Problem Set 1 - Report

Task 1: Building and Flight Documentation
(Chris, Kareem, Hubert, Steve; written by Pat)

The first Team Pegasus meeting on April 7 marked the incipient stages of the AA241X UAV design project. The team was initially separated into various subgroups to begin work on initial tasks: building the provided model airplane (Bixler 2), setting up the website, and laying out basic mission planning and initial performance parameters. At the end of the day, the model plane was completed, a preliminary mission map was set, and basic values for rate of climb, stall speed, the drag polar, and power requirements were calculated. The group also familiarized itself with the autopilot hardware and other system components.

The Bixler2 assembly was completed with the installation of the ArduPilot, transmitters for real time telemetry, a GPS sensor, and a pitot tube. The initial flight test was planned for Sunday (April 7) at 1200 on Lake Lagunita. The initial flight plan included strategies to determine both $C_{L_{\text{max}}}$ and $(L/D)_{\text{max}}$. The former involved gradually decreasing throttle while increasing pitch to maintain flight at a constant altitude until the aircraft stalled. By identifying the airspeed at the moment of stall, $C_{L_{\text{max}}}$ could be easily determined. To determine an $(L/D)$ profile, and ultimately $(L/D)_{\text{max}}$, the gliding ratio would also be calculated for multiple airspeeds, as this ratio can be equated to $(L/D)$.

An XFOIL simulation was also conducted so that we can compare flight test data to simple CFD models. Detailed geometric data of the Bixler 2 was recorded and imported into XFLR5. This will be used for comparison to flight data and to train the team using XFLR5. The main wing, horizontal tail, and vertical tail were all considered. We chose to ignore the effects of the fuselage to simplify initial simulations as recommended by documentation for non-stability analyses, but planned to include these in later analysis. The horizontal and vertical tails were split into trapezoids and modeled as symmetric NACA airfoils with 5% and 4%, respectively. The main wing was split into 7 trapezoids and modeled with a flat bottom S3021 airfoil of 10% thickness.

On April 7, the choice was made not to fly due to high winds. Instead, data tracking capabilities were tested. GPS, airspeed, and aircraft orientation were logged. It was found that the transmitter connection cut out at 60 yards, likely due to low battery power in the transmitter. The propulsion system was also unresponsive during testing, but after a system restart was found to be functional.

On April 9, the group rendezvoused at 0800 local time to fly the plane again in hopes of collecting test data with the ArduPilot for PS1. The group was able to perform test flights without the ArduPilot in order for Hubert Wong to establish his faculties in flying the Bixler 2. Robbie came out and saw that our transmitter was experiencing technical difficulties and provided us with a
new transmitter (2.4 GHz versus 72 MHz). However, once the new transmitter was received, the plane battery was depleted beyond usage, thus resulting in the conclusion of flight testing for the day.

On April 10, we established base camp at 0730 on Lake Lagunita in order to get some test reps in. At first, there was another issue with the ArduPilot in that the throttle was not working while the other control surfaces passed qualifications. Eventually, the issue was fixed when the systems were restarted. We met up later at Lake Lagunita at 1730 local time. We flew again without the ArduPilot to ensure Hubert’s ability was up to par for the winds. The team then installed the ArduPilot and made three successful flights logging data under several regimes. Tests were performed for $(L/D)$, rate of climb, stall speed, and a gamut of velocity envelopes. The team met at night to digest and analyze the data for PS1 as well as evaluate mission planning. However, it was deemed that more flights were necessary for several reasons: (a) since times had not been manually recorded during specific maneuvers during flight, it was extremely difficult to identify corresponding segments of data that were critical towards determining flight performance parameters (i.e. $C_{L_{\text{max}}}$ and $(L/D)_{\text{max}}$), and (b) not all the necessary flight strategies were accomplished.

