

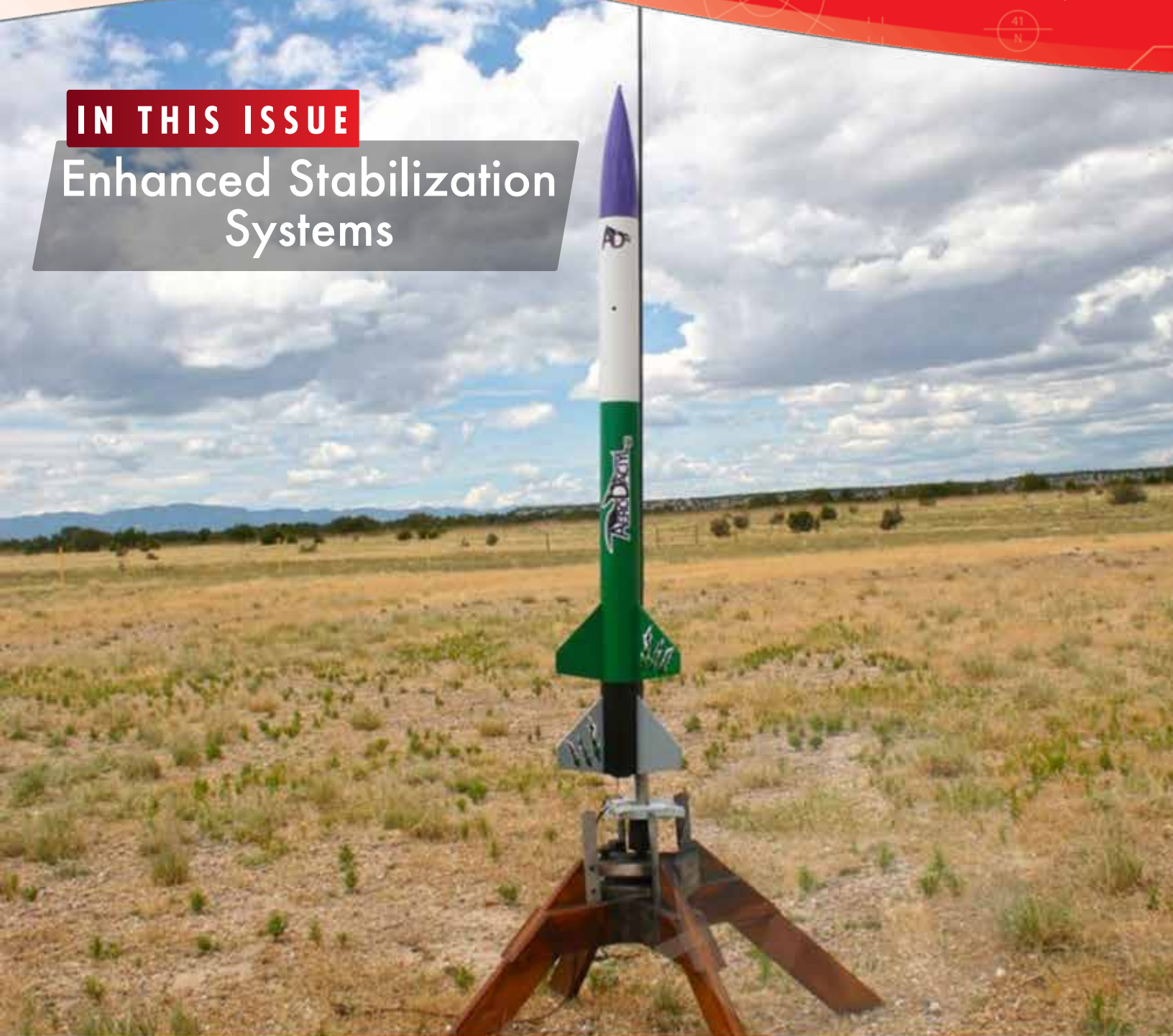
# PEAK OF FLIGHT

## NEWSLETTER

ISSUE 483 | November 27th, 2018

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## Enhanced Stabilization Systems



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# PEAK OF FLIGHT

## Enhanced Stabilization Systems

By Steve Ainsworth

### Chapter 1 : Why use an Enhanced Stabilization Flight System?

#### Introduction

The hobby of high-powered rocketry has maintained a very good safety record. I encourage anyone interested in flying an ESS rocket to do so as a member of a local club affiliated with the National Association of Rocketry (NAR) or the Tripoli Rocketry Association (TRA), and to follow the published safety code. If launch officials are concerned, I have included some add-on safety rules for consideration (**Appendix A**). The best safety advice is to have knowledge of what you are doing, follow the guidance of others and use common sense.

To be clear about the purpose of these systems, David Ketchledge called the proposed system a "Vertical Trajectory System", the goal being to achieve a flight as near vertical as possible; In other words, to go straight up (See July/August 1993 High Power Rocketry magazine). An even better name has been recently used: Enhanced Stabilization System (ESS). These systems increase the ability of the rocket to perform as intended and fly straight up.

It is my opinion that several of the problems encountered by high altitude attempts have their roots in the static fin guidance used. By maintaining a vertical flight, the ESS can reduce the velocity at apogee and thus lower the stress on the recovery system. Long burn motors, requiring ESS and perhaps staging, can reduce the aerodynamic stress experienced during the launch phase. The reliable large motors now in use can now relatively easily overcome the added weight of a vertical trajectory system.

