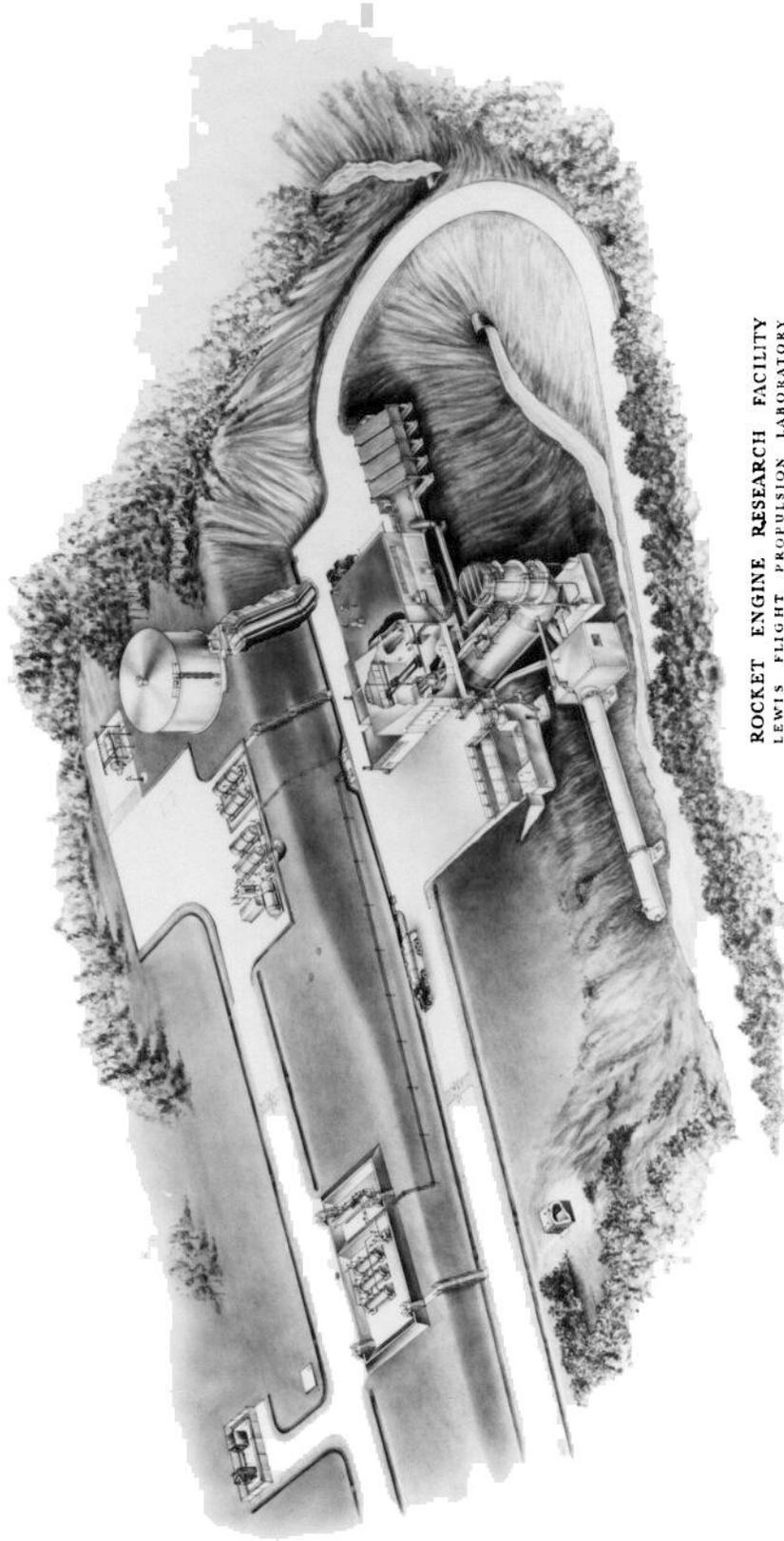
NASA  
C-65-1271

HISTORIC AMERICAN ENGINEERING RECORD  
SEE INDEX TO