ROLLERONS

Simplified Roll Control For Amateur Rocket Vehicles

by David E. Crisalli

The device I am about to describe is one of those things that inspires engineers by its absolute simplicity and brilliance. It is an elegantly unsophisticated solution to a difficult problem and has remained so well suited to its task in roll stabilizing air to air missiles that it has remained almost completely unchanged in 50 years of service. That does not happen too often in an age where technology changes so fast that the *state of the art* computer I bought 11 months ago to type these articles is now considered as technically sophisticated as a "boat anchor" by some computer affectionados. Of course, since it is a Mac, a lot of IBM types thought it was a boat anchor even before I bought it. Before I go into the design and operation of "rollerons," as they are known, I will relate a little of their history.

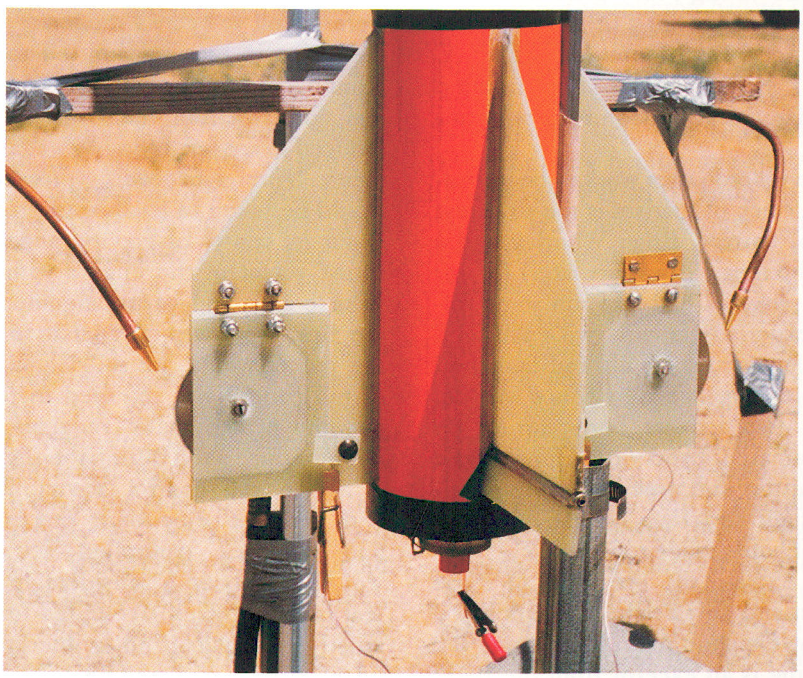
At the end of the Second World War, six years of intense air to air combat between all the warring nations had led to rapid advances in both aircraft and aerial weaponry. With the advent of jet powered aircraft in Germany and Great Britain, aircraft speed made air to air gunnery increasingly difficult to employ successfully. After the end of hostilities the U.S. military, especially the Navy, became interested in air to air rockets as weapons against jet aircraft. Unguided rockets could not be used against high speed and highly maneuverable targets, so the problem boiled down to designing and building a very small, light weight, and inexpensive guidance system.

The complete story of this undertaking is beyond the scope of this discussion, but for those interested an excellent article on the subject appeared in the Fall 1989 issue of *Invention & Technology*. Actually, it was this article that explained what a rolleron was and piqued my interest in trying to use them in amateur rockets.

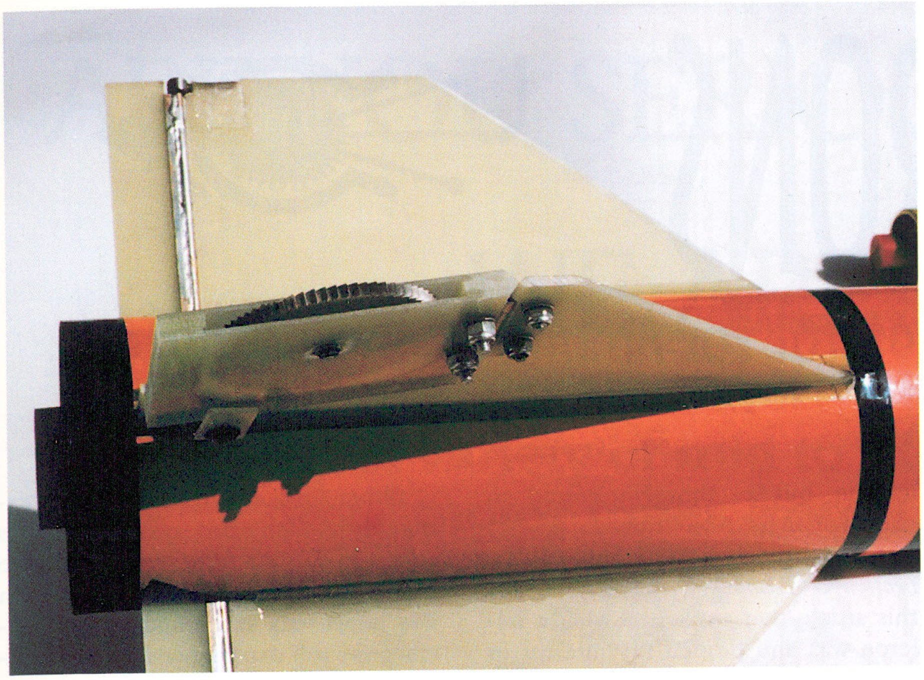
To summarize, in 1947 a small team from the Naval Ordinance Test Station (NOTS) at China Lake designed a simple, inexpensive, guided air to air missile that was so successful it is still in use today despite all the advances in the world around it. It was called "Sidewinder" and it performed better than anything else designed and tested by all the major missile contractors of the day. One of the things that made it function so well was the invention of the rolleron.

