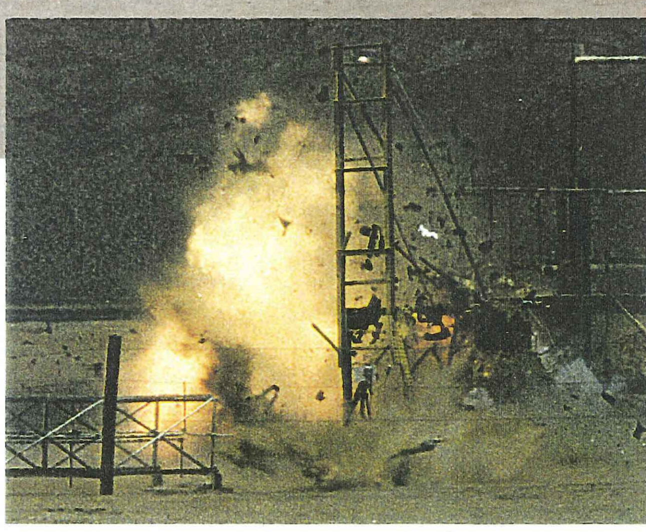
RRS News

THE OFFICIAL JOURNAL OF THE REACTION RESEARCH SOCIETY, INC.

FOR THE ADVANCEMENT OF ROCKETRY AND ASTRONAUTICS Volume 54, Number 1, March 1997

Special Issue: Hybrid Rockets



"Theoretically, one of the main advantages of hybrid rockets is safety during storage or operation."
- George P. Sutton,
Rocket Propulsion Elements,
Fourth Edition

RRS News

VOLUME 54, NUMBER 1 March 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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On the cover: Scott Claflin's 1670 lb. thrust LOX/tar paper hybrid detonates on July 1, 1990. The explosion was captured on film by Gary Perkins in the blockhouse and Bob Anderson in the observation bunker.

The Micro Hybrid - Part II

by Rene Caldera

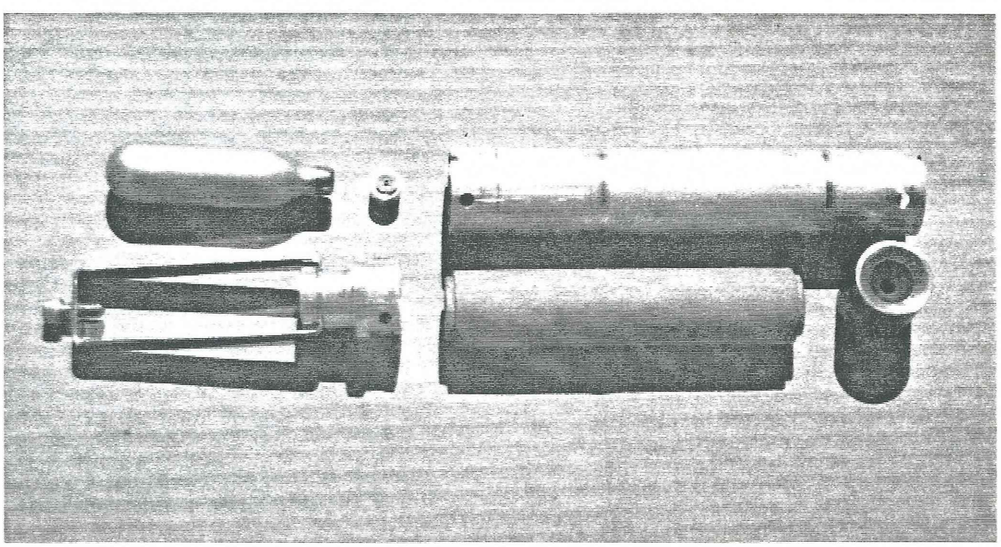
[*Part I of this article was published in RRS News, Vol 53, No. 2, June 1996*] Last time I showed how the idea for the Micro Hybrid was born. With the basic motor functionality tested and proven I have now proceeded to the construction and testing of a fully machined version.

All the parts for the motor were machined on my Sherline lathe. There's something funny about making a rocket motor in your living room. I chose to make the motor oversize just in case I under estimated the performance I would still have some fuel left over to protect the casing. I used aluminum for all the parts except the nozzle, which was made from steel with a graphite insert. I wanted it to be sturdy enough to survive my clumsiness (I did end up dropping it and had to do some minor dent removal).

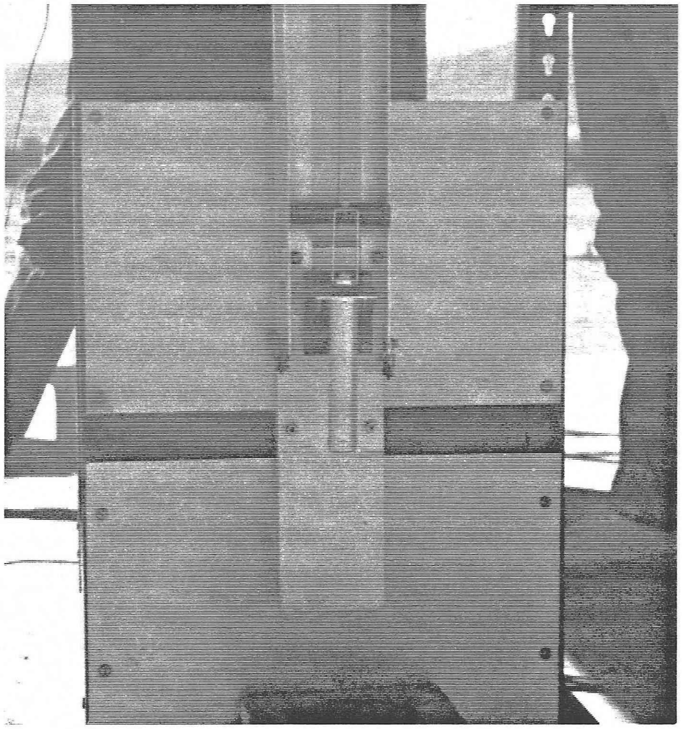
The heart of the motor is the injector unit. The nitrous cylinders I use are factory sealed and need to be pierced to release the contents. So I machined an aluminum injector. This part mounts to the top of the motor and holds the piercing unit. The piercing unit is a small piece of aluminum that has a steel needle press fitted into it. This drops into the injector unit along with an o-ring and provides a path for the nitrous to flow into the fuel core. To release the nitrous you load a cylinder onto the piercing unit and tighten the screw on the frame that goes around the cylinder. The pressure pushes the cylinder onto the needle and pierces the seal.

Well that's nice you say, but how is the oxidizer held in place until the time of motor ignition? We now turn to the motor side of the injector unit. The bottom side of the injector has a hole in it for the pyrovalve, the "on" switch. This is a pellet of compressed black powder. I had a bad feeling about compressing black powder to make a pellet so instead I took an Estes "A" motor, pealed the paper off , and turned it to size on my lathe (yikes!). When the motor is assembled the pellet presses against an o-ring on the bottom of injector and holds the oxidizer in place.

For the main event, an ignitor lights the black



The micro hybrid components. Clockwise from upper left: nitrous oxide tank, piercing unit, fuel case, nozzle, fuel grain, and injector unit.



The micro hybrid installed in the test stand

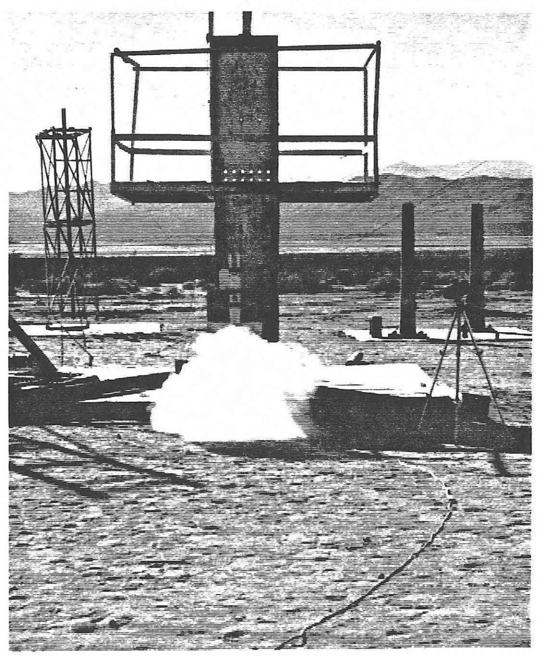
powder pellet which burns away and releases the nitrous into the fuel core. To make sure the temperature in the core was hot enough to release the oxygen out of the nitrous, a small hollow slug of propellant was epoxied to the top of the fuel grain core.

The Test

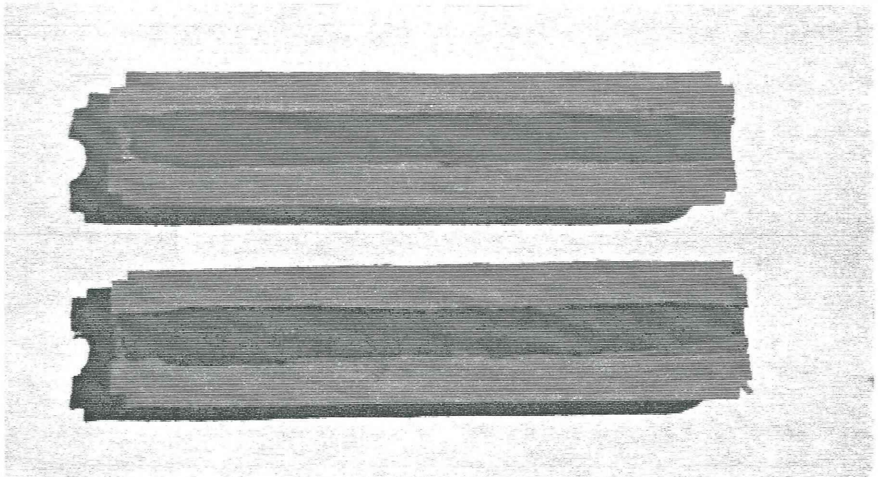
The Micro Hybrid was tested on Sept. 28, at the Mojave Test Area. It took three attempts to fire the motor. A design flaw showed itself as an ineffective seal at the pyrovalve/o-ring area. Two attempts to pre-load the nitrous resulted in venting the contents of the cylinder out of the motor. Lots of helpful suggestions and a little epoxy helped make a seal that was effective. When the fire button was pushed there was a little wisp of smoke and then a long narrow burst of flame. Mach diamonds were clearly visible! The burn time was about 1 second, due to full oxidizer flow.

Initial inspection of the motor revealed no obvious damage to the hardware. Inspection of the fuel grain showed an increase in the core diameter from the initial 1/4" diameter, and an even burn from top to bottom. Cutting the grain in half showed an even burn with a slight increase in the burn pattern at the top of the core. Thrust was measured and the graph showed a peak thrust of 10 pounds with an average thrust of about 6 pounds. The thrust graph has been found to be very similar to a popular motor manufacturer's "E27" motor .

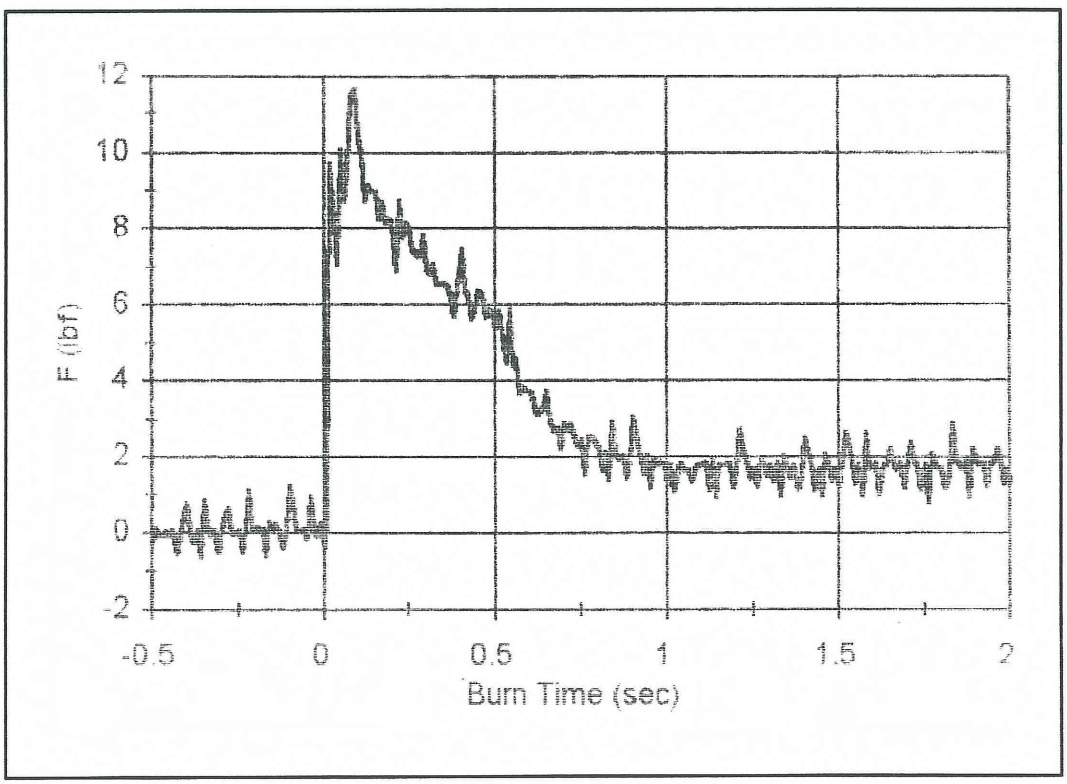
The next step is to make the flight hardware and to optimize the motor's performance, yet still using the same size nitrous cylinder (it's too easy to just flow more nitrous through it). After that, it's into a rocket and up, up, and away, to be recovered and flown again and again. Look for a report on the final tests when they are complete.



During a successful hot-fire test, the micro hybrid is obscured by smoke and dust.



The sectioned fuel grain revealed relatively uniform burning along the length of the fuel port.



The thrust trace for the September 28, 1997 firing of the micro hybrid showed that plenty of thrust is generated for getting a small rocket off the ground.

A Summary of Recent RRS Hybrid Testing

A. Mark Ventura tested his 85% hydrogen peroxide/polyethylene motor in April 1994. The motor produced approximately 50 lbs. of thrust for 5 seconds. Both the peroxide tank and motor case were made from PVC pipe. Ignition was accomplished with a solid catalyst molded into the injector end of the polyethylene fuel.

B. Korey Kline's first hybrid test at the MTA took place on October 16, 1993. The motor used nitrous oxide and hydroxyl terminated polybutadiene (HTPB) as the propellants. The motor produced approximately 200 lbs. of thrust for 10 seconds. The motor case was fabricated from commercial iron pipe and fittings. A commercially rated nitrous oxide tank was placed in the blockhouse and Korey regulated the flow of nitrous oxide by manually controlling a ball valve at the tank outlet. About 70 feet of copper tubing were run from the tank/valve in the blockhouse out to the motor. Not surprisingly, when the motor lit it immediately went into a feed-system coupled instability. Since the motor was only bolted to a plywood disk which was not secured to the ground, the oscillations caused the motor to dance around at the end of the long copper feed line to the amusement of the spectators.

