HIGH POWER ROCKETRY

NOVEMBER 1997

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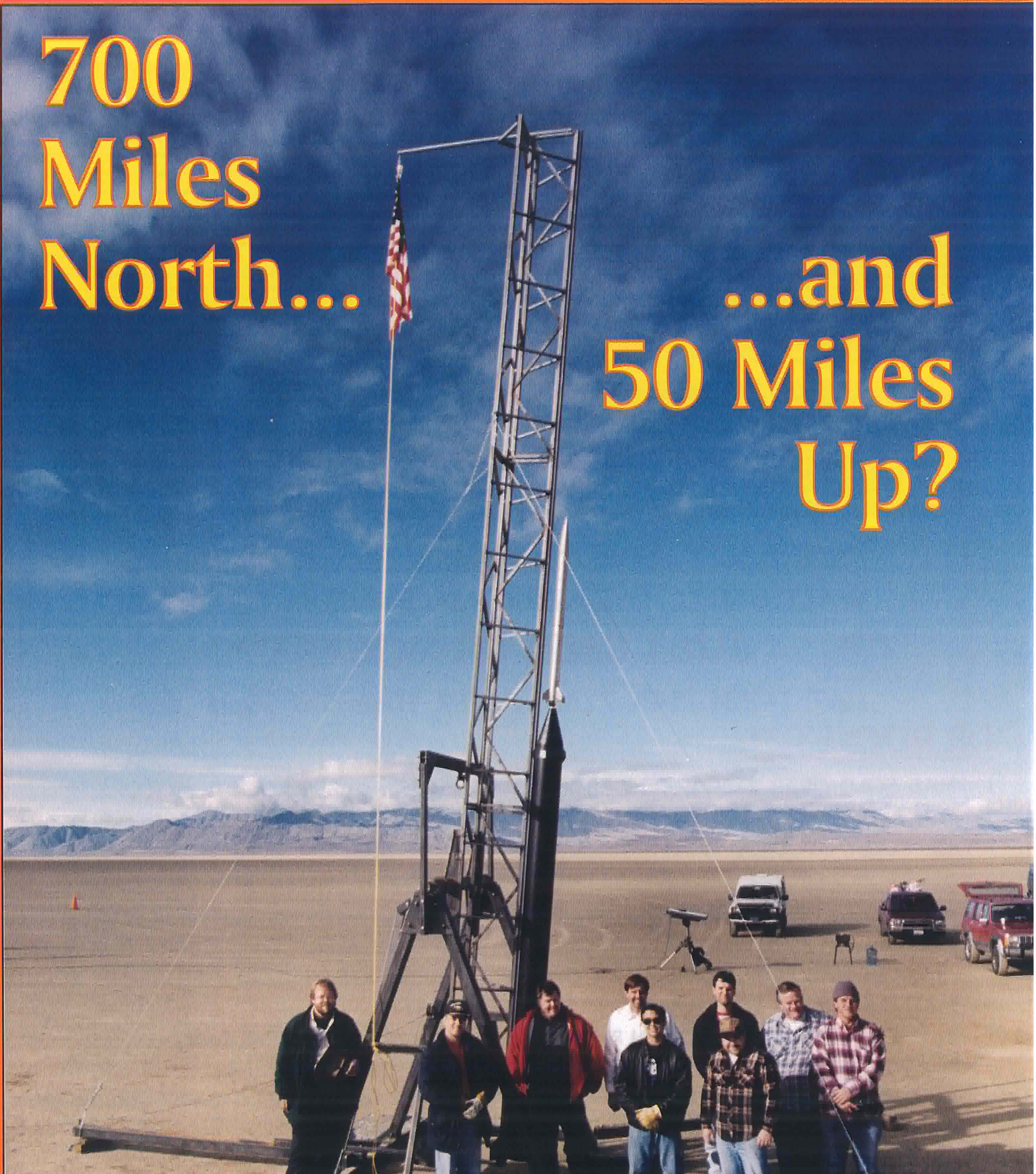
700 Miles North... ...and 50 Miles Up?



by David E. Crisalli
Photos by Stan Curry and Emily Overmier

The Beginning

Over the years, I have been involved with many amateur experimental rocket launches. Solid propellant, liquid propellant, large or small - they are all unique, educational, exciting, and exhausting. But the story I am about to relate is, without question in my mind, one of the most remarkable events in the history of any non governmental rocket project. So much technical effort, sweat, logistical planning, rocket propellant, and steel went into this launch so quickly that I am still amazed at how well it all fell into place.

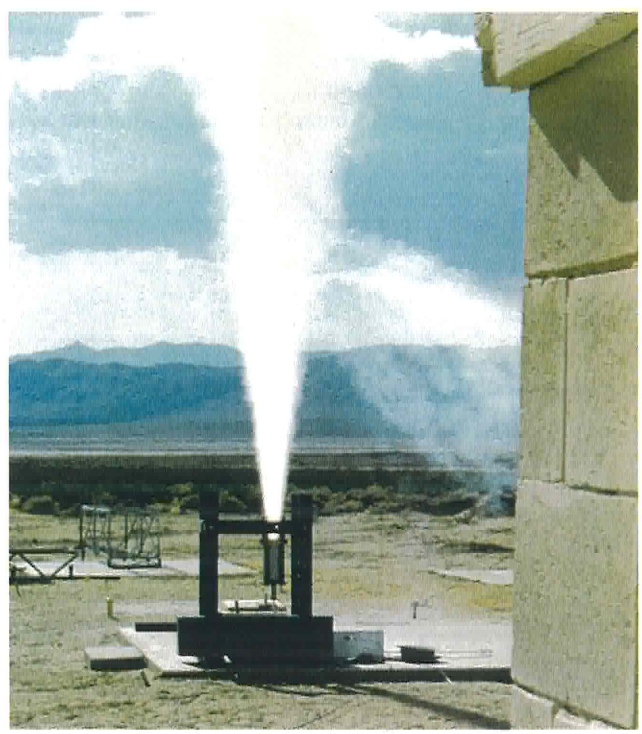
In late November of 1996, a small group of Reaction Research Society members were about to embark on an adventure far away from their traditional testing grounds in the Mojave Desert. Seven hundred miles to the north, traveling independently or in small groups by almost every means of transportation except submarine, several of us were about to converge on a single, desolate spot in the center of the vast Black Rock Desert of Nevada. We would bring with us a rocket designed, built, repeatedly static tested, and readied for flight in just ten weeks. Along with the flight vehicle would come a one and a half ton, 30-foot tall launch tower, ground handling carts, a Doppler radar, propellant processing equipment, curing ovens, generators, welders, hand tools, computers, and enough nuts, bolts, wire, fittings, hoses, pipes, ladders, lumber, rope, chainfalls, and hand trucks to open a fair sized hardware store. And finally, designed and built in the last week and a half before the launch, was the remarkable payload that was about to successfully reach the edge of space.

The story really begins in mid September of 1996 when George Garboden, assisted by Niels Anderson, Chip Bassett, Craig Tang, Randy Thompson, and myself began the design and initial propellant characterization for a 14,000 pound peak thrust solid propellant rocket motor. Based to a large extent on the work done earlier by George and Niels in developing the much smaller motor used in the RRS solid propulsion course, this motor would be a quantum leap in size. Nine inches in diameter, twelve feet long, and containing 230 pounds of propellant, it would produce a peak thrust of 14,000 pounds for a burn time of 4.5 seconds and would generate over 56,800 pound-seconds of total impulse at a delivered specific impulse of 247 seconds. As near as I can tell, this would be an "R" or an "S" motor by High Power Rocketry standards.

George began the work by modifying a formulation of the aluminized ammonium perchlorate/HTPB propellant he and Niels had developed for the propulsion course motors (*HPR*, January 1997, pp 53-60). The manufacturing technique they had developed allowed the propellant to be prepared in the field and produced excellent quality, high performance propellant grains in just several hours without vacuum mixing or casting. Starting with subscale five-inch diame-

← The last picture of the booster and dart with some of the launch crew before the flight. From left to right: Niels Anderson, David Crisalli, Brian Wherley, George Garboden (back), Craig Tang (front), Tom Mueller (back), Chip Bassett (front), George Overmier, and Paul Montgomery.

The initial propellant characterization testing was conducted with subscale 5-inch diameter hardware. Here, George Garboden installs the test article in the static test stand at the Mojave Test Area.



Hot fore testing of the 5-inch hardware.

Components of a "single grain" motor awaiting assembly and test.

Preparations are made for the first full motor static test in late September 1996.

ter test grains and their associated thrust chamber hardware, propellant characterization tests were run to determine the optimum formulation and processing method for the much larger grains required. More than two dozen sub scale tests were run soon after the start of the project. From the data generated, an eight segment "Bates" (nearly neutral burning) grain design was generated for the full size motor.

To avoid the difficulties associated with meeting all the local, state, and federal requirements for transporting mixed propellant, the motor was designed to be field processable with no facilities or elaborate infrastructure. "Field Processable" was defined as building up the booster from component parts shipped disassembled to the launch site. This included being able to manufacture the propellant grains on site from constituent materials and loading the motor just prior to launch - and all in less than 48 hours.

