Civil Engineering and Rocket Science

by David Crisalli

Introduction

This article is a little out of sequence. It covers some of the important construction and test activity that was conducted in preparation for the liquid propellant rocket launch documented in the January 1996 issue of *High Power Rocketry*. Sorry about the order of these things, but I think the information may still be of some use. All too often, rocket projects must take a back seat to the less glamorous effort required to build the ground support equipment necessary to support a static test or a launch. You never know when you may be called upon to shift over from rocket science to civil engineering.

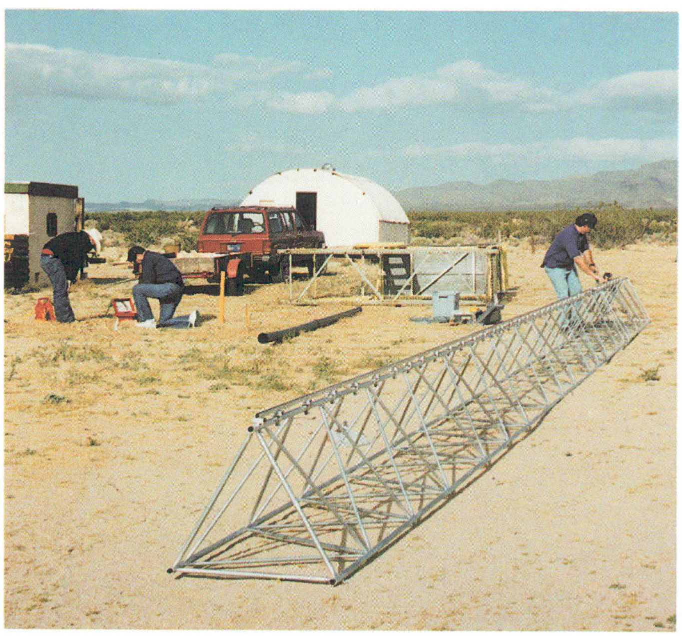
The Tower - 1993

A few years ago (when I was making more rapid progress on my 23 foot tall liquid oxygen/kerosene vehicle and Brian Wherley was building a large nitric acid/furfuryl alcohol rocket), we often reflected on the problem of constructing a suitable launch tower. For large liquid propellant rockets, take off accelerations are usually fairly low. As a consequence, the effect of a high surface wind condition on the flight profile of a fin stabilized rocket is pronounced and of great concern to those of us who build and launch such vehicles. In the absence of an active guidance system, there are only three methods to help ensure this type of rocket remains as close to the intended flight path as possible.

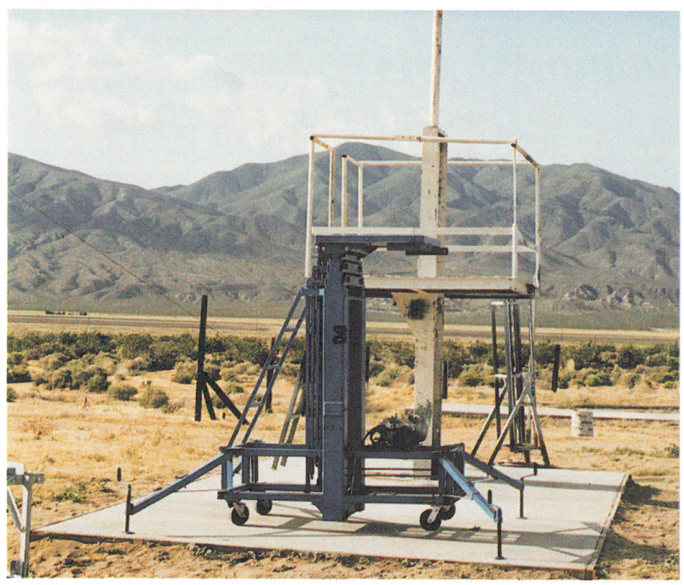
1. Do not launch if there is any wind to speak of. This is not a good choice considering the average wind conditions at our launch site and the amount of trouble it takes to set up for a launch. One might be waiting for days and days to launch with no wind.