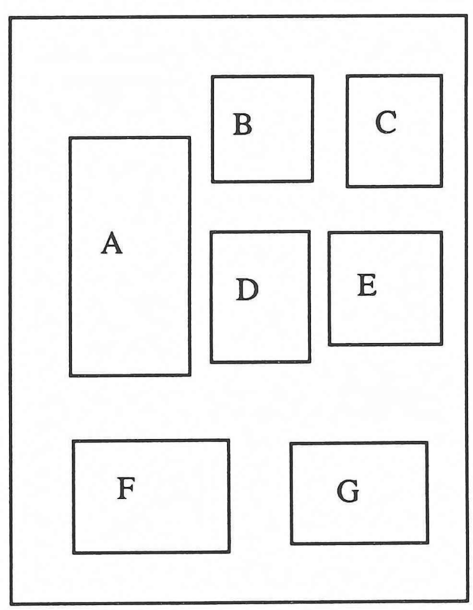
C. Keith Batt tested a 450 lb. thrust LOX/HTPB hybrid in September 1996. His motor experienced severe pressure oscillations which physically moved the static test stand and destroyed the load cell used for measuring thrust. The nozzle was also ejected from the motor towards the end of the test. The photo shows the motor at a low point in the pressure oscillations.

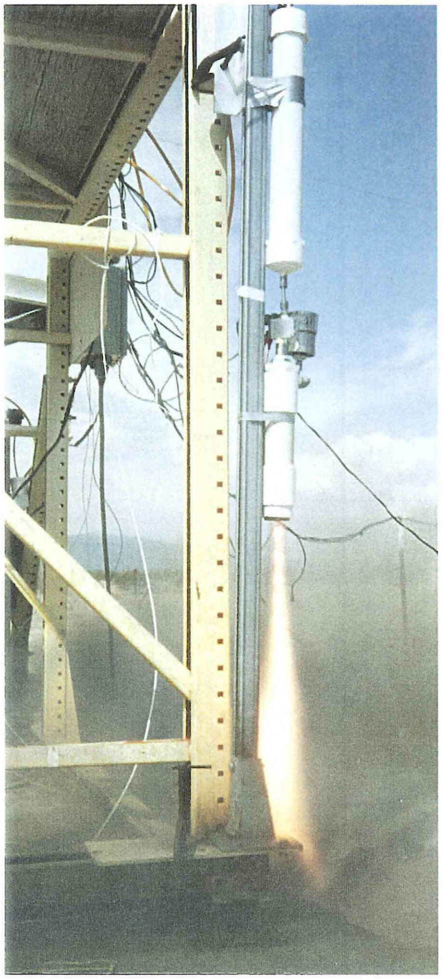
D. Korey Kline tested a 700 lb. thrust nitrous oxide/HTPB motor in April 1994. This time, the motor was secured to a portable test stand and the nitrous oxide tank was located near the motor. The motor burned for 21 seconds. Ignition was accomplished by electrically igniting a small piece of solid propellant located at the injector end of the solid fuel.

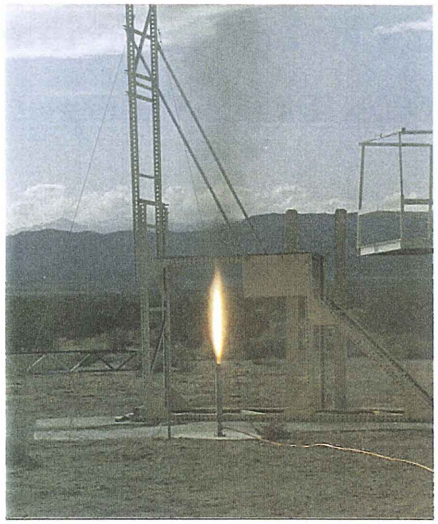
E. Rene Caldera's micro hybrid uses nitrous oxide and paper as the propellants. This test was conducted on September 28, 1996. The motor averaged about 6 lbs. of thrust for 1 second.

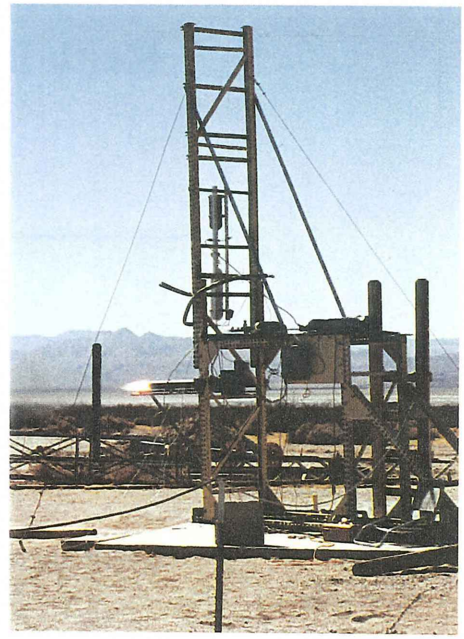
F. The GOX/plexiglas hybrid developed by several RRS members in 1988 has been fired dozens, if not hundreds, of times. The motor is useful for generating either data or enthusiasm for amateur rocketry. It is always a big hit with school kids and scout troops. The motor produces about 3 lbs. of thrust.

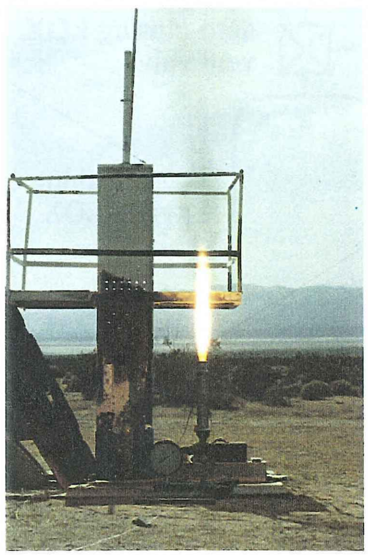
G. A night firing of the Wherley and Crisalli LOX/particle board hybrid on March 16, 1991 proved somewhat disappointing. The particle board burn rate was so low that the chamber pressure barely rose high enough to choke the flow at the throat of the motor. The design used several novel features such as a cast ablative throat and fuel grain which was directly overwrapped with fiberglas/epoxy.

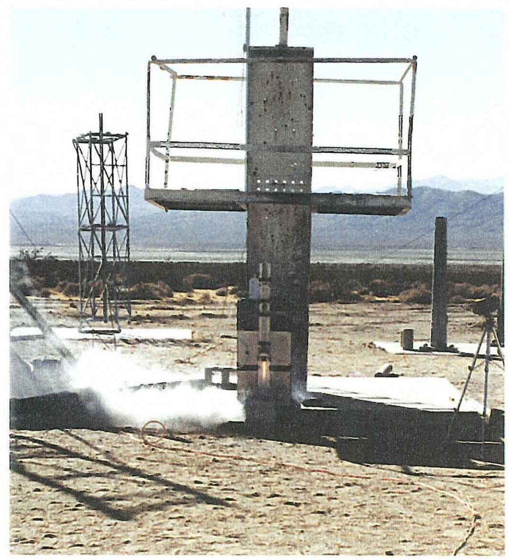


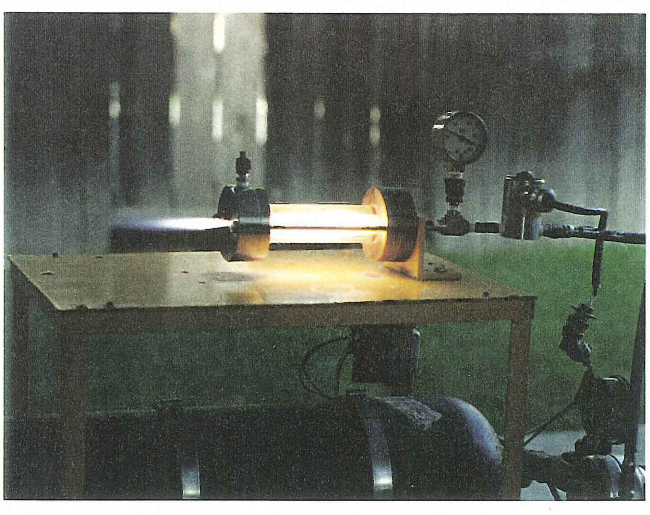


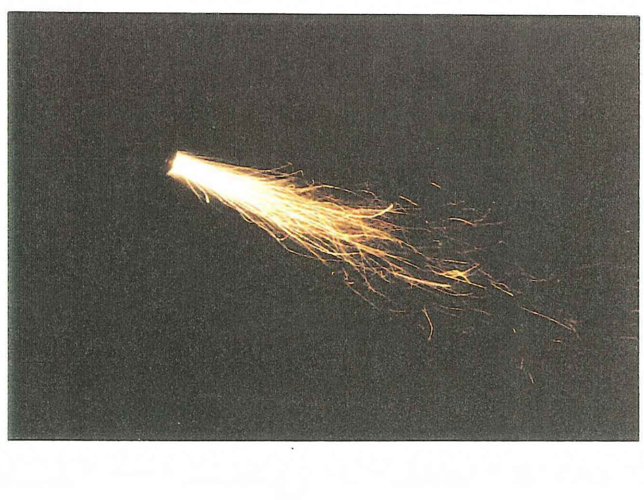






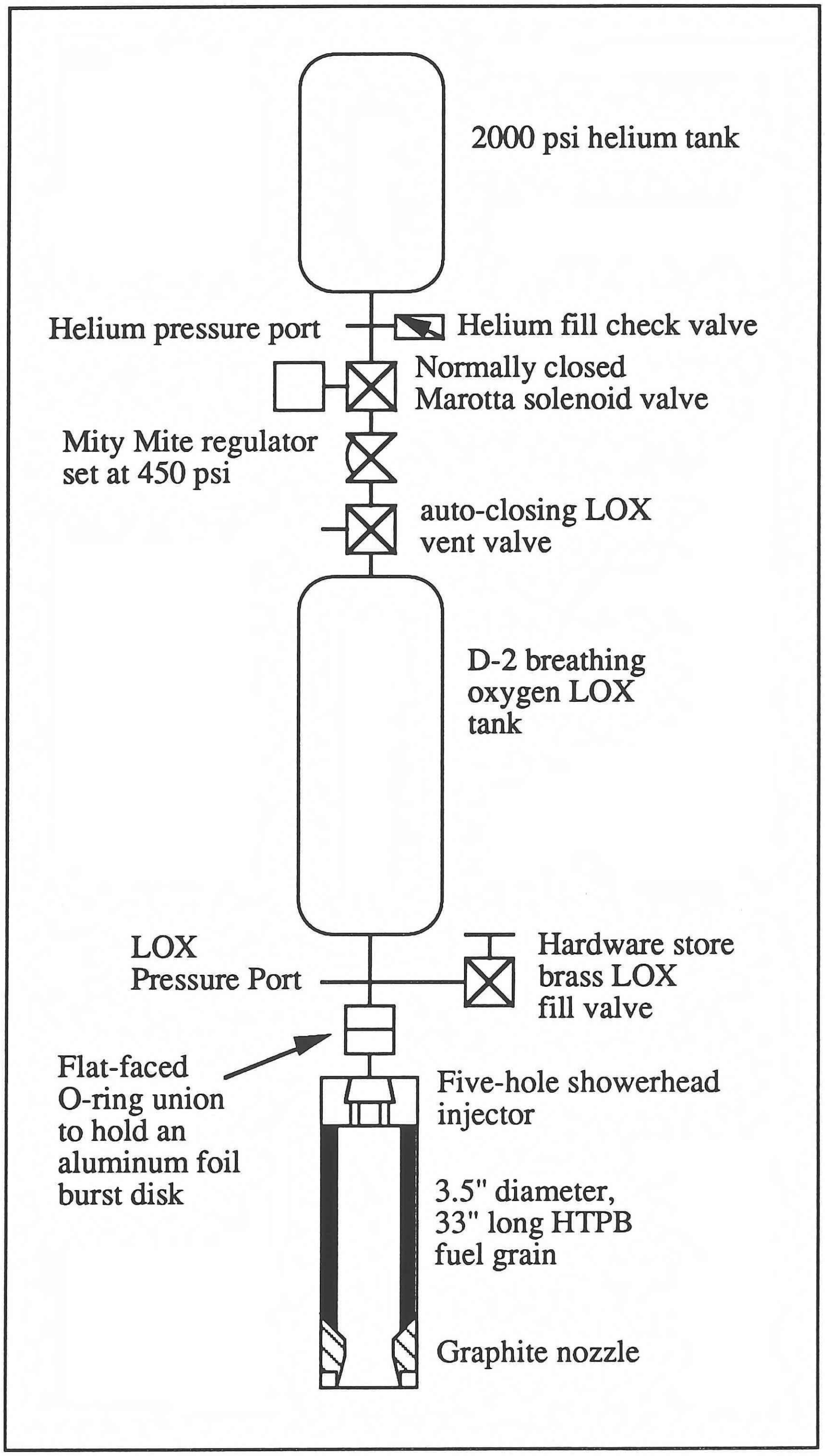






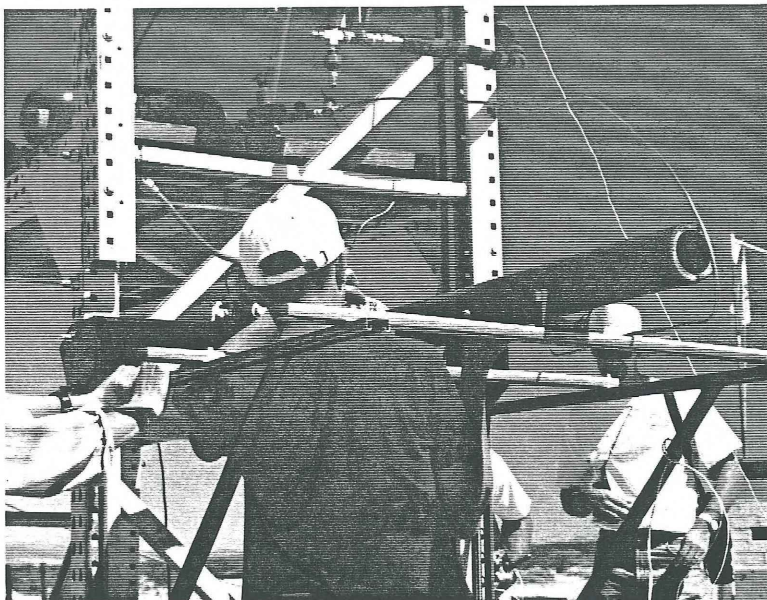
Keith Batt's Hybrid Experimentation

LOX/HTPB Static Testing

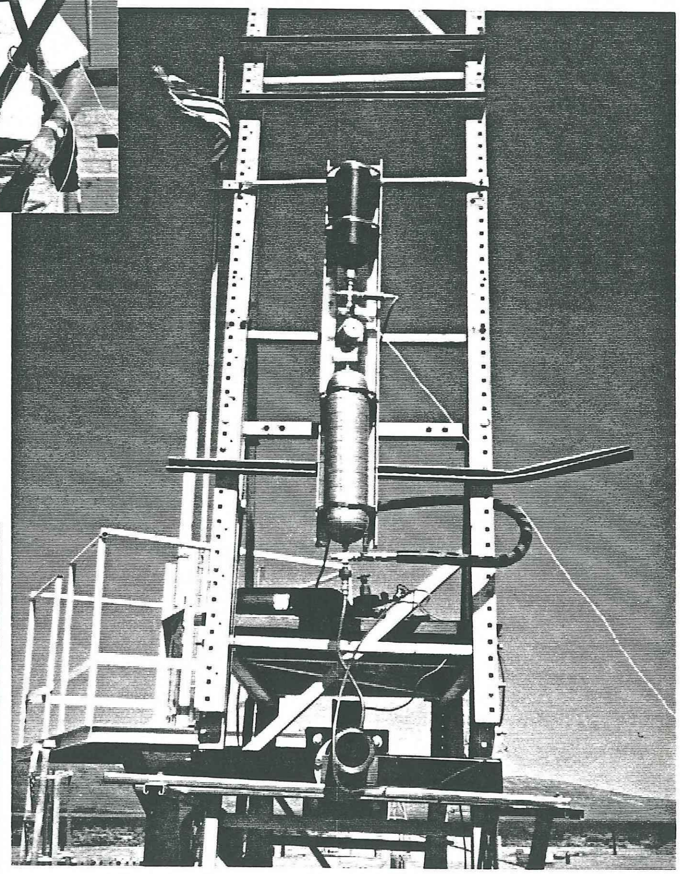


A schematic of the 450 lb. thrust LOX/HTPB hybrid rocket which was tested on September 28, 1996

