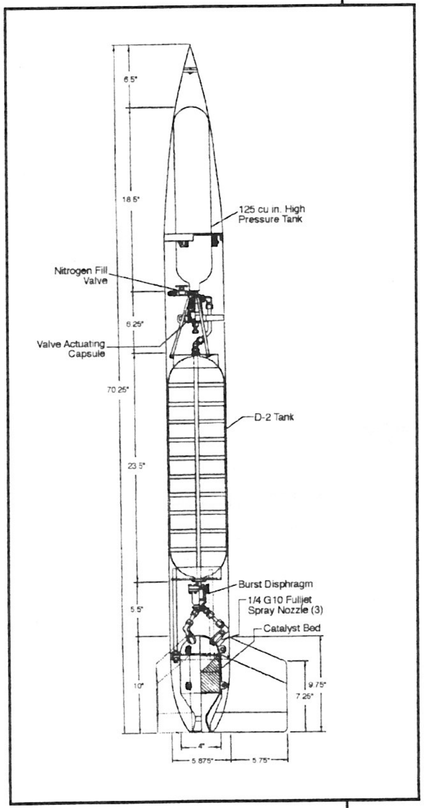
RRS News

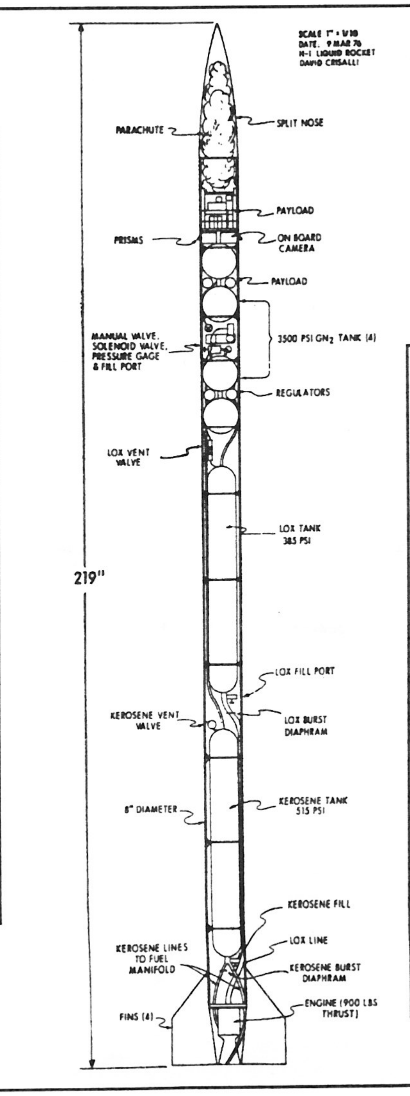
THE OFFICIAL JOURNAL OF THE REACTION RESEARCH SOCIETY, INC.

FOR THE ADVANCEMENT OF ROCKETRY AND ASTRONAUTICS Volume 54, Number 3, Sept 1997

REACTION RESEARCH SOCIETY AMATEUR LIQUID PROPELLANT ROCKET EXPERIMENTATION 1943 TO 1998

VOLUME I





Volume 1
RRS Liquid Rocket History from 1943 to 1990

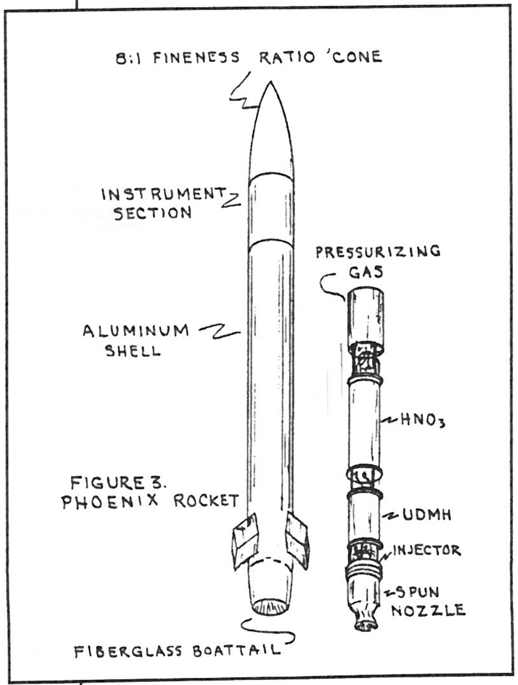


FIGURE 3. PHOENIX ROCKET

RRS News

VOLUME 54, NUMBER 3 September 1997

The Reaction Research Society is the oldest continously operating amateur rocket group in the nation. Founded in 1943 as a nonprofit civilian organization, its purpose has been to aid in the development of reaction propulsion and to promote interest and education in this science as well as its applications. The Society owns and operates the Mojave Test Area, a 40 acre site located two and a half hours north of Los Angeles. Over the years, thousands of solid, hybrid, and recently, liquid propellant rockets have been static and flight tested. Currently, there are over 250 active RRS members throughout the United States and in several foreign countries.

This newsletter is a, more-or-less, quarterly publication issued by the Society as a technical journal and is intended to be educational and to provide communication between members and other societies. It is also the historical documentation of the activities conducted by the Society, as a whole, and by its individual members. Information regarding the RRS can be obtained by writing to:

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Los Angeles, CA 90009

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Leave or hear messages)

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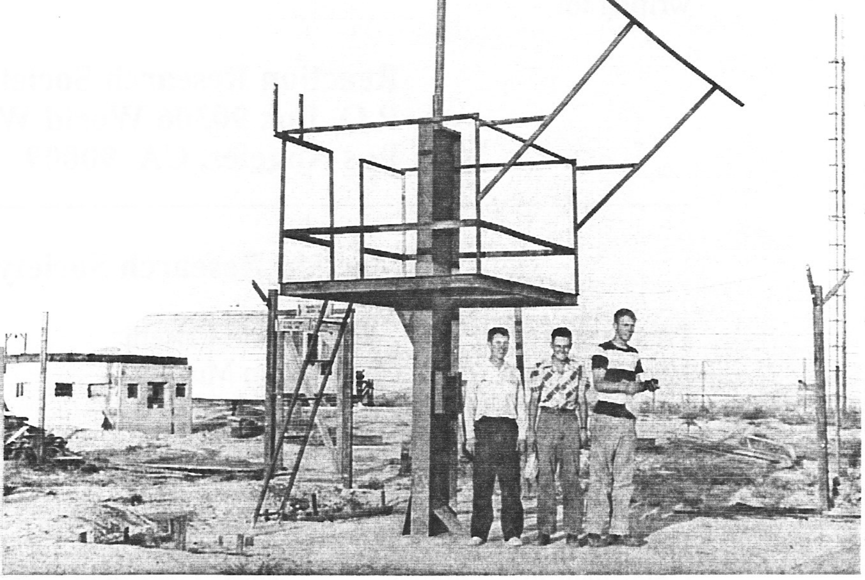
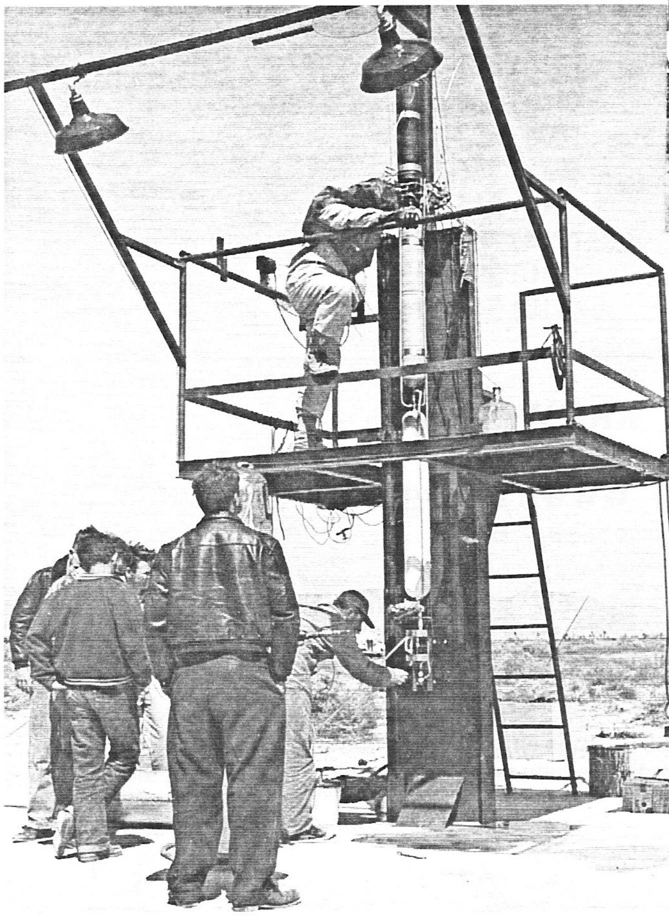




RRS Liquid Rocket Work 1953

Preparations for static testing of a red fuming nitric acid and ammonia rocket at the old MTA near Rosamond in the spring of 1953. Above, David Elliott (left), Bob DeVoe (center), and Lee Rosenthall (right) stand next to the recently completed static test stand. This same test structure was later relocated to the present MTA site.

ACKNOWLEDGEMENTS

The RRS gratefully acknowledges the contributations made in the preparation of this issue of the RRS News by the following members past and present. The list is not complete, since many of those who have worked on amateur liquid propellant projects over the years have left no record of their activities. However, it is to preserve what information we do have that these pages were collected. Their work in the field of amateur rocketry, and the assistance of many in providing orginal photographs, drawings, and advice has ensured that the magnitude of their efforts are documented for future members. The availability of this information is widely apprieciated by many interested in the field of amateur experimental rocketry.

D. Elliott
L. Rosenthal
R. DeVoe
C. Evans
E. Parker
E. Davis
B. Claybaugh
D. Girard
G. Dosa
D. Crisalli
S. Claflin
B. Wherley
M. Grant
S. Palm
B. Markle
M. Ventura
G. Garboden
T. Muller
W. Cruze
N. Anderson
D. Matthews
G. Perkins

PREFACE

In the last several years, the Reaction Research Society has enjoyed a tremendous increase in both membership and prestige. Hand in hand with this resurgence of interest in amateur rocketry, new projects have been undertaken by many members in the solid, liquid, and hybrid propulsion arenas. Because of my own involvement with liquid propulsion and because of the magnitude of the effort that has been expended over the last eight years, I thought a brief, but consolidated, history of liquid rocket work accomplished by members of the RRS would be of some general interest to the membership. I also feel that it is important to document work conducted by the Society members in a more formal fashion than has been done to date. I have been one of the worst offenders in this regard over the years. Therefore, in penance for my previous transgressions, I have written the text of this chronology and have browbeaten fellow members into contributing additional information, figures, and photographs contained in this issue.

The history of liquid propellant work conducted by RRS members over the years will be covered in three issues of the RRS News. Some of the information has been published previously, but is included here for the sake of presenting the complete story. I would like to offer my appreciation and thanks to those who have helped in this effort. To those of you seeing this information for the first time, I hope it is of interest and an inspiration. The projects summarized here stand as a bright examples of inventiveness, dedication, self education, and determination.

David Crisalli

September 1997

Reaction Research Society Liquid Rocket Propulsion
Past and Present

by David E. Crisalli

As the sun rose that morning, the desert was magnificent and the temperature almost reasonable. But by 9:00 AM, it was hot....unbelievably hot. The few brave souls crazy enough to be out moving around in the blinding sun scurry quickly from shadow to shadow with wet towels tied over their heads. The heavy tool belts and odd looking equipment they carry slow them down. They don't speak directly to one another, but whisper into the microphones of radio headsets. Several of them gather in a small reenforced concrete building with very small windows and a heavy timber roof. Wires and cables run everywhere. Not fifteen yards in front of this structure is a wierd, surrealistic, steel monolith rising almost 20 feet into the air. It appears to be built of pipe, structural steel, electrical conduit, fire extinguishers, metal boxes, hoses, wire, and wood. Rube Goldberg would have been pleased. A thin trail of pure white vapor has been pouring from one of the pipes high up on the structure and evaporates completely into the hot breeze. Gradually, everyone in view disappears under or into some kind of cover. Some enter the small block building. Many more line up over a hundred yards away in a long trench lined with rail road ties and covered with telephone poles. The vapor from the pipe abruptly stops. Everything is quiet except for the drone of a small, gasoline powered generator....and then....the wail of a siren and a voice on the P.A. system demanding everyone take cover. The voice begins to count backwards....

Five..., four..., three..., two..., one..., IGNITION! The morning quiet of an isolated site in the California Mojave desert is split by the rumble of a home built liquid propellant rocket engine roaring to life. A blinding white flame steadies itself at the nozzle exit as the engine struggles against the thrust measuring equipment with its full 1000 pounds of force. Everyone in the blockhouse intently peers through the bullet proof glass windows watching the engine run only fifty feet away. After what seems to be an incredibly long 55 seconds, the propellant tanks are empty, and the engine shuts down. The roar dies away and the quiet returns punctuated only by the continuous puttering of the electric generator and the cheers of a few hardy rocket builders.

This was the scene on the morning of 30 June 1990, when several Reaction Research Society members and interested observers gathered in the sweltering 117 degree heat of the Mojave to test fire three amateur built liquid rocket propulsion systems. This event, unusual in itself, also marked the pronounced resurgence of interest in amateur liquid propulsion within the Reaction Research Society.

The Early Years

The field of amateur experimental propulsion and the Reaction Research Society have been synonymous since the Society's founding over fifty four years ago in 1943. Organized at a time when amateur rocketry was almost the forefront of propulsion development in the United States, the Society's members engaged mostly in solid propellant work. In the late 1940's and early 50's several members of the RRS actively pursued projects involving liquid propellants. These ranged from the award winning hydrogen peroxide monopropellant rocket built by Lee Rosenthal and David Elliott (see RRS News Volume 51 Number 4) to hybrids to bipropellants.

All through the late 1940's and early 1950's, Reaction Research Society members were involved with a number of liquid rocket experiments. (Several photographs of this early work are shown in Appendix 1 at the back of this issue.) In addition to the hydrogen peroxide monopropellant flight vehicle shown at the beginning of Appendix 1, Elliott and Rosenthal also built and tested a 3,000 pound thrust hydrogen peroxide monopropellant booster and a red fuming nitric acid and ammonia bipropellant rocket. These vehicles were designed to be mated and flown in a two stage configuration. The booster was cleverly designed with three tanks around a central pressure bottle so that the booster would fit into the 30 foot tower built for the H2O2 monopropellant rocket. The three rails of the tower fit between the booster tanks and ran along the pressure bottle and booster engine which matched the upper stage diameter. This eliminated the tedious task of designing and building another launch tower. Although the entire vehicle was never flown, both stages were built and static tested.

These two prolific experimenters also undertook some projects that were very unusual. One exotic propellant combination they static tested used water as the oxidizer and a liquid metal fuel. The fuel was a eutectic alloy of potassium and sodium which was liquid at room temperature!

Early RRS members John Converse and Ernest Davis also built propulsion systems using liquid oxygen and alcohol or liquid oxygen and acetone as propellants. Ernest Davis had started redistilling and selling used acetone while he was still in high school to make a little extra money. He eventually started a company and recycled solvents for a living for many years. But while he was involved with the RRS, Ernie used acetone as the fuel of choice for his liquid rocket experiments. The choice made good sense, since he had barrels of the stuff all over the place.

Another long time member, Ed Parker, who I knew and worked with in the 1960's, shows up in almost all of these early photographs of RRS liquid rocket activity. He was always ready to lend an experienced hand to anyone who needed it. Unfortunately, very little documentation has survived detailing most of these early efforts, so we do not know as much as we would like about the activities of RRS members in the 1940's and 50's. We have some photographs, but few details of the projects and almost no drawings or technical information. We do know, however, that many other members were involved in such work and many other propellant combinations, such as red fuming nitric acid and wood hybrid engines, were static and flight tested.

The Next Decades

By the mid 50's, the first batch of liquid rocket enthusiasts were off making a living and the efforts of the RRS had been shifted mainly to the educational benefits of amateur rocketry. Solid propellants were used almost exclusively for the next many years. As an RRS member myself from 1967 to 1972, I had the opportunity to build and launch over 25 solid propellant rockets ranging from very small to over 18 feet tall and producing up to 8,000 pounds of thrust. Nonetheless, liquid propulsion was still often discussed and still held a great deal of interest for me and for many others.

In November of 1967, I attended an RRS meeting at the Society's club house in Gardena, California. At that meeting, the 16mm film of the Rosenthal and Elliott hydrogen peroxide rocket project was shown and I saw it for the first time. I was so impressed with what I saw that I could hardly contain myself. George Dosa saw my enthusiasm and asked if I would like to see an amateur liquid rocket up close. George, a long time RRS member and the first state licensed amateur rocket pyrotechnic operator in California, and another member, Don Girard, were building a magnificent bipropellant vehicle. We walked out of the club house and across a paved area to a small storage building. It was late at night, so when we walked through the door I stood in complete darkness while George made his way toward a light switch. When the light finally came on, it was a very low wattage single bulb hanging on the end of a wire attached to the ceiling. Below the light, lying in a long cradle, was a half finished liquid rocket, the XLR-1000, designed to produce 1000 pounds of thrust for 20 seconds burning 90% hydrogen peroxide and methyl alcohol. Beautifully made sheet metal bulkheads formed the structure of the rocket and supported long, gleaming, stainless steel tanks. The design was unusual in that the fuselage was octogonal along most of its length and transitioned to round on both ends. The corners of the octogonal body made perfect passage ways for interior plumbing and, through the magic of George's craftsmanship, contoured smoothly into round fibreglass boat tail and nose sections. It was a sight to behold and it fired my imagination even more strongly than the film. Over the next few years, I would ask George about it often, and visit the shop whenever I could.

During the same period, an RRS team project, called "Phoenix", was also underway. Its purpose was to develop a small, reusable nitric acid and aniline rocket for amateur experimentation. Just as had been done with the standard zinc / sulfur RRS "Beta" design, the intent was to produce a design simple and inexpensive enough to be built by interested members at large. While ultimately neither the XLR-1000 nor the Phoenix vehicles were completed for various reasons, they were examples of the continuing interest in amateur liquid propulsion and they served as an inspiration to many in the Society. Additional information about these two projects is included in Appendix 2.

In the late 1960's, and inspired by "Project Phoenix" and the XLR-1000, I had begun the design of a large liquid rocket burning liquid oxygen and kerosene. Slowly, over two or three years, the tanks, structure, and some of the engine parts took shape. However, life has a way of moving on and, in 1972, I left many things behind, including the RRS and the liquid rocket, and joined the U.S. Navy. But three years later in 1975, while I was still a Midshipman at the United States Naval Academy, an opportunity presented itself and I began to work again on the liquid rocket project that had remained dormant for three years. Large quantities of old rocket parts were recovered from storage and shipped back to Anapolis, Maryland. Over the course of one academic year, the engine was completed, a static test stand built, the engine was successfully tested, a flight vehicle was built, and the rocket was launched from the White Sands Missile Range in May of 1976. The project is summarized in Appendix 3.

Throughout the late 1970's and 1980's, there was no documented activity by Society members in the area of liquid rocketry. Although solid propulsion work continued at a low level, the RRS itself had dwindled to less than 20 members and rocket firings became very rare events. On several occassions, the Reaction Research Society came very close to extinction.

The Recent Past

In 1988, I had been working professionally as a "rocket scientist" for the Rocketdyne Division of, what was then, Rockwell International for seven years. From time to time the subject of amateur rocketry would come up in the course of my conversations with some of the younger engineers who were comming to work at Rocketdyne. Our interest level gradually picked up to the point where we began to build some simple amateur rocket hardware. As we started to get more involved, we realized that we would need a place to test the larger projects we were all contemplating. Just for fun, I thought I would try to find out if the RRS was still in existence and if they still maintained the Mojave Test Area. In late 1988, I re-discovered the RRS and joined up again. At the same time, three of my friends and co-workers from Rocketdyne signed up as well.

In 1989 four new RRS members, Mark Grant, Scott Claflin, Brian Wherley, and myself began modestly by building a small gaseous oxygen and Plexiglass hybrid static test motor. This engine was excellent for demonstration firings because the combustion chamber and fuel grain are one and the same. Therefore the combustion process could be observed directly through the clear walls of the chamber. A detailed article about this motor appeared in RRS News Volume 52 Number 1. We built the unit in a little more than two evenings and used it to demonstrate rocket combustion to family and friends and even ran it at a Christmas party. (Rocket engineers appear to be easily amused at Christmas parties). It was so successful and generated so much enthusiasm that it was not long before bigger and more complicated projects were in work.

It is worthy of note that these projects were undertaken primarily as a means of learning a great deal of practical engineering in an exciting and dramatic way. The field of rocketry is ideally suited to this goal because it alone encompasses so many other disciplines. These include electronics, metallurgy, aeronautical engineering, civil engineering, mechanical engineering, manufacturing engineering, aerodynamics, chemistry, computer modeling, photography, and a host of other areas. In addition, since these projects are funded out of pocket, a major challenge has been to build all of the required hardware out of commercially available materials and as inexpensively as possible. As an example, propellant tanks were been built out of stainless steel fire extinguishers purchased at a local scrap yard for $3.50 each. The first static test stand we assembled, capable of handling engines up to 3,000 pounds of thrust, was built from used industrial shelving again purchased from a scrap yard for about $120.

I had been building rockets of various sorts for many years and had also built the large liquid propellant rocket mentioned earlier. As a consequence of doing this project (and because of my natural proclivity to be a pack rat), I had collected a fair amount of material, hardware, test equipment, and other spare parts that would now come in handy as we began our new efforts. While the four of us decided to pursue independent projects, we would work jointly to build up the required static test facilities needed to prove out our respective propulsion systems. By late 1989 several liquid rocket projects were taking shape. These and others will be documented in Volume II of this report.

