THE DRAKE SAGA

The Development of the First Motor-Feed-Staging Rocket

By Ken Good

Black Rock Dry Lake can be a very unforgiving and cruel place. This applies not just to the environment and to those who may be ill-prepared to wander about on the playa, but specifically, to the annual BALLS events – Tripoli Rocketry Association's premier research rocketry venue. Those who attend, and attempt to fly something adventurous, frequently find out why a sense of humility and a tough skin are important ingredients in the mental outlook of a TRA research flyer. Having been involved with high power rocketry from its beginnings, I have always advised newbies that "if you can't handle setbacks and failures, better look for something else to do with your time." My personal quest to succeed in flying the first "motor feed staging" rocket has reinforced and boomeranged my own words far more strongly than I would have preferred.

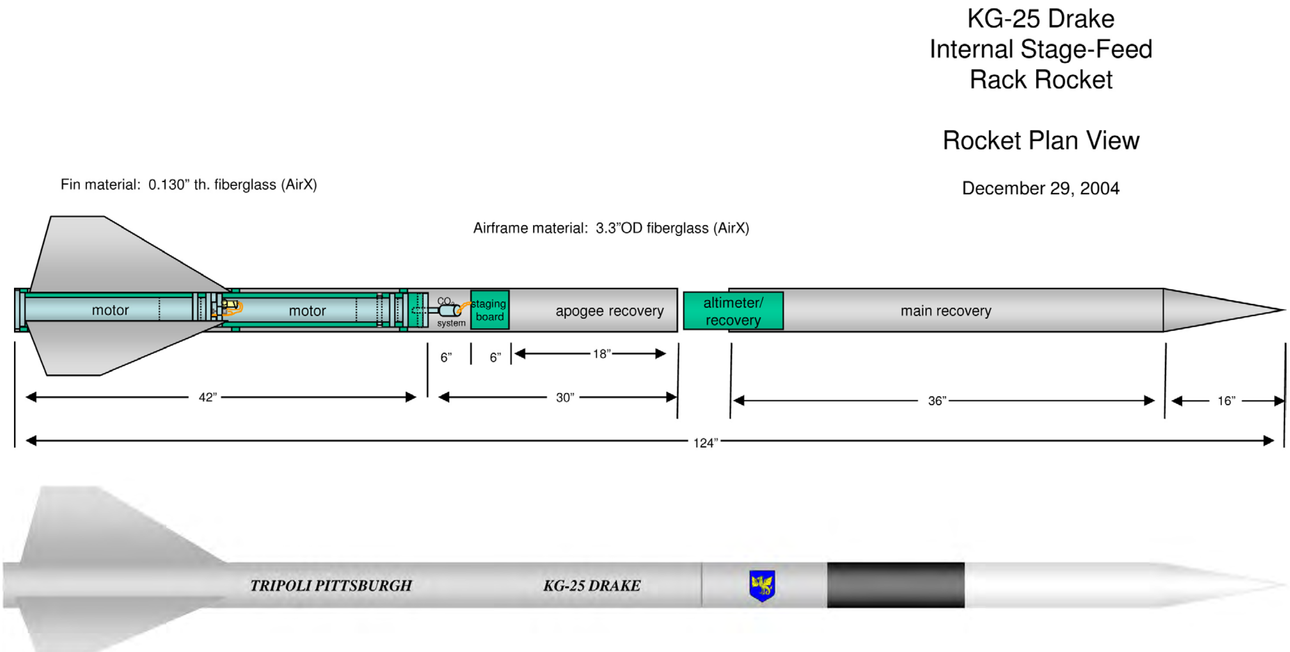
Rack-Rockets and Motor-Feed Staging

The concept of a motor-feed staging rocket was a personal idea, dating back to my high school days several decades ago. So what is it exactly? Motor-feed staging is, simply put, a means to make a one-piece airframe perform as a two-stage (or more) rocket. The design grew out of my original "rack-rocket" concept, also a staging method to make a one-piece airframe act as a multi-stage rocket. In a rack-rocket, the first of which was the KG-4 Achilles launched in February 1970, the rocket motors are held in-line in an open airframe, each motor/stage being ejected after it is spent, with the next stage firing, in-situ, further forward in the airframe. The rationale behind rack-rockets was to ensure multi-staging/massive-staging could actually work, without the weaknesses of multiple airframe couplings and excessive requisite fin area. Indeed, the Achilles was a six-stage rocket that flew successfully at a time when there were few, if any, successful rockets with that many stages. Several subsequent designs from the likes of Tom Blazanin, Korey Kline, and me flew well with 3, 4, or more stages.

While rack-rocket staging works reasonably well for low to mid-power rockets, there are design limitations. The open airframe, which originally was built up from dowel rods (hence the "rack" nomenclature) and later evolved to drilled or slotted tubes, results in airflow issues and drag. And the rack-structure must be made heat resistant, to prevent structural damage from the exhaust of the motors further forward in the rack. To avoid these problems, it seemed logical to explore a means by which an

Above: The Bellerophon – a three or four-stage aluminum dowel rod rack-rocket designed to fly on single-use 24 mm D/E/F motors.

Below: The Exeter II – a three stage rack-rocket designed to fly on single-use 29 mm F/G motors. In this case, the dowel rod "rack" is replaced by an aluminum tube, with 5/8" wide slots cut into the tube to open the motor stack area and defeat the "Krushnik Effect. "



upper stage or stages could be fed aft and locked to a firing position in a conventional enclosed airframe, ejecting the lower stage/stages as they are expended.

Of course, the idea is reasonably simple, but how it could be realized as a practical, flying rocket was not especially easy to discern. The mechanical difficulties were above my ability to resolve those many years ago, although some spring-driven, ejection gas triggered contraptions were sketched, and quickly discarded. I mentally shelved the idea for a long time, but by the mid 1990's, it was starting to re-emerge in my thinking. By that time, I had some fairly grandiose ideas on where this could lead, including a two-stage O/P/Q-motor rocket (don't laugh, Tom B.!), designed and dubbed Terra Nova. But before anything of that scale could be seriously contemplated, it would help to actually fly a proof-of-concept rocket first, using some type of actuation method that could be scaled up. Brainstorming sessions about motor-feed staging with Tripoli founder and friend, Francis Graham, resulted in him having separate subsequent discussions with Tripoli Pittsburgh member Richard Dietz. Richard assembled a possible motor-feed actuation device, largely reliant on spring tension and using single-use G-motors. It was presented to me for evaluation, and while it looked as though it could be integrated into an airframe, and possibly made to work, I felt it was not likely to be scalable to high-power motors, and thus was a design dead-end