#### Wind Cocking

Anyone who has flown rockets for a very long has learned by experience that wind causes the rocket to turn into the wind, like an old weather vane. This "wind cocking" is a result of the crosswind hitting the rocket fins. The air pressure on the static fins causes the rocket to point into the apparent wind, which is a combination of the wind caused by the rocket's velocity plus crosswind. The faster the rocket is traveling, the less effect the same crosswind has on the direction. Conversely, a slower rocket velocity as the rocket leaves the launcher allows the presence

of a crosswind to have a much greater effect on the rocket attitude.

Amateur rockets are designed so that the center of pressure (CP) is aft of the center of gravity (CG). This is done so that the rocket is stable. All motion of a rocket is either displacement motion through the CG or rotation about the CG. When a stable rocket with static fins encounters a crosswind, the air pressure forces acting on the fins (lift) due to an angle of attack of the fins with the wind will cause the rocket to rotate about its CG and point the rocket away from the vertical. The flight direction thus deviates from vertical, which results in a lower apogee. This effect can occur at higher altitudes when the rocket passes through a crosswind also known as wind shear. The more stable the static fin rocket, the greater the effect.

#### Gravity Turn

A Gravity Turn is real. Listen closely to a SpaceX launch and shortly after liftoff you can hear the callout "Gravity Turn". A Gravity Turn is a result of a combination of forces acting on the rocket. Its greatest effect on the flight profile occurs while the rocket motor is firing (**Figure 1**).



**Figure 1: The greatest effect of a gravity turn on a flight profile is when the rocket motor is firing.**

The forces on the rocket as it ascends under power are the rocket thrust (1), gravity (2), drag and aerodynamic lift on the fins and airframe. These forces are vectors (they have magnitude and direction) and can be graphically summed by drawing them pointing in the direction of the force and placing them head to tail with their length proportional to their magnitude. The resultant (3) is determined by drawing another vector from the tail of the first to the head of the second.

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## Enhanced Stabilization Systems

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Since the resulting force is at an angle to the airframe, the acceleration is also at an angle to the airframe (the rocket is accelerating somewhat sideways). The air pressure on the fins (lift) then rotates the airframe about the CG to line it up with the direction of travel. This changes the rocket attitude and consequently the direction of the motor thrust and the process continues throughout the burn.

Gravity always acts downward through the vertical, but the motor thrust that is in line with the airframe direction keeps bending, away from vertical. During the motor burn, the gravity turn diverts an ever-increasing portion of the motor impulse from making the rocket go up into making it go horizontally. The result is a lower apogee and a rocket that deploys its chutes at a high velocity and that travels far from the pad. With a very long burn motor, the gravity turn can continue rotating the rocket attitude even past horizontal to actually pointing down, accelerating the rocket into the ground. (Figure 2)

This phenomenon is why amateur high altitude rockets use short burn motors. A short motor burn time minimizes the duration of the gravity turn and its effect on apogee by applying the thrust very quickly, before the rocket has a chance to undergo much of a gravity turn. However, in order to get to a high altitude, we need to impart a lot of energy to the rocket during the short burn time. This requires a highly energetic motor that imparts its energy quickly. The result is a rocket that has very high acceleration and very high velocity at low altitude in dense air with a corresponding increase in drag.

### High Altitude

If you look at several of the previous Peak of Flight Newsletters you will find that the highest altitude for a given total motor impulse is achieved when the rocket ascends at the optimal velocity, generally remaining sub-sonic in the lower atmosphere. This requires the use of an optimal thrust curve, which is usually a long burn motor.

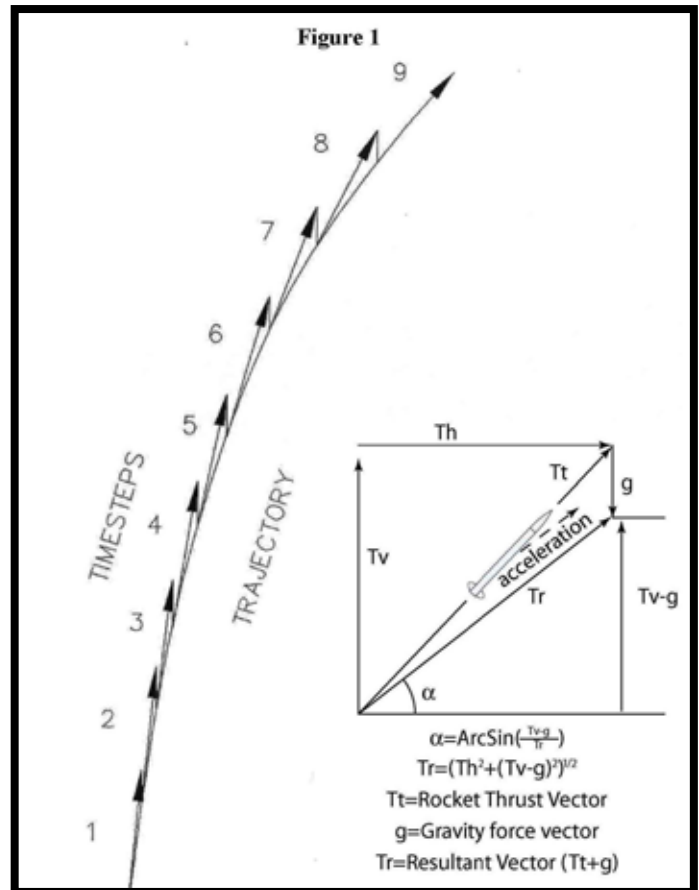


Figure 2: Formulating the gravity turn.

It is obvious that the highest altitudes can only be achieved if the rocket travels as straight up as possible. Optimal thrust curve motors are of little use if the rocket veers off vertical due to a gravity turn.