LOX/HTPB Static Testing

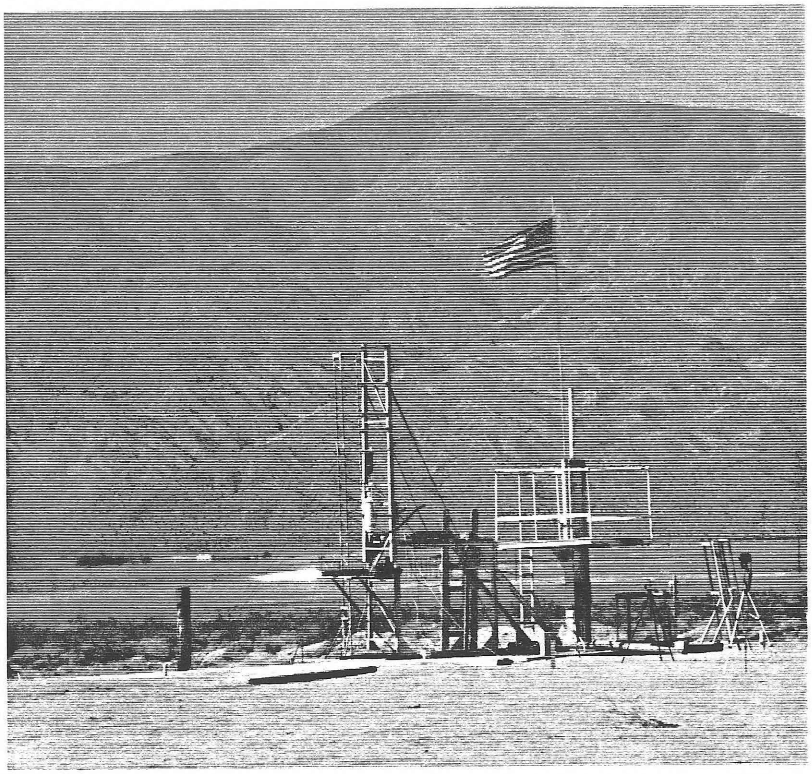


The motor is being bolted to the thrust mount and cradled on top of the unistrut support structure.

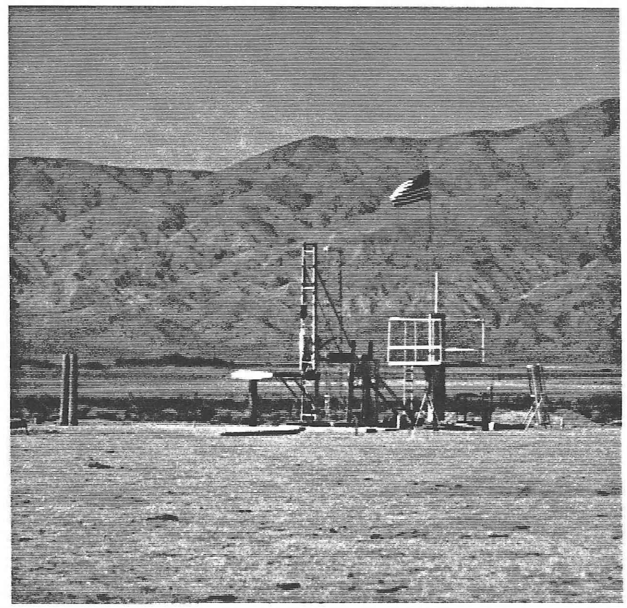


The test rig is completely plumbed except for the pressure transducers

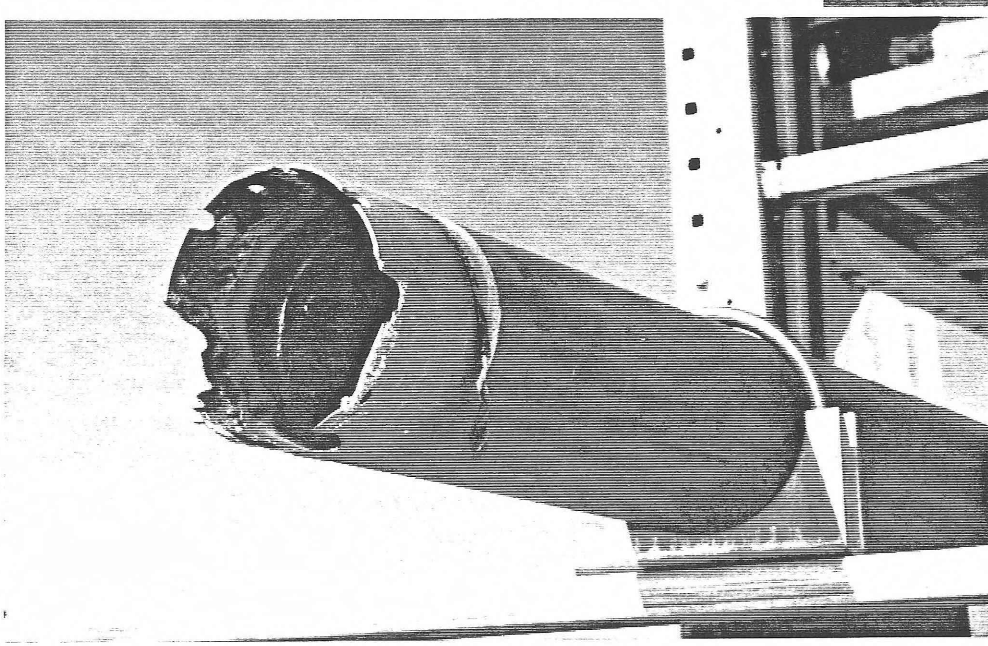
Keith is standing over the small LOX Dewar which was used to fill the D-2 run tank. Note the insulated line running from the Dewar to the bottom of the run tank. The firing was only minutes away.



The motor roars to life. This photo was taken immediately after ignition.

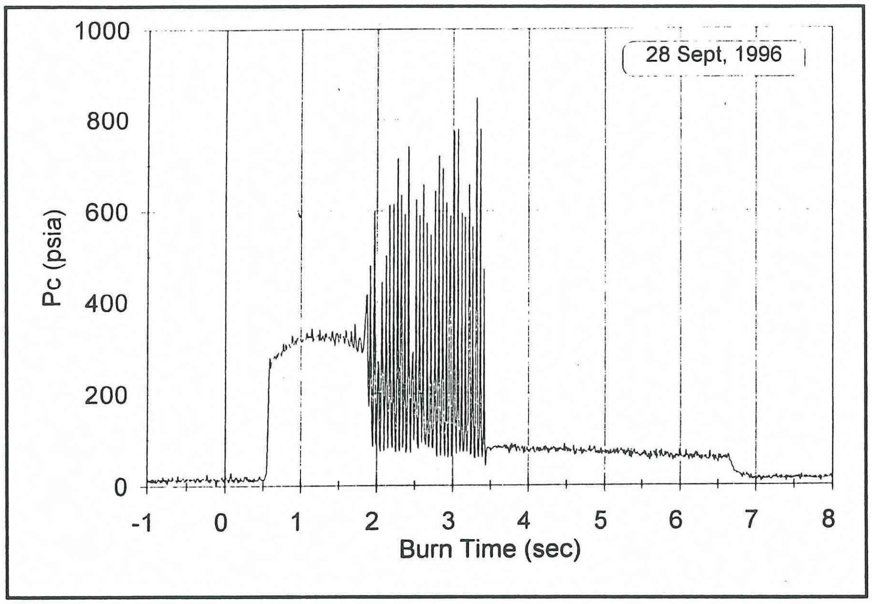


Approximately one second into the test, the motor produced severe pressure oscillations. This photograph was take at the peak of one of the pulses.

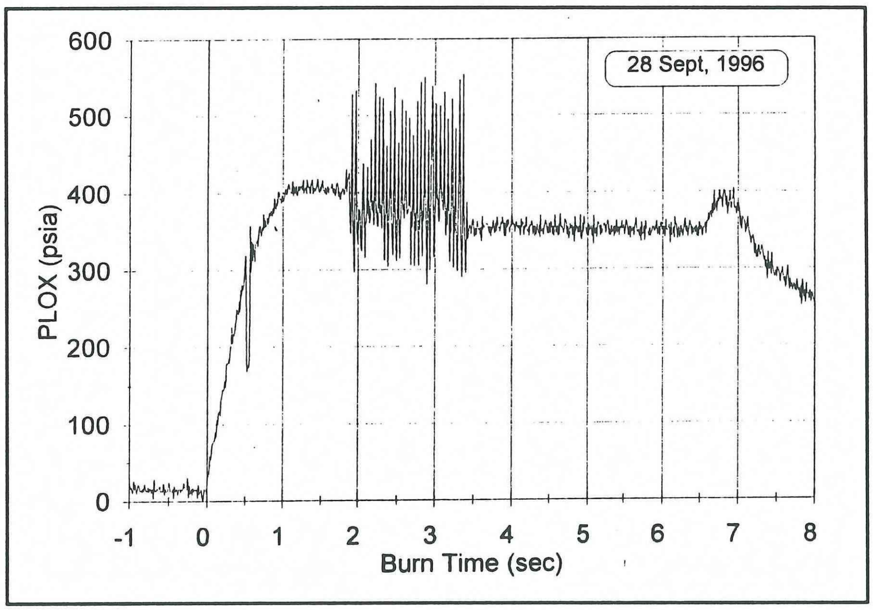


The nozzle was ejected from the motor shortly after the onset of the pressure oscillations. As this post-test photograph shows, the case was overheated and melted by only a few seconds of exposure to the exhaust gases.

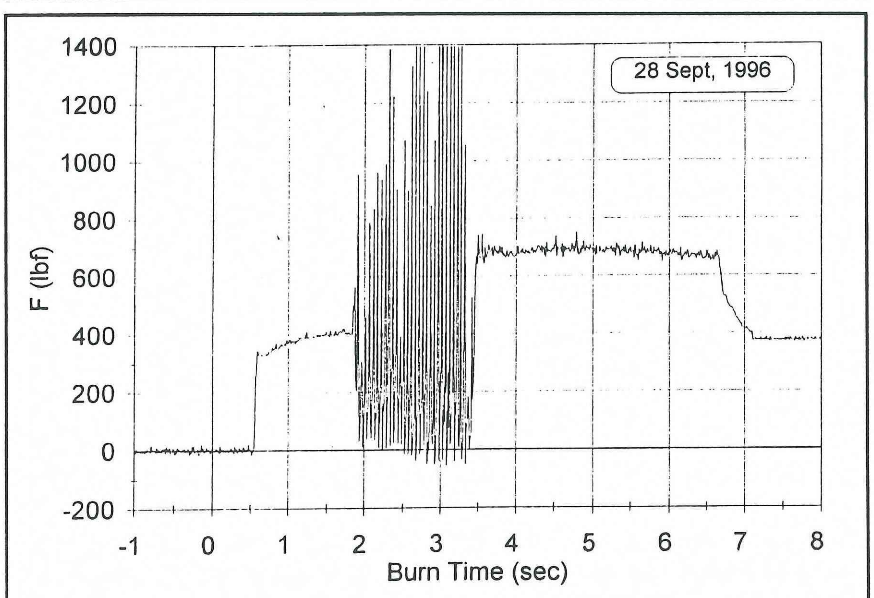
The chamber pressure trace shows normal operation for about one second before the motor experiences very high amplitude pressure oscillations. The oscillations are most likely due to a "flame holding" instability coupled with the feed system.



The LOX tank pressure clearly shows the influence of the chamber pressure oscillations on the feed system.



Thrust data shows the motor operating at 400 lbs of thrust prior to the oscillations. The load cell was destroyed by the hammering of the oscillations so thrust measurements during and after the oscillations are unreliable.



Nitrous Oxide/HTPB Rocket Bike

The rocket bike was built over a weekend as a joke. I hoped it would work, but as usual my hybrids don't. It exhibited a terrible combustion instability and wouldn't really stay lit. It did manage to push me around a little bit. After re-engineering and TESTING, the bike will run again. - Keith

The propulsion system uses two 6-lb. nitrous oxide tanks fed through a Marotta valve to the motor. The motor is fabricated from a 4" diameter, 10" long galvanized pipe nipple. The small copper line keeps the motor running between bursts of thrust.

A static test was conducted which showed motor performance to be somewhat lacking.

The manned test proceeded in spite of the static test results. Here Keith is pedalling to get some speed up while the motor is idling.

Design, Construction and Testing of a Really Bad Idea

by Scott Claflin

Let me start this report with a disclaimer. The rocket described herein detonated during a static test due to an incompatibility between the fuel and oxidizer. No one should build a similar rocket.

The purpose of the project described herein was to demonstrate low cost, safe, simple rocket technology which could be utilized by any interested rocketeer. The rocket was indeed low cost and simple. It's safety left something to be desired.

DESIGN

From the outset of the project, I wanted to build a hybrid rocket (that is, a rocket which uses a liquid oxidizer in combination with an inert solid fuel). The first design parameters to be chosen were the rocket engine propellant combination, thrust level, and chamber pressure. To find an appropriate low cost, smooth burning fuel, 39 fuel screening tests were performed using a 3 lb. thrust gaseous oxygen (GOX)/solid fuel test motor [*See "Fabrication, Testing and Analysis of an Oxygen/Plexiglas Hybrid Demonstration Rocket," RRS Newsletter, Vol. 52, No. 1, Feb. 1995*]. Tar paper promised to be a very low cost, high performance fuel so the chosen propellant combination for the full scale motor was liquid oxygen (LOX) and tar paper which was coated with a tar-based roofing cement. The roofing cement coating on the tar paper increased the density of the tar paper by over 30% so more fuel could be contained in a smaller volume. The design thrust level was chosen as 1670 lbs. The original plan was to cluster three thrust chambers to create 5000 lbs of thrust, thus each chamber was to produce 1670 lbs. of thrust. The chamber pressure of 250 psia was chosen with consideration to pressure capability of available propellant tankage (since the engine is pressure-fed from the tanks).

Overall Motor Design

The overall motor design was based around an 8-inch diameter, 48-inch long stainless steel case. The case was 1/8-inch thick. The throat section was formed by a machined piece of graphite which was retained with a mild steel ring at the exit of the motor. The injector is a two piece aluminum assembly.

