RRS NEWSLETTER

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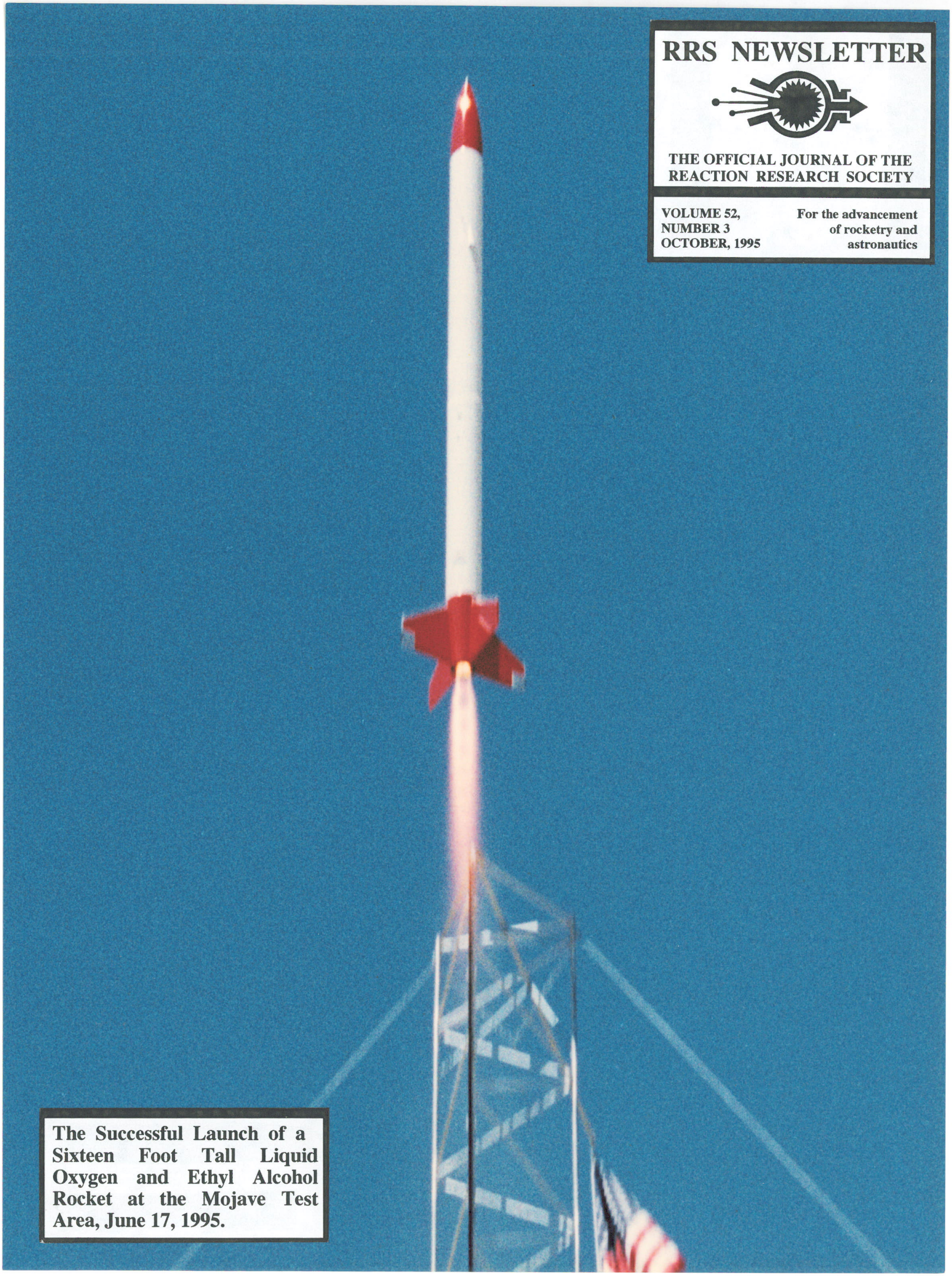
For the advancement of rocketry and astronautics



The Successful Launch of a Sixteen Foot Tall Liquid Oxygen and Ethyl Alcohol Rocket at the Mojave Test Area, June 17, 1995.

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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 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 160 active RRS members throughout the United States and in several foreign countries.

This newsletter is a more-or-less quarterly publication by the Society and is intended 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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The Work Party That Was Hotter Than Hell

(the continuation of a saga)

by David E. Crisalli

All of us knew that this was a bad idea. All of us agreed we would be crazy to even attempt it. All of us concurred we would put it completely out of our minds and never discuss it again.....So none of us talked to each other all the way out to the MTA on the twenty eighth day of July 1995 - one of the hottest days in the history of the planet. We were on our way to finish pouring another 10 yards of concrete - the load we didn't get a chance to finish back in March when the cement trucks got stuck in the mud. (See "The Work Party from Hell" Volume 52, #2, August 1995).

Among the certifiable lunatics that began this next cement pouring odyssey, George Garboden, Chip Bassett, and Niels Anderson were the first to make the journey down Munsey Road. Arriving around noon (when the sun was hot enough to melt the paint off their vehicles), they made a detour to do some work on one of the off site storage containers. Setting it up on blocks and leveling the 5,000 pound steel container was no easy task in the blinding heat. Once accomplished, they dropped off some gear and continued out to the MTA a little the worse for the wear. Brian Wherley and I found them busily preparing for the next day's cement work when we arrived at three in the afternoon. We began unloading our own gear and tried to conserve energy until the mid day heat had passed and the late afternoon sun was not so intolerable.

At about four in the afternoon, Richard and Maryann Butterfield stopped by to see what we were up to and to take us down the road to their old ranch to salvage a 60 foot tall radio tower. The tower was in three sections. Two of them were lying on the ground partially overgrown with brush. We hooked them to the bumper of George's truck and pulled them free one at a time. The third section was set up on a small concrete slab and had been a vital part of the Butterfield's television link to the outside world. It was the top section of the complete tower and it was going to take a fair amount of effort to lower it. Transport back to the MTA would also take some time and the sun was going down. We decided we would load up the two lower sections that we had already pulled free and take them back to the MTA. We would come back for the last section after we finished the concrete work on Saturday.

After careening back down the road to the MTA at the breakneck speed of, perhaps, eight and a half miles per hour, we unloaded the two lower tower sections behind the Quonset hut. Now those of you who are very astute might have noticed that I have, thus far, made no mention of the ultimate use planned for this tower. Let it suffice to say that this very topic was the subject of some considerable and lively conversation as we were heavily engaged in pulling, tugging, dragging, lifting, sliding, tying, and transporting this huge iron structure. The conversation even took some wild forays into the fanciful area of how the hell we would even stand the damn thing up. But such esoteric topics as "what are we going to do with it ?" and "how are we going to stand it up ?" have never been known to dissuade rocket guys in the midst of a scrap iron collecting frenzy. It certainly didn't dissuade us, and most of those present even reacted rather testily to anyone even obliquely questioning our sanity for working so hard to collect something we didn't have a use for. Like many other things collected for use at the MTA, we all knew that a very suitable use would undoubtedly present itself after a short ten to fifteen years. Anyway, there was no need to prolong the conversation and speculation. We had the damn thing and we were going to keep it.

That little side effort now completed, it was getting late in the afternoon and the sun would be gone soon. There were other crucial tasks to be accomplished. One such task related directly to personnel comfort. Not many trips out to the MTA ago, I was minding my own business quietly ....well .... occupied.... in the outhouse I had built and hauled out to the MTA a year or more before. As a matter of fact, I was admiring my own construction handiwork. When I had done with my immediate undertaking, I strode briskly forward the full half step to the exit, firmly grasped the door knob, twisted it forthrightly, and opened the door. At this point in the process, the bloody thing came right off its hinges and the door, the hinges, the door knob, part of the jamb, and I promptly exited the premises as a single unit and assumed a horizontal position some five feet in front of the outhouse. A large dust cloud curled up and out from under the door settling gently on my prostrate form. As luck would have it, this sequence of events could not possibly have gone unnoticed. My children, who had accompanied me to the MTA, were playing not too far afield. They did not fail to observe the unparalleled grace with which their father exited the privy that day, nor did they fail to hear his descriptive and colorful adjectives as the egress was occurring. They often remind me of the whole affair, much to their delight and amidst breathless squealing and laughter.

But I digress. The germane point to the story is that I finally replaced the door and Brian repainted the whole of the outhouse. It now looks great, works well, and provides the requisite amount of privacy.

Brian was still trying to finish painting by Braille when it got really dark. George and I were engaged in the construction of a screed board for the largest pad we would pour the next day. For any who may not know, the initial step in the finishing of newly poured concrete involves "screeding" or leveling by dragging a long board across the edges of the forms to even out the surface. Usually this is done with any odd two by four or other as long as it is tolerably straight. But since the new solid propellant handling bay slab was twenty feet wide, George wanted to build a better than average screed board. What I thought he had in mind and what he actually built were as different as night and day. The thing was huge. I couldn't figure out how we were even going to pick it up! What he built closely resembled a railroad trestle. It was the "Mother of All Screed Boards". Nonetheless, we did figure out how to pick it up and it worked well.

With the completion of the screed, we secured for the night. Brian and I camped out at the MTA while those with less stout hearts (or perhaps bigger brains) headed into town to stay at the Motel 6. By 10:00 PM, Brian had rustled up a "cowboy dinner" for us of rare steaks, beans, biscuits, and potatoes served on tin plates. And, it was "Miller Time". So we had a few beers, swatted the mosquitoes that harassed us, enjoyed the unrelenting heat of the evening, and amused ourselves by shooting bugs off the blockhouse wall with a BB gun. Don't ever let anyone tell you work parties at the MTA aren't one heck of a lot of fun!

We hit the rack (that's Navy talk for "went to bed") at midnight and "heaved out" (more Navy talk) at 5:00 AM. Shortly thereafter the rest of the crew began to arrive. Jim Swenson pulled in followed by Scott Claflin (who had driven into the compound on a flat tire - not a good omen), Mike Gottlieb, Doug Caldwell, and Tom Mueller. Chip, George, and Niels were close behind. The cement truck was right on time at 7:30 to start pouring the new solid propellant processing bay slab. The "Mother of All Screed Boards" was put into service as were several new concrete working tools purchased recently by the Society. This batch of concrete went in much easier than did the stuff, back in March, that was almost set up by the time we got it to the MTA . It makes a big difference when the truck delivering the cement does not get stuck on the road for several hours.

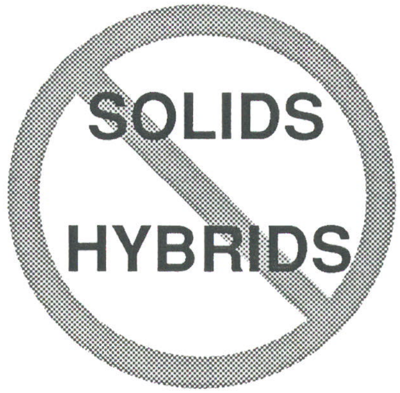
Finishing touches are being completed on the new solid propellant handling bay pad.

Smarter than the rest of us, Jim Swenson had departed the area before this picture was taken. From left to right: Wherley, Crisalli, Mueller, Caldwell, Claflin, Gottlieb, Bassett, Anderson and Garboden.

The form was filled in about a half an hour, and the truck was directed over to one of the new launch pads while several of us tamped and floated the large pad. The twelve foot by twelve foot launch pad went quickly as well, and the truck driver from Cal City Concrete was a big help to us. The residual concrete left in the truck after the little pad was done was used to continue the slab by the Quonset hut. Even with ten people in the work party, it was tough to keep up with the setting concrete when the troweling started. Doing this type of work in the sweltering sun was also not much of a help. The new slabs were wet down again with what water we had left, and covered with plastic sheeting and dirt to cure as slowly as possible. We were pretty much finished by mid day, but we all looked like we had been jerked through a knot hole...especially me.

As we were trying to recuperate a little in the shade of the Quonset hut, George said we all had to go get the remaining section of the steel tower still at the Butterfield's. I had been hoping no one would remember. No one moved. No one spoke. We all hoped George would not mention it again. But he did. So we all groaned and got up and drove down the road one more time. We got the tower down with a little trouble and a load of elbow grease. The heat was almost unbearable by now. We managed to get the steel loaded on the truck and slowly meander back to the MTA. We had not escaped unscathed, however. George had a nose bleed from the heat and dry air and looked a little comical with a grimy shop rag jammed up each nostril. I, on the other hand, had, all too quickly, sucked down a can of Hansen's Natural Mandarin Kumquat Zucchini Kiwi Rhubarb... something or other and was on the verge of dying from "healthy soda" poisoning. Jim Swenson and Chip Bassett were fairly chipper, which led the rest of us to suspect that they had only been grunting while we were lifting the tower onto the truck and not really helping. Niels Anderson, for some inexplicable reason, looked just like the little kid in the movie "Jurassic Park" after they turned the electrical power to the tyrannosaurus containment pen back on. The rest of the crew were also in various stages of disrepair.

We dumped off the tower section and packed up our gear just as fast as our little tired legs and arms would go. Then we all said our goodbyes and, in parting, swore a sacred oath that if any one of us ever suggested that we should do this again, he would be summarily shot by the others. Niels brandished a firearm just to emphasize the point. Good idea. But then, we said the same thing back in March..... Some people just never learn.



How To Build a Rocket the Hard Way

by David E. Crisalli

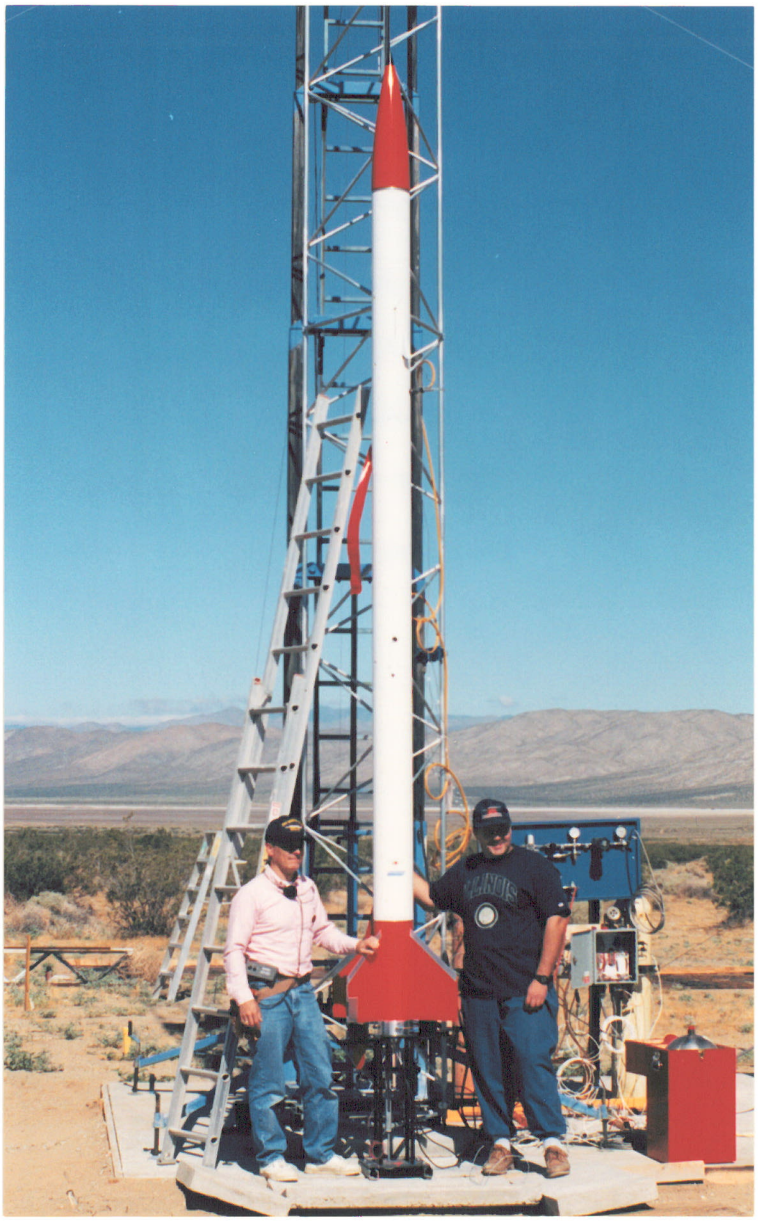
Prologue: In 1993, an intermediate goal was reached by Brian Wherley and I when we successfully static tested a small, low cost liquid propellant rocket engine and all the related tankage and valving. We had begun the project with the intent to design and build an extremely simple, very inexpensive liquid propellant rocket that would use as many commonly available components as possible. While this is not entirely possible to do because of the complex nature of liquid rockets, the eventual design of the propulsion system was about as simple as it could be without sacrificing safety or operability.

The entire story of the design, fabrication, and static test of the engine and propulsion system was the subject of a previous High Power Rocketry article (October, 1994) and an RRS news article (RRS Newsletter , Vol. 51, #3, July 1994). To summarize, the rocket motor produced 620 pounds of thrust burning liquid oxygen and 75% ethanol. The engine was an ablative design with a graphite nozzle and used an aluminum injector with split triplet elements to atomize and mix the propellants. The tanks and valves used during the static test were also to be used in the flight vehicle and were not facility type hardware. The tanks could hold enough propellant to run the engine at full thrust for ten seconds. The static test was very successful and the engine was easily refurbished for the flight.