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## Enhanced Stabilization Systems

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### Chapter 2: Enhanced Stabilization Systems

#### Roll Stabilization

Roll rates can be induced from off-alignment of fins, or other off-axis disturbances on the airflow over the rocket body. Another source is a vortex (spinning) of the exhaust gasses during motor burn.

In order to get nice in-flight photos or video, it is good if the rocket does not roll excessively. A mechanical system for roll control is the rolleron. This system was discussed in an article in the May 1996 issue of High Power Rocketry magazine. The roll-control portion of the enhanced stabilization systems discussed can also be used on their own for roll control. (Figures 3, 4)



Figure 3: Rollerons on a Sidewinder



Figure 4: Roll control on a model rocket

Continued on page 5



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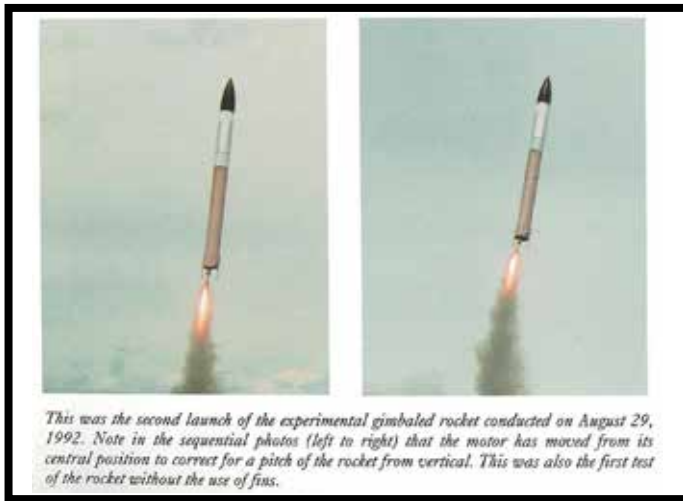
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### Gimbaled Motors

One ESS that has been attempted for High Power Rocketry (HPR) is to gimbal the main rocket motor so it moves to provide a thrust to counter unwanted motion of the rocket. In July of 1992, Richard Speck led a team that constructed and launched a home-built, two-axis (yaw and pitch) directional gyro system and used that to gimbal a G-range main motor. The rocket was even flown without fins. (**Figure 5**)



**Figure 5: Gimbal test rocket**

In October 2001, Cameron Martin designed, constructed and flew a system with gimbaled thrust vectoring "tubes" on two small "vernier" motors located in tubes next to the main airframe (**Figures 6, 7**). Cameron's system is actually more of a gimbaled thruster and the pros and cons are more like those for the thruster list than the gimbaled motor list. The clever part was that with just two vernier motors he could control roll, pitch and yaw. For safety, the first flight limited the control to the roll axis.

#### Positives:

- No added rocket motors are needed if the main motor is used
- Large thrust main motor needs small deflections

#### Negatives:

- Effective only during motor burn
- Complex mechanical mount needed to move entire motor for gimbaled thrust
- Even more difficult to gimbal the nozzle only
- Large forces require very fast guidance system
- Guidance force is not constant, as it depends upon the motor thrust curve

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**Figure 6: Gimbal on a model rocket**



**Figure 7: Gimbal model rocket on pad**

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### Active Fins

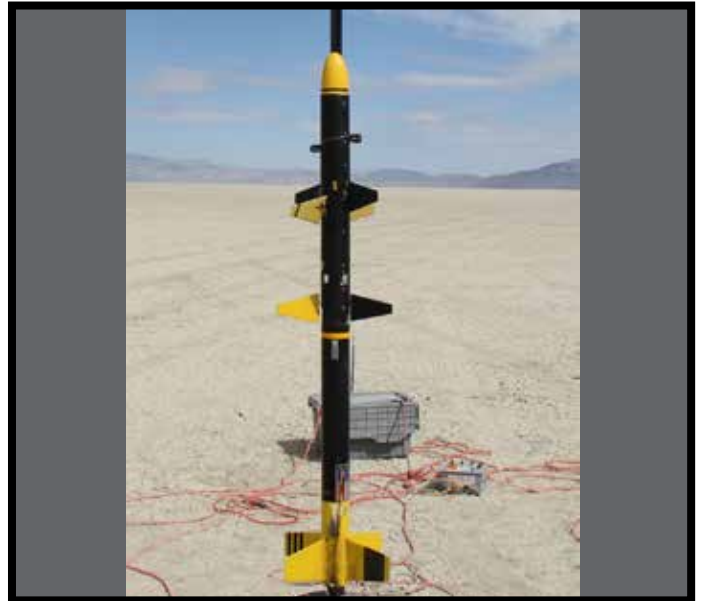
The first ESS rocket utilizing active forward fins was launched successfully on January 20, 1996 at El Dorado Dry Lake near Boulder City, Nevada (**Figures 8, 9**). There are two categories of active fin guidance. The first uses control surfaces on the aft fins and the second uses an active fins forward of the CG. Since the motor takes up most of the room near the aft fins, the first rocket was constructed with fins placed forward of the CG for Yaw and Pitch stabilization. These forward fins were sized to maintain static stability. Many flights were made successfully using this variation. (**Figures 10, 11**)



**Figure 8: The first active fin guidance rocket on pad**



**Figure 9: First flight of active fin guidance rocket**



**Figure 10: Active fin guidance rocket on pad**



**Figure 11: Active fin guidance launch**

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## Enhanced Stabilization Systems

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Fins are relatively easy to build, move and install. However, fins are terrible to analyze. The force on the rocket by a two-degree deflection of the fin is greater the faster the rocket travels upward and lower because of the thinner air at altitude.

