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Kites For Low Cost Near Earth Aerial Archaeological Photography

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KITES FOR LOW COST NEAR EARTH AERIAL ARCHAEOLOGICAL PHOTOGRAPHY
KITES FOR LOW COST NEAR EARTH AERIAL ARCHAEOLOGICAL PHOTOGRAPHY

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Arts in Anthropology

By

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ABSTRACT

This thesis presents an overview of kite aerial photography (KAP) as a platform for archaeologists to acquire time sensitive unmanned near earth aerial photography for archaeological research. The methods and tools reviewed in this thesis are limited to those that make this technology accessible to the typical poorly funded archaeologists working in remote locations. The KAP methods detailed here have a low start up cost, are easy to transport, and a can be easily learned by archaeologists. The goal of this thesis is to promote KAP as a significant and regularly utilized tool for archaeological projects.
This thesis is approved for recommendation to the Graduate Council

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### TABLE OF CONTENTS

Chapter 1. Introduction ........................................... 1
Chapter 2. Overview of Aerial Photography in Archaeology ........ 13
Chapter 3. Applications of aerial photography in archaeology ....... 27
Chapter 4. Overview of kites and equipment suitable for kite aerial photography ........................................... 39
Chapter 5. Camera suspension: Pendulums and picavets .......... 71
Chapter 6. Cameras and Software ................................ 89
Chapter 7. Weather and KAPing .................................... 96
Chapter 8. Kite Aerial Photography methodology for archaeological reconnaissance ........................................... 105
Chapter 9. KAP Results/Current Applications ....................... 111
Chapter 10. Feasibility of a remote controlled powered parachute KAP ........................................... 151
Chapter 11. Conclusions ............................................ 158
References Cited ................................................... 160
LIST OF FIGURES

Figure 1. Example of a MODIS subsets map of data sets available for downloading that are automatically generated in near-real-time.  3
Figure 2. Mayflower Archaeology Project, Belize reconnaissance plane.  5
Figure 3. Aerial view of Mayflower Archaeology Project, Belize. Note the door frame visible in the left portion of the frame.  6
Figure 4. Photo of author from helium balloon during balloon camera test flight 1991.  7
Figure 5. Powered Parachute "CAST IV".  8
Figure 6. Powered Parachute inflating in light wind.  9
Figure 7. Portrait of Nadar in 1858 15
Figure 8. The earliest extant aerial photograph "Boston, as the Eagle and the Wild Goose See It" by James Wallace Black October 8th, 1860 from the balloon "Queen of the air".  16
Figure 9. Batut photo of home after refining the camera system 18
Figure 10. Batut's first KAP kite with specialized camera attached to kite 19
Figure 11. George Lawrence Kite Aerial Photography camera 23
Figure 12. George Lawrence kite train and picavet.  24
Figure 13. George Lawrence kite aerial photograph of San Francisco after 1906 earthquake 25
Figure 14. First photo of earth from space. V2 rocket October 24, 1946 26
Figure 15. Photograph of Stonehenge from a war balloon by Lieut. P. H. Sharpe, R.E.  28
Figure 16. Henry Solomon Wellcome and KAP Camera 29
Figure 17. Henry Solomon Wellcome KAP camera and camera pulley/trolley system 30
Figure 18. Detail shot of Wellcome KAP camera and camera pulley/trolley system with the trolley wing closed.  31
Figure 19. Wellcome KAP of areas A-D at Seqadi, Jabel Moya, 1913.  32
Figure 20. Henry Solomon Wellcome detailed KAP aerial view of excavation at Seqadi, Jabel Moya, Sudan 33
Figure 21. Henry Solomon Wellcome KAP aerial view of base camp Seqadi, Jabel Moya, Sudan 34
Figure 22. Angle of attack comparing a Dopero and a Flow Form.  43
Figure 23. Parts of a kite and KAP rig.  44
Figure 24. Effect of the wind on a dihedral.  47
Figure 25. Jalbert Parafoil showing resemblance to airplane wing.  51
Figure 26. Rogallo Flexible Kite, Patent number 2,546,078 52
Figure 27. The X-38 prototype of the NASA Crew Return Vehicle is suspended under its giant 7,500-square-foot parafoil during its eighth free flight on Thursday, Dec 13, 2001.  53
Figure 28. Steve Sutton Flow Form. Patent# 3,893,641 54
Figure 29. Conventional airfoil and ram air filled airfoil.  55
Figure 30. Parafoil, Sutton Flow Form 30.  56
Figure 31. Minimalist KAP kit in process of packing. Sutton Flow Form 30, 16, and 8.  57
Figure 32. Flow Form showing low angle of attack.  58
Figure 33. Dopero.  62
Figure 34. Profile of Dopero.
Figure 35. Dopero in flight showing high angle of attack.
Figure 36. Rokkaku kite
Figure 37. Rokkaku profile.
Figure 38. Dopero keel with modification tying it together to increase drag and kite performance.
Figure 39. KAP Pendulum. Used with permission
Figure 40. Picavet assembled and on kite line.
Figure 41. Picavet suspended on line during flight.
Figure 42. Picavet lacing diagram
Figure 43. Picavet lacing diagram profile view.
Figure 44. Picavet at horizontal equal angles and simulating flight with the lines from the picavet to the kite showing equal angles.
Figure 45. Picavet cross comparison.
Figure 46. Brooxes Basic KAP Kite (BBKK).
Figure 47. Picavet Cross.
Figure 48. PeKaBe block pulley
Figure 49. Profile of BBKK with legs attached.
Figure 50. The gent360 SERVO controller allows for autonomous control of a pan servo and shutter servo.
Figure 51. Three Halo hoop winders and a Sun Oak Kites crank winder.
Figure 52. "UNBREAKABLE" Halo hoop winder
Figure 53. Flow Form airfoil showing modified fuzzy tail.
Figure 54. JR XP642 72 MHz radio.
Figure 55. Spektrum 2.4 Ghz 4 channel radio.
Figure 56. C-740 Ultra-Zoom.
Figure 57. 8 megapixel Canon SD870-IS (European model name IXUS860IS) and 6 megapixel Canon S3-IS
Figure 58. Sony TRV-17 Video Camera.
Figure 59. Example of High pressure and Low Pressure systems
Figure 60. Windmapper.com detailed hour by hour wind map for mesoscale planning tool.
Figure 61. Example of Dopero kite in tree top needing recovery by arborist.
Figure 62. High Banks Metro Park, Adena Mound. Lewis Center/Columbus Ohio.
Figure 63. Adena Mound in open field at Highbanks Metro Park.
Figure 64. Adena mound. Camera oriented southwest at approximately 22 m (75 ft).
Figure 65. Adena mound. Camera oriented west at approximately 120 m (400 ft).
Figure 66. Adena mound. Camera oriented northeast at approximately 120 m.
Figure 67. Adena mound. Camera at ground level facing northeast.
Figure 68. Alligator Mound, Granville, Ohio.
Figure 69. Alligator Mound, ground level panorama facing south.
Figure 70. Alligator Mound, Approximately 23 m (75 ft) elevation. Camera oriented south.
Figure 71. Alligator Mound, approximately 90 m (295 ft) elevation. Camera oriented west.
Figure 72. Alligator Mound, 3 image panorama.
Figure 73. Seip Mound, Bainbridge Ohio.
Figure 74. Seip Mound, Kite is at approximately 90 m (295 ft) elevation.

Figure 75. Seip Mound, panorama of two images.

Figure 76. Albany Mounds, Albany Illinois.

Figure 77. Albany Mound, ground Level.

Figure 78. Albany Mounds, camera facing west at an approximate elevation of 20 m (65 ft).

Figure 79. Albany Mounds, 4 image panorama. Camera facing south, west, and north at approximately 20 m (65 ft) elevation.

Figure 80. Albany Mounds, in relation to the Mississippi River valley.

Figure 81. Bodie Island and Currituck Lighthouse, Outer Banks, North Carolina.

Figure 82. Bodie Island Lighthouse, overview. Wetlands and Atlantic ocean visible to the east in the background.

Figure 83. Bodie Island Lighthouse, close-up detail shot.

Figure 84. Bodie Island Panorama.

Figure 85. Currituck Lighthouse, overview. Looking west from the Atlantic Ocean to Currituck Lighthouse on Currituck Sound.

Figure 86. Currituck Lighthouse close-up.

Figure 87. Aquapac© model 414 compact camera case.

Figure 88. Nikumaroro Island, Seven Site. Possible location of Amelia Earhart and Fred Noonan camp.

Figure 89. Nikumaroro shipwreck showing island drop off.

Figure 90. TIGHAR staff KAPing on Nikumaroro.

Figure 91. TIGHAR staff KAPing from the water.

Figure 92. Maid of Harlech, P-38 Lightning aircraft discovered off the coast of Wales in 2007.

Figure 93. The John A. Hedrick site, LA 91220, in southern New Mexico. KAP of room blocks by Mark Willis.

Figure 94. Mark Willis KAP photograph composite.

Figure 95. Airfoil Aviation 1/4 Scale Powered Parachute: CAST I

Figure 96. CAST IV.
LIST OF TABLES

Table 1: Beaufort Winds Speeds scale. 98
Chapter 1. Introduction

The value of air-photos in archaeology will be very great in the future. They can be used in discovering and making plans of ancient sites. They will be particularly valuable in teaching a class indoors the methods of field-archaeology.

O G S Crawford, 1921. Man and his past

One of the first questions archaeologists ask when planning a project is "Are there aerial images of the area". Because of this there has been significant research into platforms for providing high quality aerial photographs for archaeology for over a century (Kennedy 1996; Reeves 1936; Solecki 1957). Each platform has its own pro's and con's, and no one platform fills all the needs of an archaeology project.

If aerial photos are available for a site area they can often be months to years old. Old aerial photos can be very useful, but they provide no information about how the site looks today. To be able to acquire aerial photos on demand in near real time is a useful tool for archaeologists. The challenges to acquiring on demand images include: the expense of equipment, the size of the equipment, and the high level of technical skills for operation. Many aerial photos, because of the limits of resolution and the elevation of the aerial platform do not provide sufficient resolution for intrasite analysis alone.

For high altitude aerial photographs manned and unmanned platforms include satellites, airplanes, and helicopters. Low altitude platforms for aerial photography include; lighter than air gases/hot air balloons, remote control airplanes and helicopters, fixed wing ultra-lights/paragliders, poles/mechanical supports and kites (Aber et al. 2002; Aber et al. 2002; Rubio et al. 2005; Wolf 2006).

If no aerial photos exist for an area, satellite data can be acquired for nearly any location on the globe. The disadvantage of satellite data is that it is limited by the spatial resolution of the satellite sensor.
Satellite data can also be limited by the maximum resolution allowed by government. The GeoEye-1 satellite launched by GeoEye on September 6, 2008 is capable of a resolution of 40.64 cm (16 in), though U.S. Licensing restrictions prevent the vendor from selling imagery processed at less than 49.78 cm (19.6 in) resolution (GeoEye 2008). Even the best space based imagery alone can not provide the intrasite level resolution that archaeologists desire requiring the fusion of satellite and lower elevation data sensors (Campana and Francovich 2003).

The use of satellite imagery is also delayed by the processing time needed for collected data. While coarse grained meteorological data combined with other low orbit sensor data can be distributed in near real time (Turk et al. 2000) even medium resolution data from satellite sensors like the 250+ m (820+ ft) Moderate Resolution Imaging Spectroradiometer (MODIS) (Figure 1) can take 24 hours of processing before being accessed (Justice et al. 2002). These coarse grained, rapidly accessed data sets have little applicability to intrasite archaeology use. The ability to process and distribute high resolution satellite imagery in near real time is becoming realized (Agarwal et al. 2007) the availability for data of this quality on demand for researchers is not in place.
Figure 1. Example of a MODIS subsets map of data sets available for downloading that are automatically generated in near-real-time. (NASA)
Platforms for on-demand aerial photography

When archaeologists need to acquire high resolution near earth aerial photographs on demand there are a number of technologies available. For high altitude aerial photographs there are both manned and unmanned platforms. Low altitude platforms for aerial photography include; lighter than air gases/hot air balloons, remote control airplanes, unmanned aerial vehicles, fixed wing ultra-lights/paragliders, and poles/mechanical supports. The drawbacks to these technologies include the timing of when an image can be acquired, the cost of acquiring the hardware and its operation, the high level of technical skills for operation and analysis, and the varying ability to achieve high enough resolution intrasite mapping capable near earth images. (Aber et al. 2002; Rubio et al. 2005; Wolf 2006). These technologies do work extremely well and can provide excellent images and have been able to cover many of the needs of archaeologists.

As already mentioned the resolution of aerial photos from airplanes and helicopters is excellent, but is also dependent on the height of the aircraft. International regulations vary for the minimum elevation aircraft are allowed to fly, but in general airplanes are not allowed to fly at elevations below 150 m (500 ft) in the US unless they are flying in an unpopulated area while helicopters are allowed wider flexibility in flying at low altitudes (Federal Aviation Agency 2008). Besides cost and elevation constraints, airplanes and helicopters often require a researcher to be dependent on a commercial third party to provide the service which can limit the ability to produce on-demand aerial photographs. In remote areas the range of equipment can be limited. For an aerial reconnaissance of the Mayflower Archaeology Project, Stan Creek District, Belize a conventional single engine airplane was chartered with no modifications for taking aerial photographs. To accommodate taking aerial photos the pilot removed the back passenger door to provide me a clear view and duct taped my seatbelt to prevent it from accidently un-latching (Figure 2 and
Figure 3). Such modifications would not be allowed by the FAA in the US or by many other national aeronautics agencies.