<table>
<thead>
<tr>
<th>Flight Number</th>
<th>Date</th>
<th>Flight Duration [s]</th>
<th>Distance Climbed (ft)</th>
<th>ArduPilot?</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>9-Apr</td>
<td>10</td>
<td>50</td>
<td>No</td>
</tr>
<tr>
<td>2</td>
<td>9-Apr</td>
<td>15</td>
<td>50</td>
<td>No</td>
</tr>
<tr>
<td>3</td>
<td>9-Apr</td>
<td>15</td>
<td>50</td>
<td>No</td>
</tr>
<tr>
<td>4</td>
<td>10-Apr</td>
<td>30</td>
<td>100</td>
<td>No</td>
</tr>
<tr>
<td>5</td>
<td>10-Apr</td>
<td>400</td>
<td>590</td>
<td>Yes</td>
</tr>
<tr>
<td>6</td>
<td>10-Apr</td>
<td>250</td>
<td>450</td>
<td>Yes</td>
</tr>
<tr>
<td>7</td>
<td>11-Apr</td>
<td>400</td>
<td>394</td>
<td>Yes</td>
</tr>
<tr>
<td>8</td>
<td>11-Apr</td>
<td>220</td>
<td>328</td>
<td>Yes</td>
</tr>
<tr>
<td>Total Flight Time [s]:</td>
<td>1340</td>
<td>Total Distance Climbed (ft):</td>
<td>2012</td>
<td></td>
</tr>
</tbody>
</table>

Cumulative flight log

**Task 2**

*Initial Flights*
*(full team participated in flight; piloting done by Hubert; written by Kareem, Hubert, Josh)*

Flight tests with the ArduPilot Mega (APM 2.5) autopilot installed with GPS and airspeed sensing were completed and data was collected both via real-time and post flight. The graphics below depict a number of aspects of flight from testing performed on Thursday, April 11, 2013.
Location vs. Time: As provided by APM user interface (upper). XY-axes correspond with latitude and longitude values given by GPS sensor (lower).
Attitude vs. Time

Battery Level vs. Time
Hardware issues
(Chris, Steve, Hubert, Kareem; written by Hubert and Kareem)

Transmitter/Receiver

The FUTABA 8US transmitter led to some control problems, as communication was unavailable beyond 60 yards during our first ground test. This problem was seemingly fixed by restarting the system and recharging our transmitter. However, the transmitter still gave us some further troubles, as communication was sometimes shaky and control surfaces frequently fluttered without command input. Ultimately, we replaced the transmitter/receiver hardware with a SPECTRA 2.4 GHz model. After binding the new pilot communication hardware, all systems behaved accordingly for the remainder of flight testing.

Electronics/Hardware Layout

In terms of fitting the wiring and circuitry within the fuselage, everything was carefully packed so that the fuselage did not need to be cut into or significantly modified. With everything installed, the CG was located slightly forward of a third of the wing chord.

Control Surface System

During initial flights, control surfaces were trimmed and reconnected as needed. As there were four location options to adjoin the servo lever, the choice was made to link at the hole second closest to the corresponding surface to provide the greatest range of deflection without mechanical component interference (i.e. levers rubbing against fuselage). The weak plastic snap connectors prompted the use of taping to strengthen the joints.

Software Issues
(Chris, Steve, Hubert, Kareem; written by Hubert and Kareem)

Installation and utilization of the ArduPilot system posed no problems with the exception of losing connection strength with the ground station near the end of flight testing. We postulated the cause was low battery levels. However, as this issue only arose once near the conclusion of testing, we did not foresee this as an issue. Further investigation will be performed as necessary.

Task 3: Compare Flight Data

Various flight tests were conducted to collect necessary data to compute aircraft performance characteristics including maximum coefficient of lift and maximum lift to drag ratio.

Determining $C_{L_{max}}$
In order for an aircraft to maintain steady, level flight as the velocity of the aircraft is decreased, the lift coefficient must increase, as shown by the below equation.

\[ C_L = \frac{\text{Weight}}{\frac{1}{2} \rho V^2 S_{ref}} \]  

(1)

Stall will occur at the point of the maximum lift coefficient. The following figure shows a theoretical XFLR5 calculation of the lift curve slope of the Bixler 2 wing airfoil, with a \( C_{L_{\text{max}}} \) of 1.17. This value is exactly the value referenced for the S3021 in Refc. [1].

![Lift-curve slope of S3021 Airfoil](image)

At the point of stall, Equation (1) becomes:

\[ C_{L_{\text{max}}} = \frac{\text{Weight}}{\frac{1}{2} \rho V_{\text{stall}}^2 S_{ref}} \]  

(2)

