IOWA STATE UNIVERSITY

POST-FLIGHT PERFORMANCE REPORT 2014

CySLI

Flight Anomalies Analysis

On the whole the rocket launch went off without any extenuating anomalies. The single anomaly that occurred during the flight was the weather cocking of the rocket as it exited the launch rail. This was not an unexpected condition due to the combination of the rocket mass, length of the launch rail used, and windy conditions on the day of the launch (8-12 mph). To compensate the team designed the rocket to have an apogee above the competition objective 3000 feet.

Weather cocking is a phenomenon when the cross wind at a given launch site changes the effective flow direction the rocket is launching into. The result is the rocket flight path turns in the direction of the incident wind, which will change the direction of thrust of the rocket from the vertical axis and, by extension, reduce the rocket maximum altitude. The "cocking" is caused by the uneven distribution of wind force on the upper and lower sections of the rocket. This same characteristic is why the center of pressure is aft of the center of gravity and what allows a rocket to fly in a stable condition. The wind moment on the fins is higher than the wind moment on the upper section, resulting in the flight path adjustment. Weather cocking can be mitigated by having a high velocity off the end of the rail, which would result in minimal perturbing effects from the rocket fins. The larger the vertical velocity component when the rocket leaves the launch rail, the smaller the rocket will angle into the wind.

Propulsion System Assessment

The Cessaroni K400 rocket motor used has the following tabulated values:

Table 1: Cessaroni K400 Motor Data

Max Thrust (N)	Total Impulse (N-s)	Burn Time (s)	Propellant Mass (kg)
484.5	1596.7	4.0	0.9243

Maximum vertical velocity occurred four seconds after liftoff, implying an actual burn time of four seconds, matching the predicted value. By generating a linear rocket mass approximation over the duration of motor burn and multiplying it by the polynomial expression of acceleration with a correction for gravity, an expression for vertical thrust force acting on the vehicle can be obtained. The dimensional drag coefficient obtained from CFD analysis was then used to estimate drag during motor burn. The thrust force was corrected for drag and the result is plotted below:

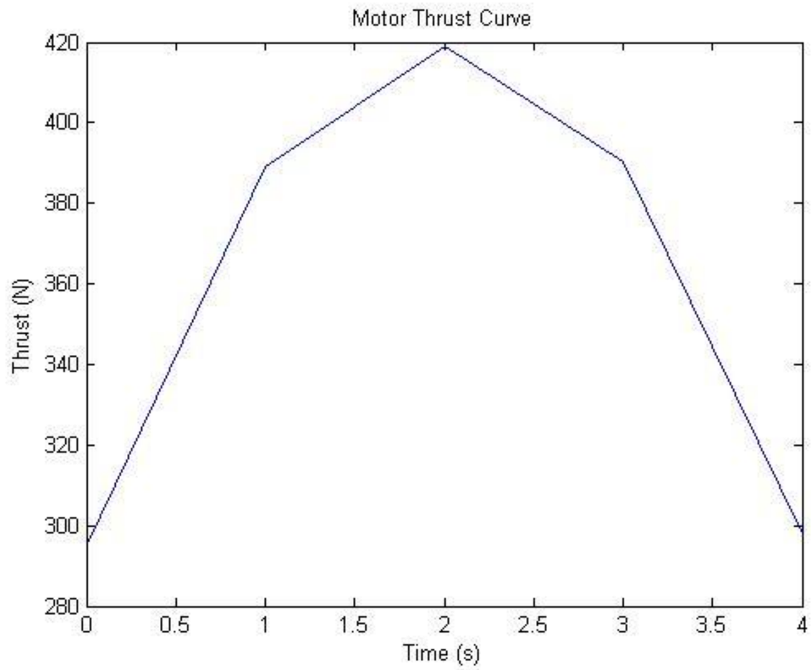

Figure 1: Experimental Motor Thrust Curve

It is easy to see that the maximum thrust experienced during flight was 420 N, resulting in an error of 13.5 percent from the predicted value. By integrating the motor thrust polynomial over the duration of burn, actual total impulse was calculated to be 1493.4 N-s. This value results in a similar error of 6.3 percent. The most probable cause of this error is the angle at which the rocket departed. However, a flight path angle of over 15 degrees would be necessary to offset the entire error. Therefore, it is likely that the motor indeed delivered less thrust and consequently less total impulse than predicted.