It was clear that a more practical way had to be considered to force a "stack" of potentially weighty motor stages to move in the direction and distance required. An obvious method to move something within a flying airframe is one we all use to push out recovery devices – gas pressurization. Ejection gas is most commonly generated by black powder charges, but a cleaner and more measurable method was seen with Tom Rouse's CD3 CO_2 recovery system. This was determined to be a preferred direction early in the design concept phase. Also, while the old rack-rockets of years ago happily spit out single-use motors to tumble freely to the ground, clearly we couldn't just start ejecting J, K, L or larger motor cases out of an airframe. Each ejected stage's motor would need to be enclosed in a recovery tube – essentially a modified motor adapter with a re-

The most essential element of the first Drake design, as fabricated by Eric Haberman. Three steel rods form the motor/sabot rack. The actuating piston and Rouse CD3 unit are on the upper right.

covery device, and which I referred to as a "sabot." It seemed feasible that a proof of concept rocket could be 3" in diameter, using two stages of 54mm reloadable motors in the J-K impulse range, and employing the Rouse CD3 CO_2 system as the actuation method. Thus was born the KG-25 Drake, as a precursor to the larger and more ambitious Terra Nova.

The Drake Moves from Concept to Reality

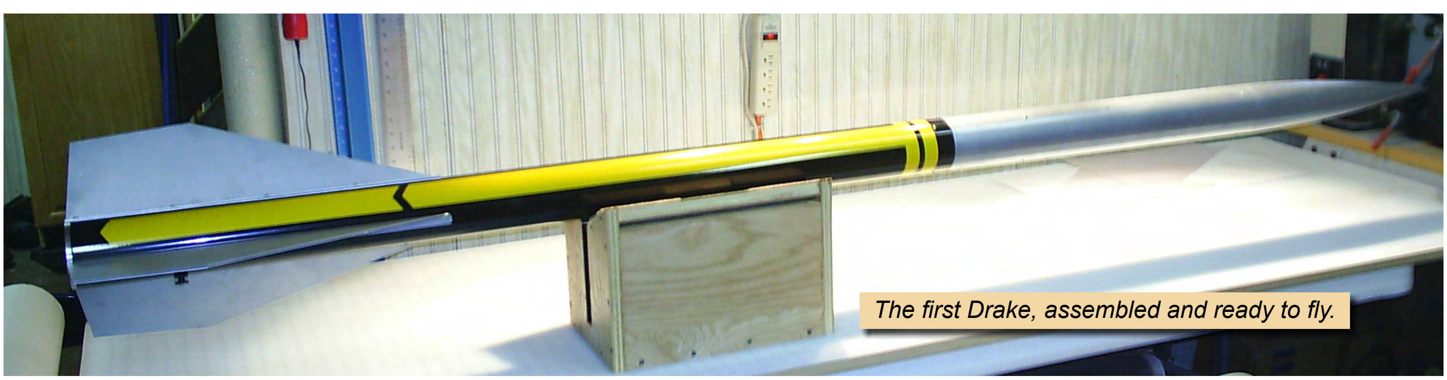
By 2003, fairly detailed drawings of Drake were taking shape, and in 2004, Eric Haberman, of Dynacom/AirX fame, agreed to be the principle engineer and component fabricator for a finalized design. As the project progressed, additional members of the Tripoli Pittsburgh prefecture formed a project team, with an initial test flight targeted for BALLS 15 at Black Rock, NV, in September 2006. Eric and I exchanged several iterations of detailed designs and conducted extended discussions to address perceived problems before agreeing to a firm direction, based upon a three-rod framework enclosed within a 3.3" Dynacom fiberglass airframe. Sliding on the framework would be two motor/sabots, one for each stage. Forward of stage two and attached to it would be a locking piston, which would be driven aft when a Rouse CD3 unit - triggered by a G-Wiz flight computer - pressurized the airframe space forward of the piston. When the correct position was reached, the stage 2 sabot would lock in place with a ball/detent mechanism designed by Eric; a simple switch connected to a battery and an igniter would be tripped and fire the stage 2 motor. The stage 1 sabot would be ejected by this movement of the sabot-stack, recovering on its own parachute.

By the late summer of 2006, the assembled airframe was available for ground testing, which turned out to be more challenging than expected. The inner framework had some inherent friction, exacerbated by a need to lengthen it to accommodate higher impulse motors than originally envisioned; an AeroTech K-1100 for stage 1 and a K-550 for stage 2 were the final motor selections. A great deal of trial and error ensued, not least of which was identifying the correct-size CO_2 canister to ensure reliable movement of the motor/sabot stack. But in the end, the Drake was ready for transport to Black Rock for its test flight at BALLS 15.

First Flight Test – BALLS 15

The events leading up to the Drake's maiden flight at BALLS could be viewed as a case study in how not to prepare for the flight of a complicated rocket which employs a novel flight profile. I had run many simulations, and knew generally what to expect…. or at least I thought I knew. My most nagging question was one that couldn't be simulated – would the rocket remain stable when the motor/sabot stack made its transitional movement from a stage 1 to a stage 2 firing configuration? Both configurations were stable, in and of themselves. But no one had really tried this actuation method before, so there was no reference data for how a moving rocket would react when a sudden internal mass-shift would alter the CG/CP relationship in quite this way, while the rocket was still ascending.

It would turn out that this wasn't the most serious worry – it was flight prep that would become the real issue. The context of BALLS 15 for the Drake team was this: I was TRA president at the time, and as such, many people wanted to speak with me while I was trying to focus on preparing the rocket. This was usual any time I attended an event and actually attempted to fly something. Also, we had a reporter on hand – Patty Brown from the New York Times. It was my responsibility to work with her, and to try to "manage" a story about TRA, BALLS, HP rocketry, the ATF litigation, etc., and it appeared at first that it may not have been Ms. Brown's intention to be especially flattering to us. This meant I was pulled away numerous times to assist



The first Drake, assembled and ready to fly.

with her fact-gathering effort. The Drake team, no doubt relying on me as the project manager to be present and available, tended to go off somewhere else when I was otherwise engaged, and it was difficult to have the people on hand who were needed when I could get focused again. All of this may seem to be an excuse for what occurred, but analyzing the facts afterward leads to a firm conclusion that errors were made because focus was lost.