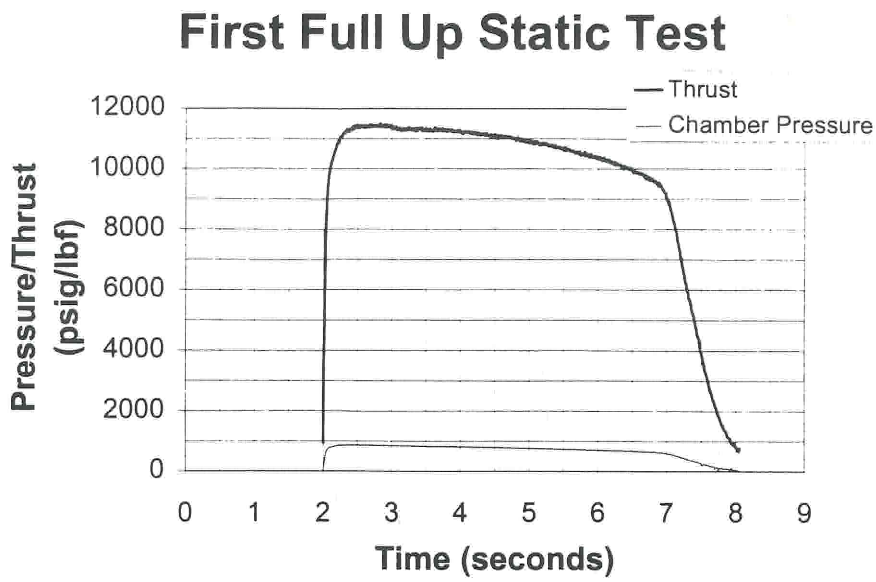
Since the propellant grains required for the flight motor would be much larger than the two and a half inch diameter grains used in the course motors, new field portable mixing and curing equipment was designed and built. Appropriately sized grain processing tooling (casting tooling, coring tools, trim fixtures, etc.) was also built along with several sets of "single grain" test motor hardware. The technique developed for propellant processing was so successful that the 27 grains ultimately produced, for both static tests and the flight, had a grain-to-grain weight variation of less than 0.3%.

The first static test is completely successful only five weeks after the start of the project.

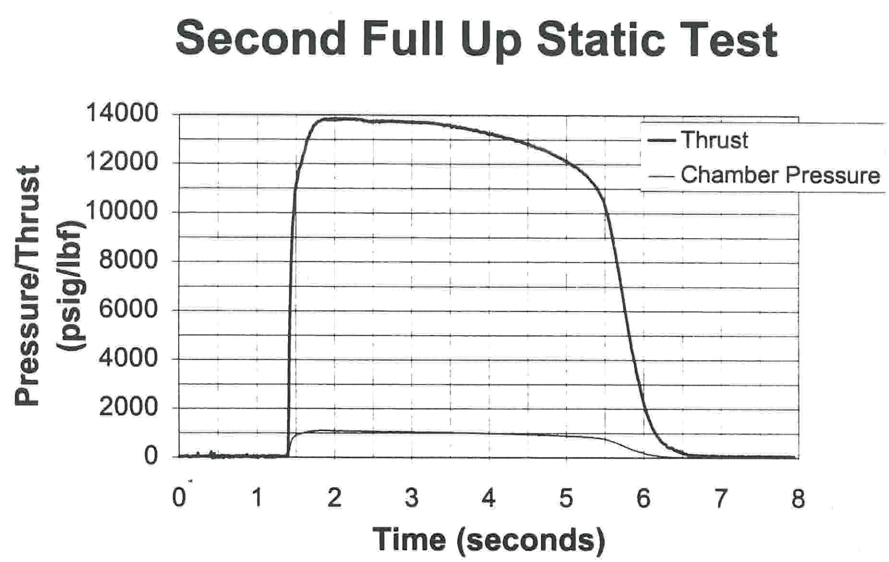
The single grain motors would be the next phase of development for the flight motor design. These single grain units would use a flight-type motor case, bulkhead, and ignition system. However, the case was shortened to accommodate only one of the eight propellant grains that would be used in the full length motor. Correspondingly, the nozzles fabricated for these units were not the same as a flight nozzle, but had throat diameters sized to generate the same chamber pressure that would be seen in the full scale motor. With the same chamber pressure and grain geometry, single grain testing would very closely represent the behavior of the propellant in the full length motor.

A total of six single grain tests were run (five in one test day) with slightly different propellant formulations. Burning rate, specific impulse, and ignition characteristics were determined from these tests. Initially, some interesting anomalies were encountered with the bulkhead mounted ignition system design. After some modifications, the ignition components and the final propellant formulation were selected. Within two weeks, full scale motor hardware had been built. In addition, George and Chip Bassett had designed and built all the required static test apparatus to attach this motor horizontally to the new high thrust test stand out at the Reaction Research Society's Mojave Test Area. On 29 September 1996 the first static test was successfully completed with an average delivered (sea level) specific impulse of 247 seconds. Three weeks after the first, a second completely successful static test was run on October 18th with similar results.

Several features of the design allowed the development to proceed as rapidly as it did and at minimum cost. The first design goal was to set performance requirements that were reasonable and then maintain those requirements throughout the program. The use of standard materials in standard sizes was also pursued vigorously. Hot gas seals were all designed to use commercially available standard size "O" rings. By designing the motor around the easily produced "bates" grains, propellant manufacture was simplified and it was possible to meet the requirement for field processability. The field processing of the propellant also greatly simplified motor transport. The "cartridge" type loading of the motor in the field was simple and safe to accomplish. The nozzle was fabricated (by Dan Mosier) from silica/phenolic and was retained with a simple, aluminum internal split ring bolted inside the aluminum motor case. Radial flat head bolts were used to retain the nozzle and bulkhead, and standard fasteners were used throughout.



Thrust and chamber pressure data from the first full motor static test.



Thrust and chamber pressure data from the final full motor static test.

First and second static test data.

The Great Idea

Shortly after the second full up static test on 18 October 1996, George, Craig Tang, and I discussed the possibility of building a third motor and flying it. Although flight had been the intent all along, we really had not considered doing it on such short notice. There were several issues to be addressed if we were going to throw one of these behemoths into the desert sky. The vehicle was much too large to fly at the Mojave Test Area. A few of us had gone some time before to Delamar Dry Lake north of Las Vegas to reconnoiter the area and decided that, as big as it was, it was also too small to fly there safely. The Black Rock Desert in Nevada was the best spot to fly, but none of us had ever been there before and it was getting very late in the year. And then there was the issue of payload. We didn't want to waste a ride on a booster like that, but what type of meaningful payload could we put together in time to fly at Black Rock before winter came on in earnest and turned the dry lake back into a real lake?

While we pondered that question, there were other aspects of flying a rocket this size that loomed large on the technical and logistical horizon. In preparation for an eventual flight, designs for a new portable launch tower had been on the drawing board (my kitchen table) for some weeks. The original intent had been to use the 60-foot launch tower Brian Wherley and I had built for liquid rockets and modify it as necessary for this vehicle (*HPR*, August 1996, pp. 44-51). As the rocket was designed, however, it became obvious that, with a thrust of 14,000 pounds and a liftoff acceleration of nearly 30 g's, the 60-foot tower was too tall and not nearly stout enough. With my normal penchant for volunteering without thinking, I announced boldly that I would take on the task of building the new tower. George chuckled to himself knowingly. This didn't look to be too hard to me. It would need to be very heavy duty, but it would only need to be 30 feet tall. Well, "heavy" was the operative term here as I was about to find out. By early November almost 3,000 pounds of steel had been assembled into a brobdingnagian launcher that, although it meet the criteria, was right at the extreme limit of what I would consider to be "portable!"

Mike Henkoski holds up the video package he put together on such short notice. The oval hole in the boat tail is the port through which the camera viewed the ground. At right, he is holding the fully assembled dart after a test fit of all components in the field.

While the tower was being built, other equipment such as ground handling carts, transport frames, curing ovens, and the like were being built or modified to support a flight attempt.

Meanwhile, back on the issue of payload, Craig and I had come up with a plan that we posed to George in one of those rare moments when he had sat down for one or two minutes out of the day. We suggested that a ballistic dart might be the simplest payload to build and that, if all went well, it would have the potential to reach a fairly spectacular altitude. We also proposed that we con, I mean convince, Mike Henkoski of Microtek Electronics to build another of his "hell for stout" video camera/transmitter rigs to throw into the sky on a trail of fire. There was silence on the other end of the telephone for a few seconds and Craig and I, having convinced ourselves by now that this was a fantastic idea, thought, for a moment, that George didn't like it. We were disappointed. Actually, he had just dozed off for a few seconds during my long-winded explanation of the plan. When we awakened him and went over it again, in abbreviated form, George said, "Sure - sounds great to me." It never ceases to amaze me how simple it is to get oneself into a world of trouble with a statement as eloquent as, "Sure - sounds great to me." Well, however it had all happened, the wheels had been set in motion and the next couple of weeks were about to accelerate into one continuous blur. Not much sleep would be had by any of us until the evening of November 23rd.

With the die now cast and only enough time remaining so that the entire effort could easily be classified as a "crash" program, I thought I should call Mike Henkoski and see what he thought of the whole idea. (By the way, the following is the definition of a "crash" program in rocket circles - it's like having nine pregnant women in a room and expecting a baby in 30 days.) When I got Mike on the phone and gave him the plan, he said, "Sure - sounds great to me." I pulled the receiver away from my ear for a second and just starred at it. Maybe it was just me, but I really had to wonder if I was making myself clear and if these people really knew what I was asking them to do. A little voice was calling from the ear piece, "Dave... Dave, ...are you there? I said, it sounds great to me." Who was I to argue. Mike wanted to know more details and another set of wheels went into motion. The dart had not yet been designed, we didn't know how much room Mike would have for his gear, and we weren't sure how anything would be mounted or where the camera would look out of the dart. There was no concept of operations, no flight time requirements, and no exact launch date. Other than that, Mike knew everything he needed!?! When it got down to the wire, Mike wound up with about six days to design and build the video package for this flight, ground test it, gather all his equipment, and get himself to Black Rock for the launch.