Figure 2. Mayflower Archaeology Project, Belize reconnaissance plane. Dr. Jeff Stomper, R. Joe Brandon, and Stephanie Decker. Photograph by Rich Williamson.
Figure 3. Aerial view of Mayflower Archaeology Project, Belize. Note the door frame visible in the left portion of the frame. Photograph by author.

The ultra light class of aircraft, both fixed wing and soft wing/parachute have recently been incorporated as a cost effective alternative to more expensive aircraft for acquiring aerial photos of archaeology projects (Hailey 2002; Kvamme et al. 2004). A distinct advantage ultralights have over conventional manned aircraft is that they are low enough priced that they are within the potential budget of a larger company or university. Ultralights are also small enough they can be reasonably transported by trailer, or flown, into even remote project areas with roads for frequent on demand use. In the case of back pack powered parachutes, where the operator actually wears the engine and parachute the entire apparatus can fit in a conventional car trunk. A disadvantage of this technology is the amount of training and maintenance required for the operator as well as off season storage.
Balloons, in particular tethered balloons and blimps, can provide exceptional near earth aerial photos (Aber.J.S. 2004; Marzolff and Ries 2007). Balloons though are limited by the transportation issues of expensive to fill helium tanks and the storage logistics for an inflated balloon. Balloons are also limited by the maximum wind ranges they can safely be operated in.

![Figure 4. Photo of author from helium balloon during balloon camera test flight 1991. Photograph by author.](image)

Radio controlled vehicles: airplanes, helicopters, UAV's, and powered parachutes provide a good overlap between the time and elevation constraints of manually operated aircraft and being able to produce aerial photos on demand. These technologies have a distinct advantage over manned aircraft for acquiring aerial photos because a complete package could be purchased by a project for repeated use, saving money over renting a manned aircraft. The draw back is that these technologies also require specialized (sometimes extensive (Jones 2003)), training for safe operation of the vehicle. These platforms also have the in-
herent risk of loss of all equipment if there is a catastrophic failure of the equipment if either the remote control transmitter/receiver or engine fails.

Figure 5. Powered Parachute "CAST IV". Photograph by author.
Figure 6. Powered Parachute inflating in light wind. Photograph by author.

The one criteria that all of the above mentioned technologies have in common is that a human is involved directly in the power process that provides lift for the aerial platform. Whether it is gas for an engine, or helium from a tank, a person must acquire, store, or transport these materials. On a very remote project access to these materials of a suitable quality and quantity for use in these specialized tools could be problematic.

The only technologies that exist for a transportable system to acquire aerial images without a manual power input are poles/terrestrial platforms and kites. Poles are a great, and affordable, way to acquire very near earth aerial perspectives with using either carbon fiber rods, such as "Carp" fishing poles, which allow users to extend cameras as high as 15 m (50 ft). Or commercial masts which can elevate a camera up to 30 m (100 ft). Projects on a tight budget can use a few inexpensive 3 m (10 ft) lengths of conven-
tional PVC pipe to put together a simple camera pole system. The disadvantage of poles is that they are limited in how high they can reach.

Kites, which have been in use since ca. 200 B.C. in China, have an advantage over pole/terrestrial platforms because they are both portable and able to attain high altitudes (Hart 1967). Kites also offer many advantages over other powered aerial technologies. Kites are affordable and inexpensive to maintain. A kite can operate in a much wider range of winds than balloons/blimps. Kites can be consistently operated at significantly lower altitudes than aircraft can routinely operate. Kites operate efficiently between 25 m - 150 m (80 - 500 ft) and in good conditions can be used at altitudes as low as 2 m (7 ft) for individual feature recordation. In areas where it is permitted kites can easily fly at altitudes of 300 m (1000 ft) and above. Kites are easy to launch and control by a single operator. Kites provide images of a significantly higher resolution that satellites and aircraft and are comparable to those images from balloons and terrestrial platform.

Kite Aerial Photography (KAP) has benefited greatly from the advent of lightweight, high quality/resolution, fast ISO digital cameras and high capacity flash memory chips. Complimenting this new generation of cameras was the public release of a free, non-destructive, camera firmware "hack" for Canon cameras called Canon Hackers Development Kit (CHDK) in 2007. CHDK significantly reduces the number of remote control servos needed to take photographs by automating many of the cameras functions through the use of user created "scripts" which control the cameras actions. These scripts allow a user to create predefined shooting sequences that can be repeated until battery failure or the cameras memory capacity is reached. These technology breakthroughs combined with the easy access to a wide variety of kite types suitable for KAP has brought the technology to a level that now makes KAP accessible and affordable to almost any archaeology project.
Because digital KAP is easy to deploy it has the potential to provide archaeologists with near real time very high resolution near earth images. In suitable conditions a live video down link can also provide an operator with real time information. In regular practice digital data collected with a KAP unit can be downloaded in the field and used immediately for both intrasite and landscape analysis. These images can be utilized for survey of both existing sites as well as assist in the search for new archaeological features while the archaeologist is still in the field. The data can also be used during a project for high quality progress plan views of excavations. In limited circumstances stereo KAP data can be used for photogrammetric work.

The greatest strength of kites, that they need only wind to operate, is also their greatest weakness. The strength of wind compounds kites weakness because no single type of kite is suitable for all wind conditions. To work with this limitation a stable of at least two kites is typically carried when KAPing.

A complete Kite Aerial Photography kit including: 2 kites, line, picavet, remote control and a camera capable of producing high quality images, can be put assembled for under $750. For projects on tighter budgets a usable, but limited, KAP kit could be put together for under $500. A complete Kite Aerial Photography kit can be easily carried by a single researcher in a back pack along with other research equipment.

This thesis is concerned with determining which kite design and equipment is most suitable for use in Kite Aerial Photography for archaeological research. This scope of this thesis is limited to the acquisition of non-metric images from consumer grade digital cameras for site reconnaissance, and landscape analysis. While non-metric imagery can be used for photogrammetry (Heinz 2002; Visnovcova et al. 2001) that subject will not be covered in detail here. This thesis will also address the limitations of kites and explore the issues confronting researchers in developing a platform that is affordable, durable, and easy to operate in remote field situations.
Kites are not a panacea for aerial photography for archaeology. Instead kites are a significant addition to the aerial photography toolbox, one that stands out for its ease of use, accessibility, and ease of transport.
Chapter 2. Overview of Aerial Photography in Archaeology

Mapmakers and surveyors have realized the benefit of an aerial perspective of the landscape for hundreds of years (Burtch 2004). The development of a photographic emulsion fast enough to capture a permanent image with an aerial camera is a direct result of the convergence of photographic technologies in the first decades of photography between Louis Jacques Daguerre and William Henry Fox Talbot. Talbot, who was also a noted archaeologist for his contributions in deciphering ancient languages (Whitney 1896), privately developed the first photographic chemical process which could use a flexible paper medium in 1835 (Harrison 1888; Maynard 1989; Nickel 2001). Coincident with Talbot's work Louis Jacques Daguerre and French inventor Nicéphore Niépce utilized a chemical to produce the first Daguerreotype photographic image on a metal surface, which surpassed the quality of Talbots process (Harrison 1888). Talbot quickly moved to improve his formula to allow for faster recording of images, in particular to photograph people, which he announced in 1839 as the calotype process (Reilly 1980).

Talbot's and Daguerre's improvements to the technology of photographic emulsions was followed by the wet glass plate collodion process in 1850 by Frederick Scott Archer. The wet glass plate collodion process provided cameras with the detail of Daguerreotypes and the speed of Caolotypes. As photographic emulsion speeds increased during the 1850's professionals in other disciplines began to see a wider application of these technologies. French Colonel Aimé Laussedat, the "father of photogrammetry" pioneered the use of tall structures to capture aerial perspectives for mapmaking (Burtch 2004; Lillesand et al. 2004). It was a logical next step to try to use photography from a balloon for even higher perspectives.
The first aerial photographs

The first true aerial photograph was created in 1858 by the photographer Gaspard Felix Tournachon, a French photographer who went by the pseudonym of Felix Nadar (Figure 7) (Haynes 1882). Nadar captured a photo of Petit Bicetre, France from a tethered balloon at a height of 80 m (262 ft) (Burtch 2004; Nadar et al. 1978; Stepney 2005). Following his success of using balloons to acquire aerial images, Nadar was awarded a patent for the concept of using aerial photography for mapmaking and survey (Great Britain Patent Office 1861). Unfortunately this first aerial photo has been lost. The earliest aerial photographs which still exist are of Boston by James Wallace Black who in 1860 took a series of photos from a tethered balloon (Figure 8) (Aber 2004; Crookes and Cradock 1860; Eddy 1898). Soon balloons were being used widely in both Europe and the Americas for acquiring aerial photographs.

As the use of balloons for aerial photography increased other mediums for acquiring aerial photographs were explored as well. Rockets, with Alfred Noble, whose work with dynamite allowed him to produce the first proof of concept photo from a rocket in 1897. Cameras strapped to the chests of homing pigeons were even tested, with some success at the turn of the century (Cohen 2000; Department of Commerce and Labor Bureau of Manufactures 1909; Editors 2007).
Figure 7. Portrait of Nadar in 1858 (Smithsonian Institution Libraries 1858)
Figure 8. The earliest extant aerial photograph "Boston, as the Eagle and the Wild Goose See It" by James Wallace Black October 8th, 1860 from the balloon "Queen of the air". (Black 1981)
The first use of kites in aerial photography

Kiting saw a rise during the 1800’s as an accessible and affordable tool for lofting meteorological equipment (Hart 1967). As balloons were increasingly used to take aerial photos it was a natural outgrowth to experiment with using the more economical kites for the same purpose. Colonel Aimé Laussedat experimented in 1858 in using a string of kites to lift a glass plate camera but abandoned it after having no success (Aber 2004; Birdseye 1940; Burtch 2004; Wolf and DeWitt 2000).

The first irrefutable Kite Aerial Photographs are from the French researcher Arthur Batut. On June 20, 1888 Batut, using a lightweight glass plate 9x12cm film camera succeeded in taking a picture of his home in Labrugiére France using a burning fuse to trigger the shutter at a speed of 1/100th of a second (Figure 9) (Beauffort and Dusariez 1995; Editors 2007), Batut quickly gained recognition as a pioneer in the use of KAP (Figure 10). He also published the first guide to KAP La photographie aérienne par cerf-volant in 1890 (Editors 2007).
Figure 9. Batut photo of home after refining the camera system. Used with permission (Batut 1889b).
Figure 10. Batut's first KAP kite with specialized camera attached to kite. Used with permission (Batut 1889a).
Controversy in the first kite aerial photograph

The work of Batut is recognized as the first irrefutable example of kite photography, a controversy continues to exist regarding a potential kite photo in 1887. There is documentation, but no photographic proof, of this earlier successful use of kites for aerial photography by E. D. Archibald at Royal Tunbridge Wells, west Kent, England (Eddy 1898; Editors 1905)

A. Lawrence Rotch WBR present at one of the first flights at Tunbridge Wells, in 1887 Mr. Archibald took a photo-graph from a kite, which is also one of the first if not the very first occasion on which that was done.

Archibald describes his KAP setup (Archibald 1912)

Kites were also employed, first, by the author, in 1887, to photograph object below by means of a camera attached to the kite wire, the shutter being released by explosion

Noted aerial photographer William A. Eddy mentions receiving a copy of the Pall Mall Gazette from London in 1896 or 1897 (Eddy 1898) in which he states that it showed Archibald successfully took a Kite Aerial photograph in 1886. However I have not been able to find any extant copies of the Pall Mall Gazette Eddy refers to.

Researchers for the Kite Aerial Photography Worldwide Association (KAPWA) Newsletter reported in 1985, as documented by Geoffroy de Beaufort in Labruguiere - berceau de l'aerographie par cerf-volant - birthplace of kite aerophotography notes (Dusariez 1985):
... the evidence of the historical manipulation carried out by Archibald finally came to light, exposing his deliberate purpose to usurp at any cost on Batuts invention.

Also predating Batut's 1888 photo is a Patent number 367610, issued on Aug 2, 1887 to James Fairman for an Apparatus for Aerial Photography (Birdseye 1940; Fairman 1887). Fairman indicates in his patent application that his apparatus can be used on a kite, but there is no evidence that he ever successfully tested, or even built, his apparatus.

**Kite Aerial Photography in the 20th century**

By the turn of the century photography was maturing at a rapid rate and aerial platforms, including kites, were taking advantage of this and becoming increasingly used for aerial observation and recording photos. Larger and more complex kite and camera configurations were being built and put aloft resulting in images of higher quality (Hart 1967).

The U.S. Military began to develop an interest in using kites for aerial photography during war. In 1905 and 1906 George R Lawrence, a photographer and aerial photography pioneer from Chicago, IL, had become interested in the use of kites as well as balloons for taking aerial photos (Petterchak 2002) was invited to demonstrate his equipment to the US Navy (Bullard et al. 1906; Chandler 1905).

