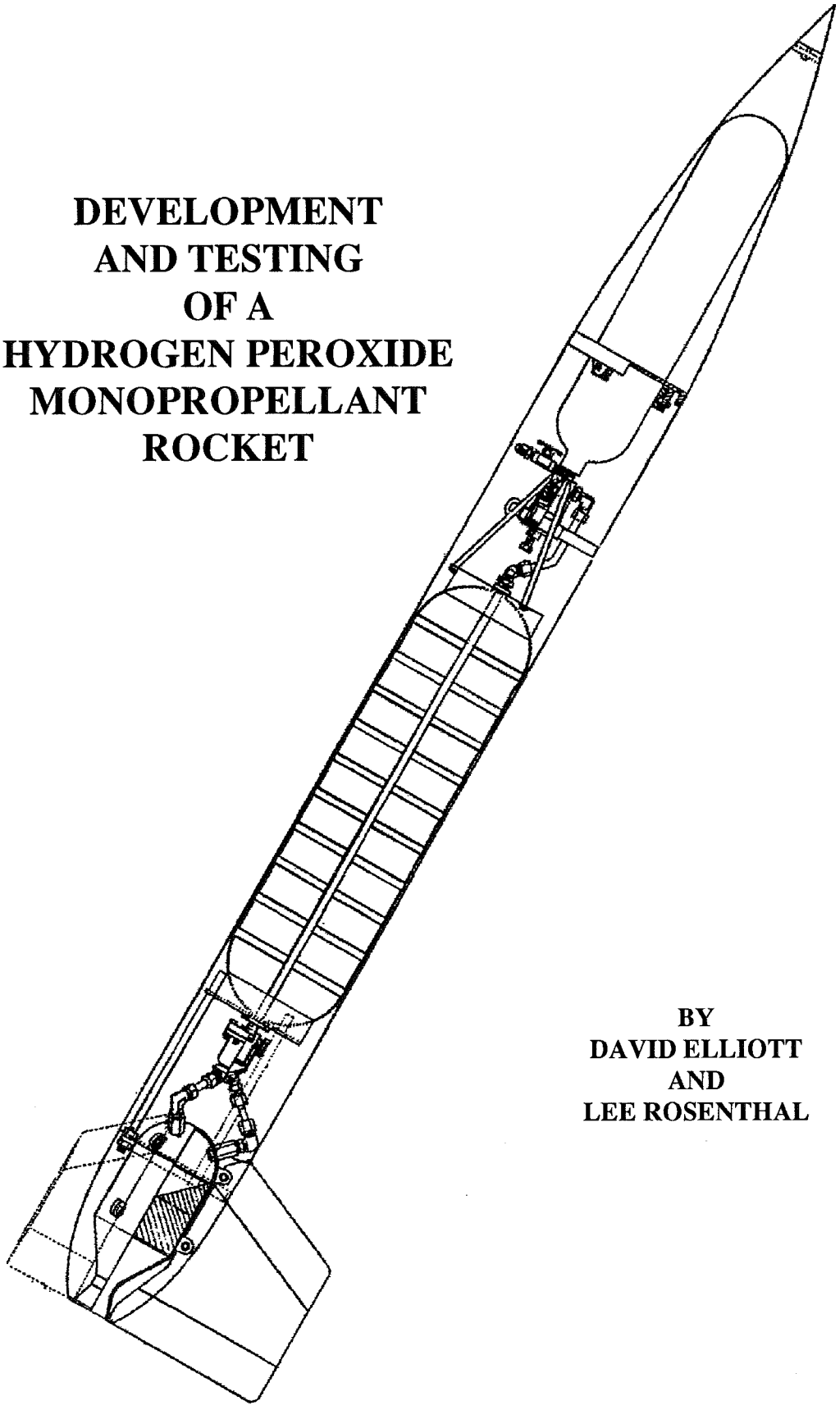
DEVELOPMENT AND TESTING OF A HYDROGEN PEROXIDE MONOPROPELLANT ROCKET



BY
DAVID ELLIOTT
AND
LEE ROSENTHAL

DEVELOPMENT AND TESTING OF A HYDROGEN PEROXIDE MONOPROPELLANT ROCKET

BY

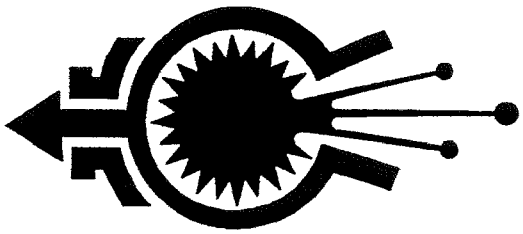
DAVID ELLIOTT AND LEE ROSENTHAL

With a Discussion of

THE PROPERTIES OF HIGHLY CONCENTRATED HYDROGEN PEROXIDE

BY

DONALD HALDIMAN



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The Reaction Research Society gratefully acknowledges the cooperation of Dr. David Elliott, Mr. Walter L. Rosenthal, and Mr. Robert DeVoe in the preparation of this third edition. Their assistance in providing original photographs, drawings, and advice has ensured the accurate reproduction of the original work. The availability of this report is widely appreciated by those interested in the field of amateur experimental rocketry. Even more than 40 years after their work was completed, it stands as a bright example of inventiveness, dedication and excellence.

PREFACE TO THE THIRD EDITION

I was eight years old in May of 1961, when on a small black and white television screen, I watched Alan Sheppard roar into the heavens on a gleaming, graceful machine. I had always been interested in science, and stories of invention had always held my attention. And there on the television that day was the culmination of all man's scientific knowledge and power of invention. Everything we had learned over the past few millennia had been brought together to allow one of our own kind to escape the bonds of earth briefly and return safely. We had opened the door, if even only the tiniest crack, to a universe beyond our traditional realm.

There was a feeling in those days that, with hard work and dedication, we would certainly travel to the moon and possibly beyond before the end of the century. It was an exciting time as the nation progressed from that first Redstone flight to the mighty Saturn V that would take the first humans to another celestial world before the decade was out. The dream of a "Space Age" had emerged from the rubble of the Second World War and now it was becoming a reality.

In those years I read all I could find about Goddard, and rockets, and space travel. I lived in southern California where many of these great space machines were being built. The excitement of the Space Age was all around. But in 1966, as an eighth grade student, I wanted to do more than read. I wanted to build and fly my own machines to really understand how they worked and to learn more than the books could teach. I first learned of, and then joined, a group of amateur rocket builders called the Reaction Research Society. They had been founded in 1943 and in their ranks I saw students, engineers, tinkerers, and philosophers. Some were engrossed with the thought of traveling to distant nebulae. Others, more practical, started smaller and only worried about how to get a rocket up to 1000 feet in an orderly fashion. I watched many of the RRS members design and build, what were to me then, fantastic rockets that exploded out of their launch racks in the Mojave Desert on towering pillars of fire and smoke. These were not cardboard models with minuscule motors producing ounces of thrust. These were metal, many feet long, producing thousands of pounds of thrust, and flew into the clear desert skies at unbelievable speeds. Their construction required machining parts and welding structures just like the

gargantuan vehicles that were taking men into space. Much to the concern of my parents, this was for me.

In 1967 at an RRS meeting in a tumble-down little clubhouse in Gardena, California, I saw something that impressed me so strongly that I remember the feeling to this day over 25 years later. It was a silent, 13 minute long 16mm film about the rocket project documented in this report. I sat in utter amazement watching the fabrication of engines, struts, nosecones, and launch towers. Two high school / college students, who at the time of the project were not much older than I was, were designing, building, and successfully flying a liquid fuel rocket. I was dumfounded. I was awestruck. I was inspired.

Over the next 25 years I built many solid and even liquid rockets of my own. But always I would compare my work to Rosenthal and Elliott and would strive to emulate their skill, professionalism, and technical excellence. Even during my many years of serving at sea in the U.S. Navy, I would often tell the engineers and ordnancemen about the rocket built by these two young students.

The significance of the project was not in its technical achievement. No new and revolutionary principles were discovered. Rather it is the story of two incredibly bright young minds that epitomized the hopefulness of the times. Before the onslaught of liability lawyers, before the environmental doomsayers (who daily invent new scenarios for the impending catastrophes that they are convinced will lead to the obliteration of life on this planet), before we became a nation afraid of all the wonders our technology had wrought, there were these bright, hopeful minds. In our more modern and enlightened world of the 1990's, our children are trained to sit mindlessly in front of the television while being entertained by mutant turtles. Reading is slowly becoming a lost art. The technical advances of the 1950's and 1960's are no longer an inspiration, but are now equated with the destruction of the "ecosystem". But there are still bright minds and dreamers full of enthusiasm to learn and build and strive. They invent and improve and advance our knowledge each day because they do not understand that it cannot be done. General Abramson, who was head of the Strategic Defense Office in the 1980's was asked once if it upset him when the news media reported that most of what his organization was working on was "impossible". He laughed, said no, and then explained, "The quickest way for us to make progress is for the news media to tell a group of American

engineers that what they are doing is not possible." I, for one, am unwilling to accept the premise that the best and brightest days of the United States are behind her. And her greatest hope is in the spirit of those with inspired vision. It is my sincere hope that this paper will inspire others as it continues to inspire me.