2. Get the thrust-to-weight up. Good idea, but hard to do on liquid rockets. The thrust, chamber pressure, specific impulse, and burn duration determine the engine size and total propellant load. The total lift off weight is a function of the propellant mass and the vehicle mass fraction... oh, just take my word for it - it's hard to do on a liquid rocket!

3. Get a bigger launch tower. This was the option we had elected early on,



The sixty foot tower being assembled on the ground for its first use in May of 1995.



The hydraulic manlifter (in the retracted position) set up on the newly cast launch pad. The extension legs have been swung out and the base leveled with the foot pads.

The tower is attached to the manlifter with a pivot arm and is raised by extending the manlifter while holding the base of the tower on the ground. The tower is then clamped to the base of the manlifter and the upper and lower guy wires are set and tensioned.

but the design and fabrication of a completely portable and easily erectable *large* tower was no simple engineering task.

I had decided that a 50 foot length was the minimum size required for my larger rocket. I was still wrestling with how to build the tower structure, and had not even approached the subject of how to stand it up, when Brian called me one day and asked me to go with him to a local junk yard. When we arrived, he excitedly took me over to what looked like either a train wreck or a rusty old welded metal sculpture built by someone, as the nautical expression goes, carrying a lot of left rudder. I couldn't really decide. Nor did I have a clue why Brian was obviously pleased with this rare find. When we had moved away some loose scrap iron that was not really connected to the primary object of Brian's desire, what emerged was a half stripped hydraulic manlifter.

For those of you not familiar with this type of equipment, it is a large telescoping device with extendible legs, wheels, a built-in ladder, and a platform on top where a workman might stand. In its lowered position, it stands about six feet tall with all five of its sections nested inside one another and connected with cables and pulleys housed in the outer frame. In the center is a five foot long hydraulic cylinder. The mechanical arrangement is such that each inch of movement of the hydraulic ram causes all five sections to extend the same amount each. Therefore, when the ram extends to its full five feet, the platform has been raised twenty five feet in the air. On all four corners of the heavy steel base are swing out legs with large screw leveling pads. These are used to widen the stance of the device and level it before the platform is raised. While the manlifter had more appeal to me now that I knew what it was, I was not at all sure how we could possibly use it or even how we would move it out of the junk yard.

"How much does it weigh?", I asked.

"A half a ton," said Brian in his usually subdued and imperturbable way.

"How much does he want for it?", I muttered under my breath and glancing toward the guy running the scrap yard.

"Twenty five cents a pound," Brian responded.

"Does it work?"

Brian gives me the rocket guy salute (i.e., he shrugs).

"What are we going to do with it?", I queried more excitedly.

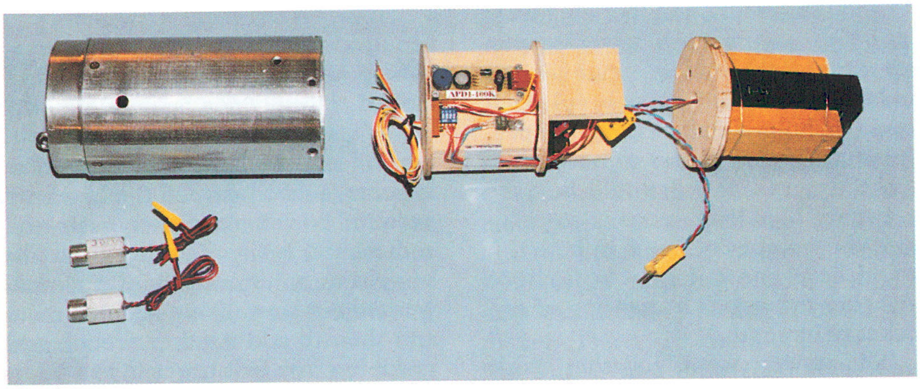
"Fix it up and paint it."

"Do you think we can use it to erect the launch tower?" (I was really getting into this now).