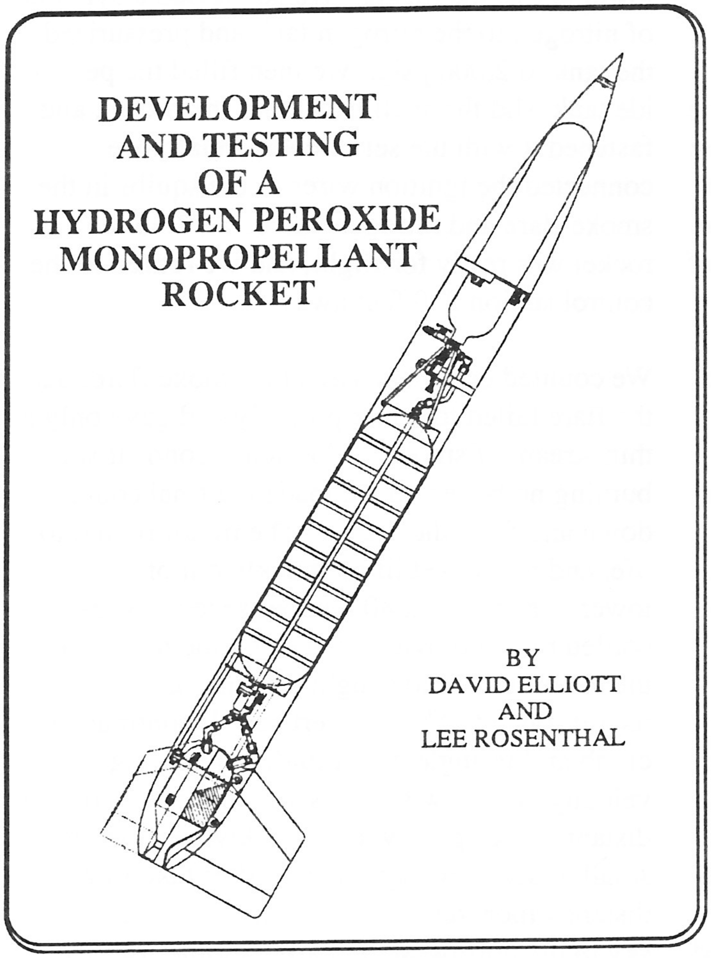
Appendix 1

Early Reaction Research Society
Liquid Rocket Activity

(1947 to 1953)

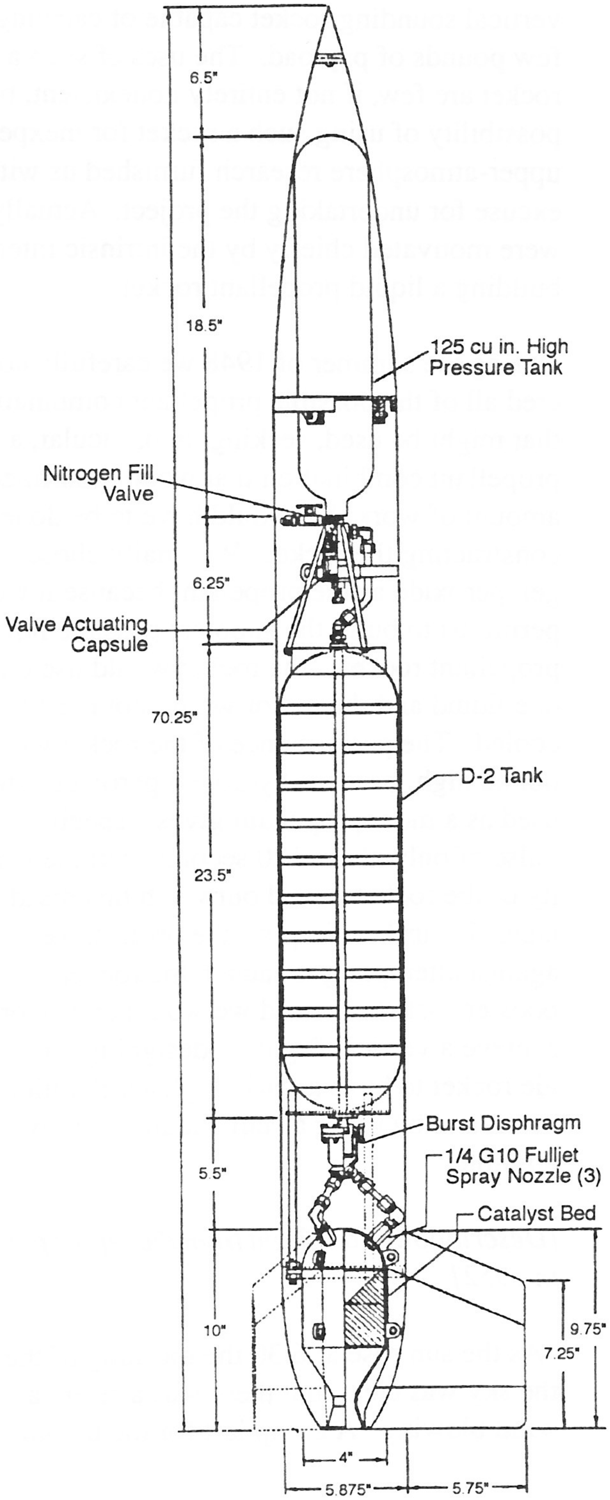
Robert DeVoe
David Elliott
Lee Rosenthal
Edward Parker
Carroll Evans
Dick Schenz
Ernest Davis
John Converse
Glen Maxon

[Excerpt from original report]



DEVELOPMENT
AND TESTING
OF A
HYDROGEN PEROXIDE
MONOPROPELLANT
ROCKET

BY
DAVID ELLIOTT
AND
LEE ROSENTHAL



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."

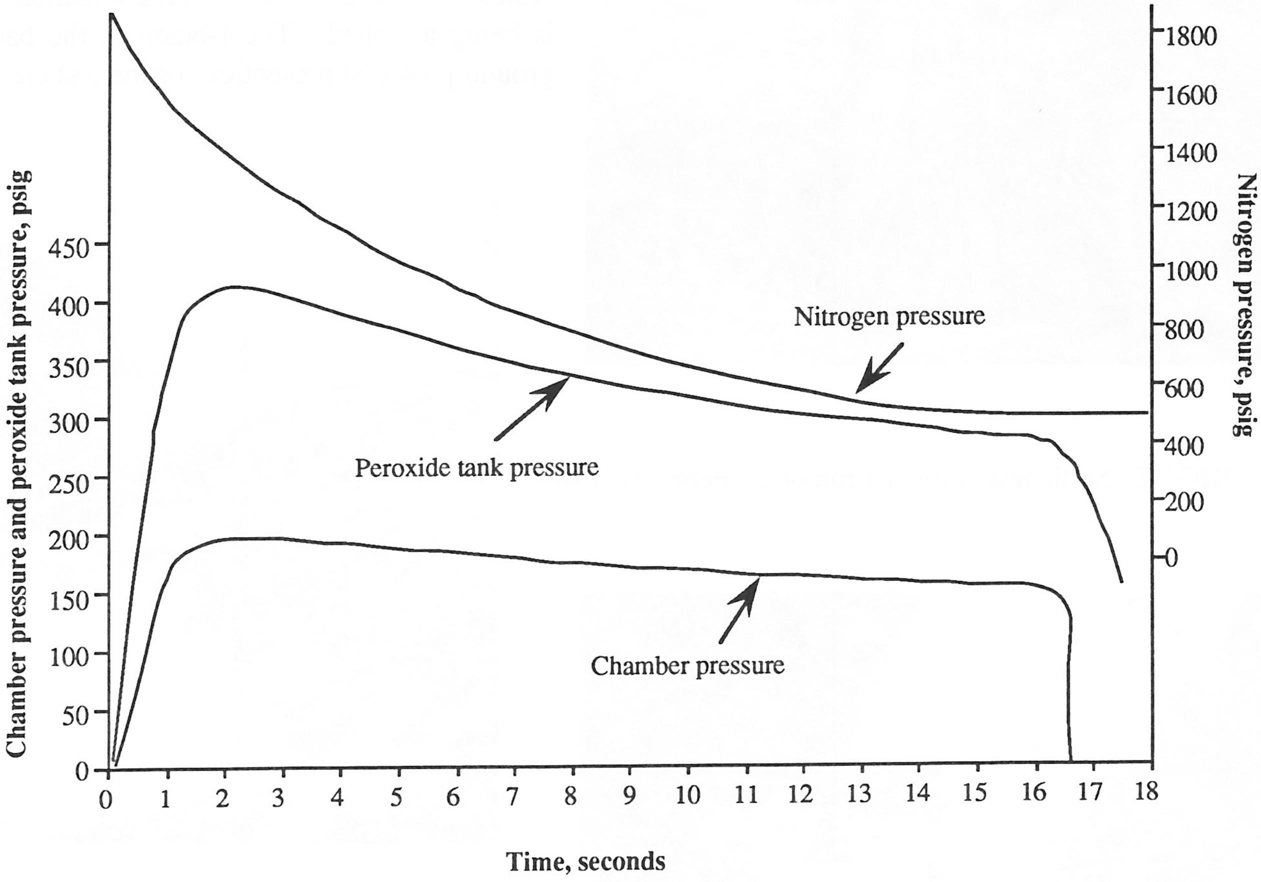
[Description of the flight from the report published in 1952]

"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 2,000 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 countdown 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 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 trail appeared, streaking across the sky to the northwest, and after another twenty seconds this also became too faint to see.

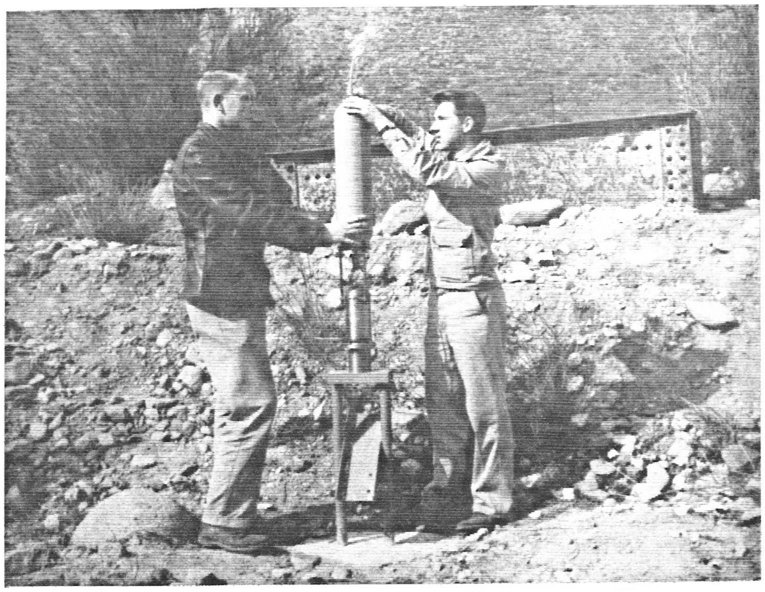
At the tracking station, the phototheodolite operator saw the rocket leave the tower, but because the smoke flare was not working properly, he was not able to follow it. Two exposures were made with the Speed Graphic at the time of burnout, but the rocket was then to the left of the camera's field of 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."

STATIC TEST DATA
Test Run #7, April 14, 1949



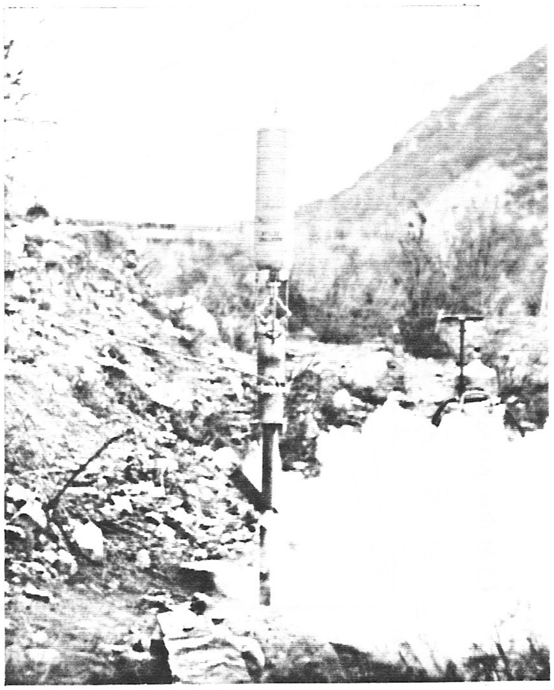
Early Reaction Research Society Liquid Propellant Work

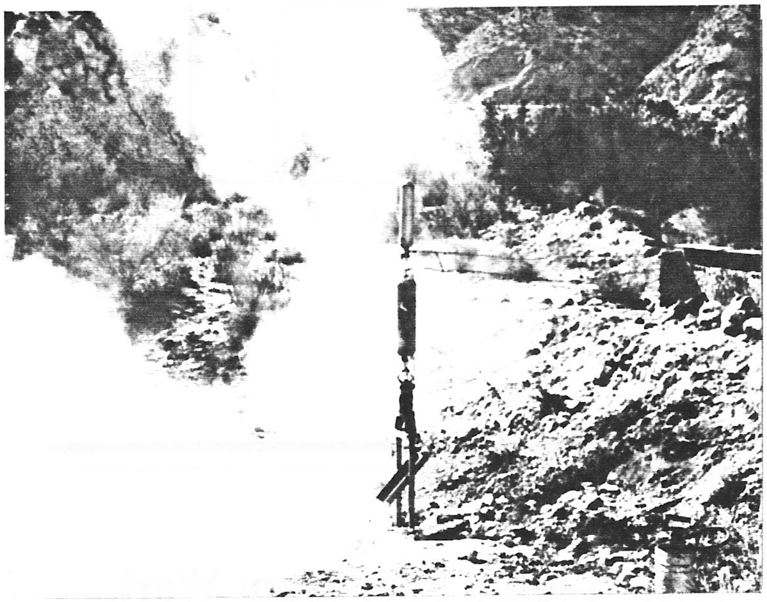
Many of the photographs included on the following pages were taken by Caroll L. Evans, Jr. and Robert J. DeVoe. Mr. DeVoe graciously provided access to his collection of early photos to allow those in this report to be reproduced. Both these early RRS members were involved with the hydrogen peroxide rocket as well as other early RRS projects.



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

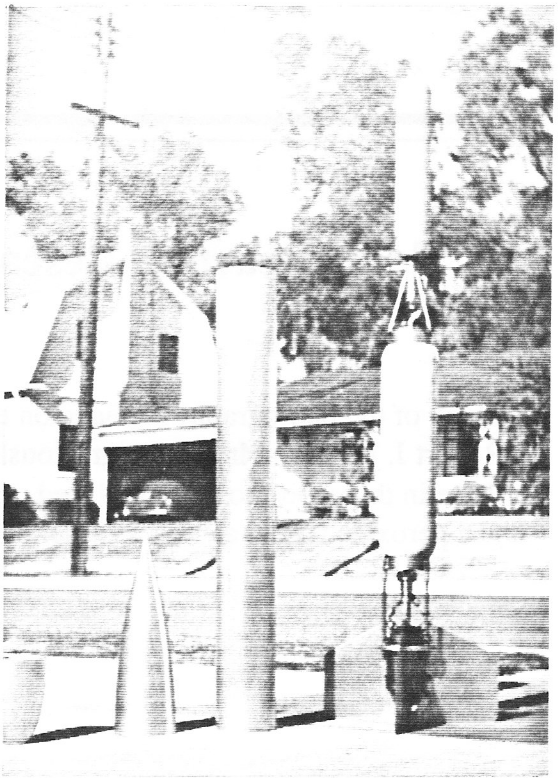
RIGHT - Static test number 1 run on 26 February, 1949.

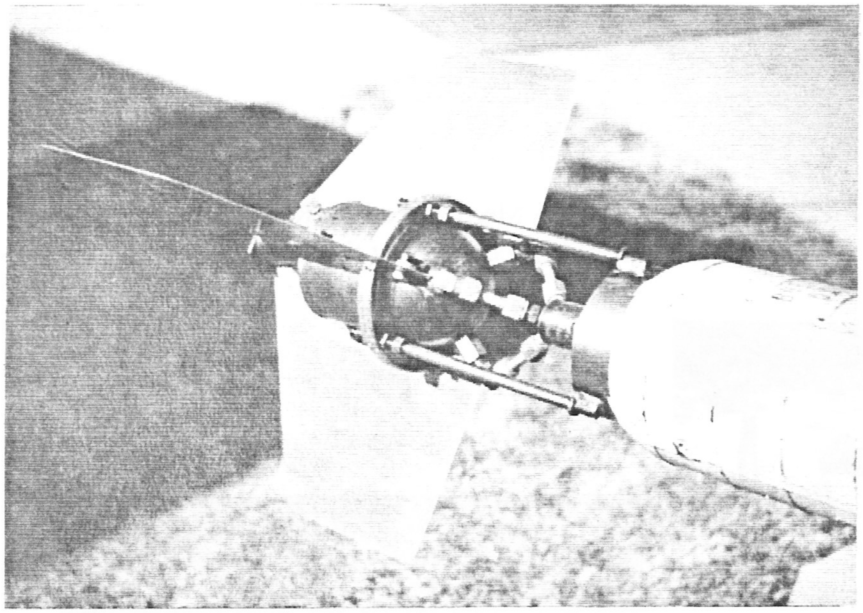




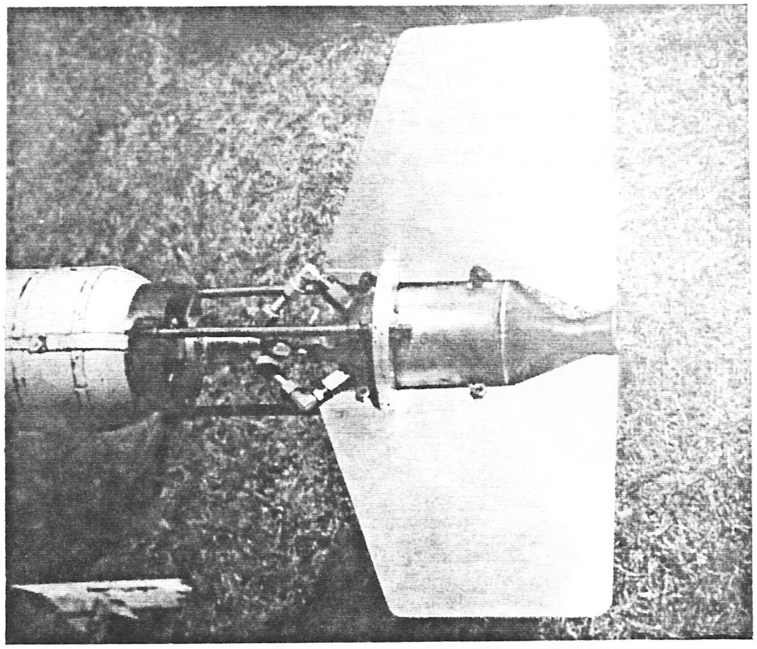
ABOVE - Static test number 6 run on 27 March, 1949. This test includes the flight pressure bottle and valve assembly.

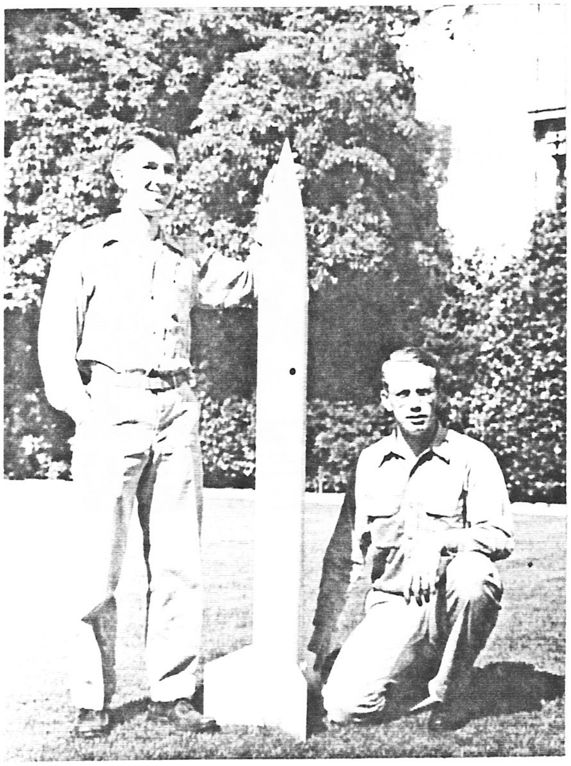
RIGHT - All major components and subassemblies of the hydrogen peroxide monopropellant rocket.





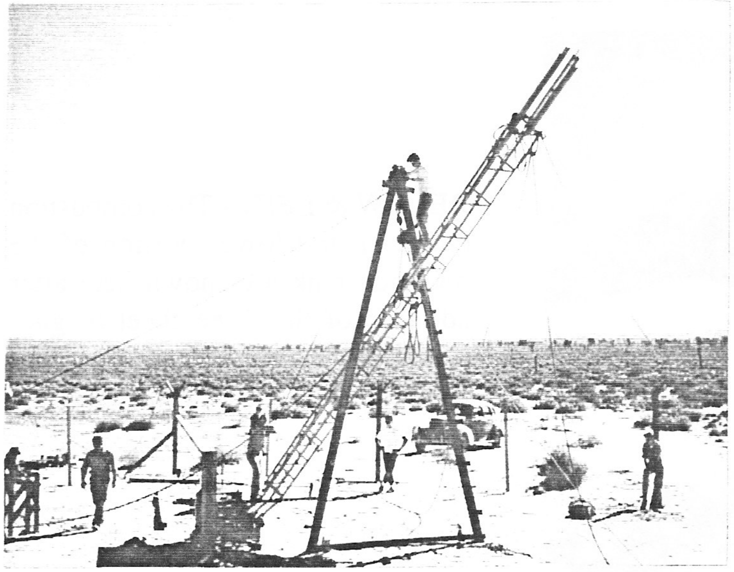
BELOW & LEFT - The combustion chamber and lower portion of the peroxide tank are shown here after addition of the three sheet magnesium fins. The burst diaphragm valve can be seen just below the tank.