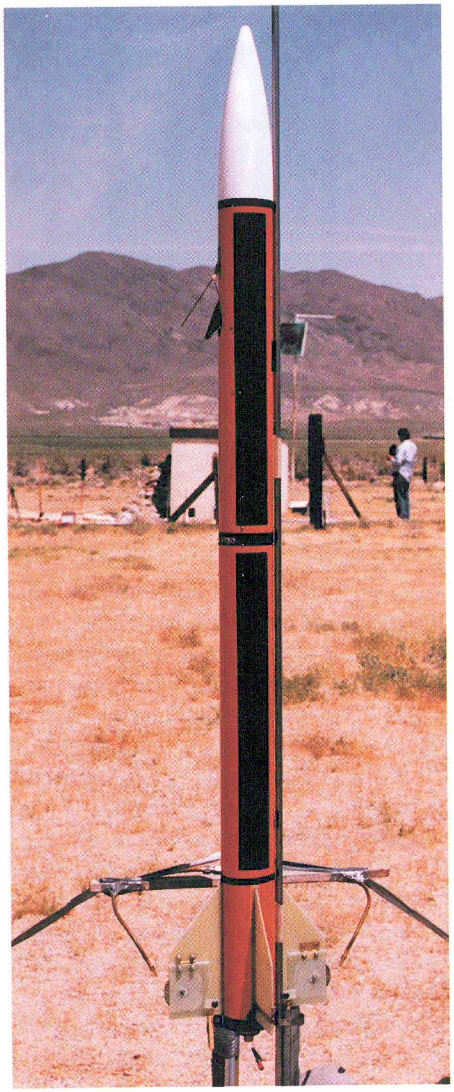
Other missiles relied on an extremely complicated system of gyros and control circuitry to guide the rocket. Part of the guidance problem was to actively sense and then counteract any roll experienced by the rocket as it was guided toward the target. This was necessary because the rocket had to know which way was up, down, left, and right. All of this gear was expensive, sensitive, complicated, bulky, and heavy.

Working on the fledgling Sidewinder was a technician named Sidney Crockett. It was his idea to control the roll of the rocket independently of its guidance toward the target and by the use of a strictly mechanical device. He suggested that solid gyroscope wheels be mounted within flaps on each of



The first rollerons and ground spin nozzles used on the small solid propellant rocket fired in spring of 1992.





This close-up of the first rolleron shows more detail of the construction of the fin, tab, and wheel assembly. To the right, the first rolleron rocket ready for launch with the "less than satisfactory" spin up apparatus.

the four rear wings of the Sidewinder. These "rollerons" had notches cut in their outer rims so that the airstream flowing past the missile would make them rotate. Should the missile start to roll, the rollerons would automatically respond gyroscopically by forcing the flaps out into the airstream to oppose the roll. As an interesting historical note, the young Navy pilot who flew the first live air firings of the Sidewinder was Lieutenant Walter A. (Wally) Schirra who later became world famous as a moon mission astronaut.

The rolleron idea worked beautifully and, since plagiarism is the sincerest form of flattery, Brian Wherley and I stole the idea (fifty years later) for our liquid rocket. I had also run some rolleron experiments with two small solid propellant rockets built and launched a couple of years ago by Bruce Markle. These two rockets both carried on board amateur band video cameras and transmitters and provided some excellent flight test data on the performance of home made rollerons.

To explain the operation of these devices and how Brian and I employed Sidney Crockett's brilliant idea, the following is an excerpt from the flight report on the liquid rocket we launched in June of last year.