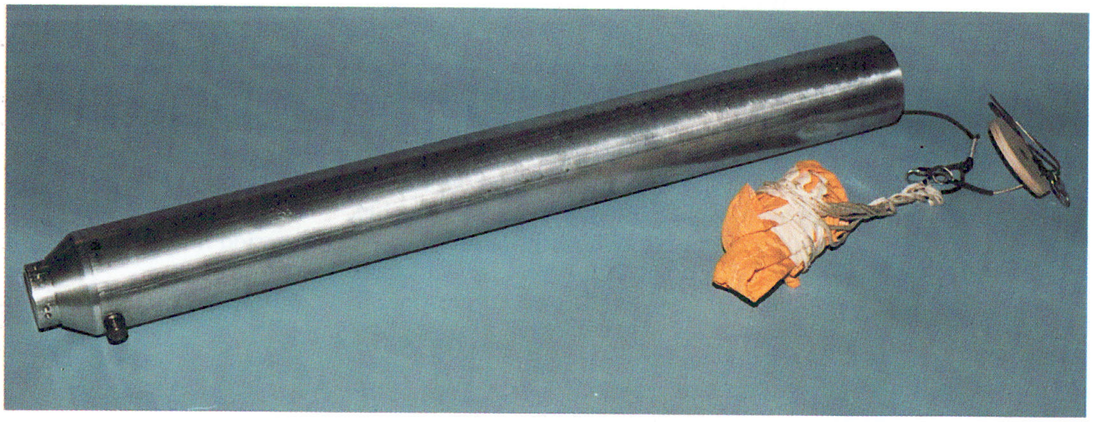
"Sure... there's bound to be... ahh... some way to use it."

Brian did not look convinced of the correctness of his last answer, but, being the impulsive types that we are (and after this extensive nine sentence discussion of the pros and cons of the concept), we paid the proprietor $250 and ran off to con all of our friends into helping us move our new found treasure. So, with a great deal of trouble, we hauled the manlifter to Brian's house and he began the laborious effort of restoration. Brian got it clean, painted it bright blue, greased it, and even got it to go up and down with a hydraulic wobble pump. It was really impressive both to look at and to climb to the top of using the attached ladder. But, for the life of us, we didn't have any idea what we were going to do with it.

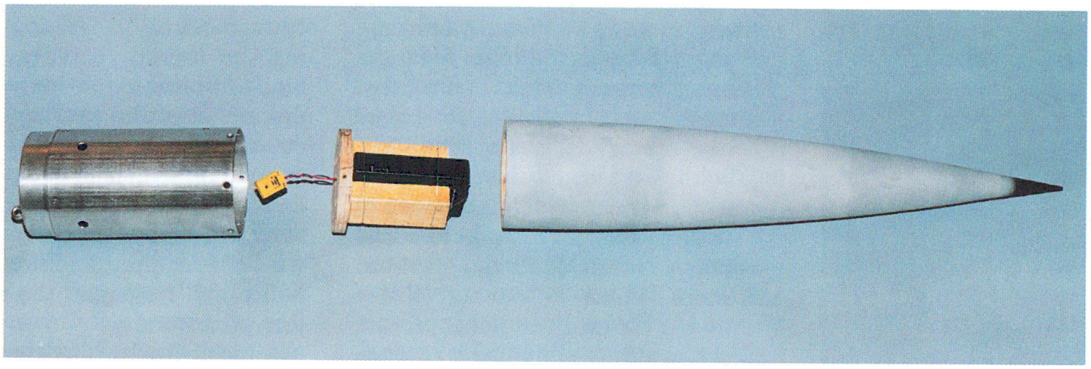
After many false starts and dozens of sketches, I had come up with a tower design using EMT (electrical conduit) for the structure. The material was plentiful, inexpensive, and came in a variety of sizes. The tower would be triangular in cross section



The payload canister and components for the Zinc/Sulfur test rocket. From left: pyrotechnic charges (lower left), canister, Adept altitude switch on plywood chassis, and the Radio Shack pager.



The parachute tube and motor adaptor. The plywood disk and drogue are shown at right. The protrusion at the lower end of the parachute tube is the upper launch lug. For the test rocket, the lugs were fixed. On the larger liquid rockets, the lugs are fully retractable.