### Positives:

- No added rocket motors needed
- Enhanced stabilization effective possible during boost and coast phases (within the lower atmosphere)
- Simple mechanical system

### Negatives:

- Force increases with velocity
- Force decreases with altitude
- Active fin deflection of a constant angle with respect to the airframe is not a constant angle with respect to the velocity vector.

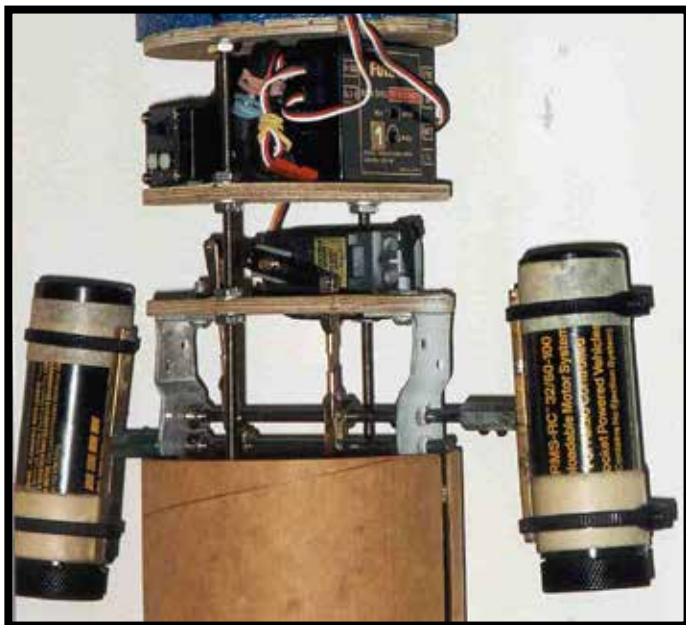


Figure 12: Roll electronics

### Hot Gas Thrusters

Cameron Martin's vernier motors are a form of hot gas thrusters, located at the aft end of the rocket. To eliminate the issues with movable fins, the next generation used Aerotech long-burn RCT motors on moveable axes at the CG as roll-control thrusters (**Figures 12, 13, 14**). The correcting force on the rocket would vary as the angle of the motors varied from vertical.

Since these are small rocket motors, they eject hot gas-



Figure 13: Hot Roll Thruster Test

ses and are thus hot gas thrusters. One tricky part with using this system is that it requires two or more extra motors, which must be ignited before the flight, but not too long before the main motor ignites or they will burn out before the boost and coast are completed.

### Positives:

- Roll control possible during boost and coast even to high altitudes
- Simple mechanical system

### Negatives:

- All motors must be ignited together
- Requires extra rocket motors
- Thrusters add drag
- Force varies with thrust curve.

### Cold Gas Thrusters

The need for a throttleable and restartable simple motor was what moved me in the direction of cold gas thrusters.



Figure 14: Hybrid motor and roll thrusters

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## Enhanced Stabilization Systems

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I landed on cold gas thrusters that used CO<sub>2</sub> for the next generation ESS. Choosing CO<sub>2</sub> results in a system that can utilize parts available from the paintball industry (Figures 15, 16).

### Positives:

- Vertical trajectory system possible during boost and coast even to high altitudes
- Constant thrust
- Simplest system to analyze
- Very flexible

### Negatives:

- Requires heavy high-pressure tank and valves
- Requires complex tank heater system
- Requires separate rocket motor system



**Figure 15: 2002 - Cold gas thruster rocket on pad**

## Chapter 3: HPR Enhanced Stabilization Flight History

**July 25, 1992, Colorado - Dave Gianakos, Tommy Billings, Richard Speck, Bruce Markielewski**

As reported in the May/June 1993 issue of HPR magazine, the rocket consisted of a 5.5" diameter, 70" long airframe and weighed 9lb 6oz at liftoff. The system utilized a homemade gyro system and standard RC servos to gimbal the motor inside the airframe. (Figure 4, Page 4)

**June, 1995 - David Crisalli, Brian Wherley**

As reported in the May 1996 issue of High Powered Rocketry (HPR) magazine. This was a liquid fueled HPR flight using rollerons for roll only stabilization. (Figure 2, Page 3)



**Figure 16: 2002 - Cold gas thruster launch**

**November 10, 1995, El Dorado Dry Lake, Nevada - Author**

The rocket was a 4" diameter modified EZI-65 (with four fins instead of three) equipped with roll control fins operated by a Futaba S9101 servo and Futaba rate gyro (Figure 7, Page 5) flown on an Aerotech I211. The RC signal generator was constructed by Brian Riordan. The flight was successful.

**December 10, 1995, El Dorado Dry Lake, Nevada - Author**

A single axis Futaba gyro was installed in an Estes Astro Blaster R/C controlled boost glider to control pitch. The Astro Blaster was launched on a D motor. The boost was very straight up, with the gyro controlling the boost glider pitch very well. At apogee, the glider turned 180 degrees and flew straight down into the ground. Ouch.

**February 16, 1996, El Dorado Dry Lake, Nevada - Author**

The booster was the 4" EZI-65 with four fins, on an Aerotech 4-jet hybrid J-210H. The total rocket weight was 11.2 lbs. Flight used two gyros, providing both yaw and pitch control by moving two pairs of 2"x 2" trapezoidal fins placed forward of the CG (Figure 8, Page 6). Tripoli Vegas observers noted the rocket reacting to control surface movements.