After the static test was completed in March of 1993, the propulsion system components sat around on the shelf for quite some time. Then, the southern California earthquake hit in January of 1994 and provided those of us who live in this area a whole new list of tasks and priorities. Brian and I both live within spitting distance of the epicenter of the Northridge quake, and spent quite some time digging out from under the rubble. It took me almost a week just to clear away enough debris to find my garage let alone get into it and work. We both lost a fair amount of equipment, parts, and tools. (At my house, one of my first priorities was to clear out the garage, jack the partially collapsed roof back up, and replace the ridge pole that had snapped in two.) Although the quake slowed us down for a while, by the fall of 1994, we started in earnest to design the LOX/alcohol flight vehicle.

Vehicle Design Summary: The size of the propulsion system had originally been established to power a relatively small rocket. Based on the length and diameter of the propellant tanks, the vehicle would be approximately 16 feet long and 7.5 inches in diameter. It would carry a video camera and transmitter system as a payload (designed and built by Mike Henkoski of Microtek Electronics, P.O. Box 3464, San Clemente, CA, 92674). The rocket would have a recovery system activated by an Adept Electronics recording altimeter. Sensing peak, the device would send a firing signal to the pyrotechnically actuated nose separation device detaching the nose and deploying a drogue chute at around 30,000 feet. The vehicle would descend on the drogue to an altitude of 1250 feet where the second output function of the altimeter would send a firing signal to a pair of redundant powder actuated line cutters. These would cut the tie line holding the main parachute in place and allow it to deploy. With an empty vehicle weight of approximately 85 pounds, 36 pounds of propellant, and 620 pounds of thrust, the take off acceleration and velocity off the 60 foot tall portable launch tower we had built would be more than adequate.

In keeping with the overall goals of the project, we decided that we would take a cue from some of the high power model fabrication techniques. To build the vehicle structure as light, strong, simple, inexpensive, and fast as possible, we would use a paper/phenolic tubular skin over a structure built of aircraft grade plywood bulkheads and aluminum longerons. The skin was commercially available in four foot long sections and would be slid over the rocket frame once all the internal components had been installed. The propellant tanks, helium tank, and engine would occupy the first two thirds of the vehicle length. The remainder would include the payload and recovery system. The nose cone would be built of urethane foam and covered with "E" glass. It would be equipped with a pyrotechnically actuated nose release mechanism, and would contain some of the recovery system electronics in an internal compartment.

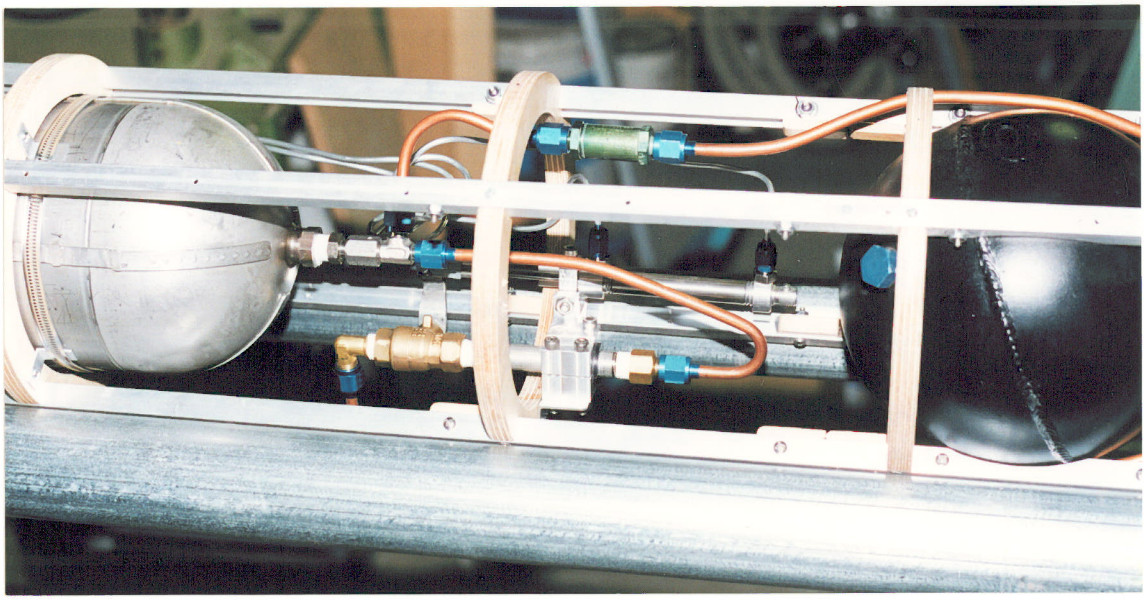


Brian (right) and I pose for one last picture before the flight (Scott Claflin said he had seen fewer pictures taken at weddings!)

The parachutes (made and installed for us by Bob Stroud of Stroud Safety, 9000 E. Memorial, Jones, OK, 73049) would be housed in a thin wall (0.040) aluminum tube (beautifully made by John Crawford at Automatic Welding ,17008 South Gramercy, Gardena, CA, 90247) just aft of the nose. The tube would be made of rolled and seam welded thin sheet stock and firmly attached to all four longerons with its own chrome-moly steel stringers. The parachute tube would be designed to slide out of the fully assembled vehicle. This was done to facilitate ground processing by allowing the parachutes, pyrotechnics, and recovery electronics to be prepackaged, attached to the nose cone and slid into the rocket during final assembly. The removal of the nose/parachute tube would also allow access to the payload area directly below where the television camera, dual transmitters, amplifiers, and antennas would be mounted on their own removable chassis.

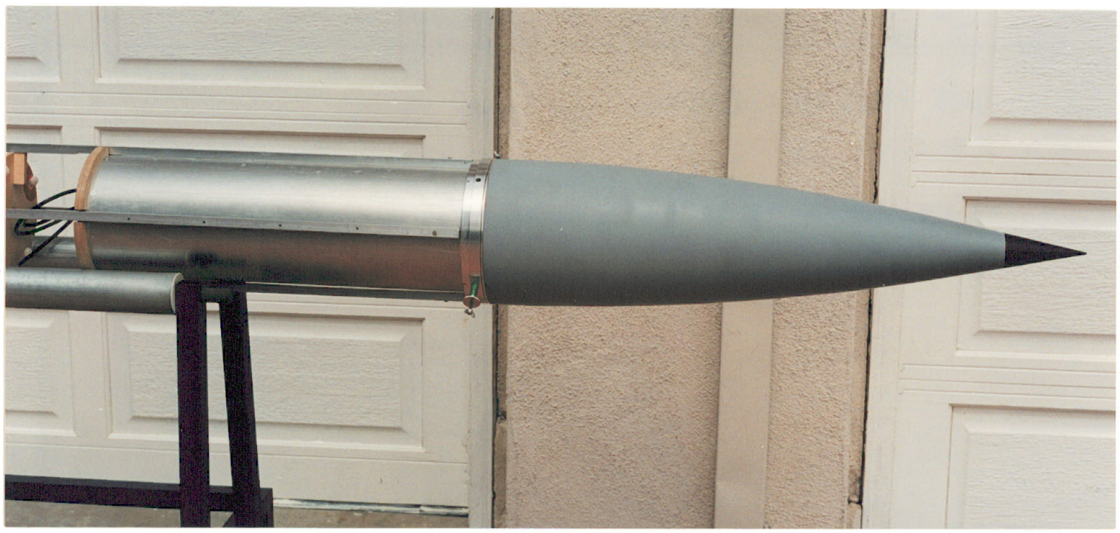
The boat tail/fin assembly was to contain some unique features. We wanted it to be removable, but easy to attach and align. It had to be light weight, easy to build, very strong, and needed to include the roll stabilization system. We also wanted to control all the propulsion system valves pneumatically from outside the rocket to save weight and to eliminate the complexity of flying the control valves. This required pneumatic control pass throughs, and one electrical connection, to be included in the boat tail as well. It would be built of aircraft plywood, "E" glass, and urethane foam.

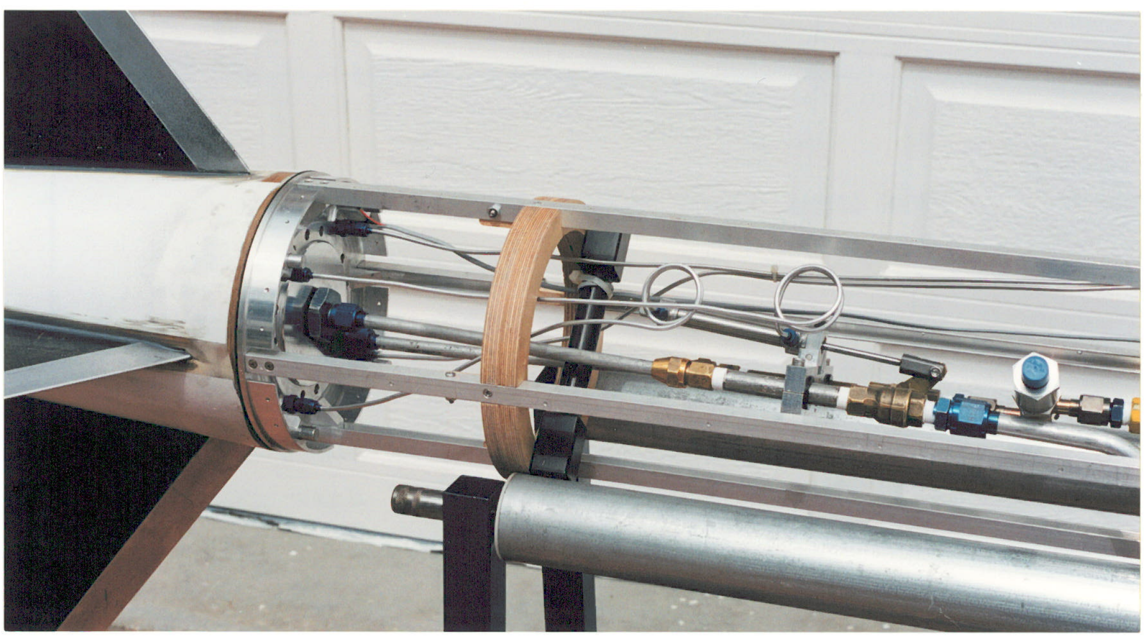
Concept of Operation: This rocket, although unique in some of its features, would be ground processed and launched in the usual manner at the Reaction Research Society's Mojave Test Area. The rocket, launch tower, propellants, propellant handling equipment, electrical generator, electrical control equipment, and payload support equipment would be transported



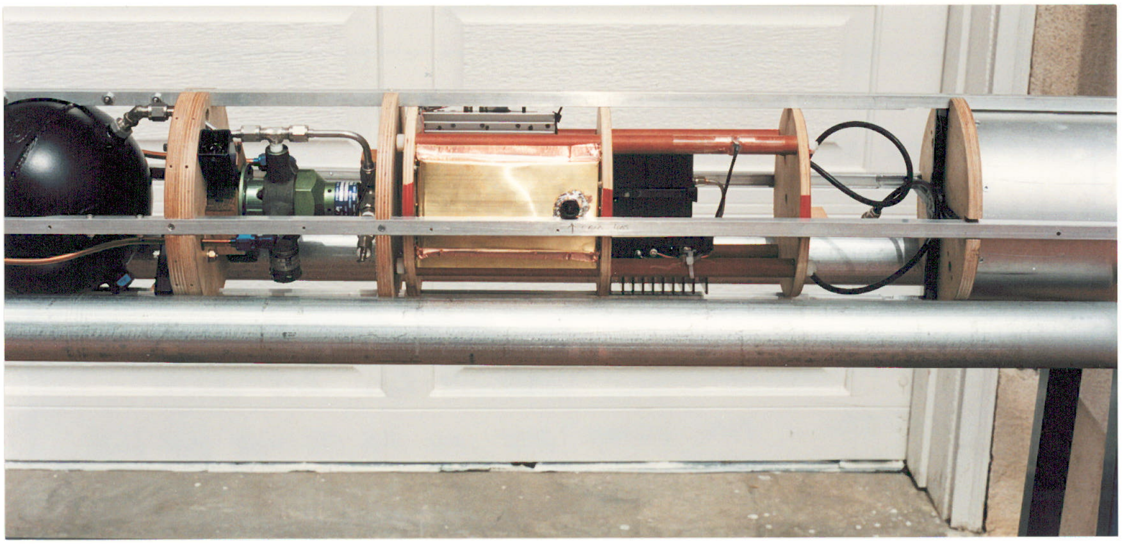
This view shows the LOX vent valve area between the LOX tank and the helium sphere (black). The bulkheads, longerons and gussetts of the structure are also shown.

The forward section of the rocket showing the nose cone, nose separation ring and parachute tube mounted inside the longerons

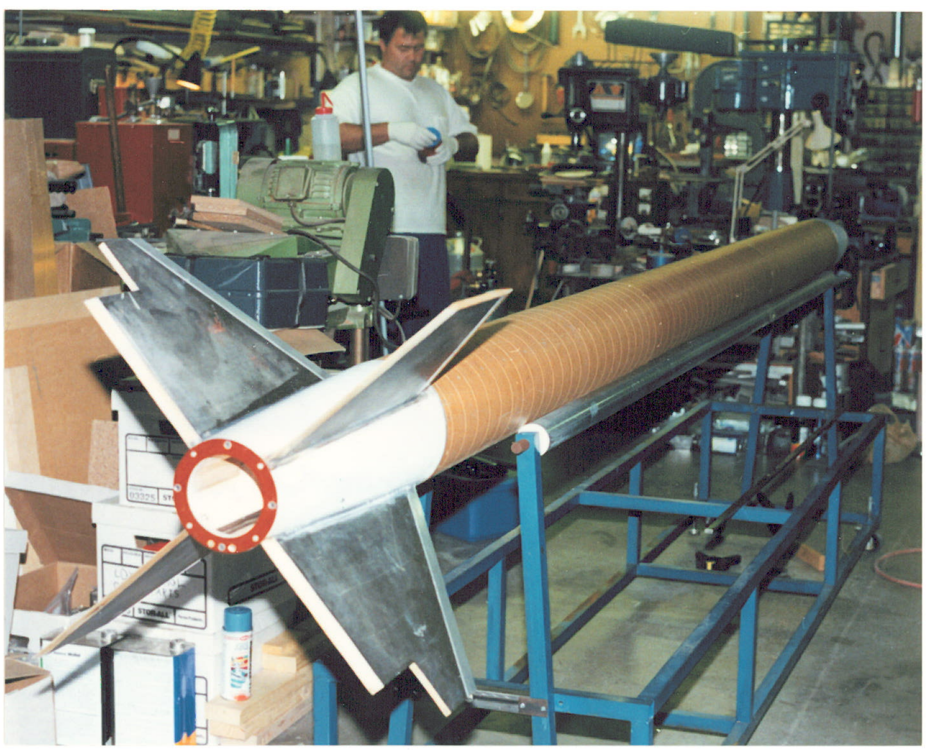




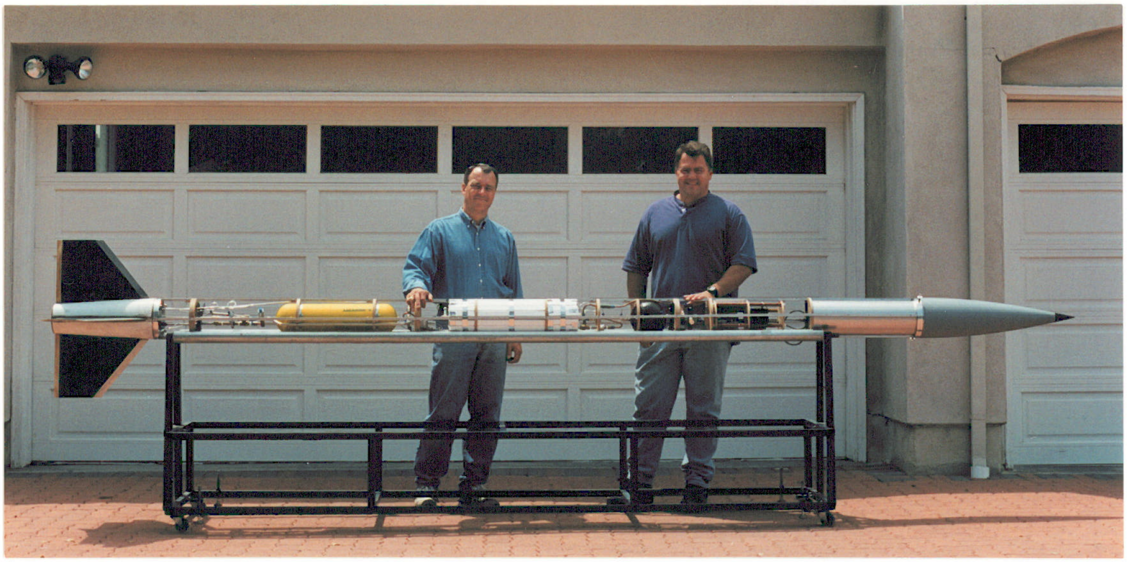
This view shows the structure of the fuselage in the main propellant valve area. From right to left: fuel load check valve, main propellant valves/pneumatic actuator, double bulkhead with lower retractable launch lug, thrust mount and boat tail.



This photo shows the camera pod mounted between the parachute tube (right) and the pressure sphere/helium regulator. The high pressure helium quick disconnect load fitting and upper retracting launch lug are also visible. The black dot in the center of the photo is the camera lens



The skin is mounted on the rocket structure in this photo. After all internal components were installed and leak tested, the skin was installed for the last time.



Brian and I with the unskinned but fully assembled rocket just a few days before the launch.

to the test site and set up two days before the launch. Although most of the rocket would be fully assembled before transport, the payload, recovery system, and boat tail/fin unit would be installed at the test site. This was done to facilitate final checkouts and to simplify transport.