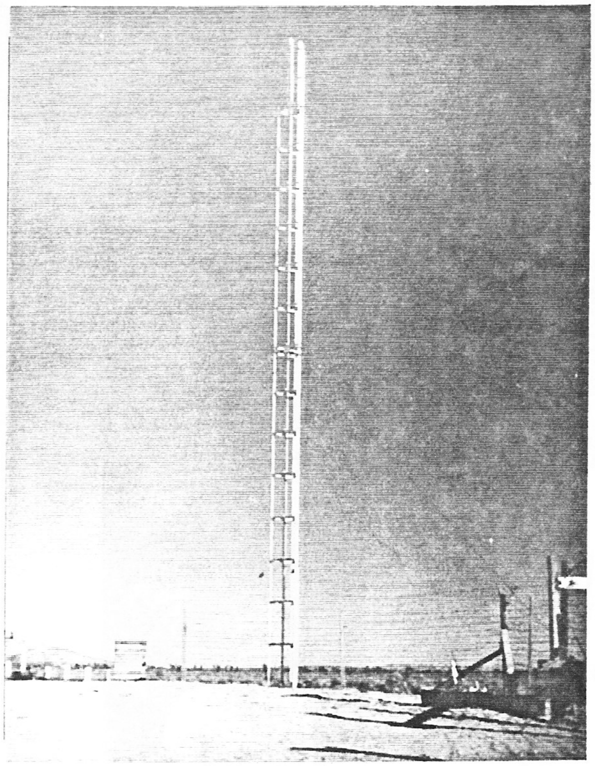
ABOVE - David Elliott (left) and Lee Rosenthal, designers and builders of the hydrogen peroxide-solid catalyst rocket, pose beside their completed product.

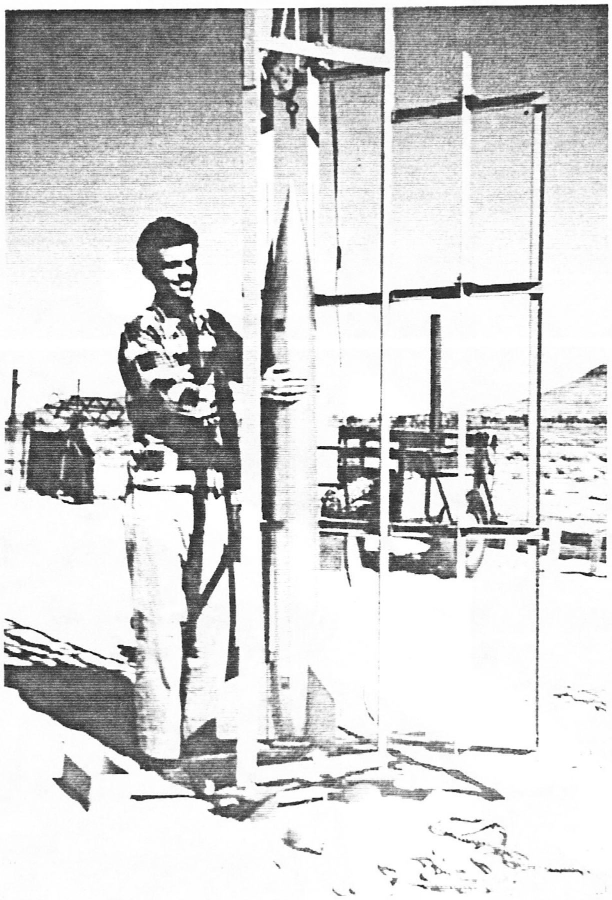
RIGHT - Lee Rosenthal poses with the rocket.



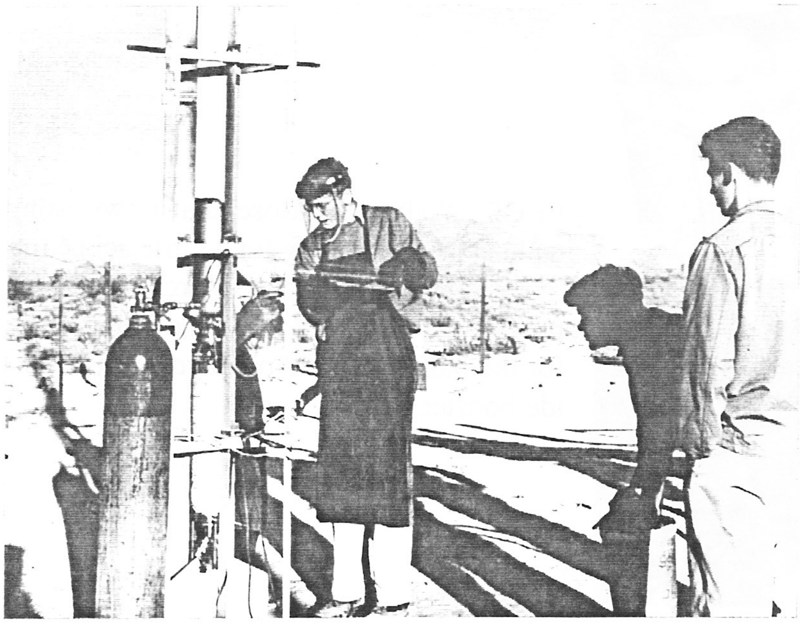
LEFT - Members of the RRS erect the 40 foot launch tower at the test site.

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

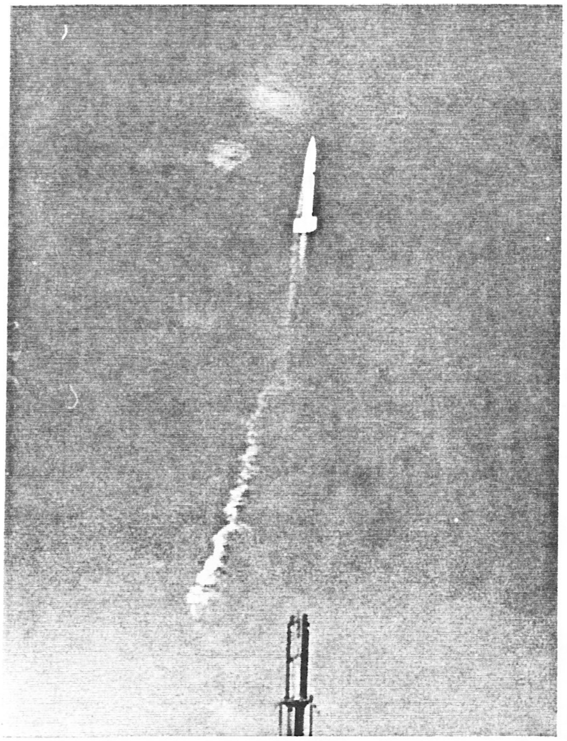


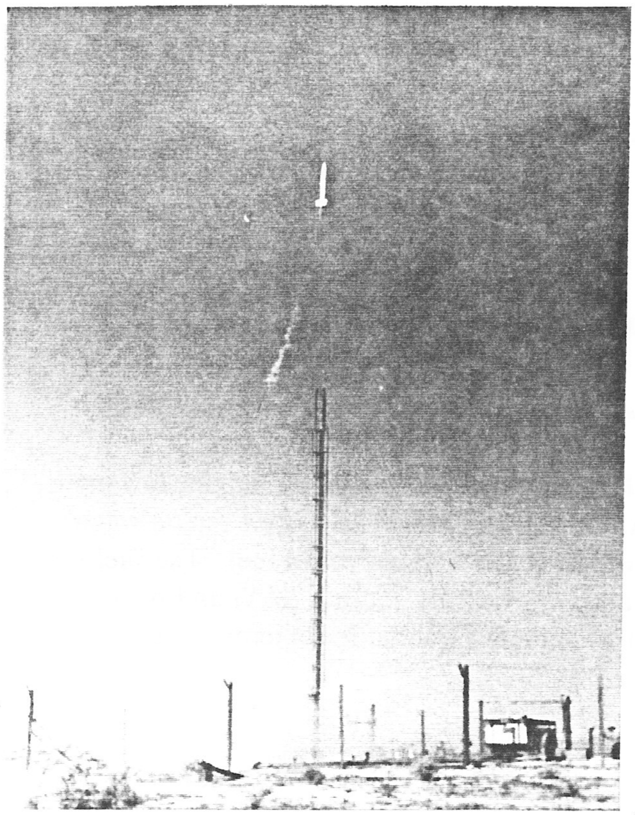


LEFT - Glen Maxon conducting a fit check of the rocket in the launch tower during final rail adjustments.

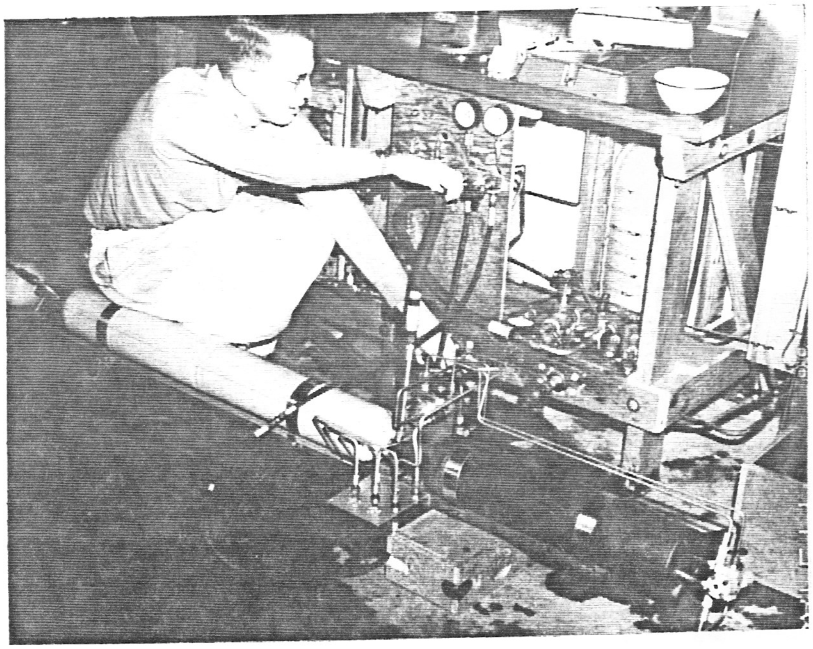


ABOVE - Lee Rosenthal adds 90% hydrogen peroxide to the fuel tank of the rocket just prior to flight. The auxiliary nitrogen tank has been connected to pressurize the flight nitrogen tank. Part of the aluminum shell can be seen resting on a crosspiece in the tower just above the rocket.



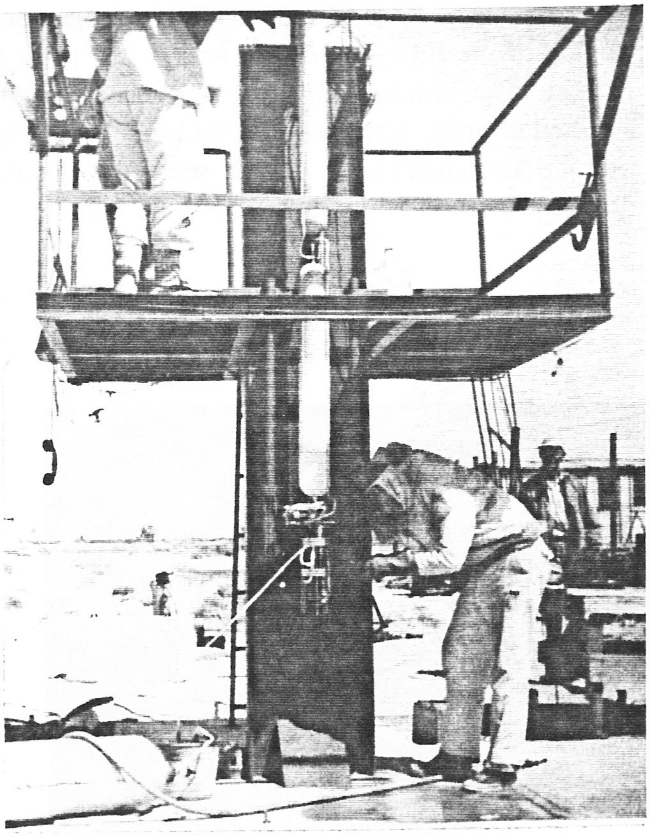


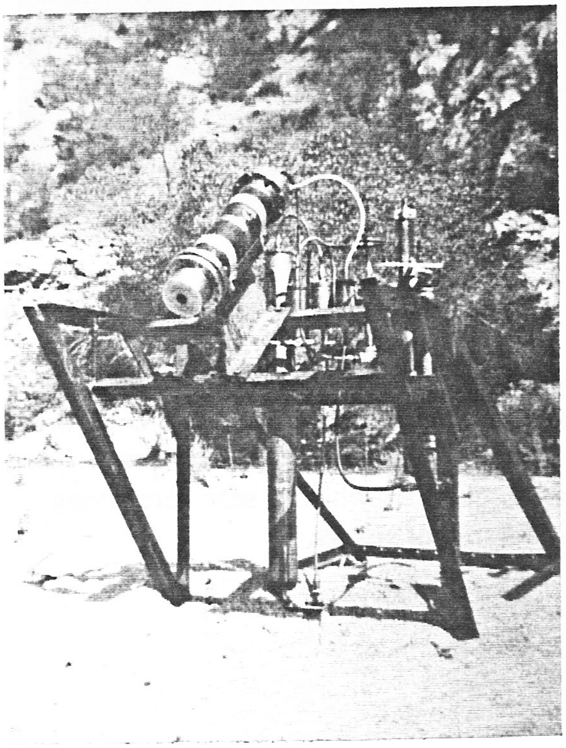
ABOVE & LEFT - The rocket is seen leaving the launch tower on the morning of May 14, 1950. Tracking was made difficult by the improperly functioning smoke flare which is seen here giving off only a thin trail of smoke.



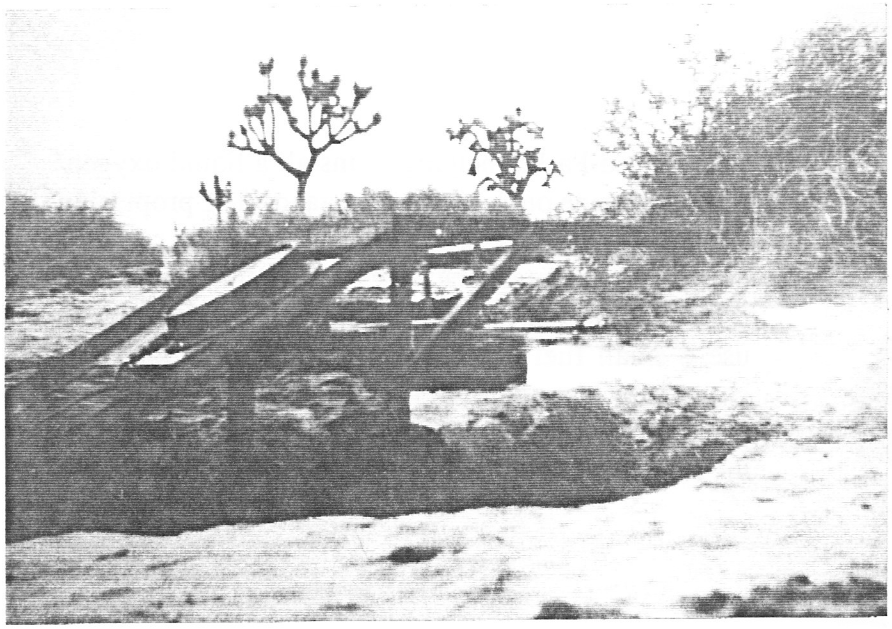
LEFT - Walter Lee Rosenthal flow testing tankage and plumbing for a nitric acid / ammonia bipropellant rocket, March 1953. This rocket was designed to be the upper stage for the 3,000 pound thrust hydrogen peroxide booster.

RIGHT - Static test preparations for the nitric acid / ammonia rocket in April, 1953 at the Mojave Test Area. Lee Rosenthal (in fume hood and suit) is loading propellant. Ed Parker watches in the background. The 16mm camera, gages, and clock (data collection) are visible in the upper left of this photo. The rocket was designed to provide 250 pounds of thrust for 80 seconds. The static test was initially successful, but the motor burned through 40 seconds after start.



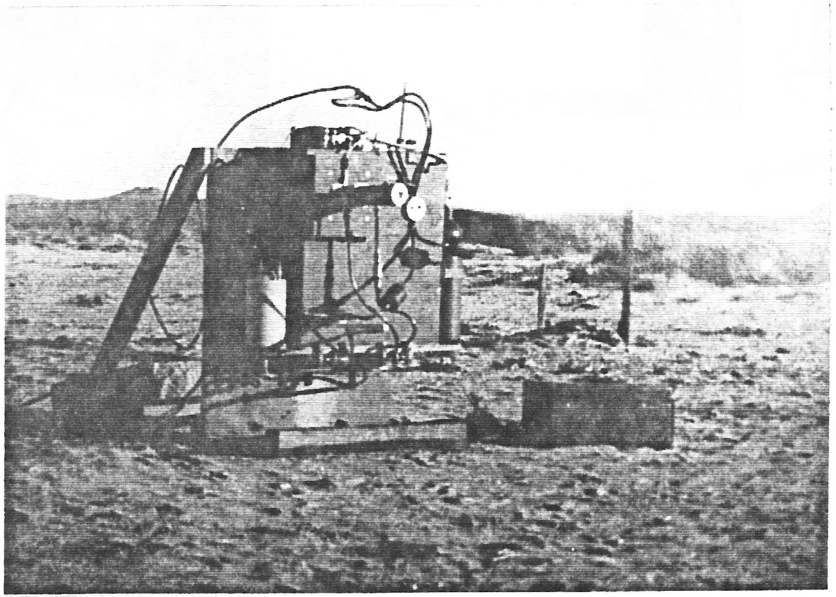


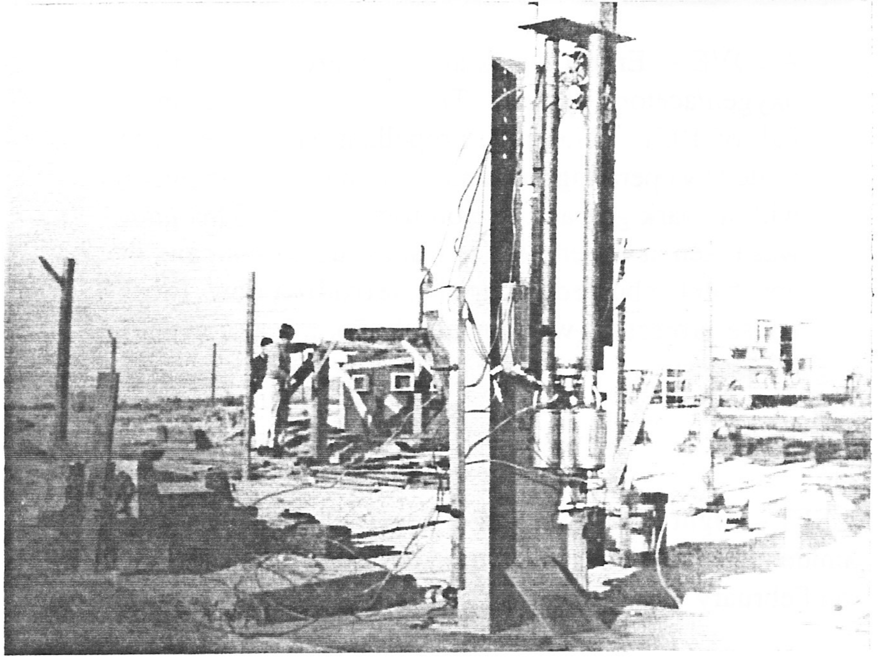
LEFT - Static test of the "NAK" engine in Saugus, CA. August 1, 1948. This engine ran on water as an oxidizer and a liquid metal fuel. The fuel was an alloy of metallic sodium (NA) and potassium (K) which was liquid at room temperature.



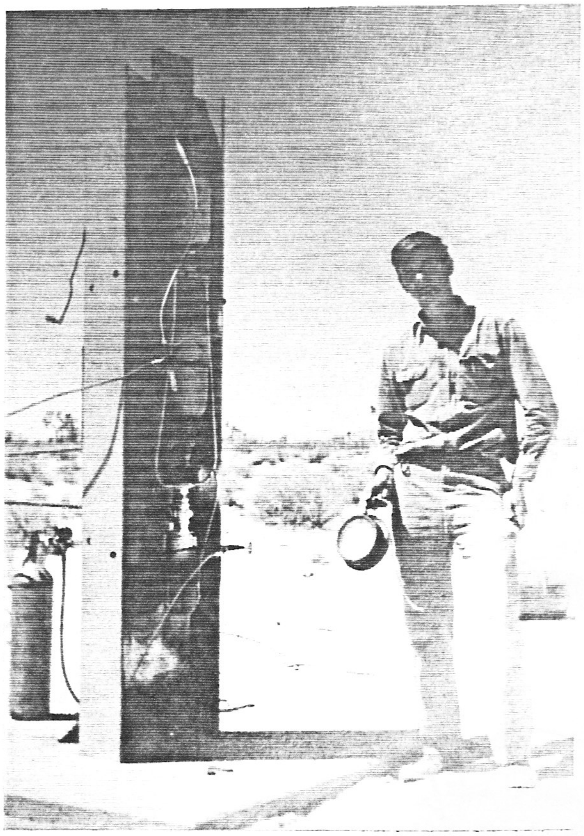
LEFT - Static test of a hybrid (liquid oxygen and wood) engine by RRS members on December 14, 1947 somewhere in the Mojave Desert.

RIGHT - Static test of a liquid oxygen/ ethyl alcohol engine built by John Converse. This test was conducted on December 9, 1951 at the Mojave Test Area.