Fuel Grain Design

The key to successful design of a hybrid fuel grain is to provide sufficient fuel burning surface area (to get the proper fuel flow rate) while minimizing the motor volume and minimizing the amount of fuel remaining at burnout. To meet these criteria, a hybrid fuel is typically manufactured with long pie-shaped passages or ports extending through the fuel from the injector end to the nozzle end. In cross-section, the fuel looks like a wagon wheel.

Data from the GOX test motor indicated that the tar paper-roofing cement fuel fuel burned at about 0.03 inches per second. To achieve a fuel burn rate (flow rate) of 2.5 lbs/second, a fuel surface area of 2800 square inches was required. This surface area proved too large to fit in the metal case I had. As a compromise, it was decided to run the motor with slightly less fuel flow and slightly more oxidizer flow than would be needed for optimum performance. The final design incorporates five fuel ports to give a fuel surface area of 1370 square inches. The fuel ports were 40 inches long.

The fuel was fabricated by laying out long sheets of tar paper and coating the sheets with the tar-based roofing cement. The sheets were then tightly wrapped around a triangular wooden mandrel which was the same shape as the fuel port. This was done

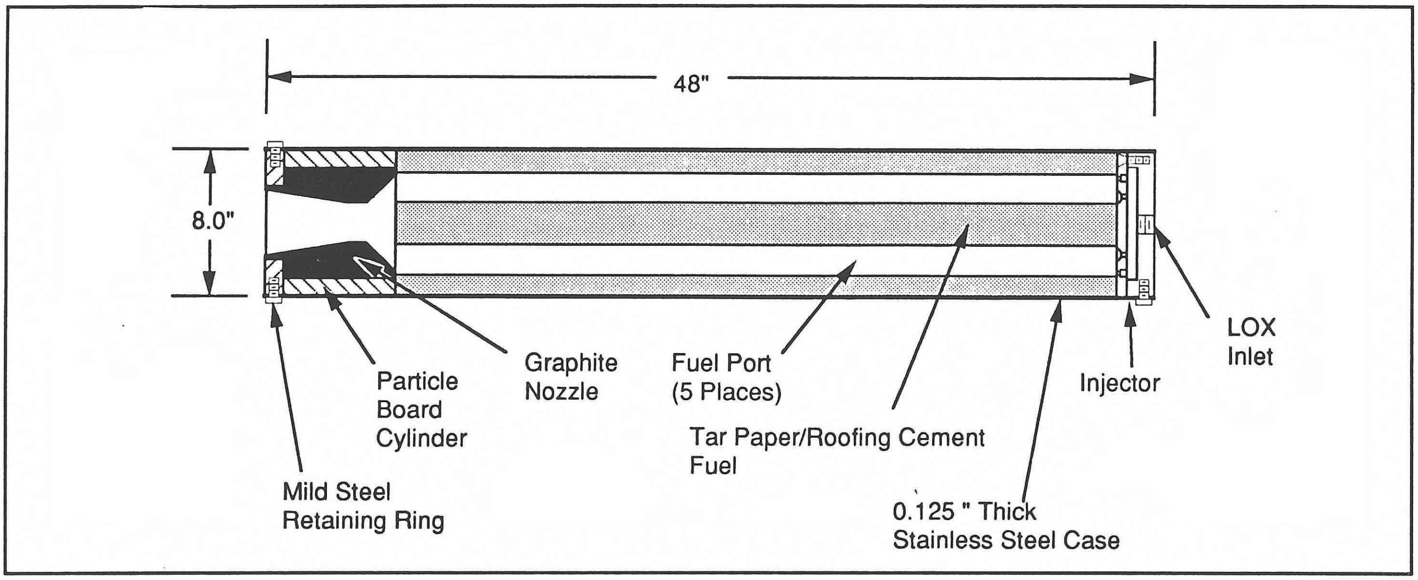


Diagram of the 1670 lb. thrust LOX/ tar paper hybrid motor.

five times. Each of the five rolled-up fuel segments was stacked inside the motor case to form the fuel grain. The wooden mandrel was removed after each segment was inserted. Getting the last fuel segment into the motor was quite difficult and required considerable coaxing with a sledge hammer.

Injector Design

The design of the injector was started by choosing the type of injector element to be used. As with any rocket injector, it was desirable to atomize the oxidizer as the oxidizer leaves the injector. To accomplish this without having to drill precise impinging orifices, a novel injection element called a "fan former" was used. A fan former element is fabricated by intersecting a drilled hole and narrow, circular slot. Each element forms a fan of LOX which rapidly atomizes and vaporizes. Three "fan former" elements were placed in a triangular arrangement aligned with each port (fifteen elements total).

LOX Tank

After consideration of the options, it was decided to fabricate the LOX tank from surplus stainless steel soda water fire extinguishers. Most are rated to 350 psia and one was hydrostatically tested to 750 psia without failure. Since they are stainless steel, the tank is compatible with LOX. Also, each surplus extinguisher cost only $3.00. Each fire extinguisher holds just over 2.5 gallons so it was decided to cut the ends off of two extinguishers and then weld them together to create the tank. A 1" stainless steel flare AN tee was welded to the outlet of the tank. At the head end of the tank a pressurant gas diffuser was welded into place.

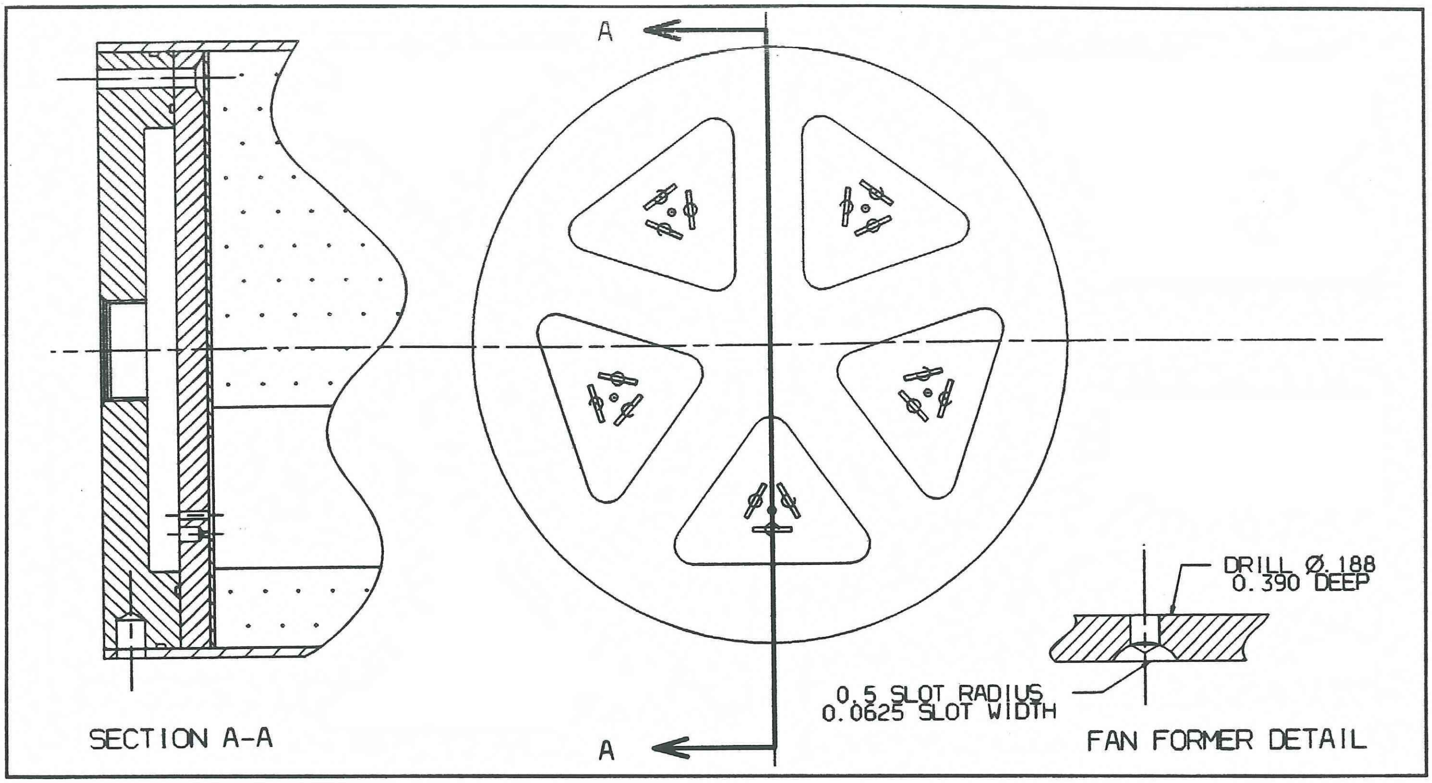
Valves

The main LOX valve for the static test was a 1-inch Annin valve actuated with a pneumatic cylinder. A LOX compatible solenoid valve was used as the LOX tank vent valve. A 1/2-inch solenoid valve was used to supply helium pressurant to the LOX tank. A mity-mite regulator controlled the pressurant flow.

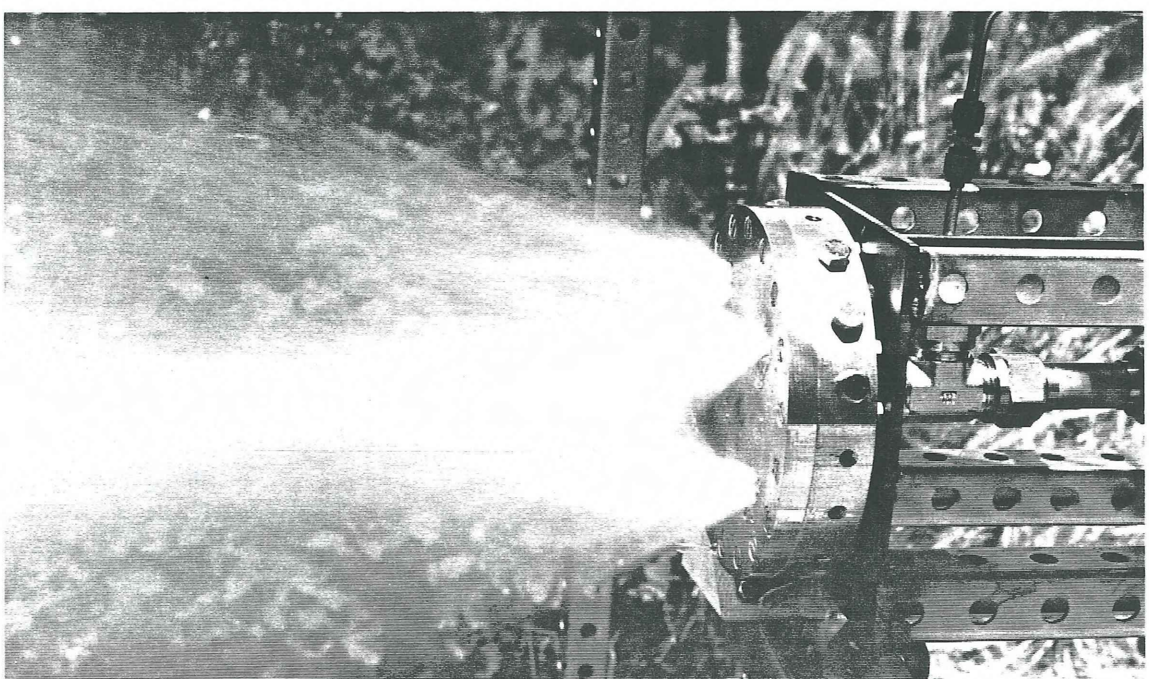
STATIC TESTING

First and Last Static Test, July 1, 1990

In preparation for the first static test, a static test stand was fabricated out of industrial shelving. The



The injector used 15 fan former element arranged in groups of three. A showerhead orifice was added at the center of each set of fan former elements after the water flow test to slightly lower the injector pressure drop.



Water flow testing proved the effectiveness of the fan former elements in atomizing the flow.

static test stand was then erected at the MTA. The static test stand was butted against the existing 18" I-beam which protruds vertically from a concrete pad. The static test stand was bolted to the concrete pad and was further restrained by guy-wires.

The igniter consisted of balls of steel wool to which a voltage would be applied. This method of igniting hybrid motors has been used with great success on small motors. In a pure oxygen environment the steel wool "explodes" when electrically heated. Each port had an individual steel wool ball and two electrical leads which protruded out the nozzle.

The ignition system proved to be the motor's undoing. An attempt was made to test the motor at approximately 10 a.m. on July 1, 1990. The LOX tank was filled and pressurized. The countdown commenced, cameras were activated, the igniters were energized and the main LOX valve was opened. Instead of the roaring to life, the motor merely spewed LOX from the nozzle. The main LOX valve was quickly closed. An ignition failure is always a serious situation in rocketry and everyone was told to remain under cover. The situation with this motor was especially serious since LOX mixed with tar forms a high explosive. The test crew and all spectators waited an hour for the LOX to evaporate out of the tar paper fuel.

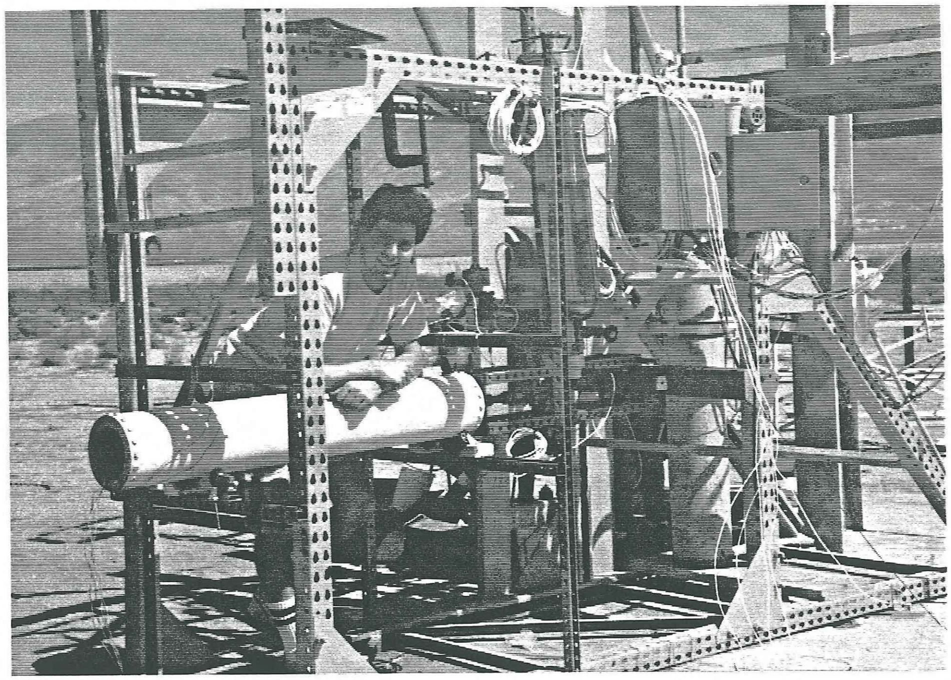
After waiting an hour, the test crew approached the test stand to remove and inspect the igniters. A quick test showed that the control panel could not supply sufficient current to all five steel wool balls to heat them. An alternate ignition system was devised in which braided strands of Thermalite fuse were snaked through the nozzle up each port. All five braids of Thermalite were brought together outside the motor so the ignition of each strand could be observed.