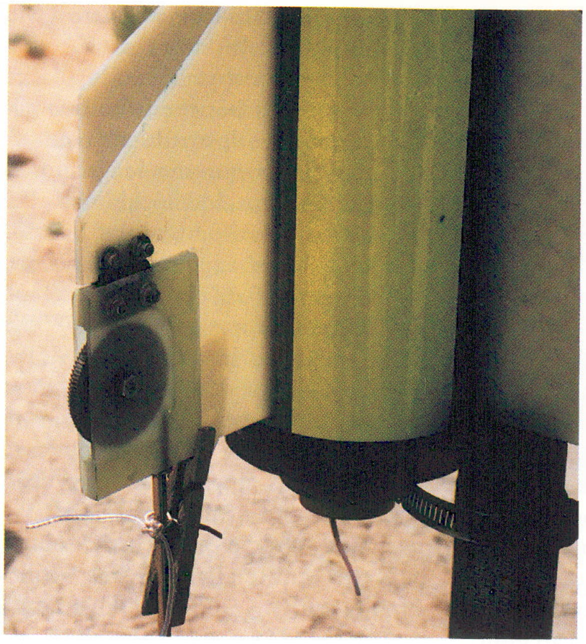
Excerpt From the Component Description Section of the Liquid Rocket Flight Report

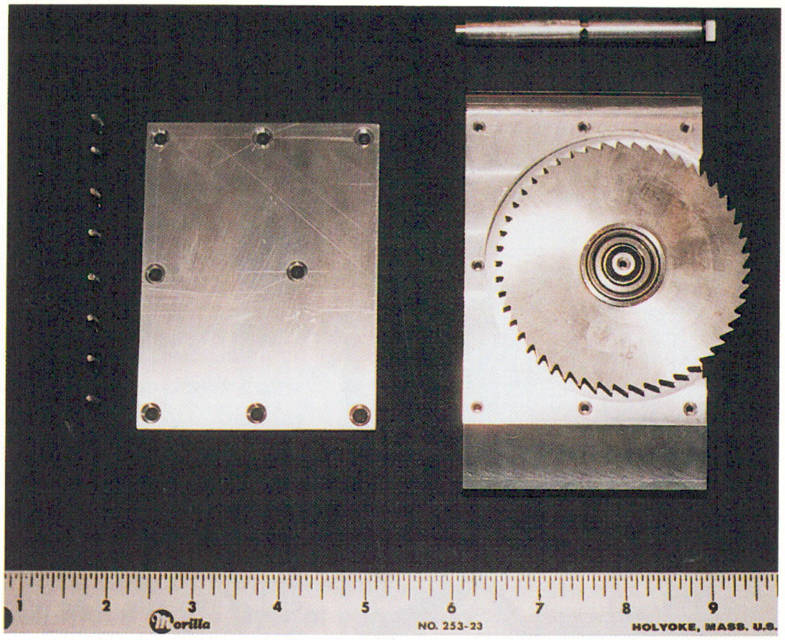
Rollerons: Since this (the liquid) rocket was designed from the beginning to carry a color TV camera and associated transmitters, roll control of the vehicle in flight became an important part of the project. If the rocket were to roll at even a moderate rate, the video images transmitted to the ground would be substantially worthless, not to mention the severe nausea induced in anyone trying to watch the video. Although every precaution would be taken to balance the rocket about its center of gravity, align the thrust vector of the engine with the vehicle axis, and verify alignment of the fins, there was no guarantee that the rocket would not roll. Some sort of roll control was required to factor out any of the many variables that might induce a roll during the flight.

Active roll control accomplished with sensors, electronic processors, and feedback controlled actuators would have been a considerable project in and of itself. We opted for the strictly mechanical and simpler method of using a device called a "rolleron." Originally invented for use on the Sidewinder air to air missile, these devices control the vehicle's roll by gyroscopic precession.

In principle, the rolleron consists of a movable tab normally at rest in the plane of the fin. It is hinged at the top so that the tab can move left or right of the fin plane in a manner that will apply an aerodynamic force about the roll axis of the rocket. The tab is hollow and contains a heavy wheel mounted on a bearing and free to spin on an axle mounted through the thickness of the tab. In operation, this wheel is spun up to high RPM while it is held in the plane of the fin before the rocket is launched. After the rocket leaves the launch stool, the tab is free to swing on its hinge to either side of the fin.