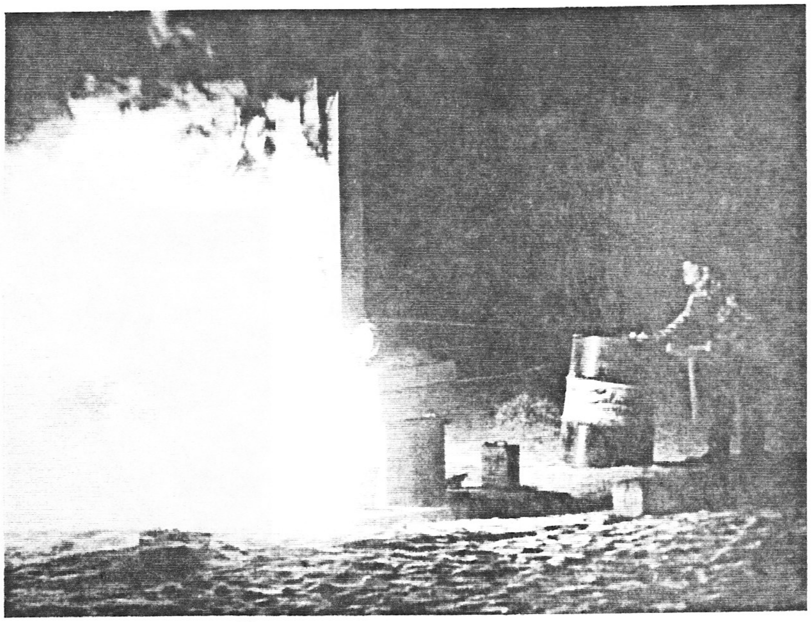




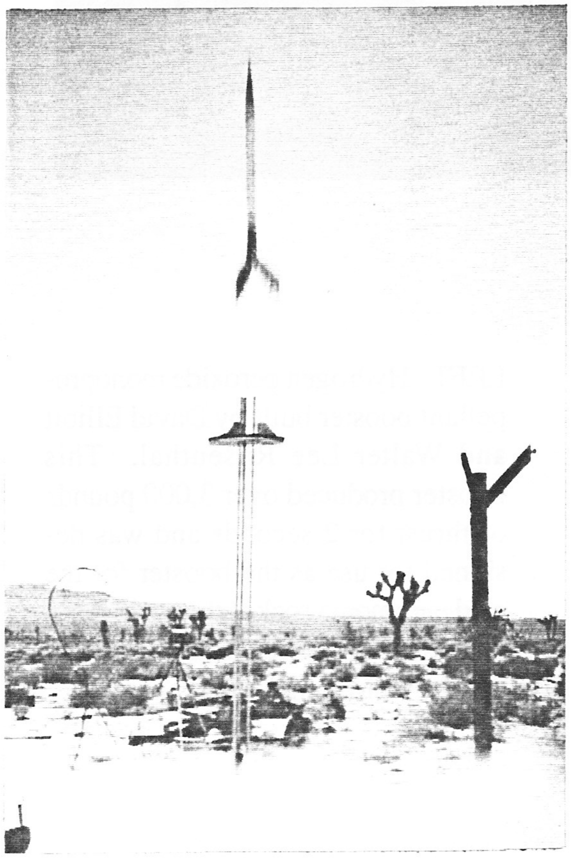
LEFT - Hydrogen peroxide monopropellant booster built by David Elliott and Walter Lee Rosenthal. This booster produced over 3,000 pounds of thrust for 2 seconds and was designed for use as the booster for the acid / ammonia rocket shown in these photos. This particular test was conducted on March 4, 1952.



LEFT - Ed Parker helping to install a liquid oxygen/ acetone engine on the MTA test stand. The propulsion system was built by Ernest Davis, in the Fall of 1951. The engine was regeneratively cooled and was designed for 200 pounds of thrust. The injector was designed to use 6 small fuel spray nozzles arranged around one larger LOX spray nozzle in the center. Pressurization of both fuel and oxidizer tanks was accomplished by the risky method of using LOX boil off.



ABOVE - Ernest Davis at the controls of his liquid oxygen/acetone system. This was a night test in the Fall of 1951. The main propellant valves were controlled by operating rods and ignition was accomplished with a spark gap and a neon transformer. This photo was taken at the end of the test as fuel ran out and the hot chamber burned through in the oxidizer flow. Blockhouse protection was apparently not a major concern for Ernest.



LEFT - Flight from the Mojave Test Area of an unidentified liquid oxygen/wood hybrid rocket on February 19, 1950.

RRS NEWS
FOR THE ADVANCEMENT OF ROCKETRY AND ASTRONAUTICS
PUBLISHED BY THE
REACTION RESEARCH SOCIETY • BOX 1101 • GLENDALE 5, CALIFORNIA

NUMBER 61
May, 1952

PROGRESS REPORT ON THE ACID-AMMONIA SOUNDING ROCKET PROJECT

Static testing of the hydrogen peroxide booster rocket has been completed. The data from the final static test—Run Number 4—are shown in the graph below in which chamber pressure, p_c, injection pressure, p_i, and nitrogen pressure, p_{N_2}, are plotted against time. The hydrogen peroxide tank pressure is slightly higher than the injection pressure and is not shown. The peak thrust for this run was 3440 lb, and the specific impulse was 110.

Design and construction is continuing on the acid-ammonia second stage. This rocket will use an acid-ammonia motor designed and built by Aerolab Development Company of Pasadena; the motor has a ceramic lined chamber, an acid cooled aluminum nozzle, and a twelve impinging pair injector. Following a series of step-by-step altitude calculations to determine the optimum thrust and size of the rocket, the following specifications were decided upon:

Thrust	160 lb	Length	12 ft
Burning time	90 sec	Diameter	5 7/8 in
Takeoff weight	130 lb	Velocity at end of boost	650 ft per sec
Propellant weight	80 lb		
Payload (telemeter) weight	10 lb	Altitude at end of boost	500 ft

Because drag is a large factor in determining the performance of a rocket this small, it is not possible to calculate the performance very accurately, but a conservative estimate would be:

Burnout velocity	3000 ft per sec
Burnout altitude	100,000 ft
Peak altitude	200,000 ft

Work done on this rocket to date has included wind tunnel stability tests, area and stress calculations for the fins, modification of the Aerolab motor to adapt it for flight, procurement of transducers for the telemeter, construction of the high pressure tank, and construction of several plumbing components.

A 1/8 scale model of the booster-sounding rocket combination was tested in the Merrill Wind Tunnel at Caltech to determine the stability of the combination during boost. It was found that the center of pressure of the combination at ten degrees angle of attack is about a foot forward of the trailing edge of the sounding rocket's fins and that the center of pressure is somewhat farther forward at zero angle of attack due to the interference of the catalyst chambers. It is concluded that the center of pressure will be sufficiently far behind the center of gravity of the combination to insure stability.

Calculation of the required fin area for the sounding rocket was made by computing the fin area necessary to place the sounding rocket center of pressure a foot behind the center of gravity at the maximum possible burnout Mach number. The resulting dimensions of the three fins are 7 in span, 16 in. root chord, 8 in. tip chord.

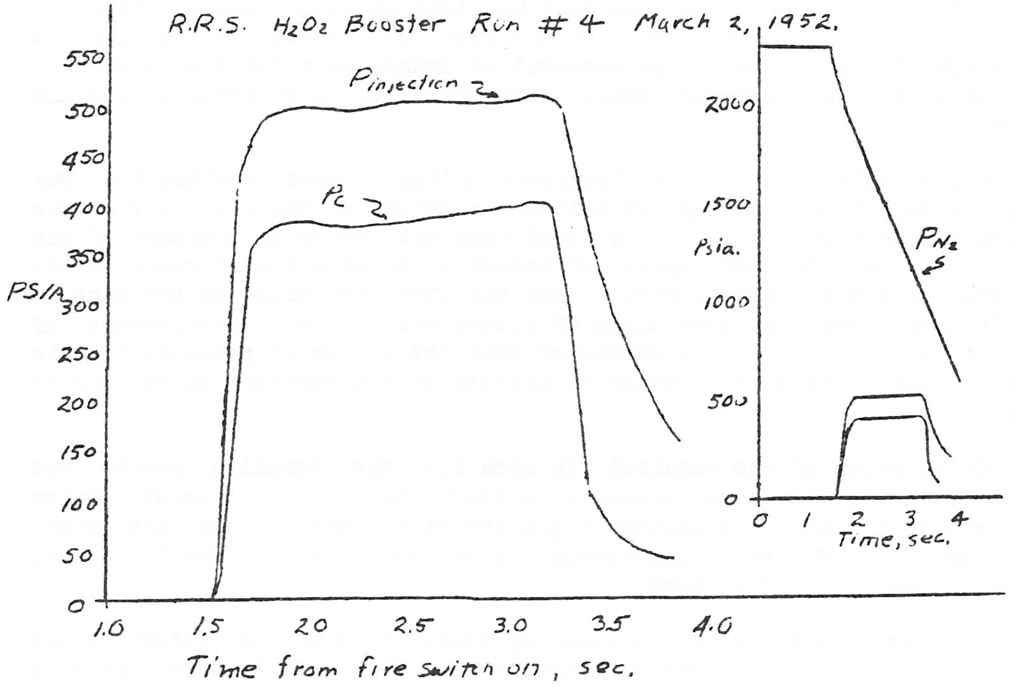
A large side force on the sounding rocket fins during flight would most likely occur at the end of boost since a large yaw is more likely to occur during boost than at any later time. The fins have therefore been designed to withstand an arbitrary 10 degrees yaw at the end of boost; in this case there would be not more than 220 pounds side force on any fin. This force can be withstood by .125 in. thick Dowmetal JS-1 sheet.

The Aerolab motor, which was built only for static testing, has been lightened by thinning the chamber walls; it now weighs 5 lb.

A 3g accelerometer and a chamber pressure transducer have been obtained for the four-channel telemeter. The accelerometer will be off scale against its stops during the 12g boost, but velocity during boost will be obtained from ground observations. The accelerometer in the rocket will permit calculation of velocity and altitude during the rest of the flight. A ½ in. diameter tube will be welded through the tankage to carry the wires from the chamber pressure pickup to the telemeter, as well as the ignition wires to the pressure regulator and the transmission line from the telemeter to the insulated fins which will be used as the antenna.

The 540 cu. in. high pressure nitrogen tank is partly constructed. The cylindrical portion has been rolled from .080 in. thick 4130 (chrome-molybdenum) sheet, and the seam has been welded and X-rayed. The forward end of the tank will be dished from .080 in. thick sheet, and the aft end which forms the top of the nitric acid tank will be dished from .150 in. thick 347 stainless steel sheet. The tank will be heat treated to 140,000 psi yield strength in the 4130, which corresponds to 3500 psi pressure in the tank. The tank will be hydro-tested to 3000 psi, and it will be used at 2500 psi in the rocket.

The nitrogen pressure regulator and the ammonia burst diaphragm have been completed; the acid burst diaphragm, the propellant fill fittings, and the nitrogen pressurize disconnect fitting are being constructed.


R.R.S. H_2O_2 Booster Run #4 March 2, 1952.

Reaction Research Society NEWS

FOR THE ADVANCEMENT OF ROCKETRY AND ASTRONAUTICS

Published by the Executive Council of the
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June, 1953
Number 71

STATIC ACID-AMMONIA ROCKET TESTING, APRIL 5, 1953

On April 5, 1953, at the Mojave Test Area, the Reaction Research Society held the first static testing of the acid-ammonia rocket that is to be used for the second stage of a two-stage high altitude research missile.

The booster which is fueled with 90% hydrogen peroxide was static tested for the fourth time on March 2, 1952, and reported in RRS NEWS #61. The booster gave a 3440 pound thrust for 1.5 seconds on both Runs #3 and #4.

The fuel of the second stage is liquid ammonia (NH_3) which is oxidized by red fuming nitric acid (HNO_3) with 20% excess nitrogen dioxide (NO_2). The motor has a regenerative acid-cooled nozzle and a zirconium dioxide lined chamber. The injector is a 12-pair impinging jet design. Hypergolic (spontaneous ignition upon mixing) start is induced by allowing the ammonia to pass over metallic lithium just prior to entering the combustion chamber. The tanks and motor were arranged in a breadboard type hookup on a 3-inch channel. The nitrogen tank, pressure regulator and motor were the only parts that will be used on the flight rocket. The propellant tanks were new 1000 cubic inch low pressure oxygen tanks. Also incorporated in the installation were two propellant control valves—one in the propellant lines between the tanks and the motor, and the other to vent the propellant tanks on shutdown—to be used for emergency shutdown.

A burst diaphragm start was used. The burst diaphragms were just upstream of the injector. The run was initiated by ignition of the powder capsule which holds the pressure regulator shut. As soon as the powder capsule was burnt the nitrogen was released, forcing the propellants through the burst diaphragm and into the motor.

The setting up of the rocket and related apparatus took from 1:00 p.m. April 4 until 4:45 a.m. April 5. Work was resumed after a few hours, and loading of propellants was completed at 11:00 a.m. The order of loading was: acid first, ammonia second, nitrogen last. The actual loading time of the acid was 8 minutes and the ammonia loading took 30 minutes.

The long loading period of the NH_3 is necessary because it is first passed through a 12-foot coil immersed in an acetone-dry ice mixture. This cooling lowers the equilibrium temperature so that the NH_3 does not boil away too rapidly and the density of the NH_3 can be determined from the pressure (atmospheric). This density was used in the design of the injector orifices. It is not necessary to do this for the acid since its density does not change appreciably with temperature changes. The starting pressure in the nitrogen tank was 2300 psi.

Data was measured by Bourdon Tube gauges. The data was recorded by a 16mm gun camera photographing the gauges and a stop watch which supplied the time base. The gauges were connected to the ammonia tank, nitric acid tank, nitrogen tank, and motor. A sound recording of the testing which was narrated by Neville Williams was made on a tape recorder.

The rocket was started from a ten-second countdown. Combustion was initiated in less than one second after the fire switch was thrown. Loud, even combustion continued until 48 seconds from fire switch on. At this time a large amount of acid fumes appeared in the formerly clear exhaust. Five seconds later the rocket was stopped by use of the emergency shutdown valves.

Upon examination the nozzle was found to be collapsed inward and burnt through in the exit section. This probably occurred due to insufficient velocity of the acid through the cooling passage, resulting in less heat transfer. The nozzle had eroded due to residual acid from previous runs and was rewelded several times before passing a leak test. This rework resulted in an oversize cooling passage which reduced the velocity and thus the heat transfer.

The combustion chamber pressure during the run held constant at 250 psia, giving a thrust of 180 pounds, while both propellant tank pressures were constant at 390 psia. At 48 seconds a sharp rise in chamber pressure to 300 psia occurred, due to the restriction of the nozzle throat. Upon examination of the injector after the run one pair of injectors was found to be clogged and was probably responsible for the low chamber pressure.

Work on this project has ceased until the plans of a completely revised and simplified motor are finished. The new motor will replace the one used in the static test. It will incorporate built-in burst diaphragms and will have no propellant lines. This will be accomplished by use of concentric tanks made of aluminum tubing sealed with "O" rings. The plans for the new rocket will be presented in a future issue of RRS NEWS.

Reaction Research Society NEWS

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Published by the Executive Council of the
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Number 72

HIGH-ALTITUDE ROCKET PROGRESS

John W. Converse
Reaction Research Society

The Reaction Research Society two-stage acid-ammonia sounding rocket—the current phase of the Society's "Project Goddard," which is devoted to the development of a high-altitude research missile—is being very extensively redesigned, in order to increase planned performance and simplify construction. The changes being made may best be illustrated by summarizing the entire missile design as presently contemplated.

The propellant combination to be used in both sustaining rocket and booster will be red fuming nitric acid (with 20% nitrogen dioxide by weight) and anhydrous liquid ammonia. This combination is cheap and easy to handle, and is generally safer and more reliable in operation than other bipropellant combinations. It has a reasonably good loading density, and high performance which is insensitive to operating conditions.

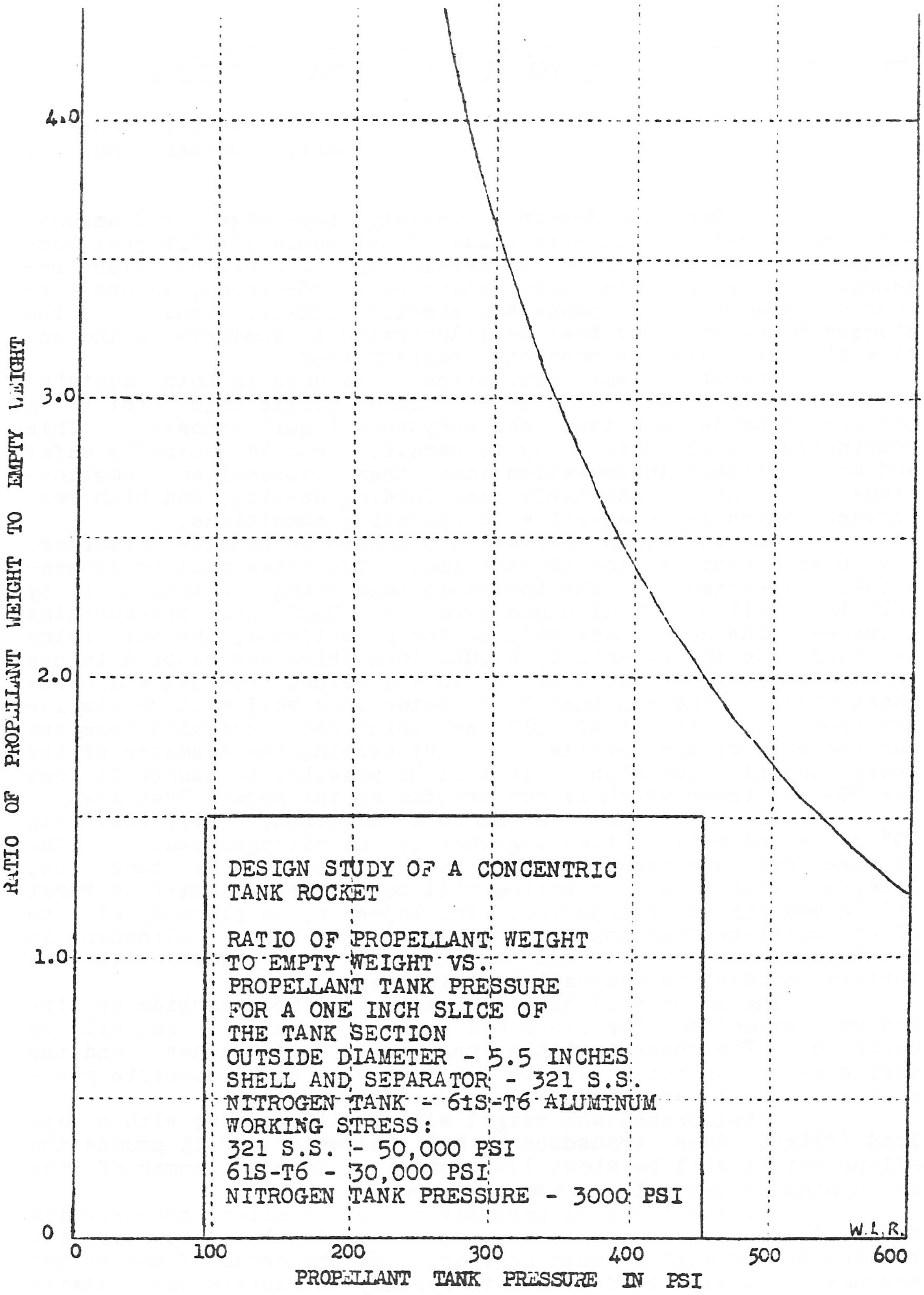
The sustaining rocket, 5.5 inches in outside diameter, will have a tank section 12 feet long. The tanks will be concentrically arranged, the innermost tank being a 2 inch I. D. by 1/10 inch wall 61S-T6 aluminum tube for 3000 psi pressurizing nitrogen. The outer tank will be for propellants, the acid being isolated from the ammonia by a .012 inch thick separator 4 inches in diameter which will be rolled and welded from 321 stainless sheet steel. The 5.5 inch O. D. outer tank wall will be similar construction, though of .017 inch thickness, and will form the surface skin of the missile. By keeping the diameter of the rocket to this dimension, it will be possible to launch it from the 40-foot tower which is now erected at the Mojave Test Area.

The tabk ends, machined of aluminum, will seal with "O"-rings and will be tied together by the nitrogen tank. The nitrogen pressure regulator will be integral with the tank top; integral with the tank bottom will be the propellant-flow burst valves and the motor injector. The injector, as planned, will be of the multi-orifice impinging stream unique type, although it may become necessary to add an Enzian-type splash plate to achieve the desired combustion efficiency.

The motor will have a ceramic (silicon carbide or zirconium dioxide) chamber liner and a ceramic nozzle, and will be uncooled. The characteristic length will be 40 inches, and the nozzle expansion ratio will be 7.0 (optimum for atmospheric pressure of 5.0 psia and chamber pressure of 225 psi).