After arrival at the MTA, the launch tower would be set up and adjusted as quickly as possible. This is normally a three to four hour job for six crew members. All electrical generating and other facility support equipment, such as the public address system, photographic gear, and cooking facilities, would be set up simultaneously by other Society members. Ground support equipment, including hydraulics, pneumatics, and propellant handling, would be exercised as it came on line to verify satisfactory operation as soon as possible after set up.

The afternoon before the launch, the rocket would be final assembled with its payload, recovery equipment, and fins. Final checks would be conducted on everything that could be functioned or operated without replacement (i.e. pyrotechnic charges were not fired). The rocket would be mounted on the launch rail and the fuel tank filled before the crew secured for the night.

The launch would occur at 6:00 AM the next morning. By 5:00 AM the helium load system would be hooked to the rocket and the final rolleron spin up test conducted. At 5:30 liquid oxygen fill would begin and be completed by 5:50. The liquid oxygen fill equipment would be broken down in the next few minutes. The engine igniter would be installed and armed just

The start of the tower assembly. The six, ten-foot long sections are being bolted together prior to installing the launch rail.

The assembled tower is mounted on the hydraulic man-lifter just prior to raising.

before the launch pad was evacuated. Helium fill would be completed remotely from the blockhouse and the count would start. The rocket would ignite, leaving the rail quickly and easily, flying out of site in an orderly fashion.

Well, that's the way we planned it. While it didn't happen exactly like this in real life, it did go very well and on the appointed date. The launch was only six hours behind schedule. We didn't think that was too bad after establishing the date and time of launch some months before we had even built the flight vehicle.

__Component Fabrication:__ Any rocket contains a myriad of parts. The more complicated the rocket, the greater the number of parts. As we were about to learn, even the simplest of liquid propellant rockets contains a myriad squared! As one thinks through the conceptual design of any given sub system, there is a tendency to say "Oh, that's simple.... We can just bolt a left-handed chortlewort right up to the tushing with a short linkage to the two schnacklegangers." It is only later as the design progresses from mental concept, to drawing, to actual hardware that you realize that there are approximately four hundred and eighty three more parts required just to mount the schnacklegangers let alone hook them to the chortlewort/tushing assembly. For anyone contemplating building a liquid rocket, it is wise to apply a factor of at least eight to any time estimates you may make on the completion of any subsystem.

When I sat down to write out all the details of the component design and fabrication work Brian and I had accomplished, it took me almost thirty pages just to cover the major items (with no photographs or drawings!). The details about rollerons, bulkheads, gussets, fins, longerons, tanks, valves, pneumatic control systems, line cutters, nose cones, launch stools, and all the other parts would each make a full size article in themselves. As a consequence, we will leave all those details for future articles and a soon to be published full report on the whole project.

__Launch:__ During the first two weeks of June, Brian and I worked almost round the clock to finish the innumerable parts, tests, redesigns, and planning required to launch this rocket. By Thursday, the 15th, we were packing up to transport all our equipment out to the Mojave Desert. We still intended to launch at precisely 6:00 AM on Saturday, the 17th and were hoping to get out to the test area on Thursday afternoon to start setting up. Due to several delays with some of the vehicle assembly and improvements to ground support equipment, we delayed our departure until mid morning on Friday, the 16th. After a very late night on Thursday (and with the invaluable help of George Garboden and Chip Bassett in assembling the shipping crate, completing the pneumatic control panel, and mounting the camera periscope), we finished loading up Friday morning in the midst of an unseasonable rain storm.

We arrived at the test site late in the afternoon and began immediately to unpack our equipment. Set up for the launch went into high gear to try to finish all the major work before sundown. A small crew went to work on the sixty foot launch tower and did manage to get it erected, pointed, and guyed before dark. The rocket was uncrated and set up on its handling cart in the Quonset hut where the final assembly and checkout would occur. Bob Stroud and Mike Henkoski had arrived and were working on the subsystems they had volunteered to take on. Bob, assisted by Dick Embry, began the task of packing the parachute for the rocket. (Bob had made three different parachutes because he was not sure exactly what we would need!) Mike Henkoski started final assembly of the power supply for the on board video equipment and set up of all his receiving and recording equipment.

Sometime near midnight, Brian and I assembled the rocket for the last time. The video equipment was in and was working well. The pyrotechnic charges were installed, the parachutes were in, and the nose was attached. The final step was to slide the boat tail into place and secure it to the engine with the threaded ring and spanner. Mark Grant, who had come down from Oregon to help with the launch, completed the effort by painting the video camera periscopes white to match the rest of the rocket.

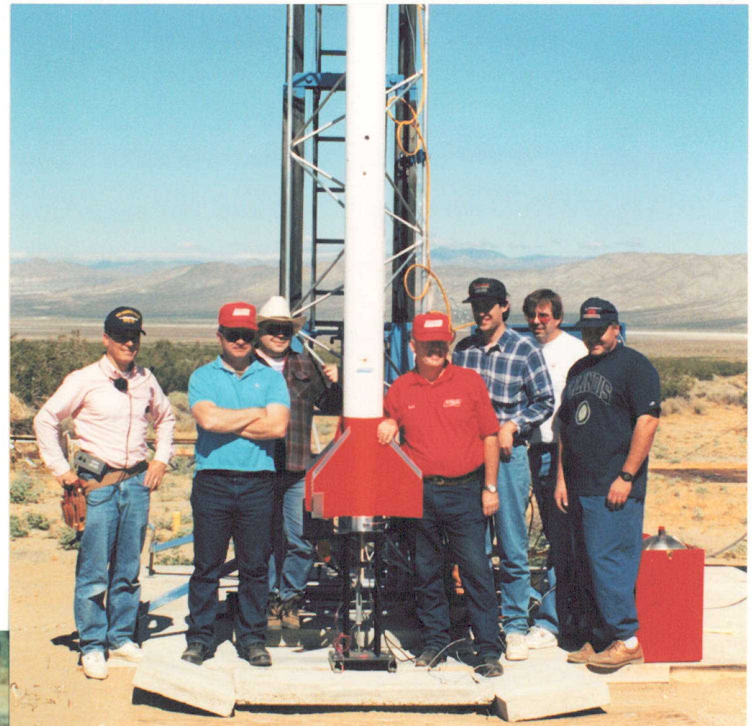
It was now nearly 2:00 AM and none of us could see straight any longer. After days of being up all night, we were running on empty. We decided to secure for the night and do the best we could in the morning to hold schedule. We had hoped to get the rocket out on the launch tower Friday night and even get the fuel tank loaded. But it was not wise to try to accomplish the delicate maneuver of putting the rocket on the rail with a bone-tired crew and in the pitch dark of the desert night. We would all get some rest and start as fresh as we could in the morning.

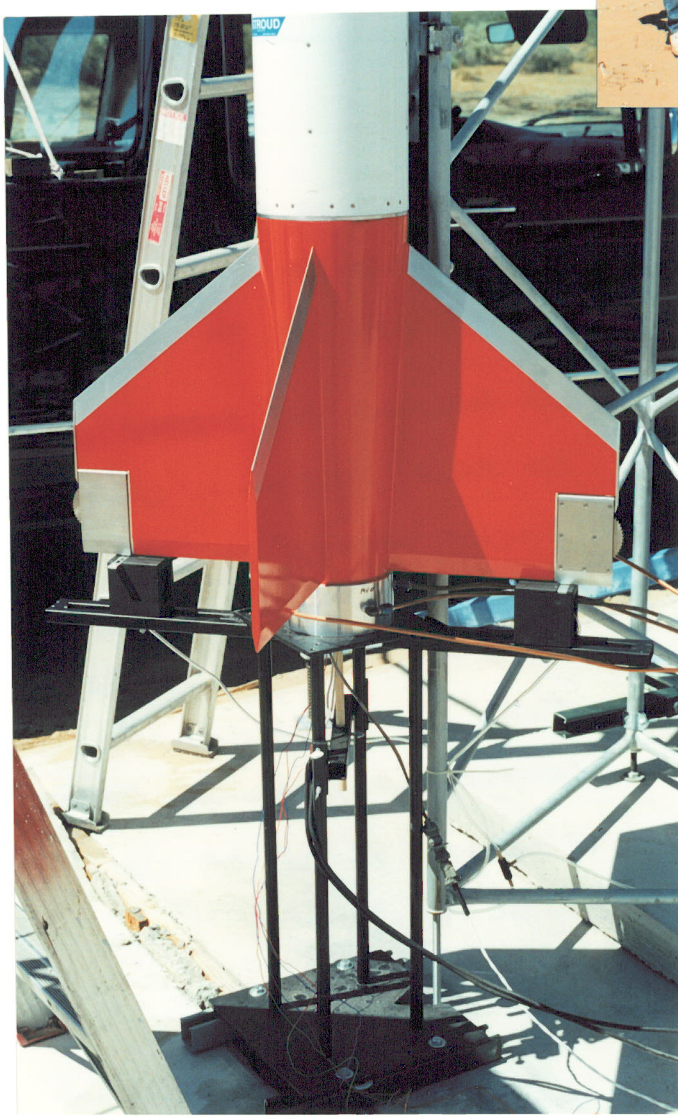
Final assembly in the Quonset hut sometime after midnight on 17 June. The engine is being mounted here.

Several of us drove into Mojave to spend what was left of the night in a hotel. Many others camped out at the MTA. By 6:45 Brian had a crew of people helping to get the rocket on the rail. I got back out to the test site at about 7:30 and started, with Brian, loading the alcohol fuel and hooking up the control pneumatics. It was obvious that we were not going to be able to hold to our original time table for a launch at 6:00 AM, but we thought we could get the launch off before noon. So far the weather was absolutely perfect and the winds were very light. Two other solid propellant rockets were also scheduled to be launched that day. A large two stage zinc/sulfur rocket built by Bill Claybaugh and a standard RRS Beta built by Jim Swenson. There was considerable activity occurring in support of these two launches as well. Propellants were being mixed, motors loaded, and payloads being checked out as these two vehicles were readied for launch.

About 10:45 that morning, the liquid rocket was ready to be loaded with liquid oxygen and helium. If all went well, this would take about a half an hour. As the head pyrotechnic operator for this firing, I assembled all the people who had come to watch this flight in the compound area and held a quick briefing. This is a routine event at Reaction Research Society launches and is done to pass along general safety information about rocket firings

The builders and contributors (from left): David Crisalli, Dick Embry, Chip Bassett, Bob Stroud, Mike Henkoski, George Garboden, and Brian Wherley





The rocket is mounted on the launch stool at the base of the rail. The rollerons are sitting on their alignment/spin-up blocks mounted on the stool arms. The aluminum ring at the base of the rocket is the pneumatic control manifold. The igniter is mounted to two of the stool legs.

The rocket's view up the 60-foot rail just before launch. The video camera periscope and 434 MHz whip antenna are visible on the side of the rocket.

and the desert environment, and to explain, in some technical detail, what we think is about to happen. We also explain what might happen if things do not go as planned and try to pass along the best techniques for headlong diving under cars without hitting one's head.

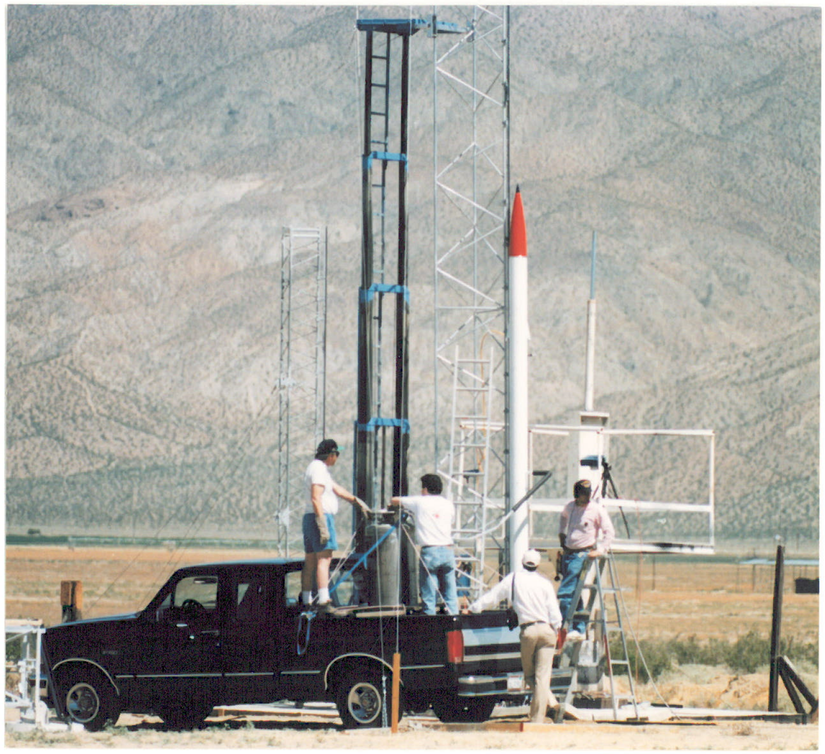
With the briefing concluded, everyone reported to their stations. The majority went to the observation bunkers to watch the flight. A few went to the tracking station 1000 feet from the launch tower. The launch crew reported to the blockhouse. Scott Claflin brought up his truck with the liquid oxygen dewar in the bed. Dave Matthews was the other half of the LOX load crew and started to hook up the load hose as soon as the truck was in position. I was on a ladder up against the launch tower and completed the LOX load equipment hookup after I had called the blockhouse on the headset and asked Brian to cycle the LOX vent valve and fuel tank vent valve. We started the LOX load and things were going very well indeed.

During the twenty minutes it took to load LOX, others were busy setting up the remote still, video, and movie cameras. George Garboden had spent considerable time, money, and effort experimenting with and learning to use the Society's high speed (2,000 frames per second) 16 mm movie camera. He had set it up just outside the old blockhouse and framed just the lower half of the rocket as it sat on the launch stool. He was trying to get the ignition and lift off with the two seconds of film the camera magazine held.

With the LOX tank full, the fittings were broken down and the LOX truck evacuated the area. I armed the spark transformer and the pyrotechnic igniters, and then checked the helium load system regulators and valves. The last step on the pad was to arm the on board electronics and switch on the video camera power. Over the headset, I was informed by the blockhouse that the video picture was coming through crystal clear. I came down off the ladder at the launch tower and pulled it away from the pad. I returned to the blockhouse where Brian was manning the PA system and the launch control panel.

At this point the rocket was still unpressurized. We commanded the LOX tank vent valve closed and were gratified to see the LOX vapor jet coming from the side of the rocket stop abruptly. We opened the helium pressurization valve and watched the miniature pressure gage mounted in the side of the vehicle with a spotting scope. The tanks came quickly up to their required pressure of 320 psi. The helium load was secured and the quick disconnect system was activated. The high pressure helium load line dropped clear of the side of the rocket. Brian and I both looked at each other with that "Did we forget anything ?" look, took a deep breath and started the final sequence of events.

Blockhouse, tracking, and bunkers conducted a "road and air" check to verify that no vehicles or aircraft had wandered into the immediate area. At T-45 seconds, the rolleron spin system was activated and the high pitched whine of the spinning wheels could be heard clearly in the blockhouse. Brian started the countdown at T-20 seconds over the PA. At T-5 the spark igniter was turned on and the pyrotechnic igniters both fired. As it should, smoke from the pyros billowed out of the nozzle as the count approached zero. ....T-4, 3, 2, 1, FIRE ! The main propellant valve control switch on the panel was thrown. There was a loud venting of gas and nothing else. The engine did not fire and no propellants were coming out of the nozzle. The main valve switch was quickly returned to the "closed" position.



The liquid oxygen dewar is brought back to the rocket to top off the LOX tank.

We announced a hold over the PA and then stopped briefly to figure out what had happened and how we might fix it. After a few minutes of head scratching, we concluded that one of the solenoid valves on the pneumatic control panel that operated the main propellant valves might have stuck open or leaked. This allowed the nitrogen pressure that was supposed to open the main valves to vent directly to atmosphere. At the time, there was also some question about whether one of the switches on the control panel was operating properly or not. Whatever had caused the problem, we needed to identify it and get it corrected as quickly as possible. The first step was to back the vehicle down to a safe condition.

Just as we had designed it to work, we were able to safe the rocket by opening the fuel tank vent to depressurize the fuel tank and the high pressure helium bottle. The LOX tank was vented next leaving the vehicle completely unpressurized. Brian and I went out to examine the vehicle and figure out what to do from here.

We checked the rocket and the ground support equipment and could see nothing obviously amiss. We did find a slight leak in one of the pneumatic control valves, but not enough to be a major problem. We disconnected the pneumatic lines from the manifold ring on the launch stool and functioned the control valves from the panel. All worked well except for one malfunction caused by a bad switch on the control panel. We concluded this was the problem and that we could recycle the rocket and go again. Just in case the main valve was a little sticky at liquid oxygen temperature (-280 degrees F), we boosted the pneumatic operating pressure from 250 psi to 350 psi on the ground panel regulator.

We announced over the PA that we were going to recycle and try again. The helium load line was hooked back up, and the video camera power in the rocket was turned off. The LOX truck was brought back up so we could top off the LOX tank. The expended pyrotechnic igniter was removed and replaced with a spare brought along for just such an occasion. George Garboden and Scott Claflin also managed to replace the film in both the high speed movie and still cameras that had been expended in the first launch attempt. It took us about forty minutes to completely recycle and get back to the point of starting the countdown at T-60 seconds. Not a bad save ....if it worked this time.