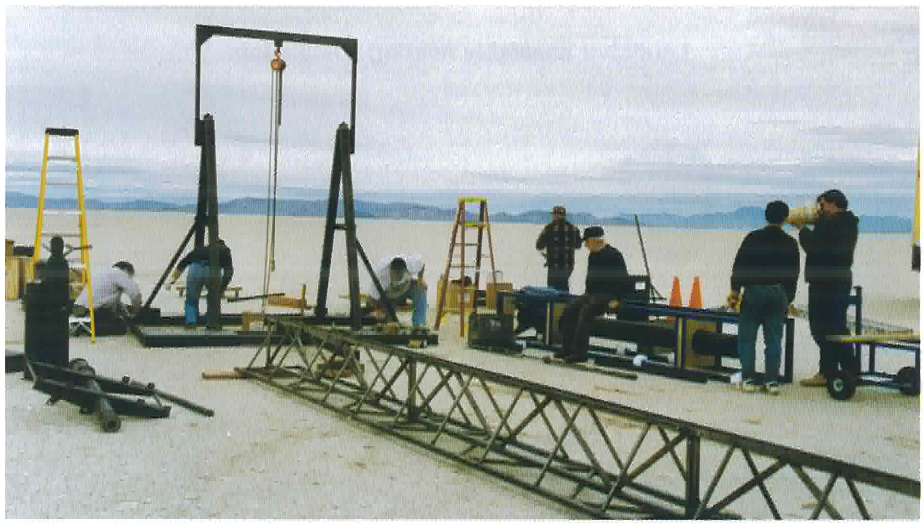
The Hardware

For the next few days, George was busy assembling all his equipment and building another set of booster parts for the flight attempt. Brian Wherley and Chip Bassett helped me haul the launch tower from my place down to George's shop for the last of the fabrication and the first attempt to stand it all up. I had also enlisted the help of a co-worker, Lathan Collins, and hoodwinked him into performing a myriad of aerodynamic analysis and trajectory plots. Using the U.S. Air Force Automated Missile DATCOM and other methods, Lathan determined the aerodynamic design and optimum weight for the ballistic dart. As the design congealed, Craig made drawings, George and Chip made parts, Mike made transmitters, Lathan made plots, and I made phone calls and coffee to keep the information flowing.

As things progressed, arrangements were being made with the FAA for a launch window between the 21st and 24th of November. At this point, in mid November, Black Rock had already had several days of rain and it looked as if the weather was deteriorating quickly as winter approached. Each day at midnight I checked the weather channel for Nevada and we kept a constant watch on the weather reported for that area on the Internet. Things were not looking good as one front after another transited the Reno area.

On the hardware side of things, George was making parts as fast as Craig could turn out drawings - sometimes faster. In actuality, as is usually the case, George was making parts to pencil sketches or just off the top of his head and the drawings came along as rapidly as possible to document the configuration or to help define difficult areas. Two such areas were the placement of the video camera and the recovery scheme.

The booster is unloaded (with all the other junk) onto the lake bed. Here it waits in its transport frame for propellant loading and final assembly.



Assembly of the launch tower from all its component parts is a few hour job for utilizing all available hands.

The design of the dart was somewhat driven by how small the video transmitter could be packaged. Due to the time constraint, Mike wanted to use a transmitter he already had built. The minimum dart inside diameter had to be three inches to accommodate the existing transmitter. With this one feature established, Lathan designed the dart to have the minimum drag possible for that diameter and ran several trajectory plots to determine the optimum dart weight to maximize altitude. Mike had also selected a Sony color camera that was about one inch in diameter and over five inches long. This was going to be another packaging challenge. Craig made some preliminary drawings defining a scheme for mounting the camera at an 18° angle off the longitudinal axis looking out through the wall of the dart's boat tail. This allowed the camera to look aft and see the flyout from liftoff. This arrangement also left real estate on the end of the dart available to mount the circularly polarized patch antenna that Mike was developing. If the dart really did reach an altitude of 50 miles, the antenna needed to be pointing at the ground to maximize gains and ensure that the signal would be received on the ground. This arrangement was the result of many conflicting requirements and took some excellent engineering to attain. (Mike was going to use a black and white camera since the likelihood of successful recovery was slim - as usual. I told him I would spring for a color camera if he would get one. He said he would and then made me a deal. If the camera was lost I would pay him for it. If it came back intact he would keep it and I didn't owe him anything. I thought it was a great offer.)

George bought some 3.375-inch OD stainless steel tubing for the dart body and machined a solid stainless steel Von Karman nose cone to the contour developed by Lathan. The dart would be assembled from two main pieces. The forward section, a straight length of tubing with a nose welded to the front end, would contain a recovery streamer (made by Bob Stroud of Stroud Safety) and would make up about half the length and more than half of the weight of the dart. The nose and streamer compartment would be separated at peak and not recovered. This was easier to do and reduced the weight that would need to be recovered by the streamer. The aft section would contain Mike's video gear and would be recovered. The two halves of the dart would be joined by a stainless steel bulkhead and would be held together with vacuum. On the ground, this arrangement resulted in about a hundred pounds of force holding the halves of the dart together. As the dart gained altitude, this force would drop off to zero except for the frictional force of the "O" rings used to seal the forward section. At peak, a small pyrotechnic charge would impulse the two halves away from one another and allow the streamer to deploy. George wasn't completely comfortable with the vacuum arrangement, so a couple of nylon sheer screws were added to the joint.

The aft section of the dart was built

Launcher assembly nearing completion.

The finished propellant grains are prepared by George Garboden and Brian Wherley for installation in the motor case.

of the same stainless steel tubing and had four knife-edged stainless steel fins welded on. The boat tail was made of aluminum and had a cylindrical projection on the aft end that slid into a mating sleeve on the front end of the booster adaptor. This slip fit arrangement would allow a simple drag separation of the booster and dart at booster burn out. The adaptor itself would be made of composite materials so that the transmitted signal being radiated from the antenna on the end of the dart could get out to the receive antenna. This would allow us to see the fly out of the booster on the video downlink. Inside the aft section of the dart, a stack of aluminum plates supported by threaded rods formed an adjustable chassis on which Mike would mount his transmitter, batteries, amplifier, and connectors. The solid aluminum boat tail was bored with a one inch hole at an 18° angle off axis in two places. One port would be used to mount the camera and the other would house the "safe and arm" switch assembly used to arm the recovery pyrotechnic charge and switch on the video transmitter. The chassis was delivered to Mike for installation of the video equipment just a few days prior to the launch. Within those few days, all of Mike's gear was installed and checked out and antenna reception testing had been successfully accomplished at a simulated range of 60 miles. With the delivery of some of the video ground support equipment to George for transport to Black Rock, all was in readiness from Mike's end.

The Journey

Things were going along quite rapidly enough for us when someone pushed the fast forward button on the VCR of life. For the next several days, everyone and everything went by in a blur of accelerated and cartoon-like animated motion. Imagine yourself inside a giant blender. At some point, mostly when you least expect it, the hand of Providence sets the control knob on "high" and then pushes the "frappé" button. When this happened, I noticed almost immediately (being the quick witted sort of fellow that I am) that this has a most disorienting effect on one's outlook. Your view of life is reduced to a series of disjointed glimpses provided randomly as one is tossed against the glass walls of the blender... Well, I'm sure this happens to everyone from time to time. Needless to say there was a lot of activity and very little adult supervision as the various parts of the project came together and time was running out.

And there was still a lot of work to do when time did run out. Sometime during this rush of adrenaline in early November we had decided that we would transit to Black Rock on Wednesday the 20th. I had made arrangements with the FAA to open a launch window that extended from the 22nd to the 24th. Since none of us working on the project thus far had ever been to Black Rock, I contacted a new RRS member who was also an experienced high power rocketeer. Having been there many times and also, as we were about to find out, being as crazy as the rest of us, George Overmier accepted an invitation to be our point man and guide on this adventure. George quickly became instrumental to the success of the project. As an added bonus, Emily Overmier, George's lovely wife and a damn fine photographer, also came along to keep us all out of trouble.