David E. Crisalli
24 July 1993

PREFACE TO THE 1952 EDITION

This is the first report on the Reaction Research Society's liquid propellant sounding rocket project. It describes the design, construction, and testing of the first liquid propellant rocket to be fired by the RRS. This work was recently honored with an award by the American Rocket Society. Although over a year and a half has elapsed since the testing of this rocket, the Reaction Research Society feels that because it is an award winner, it is of sufficient interest to now publish it.

The rocket was designed and built by David Elliott and Lee Rosenthal, and was tested with the assistance of other members of the RRS. The photographs and drawings in this report were made by Carroll Evans and Dick Schenz.

The development and use of highly concentrated hydrogen peroxide has only occurred within the last few years. Because of its newness and its generally unfamiliar properties, it was thought to be of value to include a discussion of these properties. A short account of the uses to which concentrated hydrogen peroxide has been applied concludes the report.

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THE PROPERTIES OF HIGHLY CONCENTRATED HYDROGEN PEROXIDE

The following discussion has been included to acquaint the reader with those properties of hydrogen peroxide that make it a useful as a source of energy for propulsion purposes.

The properties of hydrogen peroxide in lower strengths, that is, less than 10%, are more or less familiar to all; its use as a bleaching agent, disinfectant, and mild oxidizing agent having been well-known for years. Concentration up to 35% had found limited application in the laboratory, but higher percentages were considered highly unstable, and hydrogen peroxide as a power source was looked upon with only theoretical interest. Since the early part of World War II however, improved manufacturing and purification processes have allowed the production of hydrogen peroxide in much greater strengths. Today, an essentially stable 90% hydrogen peroxide is commercially available. It is in these strengths that it becomes valuable as a source of energy. Whenever hydrogen peroxide is referred to, it shall be assumed to be highly concentrated, that is, 65-90%.

Physical Properties

Highly concentrated hydrogen peroxide solutions are quite indistinguishable from water in appearance. They are clear, colorless, and generally odorless, though an ozone-like odor may sometimes be evident if any decomposition is taking place or the solution is being subjected to heat. The outstanding physical difference from water is seen in its density; 90% hydrogen peroxide is almost one and a half times as heavy. The more significant properties of 90% hydrogen peroxide are summarized in Table 1. Additional properties for various peroxide concentrations are shown in Table 2.

PROPERTIES OF 90% HYDROGEN PEROXIDE

Color	clear, colorless
Odor	slight
Density	1.393 at 18° C
Viscosity	0.0130 poise at 18°C
Freezing Point	-11° C
Boiling Point	140° C with decomp
Refractive Index	1.3998 $n^{20/D}$
Dielectric Constant	97 at 0° C

Table 1

PROPERTIES OF HYDROGEN PEROXIDE AT VARIOUS CONCENTRATIONS

	HYDROGEN PEROXIDE, % BY WEIGHT							
	100	90	80	70	50	35	27.5	0 (H_2O)
Density @ 20°C (gm/cc)	1.46	1.39	1.35	1.30	1.20	1.13	1.10	1.00
Active Oxygen (% by weight)	47.1	42.3	37.6	32.9	23.5	16.5	12.9	0.0
Pounds/Gallon	12.1	11.6	11.2	10.8	10.0	9.4	9.1	8.3
Freezing Point (°C)	-0.89	-11	-23	-39.5	-52	-37	-23	0
Boiling Point (°C, Approx.)	150	140	130	125	117	108	106	100
Heat of Decomposition (Calories/gm)	690	621	551	483	345	241	189	---
Temp. of Decomposition Vapor (°C)	940	750	460	205	130	100	95	---
Vapor Pressure @ 15°C (mm Hg)	1.0	1.65	2.8	4.0	7.0	8.8	10.0	12.9

Table 2

Stability

The decomposition of hydrogen peroxide is an extremely slow reaction in the absence of catalysts. It has therefore been found that the best method of attaining stability is to increase the purity of the solution. The only known materials which actually increase the stability of hydrogen peroxide are acids. Other substances such as phosphates, fluorides,, cyanides, and various tin compounds have been found to exert stabilizing action, but such action is probably due to inactivation of decomposition catalysts present as impurities. While stabilizers are sometimes added to make up for container deficiencies, or to protect against accidental contamination, the present tendency is to increase purity and decrease stabilization. No stabilizer will protect against gross contamination. Temperature is an important consideration also, especially during periods of extended storage. The rate of decomposition is doubled for every 10° C. rise in temperature, and the effect of temperature becomes particularly noticeable at about 50-60 degrees. Table 3 below illustrates the effect of various storage temperatures.

HYDROGEN PEROXIDE STORAGE TEMP. VS. DECOMPOSITION RATE

Temperature	Approx. Rate of Decomposition
30° C.	1% per year
66° C.	1% per week
100° C.	2% in 24 hours
140° C.	Decomposes rapidly with boiling

Table 3

Decomposition Catalysts

There are a wide variety of organic and inorganic substances that will bring about rapid decomposition of hydrogen peroxide. Ferments, enzymes, and most varieties of dust and dirt will act as catalyzing agents. Particularly noteworthy are the cations of certain heavy metals, which have the property

of exerting large effects when present in only minute quantities. This makes them very suitable for use as combustion chamber catalysts. The cations of iron, copper, and vanadium are particularly active. As little as 0.1 parts per million of copper are sufficient to bring about complete decomposition. Somewhat less active are the cations of nickel, chromium, and manganese. The actual mechanism of the decomposition by these positive catalysts is not completely understood. The presumption is that only those metals having more than one valence state, correctly placed as to redox potential, can so act.

Storage and Handling

Hydrogen peroxide of high concentration can be handled and stored without hazard. Special methods, however, are required in conformance with its properties.

Containers made of 99.6% aluminum are unexcelled for the transportation and storage of 90% hydrogen peroxide. Porcelain and Pyrex containers are suitable for small laboratory quantities, but are not advisable for extended storage of large quantities because of breakage danger and consequent fire hazard. Pumps can be made of stainless steel. Porcelain or glass piping and fittings are quite satisfactory. Several kinds of plastics such as polythene, Teflon and certain polyvinyls are suitable for gaskets, packing, and flexible connections. All conventional piping and fittings made of copper, iron, etc. must be excluded, and it is absolutely essential that all containers and apparatus be completely free from contaminating material.

Hazards

Concentrated hydrogen peroxide has developed a somewhat exaggerated reputation for being hazardous. An understanding of its properties and the adoption of adequate safety precautions render its use quite safe.

While being non toxic, both the solution and the vapors are irritating, causing discomfort to the eyes and nose. The liquid causes whitening of the skin and a more or less severe stinging sensation. In most cases the stinging subsides quickly and the skin gradually returns to normal without damage. Blistering is possible if extended skin contact occurs, however immediate

flushing with water will halt any reaction by dilution of the peroxide. Face hoods should be worn when handling to protect the eyes against splashing. Rubber gloves and aprons are in order and an adequate amount of water for flushing down spillage should be available. Care should be taken in disposal of contaminated hydrogen peroxide solutions, since concentrations greater than 65% will decompose with enough heat to cause spontaneous ignition of combustible materials.

It is apparently impossible to obtain a propagating detonation in 90% hydrogen peroxide. The material has been subjected to mechanical impact, rifle and machine gun fire, and blasting cap detonation without effect. Mixtures of oxidizable materials such as organic solvents with hydrogen peroxide can be regarded as a definite explosive hazard, especially if the material becomes well dispersed or dissolved in the peroxide. Acetone, ethanol, and glycerol are among those substances forming detonable compositions. Experiments have shown that the mixture must contain at least 30% of 90% hydrogen peroxide to be detonable. The Society in a series of experiments, found that the alkali metals, lithium, potassium, and sodium react explosively with hydrogen peroxide (as well could be expected!) A very violent detonation was produced by the combination of a metallic sodium dispersion in toluene and 90% hydrogen peroxide.

As Source of Energy

Hydrogen peroxide decomposition is an exothermic reaction:

$$H_2O_2 \rightarrow H_2O + {}^1/_2\, O_2 + 23,450 \text{ calories}$$

Upon complete decomposition, one liter of 90% peroxide yields 589 grams of oxygen gas and 801 grams of steam. Under adiabatic conditions the calculated temperature of these products is 750° C., and their volume is about 5000 liters at one atmosphere pressure. This system has obvious possibilities as a power source.

SECTION II

DEVELOPMENT AND TESTING OF A HYDROGEN PEROXIDE ROCKET

During the 1930's much of the liquid propellant rocket development done in the United States was carried on by amateurs and, although today thousands of people are working on large, well-financed rocket projects, amateur rocket building is still as fascinating a hobby as it was then. Most of the present-day experimental amateur rocket development work is being carried on by the Reaction Research Society.

