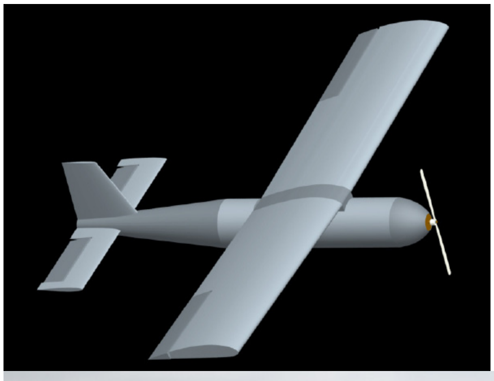

Vanderbilt Aerospace Club

Design, Build, Fly

March 09

Vanderbilt Aerospace Club USLI 2008-09 Final Report

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I. Introduction

The goal of the 2009 Vanderbilt University Student Launch Initiative was to design, build, test, and successfully fly a reconnaissance UAV following deployment by a rocket. The reasoning behind the rocket launch is that the UAV can be quickly flown to an area of interest and thereby conduct reconnaissance for a longer duration (endurance) from any altitude. The project was motivated in part by the DARPA *Rapid Eye* project, which seeks to deploy a reconnaissance UAV from an InterContinental Ballistic Missile (ICBM) for rapid-deployment reconnaissance in the visual and infrared spectra; a proposed development that could benefit the US Military.

Ia. Payload Description

The payload for the mission is a Reconnaissance UAV, completely designed and built in house using *Profili*, *Fluent, Winfoil,* & *ProMechanica* software, along with several airplane design guides. The UAV was built from fiberglass, foam and balsa wood. Design innovations included a rotary mechanism that locks the wing in perfect horizontal configuration following deployment, an elegant folding V-tail, and a protective sabot packaging for carrying the folded UAV inside the rocket. The UAV has an onboard flight computer with a GPS system for terrain mapping in conjunction with two high-resolution cameras. Further, it has a folding propeller working in conjunction with a brushless DC motor, and is 8.5 lb in overall weight.

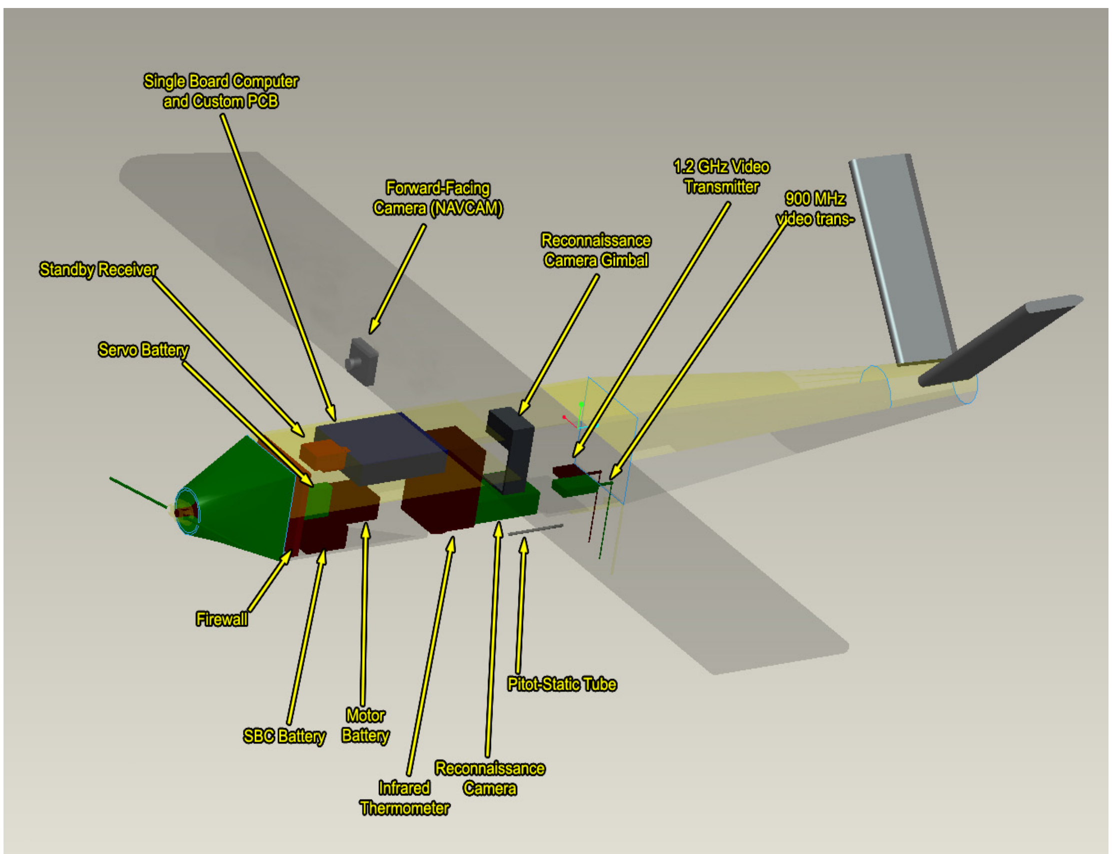


Fig. 1a1: Schematic layout of the Payload (Reconnaissance UAV)