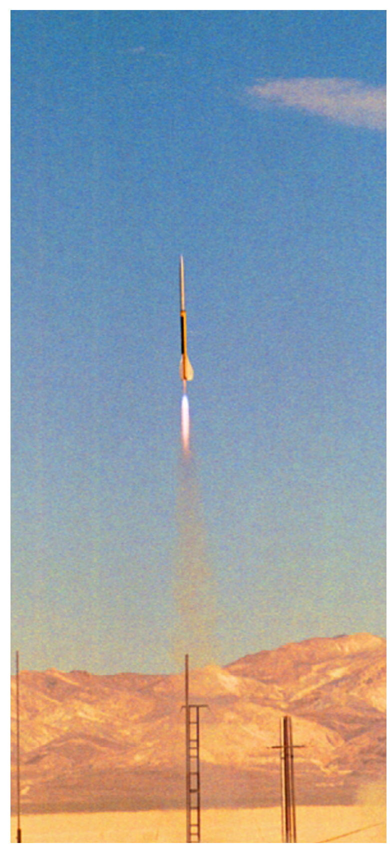
After many long hours of getting the Drake ready, it was finally taken to the pad on the morning of October 1, 2006. When the LCO pushed the launch button, it flew briskly upward on stage 1…. and just stage 1. After a modest boost, Drake arced over and pushed out its drogue parachute, followed by the main at 1000 ft. While we were contemplating why stage 2 never fired, an even more unexpected event happened – just as the main 'chute fully inflated, stage 2 ignited! The BALLS crowd was then amused by a comical "fire dance on a parachute." After motor burn-out, the Drake's smoking airframe drifted in for a landing.

The post-mortem wasn't pretty. It was clear that the sliding motor sabot sequence did not fully take place. The first stage sabot had fallen free at some point, but the second stage had not locked into firing position. However, in the recovery phase, the main parachute deployment had jostled the second stage sabot such that although it was not locked in place, the firing switch was triggered, resulting in the sabot shooting back forward into the airframe with the motor burning out the guts of the rocket - all while twirling furiously on the parachute. After cursing the G-Wiz board for not firing the Rouse CD3, I disassembled the CO_2 unit and found the trouble. The CD3 arming charge had fired, but I had failed to block the extra, unused e-match hole (although I had done so many times during ground tests), and the pressure needed for the puncturing piston to hole the CO_2 canister had been lost. No CO_2 pressure, no motor-feed staging. As a result of the stage 2 motor actually burning well inside the airframe, the main internal components of the design were destroyed. Too many distractions coupled with too little verification of prep steps meant that the project manager had killed the project.

It could have all ended there. It was a sore disappointment, especially since we had every reason to believe the Drake would have flown as designed, but for the simple mistake of not blocking a tiny hole. But there were more lessons learned. As designed, there was no easy way to "safe" stage 2 if it didn't fire. That parachute dance showed how dangerous such design naiveté was. If the Drake was to be revised and rebuilt, a fail-safe method for stage 2 had to be part of the design.

The original Drake team – Christine Rial, Dave Rose, Joe Pscolka, Ken Good, Ernie Marsh, and Tom Blazanin (Eric Haberman and Francis Graham not pictured). All trusting that the rocket is ready for flight.

But immediate renewed effort did not occur. Years passed, and the original project team, or many of them, went their own way onto other projects. Critically, the often-elusive Eric eventually "got out of rockets" for a period of time, and the original design would be difficult to replicate without his expertise and access to the machining equipment used to fabricate vital components. Although the team discussed a Drake II and how it could be built, other priorities got in everyone's way, and 2007 – 2009 passed with no real activity.



Drake takes off, headed for what we hoped would be an historic flight.

Reboot – Drake II

Maybe it was stubbornness, persistence, or just plain foolishness, but I couldn't let it go. We hadn't given the motor-feed staging concept a realistic flight test, and I was chiefly to blame. I had held some misgivings of the complexity of the original design, including the nicely engineered framework and locking mechanisms, and I felt a simpler approach could be made into a more reliable flight vehicle. In late 2009, a project team was re-formed around several revised design directions, which included:

- Elimination of the internal rack structure, but retention of the Rouse CD3 unit.
- Two 54 mm motor sabots, fitted with centering rings to slide along the inside diameter of the 75 mm ID airframe. A K-1100-stage1/K550-stage2 combination was retained (for this and all other Drake II flights).
- Both sabots notched to match an anti-rotational guide, screwed to the inside of the airframe
- Stage 2 sabot using a special spring-pin assembly to lock it into the firing position. Two pins are oriented at 180^{o} of each other, and extend into two corresponding locator holes in the airframe when the sabot is pushed to the lowermost position.

The question remained of how it would best to trigger the CD3 unit, but also provide stage 2 ignition with a "safe mode" to defeat ignition in case the stage 2 sabot did not lock into firing position. A simple staging board would not meet both requirements. After several tentative electronic possibilities were considered, involving off the shelf flight computers/boards, timers, relays, switches, etc., no combination of which seemed to be ideal, Tom Blazanin suggested contacting Tripoli Pittsburgh member Dave Cooper about burning a custom board to meet the exact requirements. "Coop" was eager to join the team and to provide the needed custom board. The "Cooper board" was quickly fabricated; its design features included:

- G-switch triggering
- Programmable timing to initiate an output to fire the Rouse CD3 unit
- Programmable timing to initiate an output to fire stage 2
- Connectivity to an interlock switch (on sabot #2) that would only close if/when the sabot was in firing position – no fire of the stage 2 output unless this switch is closed.
- Programmable timing to shut down all outputs after the specified time if continuity to the interlock switch is not sensed.

This board addressed all flight profile requirements, including the safe mode to ensure stage 2 ignition could not be triggered outside the desired ascent phase timing window. Ground testing proved that the board functioned perfectly.