We all reported back to our stations and announced to the spectators that we were pressurizing the helium system. The LOX vent valve closed and the tank pressures came up to required levels. The helium load quick disconnect was activated. There was a slight movement of the hose attached to the rocket but it did not drop free. We held the count briefly while I went out with a long pole and tapped the hose fitting. The hose dropped free. Brian activated the rolleron spin system at 45 seconds and started the count over the PA at 20 seconds. The tension level is usually very high by this time in the count, but was even higher now after the first launch attempt problem.

At T-5 the igniters came on again....four, three, two, one, FI.......The last word coming over the PA was cut short by the roar of the engine bursting to life. From inside the blockhouse, with the very limited view afforded by the small windows, the rocket was gone in an instant, but the steadily receding roar told us it was in flight and functioning well. All of us in the blockhouse bailed out the door just as fast as we could to catch a glimpse of the rocket as it flew heavenward. Mike Henkoski was watching the video screen and was reporting aloud that he had a great picture of the flight from the on board camera. As I came out, I could see the rocket through its own exhaust plume disappearing at a remarkable rate. The sound it made as it approached Mach 1 was even more impressive than the visual image I was watching. The flight path was straight and true with no detectable deviation from the intended trajectory.

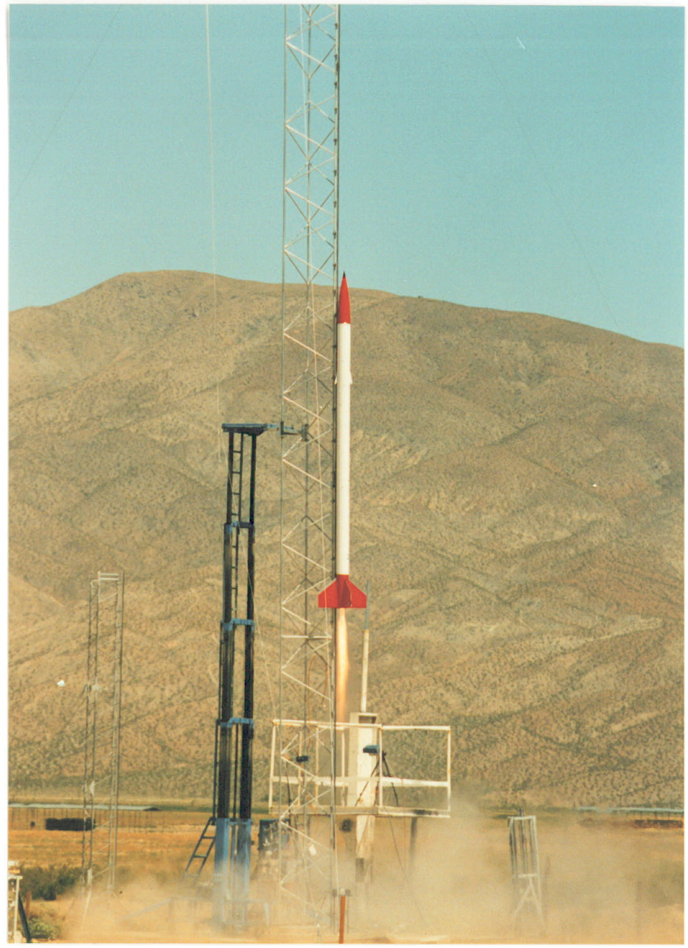
It had taken us only a couple of seconds to get out of the blockhouse and visually acquire the rocket. We had been watching it for several more seconds when I saw something unusual. The rocket was very small now and was still gaining altitude fast, but I thought I saw a speck of red tumbling free of the rocket. At first I wasn't sure, but then I saw it again glinting in the bright sunlight. I thought at first that a fin had come off, but the rocket was still flying in a stable manner although the flight path had deviated a slight amount to the northwest. Then I saw something black fluttering slowly down from high altitude. It dawned on me that the nose had detached prematurely, and the drogue had deployed. The nose was the intermittent red dot I could see as it tumbled back to earth, and the black shape was the shredded drogue chute torn loose and slowly descending. The rocket, however looked to be above 10,000 feet and was still on its way up.

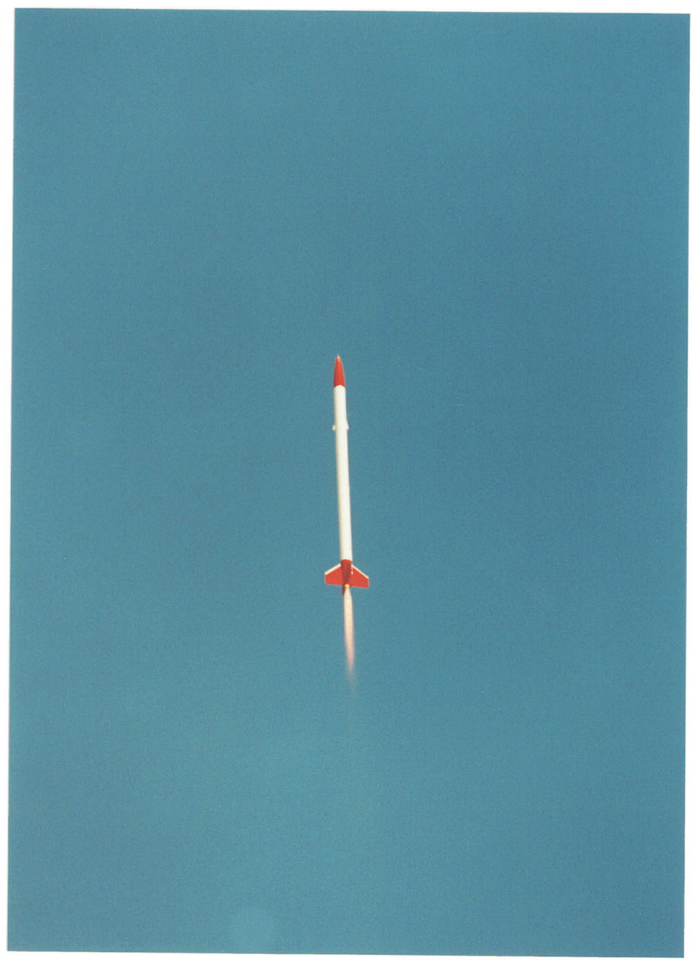
At some point, the engine had shut down as the rocket depleted all of its propellant. After several more seconds, the rocket, still visible as a white speck against the blue sky, reached peak, lost its fight with gravity, and started its return. The sound of the rocket as it plunged back through the atmosphere was as impressive as it had been going the other way. I watched it all the way to impact and heard a rather unusual "POP" as it hit. I was expecting the traditional "THUD" that a solid propellant rocket makes on impact and was a little puzzled by the sound. The answer was to come later at the crash site.

Well, the rocket flew fine but, as usual, the recovery system had malfunctioned. I was not in any rush to view the new form of the rocket that had taken six months of on and off labor to construct. I walked out to the launch pad to safe the area and close down the valves on the pressure bottles. I figured I would take my time to walk out to the crash site to see what was left. But while I was out on the pad, I heard someone yell "FIRE !" I looked in the direction of the crash site and saw the dry grass in that direction burning. We had foreseen such a possibility and had Tom Mueller's truck standing by as the fire vehicle with a pressurized tank of water in the back. The truck went past me as I watched. Then Brian ran by with a fire extinguisher on his shoulder. I figured I had better get down range as well. As I was jogging to the crash site, Rori Wherley, Brian's lovely wife, drove up behind me and offered me a ride in their truck. I hopped in and we beat Brian to the crash site.

Chip Bassett, Jim French, and several others had the fire under control by the time I arrived on the scene. The wreckage was scattered over a circle about 30 yards in diameter. In the center of the circle was a shallow, smoldering hole in which sat a burning parachute. All around were smashed tanks, scattered fragments of skin, twisted longerons, and completely pulverized electronics. The pyrotechnic line cutters were found and had functioned. The tie lines to the main parachute had been cut, but the drogue had not been there to pull the main out. One rolleron was recovered. The boat tail and engine were several yards away and in fairly good condition. The engine was in excellent shape and will be flown again.

The "POP" I had heard on impact was the bursting of the rocket's skin and tanks. When a solid propellant rocket (usually built of steel tubing in the experimental rocket world) hits the ground, the "THUD" is the sound of the rocket transferring all of its kinetic energy into the ground. The rocket usually remains intact. With a liquid rocket, its very light structure and large, empty, internal volume behave differently on impact. As the vehicle structure begins to



collapse on impact, its internal volume is decreased much faster than the residual gases inside the skin and tanks can escape. The result is a pressure burst of these components with a loud "POP" and a scattering of fragments over a wide area. In this case, the rapid compression and heating of the fuel tank, along with a small amount of residual alcohol in it, resulted in a fire as well.

We put the grass fire out, took several pictures, marveled at how beautiful the flight had been, and lamented even bothering to put a parachute in the damn thing. Mike Henkoski and I dug around in the ground near the burning parachute looking for any sign of Mike's video equipment. All of it was completely obliterated except for the 2.2 GHz transmitter which had survived with only the loss of a component or two. While we were on our hands and knees digging, my six year old daughter, Andrea, asked me what we were doing. Without looking up, I told her we were looking for some of the parts of the rocket. She blinked at me, surveyed the burned out wreckage and scattered debris (none of which was even recognizable), and then asked me very quietly, "Why ?"

Mike and I both stopped digging when she asked the question. I didn't have an immediate answer, but Mike sat back on his heels and told her very kindly, "It's just part of the grieving process." Andrea shrugged and went on her way. Mike and I laughed at the futility of what we were doing. Out of the mouths of babes.....

The debris was gathered up and transported back to the compound. There was little time to ponder. There were other rockets yet to launch that day.

Epilog: The rocket should have reached an altitude of almost 30,000 feet. When the firing was done and we had returned home, we began to pour through the wreckage, video tape and film footage for clues about what went right and what went wrong. We started with the on-board video footage and the high speed film of the lift off.

The 16mm film from the high speed camera could not have been more perfectly timed. When projected at the normal speed of 24 frames per second, the engine ignition and vehicle lift off appear in extreme slow motion. The ignition of the engine is remarkable to see at that film speed. The engine started smoothly with a clean ramp up to full thrust in less than a quarter of a second. The rocket starts to lift off the launch stool even before the engine is up to full thrust and flies swiftly out of the frame. Everything looked excellent from the propulsion end.

Spectators scour the crash site for bits of debris

The on board video was equally remarkable. In addition to the camera, Mike had put a microphone on the video package, and we had terrific audio from inside the rocket. You could hear the series of "ready" beeps coming from the Adept recording altimeter, as well as the whine of the rollerons spinning. You can clearly hear the announcements over the PA system and the countdown. At the moment of ignition, there is a loud roar and a burst of flame and dust from around the base of the rocket. The vehicle flies straight up at a remarkable rate with no spin whatsoever. The rolleron in view of the camera can be seen to move slightly from side to side correcting out any minor roll that is induced as the airspeed increases. The blockhouses, then the Quonset hut, and finally the bunkers are in clear view as the rocket ascends. It all looks perfect.

Then, approximately seven seconds into the flight, the video on the 2.2 GHz transmitter goes black and the 434 MHz image is lost as well. At first, we thought that the camera power had been lost. But the audio track continued, demonstrating that the transmitter was still functioning. In fact, the audio signal continued for more than a minute until the transmission ceased upon impact. After repeated rerunning of the video footage and much pondering, we discovered why the video had gone black. Seven seconds into the flight, just when a pre-flight trajectory analysis predicted the rocket would be passing Mach 1, the Adept electronics altimeter mistook the pressure disturbance of going transonic for the pressure minimum at peak. It sent a firing signal to the nose pyrotechnic separation mechanism (confirmed by the recovery of the nose with two fired pyro charges in it) and prematurely separated the rocket's nose. Knowing full well that a pressure perturbation would occur as the rocket went through Mach 1, I had discussed the issue at great length with Tommy Billings. Based on his previous experience with smaller rockets, he believed that the algorithms and data timing scheme used in the altimeter would prevent the possibility of such an error. But Edsel Murphy thought otherwise.

The drogue chute was spring loaded just beneath the nose and deployed while the rocket was passing the speed of sound. The drogue was ripped to shreds upon deployment, and caused a violent and instantaneous deceleration of the still thrusting rocket. (This event also caused the slight deviation in trajectory visible from the ground). The video camera was mounted on a rigid chassis just below the parachute tube. It was carefully aligned to look out through a 1/2 inch diameter hole in the skin and at the periscope mirror. The mirror was mounted at a 45 degree angle to view directly down the side of the rocket toward the ground. The video chassis was held in place longitudinally with one mounting screw through the skin and radially by four small blocks keyed into the open channel of the longerons. When the rocket was decelerated by the deployment of the drogue, the small screw holding the chassis in place was sheared and allowed the chassis to slide forward three inches until it contacted the bottom of the parachute tube. This put the camera lens in total darkness inside the rocket completely out of alignment with the hole in the skin and the periscope. The video signal was black because that was what the camera was viewing.

The movement forward of the video equipment chassis was also confirmed by the loss of the 434 MHz video signal. When the chassis moved forward, it pushed the inboard end of the 434 MHz quarter wave whip antenna forward. This caused the antenna to lay flat down against the fuselage and against its ground plane resulting in a loss of clear signal.

From the timing provided by the video system audio track and from visual observation of the flight, it is estimated that, despite the loss of the nose and deployment of a drogue, the rocket reached a peak altitude of between 12,000 and 15,000 feet.

After many hours of investigation, it looked as if everything had gone right except for one key event. Tommy Billing's Adept Electronics recording altimeter had mistaken the pressure perturbation of going transonic for the minimum barometric pressure experienced at peak and had sent the first firing signal out too early. It was ironic to us that the only component of the rocket that we had purchased instead of building was the one that had failed us. We told Tommy about our flight, and he has informed us that he has improved his algorithms to preclude this type of failure in the future.

As of noon on the 17th of June, 1995, our project had come to a dramatic end. While the flight was a great success, the recovery left something to be desired. But the success or failure of this effort is not really of much significance. Brian and I did not do this to attain any altitude records, impress beautiful women, be the first two amateur rocket engineers to reach Pluto, or win some mythological $100,000 (or is it $50) prize for throwing any nondescript piece of hardware into the sky to some arbitrary altitude. We did it to learn something. Not for mankind, or humanity, or even for the amateur rocketry community. We carried on with the project quietly and steadily, and for our own education. It took us a long time, from start to finish, but we were not in a race with anyone. And we did it the hard way (with a liquid propellant rocket) because there was more to learn by that route. Each machined part, valve, thrust mount, and separation mechanism was a series of lessons, studies, failures, and triumphs in itself. (I cannot tell you how many times I tore down, modified, and rebuilt the nose separation mechanism until it worked right - or how long Brian worked to get the thrust mount designed and built.) And finally, being the gambling sort, we bet we had done every bit of it right by risking it all and throwing all those months of effort, and buckets of dollars straight up into a limitless blue sky on an iridescent tail of rumbling fire. Those few seconds of beautiful, graceful, magnificent flight were more than worth the cost.

Brian and I discuss how easy it will be to rebuild the slightly damaged parts. Note that I am holding our trusty "back up recovery system."

Assembly of a LOX/Ethanol Flight Vehicle

by Scott Claflin

INTRODUCTION

In last month's newsletter, I described the development of the injector and combustion chamber for a 1670 lb. thrust LOX/ethanol rocket. This month, I will describe the fabrication of the other propulsion system components and the assembly of the flight vehicle. It is important to remember that the purpose of the project is to demonstrate low cost, simple rocket technology which can be utilized by practically anyone. During the development of the rocket described in this report, an effort was made to use off-the-self components and simple fabrication techniques wherever possible.

PROPULSION SYSTEM DESIGN AND FABRICATION

A schematic and a listing of the characteristics of the propulsion system during static testing are shown in Figure 1. The major components of the propulsion system are the thrust chamber, propellant tanks, valves, and pressurization tank. Since the development of the thrust chamber was discussed in detail in last month's newsletter, it will not be repeated here.

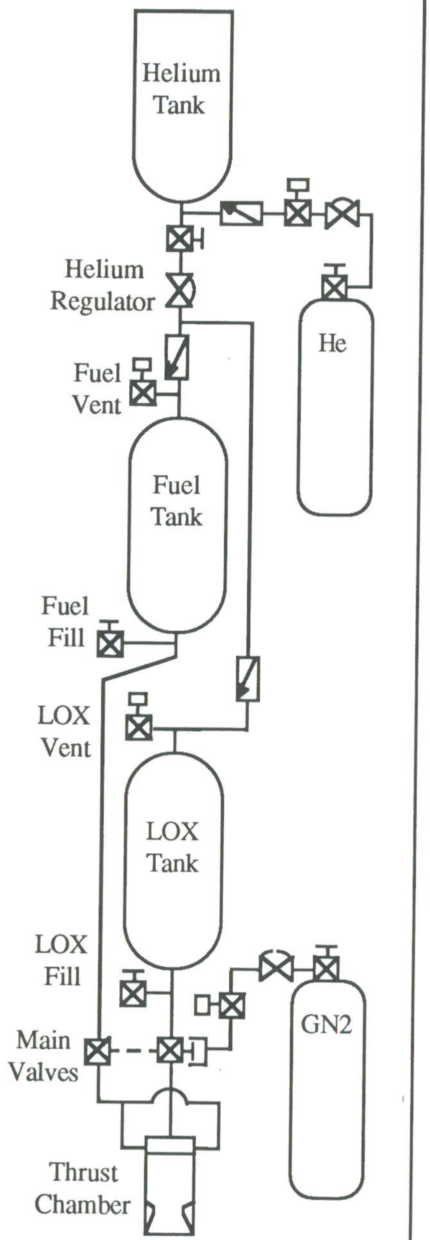
Propellant Tanks

Obtaining properly sized tanks can be very difficult and often it is easier to design a rocket engine or vehicle around existing tankage. For this project, the tanks had to be capable of containing 360 psia, be relatively lightweight, and be compatible with each propellant. The latter criteria eliminates the use of carbon steel tanks for LOX containment since carbon steel becomes brittle at cryogenic temperatures. The tanks also had to be the correct size (obviously). Since the nominal burn time was chosen to be 10 seconds, the tanks had to contain 48 lbs. of LOX and 35.5 lbs. of ethanol. Thus each tank must have a volume of 0.67 feet^3 or 5 gallons. The options for tankage ranged from commercially available propane tanks to surplus stainless steel aircraft breathing oxygen tanks to stainless steel fire extinguishers to homebuilt aluminum tanks. After consideration of the options, it was decided to fabricate tanks 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, one tank design can be used to fabricate both the fuel and LOX tanks. 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 each tank. A 1" stainless steel flare AN tee was welded to the outlet of each tank. At the head end of each tank a pressurant gas diffuser was welded into place. The diffuser was a length of 1/2" stainless steel tubing which was flared on one end. The other end, which was inserted into the tank, was plugged and then four 0.25" holes were cross-drilled in the tube. In this way, the pressurant gas is blown radially outward at the top of the tank and does not directly impinge on the propellant. The final tank assembly has a volume of 0.77 feet^3. An exploded view of the tank design is shown in Figure 2.