Fig. 1a2: The actual Reconnaissance UAV that was hand-built from CAD drawings

Ib. Launch Vehicle & Project Summary

A 16'-tall, 10"-diameter rocket carries the fully functional UAV to altitude. At altitude, the UAV, packaged inside the protective sabot, is deployed from the rocket. Once deployed, the UAV is controlled by an operator/ pilot. The pilot flies and navigates the aircraft by monitoring a graphic user interface which provides data from an array of sensors onboard the UAV. After conducting the reconnaissance mission, the UAV is navigated back to the ground station, where it is landed visually.

Rocket is based on the 10" Thumper Kit from Polecat Aerospace. In-house carbon-fiber fins replaced the plywood fins, supplied with the kit, to save weight and to raise the center-of-gravity of the rocket. Additionally, a 8'-tall payload section was built to house the UAV. A specialized triple deployment scheme was employed to facilitate the safe deployment of UAV and parachutes.

The UAV is packaged inside the payload tube using a foam sabot that protects it during launch and deployment. Black powder charges eject the sabot, which will then fall away to release the UAV. Folding propeller and control surfaces allow the UAV to be packaged inside the sabot.

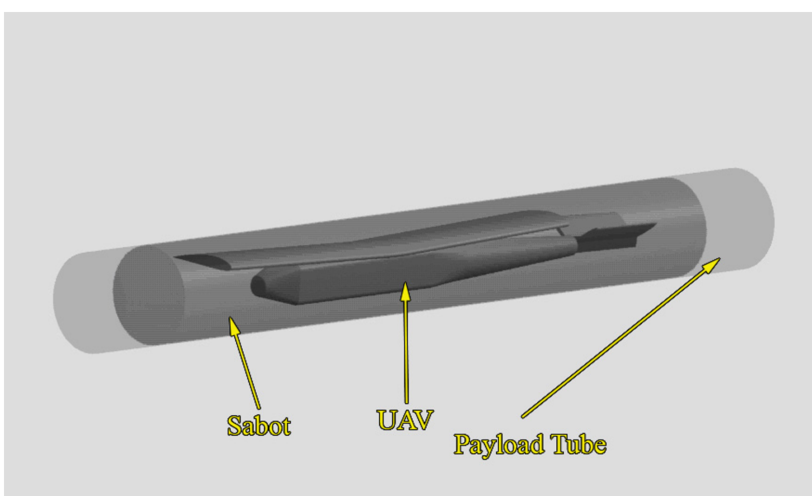
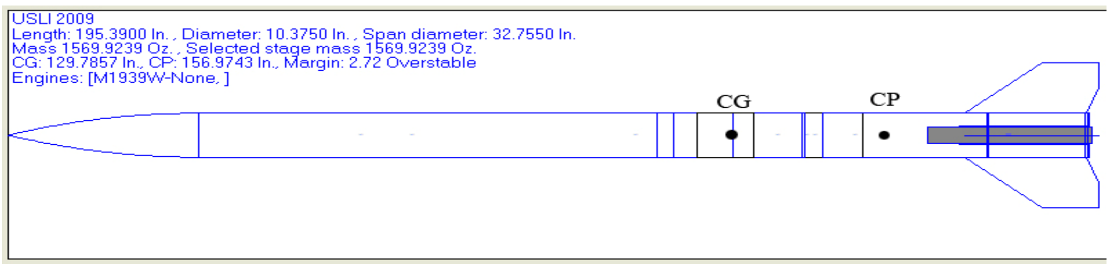


Fig. 1b: UAV packaged inside the sabot

Ic. Launch Vehicle Specifications

- Rocket 16’ tall and 10” nominal diameter
- CP: 157.0” from nose
- CG: 129.8” from nose
- Stability Margin: 2.72 calibers
- Avg. Thrust to Weight Ratio: 4.33
- Motor: *Aerotech* **M1939W**; Total Impulse 10340 N-sec
- Total Rocket Weight: 63 lb (28.58 Kg), without motor
- **Mass as launched with motor: 82.5lb (37.45 Kg)**
- **Altitude reached: 2900 ft**