Drake II is built – a new motor-feed process is tested

In early 2010, work was initiated on constructing the Drake II rocket in accordance with the new design. To achieve the goal of having the rocket ready for a flight test at BALLS 19 (Sept. 24-26, 2010), the project team was tasked with specific responsibilities and associated due dates, all tracked on a proper project plan. The Drake II team was comprised of:

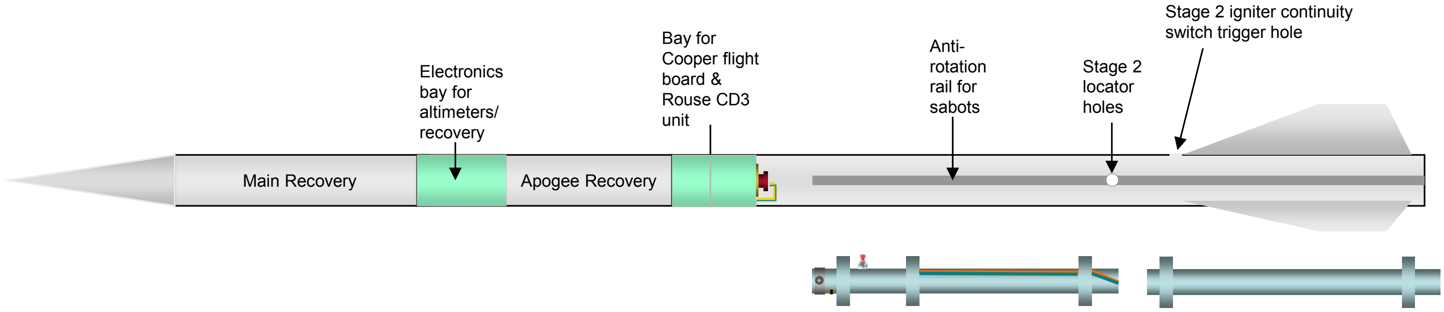
Ken Good – project manager; Tom Blazanin – fabrication/finishing; Dave Rose – fabrication/graphics; Dave Cooper – electronics; Francis Graham, Larry Benek, George Pike, Jim Callahan – testing/consultation.

By late July, Tom and Dave had provided a completed airframe, ready for ground testing. Time was tight, but the project was moving along, until ground test #1 revealed the first obstacle. This test focused on verifying the revised motor feed actuation configuration. The Rouse CD3 unit would be manually fired and the sabot #1 ejection/sabot #2 locking actions would be confirmed. It had been assumed that the spring-loaded locking pins would extend outward once the airframe locating holes were reached by sabot #2, locking it into place. But in our first test, not only was sabot #1 energetically ejected, sabot #2 went sailing right out of the airframe as well! Repeats of the test, including adjusting the locking pins' spring tension, yielded the same outcome. Clearly, the pins just couldn't spring out in time to arrest the aft-ward motion of sabot #2. Time for a re-think.

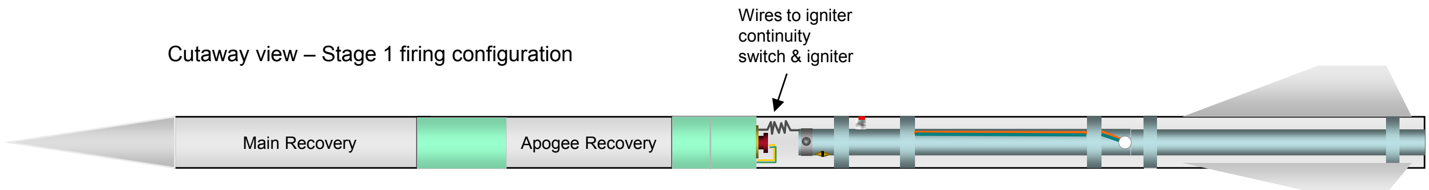
It was clear that we had to ensure a positive stop of sabot #2. We arrived at the solution of building up a reinforcement point behind the internal nut for the lower rail button, notching sabot #1's centering rings

DRAKE II - 2009-2010 DESIGN DRAWINGS

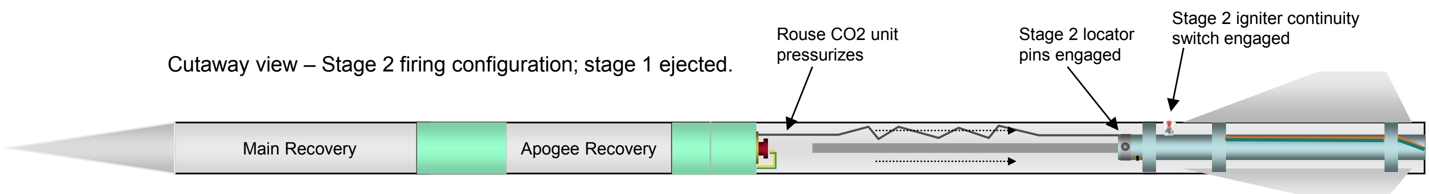
Components & orientation - cutaway view



Cutaway view – Stage 1 firing configuration

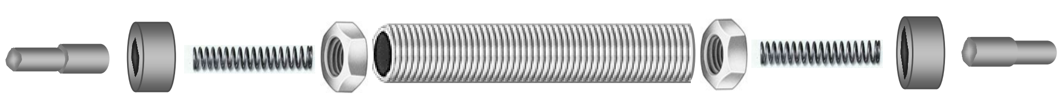


Cutaway view – Stage 2 firing configuration; stage 1 ejected.

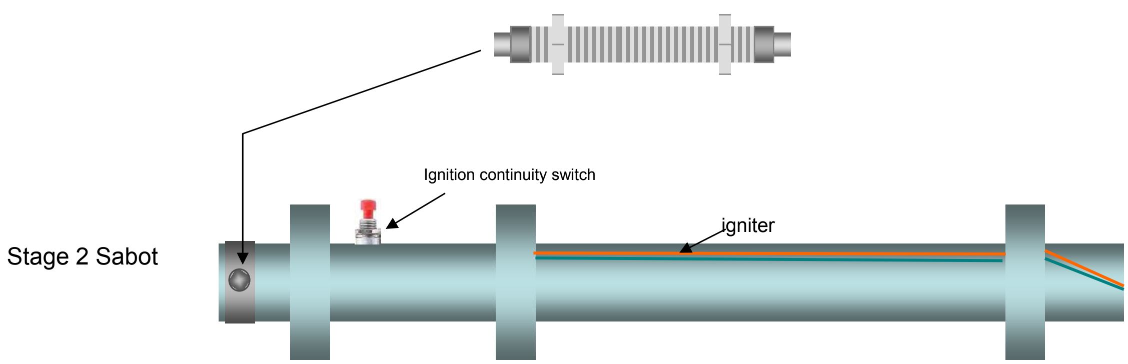


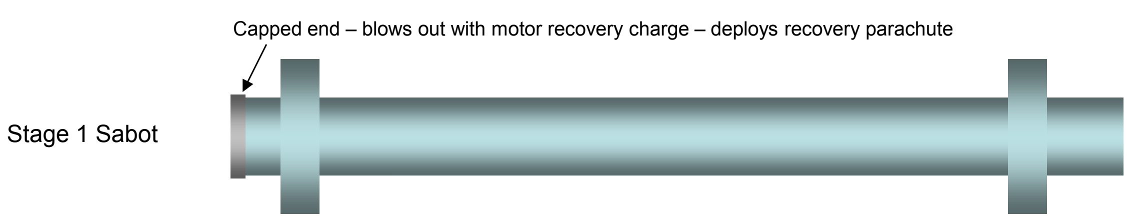
Staging sabots – detail view

Stage 2 Sabot locking assembly – exploded view



Stage 2 Sabot locking assembly – assembled view





Drake II, assembled and painted, prior to adding graphics, but tested and ready.

to clear it, but not sabot #2. Sabot #2 would have to be loaded from the forward end of the airframe, and when the stack was pressurized, sabot #2 could only go aft as far as the stop. Tom made the changes, and further ground tests (some necessitated by a nagging issue with the Rouse CD3) eventually confirmed that this change permitted sabot #2 to lock in place with the spring-loaded pins, and also that the pop-up interconnect switch to arm the stage 2 firing circuit functioned correctly. In the few remaining days, Drake II was readied for the trip to Black Rock.