Flight Path Assessment

As mentioned earlier, the motor burn stage was defined as the period of time from liftoff to maximum velocity, which lasted four seconds. This occurred at an altitude of about 709 feet above the ground with a corresponding velocity of 417 ft./s. Observation from the ground revealed significant weather cocking which reduced the altitudes of all flight events leading to apogee. The stage in which the rocket drifted without thrust to its apogee lasted approximately eight seconds. The apogee altitude obtained during this stage was 2823 feet as recorded by the StratoLogger altimeter and 2815 feet as recorded by the ZLog7 altimeter.

As expected, a substantial acceleration occurred at apogee, indicating main parachute deployment. The next stage of the flight is defined as the time from apogee to the time when the main parachute was deployed. This stage lasted 21 seconds and the transition to the final stage was characterized by another large positive acceleration induced by the chute deployment. Fifty-six seconds after main parachute deployment, the rocket touched down near the launch pad.

Recovery System Analysis

During the team's test launch on April 20th it was determined that with the main parachute deployment of 800 feet, the ground impact velocity of the rocket was higher than expected. When the rocket impacted the ground, part of the body tubing caved in and one of the fins displayed cracking. After repairing the minor damage with a coupler tube, epoxy, and a little innovative thinking, the rocket was flight-ready by the end of the week. In order to mitigate this problem, it was decided to have the main chute deployment at 1500 feet. Although this would allow the rocket to drift a longer distance, it would also give the parachute more time to open and slow down the rocket.

Rocket Location and Recovery Analysis

This objective of the competition forced the team to make a guess on the coordinates of their rocket before team members were allowed to go out and proceed with their post-flight checklists. CySLI was fortunate in the landing location of the rocket; it landed not 30 yards away from the launch rail in a wet, muddy region of the field. This allowed the team to essentially line up their east-west longitude with good accuracy. For the latitude estimate, two people at either end of the launch perimeter were used to take a heading angle measurement and coordinates using team member iphones. The two measurements were then used to triangulate where the rocket landed.

The result was a remarkably accurate prediction of both longitude and latitude. The official guess was 45.544400 N and -92.927041 E. In order to minimize the amount of error introduced into the forecast, the same measurement device was used for both the location estimate and official recording. An iphone GPS app was selected for the task. The official recording of the rocket location was 45.544539 N and -92.927028 E.

Pre & Post Flight Launch Procedure Assessment

Located in Appendix I is our launch procedure for the preflight, launchpad and postflight procedure. The pre-launch procedure consisted of numerous safety checks amongst team members and the competition appointed RSO. The safety meeting allowed the team to prepare the rocket and payload systems for a safe and successful flight. This included checks on actual center of gravity as well as center of pressure. Both of which were marked clearly on the exterior of the rocket body tubes. On the day of the launch, the team had a long list of checklists and sub checklists to follow closely. Among those tasks were preparation of the black powder charges, the payload bay, parachutes, and shear pins.

One component that was changed between the test launch on April 20th and the competition launch was the procedure for preparing the black powder charges. Previously, a back-up charge was utilized in the deployment of the main parachute. On the day of the official launch, the team was presented with the official Parrot altimeter to be used for the scoring of the altimeter. The only location available to mount said altimeter was where the team's backup StratoLogger Pro altimeter was positioned. The decision was made to trade out redundancies in the black powder charges to allow for the competition altimeter. The launch pad procedure was followed to a tee: the rocket was successfully placed on the rail and, for the first time, a key ignition system turned on the altimeters and armed the black powder charges. After a green light on the continuity check of the launch igniters, the team cleared the obligatory safety zone and waited for the launch of the rocket.