PHOTOGRAPHS FOR CAPTION

HAER No. OH-124-9



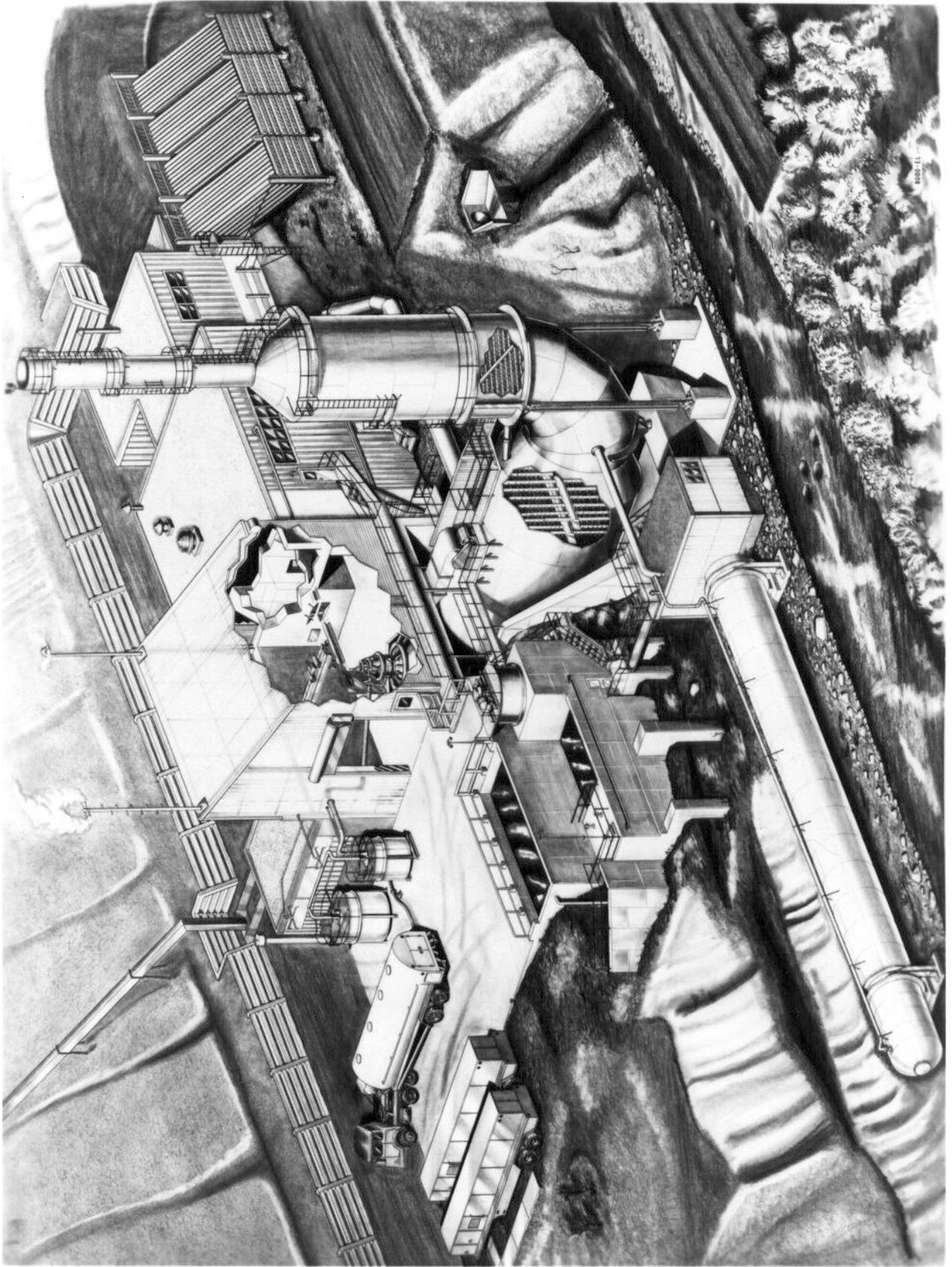
NASA  
C-65-1270