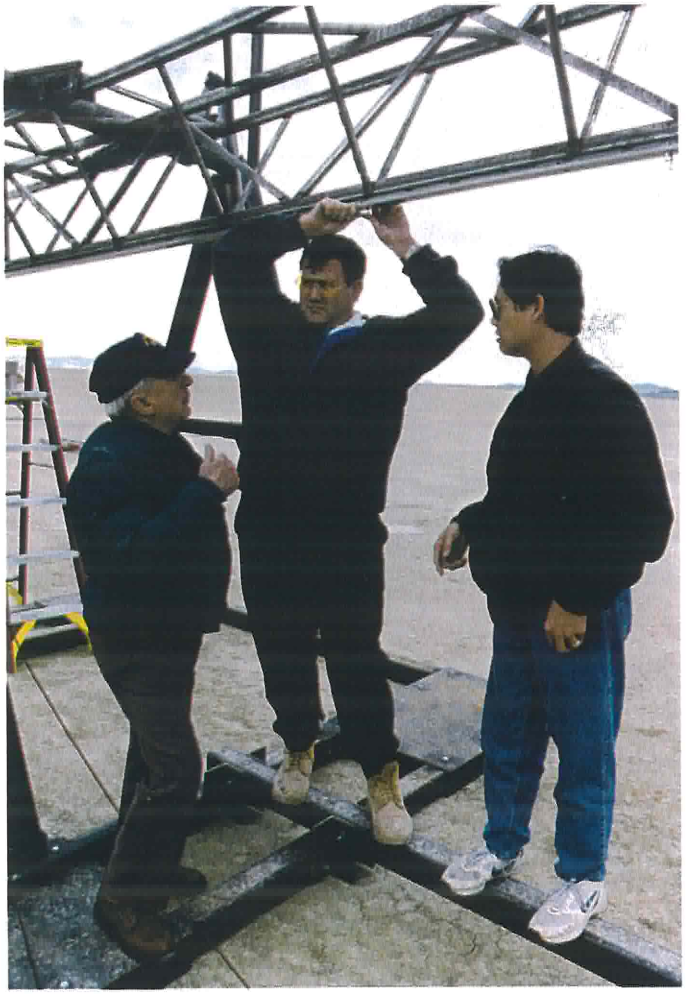
For several days before we were to go, George Overmier kept up with the weather conditions and called me daily. The weather was bad for several days in a row and was not predicted to get any better. The people George called and spoke to up near Black Rock continuously recommended that we not make the attempt. There had been too much rain. More rain was coming. The winds were bad. The temperature was below freezing at night. The lake bed could probably not support heavy trucks. When we were down to the wire on the 17th of November, I was trying to make the final decision to go or not. It was going to be a tremendous amount of wasted effort if we packed up all the tons of equipment, drove 700 miles, and then were not able to fly or even get out on the lake bed. I called George "O" and asked for one last opinion. He told me everything he had heard about the area sounded bad and if we looked at the situation logically, we would call it off. But, then again, we might get a break if we were lucky. And then he said, "You know, Dave, if we don't go up there and see for ourselves it's a 100% guarantee that we won't fly." That was it. No one had ever accused any of us of looking at a situation logically. I told George we were going to go for broke and see the lake bed for ourselves. The trip was on.

Down at George Garboden's shop, Chip and I started the exhausting job of packing by disassembling the launch tower and putting all the pieces in a rented truck. Then the steady stream of additional equipment was packed on top. George was still making parts for the dart and keeping up with all of his other shop work as the truck filled up. Meanwhile, at various locations all over southern California, the motley members of the launch crew were filling their sea bags and preparing for the long voyage. Some would drive. Chip Bassett in the truck, George and Emily Overmier in their jam-packed pickup, Niels Anderson and Stan Curry (our official photographer for the launch) in a rented, sand colored, "Baja" Nissan something or other, and me in my little red Jeep Chikadee took off at various times on the morning of the 20th. We were supposed to convoy, but didn't manage to link up with one another until late that night at Donner Pass just as the snow started to fall sporadically. By 11:00 PM or so, those of us in the first wave were all settled in at Bruno's Country Club in the town of Gerlach 107 miles north of Reno and 24 miles from the launch site. It was overcast, cold, and drizzling. The situation did not fill one with confidence.

Other crew members flew in over the next two days. My dad (Cris), Brian Wherley, and Craig Tang flew into Reno on Thursday and rented a Chevy Blazer. Mike Henkoski did the same and so did Bill Claybaugh who came in from the east coast. Jorgen Groth, the radar operator, was in Gerlach with all his gear on Wednesday night, but we didn't meet up with him and introduce our-selves until Thursday morning. Tom Mueller and Paul Montgomery drove into Gerlach sometime in there, and two other observers, Marty Bradley and Phil Dunlap, came in on Friday.

George installs a lightly greased grain in the lower end of the motor case.

David Crisalli was the official rammer for this load operation. His years of experience loading cannons in the U.S. Navy came in handy. Emily Overmier is in the background taking many of these pictures.



From left: Cris Crisalli, Brian Wherley, and Craig Tang fit and shim the rail to the launcher.

George Overmier finishes tightening all of the launcher fasteners.

Arrival at the Black Rock Desert

After the first few uninterrupted hours of sleep in days, several of us met for breakfast in Bruno's restaurant early the next morning. The weather was still overcast, but it was not raining. We saddled up and followed George and Emily Overmier out to the lake. Several miles down the paved road, we found the most promising entrance onto the dry lake. The ground was damp and we took the lighter vehicles out onto the surface first to see how they would fair. We even dug a few shallow holes to see what it looked like under the surface. We weren't sure the big truck wouldn't sink into the surface. So George and I were bent over looking at the ground discussing tire loading and calculating the number of square inches of each tire on the big truck that were actually in contact with the ground, when Chip drove past us with the truck and was heading off down the lake hell bent for leather. The discussion George and I were having became mute at that point, and we scrambled to get into our vehicles and catch up with Chip. As Chip had adequately demonstrated, sometimes, you can "over engineer" a problem.

Before I go on with the story, and as one who had never been to Black Rock before, I must say a few things about the lake bed... it was UNBELIEVABLE!!! It was dramatically and eerily beautiful. The sun was just up, the air was crystal clear and freezing cold, and the mountains were awakening in many colors from dark purples to bright orange. Their peaks were covered with fresh drifts of stark white snow. The lake bed itself was like an infinite beige ironing board stretching for miles and miles and miles. I felt as though I were in the Sea of Tranquillity on the moon - except that I could breathe. At first I drove on it gingerly and with a good deal of apprehension, half expecting to drop into a giant sea of quicksand at any moment. But as we got farther and farther out onto the lake, I noticed that my confidence and speed were increasing simultaneously. All of a sudden, I found myself hunched over the steering wheel and going for the land speed record in a 1989 Jeep Chikadee with three good tires and 135,000 miles on it. The speedometer was pegged, but my trusty Garmin GPS unit said my speed over the ground was 103.4 miles per hour. The windows were rolled down, the cold wind was whistling through what little hair I have left, and I found myself screaming something that sounded like "Yaaa Hoooo" out the open

The dart electronics undergo checkout before final assembly and launch.

Tom Mueller (left) and Craig Tang finish the last of the internal wiring in the dart.

window. And then ...I closed my eyes ...tight ...for quite some time. Wow! Have you ever driven anywhere in your car for five minutes at 103.4 miles per hour with your eyes closed tight? It was exhilarating... it was magnificent... it was... stupid. Let it suffice to say that I went temporarily nuts and leave it at that.

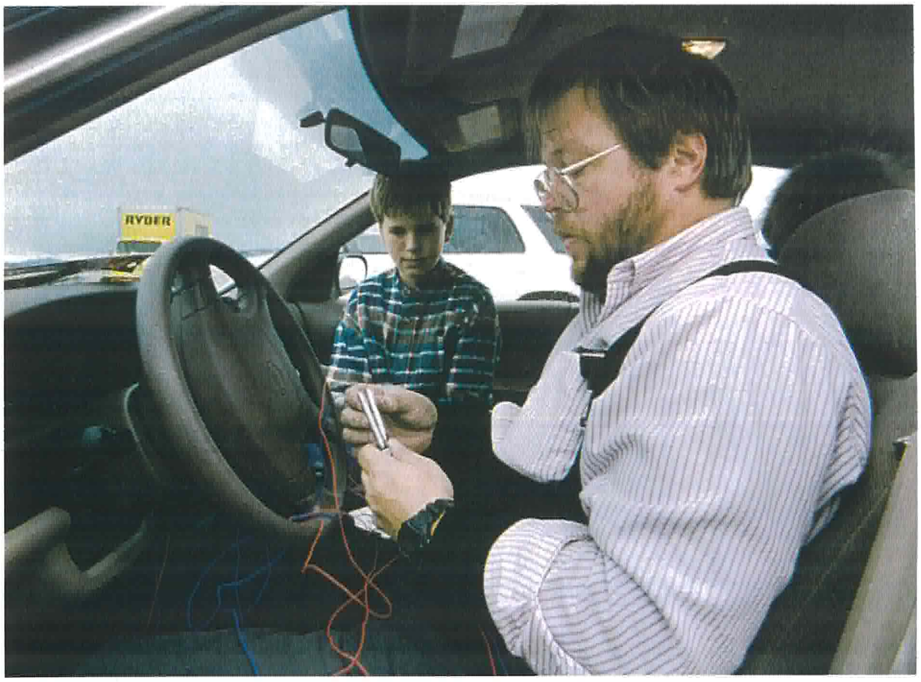
After I regained control of my senses we stopped several times to find out where we were by use of my GPS. We kept moving to the east until we were on the latitude and longitude from which, as we had arranged with Larry Tonish at the FAA, we would launch. The ground was hard enough and everything looked good, so we picked a likely spot and started to unload the gear by 9:00 AM. By noon my Dad, Brian Wherley, and Craig Tang had arrived. We started assembling the launch tower and it took the rest of the day to get all the gear in place, set up the Doppler radar, and complete preparation of the propellant. There was a lot of work and not much daylight left.

At sundown (not long after 5:00 PM), it got dark quickly and we were going to quit for the night. Someone had to stay on site to keep an eye on all the equipment and keep the generator running to provide power to the three propellant curing ovens. I volunteered and set up camp for the night while the rest of the crew went back into town for dinner at Bruno's and a good night's sleep. It was already getting really cold and it started to rain again just after dark. Although I was doubting the wisdom of my decision to make the launch attempt while standing out there in the rain, I had also decided that all the work to get there was worth that 103.4 Mph blind drive that morning.

Conspicuous by his absence in all this was George Garboden. While the initial assault team was traveling on Wednesday, he was still down at the shop making the last parts for the dart and getting no sleep at all. We had all gone ahead to find the launch site, spot the equipment, and set up the launch tower on Thursday. George was to arrive late that day and we would launch on Friday the 22nd if the weather cooperated. It didn't and we didn't. And George didn't get there until late Thursday night.

Sometime after 9:00 PM I was alone

The first field test of the dart video camera/transmitter system. It was working just fine and then, at an inopportune moment, went dead. Quick thinking and ingenuity on the part of Mike Henkoski saved the day.