The LOX tank was refilled and repressurized and the countdown was reinitiated. The Thermalite was electrically initiated outside the motor and allow to burn into each port. The main LOX valve was opened and the motor ignited. The chamber pressure ramped up beautifully for 0.400 seconds then the motor detonated. The detonation knocked all of the windows out of the blockhouse and demolished the static test stand. The stainless steel case was turned inside-out and ripped to shreds; a piece of the case was found 1/4 of a mile away. The main LOX valve actuator was bent and the fitting on the bottom of the LOX tank had sheared off. The desert was littered with tar paper.

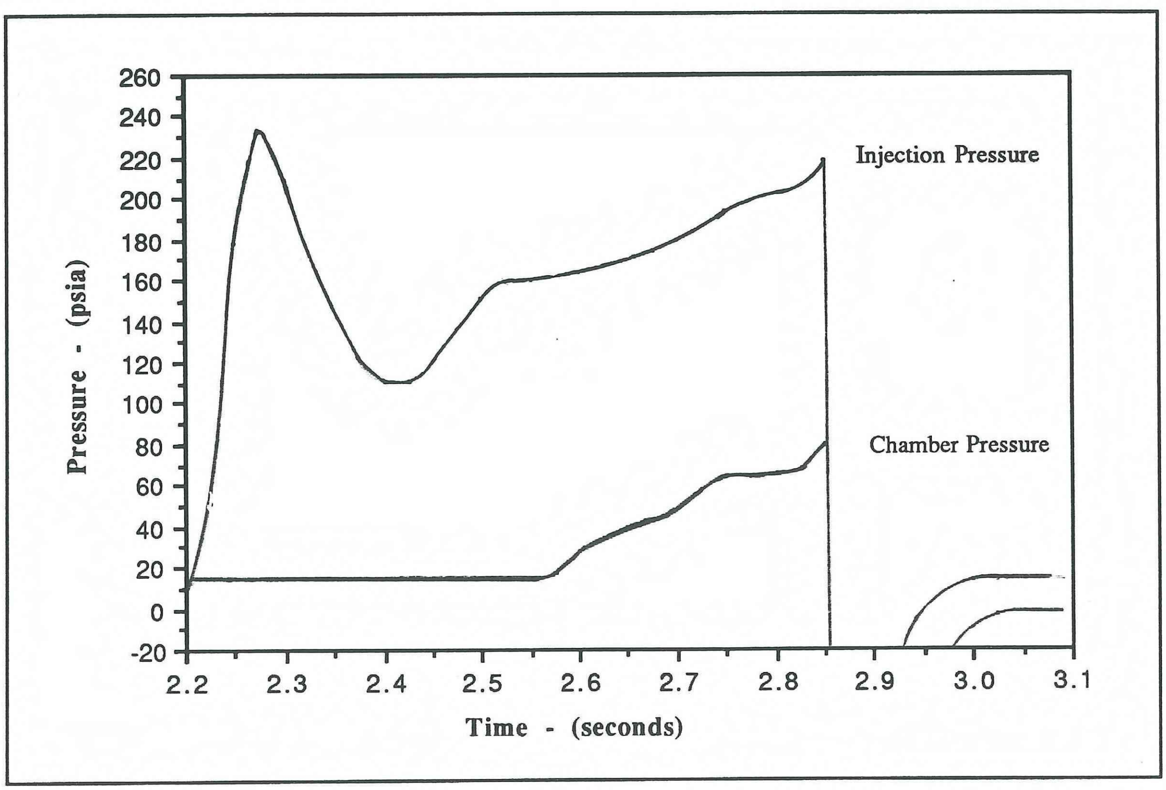
The fact that no one was hurt in the explosion is a credit to the safety precautions which are followed at all RRS firings. The test crew and all spectators were well protected in the blockhouse or observation bunkers.

The detonation has been attributed to one of two scenarios. First, the fuel was still sensitized from

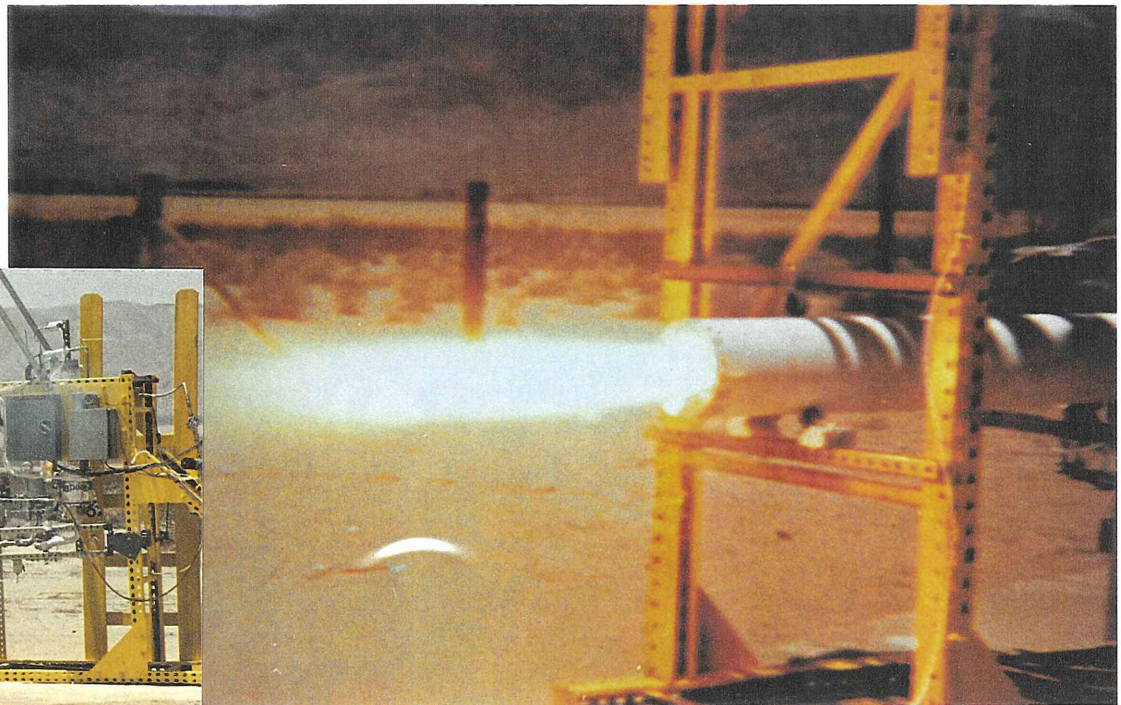
Mark Grant (top) and Gary Perkins (right) assist in installing the LOX tank and connecting the helium pressurant.

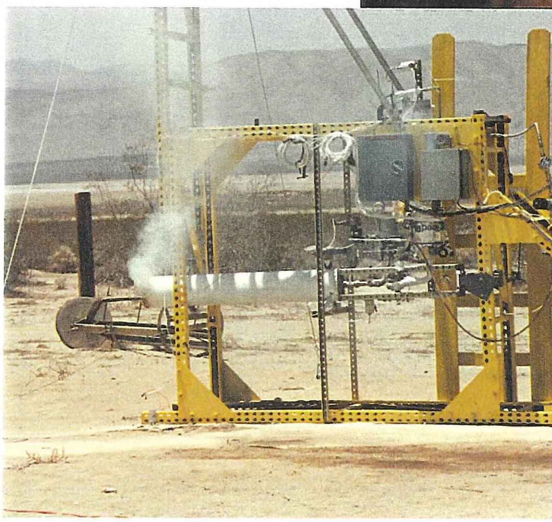


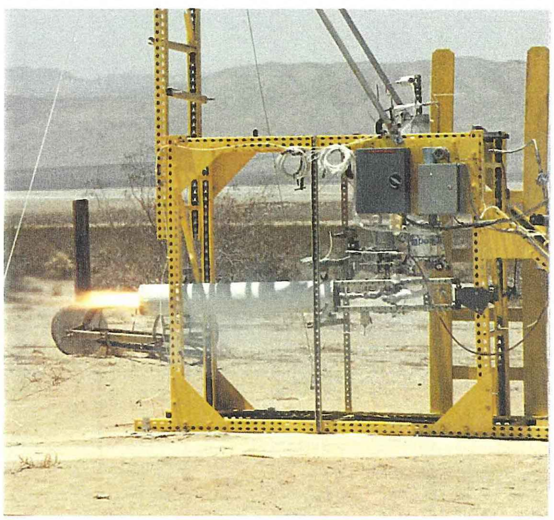
The static test assembly was mounted inside a framework of industrial shelving supports which carried the thrust load into the I-beam.

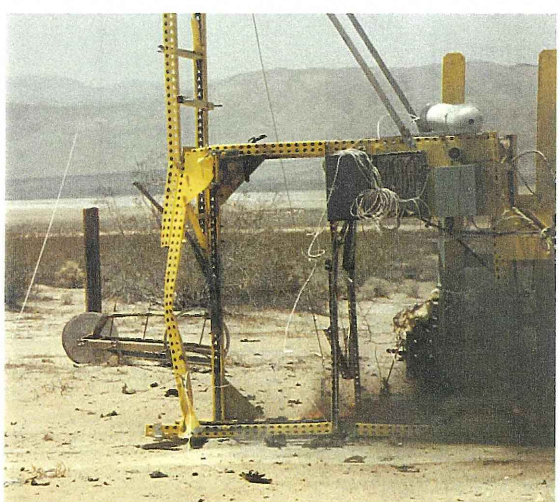


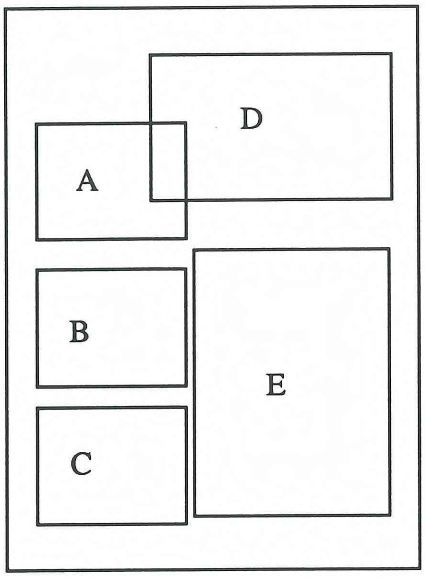
The chamber pressure and injection pressure traces looked normal...until the motor detonated.











A. On the second attempt to test the motor, thermalite fuse was snaked up each of the five fuel ports from outside of the nozzle. The ignition of the thermalite was easy to visually verify.

B. The motor ignites and chamber pressure rapidly ramps up. Now you see it...

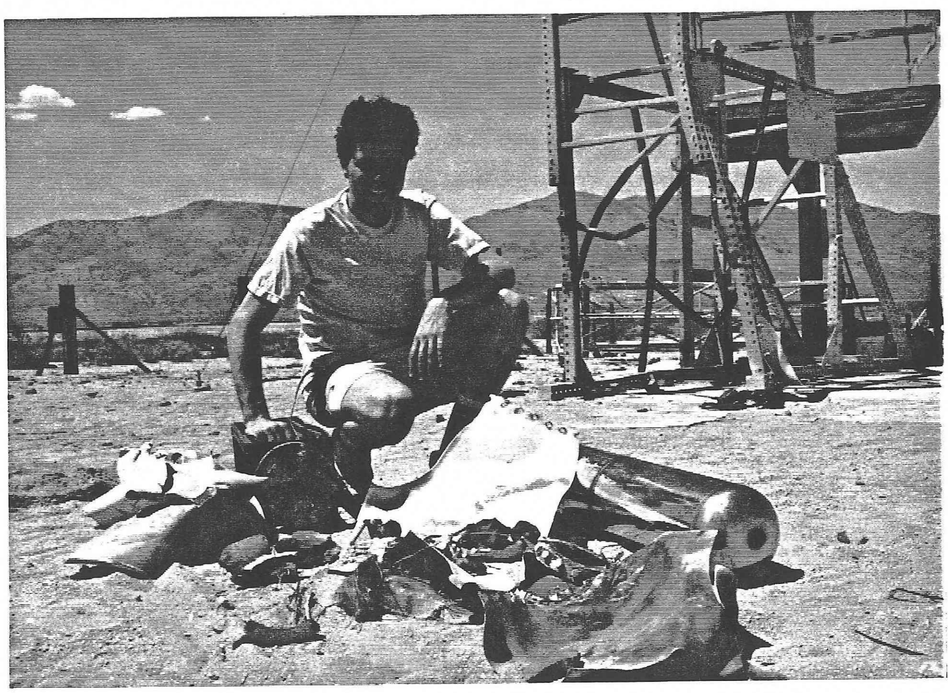
C. ...now you don't! The detonation obliterated the hybrid motor and did significant damage to the test stand. At the time this picture was taken, the personnel in the blockhouse were on the floor hugging each other in fear. Numerous expletives were also being uttered and recorded by the blockhouse video camera.

D. The remote camera captured the motor at peak performance just milliseconds before the detonation.

E. Amazingly, Bob Anderson captured the fireball milliseconds after the detonation. Notice how far the tar paper at the top of the picture had travelled (about 40 feet) within those few milliseconds. No one who witnessed the detonation will be able to forget the power of the blast.

the first ignition failure. In other words, sufficient time was not allowed for LOX evaporation from the fuel. Second, since the motor was ignited from the nozzle end, LOX was soaking the injector end of the fuel while the flame was propagating up each port. In either case, the cause of the detonation can be attributed to the high explosive which is formed when LOX is mixed with a thermoplastic polymer (like tar). Because of this danger, all work was stopped on any hybrid motors which use thermoplastic fuels.

It is somewhat ironic that one of the main reasons for pursuing a hybrid rocket was the claim of safety. Indeed, hybrids which utilize thermosetting fuels such as polybutadiene (synthetic rubber) are very safe and cannot detonate because oxidizers cannot be absorbed into the fuel. However, fuels which can absorb oxygen (such as tar) can be very hazardous and should be avoided. This was a very expensive, though momentarily exciting, lesson to learn.



The major pieces were gathered for a post-mortem. The motor case was literally turned inside out. The fitting on the bottom of the LOX tank sheared off cleanly. The graphite nozzle was shattered into a dozen or more pieces. The static test stand would eventually be rebuilt to support numerous liquid (and hybrid!) motor firings.

LOX/Particle Board Hybrid Rocket

Motor Design, Fabrication and Test

by David Crisalli and Brian Wherley

The purpose of this project was to try to develop an extremely simple, very low cost amateur experimental rocket that would have better performance than conventional zinc and sulfur rockets but be almost as easy to build. In addition, from a logistical standpoint, it was also desirable that it operate on readily available, inexpensive propellants and could be assembled from commonly available components. The avoidance of complicated and fabrication techniques would minimize both construction time and the use of specialized equipment such as metal lathes, welders, and milling machines.

Several concepts for producing a higher performance amateur rocket were contemplated. To increase the performance of a solid propellant rocket, higher energy propellant must be used. These propellants are often costly, dangerous, or difficult to process. With some propellants, they are all three. Transportation of mixed propellant is also regulated by law, usually resulting in the requirement to mix and load propellant at the launch site. This results in further difficulties concerning the mixing, loading, and curing of propellant grains under field conditions. This was not the best option for us.

An all liquid propellant rocket was not only an option, but was being done routinely by several RRS members. However, the tankage, control, plumbing, injector complexity, etc., required for a bipropellant system did not readily lend itself to a simple, easy to assemble system.

A hybrid design was the third option. While hybrid rockets have their own type of peculiar problems, from an amateur standpoint they are very simple in concept. They can be built with fewer parts and use low cost, available propellants. This looked like the best place to start.