Lawrence had developed a series of mammoth cameras for creating aerial photographs of previously unseen proportions (Figure 11). In order to lift these large cameras Lawrence had become an expert at the application of kite technologies for aerial photography (Figure 12) (Petterchak 2002). Following the great earthquake of San Francisco in 1906 George Lawrence brought Kite Aerial Photography to national atten-
tion when his aerial photos of San Francisco showed an comprehensive panorama of the devastation (Figure 13).
Figure 11. George Lawrence Kite Aerial Photography camera. (Baker 1988)
Lawrence’s kite train (left) included bamboo poles to keep the kites from becoming entangled.

The Captive Airship was stabilized by three poles with weighted cords hung from the ends.

Figure 12. George Lawrence kite train and picavet. (Baker 1988)
In 1909 Wilbur Wright is the first to use what will become the most popular platform for aerial photographs in the 20th century, the airplane, when he records a photograph of Centocelle, Italy from his airplane on a demonstration flight (Birdseye 1940; Campbell 2002). Thirty seven years after the Wright's aerial photograph, and 91 years after Nadar's first aerial photograph, the last significant platform for aerial photography is conquered when the first photo of earth from space is taken on October 24, 1946 from a V2 rocket (Reichardt 2006).
Figure 14. First photo of earth from space. V2 rocket October 24, 1946. (Reichhardt 2006)
Chapter 3. Applications of aerial photography in archaeology

By the turn of the 19th century aerial photography had seen widespread use in both military and scientific applications (Crawford 1921), in particular meteorology and geography (Editors 2007; Hart 1967). But nearly 50 years pass since Nadar's successful demonstration of using a balloon for aerial photos before the first aerial photo of an archaeology site documents Stonehenge in 1906.

Lieutenant Philip Henry Sharpe, who was assigned to the Royal Engineers' Balloon Section, used a tethered war reconnaissance balloon to record three aerial views of the Bronze age site Stonehenge. There is no record of why Sharpe, who was temporarily stationed at Bulford Camp located on the Salisbury Plain of England only a few miles from Stonehenge took these photos. By December 1906 the photos were exhibited by Sharpe's commanding officer Colonel John Edward Capper at a meeting of the Society of Antiquaries in London and reproduced in Archaeologia Aeliana (Figure 15) (Barber 2006)(Capper 1907; National Monument Record 1906). The only information about this images is summed up in Colonel John Edward Capper's 8 line description in Archaeologia:
The accompanying illustrations (Plates LXIX and LXX) were recently taken from a war balloon by Lieut. P. H. Sharpe, R.E. and represent Stonehenge from a point of view from which that famous monument has probably never before been photographed. The photographs give a very complete record of the stones in their present positions and of the paths leading to them. They also illustrate in a remarkable and unique manner the relative positions of the stone circles and the accompanying earthworks.

Figure 15. Photograph of Stonehenge from a war balloon by Lieut. P. H. Sharpe, R.E. (National Monument Record 1906)

The first use of a kite for the purposes of documenting an archaeological excavation was by Henry Solomon Wellcome in 1911 at Seqadi, Jabel Moya, Sudan (Adeel 2000; Kleyn 1999). Wellcome's used a pulley system to move the camera to different elevations while leaving the kite stationary (Figure 16, 17,
Using this apparatus Wellcome was able to acquire both vertical and oblique shots of his excavations and project area (Figures 19, 20, 21).

Figure 16. Henry Solomon Wellcome and KAP Camera (Wellcome Images 1911)
Figure 17. Henry Solomon Wellcome KAP camera and camera pulley/trolley system (Wellcome Images 1912)
Figure 18. Detail shot of Wellcome KAP camera and camera pulley/trolley system with the trolley wing closed. (Wellcome Images 1911)
Figure 19. Wellcome KAP of areas A-D at Seqadi, Jabel Moya, 1913. (Wellcome Images 1913a)
Figure 20. Henry Solomon Wellcome detailed KAP aerial view of excavation at Seqadi, Jabel Moya, Sudan (Wellcome Images 1913a)
With the onset of World War I in 1914 the applications of aerial photography in archaeology saw little systematic application for another 15 years. World War did facilitate aerial reconnaissance by providing a
proving ground where aerial techniques were rapidly advanced. By the end of World War I these techniques began to be applied to other fields. The first occurrence of the application of the modernized aerial reconnaissance techniques was in 1919 when Lieutenant-Colonel G. A. Beazeley with the Royal Engineers Survey of India publish the paper "Air Photography in Archaeology", in the Geographic Journal. In this article Beazeley is the first to elaborate on the vast increase in comprehension of site layout and interrelation an observer has when looking at an aerial perspective, compared to ground level (Beazeley 1919). In a response to Beazeley's article archaeologist Aurel Stein sums up the awareness archaeologists are beginning to have of the utility of an aerial perspective (Stein 1919).

That air photographs would reveal a great deal that is new of such important and large sites of Indian antiquity as Rajgir, Ujjain, Besnagar, Kapilavastu, etc., still marked by extensive mounds but not overrun by scrub and jungle, appears to me certain.

In 1920 British archaeologist OGS Crawford, who had been a member of the Royal Flying Corps, the predecessor to the Royal Air Force, is appointed to become the first Archaeology Officer in Great Britain's Ordnance Survey (Ordnance Survey 2007). At the Ordnance Survey Crawford was instrumental in promoting the significance of documenting archaeological sites and he recognizes the need for a systematic process for aerial reconnaissance and aerial photographs to archaeology research (Charlton 1999). Crawford actively uses and promote aerial photographs as a staple for archaeology research and in March 1923 he presented his initial work on Windmill Hill, Hampshire, England to the Royal Geographical Society in March, 1923 (Crawford 1923). Crawford introduce the concept of systematic aerial archaeology with:

It is the great merit of air-photographs that they reveal earthworks upon ploughed land which are invisible to the observer on the ground, or which appear to him only as a confused tangle.

and he conclude his talk with:
A paper of this kind seems called for to inaugurate what will prove to be a new epoch in the history of British archaeology.

In a short presentation, and the discussion which followed Crawford neatly summed up what a pivotal role aerial archaeology would hold in the field of archaeology (Williams-Freeman et al. 1923).

Following up on his earlier aerial work in 1928 Crawford publishes the first book on aerial archaeology, *Wessex from the Air* (Crawford and Keiller 1928). On the footsteps of this pioneering volume Crawford began to assemble all of the "obsolete" negatives taken by air force pilots of the mid-east in the previous decade (Crawford 1929). His work resulted in a collection of 1,700 aerial photos, which while not part of a systematic survey, are profoundly valuable historic references (Close et al. 1929).

By the late 1920's archaeologists in the Americas recognized the positive impact of OGS Crawford's aerial photography work. American aviation pioneer Col. Charles Lindbergh and his wife Anne developed an interest in documenting archaeology sites from the air. They succeeded in demonstrating the utility of aerial reconnaissance in the America's by finding previously undocumented cliff dwellings in the American south west in 1929 (1929). In 1929 an editor for *The Science News-Letter* compared Lindbergh's pending aerial reconnaissance of Central America with that of the ground breaking Central American explorations by John L. Stephens in 1839-1840 (Stephens 1858). The editor summarize the potential of aerial archaeology (1929):

*The airplane offers a rapid method of discovering this much-discovered country. More than that, it offers the possibility of revealing plans and explaining mysteries which the groundling scientist could not solve.*

Through the 1930's archaeologists around the globe begin to more routinely incorporate the benefits of aerial archaeology into their projects. It is a significant step forward when it is recognized that subsurface
features, in an area with standing monumental architecture, are capable of leaving a visible "footprint" of the features buried below. These features manifest themselves in various ways depending on the construction style of the buried feature and the type of vegetation soil, or temperature above the feature (Darvill 1996).

It was discovered that the time of the day, the season, the ongoing climate conditions (wet/drought) and the ground cover all impact the usefulness of looking for feature "marks". By using ongoing aerial documentation of a site it was possible to located subsurface features in areas where there was no standing monumental architecture (Joseph 1945; Solecki 1957).

As the Great War had brought the technologies of aerial reconnaissance/photography into the mainstream, the second World War brought further rapid advancements in both film and cameras for aerial photography. Following World War II there is a perceptible increase in the application of aerial photography in archaeology. And while there is general acknowledgement of the genuine utility of aerial photographs there is not a major leap forward in the application of the technology.

While the ability to acquire aerial photographs became easier, the reality is that aerial photography is a sizable financial and time investment, and often requires the need to coordinate with a third party to take and process the images. These factors that limited the use of aerial photography to sporadic occurrence for archaeology projects in the post war era are still in place today. Unique to archaeology is the fact that as well as being interested in the landscape perspective aerial photographs offer, archaeologists often are interested in having a micro-scale view of a site area, something high flying airplanes can not deliver.

Other technologies have been explored to provide archaeologists with this on-demand need for high resolution aerial photographs; model airplanes and blimps being the most prolific. But the technologies are still being used sporadically on archaeology projects. As stated before I believe that a driving reason for why
these more accessible technologies have not been implemented is that their cost and the technical skill required can be more than an average archaeology project or researcher can afford to expend. I believe that this is where kites can fill an important niche for aerial archaeology by allowing archaeology projects to have an inexpensive, easy to learn, high quality platform for providing on-demand aerial photographs. Kites cannot fly in all areas at all times, but the potential is here for kites to be used successfully, and affordably in their window of opportunity. A benefit to kites for aerial archaeology is that the camera platform of the KAP kit, the picavet, which is lightweight by design, can also be used on other near earth aerial photography platforms such as poles, platforms, model airplanes, helicopters and blimps.

This thesis explores how the best kites can be used to meet the needs of archaeologists looking for near earth aerial photography. I will look at both the cost of different kites, and their unique characteristics that allow them to be best utilized in the varying conditions that confront field archaeologists. I will also examine the ideal camera and support system that can be easily deployed by an archaeologist.
Chapter 4. Overview of kites and equipment suitable for kite aerial photography

The aerodynamics of kites potentially allow most designs with sufficient lift to be used for Kite Aerial Photography. Flight characteristics vary among kites depending on construction differences, materials used, and intended applications and these variable effect which type of kites are most suitable. Some kite designs are very stable (Parafoils, Dopero), and others are designed to be stable, but also highly maneuverable for use in sport kiting (Rokkaku, Deltas), other kites are simply flown for display (Rotor, Show kites). With the exception of powered kites, such as a remote control parafoil, all kites are controlled by a tether line, which can be a single line, or for sport kites, multiple control lines.

The requirements for effective kites suitable for KAP are:

1. Ability to lift camera and picavet of .450 k (1 lb)
2. Easy to operate with limited training
3. Mechanically simple to construct
4. Able to be field repaired
5. Portable by a single researcher
6. Launch-able and operable by a single researcher
7. Ability to carry at least one KAP device
8. Stable enough for controlled flight.
9. Capable of reaching at least 152 m (500 ft)
Kite Disadvantages

Kites can be a great tool for aerial photography in archaeology, but to fully appreciate the niche they can fill it is important for researchers to understand the inherent limitations of this technology. If these limitations are not fully incorporated into a research design it risks both damage to the kite, camera and operator.

The most frequent disadvantage of kites is also a function of a kite's greatest strength. Kites require no power, other than the wind, to operate and if there is no wind, there is no kite flying. Some kite types, such as the Delta and Maxi-Dopero can launch in as little as wind as 1.1 - 5.5 kph (.6 - 3.4 mph) and fly comfortably in winds of 5.6 - 11 kph (3.4 - 6.8 mph). A light wind can not be an intermittent breeze though, it must be sustained at least at the minimum force needed to keep the kite aloft.

Awareness of the force of wind illustrates the point that it is not until you have flown a kite that a researcher develops a full appreciation of how variable wind can be. Wind can change both direction and speed in a matter of seconds, and if its speed drops below the sustainable force needed to keep a kite aloft a researcher must have a clear plan in place for how to take up the slack in a line and a plan for how to recover the kite and camera.

Intra-daily weather conditions can affect the ability for successful Kite Aerial Photographing (KAPing). Wind speeds can also quickly move beyond what is the maximum range that a kite type is designed to handle. This requires an operator to always be aware of intra-daily wind forecasts and to understand that if wind speeds will be shifting beyond the wind range of a particular model of kite a backup kite must be
prepped and ready to go. Inclement weather; snow, rain, and hail can all present hazards to a kite or its operator and prevent a successful flight all together.

Another disadvantage of a kite, though this affects all non structural near-earth platforms, is the weight of the camera payload. For a successful KAP flight an operator must be able to estimate what the payload capability of each kite type is for any given wind condition. Some kites, like the Dopero and the rokkaku have the reputation that if there is enough wind to fly the kite, then it can successfully carry a load aloft. Other kites, such as the delta and parafoil need more wind than just that which will allow the kite to fly alone. Often raising the kite up to a higher elevation will allow it to encounter enough force to be able to lift its payload.

The operation area for a kite must be free of hazards to both the kite and the operator. Obstructions such as trees and building can be an inconvenience, or render KAPing impossible. Even low level brush can present challenges if the kite is downed and it is necessary to retrieve the kite on foot. Utility lines are a perpetual hazard, and this factor can not be emphasized enough: kites can kill.

The target area must be reachable down wind of your flight, or at least be viewable by an oblique angle. There will be occasions when obstructions require a kite to be launched at a point distant from the objective. In these cases the kite must be able to maneuver to a position where the target is within range of the optics.