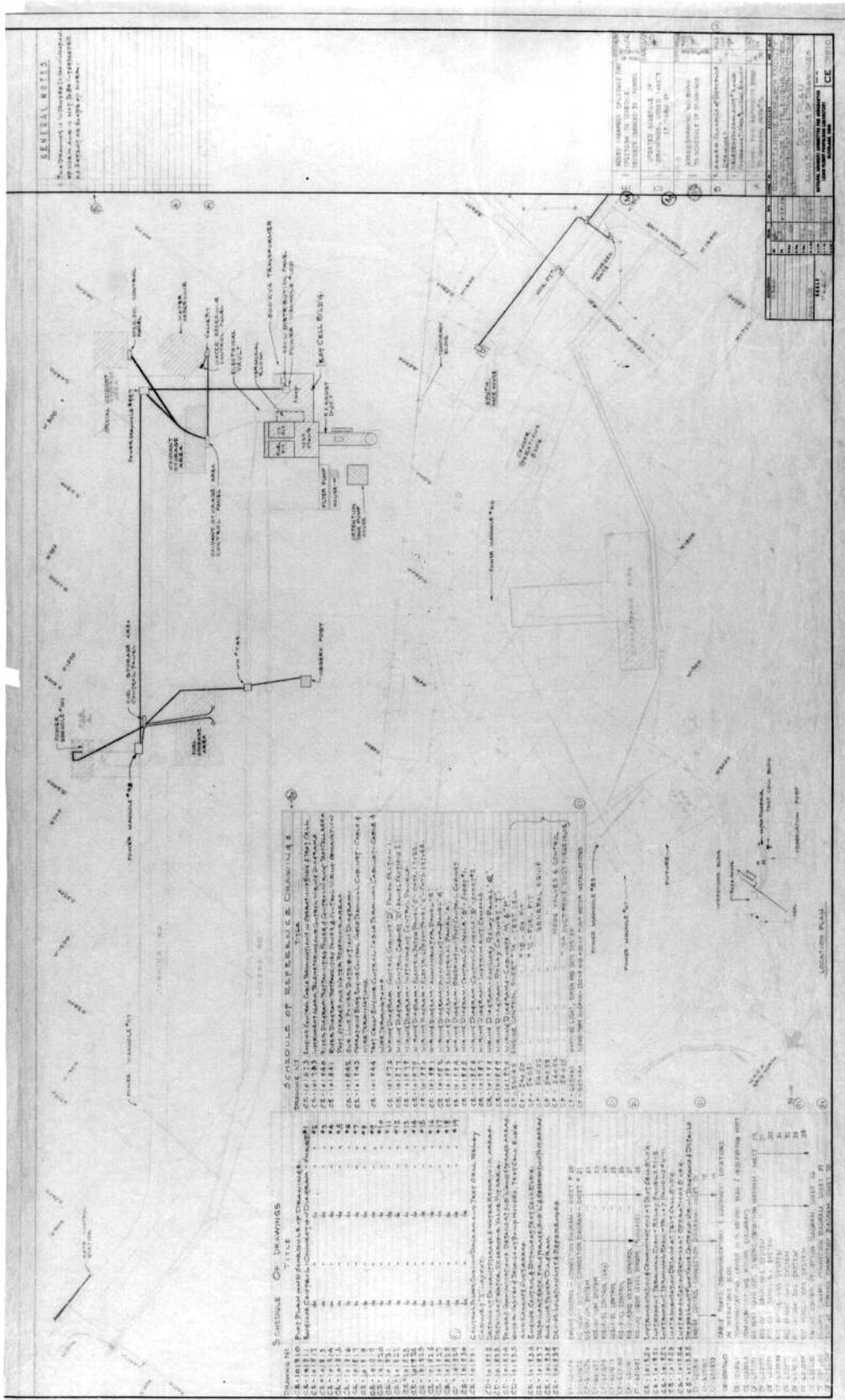
ROCKET ENGINE RESEARCH FACILITY  
LEWIS FLIGHT PROPULSION LABORATORY  
CLEVELAND, OHIO