The pager unit was housed in the hollow base of the nose cone. This put the pager antenna in the non-metallic nose. The nose was built of two part foam, turned on a lathe, and covered with "S" glass and epoxy resin.

and could be built in ten foot long sections. Five of them would be bolted together with slip joints to make a 50 foot tall tower. I showed the sketches to Brian and we discussed a few improvements to the design. Not long thereafter, we went out and bought a truck load of EMT and began construction. We built special fixtures to cut all the required angled cross bracing and then built a ten foot long weld fixture to ensure each tower section was as straight and accurate as we could make it. The launch rail itself would be built of half size, "C" shaped, Unistrut channel bolted to one corner of the tower. The rail would be used in twenty foot long sections to minimize the number of joints in it, and it would have one rail gate to facilitate engaging the upper launch lug of any rocket to be fired.

The tower went together fairly quickly and when we assembled it on the ground for the first time, we were amazed. We had expected that the tower would flex a little since it was only about two feet wide on an edge and fifty feet long. We thought this would not be a problem, though, since the tower could be guyed rigidly after it was vertical. When we got it all together, Brian (who is strong enough to pick up a Buick by himself) grabbed the tower at its mid point and lifted it over his head. He asked me to run down to one end and see how much sag there was by eyeballing down the top rail. When I looked, I could not believe that the tower was perfectly straight without any sag at all. Brian could not believe it either, so we propped the tower up between two stools, one on each end, and looked again. The tower was as straight as an arrow. The design had worked out so well, we decided there and then to add another section and make it a *sixty* foot tower. As an interesting side note, while we were assembling the tower on the front lawn, several people came over to talk to us. They were all worried that we were amateur radio operators and would annihilate their TV reception with whatever we were going to broadcast from this tower. When we explained that it was not a radio tower, but that we were going to launch large, dangerous, liquid propellant rockets, they were no longer concerned and went away happy.

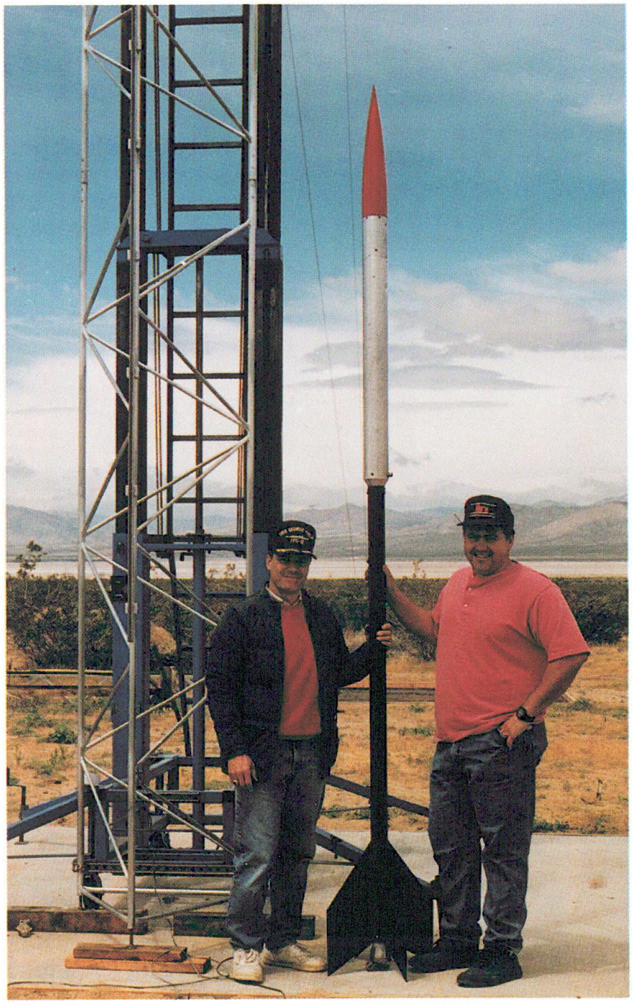
Bolstered by the success of the tower structure, we started to kick around several schemes to stand it up. I had come up with all sorts of cockeyed schemes using "A" frames, hydraulic rams, giant scissor jacks, and even the odd hot air balloon or other. I had also suggested to Brian that we lay the tower on the ground with one end pivoted at the base of the manlifter. We could put a large pulley on top of the manlifter, extend it to its twenty five foot height, guy it down firmly, run a cable over the pulley and down to the middle of the tower. The other end of the cable could be attached to the trailer hitch on my Jeep and I would drive slowly forward to erect the tower. What a sight that would have been. (On later reflection, I had these vivid mental images of having driven forward just a few inches too many and then trying to extricate myself from a Jeep smashed flat by a toppled launch tower and a thousand pounds of manlifter.) Brian didn't seem any too keen on any of the schemes I had come up with so far.