Thus, in order to experimentally determine the maximum lift coefficient, a controlled flight test was conducted with the Bixler 2 in which the aircraft was intentionally stalled. The Bixler 2 was stalled by establishing stable, steady, level flight, while slowly decreasing the throttle and increasing the pitch, and finally maintaining a constant altitude until the nose dropped, signalling a stall. This process was repeated multiple times, and the \( C_{L_{\text{max}}} \) was determined by noting the
velocity at which the stall occurred, and solving Equation (2) for the corresponding maximum lift coefficient. The following figure show the altitude, pitch, and velocity versus time of one of the stall flight tests used to determine the maximum lift coefficient.
As shown by the figures above, stall was reached by decreasing the velocity and increasing the pitch, while maintaining a steady altitude. The pitch figure displays the sudden drop of the nose of the Bixler 2 upon reaching stall speed, at 224.5 seconds. The velocity at which this phenomenon occurred was $V_{\text{stall}} = 25.253 \text{ ft/s}$. Applying this velocity to Equation (2) yielded and experimentally determined maximum lift coefficient value of $C_{L_{\text{max}}} = 1.1860$.

**Determining (L/D)$_{\text{max}}$**

(Josh, Pat, Hubert, Kareem; written by Hubert)

The lift to drag ratio is a fundamental aircraft parameter that heavily impacts aircraft performance. Before the test flights, theoretical data for the lift to drag ratio versus airspeed was determined. The lift to drag ratio is evaluated based on the lift and drag coefficients, where the lift coefficient depends on angle of attack and airspeed and the drag coefficient is a function of the parasite ($C_{D,0}$) and induced drag ($KC_{L^2}$) as expressed by equation (3) below

$$\frac{L}{D} = \frac{C_L}{C_{D,0} + KC_{L^2}} \quad K = \frac{1}{\pi eAR} \quad (3)$$

A theoretical line of lift to drag ratios was determined for a given velocity envelope for the Bixler. The values for lift to drag ratios versus velocity are seen in the plot below. The theoretical maximum lift to drag ratio was determined using MATLAB and was found to be 13.965.
Finally, experimental data was gathered and compared against the theoretical data. In order to determine lift to drag experimentally, a glide slope test was done. Because the lift to drag ratio is the inverse tangent of the glide angle, a glide test was done for several velocities including the velocity for the maximum lift to drag. The velocity for maximum lift to drag was determined theoretically by equation (4)

$$V_{(L/D)_{max}} = \left( \frac{2}{\rho \infty} \sqrt{\frac{K}{C_{D,0}}} \frac{W}{S} \right)^{1/2}$$

(4)

Test flights were conducted in which the aircraft climbed to a sufficient altitude that would allow for an extended glide period. For a given airspeed, the lift to drag ratio can be equated to the glide ratio, which is simply the ratio of the horizontal to vertical distance covered during the glide.

However, it was found to be extremely difficult to achieve satisfactory glides while maintaining airspeed and a steady heading. For most attempts, wind gusts resulted in unavoidable banking during glides. Though using stabilize mode was an option, it was not suitable for achieving glides while maintaining lower airspeeds, since elevator control was inhibited by the mode. Stabilize mode resulted in a satisfactory glide in the case of an 11 m/s airspeed. The altitude profile for
this glide is shown in the figure below.

Using the fact that the glide occurred between 152.4 and 237.8 seconds ($\Delta t = 85.4$ seconds), the distance covered was calculated as the product of airspeed and $\Delta t$. Based on the altitude profile, it can be seen that there was a drop in altitude of 84.7 m during the glide. The glide angle was determined to be 5.15 degrees, corresponding to a lift to drag ratio, $L/D = 11.09$. This matched our theoretical predictions extremely well as depicted by the red 'x' on the figure below.
Applying an offset of -0.5 to account for the slight error between the theoretical prediction and our experimental data point at this airspeed, we concluded that our maximum lift to drag was 
\[(L/D)_{\text{max}} = 13.5\] at near 26 ft/s. However, realistically our in flight L/D will likely be around the 11 found.

**Predictions Using XFLR5**

(Alex, Brian; written by Alex)

The Bixler 2 was modeled and analyzed in XFLR5. The geometry was defined by breaking the wing, horizontal stabilizer and vertical stabilizer into trapezoidal sections. This was done in order to attempt to capture the significant geometry of the surfaces. The main wing was designed using seven trapezoids, whereas the horizontal and vertical stabilizer used only four trapezoids. For each section of the wing the root and tip chord, dihedral, and offset were provided and used to define the geometry of the wing. These values were measured directly off of the Bixler 2 aircraft. As mentioned earlier, the wing airfoil used was the S3021. This is a flat bottomed airfoil. The horizontal and vertical stabilizers used NACA 0005 and NACA 0004 airfoils, respectively. The body was neglected due to recommendations provided in the XFLR5 documentation. It is expected that the horizontal and vertical stabilizers have minimal effects on the aerodynamic performance of the craft, but they were included for completeness in defining the geometry of the
The simulations run included the viscous approximations provided by the program. The analysis method used was a mixture of a three-dimensional panel method and a vortex lattice method. The current model does not include any weight measurements relating to the aircraft. In the future this information may be added in order to allow for stability simulations to be performed. The flight conditions were chosen in order to attempt to match those of the actual flight conditions during testing. The following figure shows the modeled wings with the panel distribution that was used for all of the analyses.