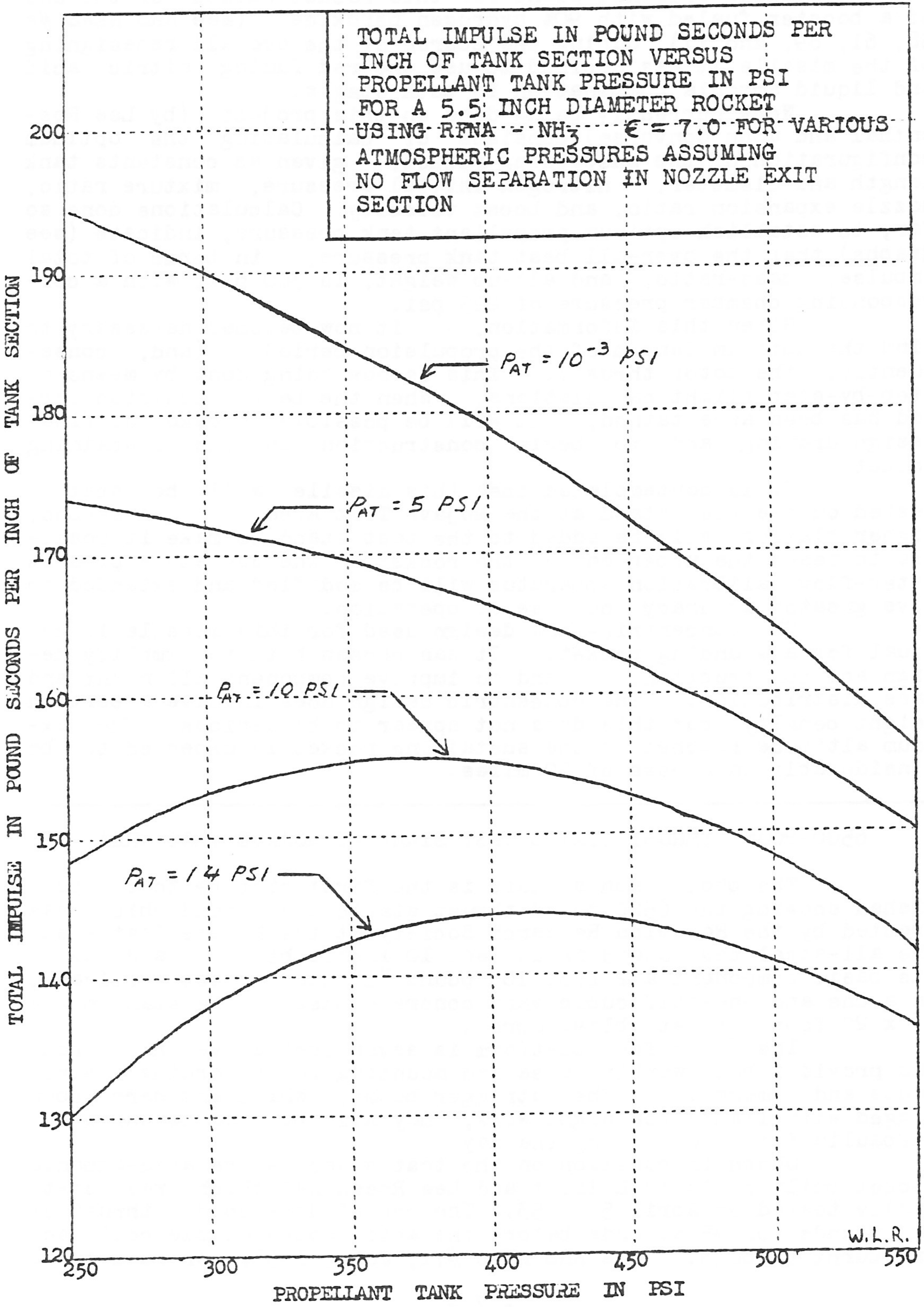
Total propellant weight will be 112 pounds; with a payload (flight data transducers and telemeter) of 15 pounds the all-up weight will be about 174 pounds. Overall length of the sustaining rocket will be about 15 pounds.

The booster will probably be of similar construction and will have approximately the same total impulse; however, its burning period will be much shorter, on the order of one or two seconds. It will be designed to rapidly accelerate the sustaining rocket to a velocity of more than 1000 ft/sec.



DESIGN STUDY OF A CONCENTRIC
TANK ROCKET

RATIO OF PROPELLANT WEIGHT
TO EMPTY WEIGHT VS.
PROPELLANT TANK PRESSURE
FOR A ONE INCH SLICE OF
THE TANK SECTION
OUTSIDE DIAMETER - 5.5 INCHES
SHELL AND SEPARATOR - 321 S.S.
NITROGEN TANK - 61S-T6 ALUMINUM
WORKING STRESS:
321 S.S. - 50,000 PSI
61S-T6 - 30,000 PSI
NITROGEN TANK PRESSURE - 3000 PSI



TOTAL IMPULSE IN POUND SECONDS PER INCH OF TANK SECTION VERSUS PROPELLANT TANK PRESSURE IN PSI FOR A 5.5 INCH DIAMETER ROCKET USING RFNA - NH_3 $\epsilon = 7.0$ FOR VARIOUS ATMOSPHERIC PRESSURES ASSUMING NO FLOW SEPARATION IN NOZZLE EXIT SECTION

While original plans for this rocket called for the use of a booster fueled with 90% hydrogen peroxide (see RRS NEWS #s 58, 61, 69, and 71), during the course of the overall redesigning of the missile it was decided to use the red fuming nitric acid and liquid ammonia combination in both stages.

Work currently being done on this project (by Lee Rosenthal and John Converse) consists of calculating the optimum configuration of the sustaining rocket, given as constants tank length and diameter, nitrogen initial pressure, mixture ratio, nozzle expansion ratio, and boost velocity. Calculations done so far, to establish optimum propellant tank pressure, indicate (see graphs) that the over-all best tank pressure, in terms of total impulse, mass-ratio, and all-up weight, is 300 psi, with a corresponding chamber pressure of 225 psi.

Given this information, it now becomes necessary to find the optimum length of the propulsion period (and, consequently, the motor thrust). This is now being done by means of step-by-step flight calculations. When the best propulsion period has been ascertained, it will be possible to make the final design drawings and to begin construction on the sustaining rocket.

It is contemplated that this missile will be static-tested on the test stand at the Mojave Test Area. A second, higher platform will be added to the test stand to make it possible to reach the upper end of the rocket. The Society's present water-flow calibration apparatus will be modified and extended to give greater accuracy and ease of operation.

The concentric-tank design used for this missile is unusual for a sounding rocket. It was chosen both to simplify design and construction, and to improve component alignment and mass distribution. The concentric design does involve a certain weight penalty, but this does not appear to be serious. The maximum altitude reached by the sustaining rocket is expected to be considerably in excess of 50 miles.

6500-POUND THRUST STATIC TEST STAND AT MOJAVE TEST AREA

The photograph at left is the first picture to be published showing the 6500-pound thrust static test stand which was erected by the Reaction Research Society at the Mojave Test Area. The all-steel test stand is 16 feet 10 inches high, and has as its basic component a 2-foot 105 pound "I" beam, set vertically in a one and one-half cubic yard concrete base. The stand has a 16 x 20 foot concrete blast apron.

The 6 x 8 foot platform is seven feet above the apron, and provides both working area and mounting for recording instruments and cameras. The outrigger booms, which are here shown rigged with lights for night work, may also be used to support a tarpaulin for shade during the day.

Shown in position on the test stand is the acid-ammonia rocket built by David Elliott and Lee Rosenthal which was statically tested on April 5, 1953. The rocket developed a thrust of 180 pounds for 45 seconds before the acid-cooled nozzle collapsed and burnt through. See RRS NEWS #71, June, 1953, for full data.

RRS News

December 1960 Number 94

PROGRESS REPORT AND BRIEF HISTORY OF THE ETHYLENE OXIDE ROCKET

Approximately three years ago four members of the Reaction Research Society got together and decided to attempt the construction of a liquid propellant rocket. These members were Donald culver, Ronald Nelson, David Thalimer, and Calvin Van Wagner.

The first problem which we faced was the choice of a suitable fuel, one which was cheap, easy to handle, and would give us the performance which we desired. Not knowing exactly what we were getting into we went ahead and designed a motor using Nitric Acid and Ammonia. After running into some difficulties we changed to Nitric Acid,Alcohol. At one of our many discussion session we decided that none of us had the machine shop experience that was needed in order to drill the impinging injector holes. This along with many other problems forced us to change to a mono-propellant for our first attempt in the realm of liquid fuel rockets.

After acquiring all the information we could about monopropellants we chose ethylene oxide and decided to stick with it no matter what the problem. So we went ahead and designed the rocket setting the thrust at 2400 lbs. and the diameter of the rocket at six inches. When the rocket was just about to come off the drawing boards we were given a piece of five inch aluminum tubing six feet in length which had been hydro-tested to 2400 psi. This was just perfect for a fuel tank so we went back to the slide rule and drawing boards and designed a rocket which was five inches in diameter. About this time we had our biggest set back when Don Culver moved to Sacramento.

After a few more calculations we felt it necessary to reduce our thrust to 1200 lbs. which would allow for about a four second burning time. The reason for the high thrust low duration was to get away from any guidance system that would be necessary to achieve a vertical flight.

Because of school and jobs it was almost an impossibility for all of us to get together at one place at one time so the jobs on the rocket were broken up into parts. Due to the fact that Dave had a small machine shop he took on the job of machining the rocket plus building any electronic gear that was to be aboard. The job of testing all the component parts as well as the over all rocket fell to Ron Nelson and Calvin Van Wagner.

The next major problem that we faced was finding some way to reduce the L* of our motor. We were quoted many figures by experts but none were the same and they ranged from 400 to 2000 in. This was very undesirable because it would make the combustion chamber longer than the fuel tank. After considerable thought it was decided to put a long burning-high energy solid propellant motor above the injector head and have its hot gases spray down onto the incoming fuel.

As far as the actual construction of the rocket goes, the following has been accomplished: The fuel tank has been cut to proper length and the ends fave been finished; the top tank plate has been completed; the fuel manifold has been completed; the solid propellant motor has been completed; the injector is complete except for the holes; the nitrogen tank is completed; and the nozzle is almost finished.

We hope to begin hydro-tests in a few weeks and finish them sometime around the Easter holiday. The reason for such a long delay is that we all three will be going to different schools and our time is very limited. Actual static tests on the motor and rocket itself will begin the first part of next summer. We estimate that there will be about five such static tests. The actual flight test of the rocket will, we hope, take place about this time next year.

Reports will be appearing from time to time in the RRS NEWS giving results and progress of this project.

C.V. D.T. R.N.

PROGRESS REPORT
OF THE
ETHYLENE OXIDE MONOPROPELLANT RESEARCH ROCKET

Since the last report, in the April issue of the R.R.S. News, there has been quite a bit of progress shown in this project. The completed motor assembly has been completely anodized. This provides protection for all of the metal component parts.

During the hot summer months there was only one trip to the M.T.A. and it consisted of static pressure tests of the completed motor assembly. During this test the small solid fuel sustainer rocket motor was static tested on the Test Stand. It gave a good performance in a 5 second duration firing. This is only a porportion of the actual time that is was designed to run at. This small sustainer rocket is designed to be run inside of the rocket motor chamber of the larger ethylene oxide rocket to maintain the proper heat for combustion of the ethylene oxide monopropellant. (CH_2 OCH_2)

Along with these tests, there was quite a bit of welding and modification of the Test Stand itself. Re-inforcements were made on the large I beam for future static runs of the ethylene rocket motor at a future date.

With these successful runs completed, the following technicians on the project are to be commeded on their work: Ron Nelson, Ed Von Delden, Cal Van Wagner, and Dave Thalimer.

Appendix 2

Early Reaction Research Society Liquid Rocket Activity

(1965 to 1972)

XLR-1000 and Project Phoenix

George Dosa
Don Girard
Bill Claybaugh

RRS News

April 1966 Number 100

FIRST PROGRESS REPORT ON HYDROGEN PEROXIDE AND METHYL ALCOHOL ROCKET

By Don Girard,
Reaction Research Society

On May 1, the Exceutive Council of the Reaction Research Society approved a research contract to design, build, test, and fire a hydrogen peroxide-methyl alcohol rocket of approximately 1000 pounds thrust. An initial appropriation of $30 was given, followed by another $30 in June.

One of the first considerations is proposing a project of this nature is cost, and particularly the cost of the hydrogen peroxide. Following a lead presented in David Elliott's work, we contacted the Buffalo Electro-Chemical Company, and were rewarded with a bonanza of information, from which much of the preliminary survey was drawn up. Becco also distributes 90% H_2O_2, and the purchase of 300 pounds will cost 61.5 cents a pound.

The structure of the rocket, as originally conceived, was to be 10.6 feet in length, and about 7 inches in diameter. Again following a lead from Elliott and Rosenthal, we investigated the purchase of flight tanks, and decided upon the F-2 stainless steel tank for the peroxide, and the D-2 stainless steel tank for the methyl alcohol. The size of these tanks, when considered with the other space requirements, forced us to lengthen the proposed structure to 11.7 feet.

For the basic shape, it was decided to go perhaps a somewhat unusual route. Mr. George Dosa suggested that we consider an octagon body, that is, an eight-sided figure rather than a circular tube. He did so for the seven-inch tube would be both difficult to make and difficult to obtain, which a seven-inch octagon would be easy to make. It would have other advantages too. The transition from octagon to the round nose cone could be done easily in the instrument section, bulkheads would be easy to fabricate, access panels easier to fit, and finally, the corners would permit passage for plumbing.

Working from this shape, then, it was easy enough to decide upon a structural scheme. Four channels of aluminum alloy, each eight feet long, were positioned by a series of bulkheads. See Fig. 1. For an outer skin covering, wall thicknesses of 0.065 inches and 0.040 inches were considered, with the final choice of the smaller size covering made for reasons of weight.

The flight tanks are about five and a half inches in diameter; the peroxide tank has a volume capacity of 1000 cubic inches, the alcohol tank 500 cubic inches.

The system is designed for a chamber pressure of 300 psi, created by a 3000 psi nitrogen pressurization. The methyl alcohol is used in regeneratively cooling the motor.

The nose cone for this rocket is made from fiberglass and has several interesting features. It is seven inches in diameter at the base and is 28 inches long; it is based on a selected fineness ratio of 8:1. Its shape is a secant ogive, designed for minimum drag at its maximum velocity. The cone is fabricated from shell halves joined along the seams. The shell halves were laid-up in a plaster mold produced by a precision made sweep template. The calculations for this shape are based on the work of the noted aerodynamicist Theodore Von Karman.

The forward nine inches of the cone contain a sealed compartment for the smoke generator to be used for tracking. The rear section, with its locking ring adapter, will house the parachute and 'chute ejection mechanism. The finished assembly weighs just under one pound.

The instrument section is 12 inches long, and is the transition piece from the octagon to the tubular shape. At this stage, instrumentation is entirely open, and dependent on outside assistance. The following table perhaps gives some idea of the possibilities. The items listed under "Type" are those that are immediately available to the society.

TABLE II

INSTRUMENTATION

PRIMARY DATA

Data	Instrument	Type
Acceleration	Accelerometer	
Attitude	Gyroscope	Modified Summers K-7
Pressure	Pressure Transmitter	Giannini 46139
Altitude	Barograph	FAA sealed (?)
Radiation counter	Geiger-Muller	
Homing device	Transmitter	
Time base	Time generator	
Photographs	8mm movie camera	

CONTROL DATA

Function	Instrumentation	Type
Primary Parachute ejection		
Ejector back-up	Timer	
Ejection indicator	Microswitch	

POWER SUPPLY

Function	Instrumentation	Type
8-10 Channel telemetry	Transistor power supply	
D.C. power	Battery pack	
Ejector squib	Electric squib	Du-Pont S-67
Recorder supply	Gasoline generator	