Niels Anderson shows Clayton Mosier how to make igniters. Niels had to do this in the car with the heater running to get the epoxy to cure in the cold weather!

The booster has been loaded on the rail and the dart is set in place.

at the launch site and trying to stay warm by hovering over a camp stove when I saw lights far off to the west. Over the next few minutes, they got closer and brighter and I realized that there were several vehicles heading out toward me. When they arrived, it was George Garboden accompanied by almost everyone else. They had all led George out to the site and had brought me a steak dinner in a box. It was still warm and tasted a hell of a lot better than the cold sandwich I had eaten hours earlier. We talked for a while and George volunteered to take the rest of the night watch. He sacked out in his van and I went back into town with the rest of the crew. The weather was still not very good with high overcast and occasional drizzles. And George didn't get much sleep again because the generator, which was being used to power the propellant curing ovens, kept shutting down and he wound up wrestling with it on and off all through the night.

Waiting for Weather

Early Friday morning the weather looked much better. At sun-up, we started back toward the launch site after another breakfast at Bruno's. The sky had cleared considerably, but there were still large masses of clouds hovering threateningly around the edges of the lake bed. Nonetheless, we all pressed on. When we got to the site, George was standing out on the freezing playa in nothing but his skivvies and with an icy wind blowing about ten knots. He was pouring ice cold water out of a gallon jug over his head. Some observers thought he had gone "plumb loco" but, for anyone who has been to rocket firings with George, they would recognize this as his normal morning ritual. Now, just the thought of being naked in freezing weather and pouring cold water over my head sends me, personally, into convulsions. However, I am broadminded enough to let George kick start his cardiovascular system in this insane fashion without comment. So I didn't say anything... but I sure thought he was crazy!

We began the work on Friday assuming that we were going to launch. The clouds had begun filling up the few blue patches of sky, but we were trusting to Providence that the weather would clear again. Dan Mosier and his son, Clayton, had arrived during the night and were lending a hand with the ongoing preparations. Jorgen checked his radar and the data collection equipment in the back of his van. The tower rail was shimmed perfectly straight and dressed by Brian. George Overmier helped me with some last minute preps on the launcher while Emily continued to document everything on film. George Garboden, Chip Bassett, and Craig Tang started preparing the booster for fuel loading. Tom Mueller was working on the dart electronics with Bill Claybaugh, and Mike Henkoski was setting up his ground equipment to receive the onboard video. Niels was working with Clayton making up the igniters for the booster and stringing out the 1,000 feet of firing cable. Stan Curry was taking more incredible pictures and began to place two of his cameras on tripods 300 feet from the launcher. The hope was that he could catch a great shot of the liftoff. (The launch photo included in this article attests to his expertise and success. It should be mentioned here that many of the photographs included in this article were taken by Stan and the RRS owes him a debt of gratitude for his stamina, technical expertise, artistry, and talent under adverse field conditions. Most of the other photos were taken by Emily Overmier. The Society would also like to thank Emily for her excellent pictures, steadfastness, and great sense of humor. If it wasn't for Stan and Emily, we wouldn't have any pictures that were worth very much since the rest of us can't hold a camera without hurting ourselves.)

By 11:00 AM and with the weather still decidedly marginal, George Garboden and I made the decision to load propellant into the booster motor. This move had a certain amount of risk associated with it. Not from loading the fuel itself, but what to do with the motor if we couldn't launch. The process for loading the fuel cartridges bonds them into the motor case. As a consequence, they cannot be removed. If the weather never cleared and we could not fly, the motor would have to be burned off to render it safe. The bulkhead, fins, and nozzle would be removed and the motor placed horizontally on the ground. The propellant would be ignited by placing a small ignition charge in the center of the propellant grain. The motor would then burn off rather slowly exhausting gasses from both ends of the case at low pressure. This would keep the motor non propulsive. While this would safe the motor, it would also be a hell of a waste since the motor case and 230 pounds of propellant would be lost in the process. As we began propellant loading, we were all hoping the weather would cooperate.

By a little after noon, the motor was fully assembled, the front end of the dart was assembled, and all the ground gear was set up. We began the wait for a break in the heavy overcast and light sporadic rain showers. We waited... and waited... and waited. Members of the launch crew found things to amuse themselves. Tom Mueller had brought his dirt bike and several people took turns making high speed runs across the playa on it. Mike Henkoski took a drive 16 miles directly north from the launch site and found an upright piano sitting all by itself in the middle of nowhere. He brought back video tape to prove it. The hours ticked by slowly and still the weather was not acceptable.

All Dressed Up and Nowhere to Go

At 3:00 PM George Garboden and I met up and decided to scrub for the day. The weather was still not good and it was getting so late in the day that, even if we did launch, we might be trying to recover the hardware in the dark. Now we had to secure everything for the night before dark and we would try again on Saturday the 23rd of November. The radar antenna was covered with plastic, cables secured, and the cameras taken in. The booster, now fully loaded with propellant, was put back into its transport frame and placed back inside the truck. We had never fired this propellant cold, so we decided to keep a small electric space heater running in the enclosed truck all through the night to keep the chill off the booster. We had all these preparations completed by early evening and the crew started heading back into town. Dan and Clayton Mosier, George Garboden and I stayed out at the launch site to watch over the gear and spend a miserable night jammed in our vehicles. It rained on and off and each time we got up to refill the generator gas tank or check equipment, our shoes would get bigger and bigger as we walked. The damp surface of the lake bed turned into a very sticky clay in the light rain and it stuck like glue to everything. To get back into my Jeep to try and get a little sleep without bringing a hundred pounds of mud in with me was a half hour job of scraping, shuffling, cursing, hopping on one foot, falling, and grumbling. I did this three times. This was not a fun night.

Before sun-up the next morning and in sub freezing temperatures, George was naked again and taking another of those lunatic ice water showers (he is the cleanest rocket guy I know). While he was doing that, I went way out on a limb and brushed my teeth while dressed in a giant down jacket, a hood,

The launcher is raised to the firing position.

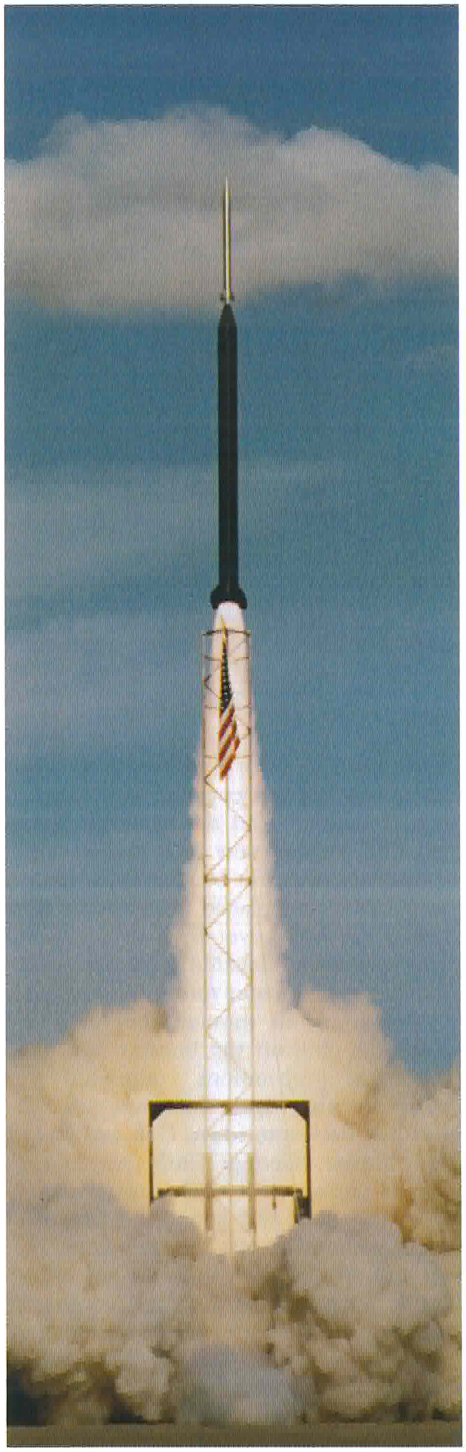
The last minute preparations; the national colors are raised on the launcher.

and my Bozo the Clown mud shoes. Too bad Emily Overmier wasn't there yet... it would have made a great picture. The crew started to arrive just after the "George and Dave" show of early morning, sub zero, rocket launching, desert hygiene was over. Everyone knew what to do and quietly went about their tasks. The weather was still bad, but we went ahead knowing (read that *hoping*) it would get better soon. What we didn't know yet was that it was going to get perfect.

Last Minute Panics

About 10:00 AM Mike Henkoski and I and a few others were putting the video package into the dart fuselage in the back of the big truck. As the chassis was being slid into the tube that made up the aft body of the dart, there was a shower of sparks and a cloud of smoke came pouring out of the front end of the tube. A wire on the battery stack had been pinched and shorted. We immediately pulled the sections apart and Mike started to do a damage assessment. After a quick checkout, it was determined that the video gear was OK. Mike fixed the wiring, quick charged the batteries, and brought the gear back to the truck. We then wrapped the battery section in one layer of thin plastic cut from the inner bag of a box of "Cheez Its." We used this material because it had proven nearly impossible to tear the previous day when several of us worked like hell to get into the bag. After quite a struggle, the bag had not yielded and the "Cheez" wiggies inside had been pulverized into some sort of quasi edible cheese/cracker dust which I eventually sucked up through a straw after drilling a hole in the bag with a carbide drill. I believe these bags are made by the same sadistic fiends who make "child proof" caps. Children don't seem to have any problem with these either, but I always have to bandsaw the top off my Flintstone vitamin bottle. But I digress again. We used the bag material because we were sure you couldn't tear it and it would make a good insulator between the battery compartment and the metal fuselage tube.