BALLS 19 – Drake II's first flight test

I had certainly learned some lessons about prepping a complicated rocket while in the presence of many rocket friends, not least of which was to get as many prep steps out of the way in the cramped solitude of my room at Bruno's! This version of the Drake was actually easier to prepare, and the distractions of BALLS 15 just weren't on my plate this time around (I wasn't even TRA president by then). Also, a very detailed checklist was followed to ensure nothing was missed.

Accordingly, the Drake team had every expectation of a successful flight. The rocket was ready to fly on the fine, clear morning of September 25, 2010. We did not envision a repeat of the BALLS 15 fiasco, and we didn't get one. What we did get was another strong boost on stage 1's K-1100 motor, followed by a clear ejection and parachute deployment of that stage's sabot, followed by.… nothing from stage 2. The Drake II recovered perfectly, and as we trudged out to retrieve it, we were perplexed about what could have happened. When it was examined, it was clear the mechanical actuation had worked as designed, but we failed to light the stage 2 motor. The post flight assessment was summed up in a message I sent to the project team and interested parties on September 27:

The Drake II project team readies the rocket for its first test flight.

Drake II Project Team:

Drake II flew as planned at BALLS 19. The staging mechanism and scheme worked perfectly. However, stage 2 did not ignite, and I think it was because the igniter we selected, despite passing direct 9 volt ground tests, did not get enough current or duration to fire when driven from the flight *board. An enhanced e-match should have been used, but was not.*

What was learned:

1) The mechanism and scheme works very well.

2) Stage 1 ejection and recovery was perfect.

3) Stage 2 movement and locking was perfect.

4) No disturbance to flight trajectory, or any flight path anomalies at all, were observed by the motor feed process. A normal upward flight path was all that was observed.

My thanks to all who worked hard to make this flight happen. Clearly, it was a partial success, and a partial failure. We proved "motor feed" but not "staging."

Future plans for Drake II or Drake III???? Don't know. Much disappointed at the moment, and not convinced of any future plans for this or other of the KG series.

Ken

I was obviously very upset, and was initially ready to just walk away from this project and others, and follow my own advice of "better look for something else to do with your time." I needed some time to cool off and mentally heal. It is at times like these that one realizes how much emotional investment can be plowed into making dreams into realities, and just how deflating it can be to experience a reality that falls far short of the dream.

Drake II, 2011 – Trying it again

Through the winter and spring, I regained the desire not to let the project die, and the Drake II project team agreed that there was no reason not to give it another try. The BALLS 19 flight had proven most of the design, including the safe-mode for stage 2. Actually, the rocket had suffered some minor landing damage, and the reinforcement material of the sabot stop point was also found to have cracked. This latter issue appeared to be the result of the very energetic way that sabot #2 slammed home and locked in place (no doubt repeated ground tests and the actual flight had not helped). Tom made repairs to both areas, and added additional internal reinforcement for the stop point. Limited ground tests were conducted, if only to preserve the components, but everything looked promising for another flight at BALLS 20.

So on yet another October 1, a Drake flight vehicle made a test flight at a BALLS event. Hopes were high that we would nail it this time – there appeared to be no reason it should fail. Repairs had been made, a lower current stage 2 igniter had been selected, the rocket was thoroughly tested and carefully flight prepped. Surely, this iteration of the project should see success. But once again, we experienced almost a repeat of the flight of the previous year. The boost on stage 1 was fine, that stage's sabot ejected (but stripped its recovery parachute), and again stage 2 just didn't fire.

The Drake II takes off at BALLS 20.

The team frustration, and mine especially, was tangible and vocal – some of our expressions are not fit for print! When we recovered the rocket, a brand new failure mode was detected. In this case, the "impact zone" on the sabot #2 centering ring had cracked when the sabot hit the stop point, which had been strengthened with an aluminum block as part of the rebuild. This damage permitted the sabot to slide just a few millimeters too far aft, bending the locking pin tube. The pins stayed locked and likely would have held had the stage ignited, but the excessive travel meant the stage 2 interlock switch went past its pop-up hole, jamming the switch in an open position. Thus, the Cooper board never sent the output to the stage 2 igniter, since it sensed that the sabot was not correctly locked.

After my return home, I once again questioned whether his was a fruitful endeavor. An excerpt of a message to Francis Graham is telling: "I am just not sure whether the time spent on this project, or on anything in rocketry, has a point, or is important enough. Maybe I'm spinning my wheels and wasting time I'll never get back. Some arcane rocket staging project that has only 'quirky value' in the eyes of many could just be a human version of the proverbial dog chasing hi

Drake II, 2012 – "Grim determination"

I suppose it may be most accurate to say I got extremely annoyed. This damned rocket just wasn't going to beat me, and I became willing to wrestle with the beast until it behaved as it was supposed to. Fortunately, every failure offered something new to be learned, and a path toward an improved design was revealed. In particular, it seemed to me that we were beating the innards of the rocket to death with the CO_2 pressure actuation. I became convinced that the generated pressure was likely too high, and the shear pin we were using to retain the sabot stack before sabot 1 ejection may have been too strong, thus exacerbating the violence of the movement when the pin finally let go. These would be the improvement points on which a renewed Drake project would be based, with the intention of another flight test at BALLS 21.