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### **March 9, 1996, El Dorado Dry Lake, Nevada (Springfest) - Author**

The booster was the 4" EZI-65 with four fins, on an Aerotech 4-jet hybrid J-210H. The total rocket weight was 11.2 lbs. The flight used two gyros, providing both yaw and pitch control by moving two pairs of 2"x 2" trapezoidal fins placed forward of the CG. The flight was videotaped by Jodi Michaelson and is on the Rocketman 1996 Springfest videotape, together with an interview and demonstration of the system. The flight was successful and rocket response was observed.

### **May 18, 1996, Delmar Dry Lake, Nevada - Author**

The booster was the 4" EZI-65 with four fins, on an Aerotech J-90 motor. This flight used two gyros, providing both yaw and pitch control by moving two pairs of 2"x 2" trapezoidal fins placed forward of the CG (**Figure 9, Page 6**). Since this launch took place in a 20 mph wind, control responses were easily seen, and a near vertical flight was made.

### **June 22, 1996, El Dorado Dry Lake, Nevada - Author**

The booster was the 4" EZI-65 with four fins, on an Aerotech J-275 motor. This flight used two gyros, providing both yaw and pitch control by moving two pairs of 5"x 5" nearly square fins placed forward of the CG. The initial ascent went fine, but the guidance system over-controlled the rocket, and the rocket made a complete 360-degree loop in the air. This flight was followed by ground tests, calibration of the control system, and the addition of a two-channel radio telemetry system for monitoring flight control fin position.

### **November 30, 1996, El Dorado Dry Lake, Nevada - Author**

A telemetry system was added for this flight. It had ground indicators for the control system position in flight. The booster was the 4" EZI-65 with four fins, on an Aerotech J-210H motor. This flight used two gyros, providing both yaw and pitch control by moving two pairs of 2"x 4" trapezoidal fins placed forward of the CG.

### **December 21, 1996, El Dorado Dry Lake, Nevada - Author**

The booster was the 4" EZI-65 with four fins, on an Aerotech 2-jet hybrid J-145H. This flight used two gyros, providing both yaw and pitch control by moving two pairs of 2"x 4" trapezoidal fins placed forward of the CG. The flight included the telemetry system, but telemetry ceased immediately after launch.

### **March 22, 1997, El Dorado Dry Lake, Nevada - Author**

The booster was the 4" EZI-65 with four fins, on an Aerotech 4-jet hybrid J-210H. This flight used two gyros, providing both yaw and pitch control by moving two pairs of 2"x 4" trapezoidal fins placed forward of the CG. This was the third test of the telemetry system.

### **April 19, 1997, El Dorado Dry Lake, Nevada - Author**

The booster was the 4" EZI-65 with four fins, on an Aerotech 4-jet hybrid J-210H. This flight used two gyros, providing both yaw and pitch control by moving two pairs of 2"x 4" trapezoidal fins placed forward of the CG. This was the fourth test of the telemetry system. The launch was made in a 25 mph wind. Very straight liftoff and flight despite the wind.

### **May 11, 1997, El Dorado Dry Lake, Nevada - Author**

The booster was the 4" EZI-65 with four fins, on an Aerotech 4-jet hybrid J-210H. This flight used three gyros, providing yaw, pitch and roll control by moving two pairs of 2"x 4" trapezoidal fins placed forward of the CG, and one pair of counter-rotating 2"x 2" fins near the CG. The guidance section length was increased to allow for the roll axis controls.

### **May 17, 1997, Delmar Dry Lake, Nevada - Author**

The booster was the 4" EZI-65 with four fins, on an Aerotech K185W motor. This flight used three gyros, providing yaw, pitch and roll control by moving two pairs of 2"x 4" trapezoidal fins placed forward of the CG, and one pair of counter-rotating 2"x 2" fins near the CG.

Two of the Yaw/Pitch fins were lost during the flight, and the other two were bent back. The bent fins caused a severe roll torque that the roll fins could not overcome (the roll fins remained intact). The rocket did have a successful recovery. The brass axles were replaced with steel wire axles for future flights with hot gas thrusters. This was the last flight of the 4" diameter rocket forward fin system.

### **September 9, 2000 Blackrock - Author**

The booster was the 4" EZI-65 with four trapezoidal fins, using counter-rotating axles to move the two thrusters for roll control. It was flown on an Aerotech 3-jet hybrid J-170H. This was the first launch of a rocket utilizing thrusters.

Roll control only was selected for the first flight, so any malfunction of the control system would not cause a danger to observers due to altering the flight path. The thrusters were Aerotech RMS-RC G12-RCT

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motors with an 8.5-second burn time. The control system was an advanced version of one used on previous flights, which used moveable fins for yaw, pitch and roll control.

Both chutes deployed properly and recovery was made about 1/2 mile from the pad in strong wind. The only damage was caused by the wind dragging the rocket on the playa.

Inspection of the photos taken by the onboard camera showed that one of the thrusters over-rotated, and "locked" the linkage in the roll left position. The servo was unable to move it from that position, creating a high roll rate. The linkage problem was corrected and the servo size increased for the next test flight.

### August 25, 2001, Blackrock - Author

The second test of this configuration took place at Black Rock on August 25, 2001. The booster was the same 4" EZI-65 with four fins, flown this time on an Aerotech Turbo-K485WH hybrid. The total rocket weight was 15.5 lbs.

The Aerotech RCT roll thrusters were loaded with G12 reloads with an 8.5-second burn time. This flight used one gyro for roll control, with a programmable controller that, following launch detect, was to roll the rocket left for one second, right for one second, and then stop the roll. As the thruster ignited and came up to thrust, the pad started to tip. The main motor fired and the rocket leapt from the pad on the turbo motor. The previous problem with the servo linkage had been solved and this flight was very successful, with the thrusters damping the roll.