**Specific Kite Designs**

Kites useful for KAP can be broke down into two distinct categories of construction. Framed kites are those which have some type of a frame work that is assembled prior to flight. Soft kites are those which
have no solid frame work and whose shape is defined by the shape of the kite fabric as air pressure forces against it when filling.

Neither framed or soft kites are universally better for KAP. Often the type of kite chosen is influenced by predominant weather conditions in the research areas and operator preference. In many circumstances it is necessary to alternate between kite types as wind conditions change throughout a day. As a general rule framed kites launch and fly in the least amount of wind and the kite flies at a higher angle of attack (Figure 22) on a shorter amount of string. This is useful for obtaining high elevation plan views of your immediate area. Soft kites tend to fly at a lower angle of attack on a longer length of line, this is useful for photographing targets at a distance down range.
A kite is a complex cluster of parts which allow for a piece of fabric, sticks, and line to be used as a wing. Understanding the relationship of the parts is necessary to be able to successfully fly a kite.
Figure 23. Parts of a kite and KAP rig. Illustration by author.
The parts of a KAP kit in (Figure 23) are described from operator to kite:

1. Spool - A spool, also called a winder, is where the operator releases and retrieves the kite line.
2. Line - Typically a braided Dacron material is chosen to be able to withstand the maximum force without having to much stretch.
3. Picavet - support platform for camera. This can be as simple as a piece of cloth suspended at four points to a fully automated pan/tilt rig.
4. Tow point - A tow point is the point at which the line is connected to the bridle.
5. Bridles - A bridle is the line between the fabric of the kite and tow point. A bridle serves to distribute the load evenly throughout a kite while allowing the operator to maintain control.
6. Keel - A keel, if present, is located parallel and below the kite. A keel can be along the center or symmetrically spaced.
7. Airfoil - An airfoil is the physical kite. This is the shape that acts as a wing to fly in the air.
8. Spars - Spars give a kite structure.
   A. Spine - A spine is a spar which runs the axis of the kite parallel to the wind.
   B. Spreader - A spreader is a spar that is located at an angle to the spine to define the shape of the airfoil.
9. Fittings (not labeled on diagram) - Fittings, such as pockets, glue, tape, or grommets are located where spars connect to the airfoil.

**Physics of kite flying**

To achieve flight a kite must have a shape that can equalize the opposing forces of lift v.s. gravity, roll/pitch/yaw, and line tension v.s. drag.

In order for a kite to rise wind must generate enough of a force against gravity to allow the kite to reach a state of equilibrium and maintain flight. The wind must exert a greater force to allow the kite to rise. The weight of a kite, and any attached apparatus is critical in determining how much wind is needed to lift a kite of a given size.
A kite lacks maneuverable sections, like ailerons and rudders found on an airplane wing. To compensate a kite must use its design characteristics to maintain an equilibrium in flight.

The most important part of a kite's design, like the keel of a boat, is the dihedral. The dihedral is the "V" shape along the central axis of the kite. A dihedral, which is typically between 15-30 degrees, prevents a kite from rolling and loosing control. As a kite pitches to either side there is a greater force exerted on the plane surface of the kite that is against the wind. This oppositional force creates an equilibrium between the roll and yaw keeping the kite steady.

The angle of attack, also known as pitch, is the angle at which the kite is positioned in the wind. Different wind conditions require different angles of attack on the same kite and are adjusted by altering the location of the tow point on the bridle. In low winds a kite will need a high angle of attack and in heavy winds a kite will need a low angle of attack. To increase the angle of attack the bridle is adjusted away from the nose of the kite, this can also be called "back" or "down". By increasing the angle of attack the nose of the kite is lifted higher into the wind which increases the surface area of the kite. To decrease the angle of attack the bridle can be adjusted forward, towards the nose of the kite. This decrease in angle allows more air to flow over the top of the kite which allows the kite to move through the wind with less pull.

Drag is necessary to prevent kites from moving too quickly into the wind and exceeding the state of equilibrium resulting in a loss of control. Drag can be easily added to a kite in the form of a light weight "tail" of fabric trailing behind a kite. The tail also acts as a rudder to help the kite stay turned into the wind. It is important to note that to much drag can be a liability for the operator and if drag exceeds 1/4 of the operators weight the kite line should be staked or an additional person should help to support the line.
Figure 24. Effect of the wind on a dihedral. (Davison 2002)

Kite types examined in this thesis.

For the research reported in this thesis I tested seven different kites, both soft kites/parafoils and rigid kites. The parafoils sizes are identified in the kite industry by their US square foot surface area instead of a metric designation: Sutton Flow Form 8, Sutton Flow Form 16 and a Sutton Flow Form 30. The rigid kites are: 2.7 m (9 ft) G-kites Dopero and a 2 m (78 in) Rokkaku. A Levitation 2.7 m (9 ft) delta kite and a Premier 2.7 m (9 ft) Eagle of Paradox Rokkaku were initially tested but not used. The Levitation did not fly as predictably as I would like. The Eagle of Paradox Rokkaku was very bulky to transport and had heavy spars which required a stronger wind than I was comfortable flying this large of a kite in.

Kite sizes:

Soft Kites / Parafoils:

- Sutton Flow Form - .75 m² (8 ft²)
- Sutton Flow Form - 1.48 m² (16 ft²)
- Sutton Flow Form - 2.78 m² (30 ft²)
Rigid kites:

- Rokkaku - 2 m (78 in)
- Rokkaku - 2.7 m (108 in)
- Dopero 100 - 2.7 m (9 ft)
- Delta - 2.7 m (9 ft)

**Soft Kites/Parafoils**

Parafoils are unstructured airfoils with no rigid parts. The concept of an unstructured fabric parafoil derives parachute technologies and was invented by Domina Jalbert during his research into space vehicle recovery "gliding parachutes" in the 1950's. He was awarded the patent Multi-Cell Wing Type Aerial Device in 1964 (Domina 1964). Parafoils should not be confused with the Rogallo wing patented by Francis and Gertrude Rogallo in March 1951 (Figure 26) (Rogallo and Rogallo 1951; Webster 2001; Webster 2005).

Streeter (Streeter 2002) describes Jalbert's research objective for the parafoil beginning in 1957 as:

> His idea involved joining the airfoil form of an airplane wing, the shaped definition of a sewn gored fabric parachute, the ram-air inflation of a tapered windsock, and the keel-like bridling system of a barrage balloon.

Jalbert was able to meld these concepts together producing an airfoil that could function as both a parachute and a wing. The combination of the flight characteristics of a parachute and a wing represented in a parafoil create one of the more stable kite types. The first patents for a parafoil were issued to him in 1963 (Patent 3,131,894 and 1964 Patent 3,285,546). The parafoil saw its first commercial use when NASA began testing Jalbert's "Multi-Cell Glide Canopy Parachute", also referred to as a ram-air-inflated fabric wing, in 1966 as a suitable recovery parachute for space missions (Burke 1967). The Jalbert de-
sign has recently been re-implemented in NASA’s work on developing a “lifeboat” for the International Space Station (Figure 27), (Hur and Valasek 2003; Matos et al. 1998).

In 1974 Steve Sutton improved on the Jalbert design by adding holes on the back of the airfoil and a larger air intake at the front to increase stability for parachutes (Figure 28). He introduced these modifications in 1979 in a kite model which is beneficial since it requires fewer bridles (Webster 2005). Airfoils based on Steve Sutton’s Flow Form are the most commonly used parafoil for KAP.

The distinctive parafoil shape, which resembles the cross section of an airplane wing (Figure 29), is created when the fabric cells fill, or are "rammed" with air (Figure 30). Because of its similarities to a conventional airplane wing this design is inherently stable and is capable of generating strong lift. This design allows for exceptionally stable control as the parafoil steers itself through the wind.

For KAP use parafoils of 8 square feet, 16 square feet, and 30 square feet are commonly used. The 16 and 30 square foot models get the most routine use while 8 square foot models are only used when there are higher winds or ultralight picavet/camera combinations. Since these kites have no framed parts even a Flow Form 30 can be packed down to a very small size. A complete minimalist KAP kit using a parafoil can be carried in small bag (Figure 31).

A benefit of Parafoils in KAP is that because of their parachute ancestry, they are designed to generate sufficient drag to slow the descent of a suspended object. This design characteristic can assist in the successful recovery of KAP equipment even in the event of a catastrophic failure, such as a line being severed or loss of kite control. If control of the kite were lost there is a reasonable chance that the camera may descend at a slow enough rate to avoid mechanical failure, or at the very least allow for recovery of the intact memory chips.
Another feature of parafoils parachute history is that they are designed to have sufficient drag in the air to slow down a parachutists. When used as a kite this characteristic translates into the kite having a low angle of attack, i.e. the kite tends to fly at an angle between 55-75 degrees from the operator (Figure 32). This low angle of attack allows an operator to move a kite a long distance down range to reach a distant target from the operator without exceeding height restrictions on kite flying. Modifications can be made to the kite bridle on a parafoil to allow for some flexibility in the angle of attack.

Parafoils are one of the easiest to launch kites because the operator can minimize the surface area exposed to the wind until ready to launch. This limitation of available surface area allows the operator to move to the desired launch location easily. This contrasts with structured kites, which are by design increasing their surface area during field assembly and can often try to fly prior to launch. Parafoils readily take flight as soon as the parafoil is allowed by the operator to fill with wind and create the aerodynamics of a wing.

Because of a parafoils parachute heritage they are inherently slow moving and easy to control. Parafoils are not prone to rapid changes in direction that users may experience with faster moving framed kites. Parafoils are also less likely to experience uncontrolled dives when encountering turbulence.

The simplicity of the construction of parafoils allows them to be one of the easiest kites to repair in the field. Because the parafoil has no spars most repairs can be completed quickly using kite repair tape, knots, or simple stitching.

A disadvantage of a parafoil is that like a wing, it requires a significant amount of surface air moving over it to generate lift. Because of this parafoils are not considered light wind lifters. This does work to a
KAPers advantage because a parafoil is capable of flying in stronger winds when flying a framed kite would be unadvisable.

Figure 25. Jalbert Parafoil showing resemblance to airplane wing. (Domina 1964)
Figure 26. Rogallo Flexible Kite, Patent number 2,546,078. (Rogallo and Rogallo 1951)
Figure 27. The X-38 prototype of the NASA Crew Return Vehicle is suspended under its giant 7,500-square-foot parafoil during its eighth free flight on Thursday, Dec 13, 2001. (Landis 2001)
Figure 28. Steve Sutton Flow Form. Patent# 3,893,641. (John 1975)
Figure 29. Conventional airfoil and ram air filled airfoil. Illustration by author.
Figure 30. Parafoil, Sutton Flow Form 30. Photograph by author.
Figure 31. Minimalist KAP kit in process of packing. Sutton Flow Form 30, 16, and 8. Photograph by author.
Figure 32. Flow Form showing low angle of attack. Photograph by author.
Framed Kites

Framed kites have semi-flexible spars providing the framework for the fabric of the kite. The design of framed kites is such that when fully assembled they are ready to fly, unlike a parafoil which needs a wind strong enough to inflate the chute to create the shape of the airfoil, and then enough wind force over the airfoil to generate the lift. This design difference allows framed kites to fly in lower winds than a soft kite.

The spars that provide the framed kite the advantage to fly in lower winds than soft kites are also their greatest weakness. While not a frequent occurrence, spars can and ultimately will, break. This requires an operator to have on hand parts and tools which can be fashioned into replacement parts when needed.

The spars used to frame a kite can also be a challenge to transport to a site area. Some spars are 36" long, and on larger kites they can go up to 48". These lengths can present a challenge to an operator when needing to transport a framed kite into the field. To minimize catching on brush a kite and spars can usually be nicely rolled up into a sturdy tube, or nylon pouch minimizing some of the hazards of carrying long objects. When traveling by plane it is recommended that the spars be put into a conventional fishing gear tub or capped PVC tube to allow them to be brought on as a carryon.

An advantage of using spars is that an operator is not limited to a single type or weight of spars. If an operator knows that they are going to be flying at the low end of a wind range, with little potential for exceeding the kites capacity, a set of lighter weight, but more fragile, spars can be used. If an operator knows that the winds will be shifting into a stronger category the spars can be easily swapped out for a heavier, but more robust set.
Framed kites tend to have a much higher angle of attack than a soft kite. Framed kites typically fly between 70 degrees, up to 90+ degrees. This high angle of attack can be advantageous when the photo target is located near the operators position, or when there are potential hazards in the area and the kite needs to be kept in a small area.

The three framed kites for KAP I looked at for this thesis are, in order of amount of wind needed to lift them: Delta kites, Dopero, and Rokkaku (Japanese fighting kites) kites.

**Delta Kites**

Delta kites, with the exception of a Maxi-Dopero, are the lightest wind KAP capable kites. A 2.7 m (9 ft) Delta with light spars can lift off in a light breeze of 4 kph (3 mph), and flies readily in 6 kph (5 mph) winds. Around 19 kph (12 mph), a Delta can begin to behave unpredictably and it is not recommended to fly them above that level without modifications of more robust spars or tails to add drag. Delta's provide some of the highest angle of attacks for photos and frequently allow for near vertical shots of the operators position.