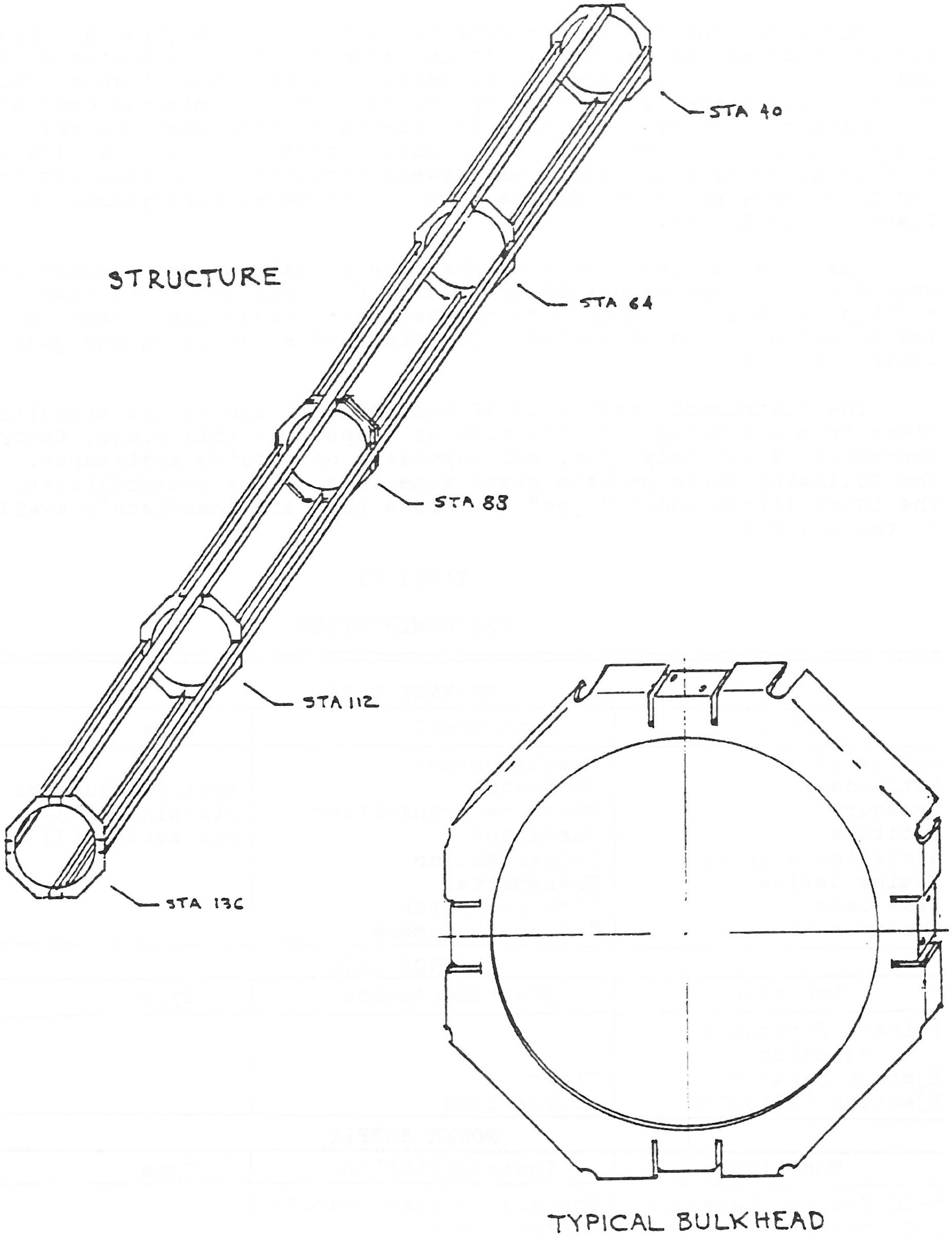

STRUCTURE
STA 40
STA 64
STA 88
STA 112
STA 136
TYPICAL BULKHEAD

FIG. 1

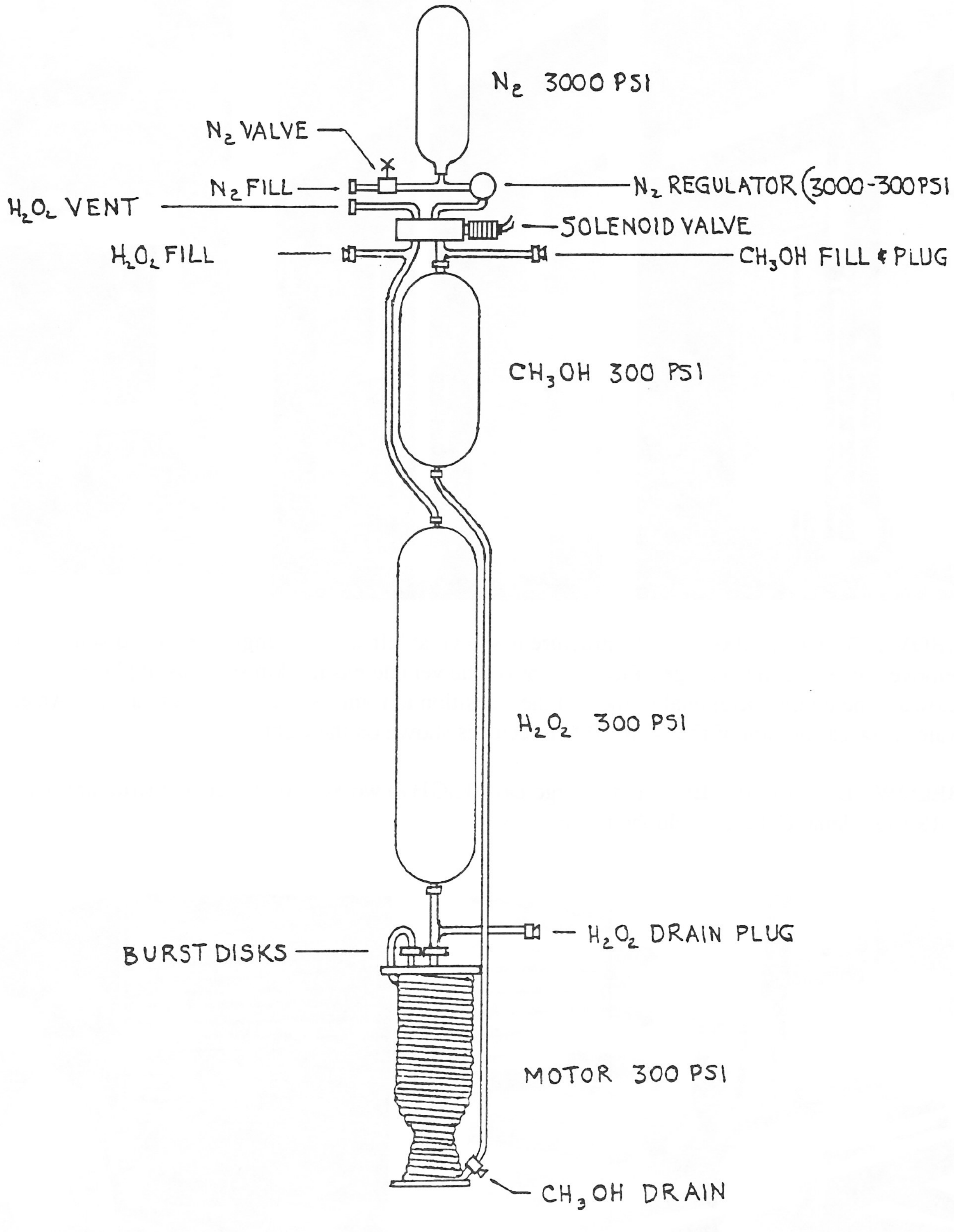
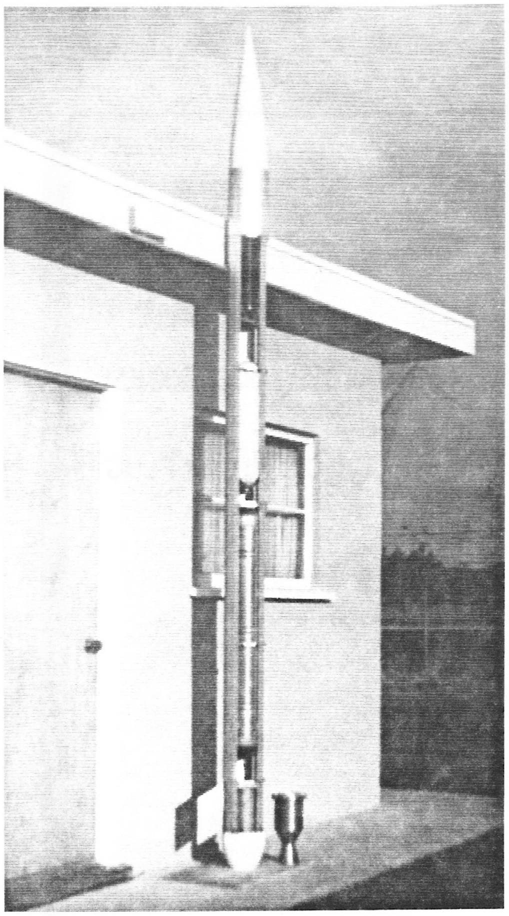
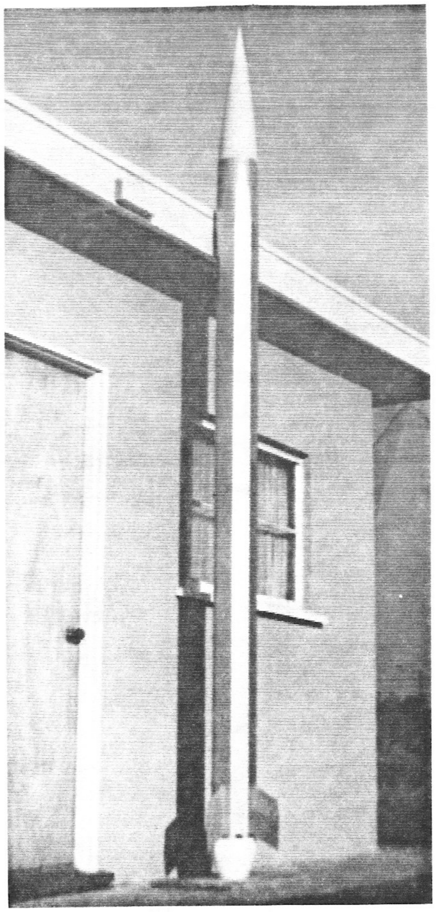
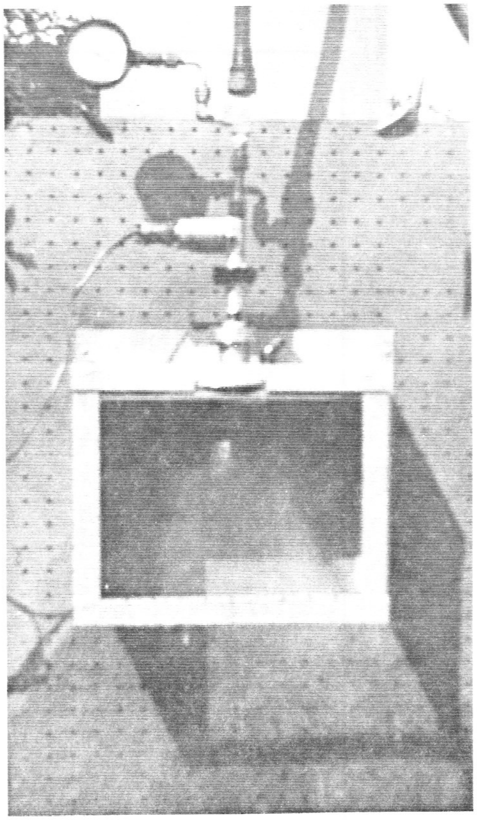

N₂ 3000 PSI
N₂ VALVE
N₂ FILL
N₂ REGULATOR (3000-300 PSI
H₂O₂ VENT
SOLENOID VALVE
H₂O₂ FILL
CH₃OH FILL & PLUG
CH₃OH 300 PSI
H₂O₂ 300 PSI
H₂O₂ DRAIN PLUG
BURST DISKS
MOTOR 300 PSI
CH₃OH DRAIN

FIG. 2

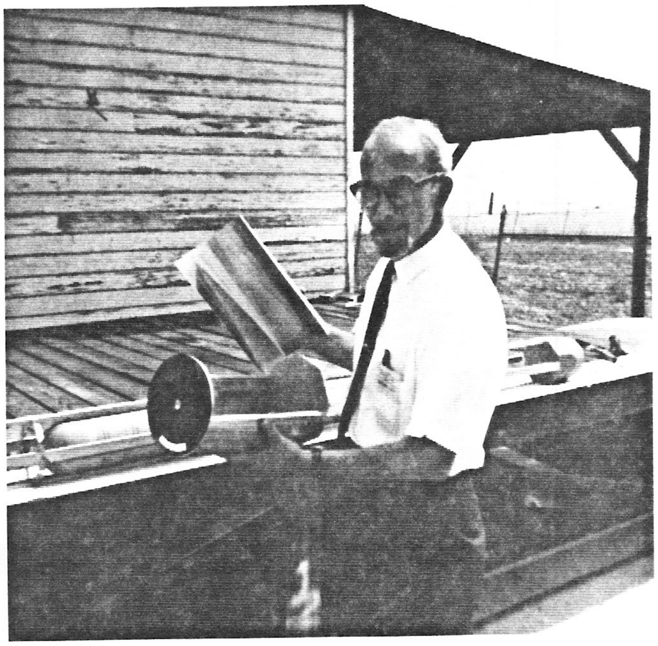






ABOVE - The XLR-1000 vehicle structure is shown at left with the engine shell and skin section removed to reveal the tankage. Pictured above the vehicle has its skin sections in place showing the unique octagonal shape and the transition to round at the nose and boat tail. An early water flow calibration of the XLR-1000 injector is shown on the right.

BELOW - Don Girard (LEFT) and George Dos (RIGHT) working on the rocket structure outside the RRS's Gardena, California clubhouse in 1965.



[*Excerpt from RRS News #103, 1968*]

PROJECT PHOENIX: AN EPIC CHRONICLE

In 1965, George Dosa and Don Girard began work on the XLR-1000, a bi-propellant liquid rocket that used hydrogen peroxide and methyl alcohol. The rocket dimensioned seven inches in diameter by about twelve feet. The progress on this flight vehicle has been reported extensively in the NEWS. As the designing and building reached the testing stage, it became apparent that there was a serious lack of liquid rocket experience on the part of both men.

To combat this, several paths were taken. First, the Mojave Test Area was readied for liquid rocket work (reported on elsewhere in this issue). Secondly, more people were brought into the project. And thirdly, it was decided that an interim liquid rocket be built, on the lines of the furfuryl alcohol and nitric acid rocket marketed at that time by Herbert Christiansen. (Plans for this rocket are currently distributed through Star Space Systems.) This four-inch by nine-foot rocket, the Phoenix, runs on white fuming nitric acid and unsymmetrical dimethyl hydrazine (UDMH).

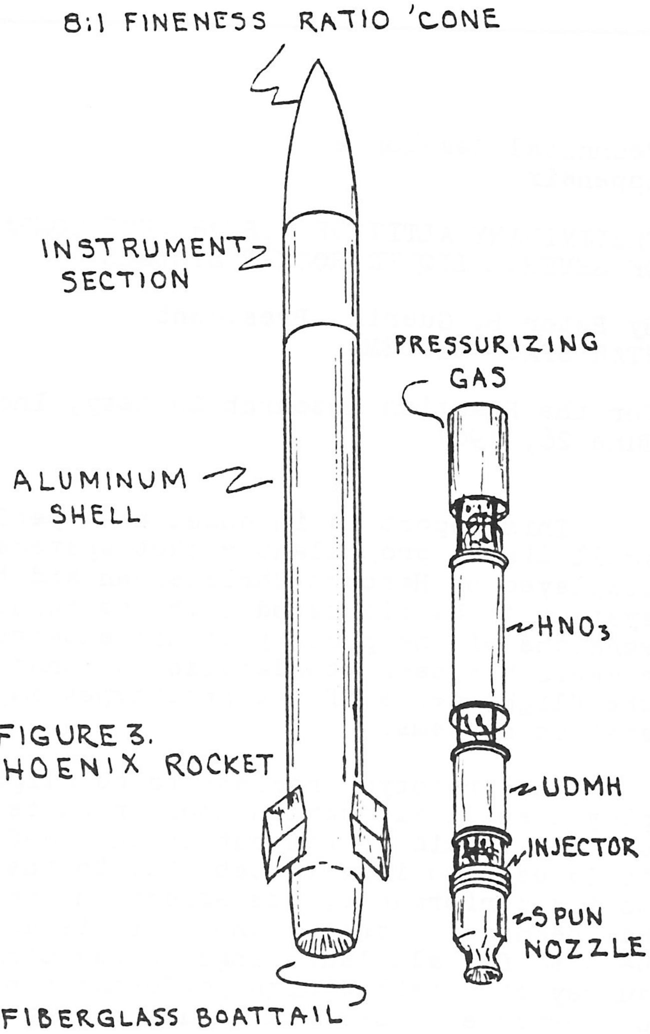


FIGURE 3. PHOENIX ROCKET

Like the Star Space Systems rocket, the Phoenix incorporates tanks that are made from machined end closures and tubing, rather than commercial hemispherical-ended tanks. Unlike the SSS rocket though, the Phoenix uses internal plumbing, and also has an outer shell. The motor is spun from stainless steel, and is of the usual design, rated for 250 pounds of thrust. The pressurizing gas in all probability will be helium.

An aluminum mock-up of the injector has been machined, with satisfactory results. The final injector will be stainless steel. A special publication is scheduled that will present a full design report on this interim rocket. Test results will be carried in the NEWS.

RRS NEWS

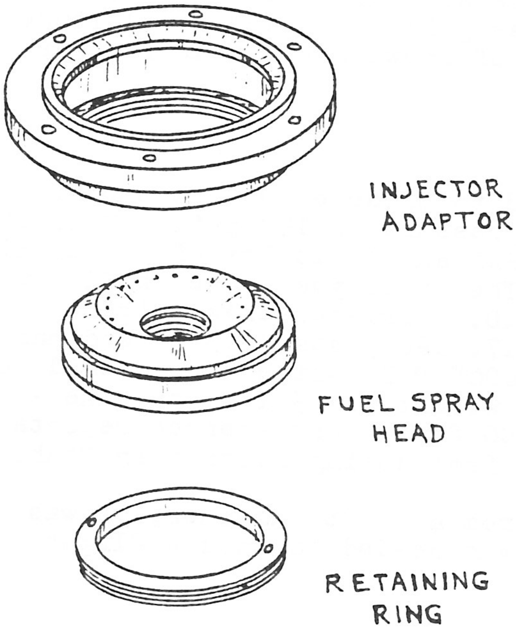


FIGURE 4. PHOENIX INJECTOR

Technical Session 2
Appendix

PRELIMINARY ALTITUDE PERFORMANCE COMPARISONS OF SEVERAL LIQUID ROCKET SYSTEMS

By Peter B. Guerin, President
STAR SPACE SYSTEMS

for the Reaction Research Society, Inc.
June 26, 1967

This report is intended as a performance comparison of several small liquid propellant rocket systems similar to those built and displayed by Herbert Christensen and the author. The actual rocket systems to be discussed might be considered "second generation" versions of the prototype; the external configuration of these rockets has been standardized so that drag results obtained from the flight tests of the prototypes may be applied to the second generation systems.

The prototype rockets to be flight tested this summer both employ a small micrograin booster whose primary purpose is to accelerate the liquid rocket out of the 24-foot tall launching rack. Since it is used to impart stability to the liquid rocket rather than add to its performance, its effect on the performance of these systems has been neglected, although it is assumed that such a booster must be used for all launchings unless otherwise stated. Finally, a brief survey of possible high performance boosters and their effect on the performance of several liquid rocket systems is given.

It should be pointed out that these altitude calculations, which neglect drag, can by no means be used as guides for actual altitudes, however, they serve the useful purpose of showing the relative performance of different rocket systems.

PROTOTYPES (100-lbs thrust, 7 seconds)

The prototype rockets are designed to produce 100-lbs thrust for 7 seconds, operating at a chamber pressure of 150 psia. Both of these rockets carry 2.317 lbs of 90% WFNA and 1.218 lbs of practical grade furfuryl alcohol (F.W. 98.10). The prototype rocket built by the author stands 5'7" and is 3.406" O.D. Christensen's original rocket, which was to be fired on June 17, 1967, stands 5'0" and has a fin section and tank section with 3.406" O.D. while the forward sections are 3.125" O.D. With a take-off weight of 25 lbs, the theoretical altitude is approximately 18,000 feet. Christensen reports his rocket reached altitudes of 10,000 feet during flights in Utah.

During these flights, conducted from a 12-ft launcher, it was found that a small micrograin booster was needed to insure flight stability.

Appendix (cont'd)

SECOND MODEL, TYPE LR-1A (100-lbs thrust, 21 seconds)

The prototype design is large enough so that the propellant load may be increased from 3.535 lbs to 10.605 lbs without requiring major modifications and without altering the external configuration. This increased propellant load would permit a burning time of 21 seconds. Assuming a take-off weight of 25 lbs, the theoretical altitude of this system is approximately 170,000 feet.

THIRD MODEL, TYPE LR-1B (200-lbs thrust, 10 seconds)

The present motor operates at a chamber pressure of 150 psia, exactly one-half of the value normally used in the industry. By increasing the chamber pressure to 300 psia the thrust would be increased to 200 lbs, with a subsequent increase in combustion temperature of between 1,000 to 2,000 degrees F. A propellant load of 10.605 lbs would enable a burning duration of 10.5 seconds. Assuming a take-off weight of 25 lbs, the theoretical altitude of this system is approximately 174,000 feet.

ALTERNATE BOOSTER SYSTEMS

There are currently two rocket systems in development that are ideally suited as boosters for the liquid rockets mentioned above.

Bill Claybaugh is currently building a hybrid rocket designed to produce 2700 lbs thrust for 4.5 seconds. Assuming a dry weight of 40 lbs and a propellant weight of 41.18 lbs, this hybrid booster should be able to carry a 25 lb upper stage to a theoretical burnout altitude of approximately 10,000 feet with a cut-off velocity of 4,907 ft/sec.

The maximum theoretical altitude of the 25-lb LR-1A rocket system using this hybrid booster is approximately 1,145,000 feet.

The maximum theoretical altitude of the 25 lb LR-1B rocket system using this hybrid booster is approximately 1,098,000 feet.

Of more immediate interest is a smaller booster being developed by Chuck Piper and Larry Ready, under the supervision of the Rocket Research Institute, Inc. The rockets are built from Navy surplus rocket engines 5" O.D. and about 2' long. The 20 lb rocket burns 25 lbs of Galcit and during a recent static firing developed 15,000 lbs thrust for 0.3 seconds. This rocket should carry a 25 lb upper stage to a theoretical burnout altitude of approximately 354 feet with a cut-off velocity of 2,558 feet.

The maximum theoretical altitude of the 25 lb LR-1A system using the solid propellant booster is approximately 584,000 feet.

A computer program, run by Chuck Piper, indicates that the solid propellant booster can carry a similar upper stage, but developing 400 lbs thrust for 12 seconds, to an altitude of 80,000 feet, based upon the drag coefficients of cyclinder of the same size as the two rocket stages.

Appendix: Technical Session 2

ENGINE SYSTEM PROPOSAL

By Bill Claybaugh

Characteristic length from the prototype:

$$V_c = \pi r^2 h_{eg} + 1/3\pi r^2 h_{cone} - 1/3\pi r_{ex}^2 h_{ex}$$

$$= 11.26 \text{ in}^3$$

$$A_t = .275 \text{ in}^2$$

$$L^* = V_c/A_t$$

$$= 41$$

Engine system: Strength:

At 2000 degrees F, the tensile strength of 302 stainless steel is 4700 psi:

$$P_c = \frac{2\sigma_\theta d}{D}$$

$$= 2(4700)(.0625)/1.937$$

$$= 3055 \text{ psi}$$

Assume safety factor of three, working pressure could be 1000 psi, maximum.

Engine system: chamber design:

Say chamber is specified as 2" O.D. and 4" long, giving an area of $A_c = 2.7 \text{ in}^2$. Recall $L^* = 41$.

Chamber volume = 12.7 in^3 less some value dependent on the area of the throat.

$$A_t = V_c/L^*$$

$$= .310 \text{ in}^2, \text{ which implies } D_t = .626 \text{ in.}$$

With this approximate value of D_t, we can recalculate V_c, and re-estimate D_t. The difference of the iterations is .001 inches, the same as machining accuracies. Therefore, our choice of chamber volume is $V_c = 12.6 \text{ in}^3$, $A_t = .308 \text{ in}^2$, $A_c = 2.7 \text{ in}^2$, $D_t = .625$ in.

Engine system: Nozzle:

Set F = 100 lbs.

$$P_c = \frac{FgR'T_c}{V_2 M A_c V_1} = \frac{100 \cdot 32.2 \cdot 1544 \cdot 4900}{6050 \cdot 25 \cdot 2.7 \cdot 250}$$

$$= 239 \text{ psi}$$

Appendix (cont'd)

$C_F = F/A_tP_c$

$= 1.36$

From available graphs, $P_c/P_x = 16.2$, $A_x/A_t = 30$.

$A_x = .924$ in^2, and $D_x = 1.084$ in^2

Engine system: Growth Potential:

Note that the chamber will hold 1000 psi. If the pressure is raised to this, the thrust is as follows:

$k = 1.20$

$P_c/P_x = 68$, $C_F = 1.59$, $A_x/A_t = 9.0$.

$F = C_FP_cA_t$

$= 490$ lbs. Note that at 1000 psi, Isp = 228 sec.

$A_x = 2.77$ in^2, and $D_x = 1.87$ in.

Engine system: Injector:

Specified for WFNA and furfuryl alcohol at 239 psi. Isp = 190 seconds, $r = 2.65$, $k = 1.2$, $t_c = 4900°F$, $C_F = 1.36$, $F = 100$.

Velocity at exit = V_2

= Isp·g = 6090 ft/sec, but with a correction factor will be considered as 5720.

Weight flow:

$\dot{w} = Fg/V_2 = .564$ lb/sec, or .154 lb/sec fuel and .410 lb/sec oxidizer.

Allowing a 30% over-injection of fuel for cooling, $\dot{w}_f = .200$ lb/sec.

Propellant injection flow vlume is them calculated, and the necessary hole areas, but these calculations do not appear in this report. The design suggests 8 acid and 8 fuel holes for mixing, and 16 cooling holes.

Appendix 3

Liquid Propellant Rocket Project
U.S. Naval Academy, 1976

Midshipman David E. Crisalli

A TRIDENT SCHOLAR
PROJECT REPORT

NO. 76

"THE DESIGN, CONSTRUCTION AND FLIGHT TESTING OF A LARGE LIQUID PROPELLANT MISSILE"

UNITED STATES NAVAL ACADEMY
ANNAPOLIS, MARYLAND
1976

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U.S. Naval Academy, Annapolis.

13. ABSTRACT

The paper describes the design, construction, and testing of a liquid fueled rocket. Design calculations for the engine and propulsion systems were performed, checked, and an engine was constructed to those specifications. A static test stand was constructed and instrumented to evaluate engine performance during full duration static firings.

The engine and propulsion system proved successful and were then incorporated into the flight vehicle. The remainder of the paper describes the design, construction, and testing of all flight hardware including an on-board camera system and recovery system.

Two unsuccessful attempts to launch the missile were made on 11 May 1976 at White Sands Missile Range in New Mexico. The reasons for the failure were corrected and the missile was successfully launched on 17 May 1976.