**HISTORIC AMERICAN ENGINEERING RECORD  
SEE INDEX TO PHOTOGRAPHS FOR CAPTION**

**HAER No. OH-124-11**



**NASA  
C-74433**



**GENERAL NOTES**

1. This drawing is subject to the conditions of the contract and the specifications for the work.

**SCHEDULE OF REFERENCE DRAWINGS**

Reference No.	Title
CE-101	General Notes
CE-102	Water Tower
CE-103	Water Distribution Tank
CE-104	Water Treatment Plant
CE-105	Water Main
CE-106	Water Valve
CE-107	Water Tank
CE-108	Water Pump
CE-109	Water Meter
CE-110	Water Pipe
CE-111	Water Fitting
CE-112	Water Flange
CE-113	Water Gasket
CE-114	Water Seal
CE-115	Water Plug
CE-116	Water Cap
CE-117	Water Nut
CE-118	Water Washer
CE-119	Water Lock
CE-120	Water Key
CE-121	Water Pin
CE-122	Water Cotter Pin
CE-123	Water Rivet
CE-124	Water Bolt
CE-125	Water Nut
CE-126	Water Washer
CE-127	Water Lock
CE-128	Water Key
CE-129	Water Pin
CE-130	Water Cotter Pin
CE-131	Water Rivet
CE-132	Water Bolt
CE-133	Water Nut
CE-134	Water Washer
CE-135	Water Lock
CE-136	Water Key
CE-137	Water Pin
CE-138	Water Cotter Pin
CE-139	Water Rivet
CE-140	Water Bolt
CE-141	Water Nut
CE-142	Water Washer
CE-143	Water Lock
CE-144	Water Key
CE-145	Water Pin
CE-146	Water Cotter Pin
CE-147	Water Rivet
CE-148	Water Bolt
CE-149	Water Nut
CE-150	Water Washer
CE-151	Water Lock
CE-152	Water Key
CE-153	Water Pin
CE-154	Water Cotter Pin
CE-155	Water Rivet
CE-156	Water Bolt
CE-157	Water Nut
CE-158	Water Washer
CE-159	Water Lock
CE-160	Water Key
CE-161	Water Pin
CE-162	Water Cotter Pin
CE-163	Water Rivet
CE-164	Water Bolt
CE-165	Water Nut
CE-166	Water Washer
CE-167	Water Lock
CE-168	Water Key
CE-169	Water Pin
CE-170	Water Cotter Pin
CE-171	Water Rivet
CE-172	Water Bolt
CE-173	Water Nut
CE-174	Water Washer
CE-175	Water Lock
CE-176	Water Key
CE-177	Water Pin
CE-178	Water Cotter Pin
CE-179	Water Rivet
CE-180	Water Bolt
CE-181	Water Nut
CE-182	Water Washer
CE-183	Water Lock
CE-184	Water Key
CE-185	Water Pin
CE-186	Water Cotter Pin
CE-187	Water Rivet
CE-188	Water Bolt
CE-189	Water Nut
CE-190	Water Washer
CE-191	Water Lock
CE-192	Water Key
CE-193	Water Pin
CE-194	Water Cotter Pin
CE-195	Water Rivet
CE-196	Water Bolt
CE-197	Water Nut
CE-198	Water Washer
CE-199	Water Lock
CE-200	Water Key