As can be seen in the picture above, the tips of the wings were approximated to have finite chord lengths. This was done in order to account for the some of the subtleties in the tip geometry. The lower left corner of the figure presents some of the significant geometrical measures.

The following figure shows the relationship between the lift to drag ratio and the angle of attack for the craft.
It was determined that \((L/D)_{\text{max}}\) was 18.95. The following plot shows the relationship between the coefficient of lift and the angle of attack of the craft.

It was found that the maximum coefficient of lift occurred at 10.66 degrees. This corresponded to a \(C_{\text{l}}_{\text{max}}\) of 1.1484. It was seen that at angles greater than 10.66 degrees the data log file returned an error saying that the value at several span locations the value could not be interpolated. Evaluation of the airfoil polars showed that it was not able to reach the given coefficient of lift at the conditions being simulated. This shows that the span locations with the given error were entering stall. The plot above shows that there was an extremely linear lift curve slope, which is expected with the stable wind conditions outside of stall.
Lastly, the stall velocity was determined. The following figure shows the relationship between velocity and the coefficient of lift.

![XFLR5 generated Cl vs. flight velocity curve](image)

As shown earlier, the maximum lift coefficient was 1.1484. It was found that this corresponded to a stall velocity of 21.7 ft/s.

**Comparison of Experimental and XFLR5 Data**

*(Alex; written by Alex)*

The values obtained experimentally and using XFLR5 are now compared. The table below shows the values for $(L/D)_{max}$, $C_{l_{max}}$, and $V_{stall}$ obtained using the two different methods.

<table>
<thead>
<tr>
<th></th>
<th>Experimental</th>
<th>XFLR5</th>
</tr>
</thead>
<tbody>
<tr>
<td>$(L/D)_{max}$</td>
<td>13.5</td>
<td>18.95</td>
</tr>
<tr>
<td>$C_{l_{max}}$</td>
<td>1.1860</td>
<td>1.1484</td>
</tr>
<tr>
<td>$V_{stall}$</td>
<td>25.253</td>
<td>21.7</td>
</tr>
</tbody>
</table>

First, it was seen that XFLR5 predicted a $(L/D)_{max}$ value that was much larger than the experimentally determined value. It is expected that this is the result of XFLR5 underpredicting the parasite drag. This is a trend that has been well documented by users of the program. The model used did not include the body of the craft, which would have also led to an increase in the amount of parasite drag. An increase in the parasite drag would bring the $(L/D)_{max}$ value down towards the experimental value. This builds confidence in the accuracy of the experimentally
determined value.

The experimentally determined $C_{\text{max}}$ value was slightly larger than the value obtained using XFLR5, but overall the two values are in good agreement. This value is believed to be well within the uncertainty of the experimental value. Additionally, it was found that the S3021 airfoil of the main wing had a $C_{\text{max}}$ of 1.17. This value is slightly higher than the experimental value, which is to be expected with the finite wing differences.

Lastly, the experimental stall velocity was found to be roughly 3.5 ft/s greater than that obtained using XFLR5. There may be several reasons for this discrepancy. First, the actual airfoil on the craft was not modeled perfectly in the simulation. The wing of the Bixler 2 had several locations with unmodeled protrusions such as wires and tape. These could cause a forced transition of the flow, which would impact the performance of the airfoil. This may play a significant role at the low Reynolds number flight conditions where the flow is highly laminar. The possible larger source of the error is the uncertainty in the experiment. It is expected that there is some degree of error in the measurements made by the equipment, as well as, difficulty in performing the required flight maneuver.

The aforementioned sources of error in the uncertainty of the equipment and limitations of piloting the aircraft were likely to have contributed to the amount of error in all calculations made. The near agreement of several of the parameters builds confidence in the accuracy of the experimental data and allows for us to accept them as valid performance parameters for future studies on the craft.