1c1. Component Weights

Nose cone	**42.6 oz**
Upper body tube	**174.6**
Upper body tube altimeter house	**39.5**
Upper main parachute	**48**
UAV + sabot + tether	**165.3**
Upper body tube construction comp	**113.6**
Middle body tube	**38.4**
Upper & lower coupler	**40.9**
Mid body tube bulkhead	**23.6**
Mid body tube altimeter board	**11.2**
Upper drogue parachute + casing + shock cord	**18.3**
Mid body tube construction comp	**25.2**
Lower body tube	**97.3**
Lower drogue parachute + casing + shock cord	**18.3**
Motor mount + retention	**18.0**
Upper & lower centering ring	**18.2**
Fins	**76.0**
Lower body tube construction compensation	**39.5**
Total	**63lb**

1c2. **Parachute Deployment Sequence**

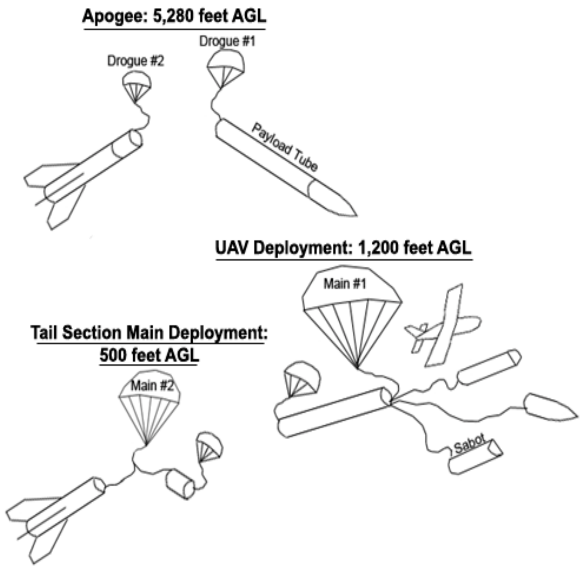


Fig. 1c2: Schematic of the parachute deployment sequence

1c3. **Motor Thrust Profile**

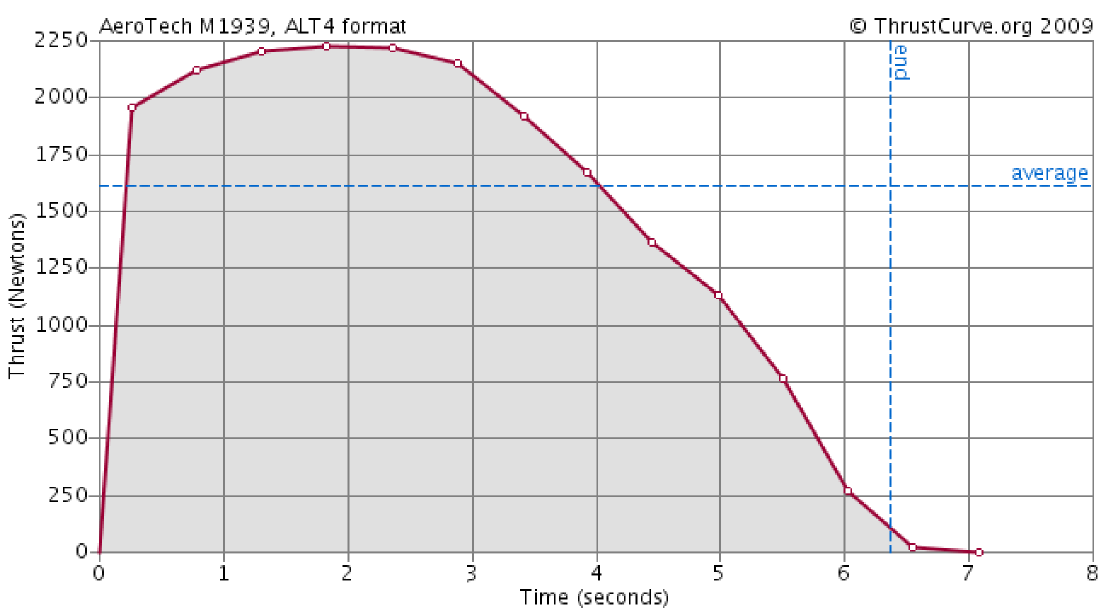


Fig. 1c3. Measured Motor Thrust curve provided by the manufacturer

II. Launch Day Flight Description

The Vanderbilt Aerospace Club went into the launch day with a highly successful rocket-based deployment and flight of the UAV in March 2009. For the USLI launch, the club had developed a new UAV which carried most of the reconnaissance systems as planned in the original design. On launch day, due to the high sophistication of the payload, it took the team almost three hours to prepare the payload for flight; all the UAV subsystems had to go through a comprehensive check before certifying them to be flight ready. The rocket was loaded onto the launch pad, and at take off looked reasonable. Due to the lower initial design thrust of the M1939W motor, and the corresponding lower velocity of the rocket while leaving the pad, the rocket launched at an angle, catching the side wind slightly, but quickly corrected itself onto a straight path. Everything looked normal at this stage.