After the financially profitable Rocket Mail Flight held by the Reaction Research Society at Trona, California in March, 1948, the authors of this report felt that the RRS was in a position to undertake a modest liquid propellant program having as its goal the development of a simple vertical sounding rocket capable of carrying a few pounds of payload. The uses of such a rocket are few, if not entirely nonexistent, but the possibility of using such a rocket for inexpensive upper-atmosphere research furnished us with an excuse for undertaking the project. Actually, we were motivated chiefly by the intrinsic interest of building a liquid propellant rocket.

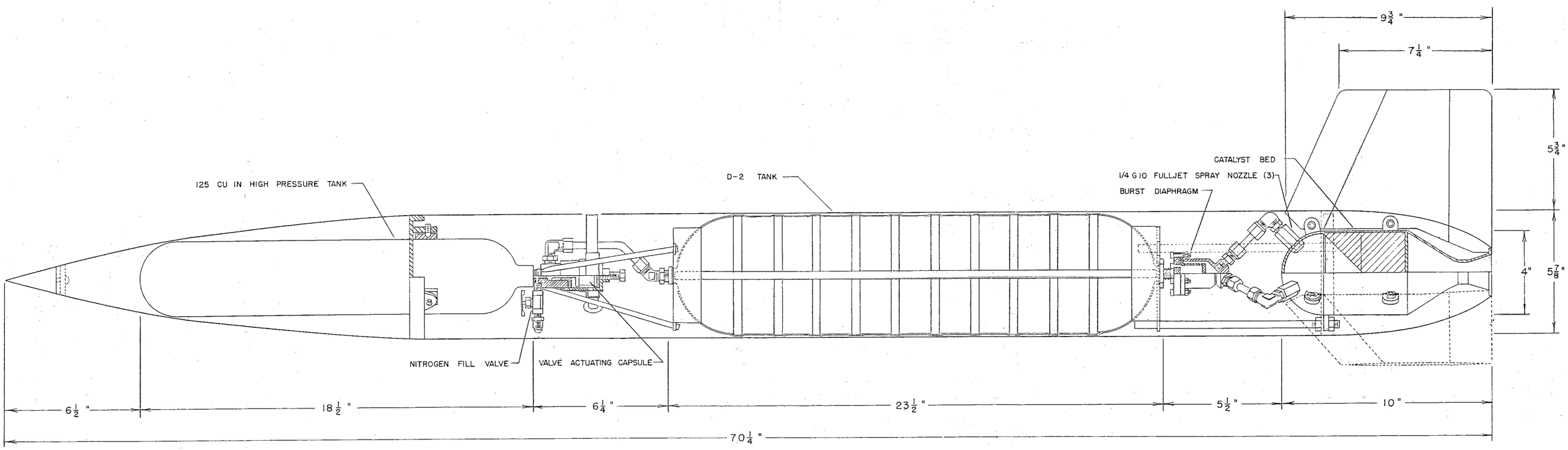
During the summer of 1948 we carefully considered all of the possible propellant combinations that might be used, seeking, in particular, a propellant combination that would minimize the amount of work that would have to be done in constructing the rocket. We finally chose hydrogen peroxide as the propellant because it would permit us to build the simplest possible liquid propellant rocket. The rocket would use only one liquid and the motor would not need to be cooled. The performance of the rocket would not be high, because hydrogen peroxide when used as a monopropellant gives a specific impulse of only about 120 seconds, but the simplicity of the rocket would outweigh this disadvantage. To further simplify the project, we decided against attempting to launch the rocket with a booster rocket. Instead we would endeavor to achieve a vertical flight by designing the peroxide rocket to have a fairly high acceleration itself, and by using as tall a launching tower as possible.

It was desired to carry about two pounds of payload consisting of some device to aid tracking, such as a smoke generator or a radio transmitter. This requirement and the requirement of rapid takeoff led us to set the thrust at 200 pounds, and the takeoff weight at 50 pounds. At this point we were able to draw up a preliminary design for the rocket.

The final design, as shown in Figure 1, was evolved after deciding that it would be possible to use a war surplus, type D-2, breathing oxygen tank as the peroxide tank. The type D-2 tank is made of stainless steel, is 23 inches long and 5 7/8 inches in diameter. It is built for a working pressure of 400 psig, weighs only 4 1/2 pounds, and will hold 25 pounds of 90% hydrogen peroxide. It was planned to build the motor, attach it to this tank, and then test run that much of the rocket using an external nitrogen supply to provide feed pressure. Once this assembly was made to operate satisfactorily, we would add the flight nitrogen tank, make final static tests, then add the fins and streamlined shell for flight.

We began by designing the motor. To allow room for mounting lugs its diameter was limited to 4 inches. The length was then determined by the length of catalyst bend required to decompose 1.7 pounds per second of peroxide, the flow rate required for 200 pounds of thrust. The catalyst for which we were able to find data was a modification of a German catalyst. It was made by preparing a 25% calcium permanganate solution, adding 25 grams per liter of potassium chromate, and boiling 1/8 inch x 1/8 inch Alundum catalyst supports in this solution. The particles were then baked. The resulting catalyst pellets had a coating of manganese dioxide. According to experimental data on this catalyst, our motor would need a catalyst bed 3 1/4 inches long, and the pressure drop across this bed would be 100 psi. Allowing 100 psi injector drop and assuming that the peroxide tank would be pressurized to 400 psig, the motor would have to operate at 200 psig chamber pressure. Accordingly, we designed the nozzle to give 200 pounds of thrust at this chamber pressure. The nozzle was correctly expanded for 5000 feet above sea level.

We machined the nozzle from a bar of 1020 steel. It was flanged and bolted to a mating flange on a 4 inch diameter, 6 inch long stainless steel tube with a 0.083 inch wall thickness. A 0.15 inch thick hemisphere, machined from 1020 steel, was welded to the other end of this tube. Into this was screwed three stainless steel, 1/4 inch, G-10 "Fulljet" spray nozzles. Inside the motor, the catalyst was held in place by a 30 mesh stainless steel screen at



HYDROGEN PEROXIDE – SOLID CATALYST ROCKET

DESIGNED BY DAVID ELLIOTT AND LEE ROSENTHAL

DECEMBER, 1948. GLENDALE, CALIFORNIA.

each end, and the downstream screen was backed up by a 1/8 inch thick stainless steel plate perforated with sixty-eight 1/4 inch diameter holes.

The motor was attached to the peroxide tank by three struts made from 3/8 inch O.D. steel tubing. These struts were welded to a ring which was held against the end of the tank by a nut screwed over the outlet fitting. The other ends of the struts were threaded and passed through lugs on the motor, where they were held by nuts. The plumbing between the tank and the motor consisted of a stainless steel burst diaphragm valve screwed into the outlet fitting of the tank and connect by short aluminum tubes and AN fittings to the three spray nozzle injectors. The burst diaphragm itself was a 0.003 inch aluminum disk which would break at 120 psig peroxide tank pressure.

During January 1949, we constructed the static test facility for the rocket in Mint Canyon north of Glendale, California. The test stand consisted of a rigid mount, anchored in concrete, which would hold the rocket in a vertical position. The nitrogen feed control valves and instruments would be located 30 feet away behind an earth embankment. The data we wished to obtain were nitrogen tank pressure, peroxide tank pressure, chamber pressure downstream of the catalyst bed, and time. These would be obtained by photographing three pressure gauges and a sweep second timer with a 16mm movie camera. Knowledge of the chamber pressure (P_C), firing time (t_p), the mass peroxide used (m), and nozzle throat area (A_t), would enable us to calculate the overall characteristic velocity c* (pronounced "cee star") for each run by the formula:

$$c^* = \frac{P_C \; A_t \; t_p}{m}$$

This value would be compared with the theoretical c* for hydrogen peroxide as a check on the performance of the motor and catalyst.

The first test runs were made on February 26, 1949. We mounted the motor-tank assembly on the test stand and connected the inlet of the peroxide tank to a 220 cubic foot nitrogen cylinder through a 1/4 inch copper line. The nitrogen cylinder was located behind the embankment, where we would control the flow of nitrogen by means of a needle valve in the line. The nitrogen line also contained a vent valve, which was left open until just before each run to prevent pressure buildup in the peroxide tank due to nitrogen leakage or peroxide decomposition. During the first runs, we

planned to watch the peroxide tank pressure gauge while opening the nitrogen valve to raise this pressure to 400 psig. The needle valve would then be left open at this setting and used as a metering orifice for succeeding runs, which would be started with a quick opening valve.

For the first run, the tank was loaded with 6 pounds of peroxide. This was done by siphoning the peroxide from the aluminum storage drum into a two liter glass graduated cylinder, and then pouring the peroxide through a glass funnel and a short length of Tygon tubing into the tank. After loading the peroxide and attaching the nitrogen line to the tank, we retired behind the embankment for the run. We closed the vent valve, started the timer and the movie camera, and cautiously opened the nitrogen needle valve. When the peroxide tank pressure reached 120 psig, the burst diaphragm opened and the motor started with a smooth roar. We continued to open the needle valve until the peroxide ran out, at which time the tank pressure was 200 psig.