If there is no tendency for the rocket to roll, no disturbing force will be applied to the spinning wheel and the rolleron will remain in the plane of the fin. If, however, the rocket tries to roll





The second (smaller) rollerons used on the higher speed solid propellant test rocket. These units controlled roll satisfactorily but experienced some flutter at higher flight velocities. Larger wheels, heavier tabs, and a hydraulically damped axle were used in later vehicles. The disassembled rolleron (above right) built by the author and Brian Wherley for their LOX/alcohol rocket fired in June of 1995. The closure plate is shown on the left and the axle in the upper right. The cutter used for the rolleron wheel is installed in the tab with its bearing.

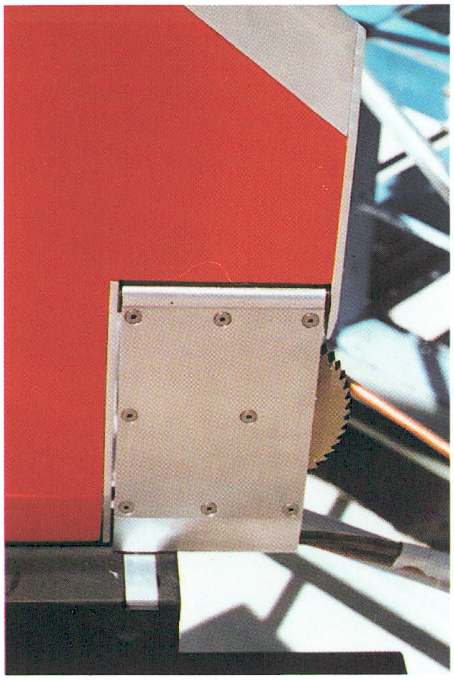
in either direction, the axis of the spinning wheel will be translated in space. Due to the gyroscopic effect the wheel will precess and move the rolleron tab out of the plane of the fin in the same direction as the vehicle roll. This movement of the tab will move it out into the air flowing over the fin and result in a force being generated normal to the tab surface. This force will be in the direction necessary to counteract the roll of the vehicle. The total displacement of the rolleron is proportional to the rate of vehicle roll, applying a small righting torque when the roll rate is small and a larger torque when vehicle roll rate is high. As the roll is corrected, the force causing the rolleron wheel to precess diminishes to zero and the rolleron returns to the neutral position in the plane of the fin.

As simple as the principle is, the mechanical application of it requires some complexity. First, the wheel must be powered to maintain its RPM. In this case, a wheel with teeth cut in its perimeter was mounted in the tab such that a small arc of the wheel protruded through the edge of the rolleron tab. With the wheel teeth exposed to the air flow, the wheel spin is constantly being driven by the rocket's movement through the air. We used a commercially available milling cutter for the wheel. These cutters can be had in a large variety of diameters and thicknesses, are precision ground, and are inexpensive. This was a much easier option than trying to make a pair of matched wheels.

Second, the wheel needs to spin at 30,000 to 40,000 RPM in flight. This RPM requires some exacting precision in the manufacture of parts to ensure bearing alignment and wheel balance in the final installation. This is not technically challenging but does require some manufacturing finesse.

Third, the hinge of the rolleron tab must include some sort of damping to keep the rolleron response from progressing into a flutter. Bruce Markle and I had flown undamped rollerons on the solid rockets and saw some fairly severe flutter at much lower air speeds than were expected with the liquid rocket. Such a flutter, if undamped at high flight speeds, would result in tremendous forces on the rolleron and, ultimately in its mechanical failure. The viscous damping system we designed for these rollerons again required some considerable precision in its manufacture. We used a hollow axle with precise clearances and a very viscous silicone grease applied hydraulically through a series of small ports and groves in the axle.

Fourth, the rolleron had to be held in alignment with the fin and spun up to high RPM before first motion of the rocket. This would ensure that the rolleron would begin to counteract roll from the very beginning of the flight. The wheel was to be spun up before launch with gaseous nitrogen supplied from the ground support pneumatic system. A special port was provided through the trailing edge of each rolleron housing. This port mated to a nitrogen nozzle mounted on support blocks that were located on the two arms attached to the launch stool. These blocks not only held the spin nozzles in place, but engagement of the nozzles with the rolleron held the rolleron in alignment with the fins. The spin nozzles could also be adjusted in two directions to allow precise adjustment of the rollerons after the rocket was installed on the launch tower and launch stool.



The liquid rocket rolleron installed on the fin and sitting on the support block. The aluminum tab holding the rolleron spin nozzle (not visible) can be seen under the inboard edge of the rolleron tab.