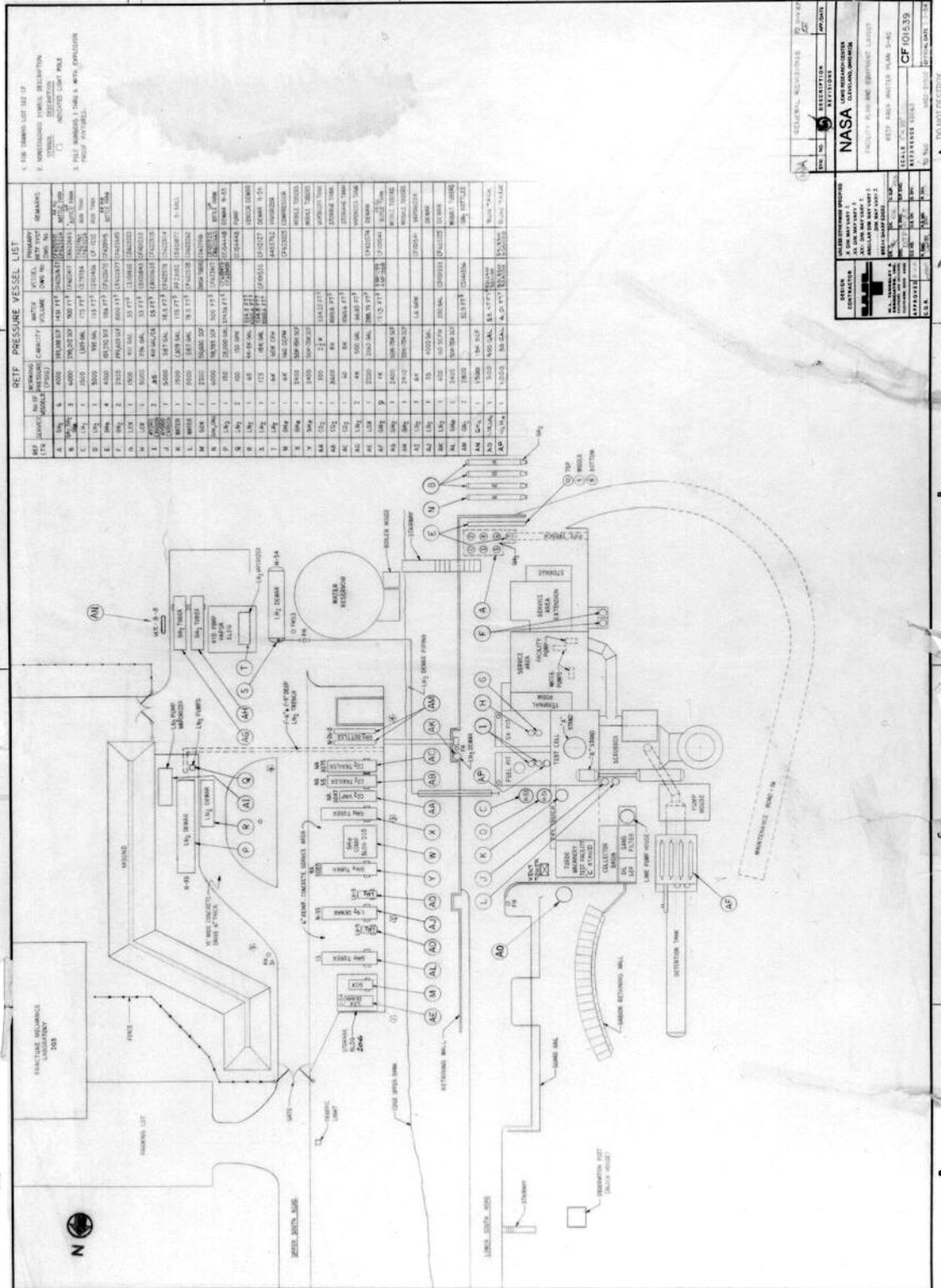
**SCHEDULE OF TRIMMINGS**

Trimming No.	Title
TR-1	Water Tower
TR-2	Water Distribution Tank
TR-3	Water Treatment Plant
TR-4	Water Main
TR-5	Water Valve
TR-6	Water Tank
TR-7	Water Pump
TR-8	Water Meter
TR-9	Water Pipe
TR-10	Water Fitting
TR-11	Water Flange
TR-12	Water Gasket
TR-13	Water Seal
TR-14	Water Plug
TR-15	Water Cap
TR-16	Water Nut
TR-17	Water Washer
TR-18	Water Lock
TR-19	Water Key
TR-20	Water Pin
TR-21	Water Cotter Pin
TR-22	Water Rivet
TR-23	Water Bolt
TR-24	Water Nut
TR-25	Water Washer
TR-26	Water Lock
TR-27	Water Key
TR-28	Water Pin
TR-29	Water Cotter Pin
TR-30	Water Rivet
TR-31	Water Bolt
TR-32	Water Nut
TR-33	Water Washer
TR-34	Water Lock
TR-35	Water Key
TR-36	Water Pin
TR-37	Water Cotter Pin
TR-38	Water Rivet
TR-39	Water Bolt
TR-40	Water Nut
TR-41	Water Washer
TR-42	Water Lock
TR-43	Water Key
TR-44	Water Pin
TR-45	Water Cotter Pin
TR-46	Water Rivet
TR-47	Water Bolt
TR-48	Water Nut
TR-49	Water Washer
TR-50	Water Lock
TR-51	Water Key
TR-52	Water Pin
TR-53	Water Cotter Pin
TR-54	Water Rivet
TR-55	Water Bolt
TR-56	Water Nut
TR-57	Water Washer
TR-58	Water Lock
TR-59	Water Key
TR-60	Water Pin
TR-61	Water Cotter Pin
TR-62	Water Rivet
TR-63	Water Bolt
TR-64	Water Nut
TR-65	Water Washer
TR-66	Water Lock
TR-67	Water Key
TR-68	Water Pin
TR-69	Water Cotter Pin
TR-70	Water Rivet
TR-71	Water Bolt
TR-72	Water Nut
TR-73	Water Washer
TR-74	Water Lock
TR-75	Water Key
TR-76	Water Pin
TR-77	Water Cotter Pin
TR-78	Water Rivet
TR-79	Water Bolt
TR-80	Water Nut
TR-81	Water Washer
TR-82	Water Lock
TR-83	Water Key
TR-84	Water Pin
TR-85	Water Cotter Pin
TR-86	Water Rivet
TR-87	Water Bolt
TR-88	Water Nut
TR-89	Water Washer
TR-90	Water Lock
TR-91	Water Key
TR-92	Water Pin
TR-93	Water Cotter Pin
TR-94	Water Rivet
TR-95	Water Bolt
TR-96	Water Nut
TR-97	Water Washer
TR-98	Water Lock
TR-99	Water Key
TR-100	Water Pin

LOCATION PLAN

NO.	DATE	REVISIONS
1	1912	Original
2	1913	As per contract
3	1914	As per contract
4	1915	As per contract
5	1916	As per contract
6	1917	As per contract
7	1918	As per contract
8	1919	As per contract
9	1920	As per contract
10	1921	As per contract
11	1922	As per contract