After fabrication of the tanks, each tank was hydrostatically tested to 420 psig. The test was accomplished by first attaching a manual grease gun to the tank. A pressure gauge was included between the grease gun and the tank. The tank was then filled completely with water (a garden hose fed water through the tank fill valve) and then shaken to ensure that no air pockets remained. Since water is incompressible, if the tank should fail while completely filled with water, the pressure will be relieved instantly and the tank will not explode. After ensuring that no air pockets remained in the tank, the tank was sealed with caps and the fill valve was closed prior to pressurization. The grease gun (without the grease) was filled with honey (corn syrup also works) and the grease gun was pumped until the tank pressure reached 420 psig. The pressure was then relieved by cracking one of the caps. The cap was tightened and the process was repeated five times for each tank.

Valves

Obtaining low cost valves is also a difficulty in liquid propellant rocketry. Valves must be capable of handling relatively high pressures, compatible with the working fluid, and capable of remote actuation. Further complications also arise because the valve requirements for a static test can be different from the flight requirements. For instance, propellant tank vent valves should be



Thrust = 1670 lbs.
Specific impulse = 200 seconds
LOX flow rate = 4.80 lb/sec
Ethanol flow rate = 3.55 lb/sec
Mixture ratio = 1.35
Burn time = 10 seconds
LOX tank volume = 0.77 cu. ft
Fuel tank vol. = 0.77 cu. ft.
Helium tank vol. = 0.40 cu. ft.

Figure 1 - Schematic of set-up used for static testing.

remotely actuated, normally-open valves for a static test but may be manually closed valves (for simplicity and weight savings) on a flight vehicle. By far, the cheapest usable valves

By far, the cheapest usable valves available to the amateur rocketeer are brass body ball valves from a hardware store. These valves can be used for main propellant valves, propellant fill valves and tank vent valves. Care should be taken to ensure that the valve seat and stem packing are teflon in valves intended for LOX service. Additionally, a vent hole must be drilled in one side of the ball for valves intended for use with cryogenic fluids, otherwise the liquid which gets trapped in the ball when the valve closes will boil-off and explode the valve.

The main propellant valves for the static tests were 3/4" ball valves which were actuated with a pneumatic cylinder. The fuel ball valve was a brass valve bought at a hardware store. The LOX ball valve was a stainless steel ball valve with a teflon seat and packing purchased at Grainger. The handle was flipped 180° on the fuel valve and both valves were placed so that their handles and axis of rotation aligned. By doing this, one pneumatic actuator could be used for both valves. For safety and simplicity, a single acting actuator was used to open the valves and a large spring was used to close the valves. This arrangement closed the main valves automatically if electrical power or pneumatic pressure to the test stand is lost.

For the static tests, solenoid valves were used for the fuel tank vent, the LOX tank vent, the pressurization valve, and the control valve for the main valve pneumatic actuator. With the exception of the LOX vent valve, the solenoid valves were purchased at a local surplus store. The LOX vent solenoid valve was an Atkomatic valve specifically designed for LOX service. The fuel and LOX fill valves were manually-actuated 3/8" brass ball valves bought at a hardware store. Both valves had teflon seats and packing.

The check valves used in the pressurization system for propellant isolation were purchased at surplus stores. The fuel check valve was originally designed for use in a hydraulic system. The LOX check valve was specifically designed for LOX service. Both check valves had 1/2" AN flared male fittings on the ends.

The pressurant regulator was an internally loaded Grove Mity-Mite regulator. The Mity-Mite regulator was required because of the high pressurant flow rate.

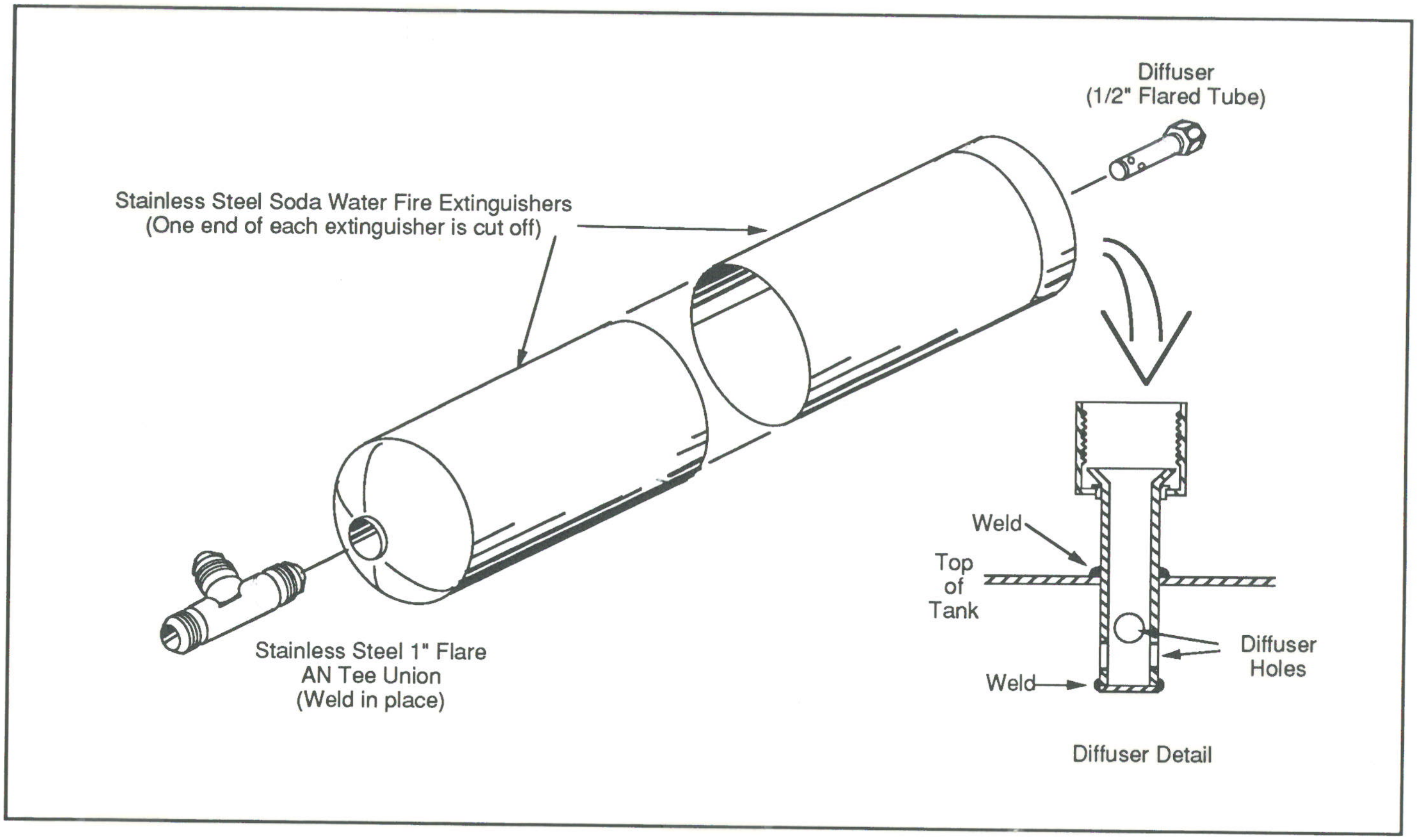


Figure 2 - Propellant tank assembly

Pressurization System

Helium was selected as the pressurization gas because of the limited solubility of helium in LOX. Nitrogen is cheaper than helium but will collapse and go into solution with LOX thus necessitating considerable amounts of nitrogen to maintain the propellant tank pressure.

For the static tests, helium was fed from the helium pressurant bottle through a manual ball valve, through a 3/8" high pressure solenoid valve, through the Mity-Mite regulator to the tanks. Helium was loaded through a check valve upstream of the manual ball valve. The helium pressurant bottle was an 80 standard cubic foot aluminum scuba tank rated for 3000 psia. The scuba valve that came with the tank was removed and a special stainless steel fitting was made to thread into the open neck of the tank. The helium load check valve could be threaded into the side of the fitting and the 1/4-inch manual ball valve could be threaded directly on the end of the fitting. The manual ball valve had a stainless steel body and was rated for 3000 psia service. The valve was manufactured by Hoke, Incorporated. The high pressure, normally-open solenoid valve had 3/8-inch AN ports and was designed for high gas flow rates. Readily available 1/4-inch Marotta valves could not handle the high helium flow rate without an excessive pressure drop across the valve so the larger valve was required.

The required volume of the pressurant tank was calculated by considering the volumetric flow rate of the pressurant (helium in this case) and by invoking the perfect gas law. First, the volumetric flow rate of the gas is found simply by dividing the actual volume of the propellant tanks by the planned time to empty the tanks.

$$\text{Volumetric flow rate} = Q = (0.77\ ft^3 + 0.77\ ft^3)/(10\ \text{seconds}) = 0.153\ ft^3/sec.$$

As the helium gas expands from an initially high pressure to a final lower pressure in the pressurant bottle, the temperature of the helium will drop. The initial temperature was assumed to be 520 °R. The final temperature is found by assuming that the expansion is isentropic.

$$T_{final} = T_{initial} (P_{final}/P_{initial})^{((\gamma - 1)/\gamma)}$$

where γ is the ratio of specific heats. For helium, γ = 1.67. The initial pressure in the pressurant tank was chosen to be 3000 psia. The final pressure in the pressurant tank was assumed to be 350 psia.

$$T_{final} = 520\ (350/3000)^{(1.67\ -\ 1)/1.67)}$$
$$= 220\ °R$$

The average temperature of the helium is

$$T_g = (520 + 220)/2 = 370\ °R.$$

By using the perfect gas law, the required weight of the gas in the propellant tanks can be calculated.

$$W_g = 144 \times (P_T \times V_T)/(R_g \times T_g)$$

where P_T = the propellant tank pressure (psia)
V_T = total volume of the empty propellant tanks (ft^3)
Rg = gas constant of the pressurant (ft-lb/lb-°R)

thus $W_g = 144 \times (350 \times (2 \times 0.77))/(386 \times 370)$
$= 0.543$ lbs.

The size of the pressurant tank required is found by assuming that the total weight of gas needed is the sum of the weight of the gas in the propellant tanks and of the residual gas in the pressurant tank. The perfect gas law can then be used to determine the pressurant tank volume.

Stored gas weight = gas weight in propellant tanks + residual gas in pressurant tank

$$(P_{initial} \times 144 \times V_L)/(R_g \times T_{initial}) =$$
$$W_g + (P_{final} \times 144 \times V_L)/(R_g \times T_{final})$$

where V_L = pressurant tank volume

$$(3000 \times 144 \times V_L)/(386 \times 520) =$$
$$0.543 + (350 \times 144 \times V_L)/(386 \times 258)$$

$$V_L = 0.330\ ft^3 = 571\ in^3$$

The actual volume of a 3000 psig, 80 scf scuba tank is 692 in^3 so the full scuba tank should contain approximately 20% more helium than is required to maintain 350 psia in the propellant tanks for the duration of the burn.

LAUNCH VEHICLE DEVELOPMENT

With the performance of the propulsion system verified on three static tests, the next step was to package the propulsion system in an airframe and launch it. Because the propulsion system will be beyond human control once the vehicle leaves the ground, many of the control and vent valves used for the static tests were eliminated in the vehicle. A schematic of the flight propulsion system and a layout of the vehicle is shown in Figure 3. A comparison of Figure 1 and Figure 3 reveals the degree of simplification achieved on the flight vehicle relative to the static test set-up. The valves which were eliminated were the pressurant solenoid valve, the pressurant manual safety valve and the fuel vent solenoid valve. The solenoid LOX vent valve was replaced by a small Hoke ball valve which could be closed immediately prior launch and manually opened if a launch abort occured. The elimination of the solenoid pressurant valve will cause the tanks to be pressurized while the pressurant tank is being pressurized. Since the pressurization will be performed remotely immediately prior to launch, pressurizing all the tanks simultaneously will not be a safety issue.

The major components of the flight vehicle are shown in Figure 4. Each component is secured with 3/4-inch plywood bulkheads except the thrust chamber which is mounted to a 1/2-inch thick aluminum thrust plate. The thrust plate has large aluminum gussets to carry the thrust loads into vehicle structure. As shown in Figures 5 and 6, 3/4-inch by 1/8-inch thick aluminum channels form the longitudinal stringers which connect the bulkheads. This structure which contains all of the propulsion components slides into a 10-inch diameter cardboard column-form tube and is foamed in place with two-part polyurethane foam.

The recovery system, if you can call it that, for the LOX/ethanol flight vehicle is somewhat novel. The scheme involves deploying four petals, hinged at the aft end of the vehicle, in the same manner as a high drag bomb. The vehicle will then descend from peak altitude nose-first, at considerable velocity, and will impale itself into the dessert. The term "lawn dart" seems appropriate. The reasons for resorting to this recovery system arise from 1) the extreme unreliability of parachute recovery systems on large amateur rockets and 2) the tremendous aerodynamic loads on a high speed rocket nose cone which make separable nose cones a dicey proposition at best.

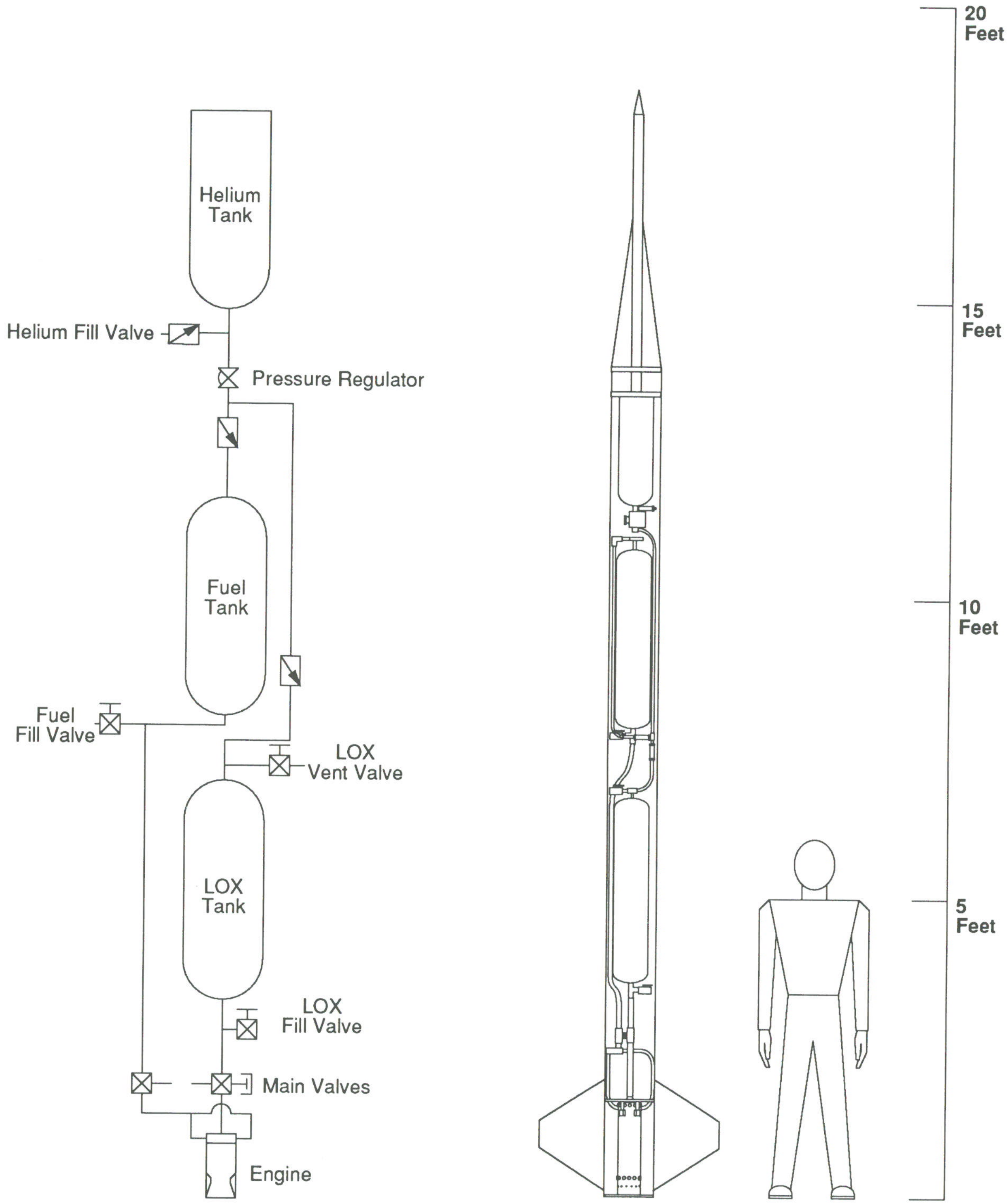
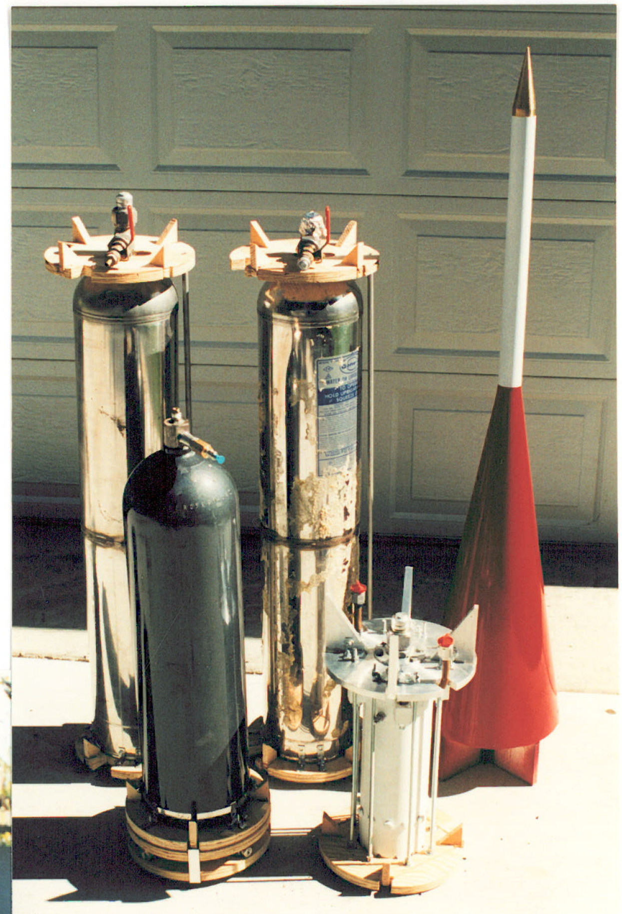