However, six seconds into flight, at about 2500 ft, the rocket disintegrated with the tail section separating from the payload section. After some careful and thorough investigation of the retrieved parts, it has become clear that the midsection connecting the payload and the tail had torn apart (figure 2 a,b). In appears that the rocket was not able to withstand the windshear /rotational forces imparted on the tail section, and came apart at its weakest junction. We attribute this to the structural weakness in the rocket body. Critical examination has confirmed that the rocket body at the mid section was weak prior to launching, as it had suffered some damage and had softened due to landing in the wet grass, during our test launch in March. The team assessed that the rocket was still structurally stable enough for the USLI launch, but this proved to be catastrophic. In hindsight, the midsection should have been fiberglassed, and the suspect area strengthened. Also, another issue that has come up post launch is: <u>regardless, was it wise to relaunch a 10" cardboard rocket, a second time around?</u>

Figure 2a,b showing the rupture at the midsection that destroyed the rocket at 2500 ft altitude.

The sequence of events to this catastrophic failure are as follows: (i) midsection ruptured, (ii) tail section fell off, (iii) payload section flipped over and took on a horizontal configuration, (iv) altimeter detected apogee and charges fired, (v) with the parachutes torn up during rocket rupture, blast from the charges dislodged the nose cone and partially deployed the sabot; (vi) partially deployed sabot and payload section took on a stable horizontal configuration while falling, (vii) payload section charges fired at set altitude (1100 ft), but being an open container failed to dislodge the UAV, (viii) UAV suffered damage at impact.

Figure 2c shows a sequence of pictures from the launch to rocket disintegration, clearly demonstrating that the failure events occurred just around the motor burnout time. It is possible that, as long as the motor was generating thrust, with the bottom pushing up, the rocket somewhat held up to windshear, but the moment the thrust stopped at motor burnout (ie 6 seconds), the upward force holding the rocket parts ceased, making the rocket vulnerable to separation due to the weakened midsection.

If the sabot had not partially dislodged at 2900 ft, and the payload section remained intact, the UAV would have deployed at the set altitude of 1100ft and the subsequent reconnaissance flight of the UAV would have been a satisfying outcome for the project, but it was not to be.

Figure 2c shows the sequence of events from launch to rocket disintegration, and landing of the payload tube (*pictures courtesy of Florida Tech & Tuksegee*)

III. <u>Data Analysis and results of the Launch Vehicle</u>

The flight data from the USLI-09 flight has been directly compared with that from the USLI-08 flight, as we were flying an identical rocket with an identical motor and almost the same launch weight. The innovation for this year's project was that we were flying a highly sophisticated reconnaissance UAV payload, as opposed to a glider in the earlier flight. In fact in the USLI-08, we carried a 6 lb. ballast in the nose cone to make the rocket flight worthy. If the rocket had not disintegrated, we were quite sure that our rocket would repeat the one-mile record we had set in 2008.

Figure 3a shows the altimeter data from the midsection of the 2009 flight, and figure 3b shows the trajectory comparison between the 2009 and 2008 flights of almost identically-weighing rockets, and thrust by the same motor. Till about 3.6" and 800ft, the trajectories are almost identical implying that the 2009 rocket in all likelihood would have reached close to the design altitude of 5280 ft. However, at around this time (ie 3.6"), the 2009 rocket appears to be charting a different trajectory. If the data were to be interpreted literally, the '09 rocket is racing away to reach a speed of 720ft/s, as opposed to the '08 rocket which reached speeds of 520'/sec at motor burnout.

At a speed of 720 ft/s the '09 rocket would reach an altitude of 6280 ft; this is estimated by simulating a coasting flight starting at 2564ft altitude, six seconds into the flight at motor burnout. The analysis uses a representative air density (1.1 Kg/m^3), coefficient of drag (C_D=0.7) and the exact mass of the rocket. The differential equation governing the rocket flight can be exactly solved.

$$\frac{dV}{dt} = -g - \frac{C_D.1/2\rho V^2 A}{m}$$

Where m= 32.15 kg, and V_0=720ft/s; apogee is reached 19.43" from lift off at 6280ft. This prediction is shown in figure 3c.