The dart was reassembled and checked out. Everything was working fine. The booster was removed from its handling frame and all hands pitched in to lift it and slide it onto the horizontal launch rail. (This was no small task since the loaded booster weighed over 420 pounds). The weather was clearing and morale was high. The dart was brought out and placed into the adaptor sleeve. While I was holding the dart, I thought it felt a little warm in the middle. I asked a couple of others to feel it. It was hard to tell, so we turned on the transmitter again as a quick test. Mike was back at his antenna and said the picture looked fine. We decided that the tube was still a little warm in the middle from the first shorting problem. The dart was reinstalled and the tower was raised to the firing elevation of 85° and an azimuth of 000° true. Craig Tang and I raised the U.S. flag on the launcher and made the halyard fast. The weather was even better now as personnel began to evacuate the launch area and retreat to the other end of the firing cable 1,000 feet to the south. It was now about 11:00 AM.



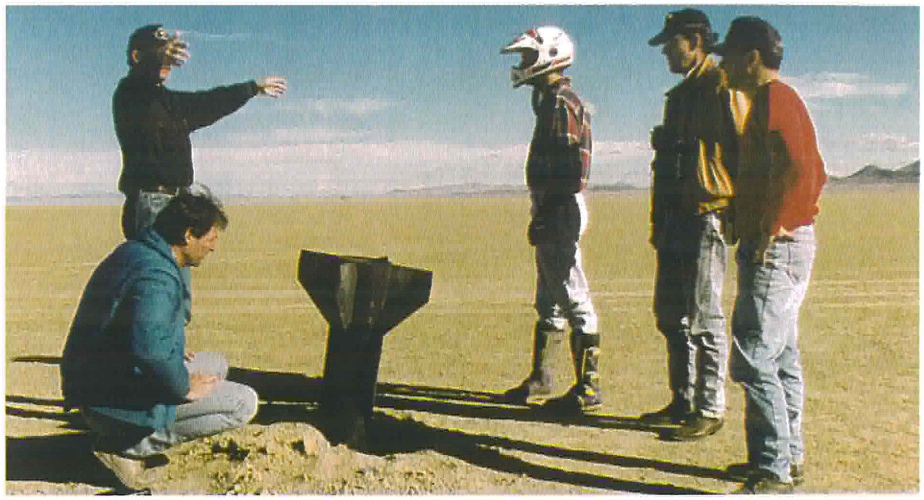
The successful maiden flight of the booster. The vehicle reached a burnout velocity of 4,431 feet per second as measured by Doppler radar. The first flight had been accomplished in just ten weeks from the start of the program. This photo and many others used in this article were taken by Stan Curry. The Reaction Research Society owes Stan a debt of gratitude for his stamina, artistry, and talent under adverse field conditions. The Society has never enjoyed such excellent photographic documentation of its efforts.

George Garboden, Niels, and I remained at the launch tower to install igniters, arm the dart's recovery system, and turn on the video system. We performed these functions in that order and were gratified to hear Mike's voice over the radio saying the video transmission was good to go. We jumped in our vehicle and drove to the launch control area. Just as we arrived, however, Mike came over and said the video system had just died. The transmitted pictures had been perfect and then went blank. Mike could tell by the picture it was the batteries going bad.

George and I discussed our options. None of them looked good. Without the video gear working there was nothing to be gained from the flight. We would never be able to tell how high it went. But if we scrubbed the launch entirely, we were back to the prospect of burning off the booster and wasting it. To lower the launch tower and recycle would take several hours. Then someone suggested that we just climb up the tower and lift the dart off the booster. We could examine it and see if it could be fixed. Great idea! Craig, George, and I took off to get the dart down. Niels shunted the firing leads as we were leaving and, when I got back to the launcher, I pulled the igniters back out of the booster to keep things safe. Then the three of us climbed ladders or hung on the tower to lift off the dart. We got the dart down and back into the van in record time. Mike, Tom, Craig and several others went to work tearing the dart apart and searching for a quick fix. Upon removing the video package and examining it closely, it was determined that the batteries had shorted again. The "Cheez It" bag had torn and the warmth I had felt handling the dart earlier had indeed been the batteries shorting through the dart stainless steel wall. The batteries were shot and we didn't have any replacements. Things were looking grim.

While the rest of us were just having a stroke, Mike Henkoski was having a stroke of genius. The nickel cadmium batteries Mike had installed originally were the standard type used in ATV work for balloon flights, etc. Mike had used them here because they would do the job and would just fit inside the available envelope. However, no one had expected the total destruction of the battery pack before launch, so there were no spares on hand (another lesson learned). As Mike was contemplating the problem, he realized that some of the video cameras people were standing around holding used a battery of the correct voltage and power density. In addition, they were very small. Mike got two of these batteries, did a quick fit check, and wired them up for a try. They fit and they worked better than the original batteries. Within 30 minutes, Mike had redesigned and rebuilt the power supply for the video payload. The problem we feared nearly insurmountable only a few minutes before had been corrected and the dart completely re-assembled. The weather was better than perfect. Bright blue skies and not a breath of wind. George, Craig, and I took the dart and dashed for the van.

We covered the distance quickly and put the dart back on top of the booster. The booster igniters were reinstalled, firing leads hooked up, and I started my own video camera mounted on a tripod about 50 feet away from the launcher. As the last action before leaving the area, I climbed up the tower one last time to arm the recovery system and turn on the video transmitter. As I turned the screws that closed the internal switches, the two meter radio handset crackled and Mike's voice confirmed that the video transmission was good.



The booster landing site was not too hard to pick out from the surrounding countryside.

The obligatory "everyone get in the picture with the crashed booster" photo.

The Moment of Truth

We raced back to the launch control area and began the last (we all hoped) road and air check to verify that the area was clear. It was almost exactly high noon and the weather could not have been more perfect. Last verifications were made - video receipt was good - radar was ready to track- all personnel were in safe areas - road and air checks were complete - photography was ready - Tom Mueller manned the PA system and began the countdown. As is usually the case with rocket launches this hard won, the pressure was building exponentially and by the second. The PA droned above the rumble of the nearby generator... 5... 4... 3... 2... 1... FIRE. There was a brief hesitation and a distant "thunk" as the two igniters fired simultaneously into the ignition cartridge mounted inside the booster's bulkhead. And then the motor roared to life - all 14,000 pounds of thrust - and the rocket screamed off the launch rail!

Following a perfectly straight flight path, the vehicle was ripping through the sky at an unbelievable rate making an incredible sound and leaving a dense white exhaust plume in the nearly windless air. For almost five seconds the motor thrusted and drove the vehicle beyond Mach 4. Jorgen was getting good data on the radar and Mike Henkoski was continuously calling out that he was seeing good video on the TV he had hooked up to the video receiver. But at the moment of burnout, my heart fell. The rocket was out of control and was corkscrewing around the sky. I thought to myself that the booster had lost a fin or that the joint between the booster and the dart had broken. My first reaction was to look around on the ground to see if everyone was in a safe position. Not like there was much I could do if they weren't, but it was my first reaction. And then I started to postulate how we would fix whatever the problem was before we tried again. I suppose I had already written off the flight as a failure within those four or five seconds based upon what I was seeing in the sky. And then the first piece of contradictory data started to come in.

Mike was still yelling, "we've got good video" at the top of his lungs and I thought, how the hell can he have good video when the damn rocket is tumbling all over the sky. So I spun on my heal and looked at the monitor over Mike's shoulder. By God, he did have good video. The dart was spinning on its axis, but it was obviously flying hot, straight, and normal and climbing fast. How could the dart be flying straight if the vehicle had broken in two or if it had gone unstable by losing a fin? Whatever the explanation, there would be time for that later. Right now my eyes were riveted to that TV screen and I had my ears cocked to hear the booster coming back. The video was breathtaking. It was in color and you could clearly see the entire out-

The dart as it was found stuck in the surface of the lake still working after its flight to the edge of space.

The crew and observers at the dart landing site.

line of the Black Rock Desert as the dart climbed higher. The timer used to fire the recovery charge had been set for 126 seconds. This number had come out of several preflight trajectory analysis that concluded that the dart could reach an altitude very close to 50 miles.

I've been to a lot of rocket launches in my time and, usually, things are over and done with pretty fast. For better or worse the flights are normally fairly short. But for this launch, we all stood in silence for a very long time. Some watched the video monitor. Over a minute had passed since the rocket had blazed heavenward on a tail of blinding light. The dart was still ascending and the image of the lake was getting smaller and smaller. Mike was still reporting he had good video to those who were far enough away not to be able to look at the monitor. They were all still scanning the sky for any hint of the returning booster or dart. Nothing yet... One minute stretched into nearly two before those of us who could see the video monitor stopped dead in our tracks. All of us had been awestruck by the speed, power, and sound of the launch, but none of us were prepared for the silent image we were now seeing on the TV screen. I had looked up at the sky for a moment and as I turned back around to watch Mike Henkoski tending his video gear, I looked at the television monitor just in time to see the dart spin rate drop off to nearly nothing, then a glint of sunlight, and finally, an ink black sky above a thin blue layer of atmosphere hugging a pronouncedly curved earth horizon... space. The image was only there for an instant, but it will linger long in all our memories. Shortly thereafter, Mike called out that the streamer had deployed and the dart began its long descent back to the planet Earth.