Fabrication

The bodies of the rollerons were made of ½-inch thick aluminum plate with a circular recess machined into its thickness to provide space for the wheel. The axle for the wheel bearing was machined integrally with the housing. During final assembly, the open side of the housing was closed with a thin aluminum plate screwed in place. The wheel bores were exactly one inch and required machined steel bushings to adapt the smaller diameter bearings used. We machined bushings with a slight (0.001) interference fit and shrunk them thermally by immersing them in liquid nitrogen. The cold bushings were then dropped into the room temperature wheel bores. As the bushings returned to room temperature, they expanded back to an interference fit tightly gripping the bore of the wheel. We had to do this a couple of times to get it right and to balance the final bearing bore diameter with the amount of interference on the bushing O.D. If the bushing had too great an interference, the final bearing bore diameter was too small to install the bearing.

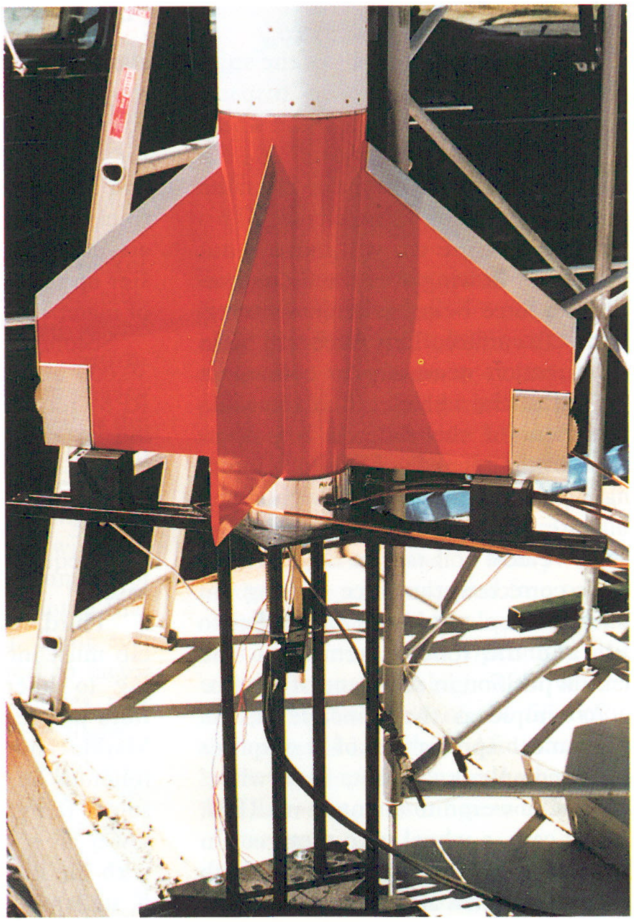
Mounting the rolleron to the fin also turned out to be a little more complicated than we first thought. The mounting arrangement needed to be strong so we opted to use aluminum doubler strips over the composite fin surface on either side of the rolleron notch. The inboard strip extended from the top of the rolleron notch to the trailing edge and was screwed in place. At its upper end was a round hole which received the inboard end of the rolleron axle. A second aluminum strip was screwed to the outboard edge of the fin and extended down past the upper edge of the rolleron notch just a half inch or so. This tab would support the other end of the axle. The hole in this tab was square to receive the matching square end of the axle. This arrangement was used to keep the axle from rotating and allowed the viscous damping system to work.

To complete the component fabrication, the parts were collected into two sets and several dimensions measured. Shims made out of Delrin (plastic) were then match machined to adjust all required running tolerances on the wheel axle and on the rolleron tab axle. All the parts were then final assembled and tested by running the wheels up to high RPM with compressed air.

Ground Support

The rolleron support blocks were fabricated out of plywood. A small open ended box was assembled out of four pieces of half inch thick material and fitted with a ¾" by ¾" hardwood guide block on the underside. This block engaged the space between the two square steel tubes that made up each arm mounted to the launch stool. This small block was fitted with a ¼-20 threaded insert to accept a thumb screw and washer. By placing the guide block between the two rails of the arm, the support block could be slid anywhere along the length of the launch stool arm and locked in place by means of the thumb screw.