Figure 3 - Schematic and layout of the 1670 lb thrust LOX/ethanol flight vehicle

Figure 4 - The major components: (from left) fuel tank, helium bottle, LOX tank, engine, and nose cone.



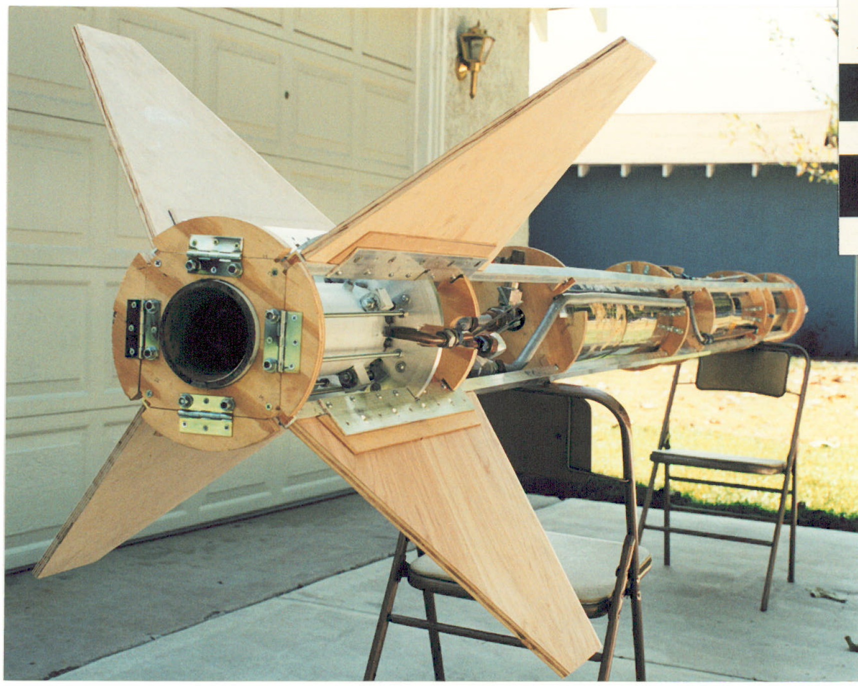


Figure 5 - Plywood bulkheads and aluminum channel longerons form the primary structure

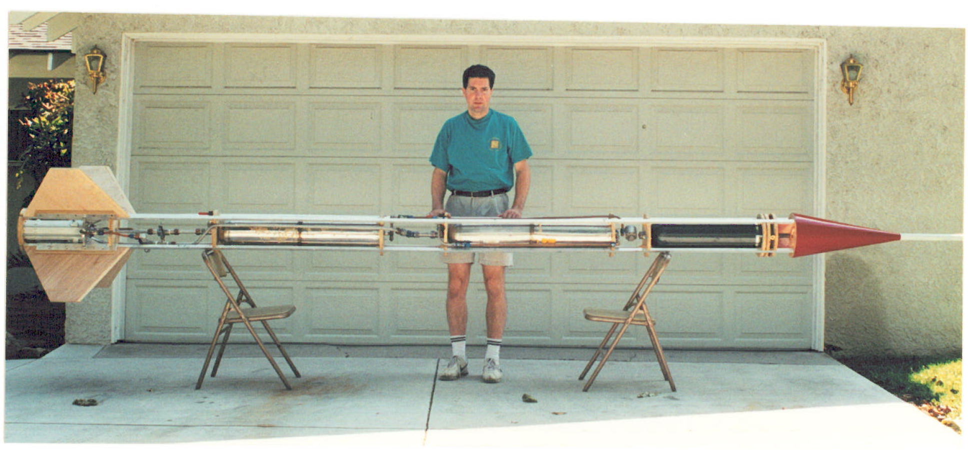


Figure 6 - The vehicle assembly minus the skin

The nose cone is designed to withstand the impact loads and decelerate the vehicle at approximately 20 g's upon impact. The nose cone has a central 1.5-inch diameter 4130 steel tube surrounded by four 1/2-inch thick plywood gores. Polyurethane foam fills the space between the gores and the wood/foam structure is covered in four layers of fiberglas. The central tube is topped with a brass tip.

The fins were sized to provide at least 15% static stability margin a Mach number of 2.0. The geometry for the fins is shown in Figure 7. The fins are made from 1/2-inch thick birch plywood. The leading edge of each fin was shaped by a router. The trailing edge was left square.

A weight break-down for the vehicle is listed in Table 1. Major contributors to the vehicle weight are the pressurant tank and the thrust chamber. The weight of both components could be easily reduced. For instance, using a filament wound fire-fighting breathing air bottle (made by MSA or Scott, Inc.) for the helium bottle would save approximately 12 lbs. Machining the thrust chamber wall from 0.25-inches to 0.125-inches thick would save over 7 lbs.

The predicted peak altitude for the vehicle is 31,000 feet. The vehicle should have a lift-off acceleration of 6.5 g's and a burn-out acceleration of 11.3 g's. Maximum velocity is predicted to be 1920 feet/sec (Mach 1.9) at 11,000 feet. Only time will tell the accuracy of these predictions!

Table 1 - Vehicle weight break-down

Component	Weight (lbs.)
Thrust chamber	25.0
Thrust mount	3.0
Fins	8.0
Main valves	2.0
Fuel tank	10.0
LOX tank	10.0
Helium regulator	1.0
Helium tank	32.5
Nose cone	10.0
Structure	25.0
Payload	3.0
Fuel	38.5
LOX	54.0
Helium	1.0
Total full weight	223.0
Total empty weight	129.5

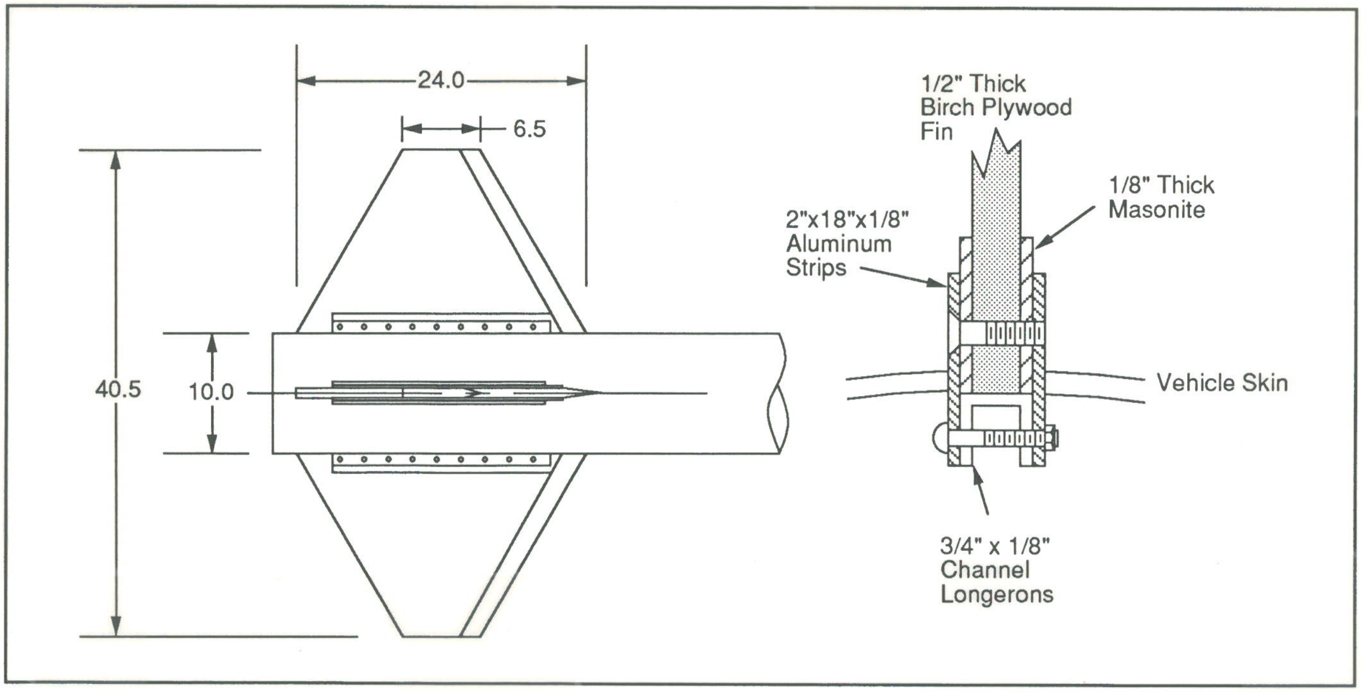


Figure 7 - Fin dimensions and method of attachment to the vehicle longerons

Gamma 2 Flight Report: Lessons Learned

by Wm. R. Claybaugh, II

The Gamma 2, a two stage, 3 inch diameter zinc/sulfur rocket was fired at the MTA on June 17, 1995. The vehicle's performance did not meet expectations; this report is intended to provide an analysis of the apparent failure of the nozzle exit cone on both stages and the subsequent sudden, high speed turn of the vehicle in flight.

Vehicle Description

The Gamma 2 consisted of two nearly identical stages, each 3 inches in diameter and 60 inches long. The first stage carried a welded forward bulkhead recessed 4 inches into the forward end of the stage, a nozzle consisting of a graphite throat insert and a Haynes 230 shell, and fins sized to provide 10 caliber stability during first stage burn. The second stage was similar but had the forward bulkhead recessed 2 inches from the forward end, and somewhat smaller fins as compared to the first stage, sized for 5 caliber stability during second stage burn. The two nozzles were identical. In addition, the second stage carried a "hammerhead" boattail which expanded vehicle diameter to 4 inches in the instrument section, which consisted of an 8 inch long cylindrical section and a 16 inch tangent ogive nose fairing. Instrumentation consisted of a flight computer (Adept OBC2) designed to sample altitude (as pressure) every 1/10th second and a backup digital altitude switch (Adept ALTS2). The flight plan called for separation of the instrument package from the spent second stage at peak, including deployment of a reefed 16 inch parachute, and unreefing of the parachute at 750 feet above ground level (AGL). The backup altitude switch operated a full double redundant separation charge at peak less 50 feet, and a fully redundant reefing line cutter at 500 feet AGL. The vehicle was sized to a 12 foot long, 4 inch diameter launcher using plywood split-ring sabots ahead of the first and second stage fins.

Flight Performance

The vehicle was successfully ignited and appeared to perform normally through first stage thrust termination. Second stage ignition was normal and the second stage burn was on the expected flight profile until about one-half way through that burn, at which time the vehicle suddenly turned from an approximately 88 degree heading to about 45 degrees from the horizontal, in a downrange direction. First stage impact was heard and seen as expected, second stage impact was not viewed or heard, and the instrument package was seen to land not far from the launcher in the downrange direction. The damaged but intact instrument package was found, with parachute deployed, about 350 feet downrange. The first stage was recovered 950 feet downrange. The second stage was not recovered. A recovered sabot ring half showed signs of having been burnt, presumably from falling through the vehicle exhaust.

Flight Performance Review

The instrument package showed signs of deployment at high speed: the central vent hole in the hemi-spherical parachute was badly shredded, with no stitching intact. The flight computer, however, was functional and was indicating a peak altitude of 5402 feet AGL when recovered.

Inspection of the instrument package showed that the parachute shroud lines and the wiring lines to the separation charges had been cut in several places. The reefing line charges were unfired. The base of the instrument package, at the slip joint with the upper stage of the vehicle, was rounded on the lower half on one side of the base, over an arc of about 180 degrees. Score marks were visible on the opposite side of the slip ring, beginning about one-half of the way down the slip ring.

Opening of the instrument package revealed that all of the cable connectors between the flight computer, the altitude switch, and the various charges had come loose. The battery for the altitude switch was loose in the instrument compartment and that device was not functioning. The memory module for the flight computer had also separated from its connector and was loose inside the instrument compartment. Finally, several electrical components on the two circuit boards were bent at an approximately 45 degree angle centered on the 180 degree rounding found on the instrument package slip ring. Replacement of the memory module and downloading of its contents showed that no data had been collected in flight; since the memory module stores data in the absence of power, this suggests the module was pulled from its connector during initial acceleration of the first stage.

The first stage was recovered intact. The nozzle, however, showed evidence of unusually high erosion aft of the graphite throat insert. This erosion had lead to collapse of the nozzle exit cone around the nozzle, evidently as a result of first stage impact. The graphite throat insert had also failed on impact and had collapsed into the rocket.

On the basis of these observations it is believed that the instrument section of the vehicle was forced off the firing second stage at the time of the sudden 45 degree turn of that stage. The internal damage to the instrumentation and the rounding and score marks on the slip joint are consistent with this conclusion, as is the evidence for high speed deployment of the parachute and the damage to the shroud and electrical lines. The apparent 5402 foot altitude reported by the flight computer appears anomalous, as neither the downrange distance nor the altitude of the vehicle at the time of the turn (estimated at several hundred feet) would support this value.

The unusual erosion of the first stage nozzle is a surprise. Haynes 230 is rated for short term (minutes) exposure to 2300 degrees, and it was expected that it would display much less erosion than the 1020 steel generally used for nozzle shells. Based on the condition of the first stage nozzle, it has been suggested (Crisalli, 1995) that the presence of Zn vapor in the exhaust may have caused formation of a molten eutectic with one of the components of the Haynes 230, which material was then rapidly eroded by the supersonic exhaust stream.

The failure of the first stage nozzle on impact suggests the possibility of in-flight failure of the second stage nozzle exit cone. If an in-flight failure did occur, it is reasonable to expect that the initial burn-through of the exit cone wall could have provided the side force necessary to turn the vehicle through about 45 degrees in the much less than 1/30th second observed. Subsequent full failure of the exit cone would have allowed the vehicle to then continue flight in the new flight direction. This failure mode, if it occurred, would lead to the expectation that the remains of the exit cone might be found along a path keyed on the launch tower and the impact site of the first stage, and downrange of the first stage impact. In the absence of this evidence or recovery of the second stage, it is not possible to positively assign a cause to the sudden turn of the vehicle during second stage burn.

Modeling of the flight of the vehicle using Rodgers Aerosciences ALT4 program suggest that a nominal mission would have achieved an altitude in the 13,000 - 14,000 foot range. If the vehicle's sudden turn occurred exactly one-half way through the second stage burn, its vertical velocity at the time of the turn would have been in the range of Mach 0.7; this vertical velocity would be sufficient to reach a peak altitude in the 5000 feet AGL range. Given the additional horizontal velocity component imparted following the turn, the vehicle would be expected to have impacted 10-15,000 feet downrange, under these assumptions.

<u>Lessons Learned</u>

1. Haynes 230 appears to be unsuitable as a nozzle material for zinc/sulfur rockets, due to unusually high erosion of this material in the exhaust stream.