We continued to watch the wild ride back on the video. The streamer had not fully deployed and the dart was in a flat spin. This was good for recovery, but hell to watch on video without taking a Dramamine. After more than five minutes in the air, the dart's video signal was lost as it fell below the visible horizon. The booster had hit some minutes before and, so, I called the all clear at last. Many of the spectators were shouting and cheering. Those of us who had built and flown the rocket and payload just blinked at one another in silent, exhausted exaltation.

Recovering the Pieces

Well, the respite didn't last very long before we were all off racing across the lake bed to find the booster and the dart. The booster had augured in approximately two miles from the launcher and was quite a sight to see sticking out of the playa. Several rounds of pictures were taken with the crashed booster before George Overmier led a recovery team to try to pull it out of the ground. It didn't come easily and George almost lost a bumper trying to drag it out of the playa with his truck.

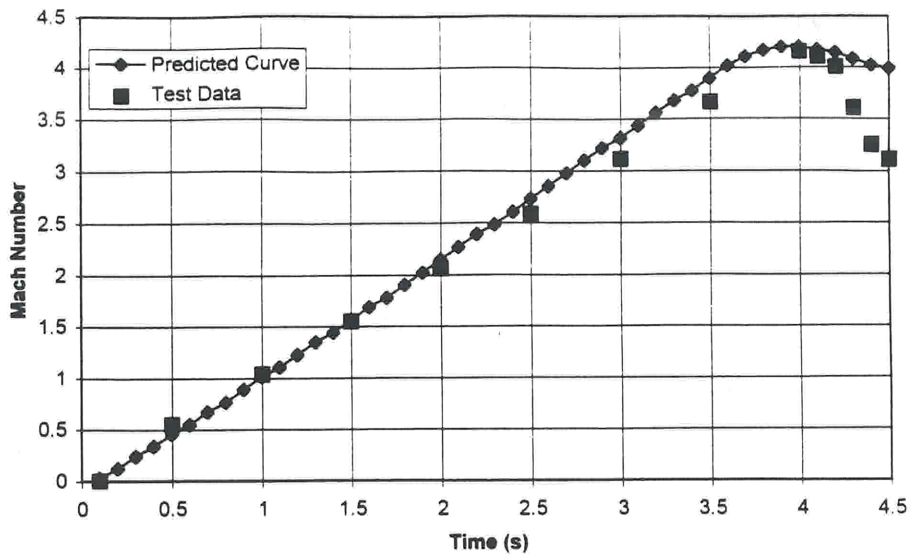
After finding the booster, Tom Mueller was off again on his motorcycle looking for the dart. We knew it was miles away, very small, and probably buried in the soft surface. As we traveled north, none of us held much hope of finding the thing. I had jumped into Mike Henkoski's rented Blazer with him to search. Before we left, he was rummaging around in all his video gear and lashed together a little tiny TV, a video receiver, and a small blade type antenna. He told me to sit in the passenger seat and hold all this junk in my lap while waving the antenna around out the window. It sounded simple enough. But then, Mike put the Blazer in gear and took off north like we'd been shot out of a cannon! The gear was bouncing all around and be coming disconnected. The blade antenna had a fair amount of surface area and, at 90 miles an hour, it was not at all easy to hold out the window with anything resembling coordinated "hand - eye" motion. As a matter of fact, the darn thing kept flying back in the window and smacking me in the side of the head. Mike was driving like Cruella Deville after a Dalmatian puppy and I was holding on for dear life ...trying to hold all the TV junk together, point the TV screen toward Mike so he could see the squiggles on it, and respond to Mike's "keep waving the antenna toward that mountain" commands. On top of that, Mike was swerving side to side like his gyro had tumbled and he was attempting to run the land speed record slalom course. It was nuts!

Nonetheless, after not very many minutes of this Mike stopped the Blazer abruptly and said, "wave it around over there," pointing off to the left of our heading. He was looking at the little TV screen intently. "Nothing. Here we go..." And off we went again for a short run. I think Mike was sensing he was close. "Wave it over there again," he said. I did. "What was that?" He was looking at a TV screen full of snow. "I didn't see anything," I said. "Keep waving that thing... look... those are sync bars!"

Now, I wouldn't know a sync bar from a granola bar and I was about to ask Michael what a "sink bar" was, but I wasn't fast enough. The Blazer was already approaching Warp and the antenna was banging against my head again, but Mike didn't need the electronics now. He could "feeel" the presence of the dart. All of a sudden, he stood on the brake and I wound up inside the glove compartment. However, when I looked down (or up - I couldn't really tell by then), the little TV had a picture on it. Mike didn't look over, but said "Here we are." We hopped out and walked right over to the dart, almost seven and a half miles from the launch point. Others had followed us (apparently because we looked like we knew where we were going!?!?) and were now on the scene. We took several pictures of the dart where it lay before picking it up. And as Mike picked up the dart, the blurry picture on the little TV screen sharpened and showed a large group of feet. It was now almost a half an hour after the launch and the video package was still transmitting. Mike looked at the video and said that the Sony color camera was working just fine and it didn't look like I owed him $700 after all. We finished at the landing site by polishing off a bottle of champagne. Tom Mueller continued to search, without success, for the nose section that had been jettisoned during deployment of the streamer, and we all headed back to the launch site.

Back at ground zero, we were in for our only disappointment of the day. When we all gathered to look at Mike's flight video, it was nothing like what we had seen on the monitor. The images were all there, but the color on the recording had shifted and/or dropped out in many areas. In the mad dash to repair the dart power supply, the primary camera for recording the flight video had given up one of the two batteries required for the dart. The second string recording camera was not up to the task and had not done well. While disappointing, the images were still amazing and impressive to watch. While some watched the videos of the launch and the flight through viewfinders, most of us began the arduous task of packing tons of equipment to go home. Many left that night for home. Others of us got a much needed night's sleep after hoisting a few at Bruno's and congratulating ourselves for living through the experiences of the past several weeks.

From left: Mike Henkoski, George Garboden, and David Crisalli share a bottle of champagne. Dave is saying "Why, the champagne is *not* Korbel!"

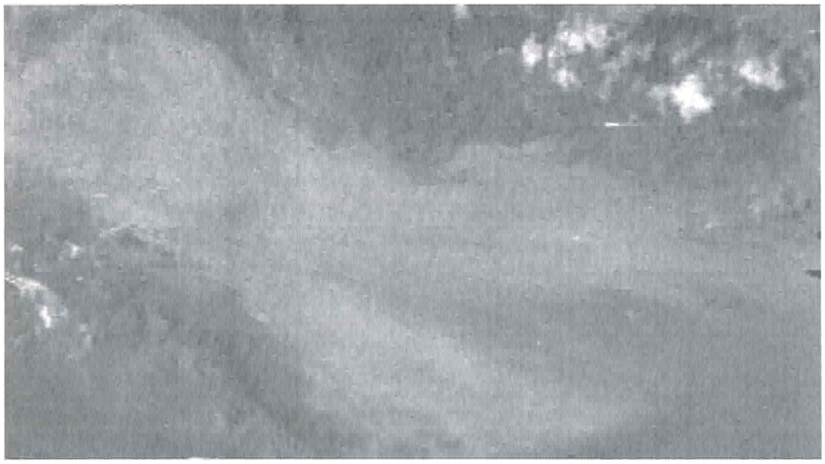


A plot of the predicted and actual booster Mach number. The down turn at the end of the actual test data curve is the result of increasing drag after dart separation.

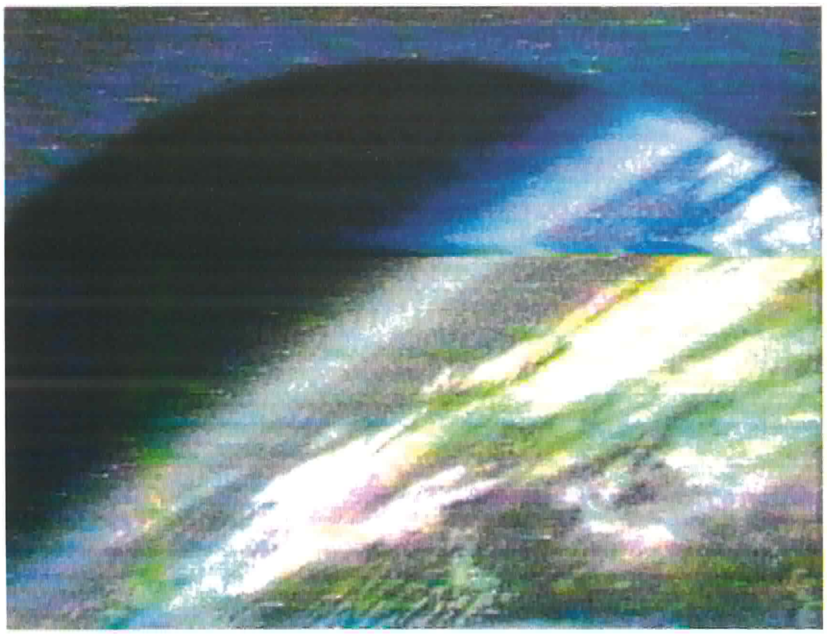
Post Test Analysis

Well, the flight was over now, but the difficult task of sorting out what, exactly, we had just done still lay ahead - and it was going to take longer than the development of the booster and the flight preparations combined.