The first efforts for the next try were conducted by Tom, who repaired/rebuilt the sabots. The project team was then able to focus on a series of ground tests from late July through early September to verify the results of the changes we felt were needed. All aspects of the flight profile were tested as much as was possible. The salient changes from the last flight attempt, confirmed through testing, were:

- Research into the actual atmospheres of pressure generated by 12 gram versus 16 gram CO_2 cartridges revealed that the 16g ones, used consistently from the time of the first version of the Drake, were excessive for the calculated volume which would be pressurized. A switch to 12g cartridges verified that they were more than adequate.
- A lighter duty plastic shear pin was selected to retain the sabot stack prior to the actuation sequence, this pin failing at a lower internal pressure than the previous type used.
- Inconsistent lighting of the stage 2 igniter in testing revealed that only a low-current type would be the correct selection for the output current level and duration of the Cooper board.

Final preflight work was completed several days before the Tripoli Pittsburgh trailer left for Black Rock. We all believed that the changes and exhaustive testing regimen had positioned us to see success with the Drake II this time around.

BALLS 21 – The Drake II fulfills its promise

It was both startling and somewhat intimidating to realize that we were now going to flight test the motor-feed staging rocket concept for the fourth time, including the first version of the Drake. I think I was acquiring a "whipped dog syndrome" - sort of just waiting for my next beating. Of course, having a healthy degree of pessimism going into the flight test guaranteed that at worst, I wouldn't be excessively disappointed, and at best, I would be overjoyed. My logical side told me that we had been thorough, and if the rocket was properly prepared, it should work. But it's hard to wholly trust logic when we had found so many fluky ways for the project to stumble.

The Drake II arrived as planned with the Tripoli Pittsburgh trailer in advance of my arrival at Bruno's on Thursday September 20, 2012. Drake team members who had made the trip were Larry Benek, Tom Blazanin, Dave Cooper, George Pike, Dave Rose, and me. Preliminary flight preparation work was conducted as soon as we arrived at the BALLS 21 launch site on Friday, September 21. We determined that although Friday's flying weather was excellent, we should not rush the preparation, and would regard Saturday as the likely launch day. In any case, several members of the Drake team were also engaged with the NASSA Q-motor Phoenix project, which likewise was intended to fly on Saturday.

The author with Drake II, ready for flight at BALLS 21.

As part of initial flight prep, it was deemed wise to conduct ground tests of the Cooper board to verify functionality, in case any shipping issues had occurred. Accordingly, the board was prepped to fire the stage 2 igniter through the wiring harness, and a test bulb was fitted to the circuit #1 output (Rouse CD3 unit). This test failed - the Rouse output circuit bulb lit for about 1 second as expected, but there was then a no-fire of the stage 2 igniter circuit, followed by a steady flashing of the circuit #1 bulb until the Cooper board timed out.

This was a most troubling situation, since the symptoms actually mirrored a similar test fault observed by Tom Blazanin and me in August, prior to the board having been submitted back to Dave Cooper for rectification. Coop was consulted and was unsure of the cause of the error, since the behavior of circuit #1 was not in keeping with the logic of the board. It was not possible for him to troubleshoot this fault without reference to the board's code, which he did not have on site.

After much consultation, it was theorized that the characteristics of the 12V automotive bulb may have been spoofing the board logic, perhaps due to the bulb sustaining continuity. In any case, Coop and I agreed that running a full test with actual igniters/e-matches, as would be flown, was in order. When this test was conducted, it performed as designed. The test was repeated to verify results, and again, the board functioned as designed. Accordingly, the decision was made (not without some worry) that the test flight should proceed.

The remainder of the day was spent in fully prepping the rocket, the only remaining operations needed before flight would be the insertion of both sabots, bolting in the Rouse/Cooper avionics bay, and joining both airframe sections.

Tripoli Pittsburgh/NASSA attendees arrived at the launch site early on Saturday, with the intention of focusing on final prep work of both the Drake II, and the NASSA Phoenix. Both projects were flight ready by 9 AM. It was agreed by all that as soon as the FAA window and flight conditions permitted, the Phoenix should be given priority, since Drake II could fly with less optimal conditions. However, cloud cover was an issue for the NASSA rocket all morning, and although partial openings materialized, BALLS flight operations could only obtain a 16K FAA window by about 10 AM. Re-conferring on the situation, the decision was made to proceed at once with the Drake II, since it was not clear when any higher flight windows would be available for the Phoenix – and it appeared such a wait could be lengthy.

The Drake II was then cleared through the RSO and LCO, and walked to one of the 1000' pads by Dave Rose, George Pike, TRA Board Secretary David Wilkins (acting as assistant and photographer), and me. There was a bit of a muddle due to the pad requiring some quick crescent-wrench work to tighten a loose assembly bolt, but once BALLS RSO Bill Robinson had provided tools, the pad was repaired, and the Drake II was slid onto the rail and erected to a vertical position.

Altimeter switches were armed, followed by the Cooper board. I inserted a special quick-light igniter for the first stage, kindly provided by Bill Good. With a call to the LCO, the Drake II was announced as ready for flight – at approximately 10:30 AM. Moving to a safe distance, a five second countdown was provided by the LCO, with the actual remote button being pushed by Dave. I attempted to capture a video, but lost the track not long into the flight.

Take off on the K-1100 motor was straight and rapid. After motor burn-out, the first stage sabot was seen to eject cleanly. A slight inter-stage delay of about 2 seconds then occurred, seeming much longer to all of us since we were all anxious about second stage ignition. But after the brief pause, the second stage K-550 was seen to ignite, to the cheers of all. The free falling stage 1 sabot pushed out its recovery parachute just as the Drake II was powering skyward.

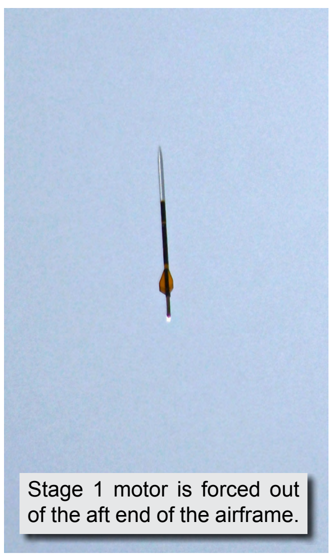
Although we supposedly had 16,000 feet of clear air below the broken clouds, it appeared

The Drake II takes off at BALLS 21.

to those of us in the launch crew area that it flew into a cloud bank, and we all lost sight of it. However, we did eventually hear the apogee/drogue parachute ejection charge, so we assumed that we at least had one parachute out.