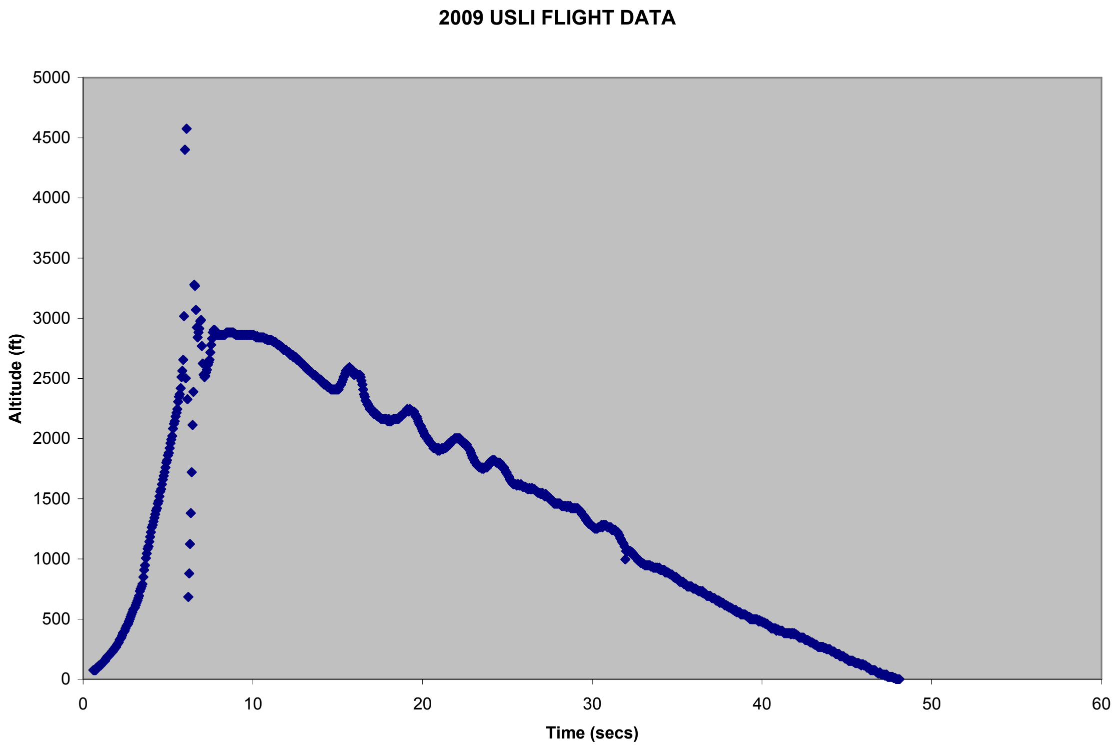


Fig. 3a: Altimeter data from the midsection region of the rocket

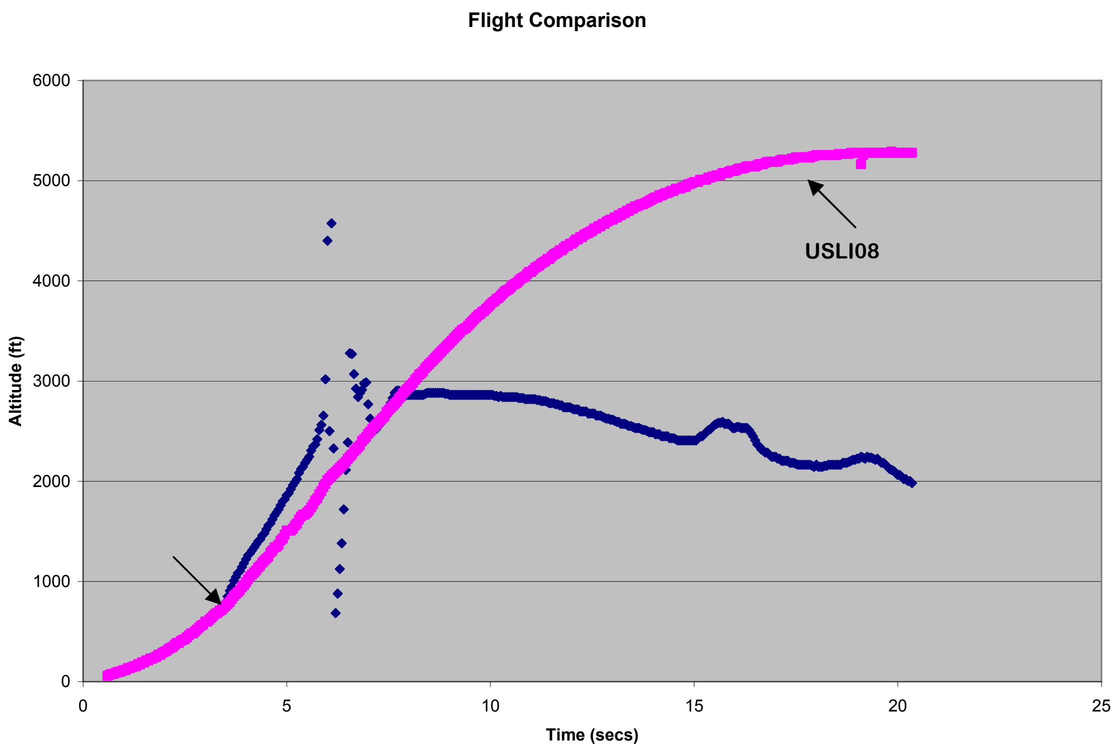


Fig. 3b. Comparison of the 2009 flight with the 2008 flight trajectory

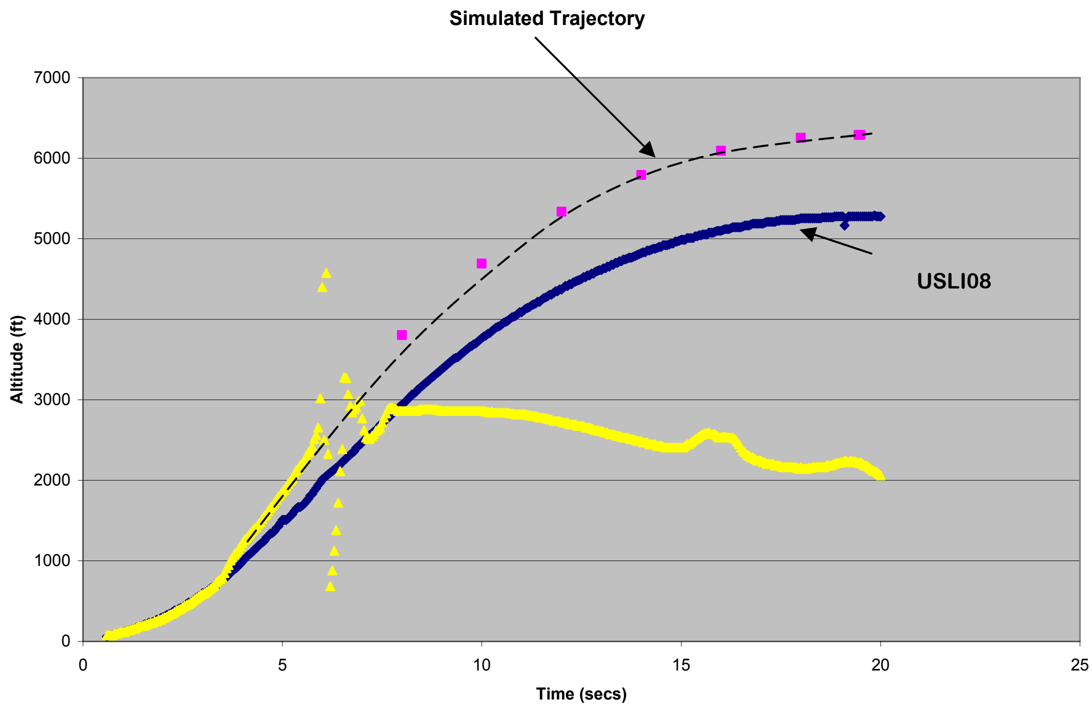


Figure 3c shows the apogee comparison with USLI flight in 2008, and that theoretically simulated for the 2009 flight, using the altimeter raw data.

However, the main issue that comes up in this analysis is: why is the 2009 rocket flight reaching a speed of 720ft/s as opposed to 520ft/s reached during the 2008 flight, for almost the same weight rocket, and the same motor M 1939W? Why is it that the two curves overlap till about 3.6" into the flight and then diverge into two different speeds? Is the 2009 motor off specification and generating a substantially higher thrust? If that is the case, then the 'g' level on the 2009 rocket would be 12g compared to the maximum '6g' for the 2008 flight. Did the rocket fall apart due to higher 'g' levels?

We posed the following question to the motor manufacturer, "Before we get too far ahead in this analysis, could you please provide us the test specs on the 1939W motor; in other words what we are looking for is a thrust measurement, and its variability if say one test fired about ten of these motors. Once we have the data, it will make it easier for us to look for alternate explanations to our rocket failure".

We got the following reply:

ROCKET MOTOR COMPONENTS INC.
AeroTech & ISP Divisions

AEROTECH® CONSUMER AEROSPACE

Dear Vanderbilt Aerospace Club 5/5/09

The M1939W reload has been manufactured continually since the early 1990's and has a very low failure rate, most fail due to operator error.

To answer your question regarding the M1939W's variability in performance, if you fired 10 motors they would not vary more than 5% +/- of each other.

I have attached a copy of the Tripoli motor certification re: the M1939 W reload, the 2003 expiration date was extended for this motor to present.

Our White Lightning propellant has been tested and well categorized as to its performance, to perform as indicated by your 2009 test, the ISP of the motor would have to exceed (300); White Lightning is closer to the 200 ISP mark.

I would look at your instrumentation system thoroughly to see if any abnormality occurred.

If you need further information regarding either our motors or related airframe materials/construction, do not hesitate to contact me.