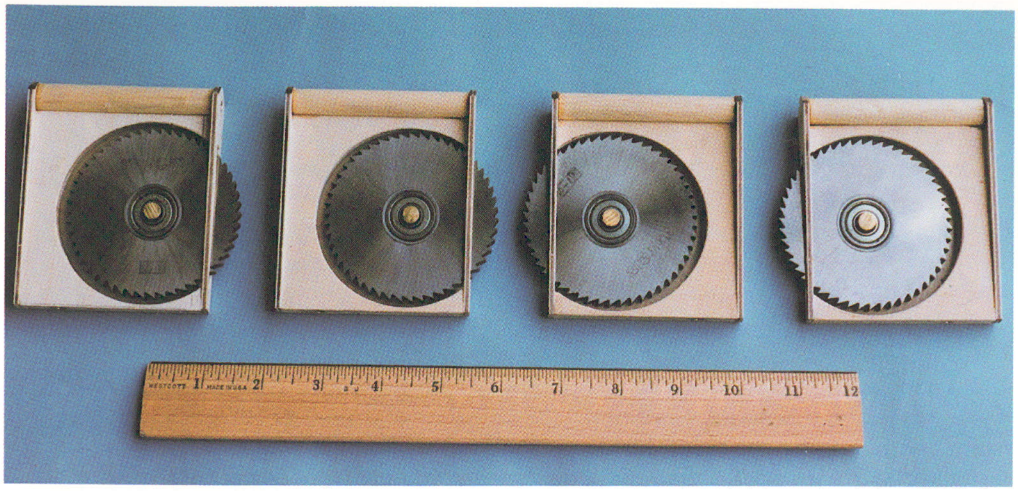
The rolleron spin nozzle was machined out of 10-32 threaded steel rod. The upper end was turned to 1/8" diameter to slip fit into the holes drilled into the trailing edges of the rollerons. (These holes emerged tangential into the wheel cavities to direct the nitrogen flow at the edge of the wheel.) The lower end of the spin nozzle was machined with a hose barb contour and the entire length was drilled through with a 1/16" drill. This nozzle was mounted in a 10-32 threaded hole in the flat side of a short piece of ½" by 1/8" aluminum strap. A lock nut on the underside of the strap allowed the nozzle to be adjusted for height and locked in place. The aluminum strap also had an elongated slot milled in it.



The boat tail of the liquid rocket showing both rollerons, the launch stool, and the launch stool arms with rolleron support blocks.

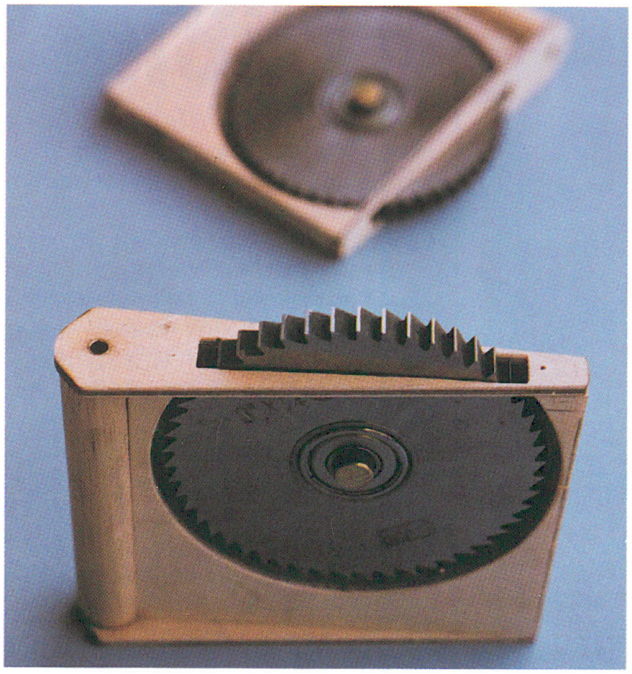
The rolleron support block had a ½" wide by 1/8" deep slot milled into its upper surface perpendicular to the guide block mounted on the bottom. The aluminum strap/spin nozzle assembly was placed in this slot and mounted with a small wood screw through the milled elongated slot. This arrangement provided side to side adjustment of the spin nozzle position and could be locked down by tightening the wood screw. This design allowed the spin nozzle to be positioned radially, laterally, and in height.

The lower ends of both spin nozzles were attached to a length of tygon tubing, in turn connected to a solenoid valve. The valve was supplied with 100 psi nitrogen from the pneumatic control panel out on the launch pad. After opening the solenoid, it took the rollerons about 30 to 40 seconds to come up to full RPM. The spin nozzles, engaged in the trailing edge holes of the rolleron tabs, held the rollerons in alignment with the fins. When the rocket engine ignited, the vehicle lifted off the milk stool and disengaged the spin nozzles leaving the rollerons free to move as required to stop any vehicle tendency to roll.



These four wood framed rollerons were built to fly on the author's 23 foot tall liquid rocket. They are constructed of 1/8 inch aircraft plywood and are airfoil shaped. The sides were closed with tapered balsa wood skins and the entire rolleron was covered with a single layer of epoxy and "S" glass. These units are also fitted with trailing edge spin ports.