After the rocket landed safely on the ground and a prediction for rocket longitude and latitude was submitted, five team members walked out to proceed with the post-flight checklist. Although it was highly probable that both of the powder charges detonated (because we had two chute deployments and only two black powder charges), the charges were double checked to ensure a completely safe environment for handling the rocket. The rocket was brought to the scoring table where the body tubing and fins would be evaluated for reusability and the Parrot altimeter was to be checked for the official altitude. To conclude the final check on the post-flight checklist, the team brought the rocket and payload back to the vehicle and proceeded with the data extraction from the payload and team altimeters.

Altitude Comparison

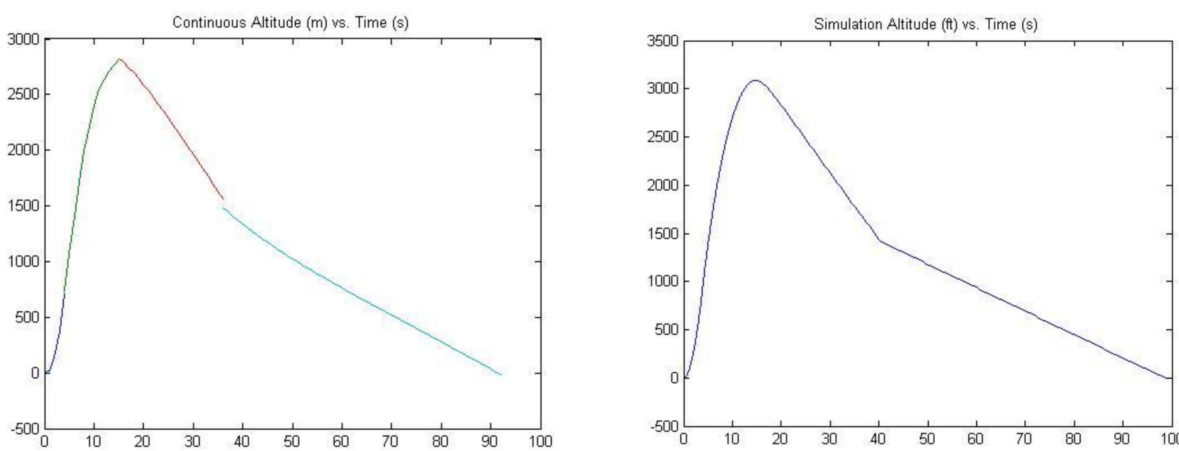

Figure 2: Best-fit polynomials of altitude versus time from the ZLog7 barometer (left) and the simulated values of altitude versus time (right)

The predicted apogee was to occur at 14.895 seconds, but the launch apogee occurred around 12 seconds. As apogee was lower than predicted at 2823 feet, the time of flight was also smaller at 93 seconds, while the simulation ended at 100 seconds. The shape of the graph of the launch still closely matched the prediction at every segment of flight.

Velocity Comparison

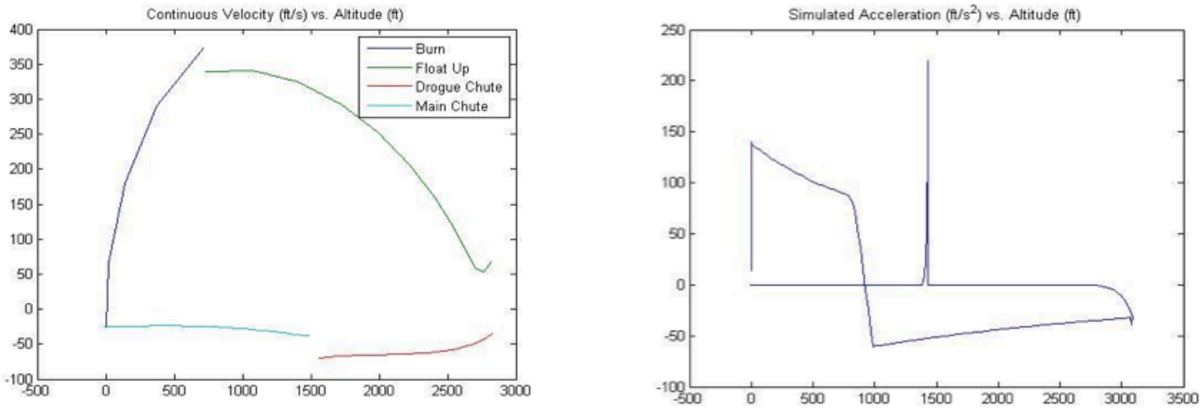

Figure 3: Best-fit polynomials of velocity versus altitude (left) and the simulated velocity versus altitude (right).