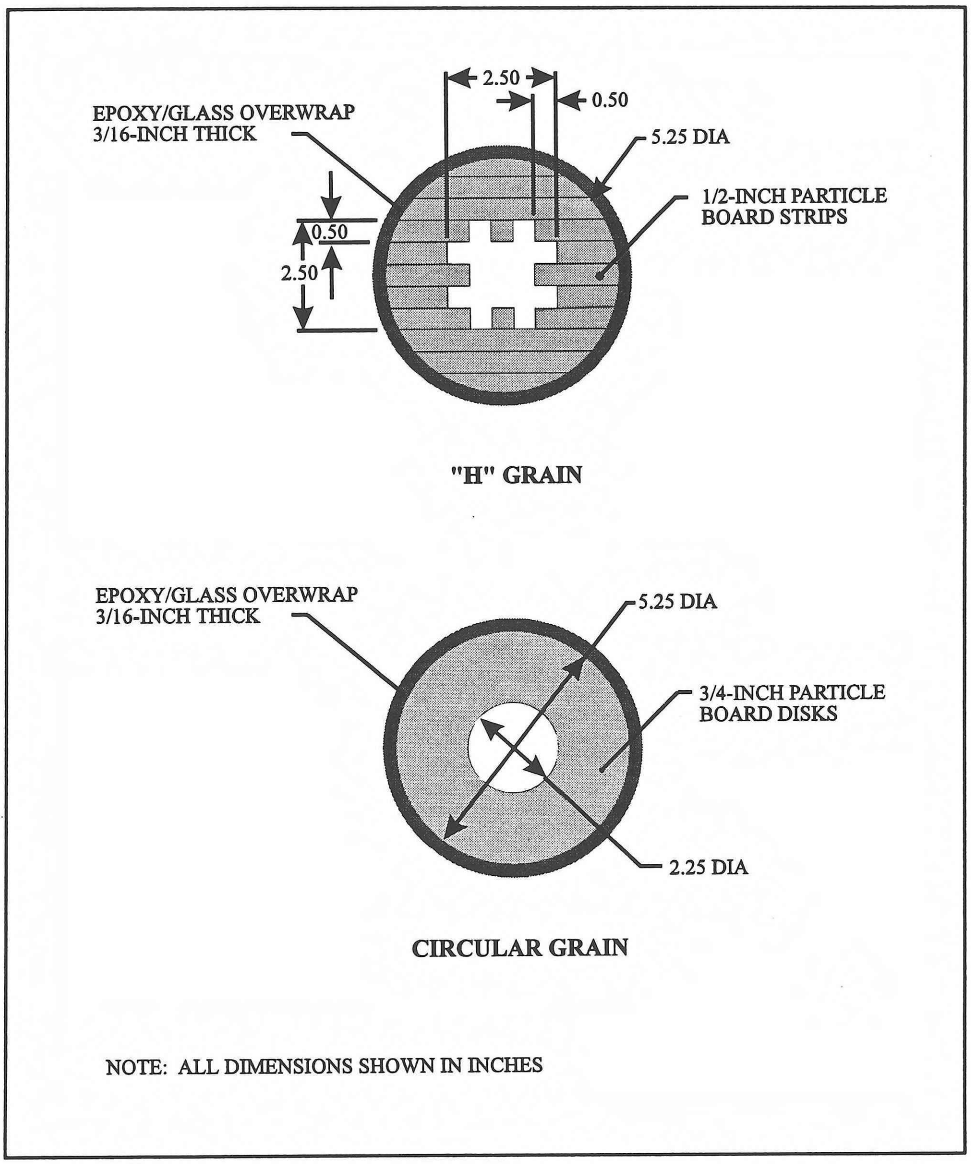
A rudimentary design was developed and included a motor with a wood or plastic fuel grain combined with liquid oxygen as an oxidizer. The LOX would be pressure fed into the engine with helium from a small storage bottle. The entire propulsion system would be enclosed in a composite or phenolic fuselage.

The engine design included a metallic motor housing and a graphite nozzle. Sized to produce 620 pounds of thrust at a chamber pressure of 250 psia and with a burn duration of 12 seconds, all required design calculations were completed and hardware fabrication was initiated. The injector would be a simple plate perforated with the required number of oxidizer orifices and would be attached with bolts to the head end of the thrust chamber. Based on earlier success with a small hybrid test motor running on gaseous oxygen and various fuels, particle board was a good fuel candidate for this vehicle. A particle board fuel grain with a simple round central port was selected. Although this sounds straight forward, several calculations and rudimentary regression rate analysis were conducted to evaluate various port configurations. (These calculations indicated that the circular port configuration was short on surface area. However, we believed it had a chance of working well enough for this application and it would be simple to build. The grain could be laminated out of disks with their centers cut out. These could be produced quickly with common wood working tools.

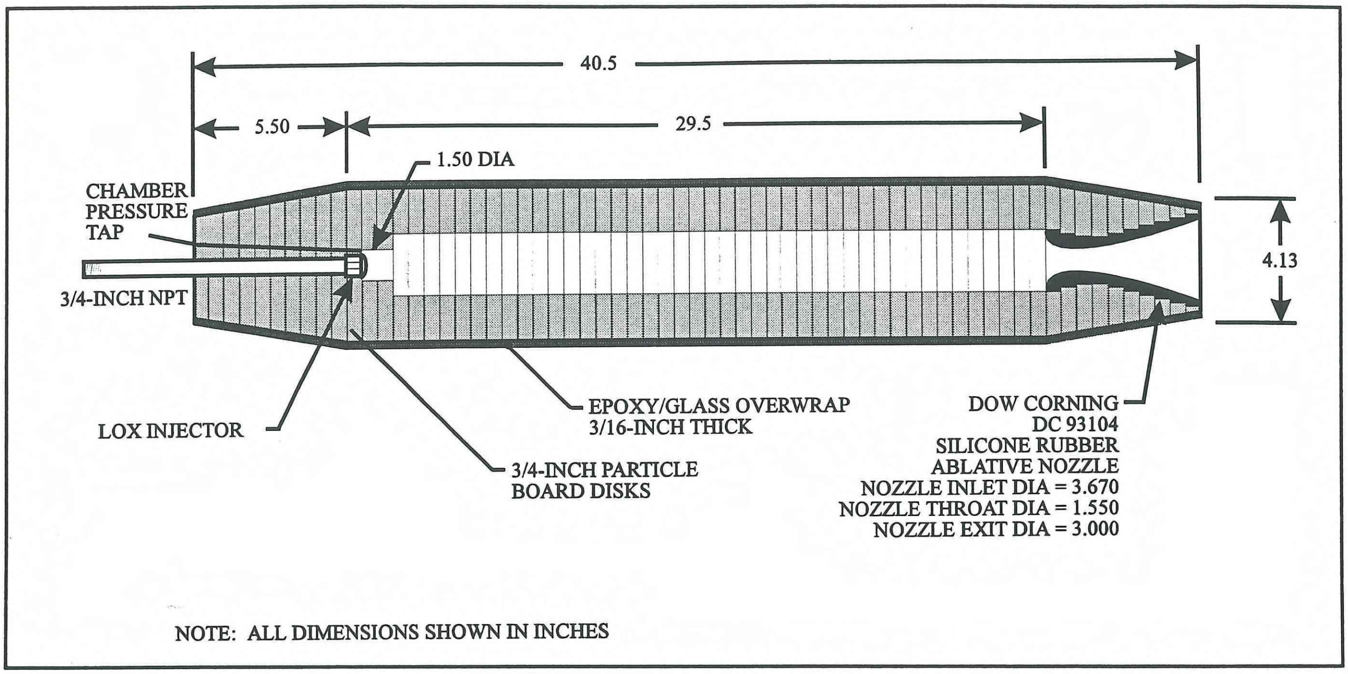
Because of the surface area question, a second, horizontally laminated grain was to be built by gluing up strips. This resulted in an "H" shaped center port with more surface area than the circular one. The intent was to test the circular ported grain first and then test the "H" section grain. The performance would then be compared between the two configurations. Two grain regression rate measurement devices were also designed to be built into the fuel grain to provide data and to anchor the regression rate estimates.

As the grain was being completed, the idea of using a metallic motor case was reevaluated. The rigidity and shape of the fuel grain suggested that a composite case might be applied directly over it. If the completed grain were to be configured with an externally tapered graphite nozzle and a tapered injector support shell, the entire assembly could be wrapped with insulation, "S" glass, and epoxy resin. This would form a more than adequately strong motor case and eliminate almost all of the major metal working.

The circular ported grain was completed first, followed by the tapered head end plug that would support the LOX injector tube. This tube was also a much simpler method of admitting LOX into the chamber than was the original injector concept. The graphite nozzle was machined next and was given the same exterior



A comparison between the circular grain and H-grain cross-sections.

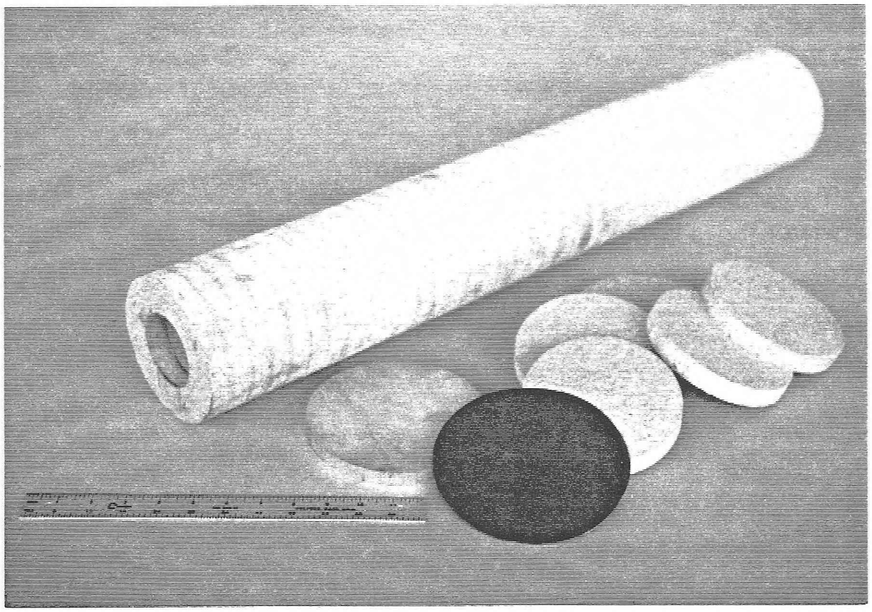


A cross-section of the composite hybrid motor.

taper as the injector support plug. When wrapped with the glass/epoxy shell, this tapered shape would provide mechanical retention of both the nozzle and the injector plug.

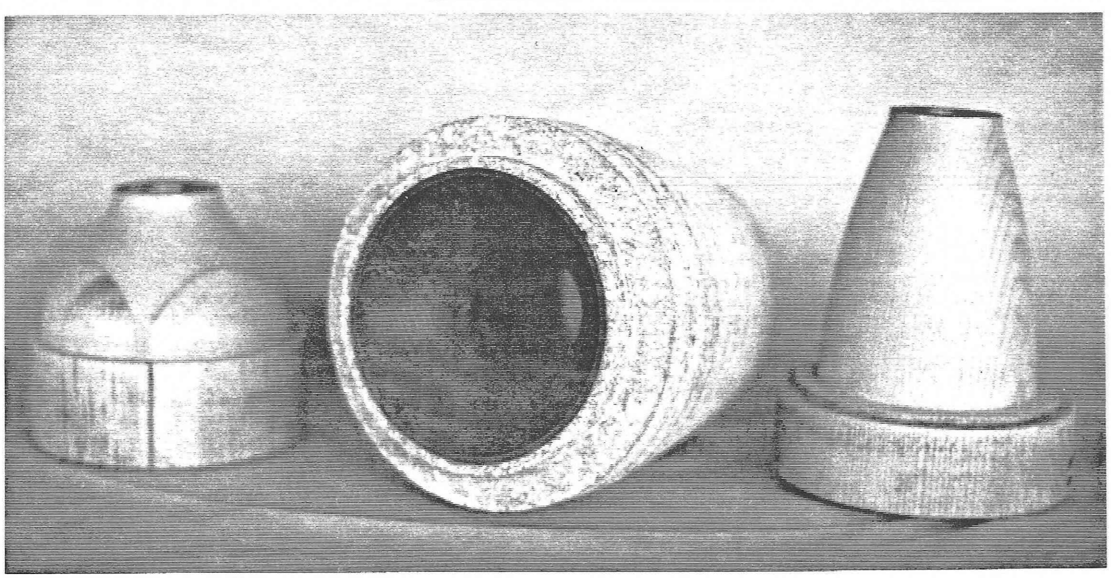
The fabrication of the nozzle, while straightforward, did require the use of a lathe. In an effort to make this step less complicated, another nozzle fabrication process was devised based on the use of a castable ablative material available from Dow Corning (DC 93-104). For this design, a particle board shell was laminated in the same manner as the fuel grain. This piece would serve as both the structural shell of the nozzle and as the mold for casting the ablative. A contoured nozzle form was turned out of two pieces of wood assembled on a piece of half inch "all thread" rod. When completed, the two halves of the nozzle form could be separated at the throat plane. As a final finishing step for the nozzle form, both halves were heavily lubricated with silicone and waxed. This would prevent the ablative material from sticking when the nozzle was cast.

To produce the finished nozzle, we started by placing the nozzle shell over the divergent portion of the nozzle form and sealed the exit end circumferential joint with wax. The "all thread" center bolt was then inserted so that it protruded out of the upper end of the shell. The ablative material was then mixed according to instructions provided with the material, and was poured into the shell filling it above the end of the nozzle form. Enough material was used here to insure that when the convergent section of the nozzle form was in place there would be excess ablative to squeeze out as the mold was completely closed. The ablative material was also mixed in a vacuum bell jar to minimize bubbles. The upper portion of the nozzle form was then slid down over the "all thread" and pressed into place. The rod nuts on either side of the nozzle form were then tightened slowly until the forms were completely seated and all excess ablative had been squeezed out. The ablative was allowed to cure and the form core was removed. This left a perfectly formed nozzle shape of ablative material bonded into the nozzle structural shell. The casting process had worked well and it only remained to see how the nozzle would work in hot fire tests.



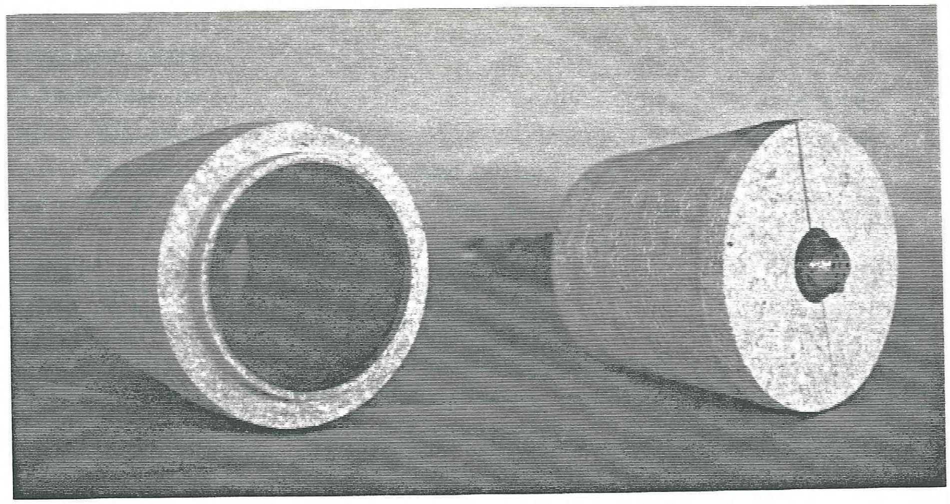
Spare particle board disks and complete laminated fuel grain.