For the second run, we replaced the burst diaphragm and loaded the tank with 18 pounds of peroxide. The motor was again started by opening the needle valve, and by the end of the run, the tank pressure had been raised to 400 psig. We then made a third run, using a full 25 pounds of peroxide. The needle valve was left open from the previous run, and the motor was started with the quick opening valve. The motor quickly reached 190 psig chamber pressure and ran for 15 seconds. The average chamber pressure was 175 psig , the weight of peroxide used was 24.3 pounds, and the throat area of the nozzle was 0.720 square inches. Thus the overall c* was 2700 feet per second. We felt that this was sufficiently close to the theoretical c* of 2950 to indicate that the motor was functioning properly. In addition, our data and calculated exhaust velocity included both starting and stopping. Using 1.33 as the thrust coefficient, we calculated that the thrust obtained was 197 pounds.

It was originally planned to use a pressure regulator between the nitrogen tank and peroxide tank, but we now calculated that if we simply used an orifice to meter the nitrogen flow, the chamber pressure would drop only about 50 psi during a run, even though the nitrogen pressure in a 125 cubic inch tank would drop from 2000 psig to 500 psig. For the sake of simplicity we decided to use an orifice and, on March 6, 1949, two test runs were made to determine the required size of the orifice. During the first run, the needle valve was opened until the peroxide tank pressure reached 500 psig. This was higher than the tank pressure used in the previous runs because we

wished to obtain higher thrust than before. Following this run, the stem of the needle valve was soldered in position, and a second run was made to make sure that the needle valve was still correctly set. Later, in the shop, various size orifices were flow tested until we found one that gave the same flow rate as the needle valve. The correct orifice was 0.043 inches in diameter.

The flight nitrogen tank, which we next added to the rocket, was a war surplus 125 cubic inch oxygen tank weighing 4 1/2 pounds. We hydrostaticaly tested the tank to 3000 psig. This tank was attached to the peroxide tank with three struts in the same manner as the motor. The outlet of this tank was connected to the inlet of the peroxide tank through a valve which was to be actuated by current from a dry cell. The stem of this valve was held in the closed position by a piece of solid propellant 7/8 inches in diameter and 5/8 inches thick, cast from a mixture of 75% potassium perchlorate and 25% Baker Casting Resin. This capsule was held firmly against the stem by a screw to seal off the compressed nitrogen, and, at the same time, keep the peroxide tank vented to atmosphere. Closing the fire switch ignited this capsule (which burned in less than a second) permitting the nitrogen to force the stem into the open position. This sealed off the system from the atmosphere and allowed nitrogen to flow through the metering orifice into the peroxide tank.

The addition of the nitrogen tank and nitrogen valve completed the working part of the rocket, and we tested this unit on March 27, 1949. The test setup was the same as for the previous runs, with the addition of a battery and switch for actuating the nitrogen valve. We filled the peroxide tank with 25 pounds of peroxide and pressurized the nitrogen tank to 2000 psig from a 220 cubic foot cylinder. After starting the recording camera, the fire switch was closed and the rocket started smoothly, reaching full pressure one second after the valve opened, but the peroxide tank pressure reached only 400 psig instead of 500 psig as had been intended. The movie record showed that the nitrogen pressure dropped to 1300 psig in the first 2 seconds of the run, and this accounted for the low peroxide tank pressure. We enlarged the metering orifice to 0.047 inches and made another run on April 14. The peroxide tank pressure was still not as high as we wished. However, we decided that it would not be worthwhile to spend more time adjusting the metering orifice, and we proceeded with the construction of the rocket. A plot of the data from this last run is shown in Figure 2.

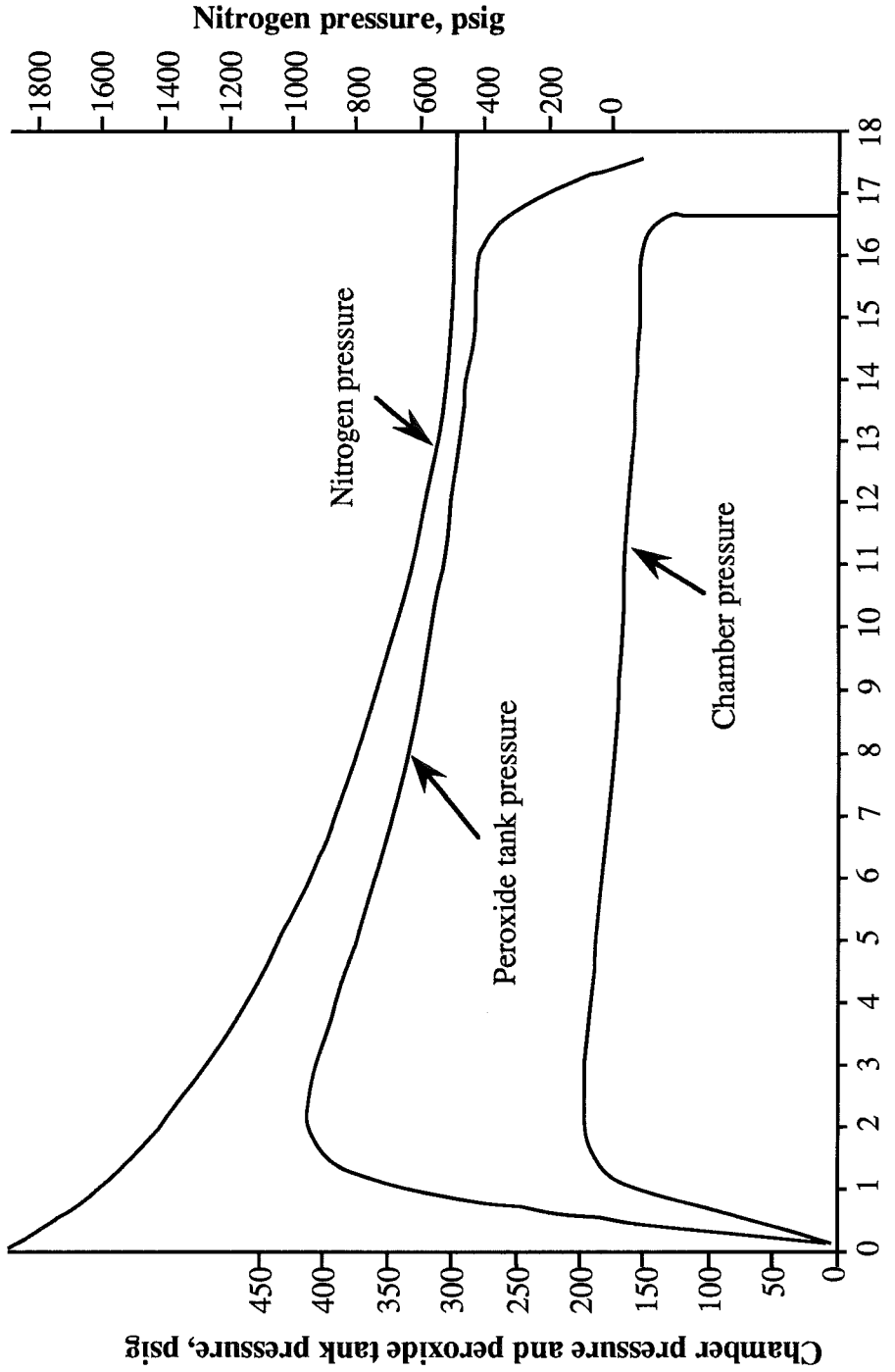


Figure 2 Test Run #7 Data Plots (April 14, 1949)

Before the last run, the motor had been lightened by removing the flanges from the nozzle and chamber and welding the nozzle and chamber directly together. This sealed in the catalyst, but no measurable decrease in its action had been observed in previous runs. It was felt that replacing it with fresh catalyst at this point would surely be effective for the flight. Now all that remained was to add the fins and shell. The fin area required to stabilize a fin-stabilized rocket increases with the Mach number at which the rocket is to operate. The highest Mach number the peroxide rocket could possibly attain would be about 1.8, and we chose the fin area so that the center of pressure of the rocket would be 6 inches aft of the center of gravity at that Mach number. The three fins were cut from 1/8 inch sheet magnesium and tapered to a knife-edge at the leading and trailing edges. They were bolted to lugs on the motor, the lugs having been carefully machined parallel to the axis of the nozzle. The shell which covered the rocket consisted of spun aluminum nose and tail sections, and, between them, an aluminum tube rolled from 0.020 inch sheet. These were supported by two aluminum rings, one bolted to the motor and the other fastened by set screws to blocks on the nitrogen tank. The set screws could be loosened to permit the nose-cone and tube to be slid off the rocket when the rocket was to be loaded and pressurized. The completed rocket weighed 24.5 pounds empty, and it cost about $100.00 to build.