One of the greatest weaknesses of a delta is a result of its otherwise excellent simple design. A delta can fly so smoothly into the wind that it can actually overfly the operator and effectively have an angle of attack greater than 90 degrees. This can present a problem to the operator because when a kite exceeds 90 degrees on its forward path it effectively introduces slack, and thereby lack of control, into the line. Deltas also perform more poorly than other kite types when wind dies down. With a Flow Form, Dopero or Rokkaku it possible for the kite and payload to descend in a mostly predictable fashion where a delta can begin to plummet quickly.
**Dopero Kites - Double Pearson Roller**

A Dopero (D0uble PEarson ROller) kite is based on two pearson roller kites put together side by side to increase lift, maintain stability and allow for a light wind lifter (Figure 33 & Figure 34). The idea of combining two Pearson Rollers was developed in 1994 by German KAPer Ralf Beutnagel. Ralf released his design and it has been a staple of the KAP since then.

The Dopero 100 can lift off as low as 5 kph (3.5 mph). A general guideline with a Dopero is that if the kite can fly, it can lift a KAP rig. A Dopero has a high angle of attack (Figure 35), comparable to the delta kites, but are not prone to overflying their operator. A Dopero is also exceptionally steady and are best described as flying "nailed to the sky". In the event of a loss of wind a Dopero can act much like the parachute characteristics of a parafoil and facilitate a more gentle landing of camera equipment.

A larger version of a Dopero, known as a Maxi-Dopero, is also manufactured. The Maxi-Dopero is capable of flying in wind as low as a 4 kph (2 mph), while carrying a KAP outfit.
Figure 33. Dopero. Photo by author.

Figure 34. Profile of Dopero. Photo by author.
Figure 35. Dopero in flight showing high angle of attack. Photo by K. Brandon.
Rokkaku Kites - Japanse Fighting Kites

The name rokkaku, 六角, is Japanese and the design resembles an elongated hexagon (Figure 36). The kite is often abbreviated to "Rok" by KAPers.

Roks became popular in Asia in the sport of kite fighting. This is a competition where contestants aim to cut each others kite line, or in Japan where the goal is to force a competitor's kite down. The Rok is a popular style of kite among kite fighters for its high angle of attack, stability, and easy flight. These same characteristics make the Ron an ideal platform for KAPing. Roks are also popular among Kapers because they have fewer spars than a Dopero and can be set up and tuned quickly on site.
Figure 36. Rokkaku kite. Photograph by author.
Kite performance

The Flow Form kites are a great to use in the field. The packability and portability makes them an all around great choice. Even when flying with another kite type it is prudent for an operator to have a Flow
Form on site as a spare kite. The only drawback to the Flow Forms is that they need at least a steady wind of at least 10 kph (7 mph) to launch. The respective wind speeds needed for the Flow Forms are:

- Sutton Flow Form 08: 14 - 40 kph (9 - 25 mph)
- Sutton Flow Form 16: 12 - 40 kph (8 - 25 mph)
- Sutton Flow Form 30: 11 - 25 kph (7 - 15 mph)

KAPers in coastal areas or other areas with steady winds have good success with the Flow Forms. In the midwest where I tested these kites I found that in areas with turbulence such as trees or buildings a steady breeze of at least 12 kph at ground level was usually needed for a clean launch. If the wind speed was below that it could easily drop below the launching threshold and impact the ability to easily launch the kite. Once in the air at operational height the Flow Form performs very well, even in variable, but sustained, winds. They are steady and strong and easily can lift a heavy load. Because the Flow Form design flies against the wind, as opposed to on top of it like sparred kites, it seems better able to resist the effect of thermals.

A disadvantage of the Flow Forms, especially the 30, is that if the wind were to pick up or gust above 28 kph (18 mph), the amount of pull generated could become dangerous. Each of the kites are a challenge to pull in when flying at their maximum wind range. This ability to fly into high winds is also an advantage as it allows the Flow Form to used when other kites can not fly. A two person team can greatly facilitate the recovery of a Flow Form if winds pick up to an unmanageable speed. I tested the Flow Form 16 in winds with consistent gusts of 49-61 kph (31-38 mph) and the Flow Form 30 in winds with sustained gusts of 40-48 kph (25-30 mph) and was able to successfully take pictures, though there was a noticeable increase in the number of blurry shots.
The Flow Form 8 was tested, but because of the weight of my rig it needed to fly at the higher end of its wind range capability to generate lift. When the Flow Form 8 did have enough power to lift it tended to be a bumpy ride and had a lower success rate than using the Flow Form 16 in the same wind.

Of the three Flow Forms I discontinued use of the Flow Form 8 for regular KAPing. If the wind is in a lower range with little chance of gusting above 28 kph (17 mph) I use the Flow Form 30 for flying. If the winds are in the 12 - 28 kph (7.4 - 17 mph) range and might be moving higher than 28 kph (17 mph) I use the Flow Form 16.

The 2 m (78 in) Rokkaku kite is a solid performer in the field. It's assembly is more complex than a Flow Form and it requires tuning in the field for variations in wind, but these tasks can be achieved in less than 15 minutes. The kite can be a little challenging to launch solo if there is turbulence near the ground and the operator must launch by hand. If the area is clear of significant turbulence the rokkaku can effortlessly take off from one hand.

Once in the air the rokkaku is a solid steady flyer. The high flight angle and steady flight make it an excellent choice for KAPing. The rokkaku is rated to fly from 6-38 kph (4-18 mph) but I found it launched solo best starting 10 kph (6 mph).

The Dopero, with its dual spines which allow the kite to be propped up and supported by the tension in the line, is an easy kite to launch solo. If the wind is low the kite can easily be propped up allowing the operator to walk away with the line under tension and pull the kite easily into the air. If the wind is at least 6 kph (4 mph), the kite lifts easily from the operators hand. A Dopero is rated for 1-19 kph (1-12 mph), and with the replacement of stronger spargs KAPers have reported being able to fly the Dopero in winds up to 40 kph (25 mph). Once in the air the Dopero flies steady at a high angle, KAPers describe the
Dopero’s flight characteristics as looking as if it is “nailed to the sky”. The only difficult thing about a Dopero is that while assembling it in the field it will try to take flight while partially built so it is important to always have a soft weight, a Halo hoop winder or backpack works well, to keep the kite on the ground.

One challenge this unmodified Dopero exhibited was an undocumented tendency to, apparently randomly, become unstable in flight and fly erratically. After consulting with other KAPers a simple solution was discovered, the keels of the Dopero need to be tied together with a string to slightly increase drag (Figure 38). With this simple modification the Dopero flies consistently nailed to the sky.

The Dopero is the first kite I go to for a KAP session. It’s ability to launch easily solo, fly in calm gentle breezes while generating sufficient lift for a picavet, and steady flight dynamics make it a great all around kite. The Dopero can even be launched when there is no wind at ground level but the operator can see wind moving across the tops of trees. By letting sufficient line out and running with the kite it climbs so fast that it is quickly up at an elevation where it can catch a breeze and become self supporting.
Figure 38. Dopero keel with modification tying it together to increase drag and kite performance. Photograph by author.
Chapter 5. Camera suspension: Pendulums and picavets

Early experiments with KAP discovered that mounting a camera directly to a kite during flight introduced the potential for blurry pictures due to vibration from the kites fabric as well as rapid movement from the kite. To decrease these negative factors and increase stability cameras were mounted on an apparatus suspended from the kite line below the camera. The two main classes of suspension are either a pendulum (Figure 39), or a picavet (Figure 40).

Pendulums are a simple apparatus and consist of a straight pole with a support on the bottom and a connection to the kite line on the top. A pendulum connects to the kite line with a single connector. Pendulums are convenient because they are small easy to transport, and easy to set up. A disadvantage of a pendulum is that they are not self leveling, which can result in photos taken at unexpected angles. A pendulum was not used for this thesis.
Figure 39. KAP Pendulum. Used with permission (Owen 2008)
A picavet is a pulley driven auto-leveling and self dampening apparatus which is suspended below a kite line at two connection points (Figure 41). The first detailed description of such a device is presented in 1912 by Pierre L Picavet [pronounced Pik-a-vey] in the French kiting magazine, *La Revue du Cerf-Volant* (Beutnagel et al. 1995). In Picavet's article he described his improvements to existing suspension apparatus to facilitate camera stability while in the air and dampen the effects of line vibration.

A picavet achieves its leveling and dampening effect by using four parallel pulleys, or rings, arranged at 90 degree intervals at the tips of a cross bar on the top of the picavet (Beutnagel et al. 1995; Oh and Green 2003). A single line, approximately 9 m (30 ft) long, is threaded through the pulley configuration in
a prescribed lacing pattern which connects to the kite line at two attachment points (Figure 42 and Figure 43). As the picavet experiences turbulence that could tilt the picavet away from parallel to the ground it counter acts those forces as the weight of the picavet causes the four pulleys to roll along the suspension line. This movement of the picavet along the suspension line results in the lines from the picavet to the kite line always being at an equal angle (Figure 44) (Oh and Green 2003). The picavet cross functions as a dampener against torque forces on the picavet's rotation (Gentles 2003). The camera lens is centered as close as possible to directly below the center of gravity of the picavet to further minimize any effects of sway or torque.
Figure 41. Picavet suspended on line during flight. Photo by K. Brandon
The original picavet design used rings for the suspension points, but the use of pulleys, in particular the finely engineered German manufactured PeKaBe model, has become more popular as they greatly reduce friction on the line as the pulleys roll across.

![Picavet lacing diagram](image)

Figure 42. Picavet lacing diagram The threading sequence is A -> 1 -> Ring -> B -> 2 -> Ring -> A -> 3 -> B -> 4 -> A. The letters represent kite line connectors, the numbers represent pulleys or eye bolts. Illustration by author
Recent studies by James Gentles indicate that a cross that has longer arms on one axis of the cross performs better than a cross with arms that are equidistant (Figure 45) (Gentles 2003). The wide cross is ori-
ented so that long axis is perpendicular to the kite line. For this research both a wide and equidistant cross were used.

![Picavet cross comparison](image)

Figure 45. Picavet cross comparison. Photograph by author.

The picavet used in this thesis is part of a Brooxes Basic Kap Kit (BBKK) (Figure 46). This picavet can accommodate both digital and 35mm cameras up to 5.5" wide by 4" high and 5.5" deep. The BBKK includes a mount for a servo which can depress a top mounted camera shutter button that allows the operation of cameras which are not capable of accepting a gentLED Peanut or CHDK for radio-less operation. The BBKK is designed to accommodate additional servos and gears which provide for panning and tilting.
of the camera. A fully loaded BBKK typically weighs less than .9 k (2 lb) and is capable of being lifted by a FF 16, a 2 m (98 in) Rokkaku, a Dopero 100, or a large Delta/Delta-Conyne (Leffler 2004).

The BBKK kit includes a compact picavet cross (Figure 47) with four small ball bearing German PeKaBe block pulleys to allow for smooth kite pivoting (Figure 48). An assembled BBKK can also use a Brooxes Bolt on Leg Bracket (BBLB) (Figure 49) which can help protect the camera when landing. It is possible to pan the picavet 360 degrees which is controlled by a Brooxes pan reduction gear and 360 degree servo.

With the addition of a gent360 Camera Remote Control (Figure 50) which allows a picavet servo to pan at set intervals with no signal from a radio, The gent360 can also send a signal to another servo to fire the shutter button after the panning has stopped.

Figure 46. Brooxes Basic KAP Kite (BBKK). © Brooks Leffler 2007
Figure 47. Picavet Cross. © Brooks Leffler 2007

Figure 48. PeKaBe block pulley © Brooks Leffler 2007
Figure 49. Profile of BBKK with legs attached. © Brooks Leffler 2007
Figure 50. The gent360 SERVO controller allows for autonomous control of a pan servo and shutter servo. © Brooks Leffler 2007

The line used for flying is 68 k (150 lb) or 113 k (250 lb) braided dacron. Typically 150 m (500 ft) of line was loaded onto a winder. Two styles of line winder were used a 22 cm (9 in) Halo hoop winder and a Sun Oak Kites crank winder (Figure 51). The Halo style hoop winders provides the operator with more consistent control over the wound line tension when retrieving the line and was easier to maneuver in the field. The only drawback to the Halo style winder is that temperatures below -12° C (10° F) make the ABS plastic, which is marked with "UNBREAKABLE" (Figure 52), brittle and more susceptible to breaking. An example of the type of break that can occur in cold weather can be seen in the winder on the left (Figure 51).
Figure 51. Three Halo hoop winders and a Sun Oak Kites crank winder. Photograph by author.
The parafoil kites use a modified 4.5 m (15 ft) "fuzzy" tail to increase the drag of the parafoil. The increased drag generated by the fuzzy tail helps to increase the stability of the parafoil in the air. The traditional implementation of a fuzzy tail is to connect it from the back left corner of the kite to the back right corner of the kite. This configuration is challenging when operating near trees because it acts as a large lasso and can make retrieving a kite from tree branches difficult. To overcome the lasso effect I split the tail into two parallel 2.25 m (7.5 ft) tails (Figure 53).
Figure 53. Flow Form airfoil showing modified fuzzy tail. Photograph by author.
Two radios were used for this project a JR XP642 72 MHz (Figure 54) and a 2.4 GHz Spektrum (Figure 55). Both models of radios allow for the operation of four independent servos, which can include pan, tilt and shutter control.