**Task 4: Mission Planning**
(Alex, Brian, Hubert, Kareem, Josh, Pat; written by Alex)

The preliminary idea for accomplishing the search and rescue mission is comprised of four distinct steps: sighting all three targets, honing in on each individual target, using the limits of the field of vision to further reduce the region of uncertainty, and lastly using the remaining power available to focus in on the target/targets with the greatest uncertainty. The four steps are explained in detail below.

**Step 1: Sighting the Targets**

The craft will initially rise to the maximum allowable altitude (400 ft). The method in which this is done is currently left unresolved until further data on the performance parameters of the aircraft become known. This knowledge will allow for optimization of this step. After climbing to 400 ft, the plane will fly in a trajectory that resembles a two dimensional spiral where the radial location of the plane (relative to the center of the lake) decreases as time passes. The initial radial distance of the craft will be such that the field of vision is able to completely resolve the outer circumference of Lake Lagunita. This will result in a portion of every photograph being out of the
bounds of Lake Lagunita. This inefficiency has been accepted based off of a conservative approach to the problem and the desire to completely remove the chance that one of the targets is not sighted during this initial maneuver. Initial calculations have found this radial distance is roughly 158 ft. Additionally, it has been determined that the radius of the inner spiral is 90 ft.

It has been assumed that the flight speed at the start of the maneuver is 13 ft/sec. This value is based off of initial calculations for maximum range and to be able to find the targets quickly to lower $t_{\text{sight}}$. As the radius of the turn is decreased the flight velocity will also be decreased in order to maintain a constant altitude. This is based off of the rationale that the maximum allowable velocity decreases as the turning radius of the craft decreases. In the future, this flight speed may be adjusted in order to maximize the final score. Initial calculations have shown that this procedure will allow for us to photograph Lake Lagunita in its entirety, without having to double back on any locations.

The picture below depicts step one of the mission plan. The large black circle shows the idealized circular boundary of Lake Lagunita. The red circles depict the pictures taken by the plane assuming that a photo can be taken every three seconds. Lastly, the blue line shows the approximate flight path of the craft.

Step one will be immediately discontinued at the point when all three of the targets have been sighted. This initial target identification scheme aims to keep the value of $t_{\text{sight}}$ as low as possible.

**Step 2: Honing in on Individual Targets**

Step two will begin instantly after the all three of the targets have been sighted.

The plane will then proceed to the target which can be reached in the shortest amount of time. Note, this is not necessarily the closest point. As the plane travels toward the target, it will begin to descend to a lower altitude and cruise at a speed for maximum endurance. Once the plane is
within proximity, it will begin to circle the approximate location of the target. The plane will circle this target a set number of times. This number is left unresolved at this point and will be dependent on the total endurance of the aircraft. After the plane completes the designated number of circles, it will then move to the next closest target and perform the same maneuvers. Lastly, the plane will fly to the third target where it again will perform multiple loops around the estimated location. Pictures will continually be taken every three seconds throughout this entire maneuver.

The figure below shows the craft circling one of the targets. The green circles represent the hypothetical photos containing the targets’ approximate locations. The figure shows two circles for each target relating to a best case scenario, but there is by no means any guarantee that this would be true in the actual flight.

Step two of the mission is done in order to further reduce the uncertainty in the position of the target. It is known that for a small encircling radius the field of vision will allow the target to be in the field of vision throughout the maneuver. It is also known that the location of the target is fixed, but the location of the target within the circle of its location can change. This will allow for the uncertainty of the target location to be continually decreased, but it has been noted that the magnitude of the decrease in the area of uncertainty will vary based on randomness of the data provided for each photograph. This leaves the possibility that after the completion of step two there will remain a large amount of uncertainty in the position of the target, thus requiring an additional step in the mission plan.

**Step 3: Using the limits of the field of vision to further cut the regions of uncertainty**

The third step in the mission plan takes a much different approach than the first two steps. In steps one and two the strategy was somewhat dependent on the randomness of the returned
circular location of the target. Originally step two was going to be continued until all of the power was used, but recently the group became uncomfortable with the role that chance would play in determining the final flight score. This led to the development of a strategy that would allow for us to be confident that a single maneuver would be able to significantly reduce the amount of uncertainty in each of the targets location.