Best Regards,

Karl Baumann
Director of Operations
RCS RMC, Inc
Cedar City, Utah

Analysis Ctd.

Clearly, the motor manufacturer is standing by his product. We need to find an explanation for the discrepancy in the flight trajectories; could it be that the two rockets , the '08 & 09' were indeed flying the same trajectories, but the '09 was slowly falling apart? We feel so. We feel that a breach started appearing in the mid section from about 3.6" onwards, exposing the chamber slowly. The pressure altimeters, attached to the back of the payload compartment, and covered by the mid section, were most likely in a Venturi channel, where the measured static pressure was lower than the ambient; the implication of this is that the altimeter is reading an artificially higher altitude than the '09 rocket was traversing!

Eventually, at around 6", close to motor burnout' the complete separation of the tail region and the payload region has occurred. Immediately, due to stability issues, the payload region has flipped into a horizontal configuration, the altimeters have detected apogee and fired the charges; further disintegrating the rocket, and prematurely deploying the sabot half way. The rocket reached an altitude of 2900 ft, and this final altitude measurement should be right.

If the rocket had remained in tact, the deployment of the drogue at apogee would have prevented any premature deployment of the sabot; the sabot, and hence the UAV, would have been deployed at 1100ft, and the flight would have been a success. A similar scenario was completely tested in the March launch, and the team was hoping to repeat it and conduct reconnaissance as planned. However, the failure of the rocket damaged the UAV too and thereby no reconnaissance was possible.

IV. Summary & Lessons Learned

Rocket as a vehicle has been traditionally used to launch spacecrafts, whether be it a satellite, a cosmic exploration vehicle, or the space shuttle. In the current challenge of launching a rocket up to a mile, the Vanderbilt team came up with the innovative concept of launching an aircraft, and using the aircraft to conduct reconnaissance. The endeavor was challenging; in fact, the design of the airplane that fits this requirement is extremely complicated. The team met this challenge and had a very successful test launch in March (watched and validated by one of our peers MTSU) and it was assumed that it could be repeated in the USLI launch on April 18th. The team made the mistake of designing and building a new aircraft after the test launch, and unfortunately, not much time could be devoted to the rocket vehicle. An oversight occurred in the structural aspect of the launch vehicle, and it cost the team dearly. Just prior to USLI launch, it was noticed that the midsection had a weak/soft region possibly due to landing onto wet grass during the test launch. Instead of strengthening that area we chose to fly as is. In retrospect it appears as if the team's efforts peaked prematurely. However, the team's activities/achievements were eagerly followed by many well wishers amongst our challengers and in the community at large. Further, the team believes that only a newly assembled rocket would have had the structural integrity to stand up to the launch. In fact, the slower burning 1939W motor was deliberately chosen by the team to lower the 'g' loads faced by the launch vehicle.

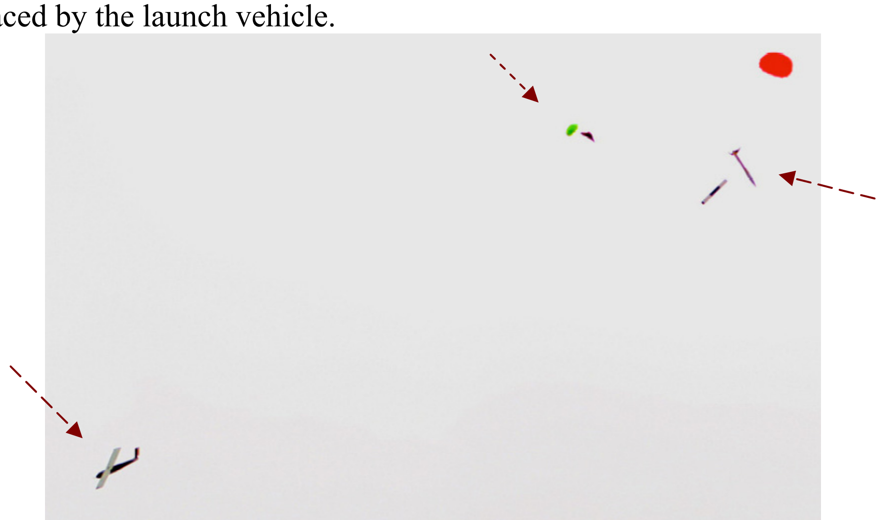


Fig. 4a shows the deployed UAV under pilot control, and the clean separation of the payload and the tail sections (flight march 2009)

Some noteworthy aspects of this program that we would like to bring to the attention of USLI:

(i) Our website, since it had a day-to-day blog of our activities, received close to 10,000 hits over the period of last two months.

(ii) We routinely got calls from prospective employers, asking if we were interested in applying for jobs in their companies; companies that we never knew existed! The internet has indeed shrunk the physical space.