Close-up of wood framed rolleron.



Flight Results

I have now been involved with three amateur rocket flights using rollerons, the two small solid rockets built by Bruce Markle and the liquid rocket Brian Wherley and I built.

The two small solid rocket flights were conducted in spring and summer 1992. Flight 5 used a low thrust motor and carried on board amateur band TV. The rocket speed was limited by the engine size and the rollerons were fairly large and heavy. The tabs were large as well. This rocket carried rollerons in two fins and radio controlled surfaces on the other two. As part of the flight test report, Bruce wrote about the rollerons:

"The rolleron system used a ground based nitrogen "K" bottle, a regulator, 50 feet of hose, and two small nozzles attached to copper lines held in place by stakes at the base of the launcher. The copper lines were adjusted to spin up the rollerons to several thousand RPM. This nozzle system was not entirely satisfactory because any small movement of the rocket on the launcher would cause misalignment with the spin nozzles and the gas jets would not impinge the rolleron teeth. Finally, a volunteer (Dave Crisalli) was selected to hold the rocket in alignment with the spin nozzles and run away just prior to ignition."

"The flight was excellent and the ATV video worked very well sending down clear black and white pictures except for a brief burst of snow at apogee due to the resulting antenna polarization. The rollerons also worked extremely well. There was no discernible roll of the vehicle even during large deflections of the radio controlled control surfaces. The rollerons could be seen deflecting slightly on the video, and never approached the stops during the ascent phase."

In flight 6, the rocket was heavier and the motor much larger. Flight speeds were expected to be much higher than on the previous tests. The rollerons were much smaller and lighter and had been modified with a trailing edge spin up port. The rocket carried TV but no radio controlled surfaces. Again from the test report:

"A new rocket was constructed similar to the original except for a larger 54mm motor mount and the fact that no radio control system or moveable control surfaces were installed. The shock cord was changed to 12.5 feet of ¼ inch O.D. bungee tied off inside 25 feet of 3/8 inch I.D. fiberglass sleeving (McMaster/Carr #8819K26). The sheathing would protect the bungee from damage, prevent it from stretching more than twice its original length, and would serve as a redundant link if the bungee failed somehow. The rollerons had worked so well on the previous flight that smaller ones were used and the stops were omitted. A second timer circuit was added to offset the loss of the R/C backup ejection system, with arming switches inside the rocket and with access through a small hole in the skin. The fins were made smaller and the rocket was made longer due to changes made in David Crisalli's liquid rocket design. The ATV antenna was relocated within the body tube to reduce drag. Additionally, the rollerons were modified to allow the new prelaunch spin up tubes to be inserted into holes in the trailing edges of the rolleron so that the nitrogen would impinge on the teeth inside the rolleron tab. The tubes were held to the rocket with spring loaded clothespins attached to the launcher with cables to pull them off as the rocket moved up the launch rod.

The only problems encountered prior to launch involved the new rolleron spin system. The vibrations induced during spin up would sometimes cause the spin nozzles to fall off the rolleron tab prematurely. The spin tubes/nozzles were taped lightly in place and the rocket was launched. The flight was perfect and the ATV sent back excellent pictures except for a brief burst of snow again just prior to apogee. However, the roll was not adequately controlled with the smaller rollerons and higher vehicle velocities. The rollerons fluttered slightly between 0.5 and 1.0 seconds after liftoff, and the rocket rolled about 270° during the first four seconds of flight. At four seconds, the flutter began in earnest at a frequency of about 30 Hz. The flutter frequency steadily decreased to about 6 Hz at ten seconds after launch, at which point it stopped completely. Roll displacement due to flutter varied between about 2° at the higher frequency up to 8° at the lower frequency. The rocket rolled an additional 180° between the four second mark and apogee. At apogee, the parachute deployed and stayed attached..."

During the liquid rocket launch in June 1995, Brian and I had the following results with the more sophisticated rollerons built for that rocket. Again from the flight report;

"The on board video was... remarkable. In addition to the camera, Mike [Henkoski] 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 looked perfect." (*HPR*, January '96 pp. 8-16, 64-68.)