After step two has been completed the plane will ascend to an intermediate altitude. This altitude is currently left undefined for future investigation. Regardless, at this altitude the exact range of sight of the aircraft will be known. The plane will fly in a manner such that when a picture is taken the field of view bisects the remaining area of uncertainty for each target. If the target is spotted, it will be clear that the target is within the field of vision and if it is not located, the target must be in the other half of the uncertainty region.

A schematic of step three has been included below for clarification. The red circles represent the range of sight of the aircraft at instances when pictures are taken. The green circles represent some combination of photos from steps one and two. The blue line shows the hypothetical flight path of the plane.

![Diagram](image)

*Bisection of known target location using FOV to guarantee area elimination for Step 3*

An inchoate trade study to determine whether it will be more efficient to perform step three or simply prolong step two has yet to completed. A MATLAB simulation of the flight, which will provide helpful numeric data in evaluating this tradeoff, is currently in development and its progress will be presented later.

Performing step three will allow for us to theoretically eliminate half of the amount of uncertainty for each image taken, but it comes at a cost. The algorithm that will need to be developed will be of a much higher level of complexity than that of step two. This opens the door for a greater number of mistakes in the execution of the maneuver, which could have detrimental consequences and result in a waste of a significant amount of power. The precision of the plane’s trajectory, as well as the snapshot times, will be extremely important in step three.
Steps one and two have been designed in a manner where from start to finish photos can be continually taken every three seconds with minimal required precision, a luxury unrealized by step three.

There are also some additional considerations that will be made in the future when greater knowledge of the aircraft performance is known. The amount of power available at the start of step three is currently ill-defined and will determine if the required maneuvers can be completed multiple times if at all. Another tradeoff that will have to be considered involves the altitude and the range the plane travels during this step three. The radius of the field of sight increases with altitude, which could help minimize the distance that the plane has to travel. Also, by rising back up to a higher altitude the plane will have the ability to take pictures while coasting to a lower altitude if the battery begins to run low on power. On the other hand, the necessary climb will require more power than maintaining a constant altitude. In the future, various case studies will be performed to ascertain any benefit of executing step three at an altitude higher than that of step two.

If there is adequate power remaining after the completion of step three, one final maneuver will be performed in attempts to further increase accuracy of target locations.

**Step 4: Focusing on the targets with the greatest remaining amount of uncertainty**

The amount of uncertainty of the position of each target will be calculated with data collected from previous steps. The plane will use any power remaining to try and decrease this uncertainty. At this point it has been decided that the plane will fly to the target with the greatest uncertainty and perform a maneuver equivalent to step two. Pictures will be taken every three seconds in order to obtain the most data possible. Power permitting, once an uncertainty area roughly equivalent to that of a circle with a diameter of 3 meters, the aircraft will traverse to the next target possessing the largest uncertainty. In the future this step of the mission plan may be changed in order to more efficiently use the remaining power.

**Progress in the MATLAB simulation development**

*(Brian, Alex; written by Brian, Alex)*

Currently the team is pursuing the development of a MATLAB simulation that will play an integral role in further defining the mission plan and evaluating its effectiveness. As mentioned earlier, this tool will allow for tradeoffs to be more efficiently considered due to its ability to provide quantitative data about the mission flight.

The most recent version of the simulation has defined the three dimensional allowable region of flight over Lake Lagunita as a cylindrical volume. The program randomly places the three targets on the horizontal projection of the volume. This random assignment of their locations will be important in making sure that the mission plan does not specially cater to certain hypothetical positions of the targets. This will allow for multiple simulations to be run in order to point out
flaws in the mission plan.

The performance of the hypothetical plane has been roughly defined. The values used are based off of performance parameters characteristic to the Bixler 2. Performance parameters are being constantly added and updated in order to more accurately simulate the flight of the plane. The program allows for the time that the photographs are taken to be precisely defined. The relationship between the craft's altitude, plane of sight, and resolution of the returned area has been incorporated. A sample output of the simulation is provided below. Lake Lagunita is outlined by the yellow line, the area covered by the photographs are outlined by the red lines, the returned approximate location of the targets are outlined in green, the location of the plane when the photos are taken are given as green diamonds, and the actual location of the targets are given as blue diamonds.

![MATLAB Simulation model currently in development](image)

The trajectory of the plane used for this simulation was a straight horizontal line crossing from left to right across the center of the area at constant altitude. At this point, the simulation is still in its early stages and has provided minimal assistance in the development of the aforementioned mission plan. It is anticipated that as the simulation is expanded and improved upon that it will become the main tool used for mission plan analysis and development.

References