(iii) For example, the Vice President of TAS (Total Aircraft Solutions) in Van Nuys, CA called up our advisor to say that he had been intensely following our blogs and greatly admired this daring project; he said that companies like his have a hard time finding students who can right after graduation take on complex engineering tasks without much guidance, and would love to hire our students.

(iv) Another noteworthy example, is the Vice President of the TV show *Myth Busters* called up our advisor to check if any of the students were available to be hired; he said that their talent search agents had identified Aerospace Club students as some who not only were good engineers but also myth busting outdoorsmen who could serve the show well.

All in all, we had a very good season. It would have been great if the team had come out with flying colors on launch day; but at the end everybody was wondering if they spent sufficient time on the rocket, and whether it was overlooked! We would like to take a moment to thank Florida Tech, Tuskeegee, MTSU and various other institutions and individuals who laboriously waited for our launch and took pictures, and have graciously provided those pictures for us to use in our failure analysis.

The club will be back next year to compete again in USLI, but probably with a much simpler payload and get the job done. One other resolution has been not to use cardboard tubes to build rockets; it is dangerous to take a year's effort of ten students and lose it in ten seconds during a ten inch cardboard tube launch!

Outreach Summary

The team's outreach activities have been going on all year round, as a lot of high schools and programs are interested in stimulating their student's interests in aerospace engineering. In fact, an outreach activity is planned for Monday May 11th on the Vanderbilt Campus for students from the School for Science & Math, a program for select students of the Metro Nashville area (see e-mail attached). In addition, for the USLI mission the team conducted two specific outreach events intended to showcase club activities, along with NASA's Space program. Additionally, efforts were directed to influence youngsters to pursue education in aerospace-related engineering.

(i) <u>Nashville Adventure Science Center</u> (2/21/09)
   a. Displayed competition rocket and UAV
   b. Provided *Realflight* G3.5 R/C Flight Simulator for kids to learn to fly R/C airplanes.

c. Provided educational exposure to over 300 elementary, middle, and high school students to NASA activities and Aerospace Engineering.

(ii) Boy Scouts and Girl Scouts of America (3/21/09)

a. Invited them to Vanderbilt campus and gave a talk in the auditorium on rocketry and space flight and the club's activities.
b. Demonstrated static rocket flight with motor burn and parachute deployment on a small rocket.
c. Displayed competition rocket and UAV in the auditorium.
d. Exposure to least 30-40 scouts, with special attention to Girl Scouts.

From: McCombs, Glenn B [mailto:glenn.mccombs@vanderbilt.edu]
Sent: Friday, May 01, 2009 1:01 PM
Subject: School for Science and Math at Vanderbilt rocketry demonstration

Dear Vanderbilt Aerospace Club,

I wrote to you last year to determine if your rocketry club could present for our School students on campus as part of our curriculum on rocketry and astronomy. We were unable to coordinate as you were attending a competition. At that time, Fisk filled in. This year, we plan to do this part of our lesson on May 11 from 1-3pm. Is there any possibility for your students to lead this for us this year? We would have 25 students and at least three instructors facilitating. We would only expect a demonstration or two and can reserve one of the practice fields in advance.

Robin may be familiar with our group as we have had strong collaboration with Derek Riley and the Student Biodiesel Initiative. Our high school students are mature, advanced, and very curious to learn.

I look forward to the opportunity.

Glenn
Glenn McCombs, Ph.D.
Director, School for Science and Math at Vanderbilt
http://theschool.vanderbilt.edu
Associate Director, Vanderbilt Center for Science Outreach
http://www.scienceoutreach.org/
glenn.mccombs@vanderbilt.edu
(615) 322-7132

Dear Dr. McCombs,

Thanks you for your request. As per Metro regulations we cannot launch a rocket in Davidson County. However, we have a static test stand, through which we can demonstrate a rocket motor burn, along with parachute ejection. This is not the real deal, but it is not bad either. Other things on the menu: we can show your students our Aerospace Club shop, a Rapid Prototyping Machine, and a Laser Cutting Machine. We can start with a ten minute lecture that on rocketry in 131 Olin Hall. Following which, our club students Matthias and James will take them on the tour; Robin, our safety officer, will conduct the demonstration outside Olin Hall.

If this fits your agenda, we need to hear back from you today.

Also, our club's outreach agenda requires that we take and post pictures of the students' visit on our web site.

Thanks
Vanderbilt Aerospace Club

Dear Vanderbilt Aerospace Club,

This sounds great. I am confirming our participation on May 11. Please let me know if you would like Dr. Eeds and I to meet in advance to walk through logistics or if we should just show up at 131 Olin at 1pm.

Students have signed releases for pictures so no problem there.

Thanks again.

Glenn McCombs, Ph.D.
Director, School for Science and Math at Vanderbilt