The issue for the flight was that when the thrusters ignited, the rocket jumped up slightly loosing the pad stand-off. The 6" fall of the rocket with the sudden stop at the blast deflector activated the "launch detect" system, which started the roll program. This rolled the rocket around the launch rod first one way, then the other. The rolling, combined with the wind, caused the pad to tip prior to liftoff. The

roll control system then prevented any roll from developing as the rocket ascended. The launch was at an angle, but the roll thrusters stopped all roll. This flight was a success for the control system. The rocket was recovered successfully.

### October 6, 2001, Blackrock - Author

The rocket was the 4" EZI-65, with four fins, weighing a total of 14.7 lbs., and flying on an Aerotech J390HW Turbo hybrid. The Aerotech RCT roll thrusters were loaded with G12 reloads with an 8.5-second burn time. This flight used one gyro for roll control, with the programmable controller. The roll thrusters were ignited using the leads from a separate pad. Following ignition of the roll thrusters, the main motor was ignited. The launch was perfect and the flight was a total success.

### October 6, 2001, Blackrock - Cameron Martin

Cameron flew a gimbaled vernier motor guidance system of his design, using the author's control electronics. This system, although capable of yaw, pitch and roll control using just the two gimbaled nozzle motors, was flown in a configuration for roll control only for safety. The verniers were the Aerotech G12-RCT motors that I used, with an Aerotech J390HW as the main motor. (Figures 5 & 6, Page 5)

The booster was based on the 4" EZI-65. The verniers were ignited first, and then the rocket leapt from the pad on the Aerotech hybrid main motor. Soon after, the left vernier was stripped from the central airframe by the aerodynamic forces, followed seconds later by the right vernier.

### 2001 - 2002 - Mike Stackpole

An ESS rocket was constructed of LOC 54 mm tubing, 67.5" long with a liftoff weight of 3.5 pounds. The system utilized two Futaba rate gyros to control the pitch and yaw axis, with no roll control. Mike made two flights with the system in winds up to 10 mph and one flight at 5 mph winds with the system turned off, as a control comparison.

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### May 2002 - Evan Gates

Evan made multiple flights of several different low powered rockets on a C motor with an RDAS (Rocket Data Acquisition System) to determine the effect of spin rate on altitude. See Evan's report entitled: The Effect of Spin Stabilization on Amateur Rocketry. The results in one sentence: spin stabilization using canted static fin rockets imparts excessive drag.

### August 3, 2002, Blackrock - Author

The all aluminum airframe cold gas thruster rocket was launched on an Aerotech L952. The loaded rocket weight was 51.8 lbs. (**Figures 15 & 16, Page 8**). The airframe consisted of a 4" ID aluminum tube 36" long, to house the 98mm main motor and aft fins, which was the booster section. At the forward end of the booster section, within the transition section, was an AltAcc altimeter with an Adept timer for backup, providing chute deployment. The parachute section was 4" OD aluminum tubing 24" long, housing two chutes – one for the booster and chute section and one for the guidance section.

The guidance section was a 4" OD aluminum tube 36" in length and housed the CO2 cylinder, electronics, gas valves and four stationary thrusters, pointing outward from the airframe just aft of the nose cone. Each thruster "fired" CO2 and produced 20 newtons of thrust. When heated, the system could fire for 12-15 seconds.

Due to time restrictions, I was not able to make the tank heating system operative prior to the first flight. As a result, the thrusters could only fire at 20 newtons for about 5-7 seconds before the tank pressure started dropping with the resultant drop in thrust.

The controller with lift-off detect that was constructed for the Hot-Gas Thruster rocket was reused which included the program to cause the rocket to briefly pitch left then right followed by straight flight.

At ignition, the igniter flashed and was ejected from the motor. The motor burned slowly on the pad for 3-5 seconds before building enough thrust to very slowly lift the rocket up the rail. The launch rail was 9 feet in length and the rocket was still traveling slowly as it left the rail in strong wind. The thrusters fired and performed the programmed left-right motion. Following that, the system kept the rocket vertical for the first portion of the boost. As the thrusters' force decreased, the rocket cocked into the wind.

At apogee, the rocket was traveling at high velocity, which stripped the chutes from both the booster and guid-

ance sections. The guidance section fell and tumbled to the ground impacting about 2 miles upwind of the launch site. The booster impacted about 2000 feet more up wind and buried itself 2 feet into the lakebed. All the electronics and fittings in the guidance section were destroyed upon impact. The altimeter and timer were destroyed in the booster, however the booster airframe survived with moderate damage.

This flight was the culmination of over five years of planning, experimenting, design, construction and testing. The aluminum airframe was needed for flexural rigidity so it would not deflect as the thrusters countered the aerodynamic forces on the vehicle. The boost was the slowest I have seen, and remained vertical, even in the wind, until the thrusters ran down. The flight failure was due to the improper ignition of the motor and subsequent low thrust flight.

### October 2007 - Author

The rocket was a 2.5" diameter airframe equipped with roll control fins operated by a S9101 servo and Futaba rate gyro flown on an Aerotech F-20. The rocket included an on-board video camera. This was a roll control only flight with the roll control fins near the CG. Two flights were made, both were successful.

### July 2009, Blackrock - Author

The rocket was a two-stage 2.5" diameter airframe with canted fins on the booster to test spin stabilization flown on an Aerotech G80. The second stage had no fins but included a weighted ring to provide a larger angular momentum value. The single flight went unstable upon booster separation. The second stage did not ignite.