The 72 MHz Futaba 4 channel radio is a conventional model airplane transmitter/receiver which operates on one of 50 available channels determined by the flyer and controlled by inserting the appropriate frequency crystal in the transmitter and receiver (Figure 54). I stopped using this transmitter when I began performing frequent test flights in an area near a popular model airplane field as there was a likelihood I could be broadcasting on the same channel as a model airplane. The potential for operating on overlapping frequencies with a model airplane could be hazardous to the operator, their equipment, or viewers.

In 2003 a new class of transmitter/receiver operating on the 2.4 GHz range which can prevent receiving or causing unanticipated interference became available. I acquired a 2.4 GHz Spektrum DX6 4 channel Park Flyer System to replace the 72 MHz Futaba radio. The Spektrum 2.4 Ghz radio uses a FCC required collision avoidance system, Globally Unique Identification Code (GUID), and time base coding. The GUID is transmitted as a 32 bit code which binds the transmitter/receiver together with any of a potential 4.2 billion codes. The binding process takes only a few seconds and after the binding is complete the receiver will only respond to signals from the transmitter it is bound to. With 4.2 billion possible bindings it is unlikely two radios will transmit on the same channel and case interference. The Spektrum also uses Direct Sequencing Spread Spectrum (DSSS) which sends its signal out on a single channel using pseudo-random noise code which allows the radio to transmit a signal farther without using more power (Horizon Hobby 2003).
Figure 54. JR XP642 72 MHz radio. Photograph by author.
Figure 55. Spektrum 2.4 Ghz 4 channel radio. © Horizon Hobby, Inc.
Chapter 6. Cameras and Software

Historically 35mm, or larger format, film cameras have been used for KAP. These film cameras have been used to produce a large number of very fine images, but there are also drawbacks to using film cameras for KAP. The primary limitation of film cameras is the limited number of exposures that are possible on a flight. With the stochastic nature of winds there is always the potential for a camera to be moving at any given moment during flight and using a 35 mm camera with a maximum 36 exposures the margin for error on a single flight is maximized. Weight is another drawback for conventional 35mm or larger cameras. Full size SLR 35mm cameras with automatic film advance also tend to be heavy and consistently weigh more than .68 k (1.5 lb) for the camera body and lens which requires strong winds or a larger kites to generate sufficient lift. 35 mm compact/point & shoot cameras are lighter than SLR's but are still limited by the 36 frames exposure limit. Compact 35mm cameras are also limited to a maximum shutter speed of 1/500 of a second because of the leaf shutter diaphragm used. The final drawback to using 35 mm cameras is that major manufacturers, such as Nikon, have announced in recent years that they plan to stop production of 35 mm cameras (Corporation Nikon 2006).

The advent of high quality, lightweight digital cameras has revolutionized the potential of KAP for archaeology. High resolution digital cameras with wide exposure ranges, and high shutter speeds are capable of recording thousands of photographs on a single KAP flight.

In 2007 a major breakthrough occurred which will allow more scientists easier and more affordable access for using KAP technology. A Canon camera firmware modification, Canon Hackers Development Kit (CHDK), was released on the internet by a Russian programmer Andre Gratchev. CHDK is a small program which is loaded onto a Canon cameras memory card and loads into the cameras memory before the cameras native firmware loads as the camera starts up. Once loaded the CHDK software allows a
user to expand on existing camera functions, add new functions not implemented by Canon and to create customizable scripts. Some of the functions that CHDK adds which are useful to KAP include: enabling RAW shooting, exposure/shutter speed bracketing, script timed shooting, re-calculting exposure of each shot, and alternating between photo and movie modes while in flight. When CHDK is combined with other automated accessories such as the gent360 SERVO a completely autonomous KAP system can be deployed.

Three digital cameras and one video camera were tested for this project:

- Olympus C-740 Ultra Zoom - 3.2 megapixel (Figure 56)
- Canon S3-IS - 6 megapixel (Figure 57)
- Canon SD870-IS - megapixel (Figure 57)
- Sony TRV-17 Video Camera (Figure 58).
Figure 56. C-740 Ultra-Zoom. © Olympus Corp.
Figure 57. 8 megapixel Canon SD870-IS (European model name IXUS860IS) and 6 megapixel Canon S3-IS. Photograph by author.
The first camera used is an Olympus C-740 Ultra Zoom 3.2 megapixel. The lens mount on the Olympus C-740 Ultra Zoom was discovered to be very susceptible to vibration from the kite and produced in flight pictures that were consistently soft in focus. After consulting with fellow KAPer Eric Wolf, who was experimenting with the same camera and having similar problems, we concluded that even with significant padding we would not be able to stabilize the cameras sufficiently. This camera is not compatible with CHDK.
The next camera tested is the Canon S3-IS (Image Stabilization) 6 megapixel. The camera is outfitted with an auxiliary lens protector and is CHDK compatible. The camera is relatively robust, with a camera weight of 410 grams (10.4 ounces) and 4 NiMH batteries of 120 grams (4.4 ounces) and required a good wind to lift. The photographs from the Canon S3-IS are very good quality but the lens was limited to its maximum wide angle coverage of 6 mm (35 mm equivalent: 36mm).

The final camera tested is the Canon SD870-IS 8 megapixel. This camera is CHDK compatible. This camera weighs 155 gram (5.5 oz) with a battery weight of 21 grams (.7 ounces). The photographs from the Canon Sd870-IS are excellent quality. Not only is this camera lighter than the other cameras tested it also has the widest angle lens, a 4.6 mm (35 mm equivalent: 28 mm). A lens wider than 35 mm equivalent is uncommon in the compact and point and shoot categories and I found that this extra coverage proved to be very useful for documentation.

The only video camera tested is the Sony TRV-17 Digital Video Camera Recorder. The camera is bulky when compared to the other cameras tested and could not fit on the standard picavet. I used a modified picavet rig to carry the video camera and the results were not very useful for general work. The camera weighed 650 grams (1 lb 4 oz) with a battery weight of 90 grams (3.1 oz). The stronger winds needed to lift this heavier camera and rig tended to be a bit more turbulent. This turbulence caused significant shaking in the video which was unsatisfactory. With heavy editing a useful video could be produced, but higher quality video was attainable from the Canon SD870-IS because of the lighter winds it could fly in.

The images from the Canon SD870-IS required very little post-processing work to be done. All software is Apple Macintosh OSX compatible. In general the cameras metering system produced images of such good quality that I found it unnecessary to take photographs with RAW mode enabled. Most image
enhancement that was needed could be performed in the basic image editor iPhoto 08. On rare occasions Adobe PhotoShop CS was used for fine tuning of details in an image.

For photos that required stitching for a panorama Autopano Pro V1.4 worked extremely well. For panoramas of 3-4 photos with image overlap Autopano Pro could process and produced a very high quality panorama using a conventional drag and drop from iPhoto into Autopano Pro. If the camera was in a very steady wind and was able to complete a full rotation a satisfactory full 360 degree panorama could be produced. Autopano Pro also provide sophisticated tools for fine tuning stitching of images with complicated alignments.

On board live video was not used for this project. It is technically possible to incorporate a light weight live video but after discussion with other KAPers who have used video the general consensus is that it is more of a drawback than a benefit. The problem with live video is that since most KAPers work independently the added complication of watching a video feed as well as safely flying a kite and operating a remote control did not produce significantly better pictures. KAPers told me that it was easy to become preoccupied with watching the video image and not being paying enough attention to the kite and potential hazards. The only KAPers who routinely are using live video are those doing commercial KAP work, real-estate in particular, and who have the client on site.
Chapter 7. Weather and KAPing

The greatest weakness of kites is their need for wind of a suitable strength to lift a picavet with a camera. Winds occur at all spatial scales and the interrelation of these scales and how they will impact kite flying conditions must always be considered when planning a KAP session. If planning a future KAP session in a remote location prevailing winds and seasonal variants in wind patterns must be understood in how they can effect flight conditions.

In most situations where a KAP system will be used regularly the wind scales of interest to the researcher are the Synoptic, Mesoscale, and Microscale winds, which are discussed below. For the most consistent KAPing using a standard KAP kit the wind in a project areas must typically be capable of sustained periods of a 5 - 19 kph (4 - 12 mph).

Because of the limited availability of anemometers in the field KAPers sometimes utilize the Beaufort Wind Scale (Table 1) as a convenient reference to wind force. The Beaufort scale, originally developed as a means to standardize nautical observations of wind speed, provides a scale of wind force ranging from Beaufort 0, 0 kph (0 mph) up to Beaufort 12, 118 kph (73 mph). For readability in this thesis the Beaufort Wind Scale has not been used.

Wind is dynamic and capricious at all times. Because of the interaction of all of the physical factors that effect wind at all scales one can never accurately predict exactly what the wind will be doing, on a scale that affects the kite dynamics, at any given moment. The best a researcher can do is develop an understanding of what the general conditions are for the wind at a flight location and always be prepared for a sudden shift in wind dynamics which can adversely effect KAPing.
It can be challenging for a researcher to develop an appreciation for the force of wind. Wind is unlike many forces we sense as wind is only felt. A researcher can not look across a field and see "wind", they can only see the effect the force of wind has on an object. The challenge is that between an object that a researcher sees being effected by the force of wind, and the researcher or their kite, is that other forces of wind are moving against the force that was observed on the object.

An analogy that is useful for developing an awareness of the wind is to visualize that wind is like water moving down a stream. When the stream is observed at a slow moving section the water appears calm, but even objects moving in the stream do not follow a perfectly straight line, the micro-dynamics of the stream are always exerting competing forces on these objects. And as these forces compound the object changes movements. When the stream encounters a raised set of rocks, like wind moving over a tree canopy into a clearing, gravity forces the stream to cascade over the lower side of the rocks. This cascade results in a visible tumultuous mixing of the water in the stream, and like in the wind, anything in the stream is tossed around in a difficult to predict pattern. Eddies can form in sheltered places that can trap an object and be removed from the force of the stream. Vortexes can form on the side of the disturbance causing a rapid increase in speed of an object.

If the volume of the stream is great, and the scale of the drop in elevation over the rocks is large, like a strong wind over a tall stand of trees, significant changes in the dynamics of the flow can occur. If the volume is low, and the elevation is slight, like a light wind over a short stand of young trees, the changes are less profound.

Because the "stream" of air does not have a surface, relative to the scale of kite flying, the dynamics go beyond just the horizontal movement. Wind is, in effect, a very deep stream and the example of wind "falling" over the edge of trees into a clearing does not just effect the dynamics of the wind from the top of
the trees to the bottom of the clearing. As the wind falls into the open area it creates a drop in pressure above that location where the wind once was and as air that once was higher begins to descend the volume of the disturbance extends up above the tree line. The general rule for kiting is that a disturbance in the wind from an obstruction extends up to twice the height of the object that introduced the disturbance. As you watch your kite fly, keep this analogy in mind to be able to visualize the effect the local topography can have on your kite.

Table 1: Beaufort Winds Speeds scale. ( Derived from (Hunt 2004) and (Huler 2004))

<table>
<thead>
<tr>
<th>Beaufort Force</th>
<th>Kph</th>
<th>Mph</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>&lt;1</td>
<td>&lt;1</td>
<td>• Calm. • Smoke rises vertically. • Flags hang limp.</td>
</tr>
<tr>
<td>1</td>
<td>1.1 - 5.5</td>
<td>1-3</td>
<td>• Light Air. • Direction of wind shown by smoke drift but not wind vane. • The far end of the flag hangs low and the entire flag only occasionally flaps open.</td>
</tr>
<tr>
<td>2</td>
<td>5.6 - 11</td>
<td>4-7</td>
<td>• Light Breeze. • Wind felt on face; leaves rustle; ordinary wind vanes move. • A flag is mostly erect and waves through flag are deep. The farthest top corner moves both front and back.</td>
</tr>
<tr>
<td>3</td>
<td>12 - 19</td>
<td>8-12</td>
<td>• Gentle Breeze. • Leaves and small twigs on constant motion. Wind extends light flag. • A flag is erect and the waves are at a higher frequency than Beaufort 2.</td>
</tr>
</tbody>
</table>
| 4  | 20-28 | 13-18 | Moderate Breeze.  
• Raises dust and loose paper; small branches are moved.  
• A flag is very erect and the frequency of the waves is very fast. An audible "crack" can be regularly heard from the fabric snapping. |
|----|-------|-------|--------------------------------------------------|
| 5  | 29-38 | 19-24 | Fresh Breeze.  
• Small trees in leaf begin to sway; crested wavelets form on inland waters |
| 6  | 39-49 | 25-31 | Strong Breeze.  
• Large branches in motion; whistling heard in telegraph wires; umbrellas used with difficulty. |
| 7+ | 50-61 | 32+  | High Wind.  
• Generally dangerous to fly kites! |
**Synoptic Wind**

When planning for KAPing in a local region, Synoptic winds are those that operate on the scale of 100's to 1000's of kilometers and occur over periods of hours to days (Emanuel 1986; McCutchan 1978). These winds which are currently associated with regional high pressure and low pressure systems are the most useful for predicting a range of days when KAPing will be feasible. Synoptic winds can be forecast with a high degree of accuracy over a one to three day period.