One major problem remained. None of the launching towers belonging to the Reaction Research Society or the Pacific Rocket Society were large enough for the peroxide rocket. We would have to build a launcher especially for this rocket, although the rails could be made adjustable for other rockets as well. We designed a 40 foot tower to be constructed of welded steel channel. It would have a triangular cross section 2 feet on a side with 1/8 inch x 4 inch steel rails held by set screws between angle-iron brackets welded to the cross pieces. A door was provided at the bottom for placing the rocket in the tower. We built the launcher between July and September, 1949, and arranged with the Pacific Rocket Society to erect it on their test area in the Mojave Desert. In September, we installed a foundation and guy wire posts, embedded in concrete, and on October 8, the tower was hauled to the test area to raise it. The raising operation proved to be of considerable magnitude, and it was only with the aid of much man-power and a large supply of ropes, hoists, and auxiliary wooden framework that we succeeded in raising the tower to a vertical position. Unfortunately, there was insufficient man-power and rope to control the tower in the high wind which

arose during this time, and the tower was blown down. This mishap demolished 10 feet of the tower and twisted the rest of it, so that we were forced to bring the tower back to the shop for rebuilding. On November 26, we returned to the test area and succeeded in raising and anchoring the tower without mishap. Finally, with the aid of a transit, the tower was aligned to a vertical position by adjusting turnbuckles on the six guy-cables.

On February 12, 1950, the peroxide rocket was given a final static run while it was anchored, completely assembled, in the launching tower. This run uncovered one flaw in the design. The exhaust gases from the propellant capsule in the nitrogen valve built up enough pressure to open the seam in the aluminum shell, even though there were three 5/8 inch diameter vent holes in the shell. We eliminated this difficulty by attaching a manifold to the valve, which would conduct the gases through three 1/2 inch diameter tubes directly to three 1 inch diameter holes in the shell. These holes would also vent the shell as the outside pressure changed during the rocket's ascent. The old shell was replaced with a new one having its seam fastened by Pliobond adhesive. This made a smoother, stronger joint than the screws used previously. Finally, we installed a 1 pound paraffin-potassium nitrate-arsenic sulfide smoke flare in the tip of the nose cone to aid in tracking, and we painted the rocket with white automobile lacquer.

We planned to track the rocket solely by optical means. We knew that this would be difficult to do because of the small size of the rocket, and the fact that decomposing hydrogen peroxide leaves almost no exhaust trail in dry warm weather. However, optical tracking equipment would be the easiest to build or obtain. A 16 mm phototheodolite was constructed by mounting a GSAP camera on a Buff Theodolite. The movie camera had a 13 inch focal length main lens and a 35 mm auxiliary lens which, with the aid of a small mirror, placed an image of the edges of an angle-of-elevation scale and a sweep second timer on part of the 16 mm frame. The operator would watch the rocket through the eye-piece of the theodolite while moving the instrument with a handle-bar. In addition, we hoped to measure the velocity of the rocket at burnout by making two successive exposures of the rocket at burnout with a 4 x 5 Speed Graphic camera located with phototheodolite three miles from the launch site. The camera would be aimed at the area of the sky in which the rocket should be at burnout, and a record of time between the two exposures would be obtained from a flashlight bulb mounted beside the timer on the phototheodolite and connected to the Speed

Graphic flash synchronizer. A 16 mm movie camera mounted 600 feet from the launch tower would complete our effort at tracking the rocket.

To try out the phototheodolite and the launching tower, on April 9, 1950, a solid propellant rocket was fired from the tower. This rocket was 2 1/2 inches in diameter and 7 feet long, and its propellant was a mixture of 85% zinc dust and 15% sulfur. We attached the peroxide rocket's six launching blocks to extension arms on this rocket; five of the blocks were flat and one was slotted to fit over one rail and prevent the rocket from rotating in the tower. In the test, the rocket fired for 0.8 seconds, left the tower at 300 feet per second, and reached an altitude of about 2500 feet. The launch blocks followed the rails without mishap and were undamaged except for a few burned streaks. The phototheodolite operator was not able to track the rocket, because the rapid acceleration of the rocket carried it out of his field of view before he could start following it.

All the components of the peroxide rocket that could be ground tested had now been checked, and we scheduled the flight for May 14, 1950.

On May 12, a small group arrived at the test area to begin preparations. We first spent several hours working on the launching tower, adjusting the rails for 1/16 inch clearance from the blocks on the rocket. The rocket was pulled up and down the tower frequently as a check. The ignition cable was then laid from the tower to the control box 250 feet away, and a radio transmitter was set up to communicate with the tracking station on a hilltop three miles to the southeast. The evening before the flight, we placed the rocket in the tower, bolted the door shut, and left everything in readiness so that the rocket could be fired as soon as possible after sunrise. Early morning in the Mojave Desert promised the least wind and the best tracking conditions.

As the sun rose at 6:30 the morning of the 14th, the sky was clear, but there was already a brisk wind blowing. A group left for the tracking station with the instruments and a radio transceiver. At the launch site we lifted the shell from the rocket and rested it on a crosspiece in the tower above the rocket. We connected a cylinder of nitrogen to the nitrogen tank and pressurized the tank to 2000 psig. We then filled the peroxide tank, slid the shell back onto the rocket, and fastened it with the set screws. Finally we connected the ignition wires to the squibs in the smoke flare and nitrogen valve. At 7:45 the rocket was ready for flight, and we retired to the control station 250 feet away.

We counted down and fired the smoke flare, but the flare failed to ignite properly and gave only a thin stream of smoke. After ten seconds it was burning no better, so we made the final count-down and fired the rocket. The motor roared to life, and the rocket lifted quickly out of the tower, clearing it at 80 feet per second as recorded by the movie camera. As the rocket left the tower, the wind caught the fins, and the rocket rotated 15° from the vertical. It continued to climb at this angle with rapidly increasing velocity. In a few seconds the rocket was only a distant white speck which quickly became too small to see. Twenty seconds after takeoff a thin, distant vapor trailed appeared, streaking across the sky to the northwest, and after another twenty seconds this also became too faint to see.

At the tracking station, the phototheodolite operator saw the rocket leave the tower, but because the smoke flare was not working properly, he was not able to follow it. Two exposures were made with the Speed Graphic at the time of burnout, but the rocket was then to the left of the camera's field of view. The rocket had obviously functioned properly, but unless we could find it, there would be no way to determine, accurately, its trajectory. We spent the rest of the day looking for the rocket, by car and on foot, but we were unable to find it.

However, the movie camera which was located at the launching site obtained pictures of the rocket for the first four seconds of flight. It was possible to obtain from their record approximate values for the rocket's velocity, position, and direction of motion during that time. By using these data, the experimental thrust curve of the rocket, and a plot of the theoretical drag coefficient versus Mach number, it was possible to calculate, step by step, a trajectory for the flight. The results of this calculation were:

Velocity at burnout	1,460 feet/sec
Altitude at burnout	9,800 feet
Maximum altitude	23,500 feet
Range	41,000 feet
Total flight time	84 seconds

This calculated trajectory ground plot is shown on the map of the launch area included as Figure 3. This flight clearly showed the need for using a booster rocket when making vertical flights with rockets of this size. The rocket did not takeoff rapidly enough to follow a vertical path even though