After some careful mental engineering, Brian noted that the manlifter could lift over 250 pounds and that the tower only weighed 200. He suggested that we put a pivot on the tower at the 25 foot mark and that this pivot would mate to arms on the top of the manlifter platform. With the manlifter in the retracted position (i.e. only six feet tall), we would place the tower on top of it, attach the pivot pins, and then extend the manlifter holding the ground end of the tower down as the manlifter was raised. When we actually did this the first time at Brian's house, and with the help of a few others, we were all impressed with how easily the few of us raised and lowered a 60 foot launch tower. Even though we didn't get the tower up until after dark, we rigged some lights and all just sat and stared at it for quite some time. We were really quite pleased with ourselves. During a launch, two sets of three guy wires, attached at the twenty five foot point and at the top of the tower, would hold the tower rigid.

So far so good. We had designed and built a large launch tower that could be disassembled and transported on two trailers. While it wouldn't fit in the trunk of a VW, it could be moved, assembled, and set up for a launch in a couple of hours with a four man crew. We added a removable loader crane and a winch to help raise the larger, heavier rockets to engage the rail. A flag staff at the very top of the tower completed the ensemble. Now, if we only had a rocket...

The Test - 1995

In mid-April of 1995, Brian Wherley and I were already working day and night to finish our liquid oxygen/ethyl alcohol rocket in preparation for a launch in late May. It became apparent to us as we labored mightily that we were quickly running out of airspeed, altitude, ideas, and time. We had originally set up a May launch date to accommodate a British film crew making a documentary about amateur rocketry. But at this point, we knew we needed more time to complete the liquid rocket, and we pushed the launch date back to 17 June. This was too late to support the British filming schedule, but we needed the time to complete the myriad of components and systems remaining to be built and tested.

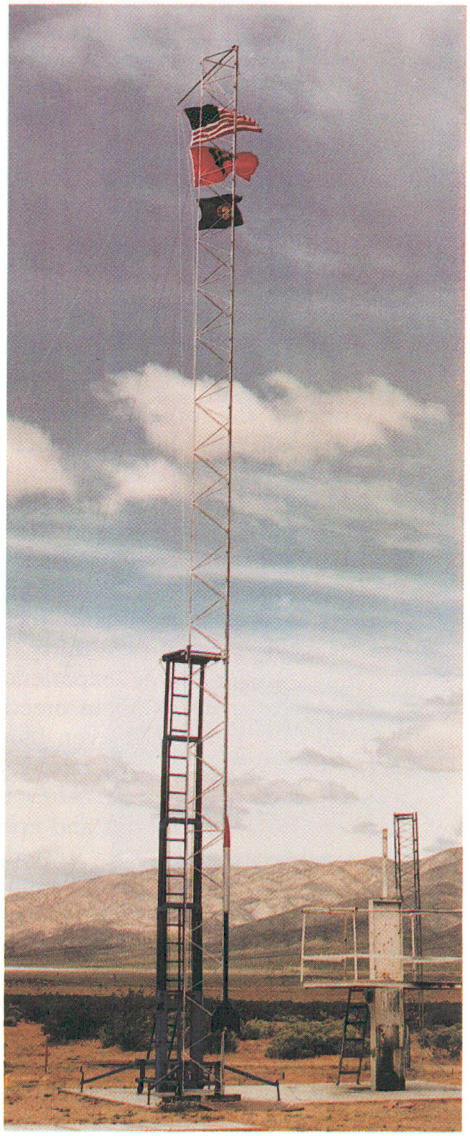


Brian and I with the fully assembled rocket just before it was installed on the launch rail.