### August 2009, Blackrock - Author

The rocket was a 2.5" diameter airframe equipped with roll control fins operated by a solid-state compass through a Parallax Basic Stamp computer and S9101 servo and Futaba rate gyro flown on an Aerotech G71. The rocket included an on-board video camera. This was a roll control only flight with the roll control fins near the CG. Flight was successful.

### October 2009, Rio Linda CA - Author

The rocket was a 2.5" diameter airframe equipped with roll control fins operated by a sol-

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## Enhanced Stabilization Systems

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id-state compass through a Parallax Basic Stamp computer and S9101 servo and Futaba rate gyro flown on an Aerotech G64. The rocket included an on-board video camera. This was a roll control only flight with the roll control fins near the CG. Flight was successful.

### November 2009, Rio Linda CA - Author

The rocket was a 2.5" diameter airframe equipped with roll control fins operated by a solid-state compass through a Parallax Basic Stamp computer and S9101 servo and Futaba rate gyro flown on an Aerotech G64. The rocket included an on-board video camera. This was a roll control only flight with the roll control fins near the CG. Motor ejection failed due to debris in touchhole in forward closure.

### April 2010, Roseville CA - Author

The rocket was a 2.5" diameter airframe equipped with roll control fins operated by a solid-state compass through a Parallax Basic Stamp computer and S9101 servo and Futaba rate gyro flown on an Aerotech G64. The rocket included an on-board video camera. This was a roll control only flight with the roll control fins near the CG. Motor experienced aft closure burn through causing off-axis thrust. Onboard video shows roll fins controlled the induced torque from the burn through. Motor underperformed and timer ejection was too late.

### July 2010, Blackrock - Author

The rocket was a 2.5" diameter airframe equipped with roll control fins operated by a solid-state compass through a Parallax Basic Stamp computer and Yaw/Pitch fins controlled by a Futaba Pilot Assist Link, which is a horizon

sensor. The rocket was flown on an Aerotech H97. The rocket included two on-board video cameras. This was a roll control only flight with tape on the Yaw/Pitch axles in view of the video cameras. with the roll control fins near the CG. Slight roll rate (1rev/5 s) as the roll fins were too small. Flight was successful.

### April 2011, Maddox Dairy - Author

The rocket was a 2.5" diameter airframe equipped with roll control fins operated by a solid-state compass through a Parallax Basic Stamp computer and Yaw/Pitch fins controlled by a Futaba Pilot Assist Link, which is a horizon sensor. The rocket was flown on an Aerotech G64 then on an Aerotech H97. The rocket included two on-board video cameras. The first flight was a roll control only flight with tape on the Yaw/Pitch axles in view of the video cameras. The second flight utilized the full ESS. The Pitch control servo was reversed and did not provide stabilization, in fact produced counter forces. The rocket flew safely up anyway. Both flights were successful.

### June 2011, Maddox Dairy - Author

The rocket was a 2.5" diameter airframe equipped with roll control fins operated by a solid-state compass through a Parallax Basic Stamp computer and Yaw/Pitch fins controlled by a Futaba Pilot Assist Link, which is a horizon sensor. The rocket was flown on an Aerotech H97. The rocket included two on-board video cameras. The flight utilized the full ESS. Nice straight flight. Successful recovery.

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# PEAK OF FLIGHT

## Enhanced Stabilization Systems

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### July 2011, Maddox Dairy - Author

The rocket was a 2.5" diameter airframe equipped with roll control fins operated by a solid-state compass through a Parallax Basic Stamp computer and Yaw/Pitch fins controlled by a Futaba Pilot Assist Link horizon sensor. The rocket was flown on an Aerotech I161 and again on an H97. The rocket included two on-board video cameras. The flight utilized the full ESS. Nice straight flight. Successful recovery.

### February 2013, Maddox Dairy - Author

The rocket was a 2.5" diameter airframe equipped with roll control fins operated by a solid-state compass through a Parallax Basic Stamp computer and Yaw/Pitch fins controlled by a Futaba Pilot Assist Link horizon sensor. The rocket was flown on an Aerotech H97. The rocket included two on-board video cameras. The flight utilized the full ESS. Nice straight flight. Successful recovery.

### Sept 2018, Blackrock XPRS - Author

The Wasp rocket was a 2.5" diameter airframe equipped with roll control fins operated by a solid-state compass through a Parallax Basic Stamp computer and Yaw/Pitch fins controlled by a Futaba Pilot Assist Link horizon sensor (**Figures 10 & 11, Page 6**). The Wasp rocket was flown on an Aerotech I154. The rocket included two on-board video cameras. The flight utilized the full ESS. Nice straight flight (**Figure 17**). Since there is insufficient space in the rocket for dual deploy, I used a very long booster tether (**Figure 18**) and a Jolly Logic Chute Release (**Figure 19**). Successful recovery.

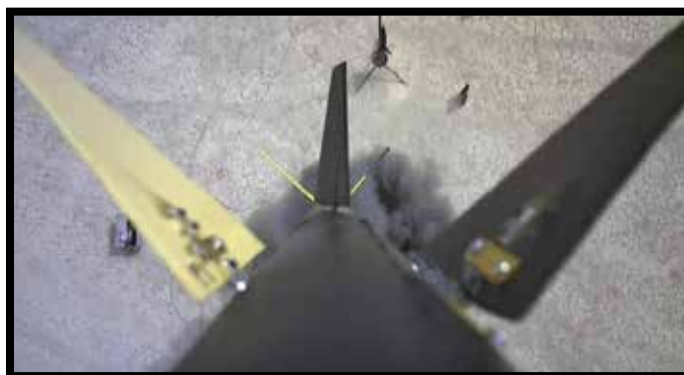


Figure 17: Wasp launch



Figure 18: Wasp launch with booster tether



Figure 19: Wasp with Jolly Logic Chute Release

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## Enhanced Stabilization Systems