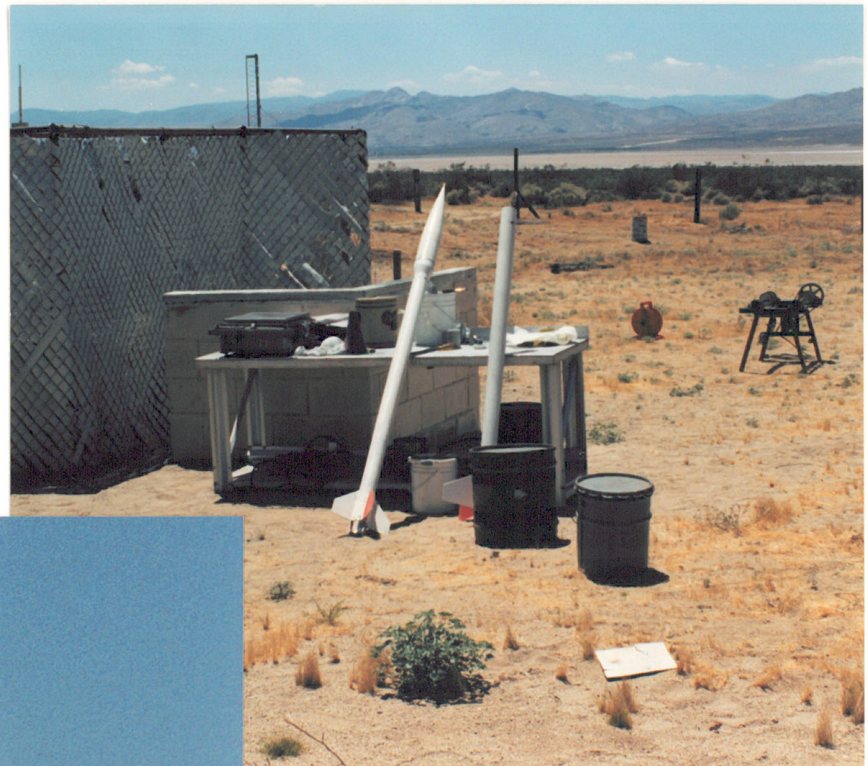
2. Slip fit joints, while suitable for normal mission performance, can undergo ductile failure during violent maneuvers. Such joints should be backed up with shear pins to help assure that the vehicle will remain intact in the event of an unexpected flight event.

3. Connectors for electronic circuit boards should be physically restrained to ensure performance under all potential flight loads. In particular, connectors should use screw pins to positively bind the male and female components of the connector.

4. The memory module of the Adept flight computer requires some form of positive restraint to its female side. In the absence of a modification to the board to allow screw pins, electrical tape wrapped around the board might work, although this solution would require moving the on-off switch.

5. Batteries need to be positively restrained and anchored against structure, not mounted on circuit boards. Snap-fit fixtures for standard nine volt batteries appear to work well, even in high acceleration environments, if supported on the base and back. Other type battery holders will require electrical tape or some equivalent to assure full retention of the battery in flight.

6. Fully welded flight structures are robust: despite the loss of its nose fairing and a very sudden turn at high subsonic speeds, the second stage resumed stable flight on the new flight heading. Similarly, the first stage was recovered intact following impact in an apparently undamaged condition (note that reflight of zinc/sulfur motor tubes is not recommended due to potential erosion of the interior of the motor tube near the nozzle entrance).



Both stages of the Gamma 2 in the fueling area

Lift-off of the Gamma 2

RRS Composite Fuel Static Tests (June 1995)

by G. Garboden

Under duress from the editor of this newsletter, I am being forced to write a brief account of our recent series of static tests. Both Niels Anderson and I have been extremely busy with work and personal endeavors. The time available for rocket related activities has been minimal. Nonetheless, since the launch of four composite fueled rockets in October of 1994, we have scaled up the size of our test motors considerably. The flight rockets of last October were 2.5" O.D. aluminum tubes with approximately 2.8 pounds of propellant. The current test motors use 4.0" O.D. and 5.0" O.D. aluminum tube, each with a .250" wall thickness. Their approximate propellant capacity is 8.6 pounds and 18.0 pounds respectively.

As in the smaller rockets, we were able to use standard size PVC pipe for the propellant liners. Minimal machining of the PVC produced the desired dimensions on both O.D. and I.D. Nozzles are machined from graphite and the forward bulkheads are aluminum. Both ends of the motor are sealed with a single silicone O-ring and retained with a snap ring.

Since the expected thrust of these new test articles would be substantially more than produced by the previous motors, a new static test stand was constructed. A goal of this test series was to explore the possibility of being able to provide a matched set of composite motors to be used as boosters. In fabricating the stand, therefore, we decided to accommodate two motors, side-by-side, with thrust and pressure measurements for each. The main element of the test stand is an I-beam of substantial cross section. The two load cells are mounted on a sub-plate with 12" center spacing. The stand can accommodate tests of two 1500 pound thrust motors in tandem. Higher capacity motors can be tested if the load cells are upgraded. Orientation of the motors in the test stand is vertical up. In addition, a four channel amplifier was constructed to interfaced with the data acquisition system.

Thanks to Chip Bassett, Tom Mueller, Pat Mullens, the Montgomery mixer, and others, we were able to process enough propellant to do four static tests of the 4" size. An incubator of increased capacity was built and allowed all of the propellant segments to be cured concurrently. After a brief period to calibrate the instruments, testing commenced in mid-afternoon.

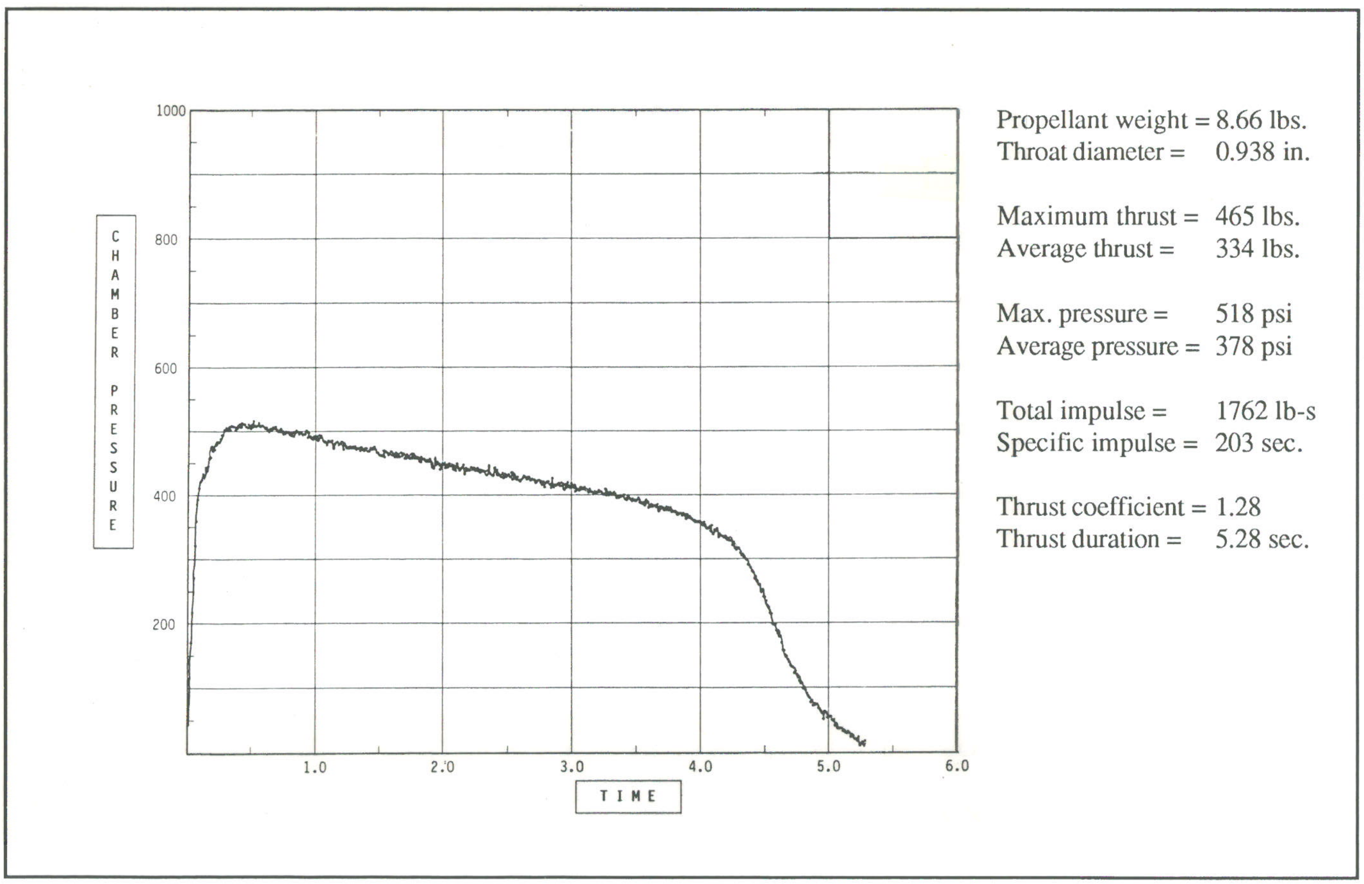
The first test was a single firing to validate the new equipment and be certain the motor operated within the expected parameters. When the count reached zero and the fire button was depressed, a loud pop was heard, but the motor did not light. Bummer. I immediately terminated the data collection, but several seconds later the motor ignited and roared to life. The thrust appeared to be substantial, but the duration was only half of what had been expected. Although I did not get data, Niels had not shut down the second computer and recorded thrust and chamber pressure. We had experimented previously with parallel data acquisition, and this time it was really beneficial. The burn profile was not as expected, showing a sharp spike shortly after ignition, with a trail off for approximately 2 seconds.

Some head scratching ensued and a few ideas surfaced. Our ignitor is a bit unique. It is a forward bulkhead type using components we fabricate ourselves. In all previous testing and flights, we had never experienced an ignition failure. Since we had used the "wag" method to size the ignitor for the original 2.5" rockets, we decided to carry the same size over to the 4". It appeared from this test that we were on the minimum threshold of ignitor size as the motor did just get running, but with considerable ignition delay. Additionally, we had brushed the core of each propellant segment during motor assembly to remove some of the surface oxidizer. This was a process we had used previously on the 2.5" motors to prevent a severe pressure spike on ignition. The high chamber pressure and subsequent short burn duration of this test remained an unanswered question. However, we suspected that the condition could have been caused by increased burning surface resulting from either a crack in the grain or burning along the propellant/liner interface caused by debonding. Post test inspection seemed to indicate the latter. An audible pop was heard toward the end of the burn and, since all the components were still intact, we think that a propellant chunk could have exited the nozzle at that time.

For the second test we chose a propellant variation that would provide a longer burn time with reduced thrust. All of our previous work had been with 200 micron ammonium perchlorate (AP) only. This particular batch used 75/25 mix of 400 and 200 micron AP. Additionally, we opted for an ignitor that was sized for future 5" motor test stand and left the oxidizer on the surface of the propellant (as in the normal state after surfacing the ends and coring). On this test, the motor lit instantly and provided us with excellent data. Since we were using a nozzle designed for the higher pressure/faster burning mix, the chamber pressure and thrust were not optimized. A specific impulse of 203 seconds was determined during a post test analysis.

Now with a full head of steam and a little more confidence, we proceeded with tests #3 and #4. It was decided to continue testing individually rather than in pairs until we could produce consistent results. In both tests, the motors lit instantly even though we had returned to the original ignitor sizing. It appears that not removing the surface oxidizer is beneficial at this scale with our current ignitor. The results obtained from these tests, although similar, were not as expected. In fact, we had returned to the same profile as test #1. Whatever it was we we're doing, we were darn consistent at it. The results of the last two tests showed that total impulse varied less than 2 pounds, even though the maximum thrust varied substantially. Since the mixer we are now using has a much larger capacity than the original K5, we were able to process a batch that yielded enough propellant for two tests. In this case we could mix and match segments of varying weight until the total propellant weight for #3 was within 1 gram of the total for #4. This bodes well for the prospect of building matched booster pairs.

Later analysis of the final two tests showed a specific impulse of about 216 seconds which is a little lower than the 225 seconds we were able to obtain in previous tests with the 2.5" size motors. Future testing will be focused on obtaining the proper burn profile and consistent results. In addition, a tubular test chamber has been fabricated with the same internal dimensions as the core of the 4" size motor. This tube will be instrumented and used to test various ignitor configurations in an effort to gain reliable and repeatable ignition.



Static test data from a 4-inch diameter composite solid propellant rocket

Design of a Nitrous Oxide/Methyl Alcohol Engine

by Peter C. Cottham

Since returning to the U.S. in April of 1994, I have had the opportunity to dig my hobby shop out of moth balls and set it up. I have been working on a design of a nitrous oxide/methyl alcohol rocket engine for about a year and a half now. The thrust of the engine ranges from 20 to 50 lbf.

After reading the article by Scott Claflin about the plexiglas hybrid motor [RRS Newsletter, Vol 52, No. 1, Feb. 1995], I decided that it would be an excellent method of determining the flow characteristics of nitrous oxide as I had no previous experience with this fluid. The components for the nitrous oxide/plexiglas hybrid I built are shown in Figure 1. I have conducted several test firings to date.

One of the design objectives of the nitrous oxide/methyl alcohol liquid rocket motor is to use as many off-the-shelf (OTS) components as possible. Such items would include solenoid valves, tanks, restrictors, etc. All of these types of hardware are available commercially from Nitrous Oxide Systems (NOS), Inc. in Cypress, California [(714) 821-0580]. The reasoning behind using these commercial products falls into three major areas:

1) It is usually more cost effective to buy OTS than going through detail design and testing of such components (however interesting this might be from an educational point of view!). Using OTS components reduces the overall design time so you can concern yourself more with the integration of the rocket motor components and isolate problem areas affecting the overall system somewhat quicker.

2) Use of OTS components results in less labor. Given the limited resources of many amateur motor builders, access to a machine tool such as a lathe is nonexistent. The use of OTS components allows individuals to put together a system which comes close to their expectations with much less effort/skill required.

3) The use of OTS items may open up more interest in the field of amateur rocket design and fabrication to individuals who would normally consider it beyond their practical skills or talents.

Though it has sometimes proved quite difficult to adhere to the above OTS requirements, it appears that it is more a case of keeping your eyes and ears open for everyday things that might be transmuted into a rocket component. A good example of this is, perhaps, the use of gas welding nozzles (the replaceable type used in inert gas welding) as pre-drilled, screw-in, replaceable, combustion chamber injectors. Take a look at the local weld shop and it can be seen that they hold a reasonable selection of copper injector/nozzle type components in sizes useful for rocket chamber designs (0.020, 0.037, 0.045 inches, etc.). Taking that a step further, using such components could make possible an acoustic baffle chamber design if somebody was so inclined to study such a concept.

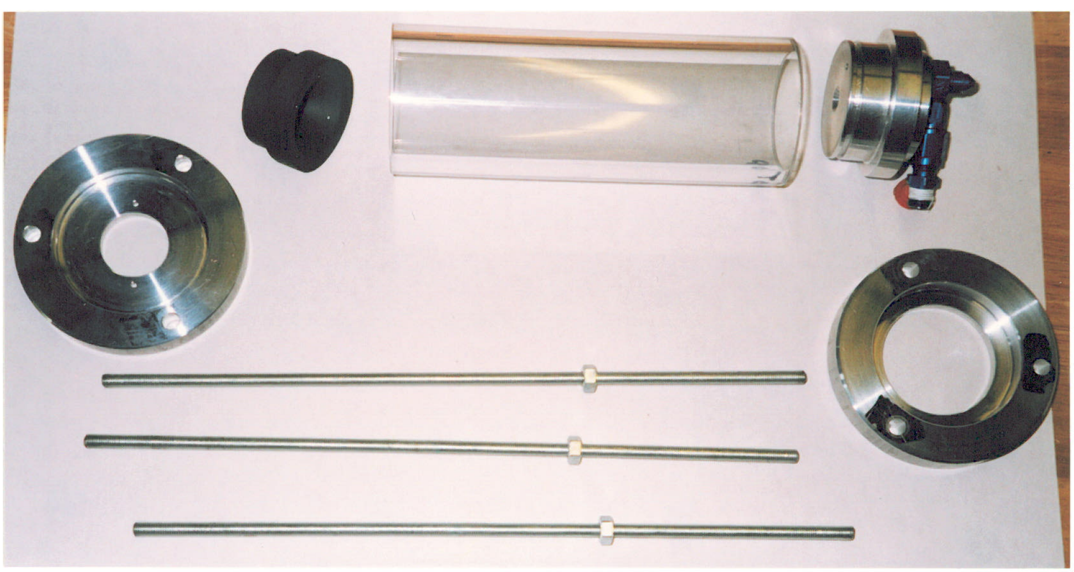


Figure 1 -Nitrous oxide/plexiglas hybrid motor components

As shown in Figure 2, the type of injector I have chosen to build is coaxial in style. The center element is used to deliver methyl alcohol and is a made from a modified 18-8 stainless steel bolt. The bolt is cross-drilled into a blind hole which supplies the fuel to the combustion chamber. The methyl alcohol pressure restrictor is a standard NOS, Inc. restrictor. The outer annulus delivers the nitrous oxide and again the restrictor is made from an NOS, Inc. standard component. The logic behind the coaxial design is that there is little or no alignment problem as associated with impinging jet style designs. This makes for a robust and producible component without resorting to universal milling machines, indexing heads, etc. The motor components are shown in Figure 3.
The propellant tanks are shown in Figure 4. Propellant tanks for this motor are a standard NOS, Inc. 1.0-pound nitrous oxide bottle and a 1/2-pound carbon dioxide bottle (used in paint-ball guns) for the methyl alcohol. These are cheap and easily recharged. If carbon dioxide is used as a tank pressurant, all tank components can be considered passive and compatible.