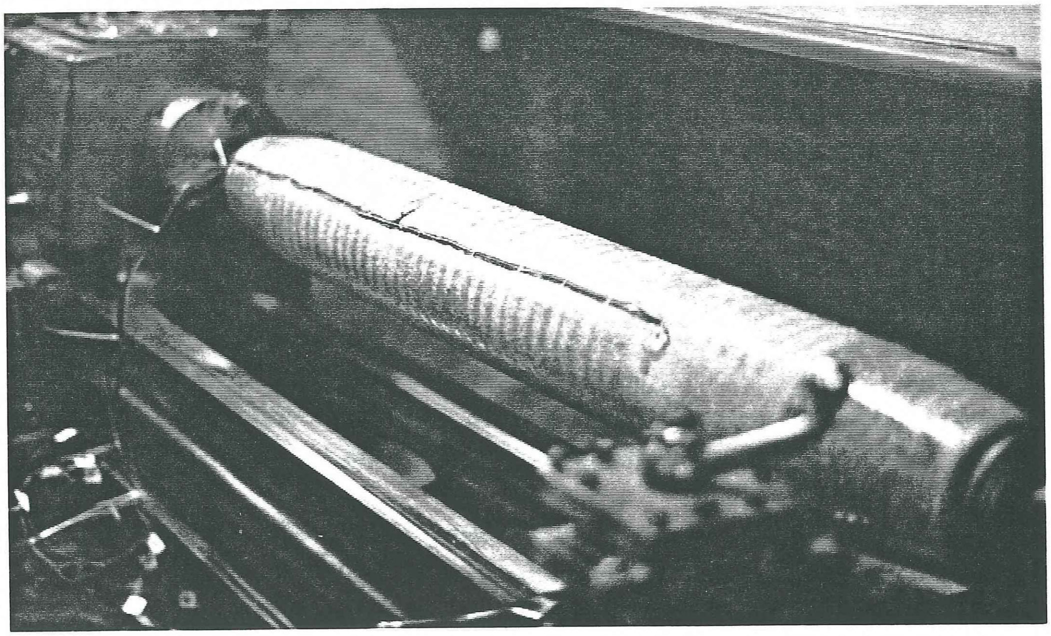
The laminated nozzle shell and the assembled nozzle form for casting the ablative liner. The form disassembles at the throat plane and was turned out of commonly available Douglas Fir.



The completed cast ablative nozzle with the two halves of the nozzle form.

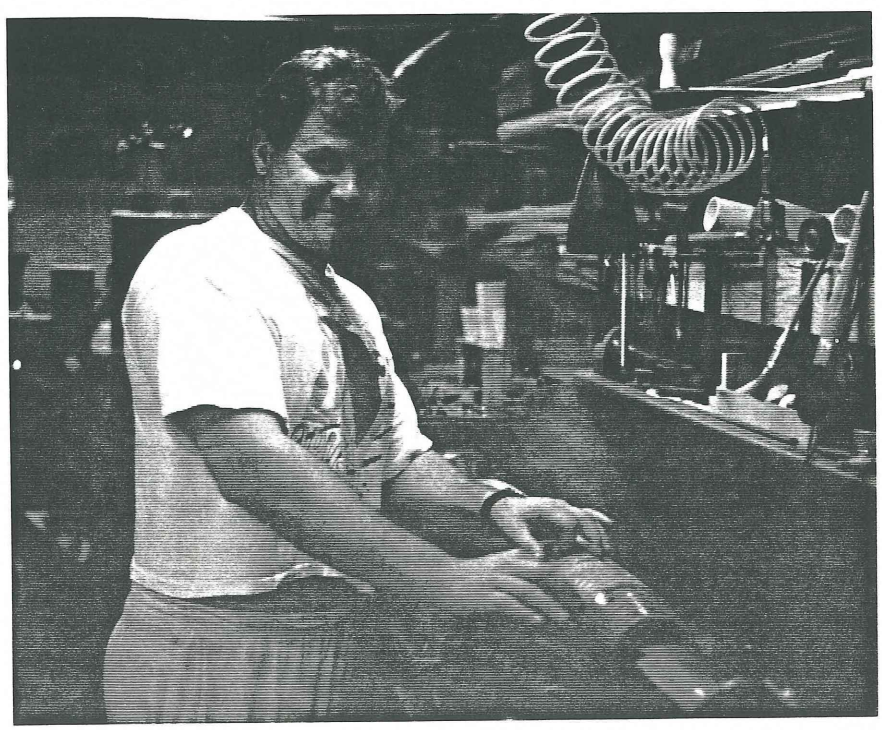
The completed ablative nozzle and LOX injector. The brass injector pipe was epoxied into a laminated particle board plug cut to the same exterior shape as the nozzle shell.





The regression rate measurement devices and wiring installed in grooves cut into the grain.

Brian Wherley starting the fiberglass overwrap on the hybrid engine.



The injector was constructed from a half inch standard brass pipe nipple available at any plumbing or hardware store. A standard brass pipe cap was installed on one end after having been drilled with seven small orifices. These were the LOX injection holes and were arranged with one in the center surrounded by six additional holes. All the holes were the same size and their combined area gave the appropriate LOX injection area. This tube was then epoxied into a plug of particle board laminated and tapered to the same dimensions as the exterior of the nozzle shell. A six inch square aluminum plate 0.375" thick was added to the top of the injector plug to serve as an attach point to the thrust mount. The plate was drilled in all four corners with 0.375" holes on a 5.25" bolt circle to match the test stand thrust plate.

The completed injector and nozzle were next bonded to the laminated fuel grain. The regression rate devices were installed along with the required wiring. The finished assembly was then wrapped with fiberglass cloth and epoxy resin.

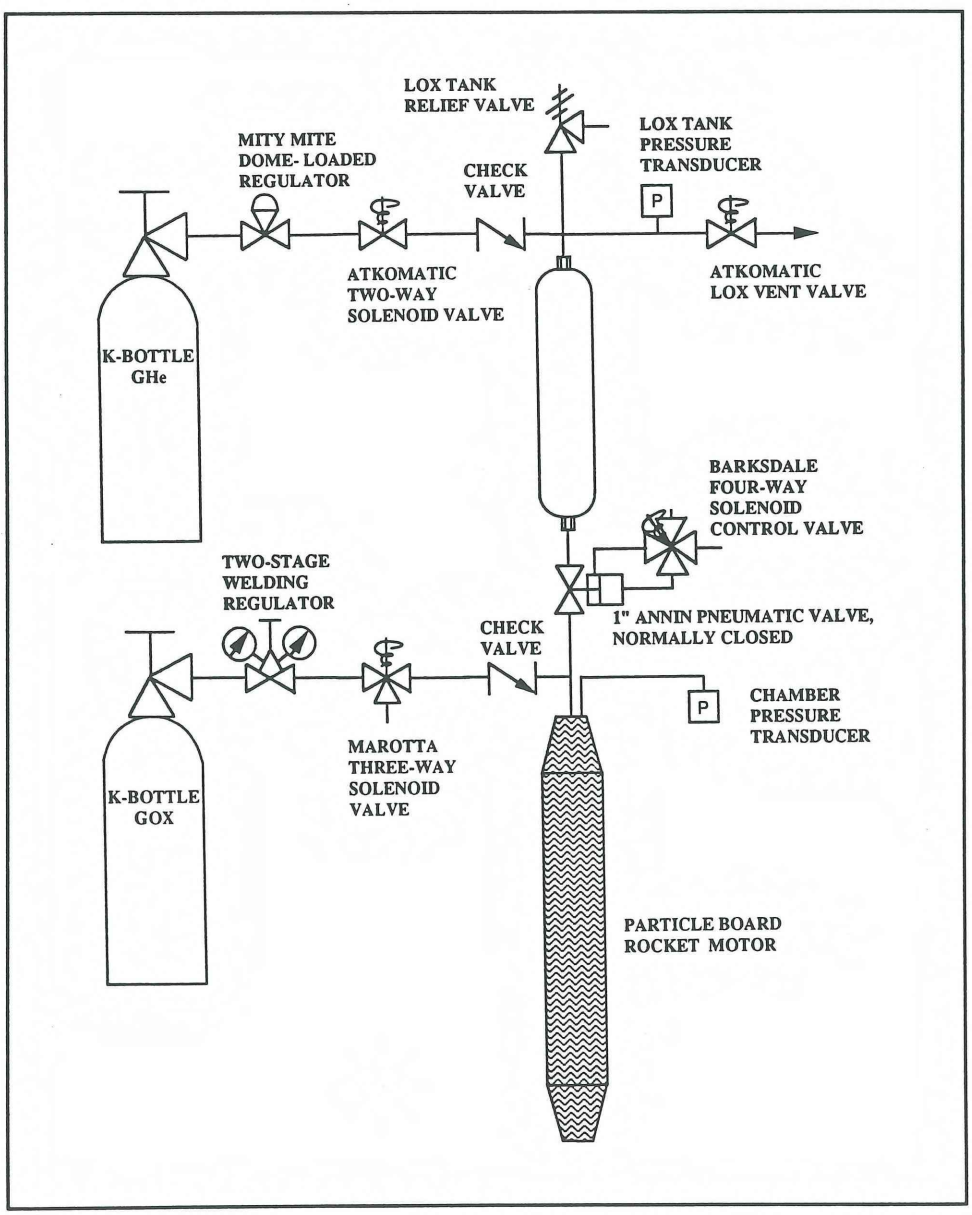
In the flight configuration, LOX would be pressure fed from a 500 cubic inch stainless steel tank and into the engine through a burst diaphragm assembly. The flight helium bottle would be pressurized to 2000 psi and a small three way toggle valve equipped with a regulating orifice would be used to control helium flow to the LOX tank. The valve would be spring loaded to the open position and would be controlled on the flight vehicle by means of an exterior pneumatic pin puller. When activated, it would withdraw a pin protruding through the skin of the rocket and allow the spring to open the toggle valve. Activation of the pin puller also causes it to fall away from the vehicle as the pin is withdrawn. The flight LOX tank vent valve was to be a spring loaded 1/4" brass ball valve again actuated with an external pin puller.

For static testing, however, pressurant gas would be supplied directly from the test stand "K" bottle through a regulator. The LOX flow would be controlled through a stand mounted, pneumatically actuated Annin valve. The flight LOX tank, a D-2 breathing oxygen tank, would be used for the test.

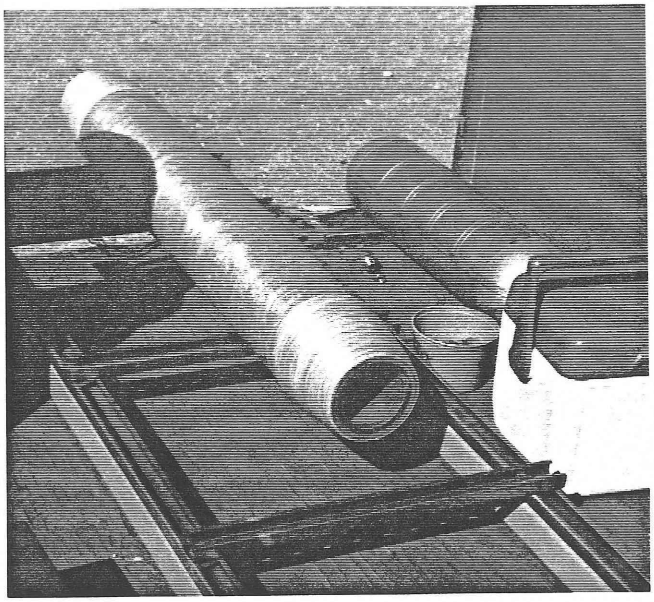
The last design issue to be addressed was the method of ignition. The small gaseous oxygen hybrid mentioned earlier had been successfully ignited time and again by passing gaseous oxygen (GOX) over a ball of steel wool mounted at the injector end of the fuel grain. With GOX flowing through the steel wool, 110 volts AC were applied to two electrodes contacting the steel wool. A wooden dowel, with two electrodes mounted on the end, was inserted through the nozzle throat serving to hold the steel wool in place against the GOX flow and to provide electrical contact. When the 110 volt potential was applied, the steel wool instantly ignited in the pure oxygen environment. This, in turn, showered the entire inside surface of the fuel grain with extremely hot (> 5,000 degree F) metallic plasma. Ignition of the fuel grain was instantaneous and dependable.

To ignite this larger hybrid, this same system was to be used. A "T" was installed in the LOX plumbing just upstream of the injector. A 1/4" LOX compatible check valve was installed at the "T" and plumbed to a source of gaseous oxygen. The GOX was supplied at low pressure (< 75 psig) from a small welding tank through a standard welding regulator and a solenoid shut off valve. The solenoid allowed remote initiation of GOX flow from the blockhouse. The ignition sequence would be as follows: The GOX solenoid would be opened initiating the flow of oxygen through the engine. Depressing the igniter button on the control panel would send 110 VAC to the steel wool ball held in the chamber with a dowel through the throat. The engine would start and run at some very low thrust level burning GOX and a minuscule amount of fuel. When ignition was verified visually, the "FIRE" button would be depressed opening the main LOX valve. As the LOX entered the injector at high pressure, the GOX ignition system check valve would close checking off the ignition system oxygen flow.