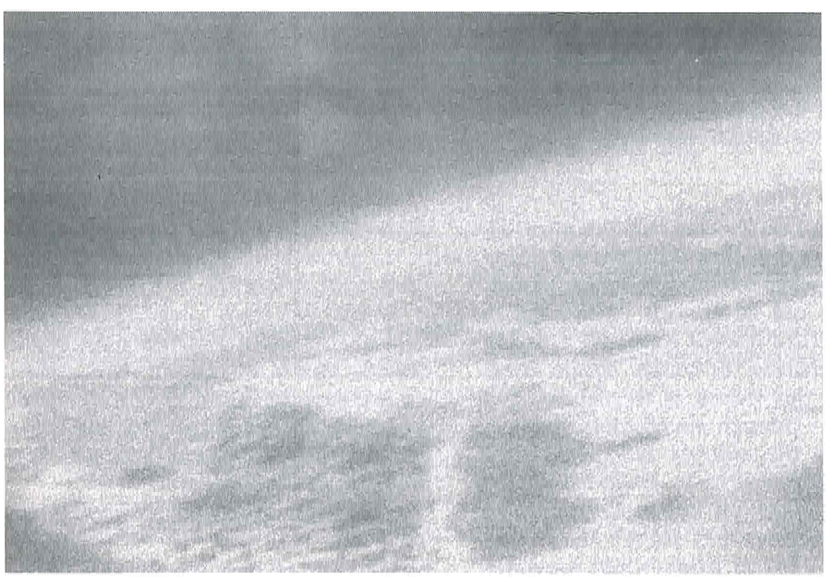
The first question on everyone's mind was how the vehicle could have corkscrewed all over the sky as it did and still have the dart fly successfully to the



A view of the entire Black Rock Desert from close to peak altitude.



One of several frames taken by the dart's video camera as the vehicle reached apogee. Even in this poor quality transfer, the black of space, the layer of atmosphere, and the curvature of the earth are visible.



Another black and white copy of a video frame near peak.

altitude it reached. The explanation lay in a part of the aerodynamic analysis that had not been done before the flight. During the design of the dart, Lathan had run an aerodynamic stability analysis for the dart at the predicted booster burnout velocity Mach 4.2 and it looked fine. He had also looked at the stability of the booster and the dart together over the flight velocity regime they would see from launch to burnout. That situation was also just fine. However, none of us had ever thought to look at what happened to the booster at Mach 4.2 when you shed 60 pounds of forward weight. As the booster/dart assembly accelerated to above Mach 4, the center of pressure was moving forward. This was not a problem for flight stability as long as the center of gravity stayed ahead of it. This condition existed until the booster burned out and the dart separated. At that instant, the booster was still moving at greater than Mach 4 (with its CP well forward), but the separation of 60 pounds of dart moved the center of gravity well aft. In conducting a post flight analysis, the center of gravity should have moved back nearly on top of the center of pressure. In this condition, the booster is neutrally stable and can (and did) fly erratically.

At the launch, however, the booster appeared to do this wild maneuver and then straighten out and fly normally. The explanation for this was that, as the booster decelerated due to the tremendous drag it was experiencing, the center of pressure again moved aft. As it moved far enough behind the new center of gravity (the one without the dart), the booster became stable again and flew in a normal ballistic trajectory.

Static Test Data

Going into the flight, we had the advantage of having run two full up instrumented static tests on the booster. There had been some minor design changes between the first and second test, but the second static test was exactly representative of the flight article. The second static test had delivered 56,563 pound-seconds of total impulse burning 229 pounds of propellant. From this, we had a very good idea of how the motor would perform in flight with the exception of whatever increased burn rate we might see as a result of vehicle acceleration loads on the propellant grains. Thrust, total impulse, and measured specific impulse data from the second test were provided to Lathan Collins, along with accurate vehicle weights, for use in the trajectory analysis he was running. The drag coefficients for the vehicle were derived by using U.S. Air Force Automated Missile DATCOM methods and Lathan designed the aerodynamic features of the dart to minimize drag to the greatest extent possible. Having no way to actually measure the drag coefficients before the launch, this type of estimate was the best we could hope to do. However, our ace in the hole was that we would be able to measure the velocity of the booster during its flight with the Doppler radar. Knowing the thrust profile (from static test data), exact weights of all the components at launch, and the estimated drag coefficients, a velocity profile of the flight was calculated. If the actual radar data matched this prediction, then the calculated drag coefficients had to be nearly correct. If the data did not match the flight prediction, the drag coefficients could be adjusted until the two did match up. Then, with these new drag numbers, a peak altitude could be projected.

Results of Trajectory Predictions

Based on all the above data and information, the pre flight analysis indicated that the dart could reach a peak altitude of 258,366 feet above the ground. The altitude of the Black Rock Desert above mean sea level (MSL) is 3,900 feet. If this is added to the calculated peak altitude, an altitude of 262,266 feet above MSL is obtained. This equates to 49.67 statute miles, or 43.71 nautical miles. The predicted velocity of the vehicle at burn out of the booster was 4,593.4 feet per second.

Measured Radar Data

Another advantage for this flight was the fact that we had radar data. This was not a tracking radar, but a Doppler radar measurement of vehicle acceleration and velocity on the fly out. The antenna was fixed and had a 15° beam width. The radar had an accuracy of +30 feet per second. The antenna was mounted 50 feet from the launcher and was boresighted along the 85° intended flight path. The data showed a measured burn out velocity of 4431.6 feet per second which compared well to the 4593.4 feet per second predicted in advance. The velocity measured by the radar was within 3.5% of the predicted value. The good correlation between the predicted and actual velocity indicated that the drag calculations were good estimates of reality and that the flight trajectory predictions, including altitude at apogee, were probably fairly accurate.

Video Data

All along, our intent had been to determine the altitude reached from the video imagery transmitted to ground by Mike's TV gear. Although the recorded image quality suffered from the problem of switching recorders at the last minute, it was possible to do some analysis. First, to get the best still images we could from the video tape, we made arrangements through Dr. David Elliott of the Jet Propulsion Laboratory Science and Technology Development Section in Pasadena, California to have some of the JPL people capture several key frames. Mr. Shegeru Suzuki and Mr. Bill Green of the JPL Science Data Processing Systems Section were very helpful in this work and we wanted to thank them and Dr. Elliott publicly for their help and support. (As a side note, Dr. Elliott is not only an RRS member but was one of the founding members of the RRS in 1943. He is also the same David Elliott who collaborated with Lee Rosenthal to build and fly an amateur hydrogen peroxide monopropellant rocket in 1950. (See *HPR*, August 1994, pp. 59-70 or *RRS News*, Volume 51, Number 4, October 1994 for an article on their project.)

Dr. Elliott also performed an independent analysis of the measured earth limb curvature from the best image captured at apogee during the flight. That analysis uses the camera field of view (FOV) and the measured curvature of the horizon from the captured video frame. However, Dr. Elliott had been given an incorrect number for the camera field of view of 55°. His numbers were corrected for the measured FOV of 50° and gave a result of 52.9 statute miles for the altitude at which the photo was taken. This type of analysis is fairly sensitive, however, to the measurement accuracy of the horizon curvature. By taking several independent measurements an accuracy of plus or minus 0.3 millimeters was achieved. The analysis was rerun with this error band applied and the possible altitudes came in at a low of 42.7 and a high of 64.2 statute miles.

To reduce the ambiguity of the curvature analysis, a second analysis of the best nearly vertical view of the Black Rock Desert was completed. The analysis was run using known geographical features from the video image, topographic maps of the area, the field of view of the flight camera, and an excellent quality photo of the same area taken from the Space Shuttle at the same time of year and nearly the same time of day. The recognizable geographical features were used to generate a scale of distance for the flight image. That scale was then used with the *measured* field of view of the recovered flight video camera to determine the altitude required to have captured that image. Again applying the error band of the measurement uncertainties, this analysis yielded an estimated altitude of 48.3 to 56.0 miles.

Epilog

To be accurate, NASA's definition of "space" is 50 *nautical* miles above the earth. The altitudes we calculated here are all in statute miles. Taking the highest possible altitude calculated from the vertical images and converting it to nautical miles gives an apogee of 49.3 nautical miles.

Did we reach "space" that day? Probably not by the strict definitions. Nonetheless, the 14,000 pound thrust booster and the dart it propelled had the potential to reach very close to that altitude. The predicted burnout velocity of just over Mach 4 had been attained and verified by Doppler radar. As I write these lines, the video imagery captured from the flight is still being re-analyzed to try to better estimate the real altitude attained. But to those of us who watched the video real time, we know the vehicle reached the threshold. Whether the final altitude number is 47 miles or 53 miles, nautical or statute, a rocket built and launched by RRS members had flown successfully to the "edge of space" and the payload had been recovered intact.

Those of us involved in this project did not attempt the flight to set any new world records, nor do we claim any. We hope that this disavowal of any claim to any record will dissuade even those inevitable few who will feel obligated to besiege us with e-mails, letters, arguments, and diatribes about why this flight doesn't count or who went higher, better, faster than whom. We are not concerned by or with such arguments and would find them exceedingly tedious. So, for anyone out there who would like to claim any altitude record they like, we congratulate you in advance and without argument. We did not seek publicity in advance of the flight and we do not seek it now. We tell the story of this effort and that day at the Black Rock Desert because of its value as an educational adventure for both the participants and those bystanders, and to give those who read this report a sense of the excitement of this flight. We also tell it because it is an entertaining story of stamina, lunacy, ingenuity, camaraderie, humor, and determination. And, it was worthy of note that a rag-tag team of private individuals working with private resources had designed, built, and flown a rocket capable of reaching the edge of space in just ten weeks. As is true in so many areas of life, it is not so much the reaching of a destination as it is the lessons of the journey that are of the greatest value. In our case, our journey took many of us 700 miles to the north... and *somewhere* close to 50 miles straight up. No matter how you look at it, it was a good day at Black Rock.