Combustion gas properties were confirmed using a commercially available version of the standard NASA-Lewis thermal equilibrium program (TEP). At a chamber pressure of 200 psia and a mixture ratio of 2.75, the combustion temperature is 5130 °R, specific impulse is 210 seconds, and characteristic velocity (c*) is 5100 ft/sec.

Well, I hope that my description of some of the rocket things I am doing up here in "sunny" (yeah, right!) Seattle will be helpful. When I am ready to fire up the large motors, I hope to get time off to come down to the MTA and use those facilities to do the firing tests.

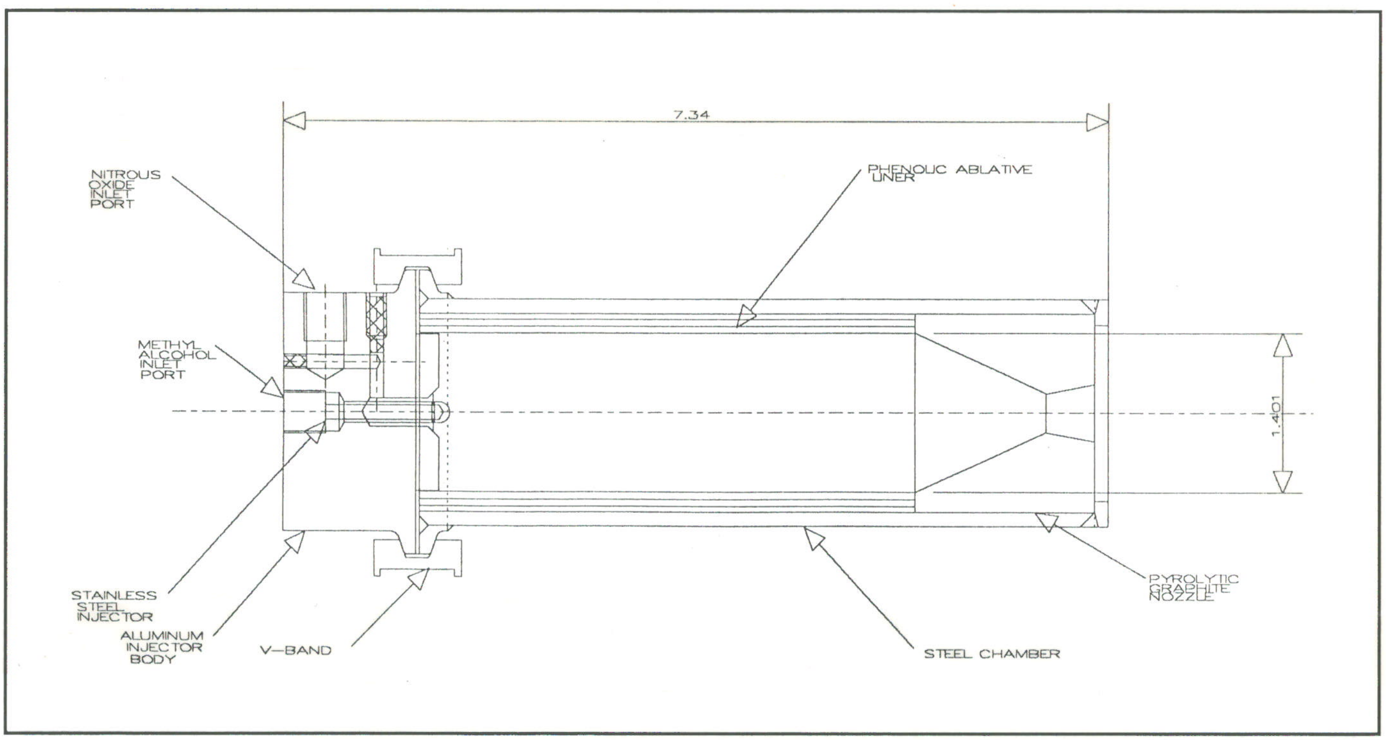


Figure 2 -Nitrous oxide/methyl alcohol ablative test motor assembly

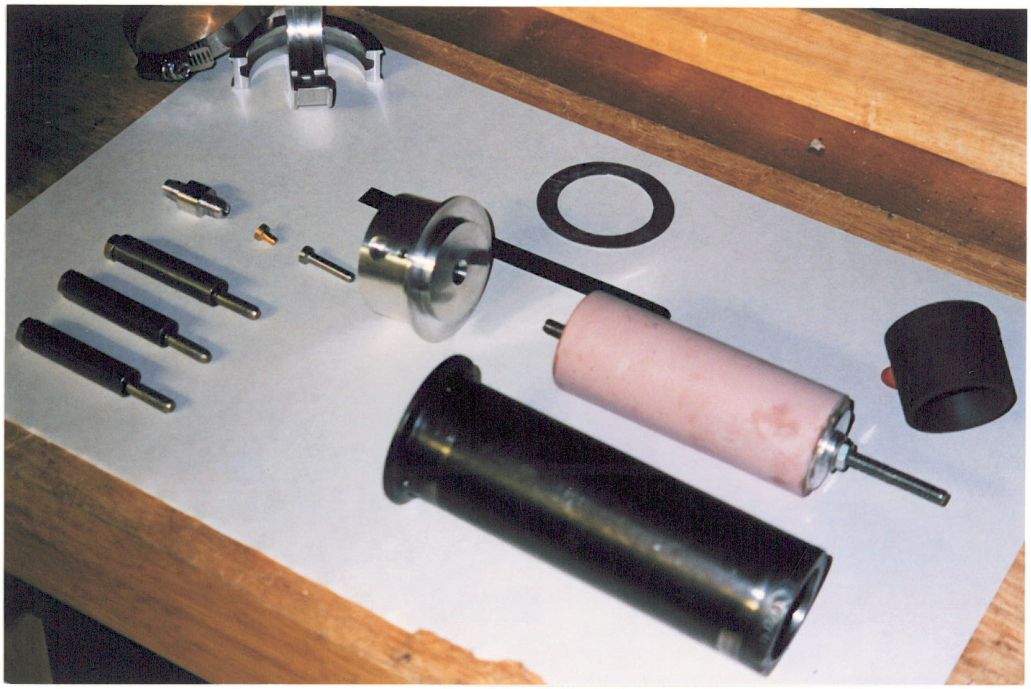


Figure 3 -Injector and thrust chamber components

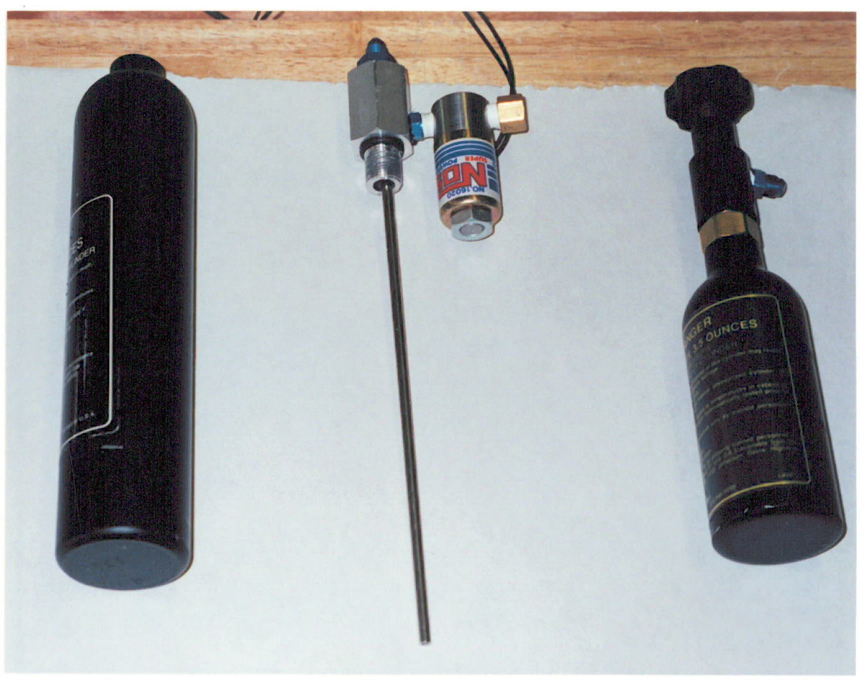


Figure 4 - Nitrous oxide tank (left) and carbon dioxide tank

In the RRS NEWS Thirty Years Ago...

RRS Standard Experimental Rocket

After due consideration, the RRS has adopted the experimental Y-4 as its standard liquid rocket test vehicle.

The preliminary design is shown in the drawing on the opposite page.

Static tests indicate that a stoichiometric mixture (1:1) of di-hydrogen oxide (oxidizer) and H_2O (fuel) is an ideal, inexpensive propellant for this program. The mixture has a specific impulse.

The nozzle will be of 4130 chrome-moly steel with a Wood's metal throat insert. Erosion is expected to be minimal. The nozzle will be held in place with three 15/32-11 ambihelical headless capscrews with counter-clockwise threading.

The motor casing itself will be machined from a billet of a special high temperature alloy (3115 steel alloyed with $BaNa_2$). The injector will be a new tri-conic design which employs the tri-axial uni-manifold. The manifolds were adapted from surplus U.S.M.C. three-pronged blivets. The manifold is to be mounted on a large ambihelicoidal manifold mounting ring which is then fused to the forward section.

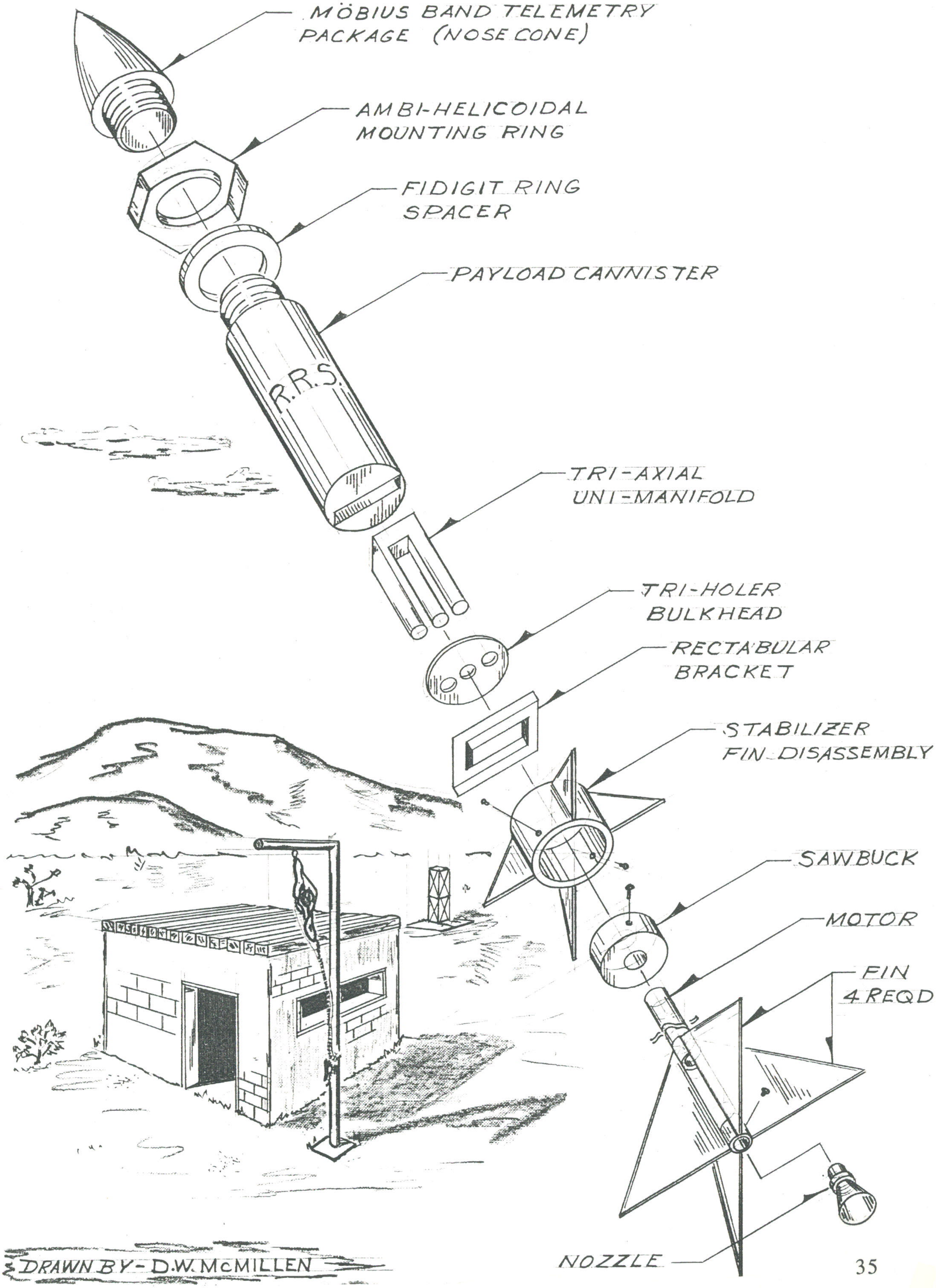
A most interesting feature of this new design is the use of the Mobius band for the radio telemetry system, a sophistication usually found only on large government-supported rockets, such as Vanguard I.

The final fuel and oxidizer tank configurations have not yet been resolved. But several designs for cryogenic stainless steel Klein bottles have been presented for use as the di-hydrogen oxide tank. The only difficulty so far with this phase of the design has been the layout of the pressurization system for the tank. The fuel tank has presented no major design problems, and a prototype is under construction.

The fuel and oxidizer pressurization system is a unique method of gas pressurization achieved by injecting pellets of sodium acetyl salycilate directly into the tanks under a pressure of 1000 millibars. The sodium acetyl salycilate pellets are 1.29 inches in diameter and 0.153 thick. As much as we would like to take credit for this unique system we must admit that it was adapted from the system used on Sputnik I.

Further refinements of the design of the Y-4, and of course all phases of tests, static and dynamic, will be published exclusively in the RRS NEWS as soon as available.

[*This article originally appeared in RRS NEWS #100, Fall 1965*]


MÖBIUS BAND TELEMETRY PACKAGE (NOSE CONE)
AMBI-HELICOIDAL MOUNTING RING
FIDIGIT RING SPACER
PAYLOAD CANNISTER
R.R.S.
TRI-AXIAL UNI-MANIFOLD
TRI-HOLER BULKHEAD
RECTABULAR BRACKET
STABILIZER FIN DISASSEMBLY
SAWBUCK
MOTOR
FIN 4 REQD
NOZZLE
DRAWN BY- D.W. McMILLEN

Bits and Pieces

Thank You : The Society wishes to extend another thank you to George Garboden, Chip Bassett , Brian Wherley, Rori Wherley, and Niels Anderson for their efforts to pick up, transport, and deliver to the MTA almost 20,000 pounds of structural steel earmarked for the new vertical static test stand and other facility improvements. They accomplished this task by making several trips from Irvine to the MTA over a two day period, stopping only to load or unload. It was a hurculean effort accomplished during some of the most abissmally hot weather we have had this year. Our sincere appreciation is extended to these benefactors.

Christmas Party: The annual Christmas party is coming up in mid-December. Keep an open for an announcement in the monthly RRS Bulletin.

Back Issues of the RRS Newsletter: For those members who may be interested, copies of the last three RRS Newsletter issues are available for $5.00 each. 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 (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 Mr. George Dosa with any corrections by telephone or mail. He is on the list and we made sure his name, address, and phone number were OK.

50,000 Foot Altitude Flight Contest - An anonymous $500 reward has been offered by a member of the Society to the first person or group within the membership that launches a solid, liquid, or hybrid rocket to an altitude greater than 50,000 feet. The launch must be conducted at the Mojave Test Area. Altitude verification may be by any means as long as the results are acceptable to a panel of judges that will be established. Those serving as judges will not be eligible to participate in the contest. The commencement of this contest is effective as of October 1, 1995 and will stand open until the prize is won. Official rules will be published and made available to any members requiring them.

Reports and Publications Price List

RRS Beta Zinc/Sulfur Rocket Plans (21 pages)	$12.00 each
Report: "The development and Testing of a Hydrogen Peroxide Rocket" (24 pages)	$12.00 each
Report: "Design of Demonstration Rocket Motor #1" (16 pages)	$5.00 each
Report: "Tracking"	$3.00 each
Report: "Nose Cones"	$3.00 each
Report: "Fin Bracket Assembly"	$3.00 each
Report: "Parachutes"	$3.00 each
Report: "Thrust and Drag"	$10.00 each
Reprint: "Amateur Rocketeer" reprint of RRS report on plasma jet research	$3.00 each

1976 United States Bicentenial first day of issue rocket mail covers.. $8.00 each

RRS decals.. 2/$1.00

RRS NEWS, **Issue #93, April 1960** - Ethylene Oxide Report, 3rd RRS Rocket Mail Flight, American Rocket Society 1960 Student Awards, (11 pages)........................$4.00 each

RRS NEWS, **Issue #95, Summer 1961** - RRS Meeting Report, 5th RRS Rocket Mail Flight, MTA Development, Hydrogen Peroxide Report, Firing Report (9/9/61), (8 pages)..$4.00 each

RRS NEWS, **Issue #96, Spring/Summer 1963** - Revival of RRS News, Outline for Research Reports, Movie Rocket and Drawings, Flame Propagation in Liquid Rocket Chambers, (8 pages)..$4.00 each

RRS NEWS, **Issue #97, Fall/Winter 1963** - Hydrogen Peroxide Information, Inertia Switch, Flame Propagation in Liquid Rocket Chambers,(12 pages)......................$4.00 each

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