The predicted maximum velocity was higher than the actual value. The best-fit polynomials give the general shape of velocity of each stage of flight, but do have some segments of large error after burnout. The discontinuities after apogee are due to the drogue chute and later, the main chute. Overall, the actual values of velocity resembled the trend of the predicted values, but were lower.

Acceleration Comparison

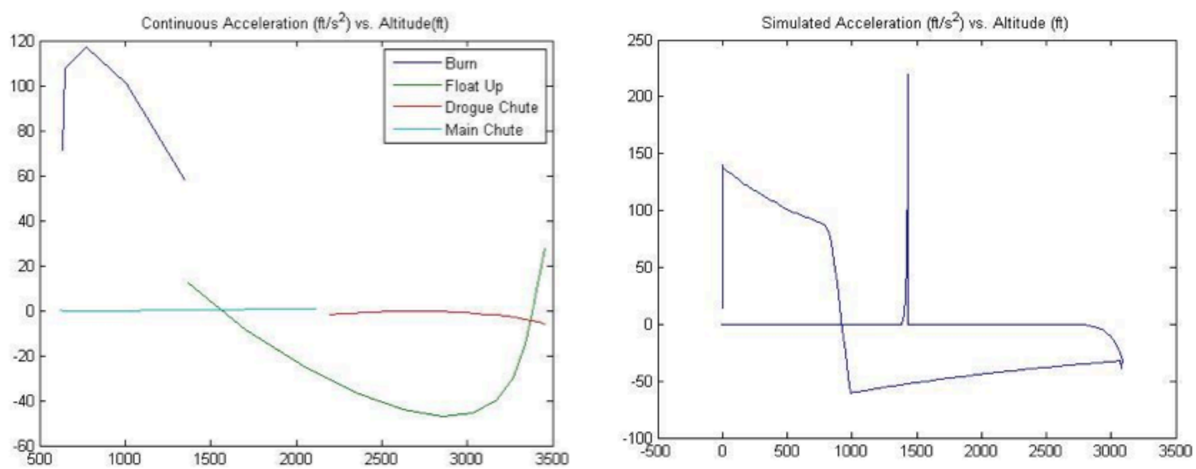

Figure 4: Best-fit polynomial of acceleration versus altitude (left) and the simulated acceleration versus altitude (right).

Again, the trends given by the best-fit polynomials did capture the essence of the prediction. Since the point where the main chute deployed was considered an outlier, the polynomials did not include it. Clearly the trends for the actual values of acceleration compared with the predicted values do not match as well as in Figure 2 and Figure 3. This is due both to the error introduced with numerical differentiation and the best-fit polynomials approximating the curves.

Measurement System Performance Analysis

The ZLog7 recording barometric altimeter successfully recording pressure and temperature data every second during the entire flight. Altitude graphs obtained from this data matched the expected shape of the flight path. No unexpected results were found from the barometric altimeter. Although the collection rate was low for this application, polynomial fits of a reasonably high order provided a good approximation of altitude on a continuous time domain.

The StratoLogger altimeter, which was used for parachute ejection charges, provided some data to compare with the ZLog7. The apogees of the two measurement systems only differed by eight feet, resulting in less than 1 percent error. However, one interesting anomaly is that the ZLog7 recorded the acceleration of the main parachute deployment at 1555 feet while the StratoLogger was set to deploy the main chute at 1500 feet. Still, the similarity of the two data sets indicate that both systems are sufficiently accurate for flight performance data collection.