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### Sept 2018, Blackrock XPRS - Author

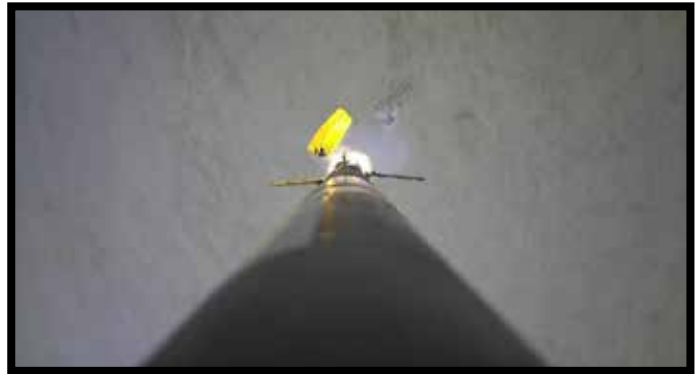
This rocket (VTSIII) moved all ESS to the booster, allowing the booster to operate as a first stage that can release the second stage in a vertical attitude. The rocket was a 2.5" diameter airframe equipped with control surfaces on all four aft fins operated by fin-mounted micro servos. The attitude sensor was an Eagle Tree Guardian controller placed in the booster airframe. The rocket was flown on an Aero-tech J90 and included two on-board video cameras. The flight utilized the full ESS, Yaw-Pitch and Roll. The rocket lost one of the four fins due to aerodynamic forces on the control surfaces as the rocket passed 250 mph (**Figure 20, 21**). Two other fins lost the control surfaces moments later. On board video shows no roll and vertical flight corrections made until the loss of the control surfaces. Nice straight flight in spite of the airframe failures! Note in **Figure 21** that the launch rail is still seen below the rocket. Successful recovery (**Figures 22, 23**).

### Aft Closure - ESS failures

There have been many ESS flights at various HPR launches. During the development process, several of my enhanced stabilization system equipped rockets have experienced ESS failures of some sort. None of these failures caused the rocket to behave very badly, or even noticeably bad. None were as dangerous to those nearby as a cluster rocket that experiences an asymmetrical thrust due to one or more motors not igniting. That includes flights that have lost fins! The most noticeable flight issues with ESS were two flights that had an issue with the motor. These flights would have had the same problems (and potentially worse problems) if there was no ESS on board. The ESS rockets are no more dangerous than a cluster of multi-stage rockets. The NAR and Tripoli Rocketry Safety Code applied at launches are sufficient to provide a safe flight for the ESS equipped rockets. None of the ESS equipped rockets



**Figure 20: VTSIII launch**



**Figure 21: VTSIII fin detachment**



**Figure 22: VTSIII recovery system**



**Figure 23: VTSIII close up of broken fin after landing**

discussed herein could be used in a manner to violate the Safety Codes/Regulations any more than static fin guided rockets. These systems do not provide any means of aiming a rocket at a target. If the RSO or LCO feels that more needs to be done, then see my recommendations in Appendix A

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## Enhanced Stabilization Systems

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<https://www.apogeerockets.com/education/downloads/Newsletter471.pdf>

Vertical Trajectory Systems (2004) available from ARA Press.

### Appendix A

#### Safety Code specifically applicable to ESS

Tripoli Safety Code (TSR) NFPA 1127

The Safety Codes/Regulations that are sometimes misinterpreted to exclude ESS equipped rockets are:

Chapter 2 Requirements for HPR Construction and Operation.

2-16-3: Do not operate a high power rocket in a manner that is hazardous to aircraft.

Chapter 6 Prohibited Activities

(b) Use of a high power rocket or high power rocket motor as a weapon against a target.

### FAA Regulations

Section 101 Subpart C – Unmanned Rockets

No person may operate an unmanned rocket (a) in a manner that creates a collision hazard with other aircraft.

### Enhanced Stability System (ESS) Rocket Add-on Safety Code

#### General

All Enhanced Stability System (ESS) rockets shall be designed to maintain a trajectory within 12 degrees of vertical.

The safety distance for ESS rockets shall be the same as a standard rocket using a motor with a total impulse one letter-size larger than the ESS rocket.

Verniers, or thrusters with less than 15% of the thrust of the main motor, need not be certified to fly as a certified flight.

**Yaw and Pitch Control:** For any ESS rocket flown at a Tripoli Sanctioned Launch (except experimental launches), the static guidance system shall be large enough to provide a safe flight trajectory in the event of ESS failure. That is, the deviation from the intended flight path with a guidance system failure shall not be greater than that experienced by a static-guided rocket launched in a 20mph wind.

**Roll Control:** Rockets with roll-only stabilization shall only be required to meet the standard Tripoli safety code.

#### About The Author:

Steve Ainsworth (**Figure 15, Page 8**) is a Civil Engineer with a Master's degree in Physics from UNLV. He has published articles in both HPR and ER since he became a "Born Again Rocketeer" in 1994. Steve joined Tripoli Vegas in 1995 and began flying his "gizmo" rockets. In 1995, Las Vegas was the perfect setting for re-entering rocketry with Gary Rosenfield of Aerotech providing motor tutoring and Tom Blazin (TRA # 003) as the local Prefect, coaching and signing for Steve's Level 1 and Level 2 flights. While on an extended engineering assignment in northern California, Steve had evening time to think about rocketry. He used that time to learn enough aerodynamics to develop a computational method for flight predictions based on Gordon Mandell's MIT Thesis articles.