One of the major tasks that Brian and I were facing was to rebuild the launch tower. It had never been used yet, but had been damaged by a trucking company when we loaned it to the U.S. Air Force Academy for a large hybrid rocket launch. As it turned out, they had never used it either due to schedule slips and had shipped it back to California after holding it for a month. The return trip (via G.I. Trucking) had the same effect on the tower as dropping it off a 500 foot cliff.

In the midst of cutting away all the damaged sections and welding in new ones, we realized that we had never completely assembled and erected the tower with all of its component parts. With all the other complexities that would surround the launch of a liquid rocket a month later, we decided that it would be wise to take a cue from Elliott and Rosenthal. Forty five years earlier, in preparation for their hydrogen peroxide monopropellant rocket launch, they had built a thirty foot launch tower. They experienced considerable difficulty in erecting it initially and it had even blown down shortly after being raised and was severely damaged. After the tower had been rebuilt and erected a second time, they tested it (and some of their ground support tracking gear) by launching a modified zinc/sulfur rocket with it.

Now it just so happened that cluttering up my storage shed was a large zinc/sulfur rocket I had built, launched, and successfully recovered by parachute twice back in 1970 just before I ran away to join the Navy. It had a 2.5 inch diameter, 1800 pound thrust, six foot long motor section attached to a four foot long, four inch diameter aluminum parachute tube. The original nose had been used on another rocket and the forward bulkhead had been damaged on the last flight, but the fins, graphite lined steel nozzle, and payload adaptor were ready to fly. Brian and I decided we would use this vehicle to serve several purposes. First, it would give us a chance to set up and test the launch tower including the launch lug and rail design. Second, we would flight test some of the recovery system components we intended to use in the liquid rocket. Third, we could still help out the British film crew (and gain some publicity for the RRS) by providing them with an opportunity to film an RRS launch before their deadline.



The twelve foot rocket on a sixty foot tall tower.

Close up of the rocket and tower just before the launch.

We finished repairing the launch tower and the hydraulic manlifter (also damaged in shipment). By the end of April, the rocket had been rebuilt as well and had been fitted with a new nose cone, parachutes, launch lugs, and some electronics. The latter consisted of an Adept Electronics altimeter switch and a Radio Shack pager. These two units were to be used as redundant parachute ejection systems. The Adept device would send out a firing signal to a pyrotechnic charge when it sensed that the rocket's altitude was no longer increasing. Small sensing ports in the short payload canister below the nose cone would allow the pressure transducer mounted on the device to measure the static pressure as the rocket flew. Shortly after peak, it would fire a charge shearing the plastic screws holding the payload section on and allowing the forward section of the rocket to separate. A drogue 'chute would deploy with the nose and would subsequently deploy an eight foot main canopy.

As a secondary deployment system, I had installed a Radio Shack pager in the nose as well. This pager is activated by a base station transmitter and was designed as an "in plant" paging system with a two mile range on the ground. The pager was modified to fire a pyrotechnic charge when it received the base station signal. The charge was identical to the one wired to the output of the Adept Electronics altimeter switch and could independently separate the nose and parachutes when fired. The pager was modified by removing the piezo buzzer and wiring in an SCR and a nine volt battery. When the pager received the signal from the base station, the SCR gate was activated allowing the firing circuit to close through the SCR. Both systems were thoroughly ground tested. The altimeter switch was tested inside a vacuum bell jar to simulate the pressure change with altitude it would experience in flight.

The two pyrotechnic charges were built into small aluminum housings and were screwed into the bottom of the payload canister. When one or the other fired, the powder gases were exhausted into a small volume formed by the bottom of the payload canister and a plywood disk resting on a narrow ring of aluminum attached to the inner wall of the parachute tube. The disk

Katie Crisalli and George Garboden in the blockhouse during the countdown. Katie did the honors by pressing the firing key for us.

could move up and out of the tube when the nose deployed, but it could not move down. The powder gasses would pressurize this volume, shear the plastic retaining screws, and impulse the nose and payload canister away from the rocket. As the forward section was pushed away, a short cable attached to the plywood disk would pull the disk out of the mouth of the parachute tube. Attached to the other side of the disk was the drogue 'chute. When the drogue caught and filled, it would tension a tie line to the main canopy and allow it to deploy as well. It all sounded fairly fool proof and, due to lack of time, this part of the system was not ground tested before the launch.