12	1923	As per contract
13	1924	As per contract
14	1925	As per contract
15	1926	As per contract
16	1927	As per contract
17	1928	As per contract
18	1929	As per contract
19	1930	As per contract
20	1931	As per contract
21	1932	As per contract
22	1933	As per contract
23	1934	As per contract
24	1935	As per contract
25	1936	As per contract
26	1937	As per contract
27	1938	As per contract
28	1939	As per contract
29	1940	As per contract
30	1941	As per contract
31	1942	As per contract
32	1943	As per contract
33	1944	As per contract
34	1945	As per contract
35	1946	As per contract
36	1947	As per contract
37	1948	As per contract
38	1949	As per contract
39	1950	As per contract
40	1951	As per contract
41	1952	As per contract
42	1953	As per contract
43	1954	As per contract
44	1955	As per contract
45	1956	As per contract
46	1957	As per contract
47	1958	As per contract
48	1959	As per contract
49	1960	As per contract
50	1961	As per contract
51	1962	As per contract
52	1963	As per contract
53	1964	As per contract
54	1965	As per contract
55	1966	As per contract
56	1967	As per contract
57	1968	As per contract
58	1969	As per contract
59	1970	As per contract
60	1971	As per contract
61	1972	As per contract
62	1973	As per contract
63	1974	As per contract
64	1975	As per contract
65	1976	As per contract
66	1977	As per contract
67	1978	As per contract
68	1979	As per contract
69	1980	As per contract
70	1981	As per contract
71	1982	As per contract
72	1983	As per contract
73	1984	As per contract
74	1985	As per contract
75	1986	As per contract
76	1987	As per contract
77	1988	As per contract
78	1989	As per contract
79	1990	As per contract
80	1991	As per contract
81	1992	As per contract
82	1993	As per contract
83	1994	As per contract
84	1995	As per contract
85	1996	As per contract
86	1997	As per contract
87	1998	As per contract
88	1999	As per contract
89	2000	As per contract
90	2001	As per contract
91	2002	As per contract
92	2003	As per contract
93	2004	As per contract
94	2005	As per contract
95	2006	As per contract
96	2007	As per contract
97	2008	As per contract
98	2009	As per contract
99	2010	As per contract
100	2011	As per contract