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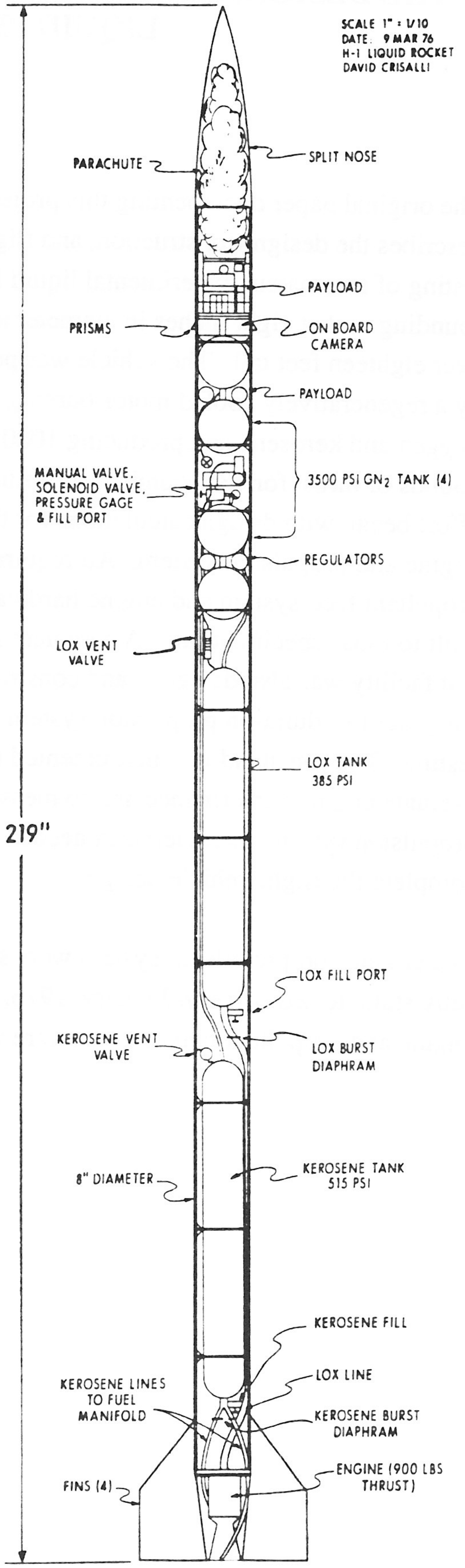


THE DESIGN, CONSTRUCTION, AND FLIGHT TESTING OF A LARGE LIQUID PROPELLANT MISSILE

ABSTRACT

The original paper documenting this project describes the design, construction, and flight testing of an amateur experimental liquid fueled sounding rocket eight inches in diameter and over eighteen feet tall. The vehicle was powered by a regeneratively cooled motor burning liquid oxygen and kerosene and producing 1000 pounds of thrust for 13 seconds. The initial effort began with design calculations for the engine and propulsion system. All required propellant feed system and engine hardware was built to those specifications. A complete static test facility was also designed and constructed to carry out full duration propulsion system hot fire testing. The test stand was instrumented to evaluate engine performance and to measure propulsion system characteristics needed to complete the flight vehicle design.

The engine and propulsion system were successfully static tested twice in January, 1976. The engine and propellant tankage hardware were removed from the test stand and incorporated into the flight vehicle then under construction. All required ground support equipment was also designed and built to support flight testing at the Naval Ordnance Missile Test Station, White Sands Missile Range, New Mexico. The rocket was equipped with an S-band telemetry transmitter, antennas, two on board 8 mm movie cameras, and a parachute recovery system.

After completing all vehicle component fabrication and subsystem testing, the rocket and all its associated ground support equipment was transported from the U. S. Naval Academy at Annapolis, Maryland to White Sands, New Mexico by air freight. Launch preparations were made at Launch Complex-36 for this flight test. After final assembly and checkout on 11 May, 1976, two unsuccessful launch attempts were made. The problems encountered during these attempts were corrected and the rocket was successfully flown on 17 May, 1976.

MISSILE DATA SHEET

ENGINE DATA (Experimental)

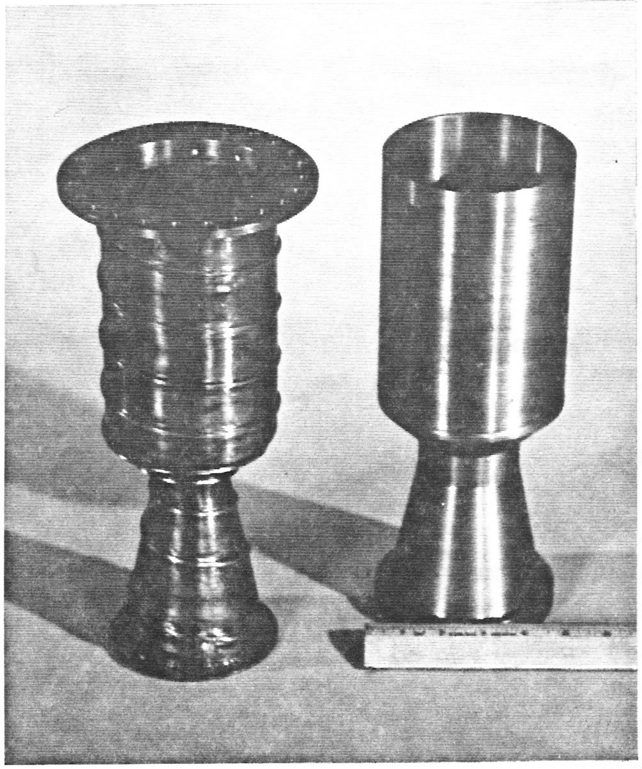
Fuel	Kerosene
Oxidizer	Liquid Oxygen
Thrust	900 lbf
Specific Impulse	212 sec
Burn duration	13 sec
Chamber pressure	300 psia
Cooling	Film and Regenerative
Effective exhaust velocity	6814 ft/sec
Total Impulse	11,700 lb/sec
Characteristic exhaust velocity	4845 ft/sec

VEHICLE DATA

Feed system	3100 psig nitrogen
GN2 weight	4.8 lbs
GN2 volume	588 cubic inches
Lox tank pressure	390 psia
Kerosene tank pressure	518 psia
Vehicle length	219 inches
Vehicle diameter	8.0 inches
Kerosene weight	30 lbs
Lox weight	42 lbs
Vehicle empty weight	138 lbs
C.G. (measured from tail)	98 in. (loaded), 106 in. (empty)
C.P. (measured from tail)	65 in.
Stabilization	Fins (4)
Fin area	200 square inches (each)
Recovery system	Parachute - drogue deployed at peak and main released at 10,000 ft. AGL
Diameter of drogue	4 ft.
Diameter of main	24 ft.
Descent rate on drogue	Approx. 80 ft/sec
Descent rate on main	Approx. 10 ft/sec

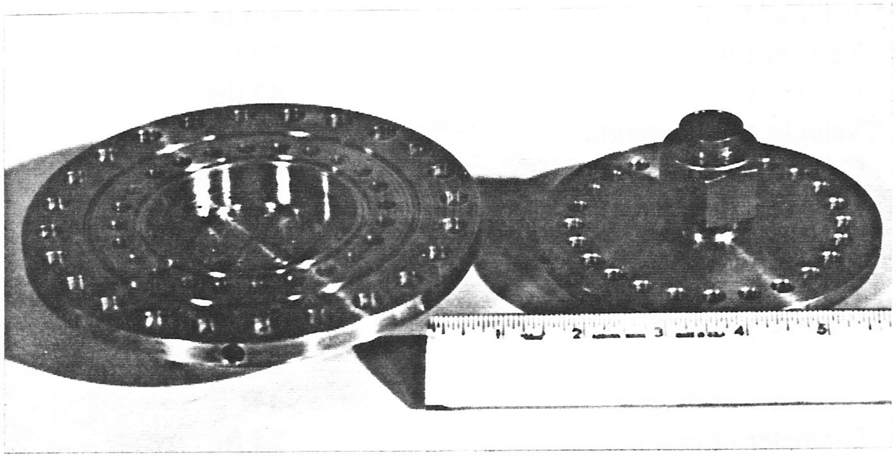
GROUND SUPPORT

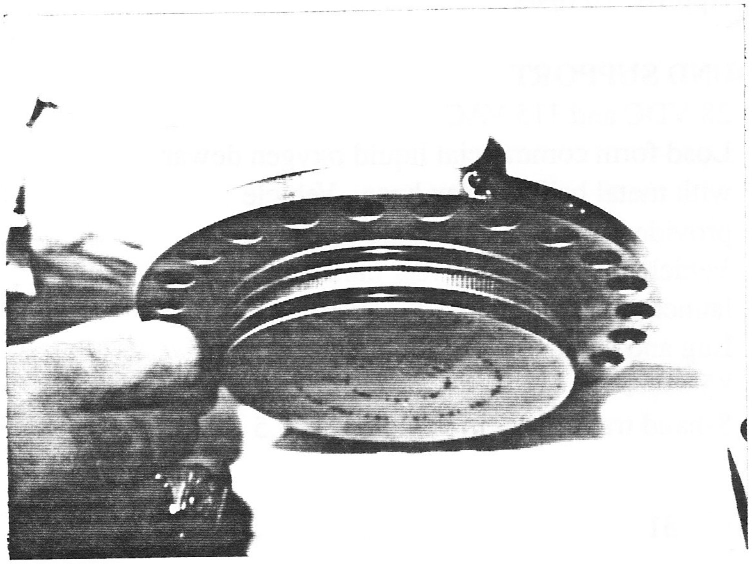
Required voltages	28 VDC and 115 VAC
Lox loading	Load form commercial liquid oxygen dewar with metal bellows flex hose. Vehicle provided with 1/2" AN male load fitting.
Launch rail	Vehicle provided with rear hard mounted launch lug and forward fly away belly band. Lug and band will fit LC-36 launcher rail.
Launch angle	85 degrees
Telemetry reception	S-band transmitter in vehicle (2259.5 Mhz)



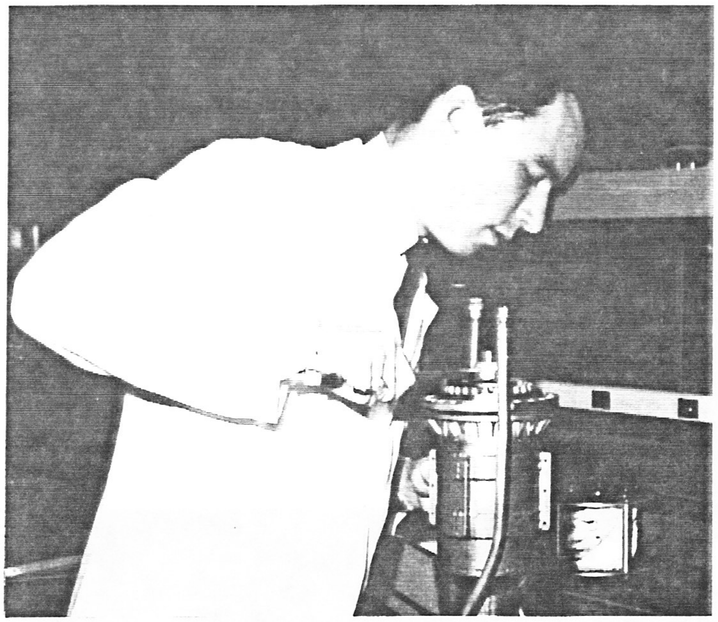
LEFT - Completed engine inner wall and cooling coil (left). The outer jacket parts are shown (right) prior to welding around inner wall. The entire thrust chamber is made of mild steel. The cooling coil is 12 gage solid electrical wire silver brazed to the inner wall and machined to final thickness.

RIGHT - Completed injector body (left) and oxidizer dome (right). The injector is made of 4130 steel.



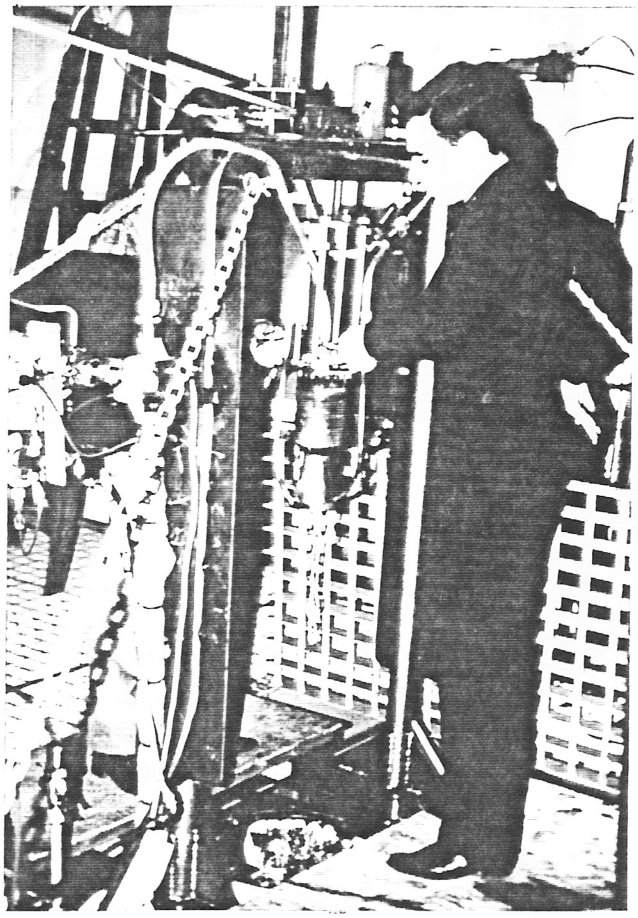


LEFT - The assembled injector showing the "O" ring seals and fuel manifold filter screen.

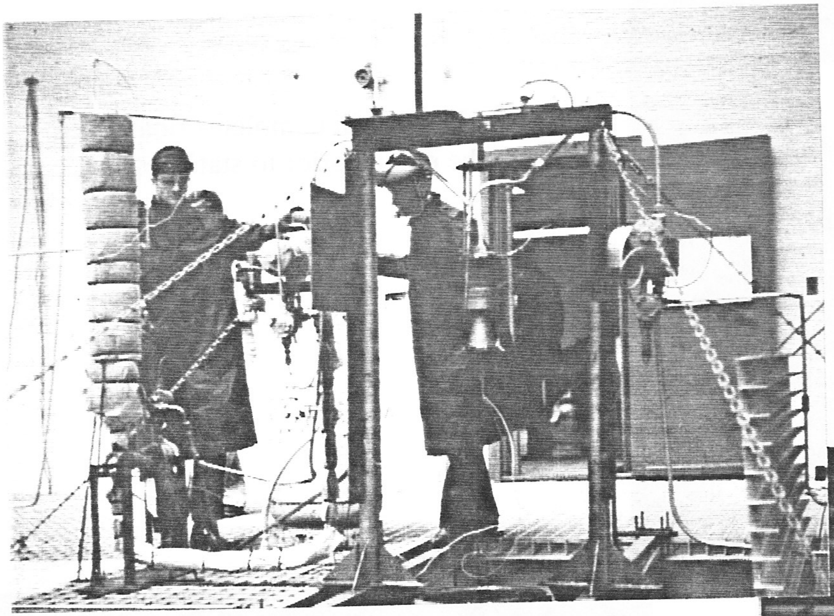


LEFT - D. Crisalli completes final assembly of the engine prior to static testing.

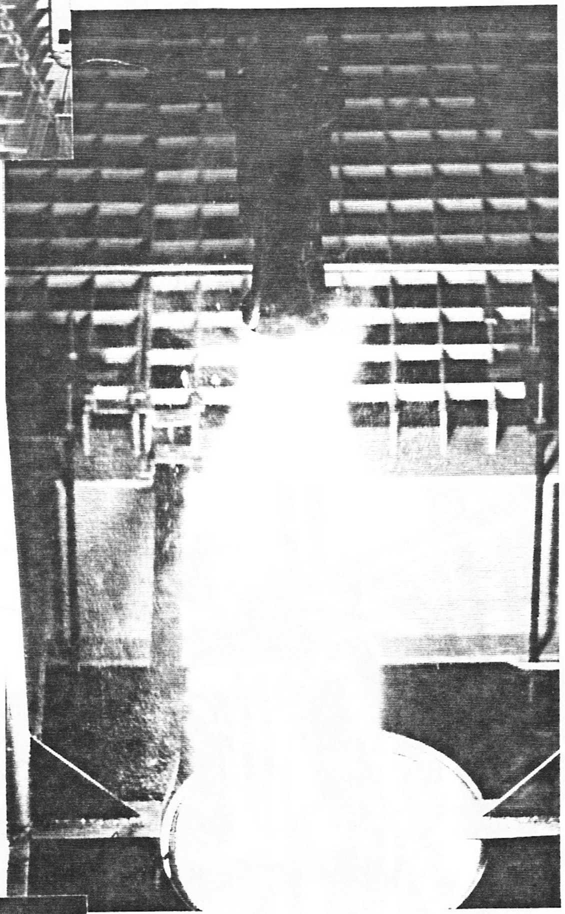
RIGHT - Nick Kirchner conducts initial checks to verify test stand control and instramentation hook up.



LEFT - Final engine assembly and installation in the test stand on 22 January 1976.

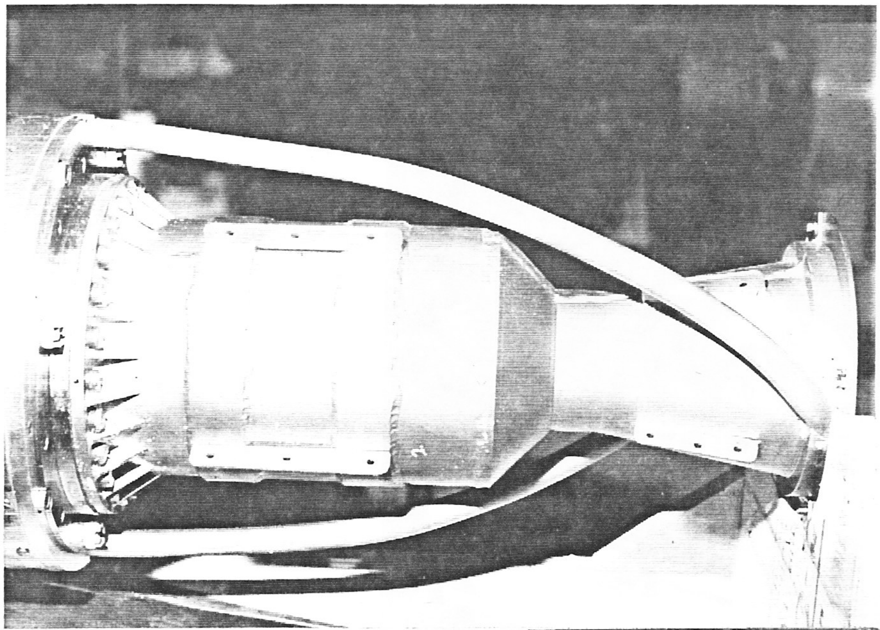


ABOVE - R. Parman (left) and D. Crisalli loading liquid oxygen. Tank and lines were chilled by dousing with liquid nitrogen prior to LOX load.



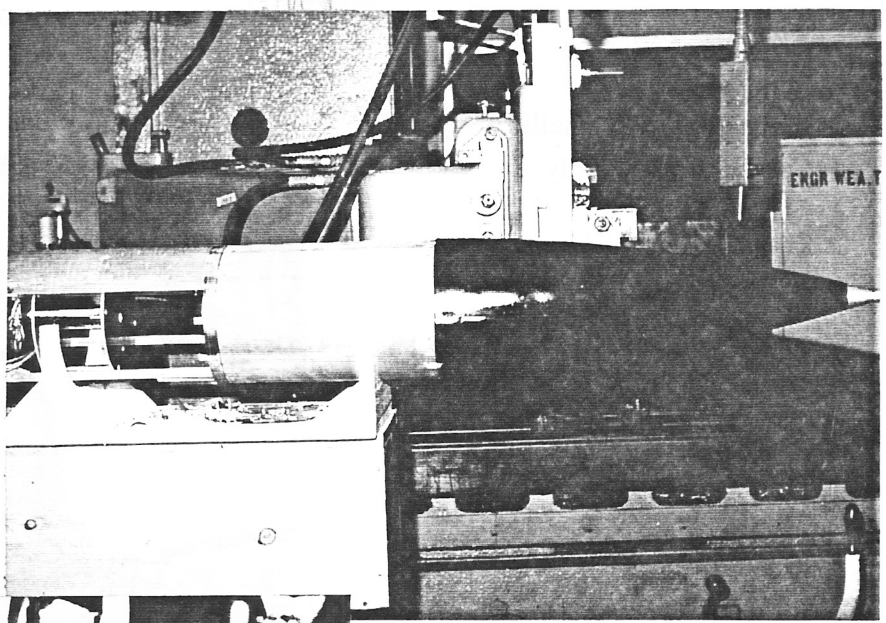
RIGHT - Static test of the engine, 24 January 1976. The engine produced 900 pounds of thrust for 13 seconds during this first test.

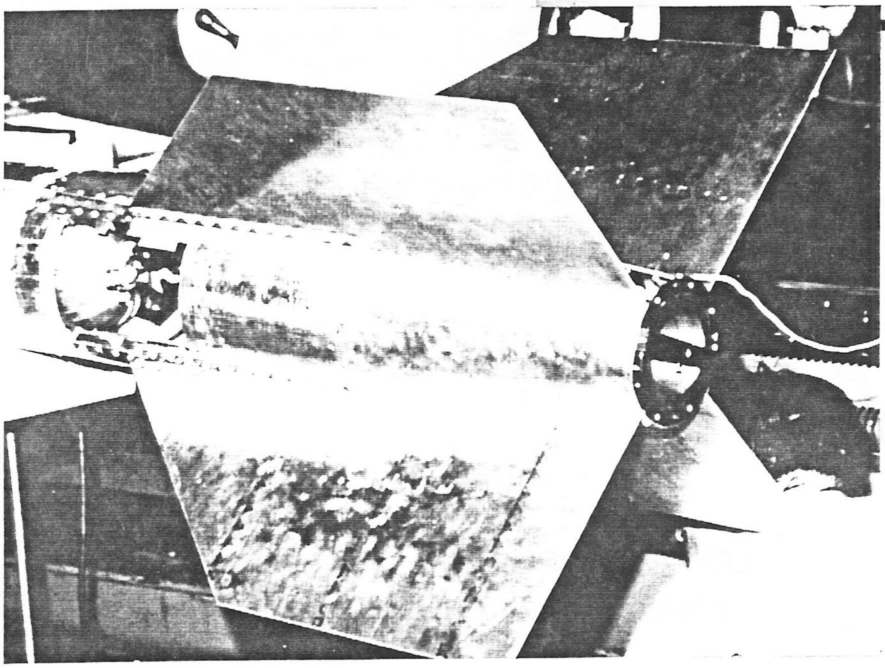
LEFT - Static test crew. From left to right; MIDN. Randy Parman, Mr. Steve Brown, MIDN. David Crisalli, Mr. Nick Kirchner, and MIDN. Al Manzi.



LEFT - Engine installed in the rocket showing fuel feed lines, welded cooling jacket, fin mount tabs, and injector flange stiffening gussets.