In addition to the StratoLogger altimeter for recovery system deployment and stand-alone barometric altimeter for primary data collection, the payload included a GPS module and accelerometer/gyroscope for secondary data collection. Upon rocket recovery, it was determined that both data files were closed approximately five minutes after the programs began. The most likely cause of failure is a voltage drop to the Raspberry Pi microcontroller introduced by disturbances while assembling the rocket. However, the phenomenon is still mysterious because of the lack of corruption in the files usually experienced with a system reset. In addition, the air braking system which was also controlled by the Raspberry Pi was responsive during brief testing prior to taking the rocket to the launch pad.

If GPS data would have been collected, several additional analyses could have been performed. Latitude and longitude data would enable the determination of the flight path angle with respect to vertical and a three-dimensional representation of the flight. In addition, the data file would have contained the projected apogee used to decide the position of the air brakes. Although the rocket did not achieve an apogee high enough to use the braking system, the accuracy and precision of the projected apogee data would have indicated the effectiveness of the brake control logic. Finally, the GPS data would have been used to validate the data discussed previously.

While the collection of accelerometer and gyroscope data would have been used to validate previous data, it would have also provided the only vehicle orientation information. The built-in magnetometer would have been used to determine initial conditions for Euler angles, while gyroscopic data would have provided rotation rates about all three axes. A major concern regarding this module was noise from the accelerometer. Position obtained in the form of a twice-integrated noisy signal would have great potential for error. Techniques such as low-pass and Kalman filtering would have been experimented with in order to make acceleration measurements an accurate way to determine all flight parameters.

Appendix I: Pre/Post-Flight Checklist

CySLI – *Iowa State University*

Safety Meeting Prep

[ ] – Prepare rocket to display
[ ] – rocket diagram/payload layup
[ ] – open-rocket simulation results
[ ] – max altitude
[ ] – launch guide velocity
[ ] – altimeter user manual
[ ] – center of gravity/pressure marker on exterior

Preflight

[ ] – rocket readied for launch
[ ] – verify no cracks/structural faults in phenolic
[ ] – motor secured in motor mount
[ ] – shock cords attached to centering rings
[ ] – launch lugs/buttons secure and aligned
[ ] – parachutes packed properly with fire retardant insulation
[ ] – verify igniter altimeter connections
[ ] – payload
[ ] – raspberry pi voltage/power ok
[ ] – connections
[ ] – gps
[ ] – accelerometer
[ ] – batteries 1+2 (charge?)
[ ] – barometric altimeter power + armed
[ ] – safety killswitch
    [ ] – Initialize data collection
        [ ] – servo actuation?
    [ ] – mounted properly on guide bolts
[ ] – payload bulkhead firmly fastened down
[ ] – body tubes, nosecone coupled + flush
[ ] – shear pins
    [ ] – 3/ nosecone

Launchpad

[ ] – arm altimeters – disengage safety
[ ] – altimeters responding with two tone pattern indicating successful arm
[ ] – correct projected altitude sequence? x2
(_______)(_______)
[ ] – bulkhead below payload altimeters firmly refastened
[ ] – payload bulkhead firmly fastened down
[ ] – shear pins
    [ ] – 3 / body section
[ ] – launch rail buttons in rail properly – slowly ascended to launch position
[ ] – continuity check on
[ ] – people outside of safety radius for launch (70 paces)
[ ] – launch

Postflight

[ ] – distance calculation from launch point
    [ ] – wind speed? _____ m/s
    [ ] – descent velocity for our rocket = $\sqrt{\frac{2W}{\rho C S}}$
    CD = .75   p = 1.225 kg/m^3   S = ____ W = ____
    = _______ m/s
    V = V_wind+V_descent
    Distancefrompad (in wind direction) = V_wind*((apogee/V_descent)-time to apogee(____))
    = _________ seconds
[ ] – verify both altimeters sounding that charges detonated (siren, pause, altitude output)
[ ] – in case of fire/danger/charge not detonated
    [ ] – notify RSO
    [ ] – safety procedures/precautions
    [ ] – engage altimeter kill switch
[ ] – cut power to both charges via center body tube
[ ] – check for structure damage
[ ] – disassemble
    [ ] – detach chutes/shock cords
    [ ] – remove payload bay if necessary
[ ] – recover flight data from altimeters + raspberry pi