DATE: 1912  
DRAWN BY: [Name]  
CHECKED BY: [Name]  
APPROVED BY: [Name]



**BREF PRESSURE VESSEL LIST**

REF. SYMBOL	DESCRIPTION	CAPACITY	REMARKS
A	1. 10000 GAL. WATER RESERVOIR	10000 GAL.	10000 GAL. WATER RESERVOIR
B	1. 10000 GAL. WATER RESERVOIR	10000 GAL.	10000 GAL. WATER RESERVOIR
C	1. 10000 GAL. WATER RESERVOIR	10000 GAL.	10000 GAL. WATER RESERVOIR
D	1. 10000 GAL. WATER RESERVOIR	10000 GAL.	10000 GAL. WATER RESERVOIR
E	1. 10000 GAL. WATER RESERVOIR	10000 GAL.	10000 GAL. WATER RESERVOIR
F	1. 10000 GAL. WATER RESERVOIR	10000 GAL.	10000 GAL. WATER RESERVOIR
G	1. 10000 GAL. WATER RESERVOIR	10000 GAL.	10000 GAL. WATER RESERVOIR
H	1. 10000 GAL. WATER RESERVOIR	10000 GAL.	10000 GAL. WATER RESERVOIR
I	1. 10000 GAL. WATER RESERVOIR	10000 GAL.	10000 GAL. WATER RESERVOIR
J	1. 10000 GAL. WATER RESERVOIR	10000 GAL.	10000 GAL. WATER RESERVOIR
K	1. 10000 GAL. WATER RESERVOIR	10000 GAL.	10000 GAL. WATER RESERVOIR
L	1. 10000 GAL. WATER RESERVOIR	10000 GAL.	10000 GAL. WATER RESERVOIR
M	1. 10000 GAL. WATER RESERVOIR	10000 GAL.	10000 GAL. WATER RESERVOIR
N	1. 10000 GAL. WATER RESERVOIR	10000 GAL.	10000 GAL. WATER RESERVOIR
O	1. 10000 GAL. WATER RESERVOIR	10000 GAL.	10000 GAL. WATER RESERVOIR
P	1. 10000 GAL. WATER RESERVOIR	10000 GAL.	10000 GAL. WATER RESERVOIR
Q	1. 10000 GAL. WATER RESERVOIR	10000 GAL.	10000 GAL. WATER RESERVOIR
R	1. 10000 GAL. WATER RESERVOIR	10000 GAL.	10000 GAL. WATER RESERVOIR
S	1. 10000 GAL. WATER RESERVOIR	10000 GAL.	10000 GAL. WATER RESERVOIR
T	1. 10000 GAL. WATER RESERVOIR	10000 GAL.	10000 GAL. WATER RESERVOIR
U	1. 10000 GAL. WATER RESERVOIR	10000 GAL.	10000 GAL. WATER RESERVOIR
V	1. 10000 GAL. WATER RESERVOIR	10000 GAL.	10000 GAL. WATER RESERVOIR
W	1. 10000 GAL. WATER RESERVOIR	10000 GAL.	10000 GAL. WATER RESERVOIR
X	1. 10000 GAL. WATER RESERVOIR	10000 GAL.	10000 GAL. WATER RESERVOIR
Y	1. 10000 GAL. WATER RESERVOIR	10000 GAL.	10000 GAL. WATER RESERVOIR
Z	1. 10000 GAL. WATER RESERVOIR	10000 GAL.	10000 GAL. WATER RESERVOIR

GENERAL RECEIPTS

RECEIVED BY: [Signature]

DATE: [Date]

PROJECT: [Project Name]

SCALE: [Scale]

APPROVED BY: [Signature]

DATE: [Date]

CF (01539)

1. FOR TANKS LIST SEE 27

2. CONTINGENCY SHALL BE 10%

3. ALL DIMENSIONS SHALL BE WITH EXTENSION

4. ALL DIMENSIONS SHALL BE WITH EXTENSION

5. ALL DIMENSIONS SHALL BE WITH EXTENSION

DO NOT SCALE