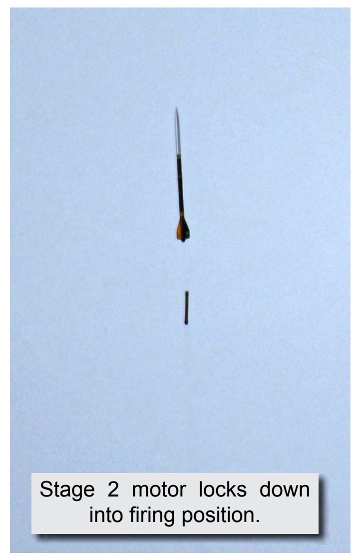
As is often the case at such times, we stared at the clouds for what seemed far too long. I focused on the direction that the prevailing winds were blowing, and after some time, I finally spotted the Drake, apparently right after the main parachute deployed (at a programmed 1,100 feet). It drifted in for a landing approximately 2000 feet away from launch point.

Stage 1 motor burn-out activates Rouse pressurization.



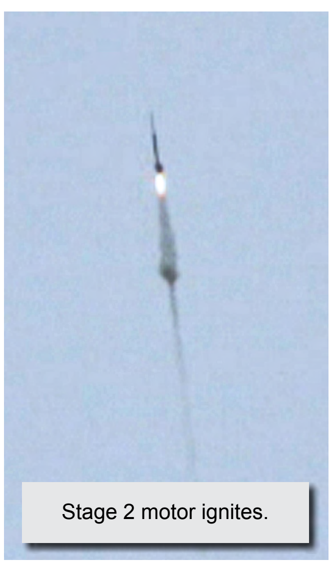
Stage 1 motor is forced out of the aft end of the airframe.

Stage 1 motor clears the end of the airframe.

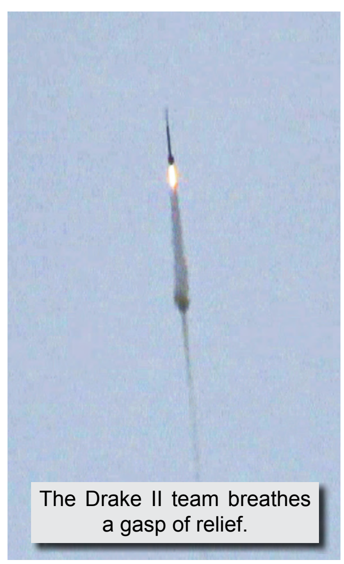


Stage 2 motor locks down into firing position.

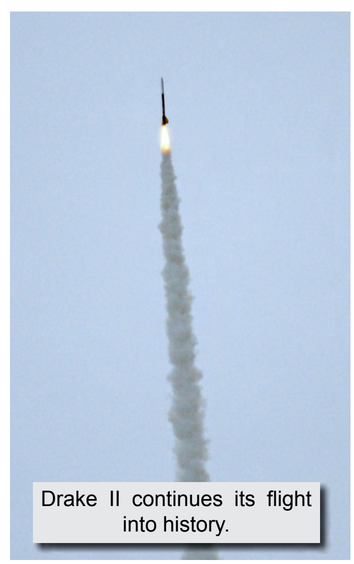
Onboard computer confirms lock and firing position.



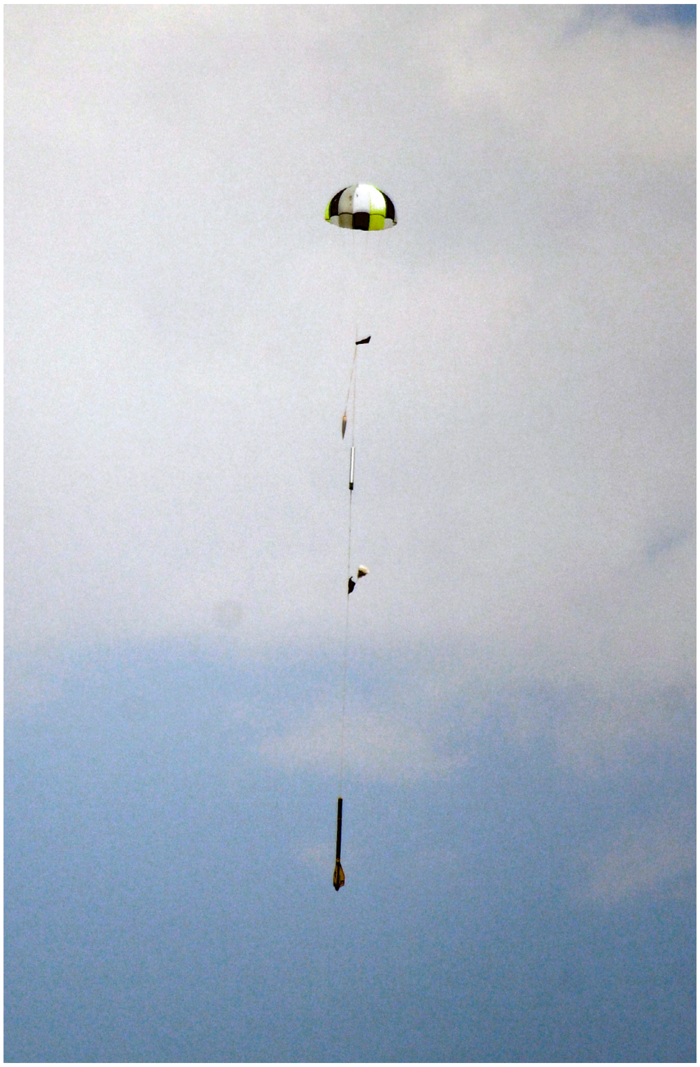
Stage 2 motor ignites.



The Drake II team breathes a gasp of relief.



Drake II continues its flight into history.



The Drake II floats in for a perfect recovery.

David Wilkins retrieved the stage 1 sabot, and I walked on to gather up the Drake II. I received a welcomed lift from Rockets magazine's Bob Utley and photographer Ray LaPanse. We retrieved the rocket, which suffered only the usual minor landing scrapes from the Black Rock playa, but was intact and in excellent condition. It could clearly be flown again immediately.

Bob Utley recorded a brief video interview before driving me back to the Pittsburgh team canopy area. I was greeted with cheers and congrats from all – it was really gratifying that so many in attendance at BALLS were so supportive, with several people making special trips to our canopy to extend their personal congratulations.