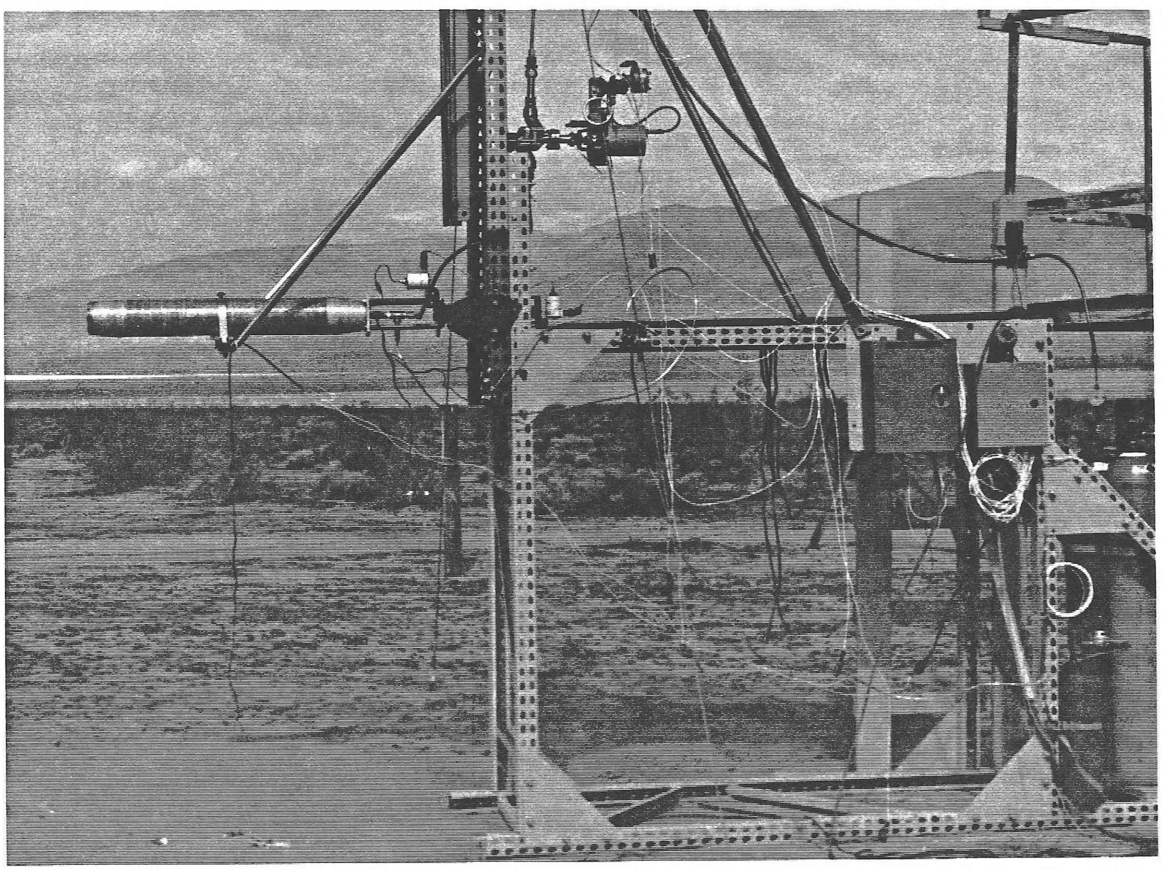
All the hardware for this system was completed by March of 1991 and the test was scheduled for the 16th of that month. The test was the last one of a series of four liquid rocket tests conducted on that date Test set up had started, just after Steve Palm's firing, at 10:00 PM on an abysmally cold night. It was difficult to install hardware and plumbing with gloves on, but hands would quickly become numb without them. Much of the apparatus had to be assembled in place, but all was ready for liquid oxygen loading by 11:30 PM and we were ready to start the hot fire test by 11:45 PM. The test stand was evacuated and we retreated to the safety, and relative warmth, of the blockhouse. The count commenced and at T-5 seconds the ignition system GOX valve was opened. At T-1 the steel wool was electrically ignited and engine ignition visually verified. At T-0 the main LOX valve went open. Although the engine remained lit, there was not the expected, and now familiar, roar as the engine came up to full power. In fact,



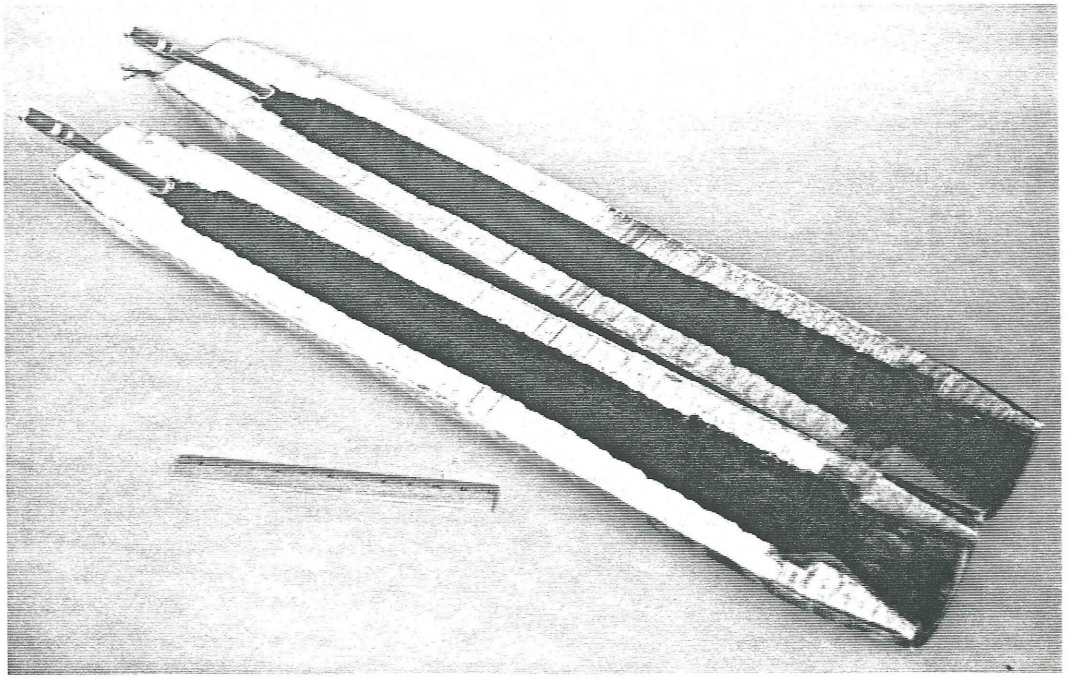
LOX/particle board hybrid rocket test system schematic



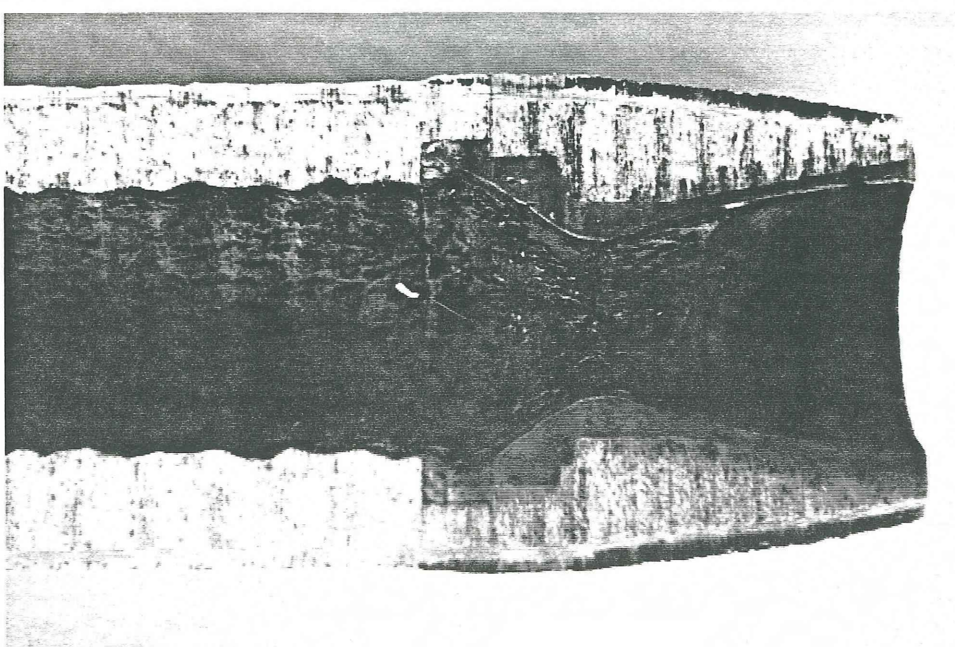
The LOX tank, completed motor, and support structure awaiting installation on the test stand on 16 March 1991.



The hybrid motor installed on the test stand and photographed here the morning after the test. The thrust mount had been reconfigured to the horizontal position for this test and additional support provided for the thrust chamber. The LOX Annin valve can be seen above and to the right of the motor.



The motor sectioned after the test. The minimal fuel consumption can easily be seen. Unfortunately, this test did not provide a good basis for evaluating the performance of the ablative nozzle.



A close-up of the sectioned ablative nozzle. This test was not adequate to verify the viability of the DC 93-104 ablative material.

the engine never got above a chamber pressure of approximately 40 psi and practically no measurable thrust was developed. The LOX was depleted 12 seconds after engine start and the engine shut down.

After all the effort involved in building this system, the results were disappointing to say the least. At the time, however, we were all so cold we were just thankful to be finished and able to warm up in the Quonset hut with a cup of coffee. There was not much data to analyze and photography had been minimal due to the darkness. Some 8mm movie film had been taken, but was of little use in determining exactly what had happened. Examination of the engine the next morning showed that very little fuel had been consumed. It appeared that the surface area of the grain , a concern since the grain was designed, had indeed been too low which severely restricted the rate of consumption of the fuel. Oxidizer could not combine with the fuel fast enough to build chamber pressure rapidly. As a consequence, the oxidizer flow rate was much too high due to the lack of back pressure in the chamber. In hindsight, a venturi in the LOX system would have limited the oxidizer flow rate and given the engine a chance to catch up. A better solution would have been to use both a fuel grain with much greater surface area and a cavitating venturi.

Although we thought briefly about incorporating these improvements and trying again with the "H" grain, we jointly decided that we were much more comfortable working on bipropellant liquid systems. Within a short time, we had converted our design to a LOX/alcohol system using as many of the hybrid components as possible. That system was subsequently built and successfully tested in March of 1993.

Bits and Pieces

Internet Address Request - 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.

Back Issues of the RRS Newsletter - For those members who may be interested, copies of the last several RRS Newsletter issues are available for $8.00 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 (50 Mile Launch, Year in Review, Sept. Firing Report)

• Volume 54, No. 1, Mar. 1997 (This issue)

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

The following excerpts from recent local bulletins are reprinted here for the benefit of those members who live outside the southern California area and do not receve these meeting notices on a monthly basis.

RRS Bulletin January 1997

Reaction Research Society, Inc., P.O. Box 90306 World Way Postal Center, Los Angeles, CA 90009

Two Meetings in January - The regular monthly RRS meeting will be held on **Friday, 10 January** 1997 at the usual meeting place, TRW. Due to the tremendous interest generated during the December meeting, Mr. Mike Henkoski will give a special presentation on amateur band TV transmission from rockets and balloons. Mike will cover information on the hardware (transmitters, receivers, cameras, ground support equipment, etc..) as well as design considerations such as power requirements, antenna placement, antenna types, and batteries. If you are at all interested in amateur band TV transmission, do not miss this meeting ! We will also discuss plans for upcoming work parties and firings.

The **second meeting** in January will be held again at TRW at 8:00 PM on **Friday, 31 January.** This special meeting is being arranged to coincide with a trip to the United States by Mr. Mark Blair. Mark is a corresponding RRS member from Australia and the Director of ASRI (the Australian Space Research Institute). This organization is comprised of many university students and corporate sponsors from all over Australia. Their primary purpose is to rebuild Australia's space exploration activity and involvement. While Mark is here in January, he has graciously agreed to come speak to interested members of the RRS about the various projects now being undertaken by ASRI members. All RRS members are highly encouraged to attend this special meeting and see first hand what our Australian counterparts (and a few Australian RRS members) are up to.

January Meetings

First Date: Friday, January 10 (second Friday of every month).
Place: (see map): TRW, Bldg. S (cafeteria), Redondo Beach, CA.
Time: 8:00 PM

Second Date: Friday, January 31 (special meeting with ASRI representative Mr. Mark Blair).
Place: (see map): TRW, Bldg. S (cafeteria), Redondo Beach, CA.
Time: 8:00 PM

Christmas Party - The annual RRS Christmas party was an outstanding success! This was, by far, the largest turnout we have ever had with more than 50 local members attending. The food was excellent (I know because I ate most of it !) and the presentation on George Garboden's rocket launch at Black Rock was very enthusiastically received. The annual elections were also held with the following results; President - Dave Crisalli, Vice President - Tom Mueller, Secretary - Frank Miuccio, and Treasurer - Pat Mullens (while Pat was nominated and elected, he is currently not able to assume the duties of treasurer, so Mike Gottlieb will continue in that position until further notice).

Reaction Research Society Hot Line

(310) 515-6458 (Anytime - 24 hours a day. Leave or hear messages)

RRS Bulletin

February 1997

Reaction Research Society, Inc., P.O. Box 90306 World Way Postal Center, Los Angeles, CA 90009

February Meeting - The monthly RRS meeting will be held on **Friday, 21 February** 1997 at the usual meeting place, TRW. **This is one week later than the normal meeting date** (second Friday of the month) due to Valentine's Day. Most of us rocket types have several social strikes against us anyway, so I figured that this change might help out the married ones (or those who might actually be dating someone) a little. For those who are not married, it shouldn't make much difference. In addition, many of the regular local members will be at WinterBlast, the annual pyrotechnic extravaganza. So based on all this, we moved the meeting date.

During this meeting we will be scheduling the next firing and the next facility work party. There will also be a demonstration of some new developments in resistor igniters by Niels Anderson. These igniters are based on the original work done by Bob Dahlquist and reported in the RRS News.

Along those lines, I would like to urge more members to participate as much as possible in the meetings. If you have any projects in work, please bring hardware, drawings, photos, or sketches you may have to share with other members. Often times I hear the most interesting information AFTER the meeting during informal discussions. If you can, please come prepared to let the entire assemblage know what you may be working on. Or, if you would like to give a more formal talk, please let someone on the executive council know. Some of our best meetings lately have been centered around lectures on various topics. This not only makes the meetings much more interesting, but it generates a lot of enthusiasm and energy to go out and do something. And, after all, that's what makes the RRS unique. We actually do something. Thanks. The Ed.

February Meeting

Date: Friday, February 14 (second Friday of every month - **except this month!**).
Place: (see map): TRW, Bldg. S (cafeteria), Redondo Beach, CA.
Time: 8:00 PM

Copyright Infringement - Within the past several month, a few of the articles from the RRS News have been duplicated by someone in their entirety and put out on the Internet. While it is not assumed that anything malicious is going on, the contents of the RRS News is copyrighted by the RRS or is used by us with the permission of the original author. If anyone is aware of who may be duplicating our newsletter on the web, please let them know that the material is copyrighted and that if they wish to copy any or all of it for public consumption, they should write the RRS for permission to do so. (See the copyright statement at the end of this bulletin).

Membership List Address Update - Please review the membership address list that comes out in each RRS News. If there are any changes or corrections, please let Frank Miuccio know by mail or phone (he's on the list). We often get a fair percentage of our mailings back because the address is incorrect or no longer current. This causes additional expense and turmoil in trying to track people down. Please give us a hand and make sure your address and telephone number are correct.

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RRS Bulletin

March 1997

Reaction Research Society, Inc., P.O. Box 90306 World Way Postal Center, Los Angeles, CA 90009

March Meeting - The monthly RRS meeting will be held on **Friday, 14 March** 1997 at the usual meeting place, TRW. During this meeting we will be positively scheduling the next firing and the next facility work party. There may also be the demonstration of some new developments in resistor igniters by Niels Anderson that was supposed to happen last month. However, Niels and several others will be involved in teaching the next propulsion course out at the MTA, so it's not certain they will make it to the meeting.

At this point I'm going to repeat the message I sent out in the last bulletin about participation in meetings. This note is all the more applicable when there is some uncertainty about planning for the meetings. "I would like to urge more members to participate as much as possible in the meetings. If you have any projects in work, please bring hardware, drawings, photos, or sketches you may have to share with other members. Often times I hear the most interesting information AFTER the meeting during informal discussions. If you can, please come prepared to let the entire assemblage know what you may be working on. Or, if you would like to give a more formal talk, please let someone on the executive council know. Some of our best meetings lately have been centered around lectures on various topics. This not only makes the meetings much more interesting, but it generates a lot of enthusiasm and energy to go out and do something. And, after all, that's what makes the RRS unique. We actually do something. Thanks. The Ed."

March Meeting

Date: Friday, March 14 (second Friday of every month).
Place: (see map): TRW, Bldg. S (cafeteria), Redondo Beach, CA.
Time: 8:00 PM

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