Synoptic wind maps are best recognized in the daily weather map graphics available in local news media. An important aspect of a weather map for predicting local wind, and related weather, conditions is the identification of high pressure and low pressure systems and what direction they are moving (Figure 59). A high pressure system, characterized on a weather map by widely spaced isobars, indicates a stable weather system. A high density of isobars indicates an unstable faster moving weather system either on the leading or trailing edge of a two pressure systems. For ideal KAP winds a non dramatic transition between pressure systems is best, characterized by a series of evenly spaced isobars. In the example image below the pattern of isobars from Iowa to Indiana indicate the potential for good winds for KAPing. The researcher must keep in mind that the direction of the winds needed for reaching your target can be affected by the circulation of winds associated with the pressure systems coming or going.
Figure 59. Example of High pressure and Low Pressure systems  (The Weather Channel 2001)
Mesoscale winds

On a day with suitable synoptic winds for KAPing mesoscale winds become an important factor. Mesoscale winds are those winds associated with small scale regional events, on the scale from several to hundreds of kilometers and which occur over a period of minutes to hours. An example of a mesoscale catalyst would be an isolated rain system not associated with a major meteorology system (Emanuel 1986) (Figure 60). Monitoring of local media weather stations during a KAPing day by radio, TV, or Internet device is critical for a successful, predictable flight. Wireless internet devices, and in the US, nationally broadcast weather advisories, are extremely useful for getting near real time weather data and these sources should be rechecked on a consistent schedule to be aware of any weather changes that may be taking place. This point was made explicitly clear to this researcher when caught in an open field in a violent lightning storm while retrieving a downed kite. Had I checked my weather maps before heading down field to retrieve the kite I would have seen the scale of an active weather system that had developed on the other side of a nearby valley, which was blocked from my view by a line of trees.

Over the course of a single day the direction of the wind can shift over 360 degrees. If your launch location is fixed and your research target is a specific direction the timing of your KAP launch and the winds can be critical. A wind needed to be blowing in a specific direction that will allow you to KAP over a remote target can be predicted to occur between 2-3 p.m. but over the course of a morning that window can easily shift one hour forward or backwards. Intra-day wind prediction tools, such as WindMapper.com are useful for fine tuning KAPing conditions (Figure 60).
Microscale winds

Microscale winds are those winds which operate at a scale of meters to a few kilometers and occur over periods of seconds or minutes (Emanuel 1986). There are no prediction tools readily available to KAPers for microscale winds other than in field observations of wind behavior. I have found that a piece of flagging tape tied off on a stake near an operator, and one near the target can be useful for in field observations of microscale wind conditions. If flagging tape is not an option watching the leaves on the tops of trees and vegetation in a target area can be used. A set of binoculars can be useful for observing
movement of leaves near a distance target. Of particular concern for KAP are microscale wind shears operating on a scale of tens of meters such as those found near structures, escarpments or tree lines. In open areas whirlwinds/dust devils which occur from strong heating of the ground on otherwise calm days are also a microscale wind hazard.

For the purposes of KAP, a researcher must expect that microscale winds behave in a stochastic behavior. When KAPing a test flight prior to lofting camera equipment is always recommended. The goal of this test flight it to evaluate wind conditions to determine if this stochastic turbulence of the microscale winds is operating at a small enough scale to not make flight unsafe, or produce unusable images.

**Temperature range for KAP**

Kites can be operated at any temperature that a human can comfortably work in with reasonable protective clothing. The limiting factor for KAP in extreme temperatures is that the batteries needed to operate the electronics, especially the batteries used on the equipment aloft are sensitive to temperature extremes (Ahmet 2004; Jensen 2002; Muhs 2003).

Batteries are typically configured to operate at their optimum levels with an ambient temperature of 20° C (68° F) (Andrukaitis et al. 2004). High temperatures can negatively impact battery performance but it is not within a temperature range where KAPing would be feasible so it is not important in practice. Cold weather has a more pronounced effect on batteries and is of greater concern. Alkaline batteries can see over a 50% drop in run time at 0°C (32° F) while Nickel Metal Hydride (NiMH) and Lithium (Li) batteries can operate at closer to 100% capacity at 0°C (32° F) (Energizer Battery Manufacturing 2001; Energizer Battery Manufacturing 2006). Lithium Polymer batteries, which are beginning to be developed for cameras have the advantage of being very lightweight do not perform well in low temperatures (Reid 2004).
Chapter 8. Kite Aerial Photography methodology for archaeological reconnaissance

For a safe and successful KAP session an operator should follow these steps prior to launch. First check the country laws regarding maximum flying height for your kite. Check regional maps to see if there are any airports, in particular rural or private airports which may have hobbyist pilots, or agricultural pilots who may be operating below recommended minimum aircraft elevation. If necessary contact those airports to notify them of your schedule for flying and to confirm that it will not conflict with their operations.

If you are using a conventional aircraft remote control for operation of your KAP equipment you must check local resources to see if there is a hobbyist remote control airplane field in the immediate area. If two radios are operating on the same frequency in the same area the overlapping signals can cause equipment malfunction. Use of a 2.4 ghz Direct Sequence Spread Spectrum (DSSS) radio can facilitate not conflicting with conventional hobbyist frequencies.

If possible visit your KAP project area prior to launch day to identify any potential hazards or conflicts that might interfere with KAPing. If this is not feasible an operator can examine existing aerial photographs of a project area and talk with field person about the layout of a project area. When discussing KAP projects with field personnel an operator needs to make it clear that a kite is often flown down range from the launch location, and in the event of a kite failure it is important to determine if there any hazards between the point where the operator is and where a kite could fail based on local wind direction.

On the night before a KAP session an operator should review the KAP equipment list to ensure that all equipment is accounted for and operational. In particular an operator should test all batteries which can be difficult or time consuming to replace or charge in the field. A back up set of batteries for all devices is strongly recommended because if a single battery fails an entire component can cease to operate.
operator should also make sure all camera memory chips are cleared prior to flight. If using CHDK confirm that the proper version of CHDK for the camera model, and the intended scripts are loaded. If feasible take the equipment through a "dry run" doing a simulated shoot with the camera mounted in its picavet. Also do an inspection of the kite, line and spars looking for any potential damage. A final check of the weather is also recommended.

Prior to departure for the KAP session it is recommended to use the following as a checklist for a basic KAP kit:

• Sutton Flow Form 16 & 30, 2 m (78 in) Rokkaku Kite, DoPero kite or Delta kite
• Fuzzy tails (used for added stability on Flow Forms)
• Halo Spool with 150 m (500 ft) of black, 113 k (250 lb). test line
• Halo Spool with 150 m (500 ft) of black, 68 k (150 lb). test line
• Heavy, but flexible, leather gloves
• Picavet suspension
• Carabiner/Brooxes Hang Ups
• Camera with extra memory chips
• Spare batteries
• Equipment box/bag with sewing kit, kite tape and spare parts
• Radio control transmitter/receiver if not using CHDK
• First aid kit.
• Cell phone.

Optional KAP equipment

• Anemometer
• Notebook computer/cables
• Apple Ipod (or equivalent) with photo transfer connection
• Any location dependent equipment needed: GPS, Maps, Aerial Photos, access authorization.
• Binoculars (useful for determining camera orientation)

On the day of a KAP project after checking the weather and arriving at the field the equipment should be taken out and set up. Prior to setting up a kite the camera and picavet should be set up, tested, and turned off until ready for attachment to the kite line. Then the kite is then assembled, and while holding the bridle with the kite flying or braced on the ground it should be examined for any equipment failures. If
operating the kite with a support crew an operator can do a review of kite flying safety and contingency plans in the event of a kite failure.

For a kite launch the operator and any support personnel should be wearing thick, but flexible leather gloves. If there is a kite assistant have them carry the kite about 20 meters downwind while instructing any unnecessary personnel to move out of way of the kite and the kite line. As a kite launches the kite and its line is at its lowest elevation and poses an immediate physical danger to anyone who might come in contact with it. Fly the kite for 5- 20 minutes to observe any turbulence that might interfere with KAPing and make adjustments to the camera settings/software as needed i.e. higher speeds.

Lower the kite to a point where the picavet can be attached. Confirm that the camera is on and that it and any servo batteries are operational. If using a remote control perform a test pan/swivel and shutter actuation and confirm that the camera settings are correct for this flight. Raise the kite to the operational height and position relative to the KAP target and being to photograph. If needed, lower the kite to access the camera and exchange the memory chip or batteries if needed and relaunch the kite. After KAPing is finished lower and retrieve the picavet being sure to securely wrap the picavet lines to prevent tangles.

If the wind speed is strong enough to make winding the line on the spool difficult an operator can "walk down" the kite. This is achieved by securing the kite line by either tying it off, or having the operator hold it in place and having an assistant use a carabiner hooked over the line and held in their hand to walk towards the kite forcing it to the ground. Once the kite is on the ground the line can be comfortably wound. While walking down the kite and winding the kite line be sure to inspect the line for any potential damage.

If there is any moisture on the kite hand dry or air dry it while it is still inflated/assembled. Then disassemble and pack the kite, and related equipment if there is to be a follow up KAP shoot within a few hours, and the winds at ground level are expected to be calm, a parafoil can be easily rolled and braced with a
heavy smooth object. For a structured kite removing the tension on several spars before laying it down with several weights on the fabric is recommended. An unattended kite can easily take flight and be destroyed so if there is any concern it is best to do a complete disassembly of the kite and storing it until again.

**KAP Hazards**

It can not be emphasized enough: kites can kill and seriously injure the operator and field personnel. If there are power lines which are in anyway within the flight path of the kite, do not fly. If power lines are present in the flying area, but are not in the flight path and a sudden change of wind forces the kite towards the line the first solution is to try and rapidly walk the kite down before it is within range of the power lines. If the kite has flown and is sufficiently above the power lines try to walk the kite back so that it can not dive and cross the power lines. If the kite is past the power lines and appears to be diving towards the power lines drop the spool and let it go, If the kite or kite line becomes caught in the power lines do not try to retrieve it yourself, call the local power company and they will come and remove it for you.

Kite line is very dangerous under tension. If a kite is flying in a strong wind an operator must be sure to not let body parts or equipment to get trapped between the line and another object as severe pinching can occur. If there is a sudden gust and the kite begins to rapidly pull out line, this line can easily slice through clothing or bare skin. Even with leather gloves a fast moving line can quickly build up uncomfortable amounts of friction heat.

The kite itself can also be dangerous, especially structured kite. If the winds are unpredictable and strong at ground level a kite can easily move laterally at high speeds and hit personnel or objects. This can be
particularly dangerous is the kite is down range and begins diving and any personnel are out of ear shot and they might not hear a descending kite.

Isolated thunderstorms are a potential hazard to KAP operators. As a general rule if you can hear or see lightning, do not fly. If an isolated storm cell forms just out of sight and appears quickly the best option it to bring the kite down immediately. If this is not an option try to secure the line to a fixed object (post, auto bumper, etc...) and seek shelter. If shelter is not available follow the general rules of lightning safety and make yourself the shortest object around by squatting if possible on a non-conductive material like a cloth field bag. Also avoid having your hands touch the ground as the path for electricity will be limited to your legs can help to avoid the major organs that an arm to ground path would allow.

The most frequent hazard to flying kites is having a kite crash land. A crash can result from a change in winds, the kite or line encountering an obstruction, a failure of a kite spar or fabric, or the severing of a kite line. While a crash can be inconvenient many kite crashes can be repaired in the field using kite fabric repair tape, spare spars, and spare (or less) kite line. Damage to photography equipment usually requires replacement with a spare camera. When a kite crash forces a kite into a tree top it is sometimes possible to retrieve the kite by throwing a weighted line over the line connected to the kite. If a kite is trapped on a canopy (Figure 61) contacting a local fire department can proved the operator with the name of a local arborist who can scale the tree and recover the kite and camera. If flying in an area with obstructions and a kite is at a high elevation and the line breaks quickly mark the location the operator is standing by and find and note a landmark on the horizon near the last location the kite is spotted. Using these two reference points the search area for the kite can be narrowed down to a useful scale.
Figure 61. Example of Dopero kite in tree top needing recovery by arborist. Photograph by author.
Chapter 9. KAP Results/Current Applications

As detailed in early chapters the convergence of high quality light weight digital cameras, CHDK and easily accessible kites with strong lift have produced an exceptional environment for a re-fluorescence of KAP. As other scientific fields have begun to re-discover, in the words of George Lawrence, this "hitherto impossible photography" has also begun to be applied to archaeology. A major goal of this thesis is to demonstrate that KAP is ready to be moved from an occasionally used tool in archaeology to a regular part of the archaeologist toolkit.

To test the equipment in a variety of settings I used my KAP equipment at several Hopewell sites in Ohio and Illinois including: Alligator mound in central Ohio and Albany Mounds in north west Illinois, an Adena mound in central Ohio, a Fort Ancient mound in central Ohio, Seip Mound and historic lighthouses on the Outer Banks of North Carolina.

Open area testing - Adena Mound at Highbanks Metro Park

Archaeology sites can be located at any point in the landscape which has the potential to limit the utility of KAP for photos of excavations. On a dense tree covered site with full foliage KAP will have little utility for photos of the excavation. Though KAP equipment can be easily modified to be used on a related photography platform, Pole Aerial Photography (PAP) which can be used in tight areas. If a clearing is located near to the site KAP can be used to acquire useful landscape views of the sites area within the environment.