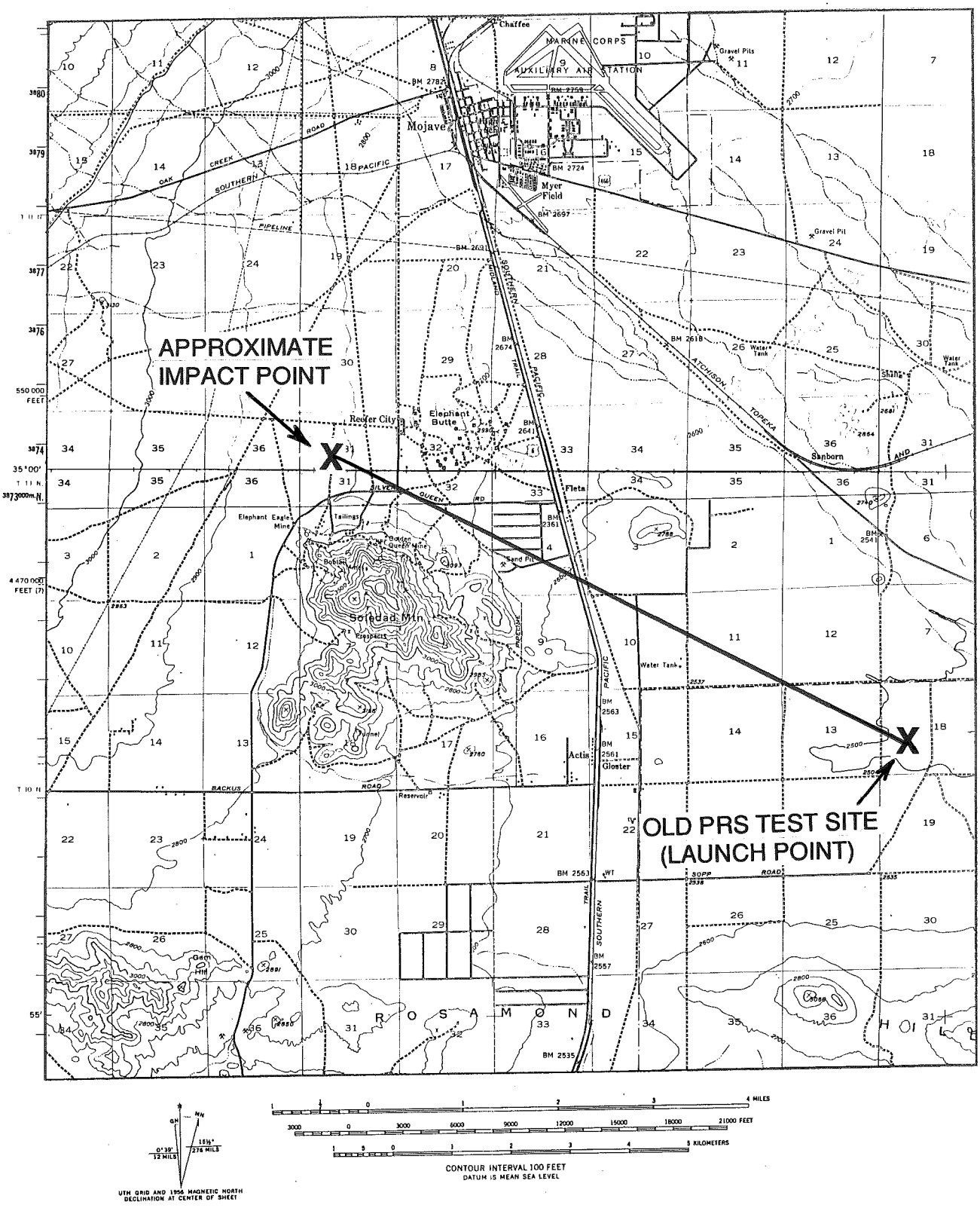


Figure 3. Calculated Trajectory Ground Plot

its acceleration was greater than the optimum acceleration for such a small vehicle. If a rocket of this size reaches its peak velocity at a low altitude, it encounters enormous air resistance. The drag on the peroxide rocket at burnout was 50 pounds - twice the rocket's weight. In order for a rocket to reach the highest possible altitude, it should be designed to reach a high burnout altitude. This requires a thrust to weight ratio which, in this case, was too low for unassisted takeoff. The addition of a booster would insure vertical flight, and greatly increase performance. Such a unit could perhaps carry out some of the lower altitude research now being done with much larger and more expensive rockets.

Lee Rosenthal
David Elliott
1950

SECTION III

APPLICATION OF HYDROGEN PEROXIDE TO POWER PRODUCTION

The methods of using hydrogen peroxide in power units may be divided into the following three main groups:

a. Its use as a monopropellant by way of catalytic decomposition. These have been called "Cold" motors.

b. The utilization of the oxygen released by catalytic decomposition for the burning of a fuel.

c. The direct reaction of hydrogen peroxide on another substance, generally liquid, as an oxidant. This reaction is characterized by spontaneous ignition.

In actual practice, it has been found more efficient to utilize a combination of these reactions.

Hydrogen peroxide has a relatively low performance as a monopropellant, its specific impulse being about 120 seconds for 90%. Nevertheless, its ease of handling compared with liquid gases, its high specific gravity, and the characteristically simple design of a monopropellant motor have encouraged experimentation and development of a few monopropellant devices.

Considerable development work on hydrogen peroxide units for airplanes was done by the Walter Works in Kiel, Germany, during World War II. This work climaxed with the production of the Walter 109-509 rocket unit, which was used for the propulsion of various fighter planes and missiles. Most important among the applications were the Me-163 fighter, the Me-262 fighter, and the BP-20 "Natter" fighter. In earlier models, the Me-163 was powered solely by decomposing 85% hydrogen peroxide. The later models utilized a "Hot" fuel mixture consisting of 57% methyl alcohol, 13% water, and 30% hydrazine hydrate, with 80% hydrogen peroxide as the oxidizer. Hydrazine hydrate can be used as a fuel by itself and, in combination with

hydrogen peroxide, it has the advantage of being hypergolic (spontaneously ignitable) so that no ignition device is required. However, as an energy source, it is greatly inferior to alcohol. For this reason only enough of it was put into the mixture to make it self-igniting. The 109-509 motor could provide power for 15 to 20 minutes at minimum fuel consumption. At full thrust, the fuels lasted for only four minutes. These planes, while having a very limited range, were spectacular performers. They were said to be capable of climbing at 30,000 feet per minute.

A more recent development in the "Cold" motor area is a British take-off unit. Called the Spirite, and designed by A.V. Cleaver, its purpose is to facilitate the take-off of the British de Havilland jetliner Comet, using two units to do so. The Spirite holds 39 gallons of hydrogen peroxide and 21/2 gallons of catalyst, weighs 925 pounds, and develops 5000 pounds of thrust for 9 seconds.

The most extensive use of hydrogen peroxide has been as a source of constant-temperature steam, something which is almost impossible by other means. One of the first applications of this was in the German Buzz Bomb, or V-1, which was launched from a catapult-like device. Hydrogen peroxide at about 80% concentration was injected into a cylinder together with a strong permanganate solution. Steam and oxygen from the resulting decomposition activated a piston to which the V-1 was attached. This accelerated the V-1 to a speed of about 150 miles an hour at which time a propulsive duct utilizing 80-octane gasoline as fuel came into play. The V-1 reached a top speed of about 360 miles per hour and had an average range of 150 miles. The aircraft carried 2200 pounds of explosive in the warhead.

In the V-2, decomposing 90% hydrogen peroxide was used as a source of steam to drive the propellant pumps. These pumps moved nearly five tons of alcohol and liquid oxygen from the supply tanks to the rocket engines during the firing time of about 65 seconds. A similar method of fuel pumping has been adapted to the Navy Viking.

Experimental submarines were operated at speeds up to 30 miles per hour submerged using the Walther cycle engine. Heat was obtained by burning fuel oil in the atmosphere provided by decomposing 80% peroxide. The resulting hot gases, principally steam and carbon dioxide, were used to operate a turbine from which the motive power was taken. Available submerged shaft horsepower and shaft horsepower hours were vastly greater

than for the conventional battery-operated sub. The peroxide was carried in huge plastic bags outside the pressure hull.

These applications well illustrate the diversified manner in which hydrogen peroxide can be utilized as a source of power, but the possibilities are by no means exhausted. There is still much experimental work to be done, and out of this will undoubtedly come many new applications. The Reaction Research Society has continued to investigate the use of concentrated hydrogen peroxide as a propellant. Considerable progress has been made toward solving those problems evolving from the first flight. Work now being carried on by the Society shows promise of producing a low cost, high performance rocket in the 60-80 mile altitude range.