We left for the MTA on May 5th and arrived with all our equipment shortly after noon. The wind was out of the southwest at 30 to 40 knots and it was cold. The high winds gave us some concern about setting up a 60 foot launch tower with a small crew. Nonetheless, with the help of several other members, we went ahead and had the tower up in a few hours. Despite the high winds, the tower set up went very well because of its very small sail area. While the tower system worked well overall, we did identify several shortcomings that were corrected before the liquid rocket launch.

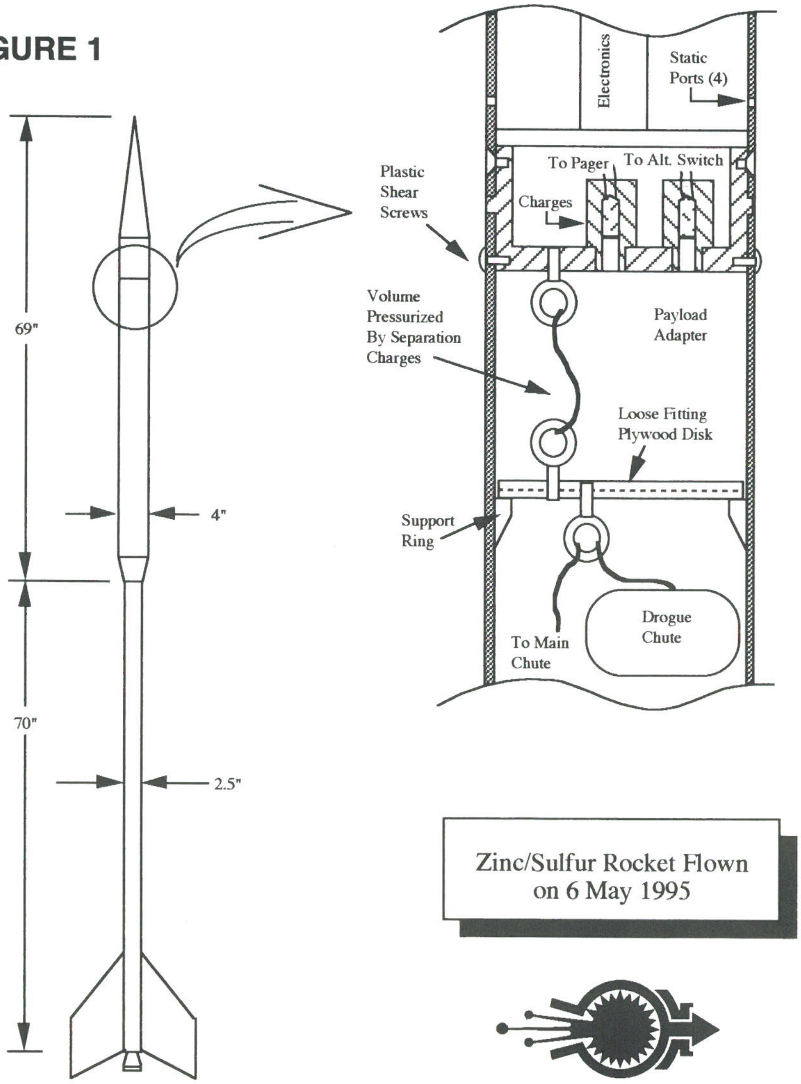
Launch preparations and mixing of the 40 pounds of zinc/sulfur required took well into the evening. Early the next morning, we took our time in loading the rocket and getting ready to fire while the British film crew shot some background footage. We launched around noon in a stiff wind. With a 60 foot launch tower and the take off acceleration of a zinc/sulfur rocket, the rocket flew straighter than I have ever seen despite the high winds. My ten year old daughter, Katie, was in the blockhouse with George Garboden and pushed the firing key for us. (Katie had built much of the nose cone as part of a school science project about chemical foams.) Brian and I were at tracking with the pager system base station transmitter. This unit operates on 110 VAC, so I had it plugged

The launch as seen from the tracking station 1000 feet from the launch tower. The rocket has been flying for about 0.4 seconds, is approximately 150 feet in the air, and its velocity is around 250 miles per hour. It will be doing about 500 miles per hour when it burns out in another few hundred milliseconds.