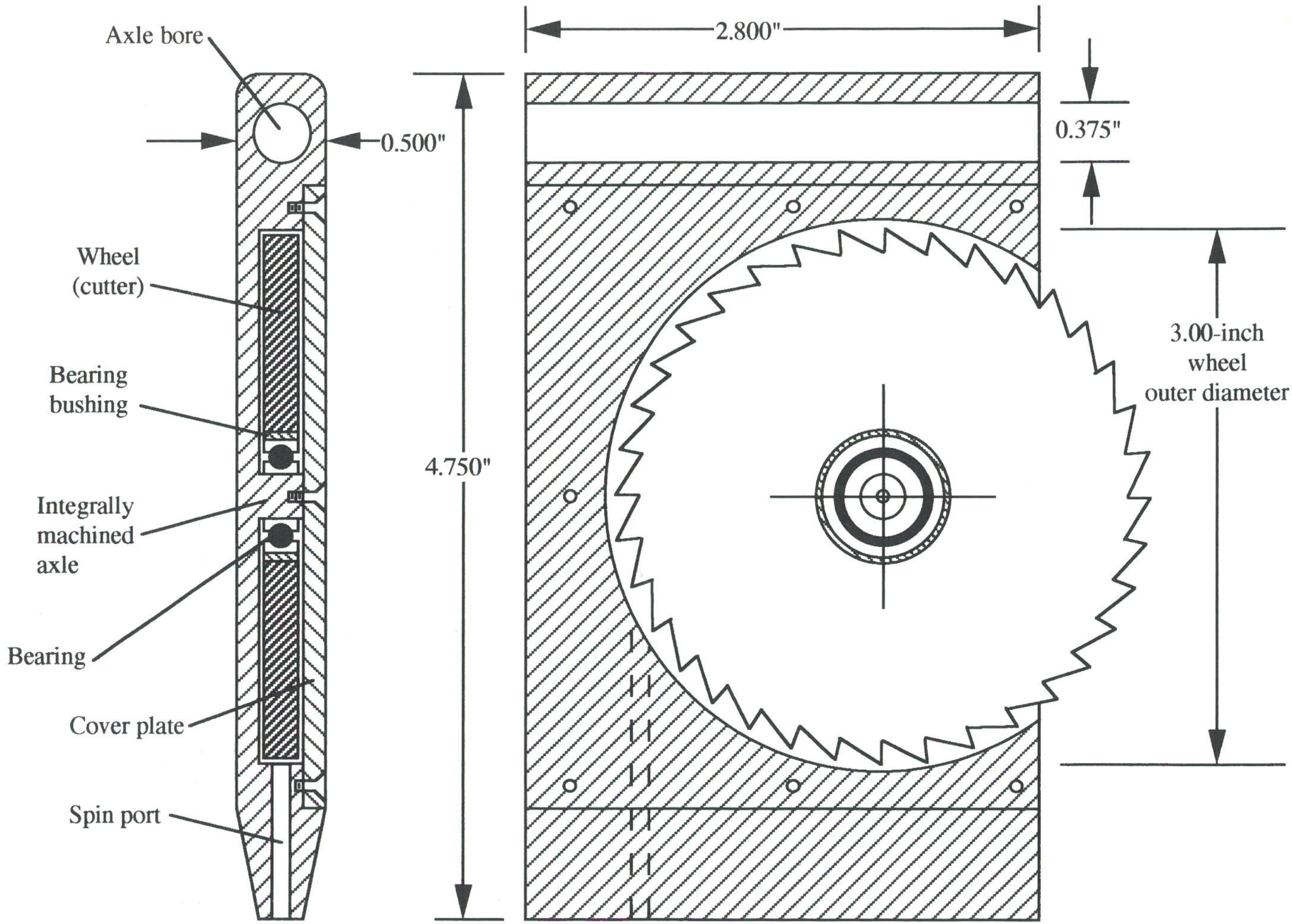
Summary

In three for three rockets, the rollerons tried have been very successful in controlling or completely eliminating vehicle roll. The rollerons used on the small solid rockets were not as sophisticated, or complicated, to build as the ones used on the liquid, but worked very well. Rollerons used on high speed vehicles should be fairly large and heavy and the tab should be damped. However, they do not need to be complicated to work. The small solids proved that a spinning wheel in a tab attached to the fin with a simple hardware store variety, undamped hinge can do the job quite nicely. For anyone interested in roll stabilizing an amateur rocket, simple home made rollerons will certainly do the job. I do not know if Sidney Crockett is still around, but I salute his simple brilliance and engineering excellence. I am sure that many combat pilots who have connected with a Sidewinder over the years would salute him also.

their camera back at tracking where they had filmed the launch. Chip Bassett, Brian and I were hiding in the sage brush with a walkie talkie about fifty feet away from the impact point. About ten feet away on his stomach in the brush was George Garboden with

and lifting the burning brush. Realizing what they have done, all four flop down on their faces in the dirt again abruptly disappearing from view leaving the camera to film empty desert once again. Michael, the good natured cameraman said later to us it

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



ROLLERON CONSTRUCTION DETAILS