Donald Haldiman
1950

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APPENDIX A

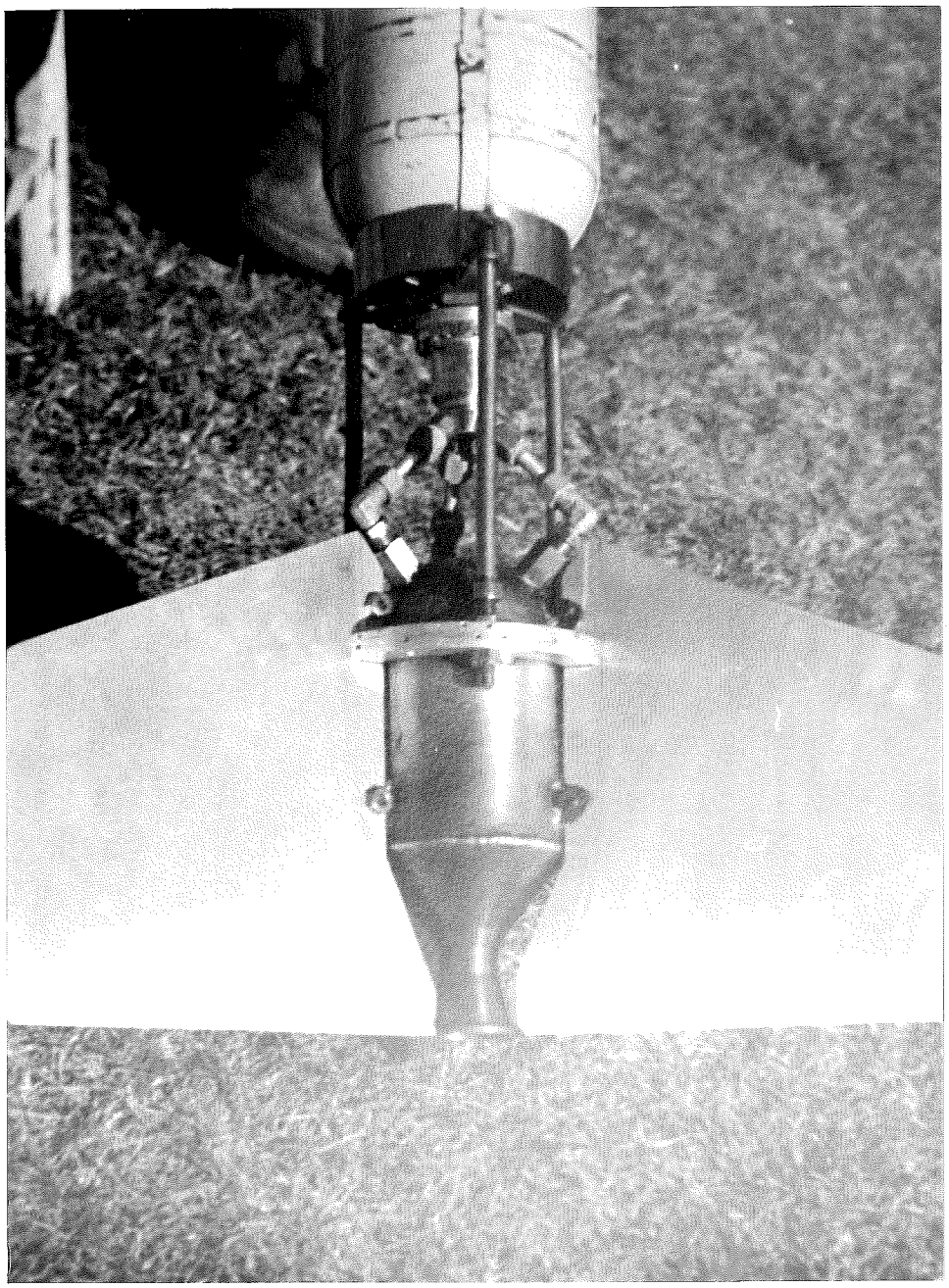
PHOTOGRAPHS

Static test number 1 run on 26 February, 1949.

Lee Rosenthal (left) and David Elliott set up the propulsion unit in the test stand for one of the first static tests. The facility nitrogen pressurization line is being attached. The I-beam in the background provided protection for the test crew.

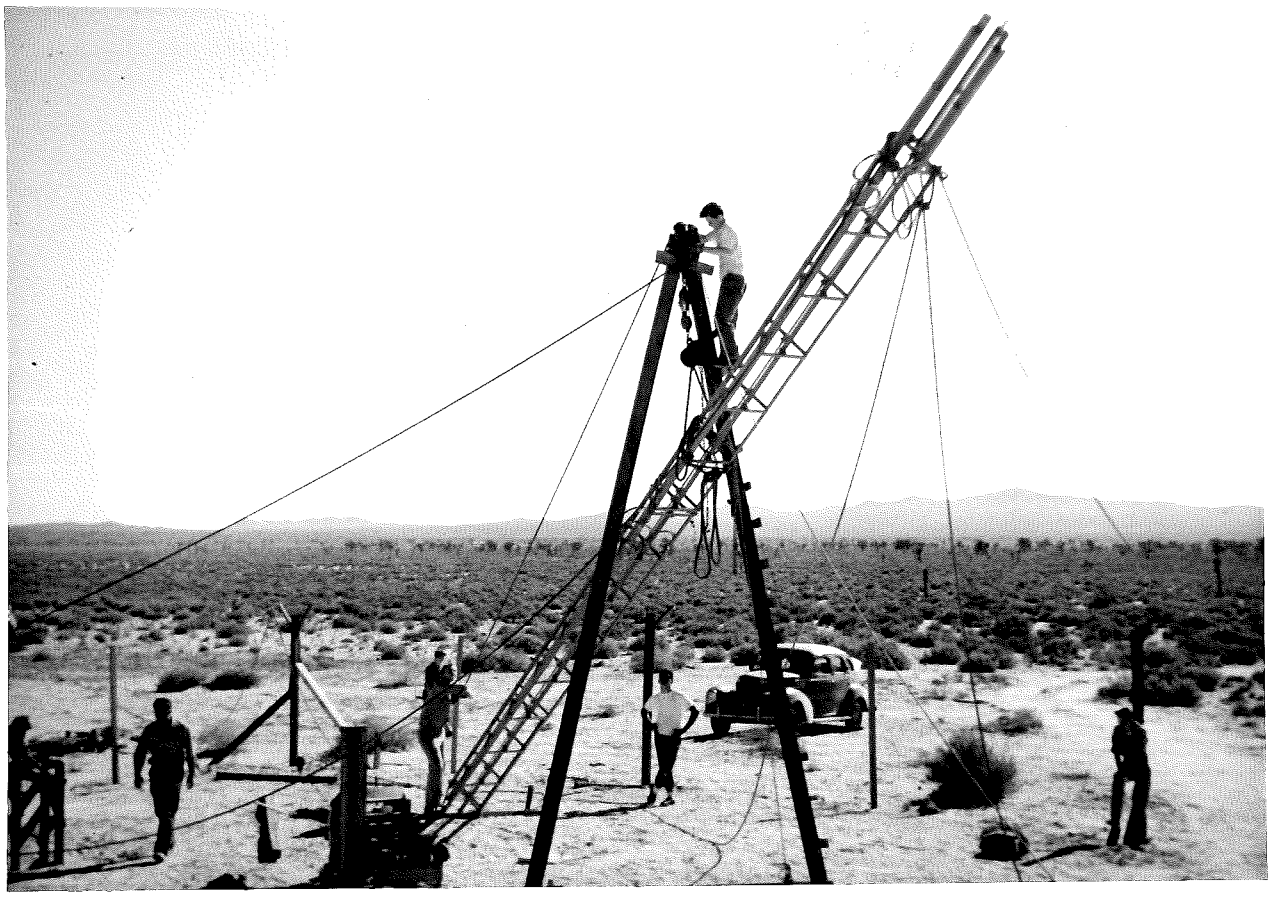
Static test number 6 run on 27 March, 1949. This test includes the flight pressure bottle and valve assembly.

The flight pressure bottle, fill valve, and pyrotechnic valve are shown connected by struts to the peroxide tank. The bolt head at the lower end of the pyrotechnic valve is used to push the propellant capsule against the valve stem closing off the high pressure nitrogen.

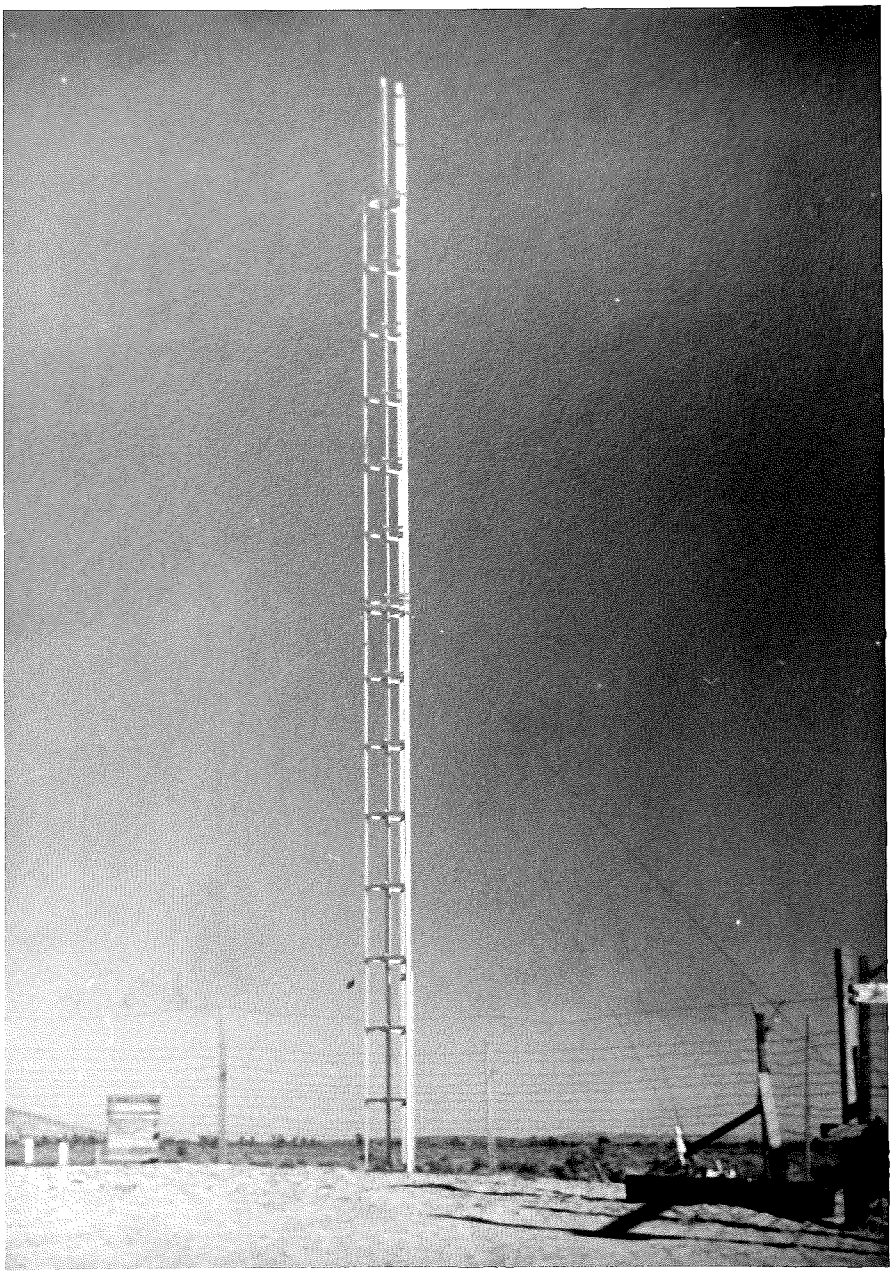


The combustion chamber and lower portion of the peroxide tank are shown here after addition of the three sheet magnesium fins. The burst diaphragm valve can be seen just below the tank.