The parachute section after impact.

The motor section after its rather high speed landing. The third launch for this rocket was not the charm. Someone at the impact point declared it another brilliantly successful test of the latest in "dirt seeking" missiles.

FIGURE 1



into a static inverter which was, in turn, plugged into the cigarette lighter in my Jeep.

As the rocket lifted off we could follow it clearly all the way to peak at an estimated 9,000 feet. It turned over and I did not see the nose separate. I gave the Adept unit a second or so more and then pushed the button on the pager base station. The nose still did not separate and within a few more seconds the rocket impacted the ground with the characteristic thud. The film crew was a little surprised by the speed of a zinc/sulfur launch and missed the impact entirely.

In an all too familiar fashion, we marched out to the crash site with the "pick and shovel" back-up recovery system. We reclaimed the wreckage and noted that both charges had fired. Both the Adept altitude switch and the pager had initiated their respective charges, but the nose section had not separated. After returning home, a detailed examination of the wreckage was conducted. It revealed that the plywood disk that was to trap the powder gases in a small volume and allow pressure to build up sufficiently to push the nose off, had shifted off its seat due to the deceleration occurring at motor burnout. It had ended up wedged at an angle into the support ring. When the charges fired, they were trying to pressurize the much larger volume of the entire parachute tube and could not generate sufficient pressure to push off the nose section. This was the only hardware not tested on the ground before the flight and it proved to be the Achilles heel of the recovery system.

The day ended with an amusing incident. The film crew had missed the impact of the rocket with its attending geyser of dust thrown into the air by the crash. Since we had to burn off a few pounds of left over propellant, I suggested that we could bury it at the crash site and ignite it remotely. This would generate a large puff of propellant smoke and throw a large dirt cloud aloft. This would be a very fair simulation of the original impact.

The film guys agreed and set up their camera back at tracking where they had filmed the launch. Chip Bassett, Brian and I were hiding in the sage brush with a walkie talkie about fifty feet away from the impact point. About ten feet away on his stomach in the brush was George Garboden with the firing box. On cue over the radio, George pushed the button and the burst of smoke and dirt went off as desired. But about thirty seconds later George, still lying on his belly in the dirt, started yelling "Fire! Fire!" The burning propellant had ignited some of the dry brush nearby and it was burning quite vigorously. We all jumped up from hiding and quickly extinguished the blaze by stomping, kicking, and shoveling dirt. While we were congratulating ourselves for our quick response, the camera was still filming. From the cameraman's viewpoint he had been filming an empty desert scene. Then there was a terrific simulated impact of a rocket. Then there was a small fire, and then, almost instantly, four crazy people with shovels rise out of nowhere thrashing and kicking the burning brush. Realizing what they have done, all four flop down on their faces in the dirt again abruptly disappearing from view leaving the camera to film empty desert once again. Michael, the good natured cameraman said later to us it was all OK, it was just going to take some "creative editing" to fix the ending.

Despite the recovery failure, several things had been accomplished. The 60 foot launch tower had been erected in high winds without incident and had worked well for the launch. The launch lugs and "C" rail had withstood a very severe overtest with the high acceleration levels of this rocket (>25 g's as compared to the 6 or 7 g's expected with the liquid rocket). It also appeared that both the Adept altitude switch and the Radio Shack pager had functioned as designed in flight and had both fired their respective pyrotechnic charges. With the launch of this rocket, we felt we were better prepared for the launch of the liquid oxygen/ethyl alcohol rocket. □

Editor's Note: The figure below belongs to the previous article published in the May 1996 issue of *HPR*, Rollerons, page 35. We apologize to the author and the readers for its inadvertent omission.