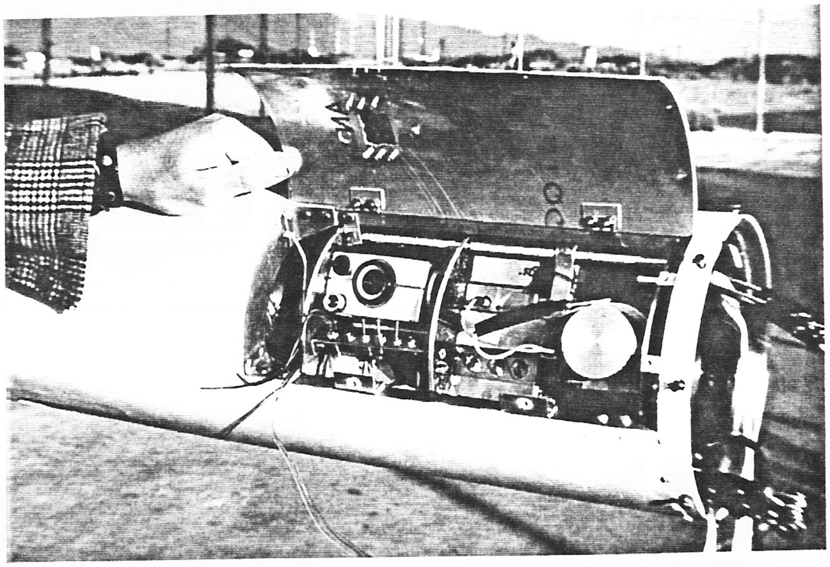
RIGHT - Forward section of the rocket showing the split nose cone, parachute tube, and payload section.



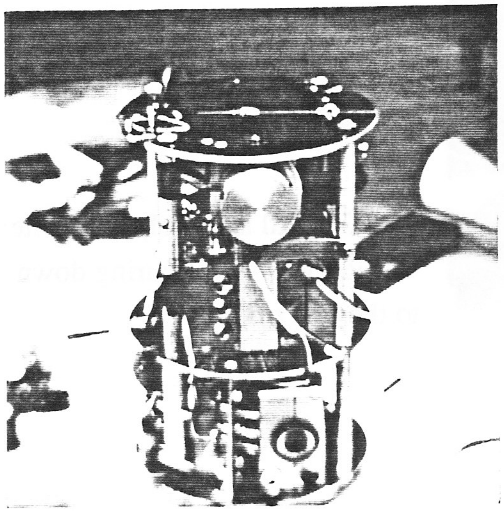


LEFT - Tail assembly complete including boat tail fairing down to the exit ring.

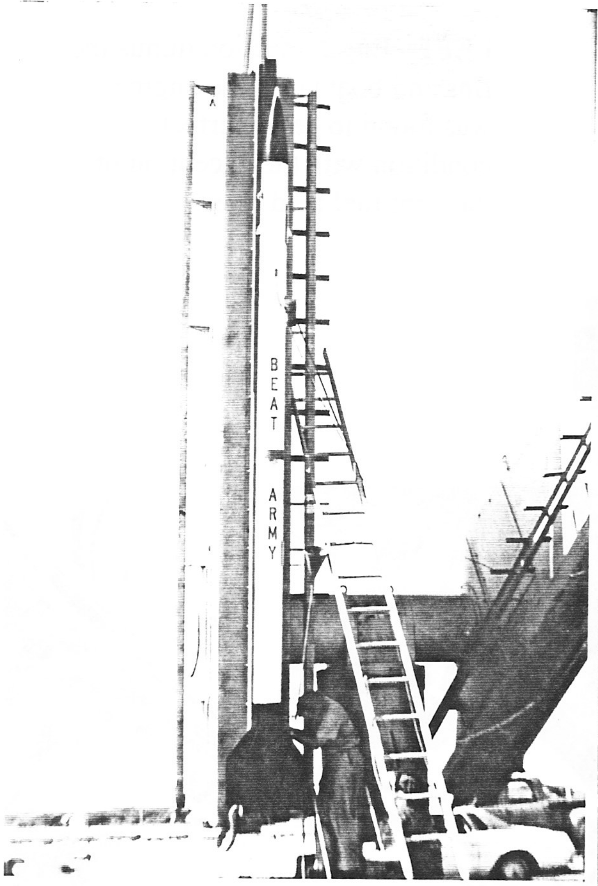
ABOVE - D. Crisalli fitting fins to the tail assembly.



ABOVE - Payload section. Prism mounted on door directs the view of the 8mm movie camera down the side of the rocket.

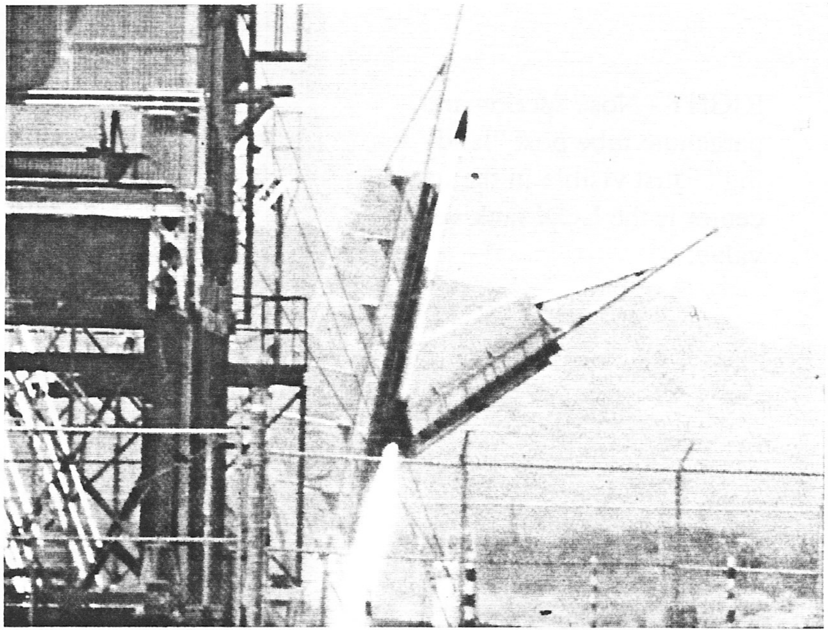


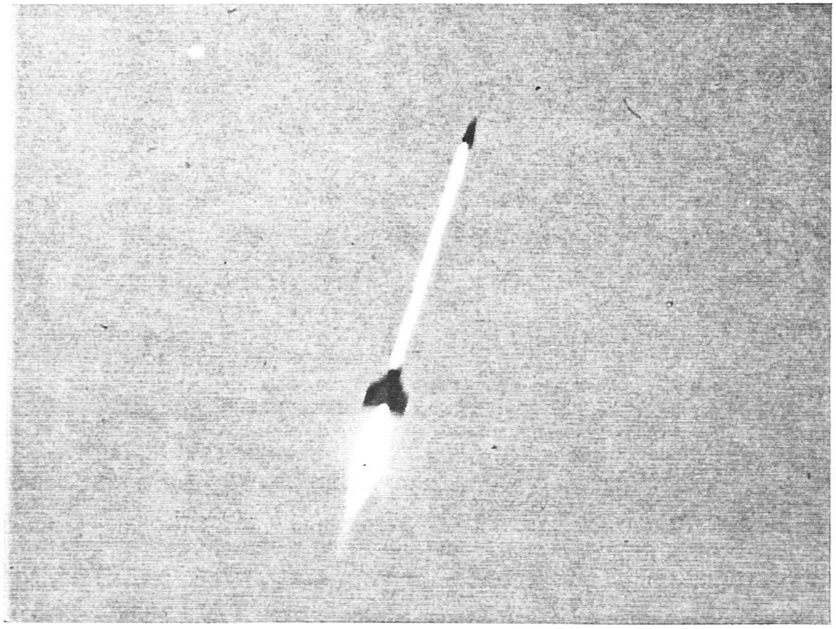
LEFT - Payload section undergoing final check-out before launch.



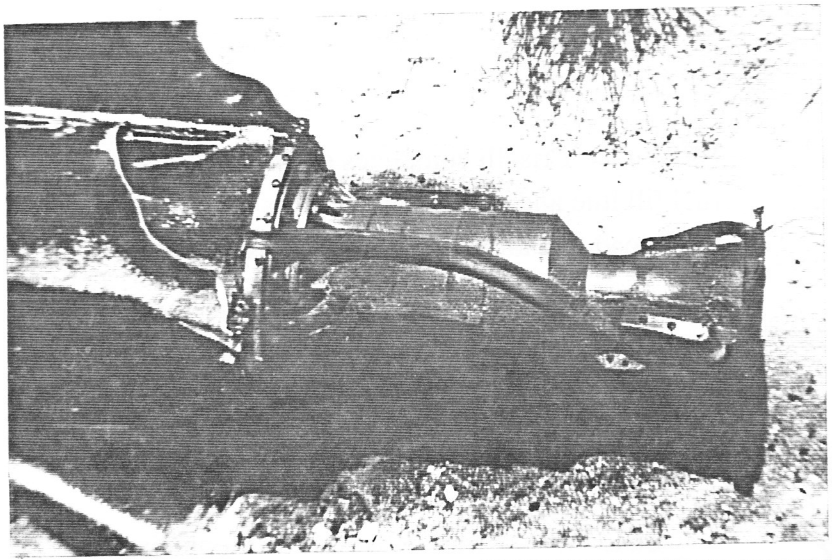
LEFT - D. Crisalli completes disassembly of fuel fill line and closes lower access door prior to LOX load and topping off GN2 pressure spheres.

BELOW - 17 May 1976, 1138 (Mountain Daylight Time), the rocket ignites and leaves the rail.



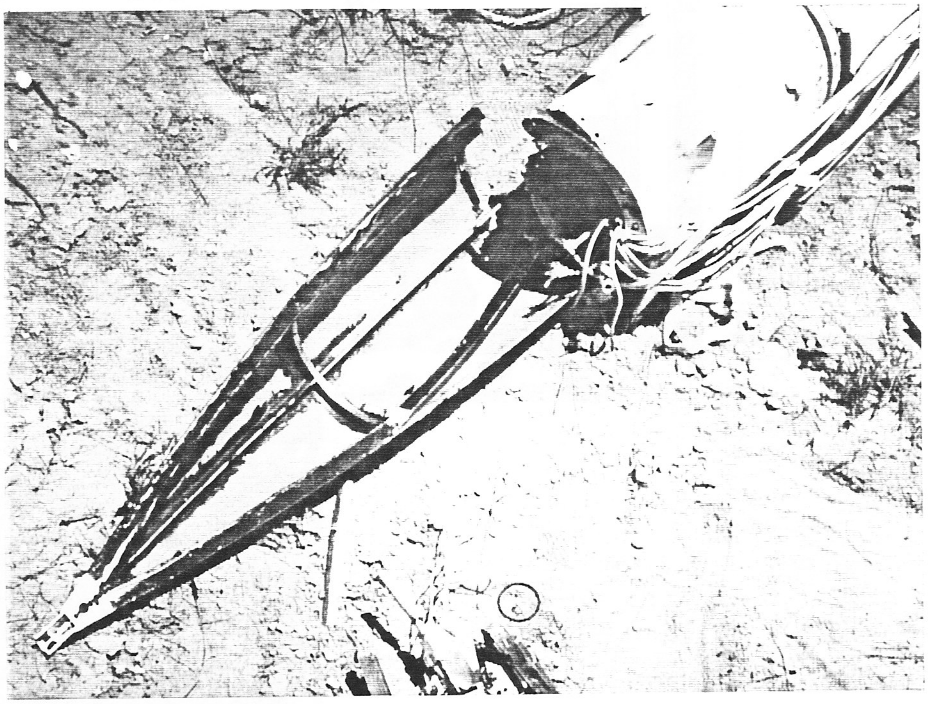


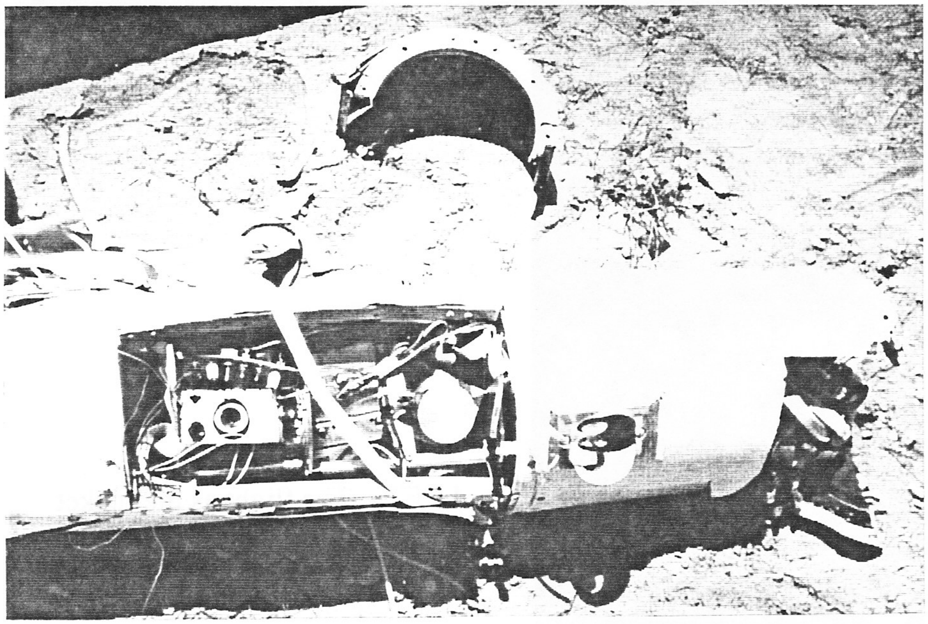
LEFT - The flight as the rocket approaches Mach 1.



LEFT - Engine section minus the fins and boat tail. The engine was found to be in perfect condition with the exception of the bent fuel feed lines.

RIGHT - Nose section and parachute tube post "landing". Just visible in the lower center is the LOX tank vent valve.





LEFT - Payload and camera section after the crash. The film in both cameras was destroyed.

FLIGHT DESCRIPTION FROM THE ORIGINAL PROJECT REPORT

"The crew arrived back out at LC-36 (Launch Complex - 36) at 0630 on the morning of 17 May. .... Everything looked go. The count continued normally down to T - 20 seconds when lox vent closure was initiated. The indicator that shows the valve was closed did not come on. The count was again held at T - 18 seconds. The valve had to be closed manually, and the easiest way to do so was through the lox vent valve charge access panel. Back out on the pad, the access panel was pulled off, the charge removed, and a drill punched through the charge hole to trip the vent valve.

It was difficult to tell if the valve had closed down, but a voice came over the loud speaker saying 'we have a green board.' The pad was cleared again and the count resumed at T - 3 minutes.

The excitement was even more intense now as people waited to see what would happen. After two complete ignition failures and the vent valve problem that morning, nerves were at maximum tension. The count droned on ... at T - 5 the camera was started, T - 3 generator on, 2, 1, FIRE. Then, through the foggy blockhouse window, a glow could be seen lighting up the ground and launcher near the missile. The glow burst into a brilliant, powerful jet emerging from the tail of the rocket. It rose, slowly at first, with grace and ease. The burn and acceleration were smooth, and the rocket was truly a sight to behold as it left the rail - white against a deep blue sky with a long brilliant tail of flame.

The rocket accelerated rapidly, the flight was perfectly stable, and the rocket did not spin as it flew. The burn continued for its allotted length of 12.8 seconds. At this point, the rocket was passing through Mach 1 (verified by radar track) and was at an altitude of approximately 8,000 feet.

In the next instant the nose charge detonated, blowing the nose halves off the rocket. The drogue deployed, snapped its tiedown to the rocket and deployed the main. Deployment of a 24 foot 'chute at Mach 1 is healthy for neither the 'chute nor the rocket. The rocket was jerked broadside to the wind stream as the canopy opened and the canopy was immediately torn to shreds. As the rocket traveled up to about 10,000 feet the fins began breaking up and pieces were falling off the air frame. There was still some propellant left in the tanks during this maneuver, and after the rocket had lost the nose section, fins and all stability, the engine sporadically cut on and off. With the liquid oxygen exhausted and only a kerosene flame sputtering from the nozzle, the rocket fell horizontally back to earth and crashed about three quarters of a mile from the launch pad."

As of 1138 Mountain Daylight Time, 17 May, 1976, the project had been concluded. A liquid propellant rocket had been designed, constructed, and flight tested as a one man project in nine months.

EPILOGUE

"Well, the project was completed. The enthusiasm and excitement of the NASA and Navy people who gathered there to see the rocket fly were beyond belief. From the cheering, shouts of joy, and hand shaking that went on after the flight, one would think Apollo 11 had just set down on the moon. The support, determination, and indomitable spirit of the people at White Sands was a marvel to behold, and I am sure that if the engine had not fired, the rocket would have left the rail powered by the sheer will of the spectators.

One could look at the launch as a feeble success, knowing the fate of the rocket as it approached 8,000 feet, but all the months of work, frustration, anxiety, and previous failures were outweighed by that 12.8 seconds of perfect flight. If I may digress from the realm of scientific reporting, only one who has seen a missile fly can understand the excitement and thrill of a launch. To see a polished metal machine, which for so long lay dormant in the laboratory, explode into vibrant, pulsating life and rise at fantastic speeds on a tail of blinding fire is an unforgettable experience. The roar of the engine tears at a man with physical violence, and to watch such a machine fight and struggle so hard to free itself from the bonds of earth is awesome.

These rockets are the simplest of machines in principle, yet the most complex in application. Of all the different types of machines, they are the most unforgiving of design or construction errors. And, above all else, they fire the imagination of men because they are the first generation of machines to take man beyond the realm of his own tiny planet.

As I stated in the beginning of this paper, this project has contributed nothing to the field of rocketry. There is little one man and $800 can do to compete with NASA. But the lessons taught the individual by such a project could never be duplicated in any classroom. The energy to learn, design, build, test, fail, and try again is generated by the anticipation of that roar, fire, and 12 seconds of flight. The enthusiasm and drive necessary to work day in and day out, round the clock, to find solutions to problems and answers to questions is found in the thrill of being able to turn ideas into working machines.

The opportunity afforded me by this project has been the most fantastic academic experience of my scholastic career. Nine months of work for 12 seconds of flight does not sound like a very good trade, but it was more than I could ask for. Rockets, like this one, are but frail against the wonders of the stars, but they are the key that will unlock the door to the mystery of the heavens."

David E. Crisalli
June, 1976

Bits and Pieces

<u>Internet Address Request</u> - There have been several requests recently for the Internet addresses of any members who have them. People have been sending them in a little at a time so, if you would like your Internet address published in the next RRS Newsletter, please send it to D. Crisalli or S. Claflin. In front of the membership roster we are including a list of the ones we have to date. For those on the list, please check to make sure we have all the dots and slashes and "@"s all in the right places. **I GET A LOT OF COMPLAINTS ABOUT E-MAIL ADDRESSES BEING INCORRECT OR LEFT OFF THE LIST - I CAN NOT FIX THIS UNLESS PEOPLE SEND ME UPDATES !!!** The Ed.

<u>Back Issues of the RRS Newsletter</u> - For those members who may be interested, copies of the last several RRS Newsletter issues are available for $10.00 each (including postage). This offer includes;

- Volume 51, No. 3, July 1994 (LOX/alcohol rocket, venturi design part I, 30 April 94 firing report and color photos)

- Volume 51, No. 4, Oct. 1994 (10,000 lb thrust liquid engine, 1950 hydrogen peroxide rocket, zinc/sulfur performance, venturi design part II)

- Volume 52, No. 1, Feb. 1995 (GOX/plexiglas hybrid engine, October '94 firing report, facility upgrade plans, liquid rocket pyrotechnic valves)

- Volume 52, No. 2, Aug. 1995 (LOX/ethanol engine design, Firing reports - March '95 (Liquid static tests) & May '95 (Zinc/Sulfur), Work party reports on facility improvements)

- Volume 52, No. 3, Oct. 1995 (LOX/alcohol rocket flight, Work party report, RRS composite propellant work, NO2/methanol engine design, Zn/S two stage flight test, Assembly of a large liquid rocket)

- Volume 52, No. 4, Dec. 1995 (Nitrous Oxide and Rubbing Alcohol Motor, United Kingdom Perspective on Amateur Rocketry, "Rollerons" - Roll Stabilization for Amateur Rocket Vehicles)

- Volume 53, No. 1, Mar. 1996 (1500 pound thrust Hydrogen Peroxide engine, 1995 in Review, Electric Matches, Legal transport of propellants, Robust nosecone design)

- Volume 53, No. 2, Jun. 1996 (Work Party Report, Lox / Kerosene - 1000 Pound Thrust Test, Rocket Powered Go-Cart, Resistor Igniters, Liquid Rocketry in Denmark, Micro Hybrid)

- Volume 53, No. 3, Sep. 1996 (Beginning Solid Propulsion Course Report, Burning Rate Exponents, Bates Grain Design, Solid Rocket Ignition, Resistor Igniters, New Building Work Party Report)

- Volume 53, No. 4, Dec. 1996 (Black Rock Flight to 50 Miles, 1996 Review, September 1996 Firing)

- Volume 54, No. 1, Mar. 1997 (Micro Hybrid Part II, RRS Hybrid History - Hybrid Bike, LOX / Particle Board Hybrid, LOX / Tar Paper Hybrid)

- Volume 54, No. 2, Jun. 1997 (WISP {Zinc / Sulfur} Rocket Testing, Low Cost, Home Made Regulator, Aeolipile Science Project, May '97 Firing Report).

- Volume 54, No. 3, Sep. 1997 (This issue).

Contact D. Crisalli if you need back issues and make the check payable to the RRS.

Membership Roster - Just a reminder again - please check the information on the enclosed membership roster and verify it. **If anything is incorrect or has changed, please contact Frank Miuccio with any corrections by telephone or mail. He is on the list and we made sure his name, address, and phone number were OK.**

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