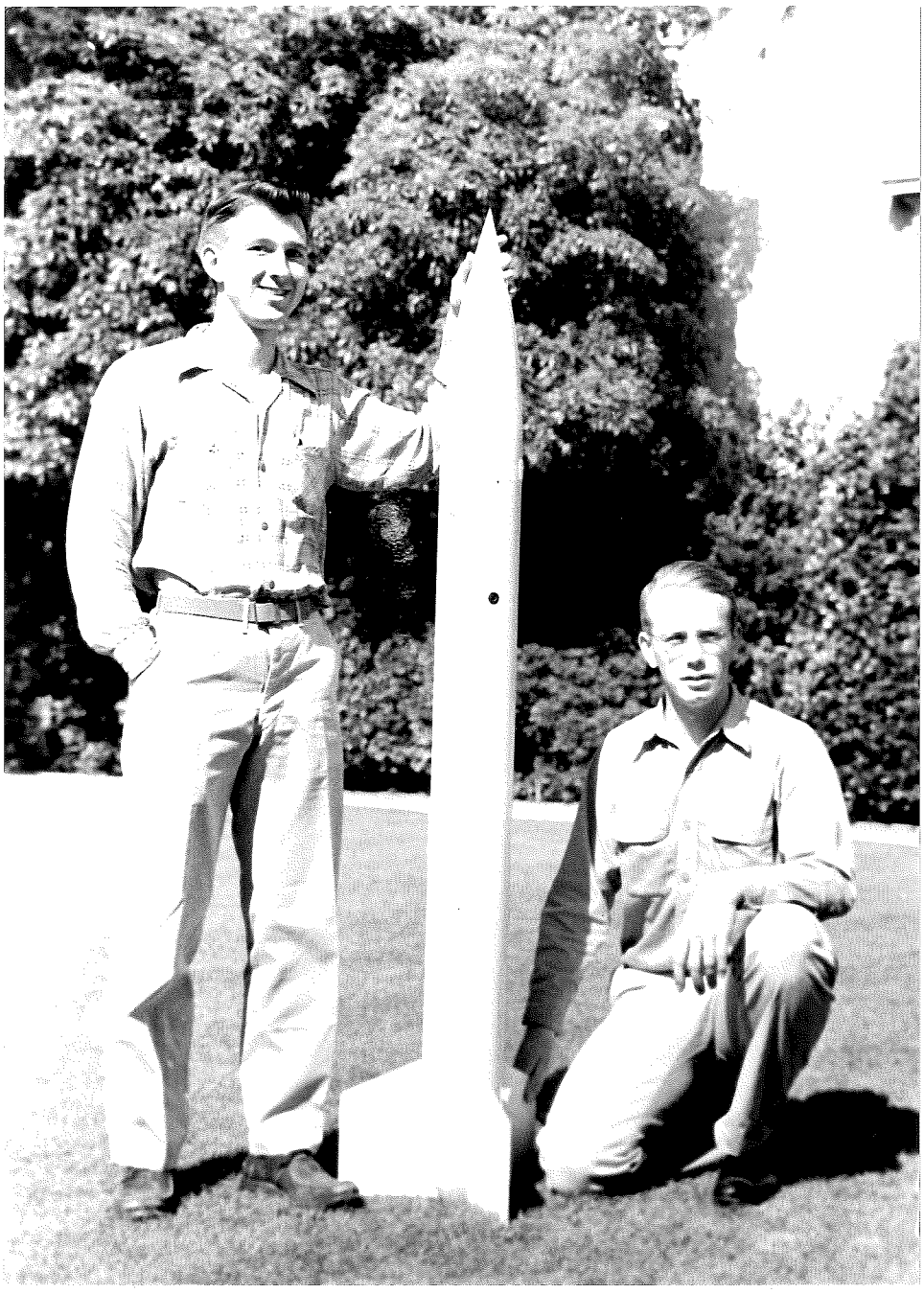
All major components and subassemblies of the hydrogen peroxide monopropellant rocket.



Members of the RRS erect the 40 foot launch tower at the test site.



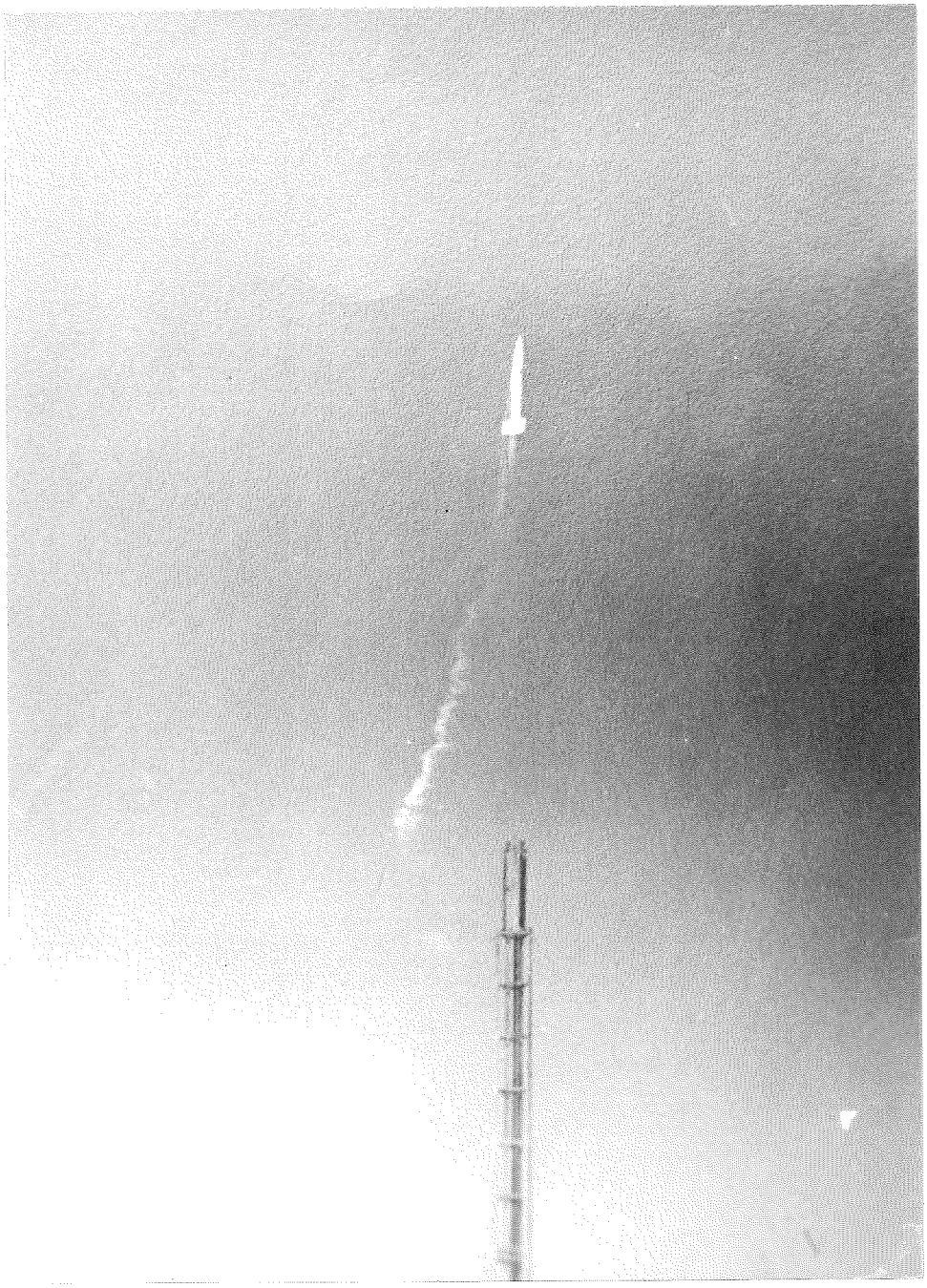
The 40 foot launch tower erected by members of the RRS at the Pacific Rocket Society's test area near Mojave, California.



David Elliott (left) and Lee Rosenthal, designers and builders of the hydrogen peroxide-solid catalyst rocket, pose beside their completed product.

Glen Maxon conducting a fit check of the rocket in the launch tower during final rail adjustments.

Lee Rosenthal adds 90% hydrogen peroxide to the fuel tank of the rocket just prior to flight. The auxiliary nitrogen tank has been connected to pressurize the flight nitrogen tank. Part of the aluminum shell can be seen resting on a crosspiece in the tower just above the rocket.



The rocket is seen leaving the launch tower on the morning of May 14, 1950. Tracking was made difficult by the improperly functioning smoke flare which is seen here giving off only a thin trail of smoke.