Post flight examination of the rocket and flight data, and discussion among the team revealed the following:

- Larry Benek reported that the complete flight was better seen from the spectator area. He noted that the recovery had functioned perfectly, with the drogue at apogee and the main at a lower altitude (those of us out in the launch area thought initially, and incorrectly, that the main parachute had perhaps deployed at apogee, explaining what seemed like a long wait for the rocket to re-appear).
- The stage 1 sabot had recovered perfectly with no damage.
- The stage 2 sabot had locked into place correctly, was undamaged, and had not damaged the sabot stop point.
- Flight data was obtained from two Missile Works Mini RRC-2 altimeters that were aboard. One recorded an apogee of 10,272 ft, and the other recorded an apogee of 10,301 ft. Clearly, the true apogee was in this range. Due to wind and launch angle conditions, the Drake had flown at about a 2-4 degree inclination from vertical, thus slightly lowering the potential apogee. However, pre-flight simulations had predicted an apogee of only 9,900 feet at best. Thus, actual apogee was 4% higher than predicted, despite some angular trajectory.
- The maximum velocity recorded by the altimeters was 1040 fps, or 709 MPH. This too was better than simulated predictions, the fastest of which was only 645 MPH. Actual was therefore 10% faster than predicted.

The entire Drake team was extremely pleased and no doubt greatly relieved – I know I was! I gained a real appreciation for everyone's effort, support, and inspiration. I truly believe we pooled our best ideas and learned from our previous mistakes - it is never easy when forging new ground with a complex flight system. Despite the worries, Coop's board performed flawlessly. The rocket clearly wholly vindicated the expectations of the design concept, with a flight test that exceeded our predicted performance parameters.

The Drake II represents a new milestone in high-power rocketry - the very first successful motor-feed staging rocket ever. Also, this is the first rocket that falls (perhaps loosely) into the rack-rocket classification, in which all stages were of a high-power motor classification. Earlier rack-rocket efforts, culminating in the Exeter II of 2001, were high-power only as a function of total installed impulse, not by individual stage.

Future Directions

Where do we go from here? As noted at the beginning, the Drake series was always intended to be a precursor to a more extreme altitude rocket, the Terra Nova. But before we are ready for a leap to truly large motors, it will be best to transition to a larger Drake – the Drake III, tentatively envisioned to be a 4” diameter rocket using two 75 mm NASSA M-motors. Also, several options for an upgraded motor feed system are under consideration, including the possible use of an electro-mechanical method rather than gas pressurization (which may be limited in scalability). These options will be evaluated in the months ahead.

Concluding this narrative, it is no doubt fair to ask why motor-feed staging should be pursued further by me or anyone else, apart from my personal advocacy of my own invention. It’s also fair to ask why one should consider staging in general for high altitude attempts versus just using one huge-motor, single-stage, minimum diameter rocket. Suffice it to say that single-stage efforts to very high altitudes (100K or above) have been successful in the context of TRA Research rocketry, but clearly, such successes, with full recovery, have not been numerous.

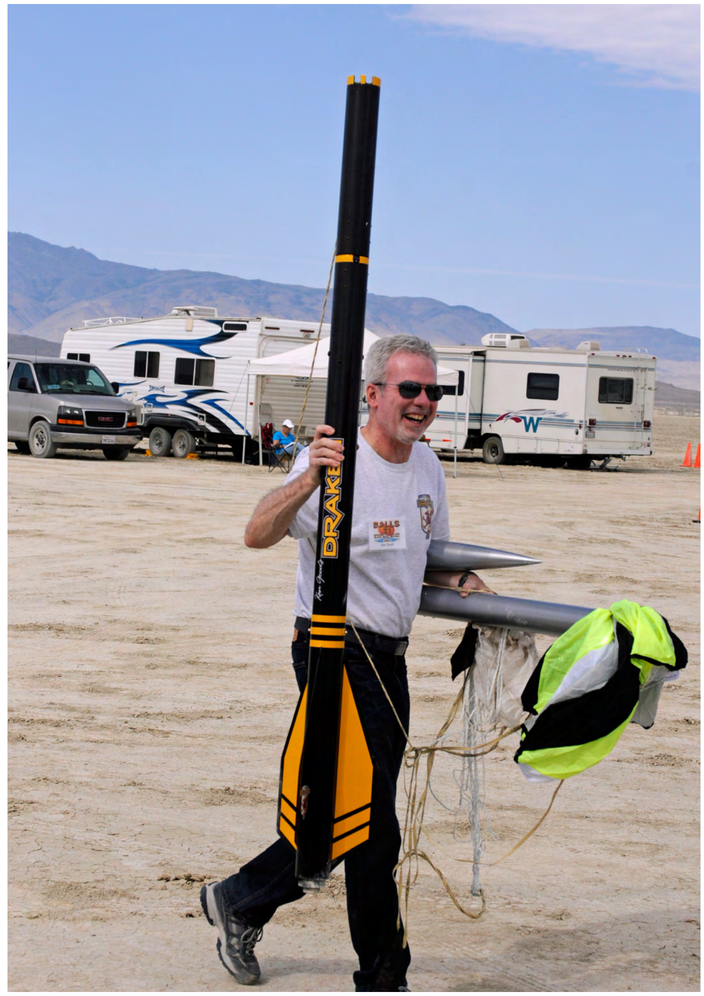
One main advantage of making such attempts with multiple stages is the ability to mix two (or more) separate motor thrust curves into one flight profile. Rather than have a monster-motor pushing a rocket to Mach 3+ in the densest part of the atmosphere, with all the flight stresses this imposes, a multi-stager can be configured to keep velocity sane at lower altitudes, while sustaining needed thrust to reach higher ones.

But conventional multi-stage rockets have their own issues as well, some of which I mentioned earlier in this article. Motor-feed staging provides a possible path of offering the advantages of multi-staging, while avoiding several of the disadvantages. A more thorough discussion along these lines must await a subsequent technical article.

My thanks to the Drake II project team, and all the fine members of TRA who have been so supportive.

Ken Good, TRA #00132

Thanks to David Wilkins, Mark Canepa, Ray LaPanse, and Rockets Magazine for the photos they submitted.



Postscript Notes

This article was originally submitted to the now defunct *Rockets* magazine in an earlier form, and was published in April 2013. Several edits have been made, and some photos have been substituted and/or made clearer through enhancement efforts by the author.

Subsequent to the time of the Drake II’s successful BALLS 21 flight, significant research and testing has been undertaken for the development of the Drake III project, which will be based on two 75mm NASSA research motors, and a largely aluminum 3.5” airframe. The original Rouse CO_2 system will be replaced by a Prideaux prototype system that provides more control of gas release, and eliminates pyro-activation. The electro-mechanical option mentioned in this article was tested and found to be too slow. Other details, such as second stage stop point fabrication and fin attachments, will be upgraded as a result of Drake II experience. And electronics that will be used for staging, with anti-tilt logic, have much improved since 2009-13.

The Drake II project was an excellent learning experience, and as intended, laid the groundwork for higher altitude motor-feed staging rockets.