For this project I selected areas where the archaeology targets were located in open fields, near trees, and under tree canopies.
For an open area target I selected an Adena mound located in Highbanks Metro park in Lewis Center/Columbus Ohio, not to be confused with High Banks Earthworks in Ross County, Ohio. This isolated mound is located about 1.1 miles east of the Olentangy River in an open area 50 acre field adjacent to the high traffic Polaris Parkway/State Route 750 corridor (Figure 62). A wide trail around the perimeter of the field provides an easy access point to stage and launch a kite. Because the mound is located centrally in the open area (Figure 63) any disturbance from the hardwood forest on three sides of the area were minimized and the wind was consistently steady for launches.

While photographing the Adena mound I tested an Olympus C740UZ, Canon S3IS with a manually operated servo shutter and picavet control and a Canon SD870IS running CHDK. I settled on using the Canon SD870IS because it is the lightest of the three camera, has the widest angle lens, 28mm, and it's operation is fully automated with CHDK. I used a GentLED Peanut to automatically rotate the picavet servo. I found that having the camera's operation to be fully automated allowed me to focus exclusively on flying and positioning the kite where I wanted it to be. I used both a Flow Form 30 and a Kites Dopero on different days of photographing this mound. As expected I found the Flow Form to be useful in stronger winds and when I did not need a high flight angle. The Dopero proved to be very useful for adapting to a variety of winds including winds much to low to lift the Flow Form. The high flight angle of the Dopero is useful for keeping the kite at a near vertical perspective directly over the target.

The kite could be easily moved to a different elevation providing a useful series of photos of the mound within its landscape. Figure 64 shows the mound from an altitude of approximately 22 m (75 ft). This low vantage point provides the researcher with a highly detailed view of the mound and its immediate location. Figure 65 shows the mound from an altitude of approximately 120 m (400 ft) with the camera oriented to the west. In this figure the mounds relationship to the Olentangy River valley, which is visible at the top of the photo, can be clearly established. Figure 66 shows the mound from an altitude of approxi-
mately 120 m (400 ft) with the camera oriented to the northeast. In this figure the mounds relation to the urban sprawl on the perimeter of the park is clearly established.

A useful comparison of the utility of KAP is to look at Figure 63 which is taken from the ground at a vantage point close to the elevated location of the camera in Figures 64 & 65. Similarly Figure 67 is taken at ground level oriented to the northeast as is Figure 66. In both of these comparisons the ability of the elevated camera to put the mound into a useful landscape setting is apparent.

Figure 62. High Banks Metro Park, Adena Mound. Lewis Center/Columbus Ohio. (Google-Earth 2008b)
Figure 63. Adena Mound in open field at Highbanks Metro Park. Photograph by author.
Figure 64. Adena mound. Camera oriented southwest at approximately 22 m (75 ft). Photograph by author.
Figure 65. Adena mound. Camera oriented west at approximately 120 m (400 ft). Photograph by author.
Figure 66. Adena mound. Camera oriented northeast at approximately 120 m. Photograph by author.
Figure 67. Adena mound. Camera at ground level facing northeast. Photograph by author.
Mixed woodland and slopes - Alligator Mound, Granville Ohio

To test the KAP outfit in a mixed woodland area associated with a sloping terrain that could introduce variable wind dynamics I choose Alligator Mound, a Fort Ancient effigy mound near Granville, Ohio (Lepper and Frolking 2003). The setting for Alligator Mound is on a bluff over looking Raccoon Creek within the village limits of Granville, Ohio. The mound is in a mostly open area surrounded by a cul-de-sac drive with a tree line or houses within 45 m (150 ft) of the target on all sides (Figure 69). To the south of Alligator Mound the terrain drops off towards Raccoon Creek. To acquire these photos the kite needed to be launched from the clearing near Alligator Mound and then the kite maneuvered to be able to include the Alligator Mound in the photos.
Figure 68. Alligator Mound, Granville, Ohio. (Google-Earth 2008a)
Figure 69. Alligator Mound, ground level panorama facing south. Photograph by author.
Figure 70. Alligator Mound, Approximately 23 m (75 ft) elevation. Camera oriented south. Photograph by author.
Figure 71. Alligator Mound, approximately 90 m (295 ft) elevation. Camera oriented west. Photograph by author.
Mixed woodland and open area testing - Seip Mound, Bainbridge, Ohio

To test the KAP outfit in a mixed woodland/open area I choose Seip Mound, a Hopewell Mound near Bainbridge, Ohio. The setting for Seip Mound is a principle mound in an open area surrounded by a low earthwork. There is a tree line within 45 m (150 ft) of the target. To acquire these photos the kite needed to be launched from the clearing adjacent to the mound and the kite maneuvered to be able to include the mound in the resulting photo.
Figure 73. Seip Mound, Bainbridge Ohio. (Google-Earth 2008c)
Figure 74. Seip Mound, Kite is at approximately 90 m (295 ft) elevation. Photograph by author.
Figure 75. Seip Mound, panorama of two images. Photograph by author.

Mounds in woodland setting testing - Albany Mound, Albany Illinois.

To test the KAP rig in a woodland area I choose Albany Mounds, a Hopewell mound site in northwest Illinois near Albany, Illinois. The setting for this target is a series of mounds underneath a tree canopy on a bluff overlooking the Mississippi River. To acquire these photos the kite needed to be launched from a clearing east of the tree line and the camera oriented to photograph the mounds at an oblique angle under the tree canopy.
Figure 76. Albany Mounds, Albany Illinois.
Figure 77. Albany Mound, ground Level. Photograph by author.
Figure 78. Albany Mounds, camera facing west at an approximate elevation of 20 m (65 ft). Photograph by author.
Figure 79. Albany Mounds, 4 image panorama. Camera facing south, west, and north at approximately 20 m (65 ft) elevation. Photograph by author.
Mixed woodland and coastal environment - Outer Banks, North Carolina

To test the KAP rig in a coastal environment and with historic structures I choose to document two historic light houses in the Outer Banks, North Carolina, the Bodie Island Lighthouse and the Currituck Lighthouse. The two lighthouse targets are located in slightly different coastal settings but both have the...
advantage of a more consistently clean and strong coastal wind for flight. The Bodie Island Lighthouse is situated in an open field surrounded by trees opening onto a small wetland area just north of Oregon Inlet. The Currituck Lighthouse is located in a dense setting of trees just east of Currituck Sound with access for launching a kite only available in a parking lot to the south of the lighthouse.

The Bodie Island Lighthouse is currently being restored by the National Park Service. This provides an excellent demonstration of the use of KAP to document different stages of work on historic structures.
Figure 81. Bodie Island and Currituck Lighthouse, Outer Banks, North Carolina. (Google-Earth 2010)
Figure 82. Bodie Island Lighthouse, overview. Wetlands and Atlantic ocean visible to the east in the background. Photograph by author.
Figure 83. Bodie Island Lighthouse, close-up detail shot. Photograph by author.
Figure 84. Bodie Island Panorama. Photograph by author.
Figure 85. Currituck Lighthouse, overview. Looking west from the Atlantic Ocean to Currituck Lighthouse on Currituck Sound. Photograph by author.
Environmental testing

One of my concerns about the limits of KAPing was the ability of KAP equipment to withstand the wide range of environmental conditions that archaeologists find themselves working. In particular CRM archaeologists who work under contract are required to work in all four seasons regardless of weather con-
ditions unless it is unsafe to be outdoors. I found through testing that under most conditions KAP can be adapted to work.

As a general rule if it is raining do not try KAPing. And as mentioned before if there is any chance of lightning, do not fly at all. If there is no chance to avoid days without rain in the KAP target area try to KAP between downpours as the weight of the water on the line and the kite have a negative effect on the kites ability to lift a load. Also kite line should never be stored wet, and drying 150 m (500 ft) of line can also be a challenge a KAPer needs to be prepared for.

KAPing over water presents many of the same challenges on KAPing in wet environments. The most fundamental issue is keeping a camera dry. If there is a chance of a camera being immersed in water, or soaked there are several light weight commercial solutions available. Products from Aquapac International Limited offer the ability to protect a camera from a complete immersion in water (Figure 87). Aquapac changed to PVC free plastics in 2008 and now use TPU, Thermo Poly Urethane, which offers advantages over PVC because it is flexible down to -40°C (-40° F). A challenge of using waterproof cases is that a manually operated servo can not be used to fire the camera because of the wire connections. As a result a camera can only be used with either CHDK, GentLED remote, or an internal intervalometer if it is in a waterproof bag. A camera's tripod socket is also not accessible to an outside connection when in a waterproof bag so the bag will need to be attached to the picavet with cable ties or other fastener. Because servos, receivers and battery packs are connected with wires there is no easy solution for protection from complete immersion. These parts can be protected from intermittent exposure to rain, but if the picavet is submerged it is likely that any of the exposed electronic products will be destroyed. In the event a digital camera is submerged and ruined there is a good chance that the solid state flash memory chip will retain the data from your KAP session (BBC News 2004)(Gilloly 2006).
Cold weather KAPing is a challenge because not only can a KAP rig get wet, as discussed on page 104 cold weather can have a negative effect on battery life. Readily available Nickel Metal Hydride (NiMH) and Lithium batteries are the best choice for use when working in extreme cold temperatures. During flight testing of this KAP rig, I was able to achieve good performance of a Canon S3IS camera with 4 NiMH 2500 mAh batteries at a temperature of -12°C (9°F) in a 40 kph (25 mph), winds with a wind chill of -24°C (-12°F) for a 30 minute flight acquiring 950 aerial images. Wind chill does not effect the operational
capacity of a battery, it does have an effect on operators and proper clothing must be worn to allow for free movement while protecting the operator.

In more extreme conditions a light weight activated carbon “hand warmer” sandwiched to the body of the camera with a light insulation such as styrofoam can help to provide extra heat to maintain the battery pack and a usable temperature. In general practice KAPers in cold weather will keep batteries in either a warm vehicle or under clothing to minimize exposure to the debilitating cold temperatures.

KAPing, other archaeological applications

In 2007 I found out that an archaeology friend was heading to the remote island of Nikumaroro in the south pacific to look for further archaeological evidence of aviation pioneer Amelia Earhart and Fred Noonan. The International Group for Historic Aircraft Recovery (TIGHAR) hypothesizes that when Earhart and Noonan could not find Howard Island on their around the world flight they flew their Line of Position of 157-337 degrees and crash landed on, or near, the uninhabited Gardner (now Nikumaroro) island (King 2001).

I was able to arrange for a Sutton Flow Form 16 and 30 and a Brooxes' Basic Kap Kit picavet to be donated to the TIGHAR project by Brooks Leffler of Brooxes.com as well as arrange for training for their field crew by inventor David Wheeler in the use of KAP. The TIGHAR team was able to utilize their KAP rig during their 14 days on Nikumaroro with excellent results in documenting the island and its environments (Figure 88 and 89). Because of the density of growth on the island the TIGHAR crew needed to KAP from both a boat (Figure 90) and standing in the ocean (Figure 91).
TIGHAR has continued to utilize KAP on other projects. When a chance discovery of a P-38 Lightning off the coast of Wales in 2007 presented an opportunity for TIGHAR to document and preserve this plane they used KAP to document its condition in the water (Figure 92).
Figure 88. Nikumaroro Island, Seven Site. Possible location of Amelia Earhart and Fred Noonan camp.

ⓒ TIGHAR.
Figure 89. Nikumaroro shipwreck showing island drop off. © TIGHAR.
Figure 90. TIGHAR staff KAPing on Nikumaroro. © TIGHAR.
Figure 91. TIGHAR staff KAPing from the water. © TIGHAR.
A long time KAP collaborator and archaeologist Mark Willis has been active in promoting the use of KAP in Texas and other areas. Mark uses both blimps and KAP to document archaeology sites, but most frequently uses KAP because of its wide range of application and ease of deployment (Figure 93) and its in-

Figure 92. Maid of Harlech, P-38 Lightning aircraft discovered off the coast of Wales in 2007. © TIGHAR.
teroperability with other technologies (Figure 94). Using KAP with other technologies Mark has been able to create detailed educational 3 dimensional fly-throughs of archaeological sites (Miller 2008).

Figure 93. The John A. Hedrick site, LA 91220, in southern New Mexico. KAP of room blocks by Mark Willis. (Mercado-Allinger 2006)
Figure 94. Mark Willis KAP photograph composite. This overview demonstrates how KAP images can be combined with other technologies to illustrate how prehistoric art is situated in the landscape. A KAP overview photo (center) and zoomed detail of petroglyphs (left) are superimposed on a surface map of a petroglyph site (Dial and Smith 2008)
Chapter 10. Feasibility of a remote controlled powered parachute KAP

As an supplement to conventional KAP I experimented with building a remote controlled "Powered Parachute" derived platform for acquiring low level aerial photographs for archaeology in areas where there was no wind, or a target could not be reached because of the direction of prevailing winds. This flight system consisted of a ram-air parachute tethered to a picavet with a gasoline powered .40cc engine. In this configuration the engine speed controls elevation while two servos control direction. This design is based on the a smaller version of the hobbyist ultra-light Powered Parachutes which typically have a carrying capacity of one to two people (Hailey 2005) (Hailey 2002).

The powered parachute design was chose because it offers several advantages over R/C airplanes and R/C blimps. Powered parachutes represent a potential ideal mix of the advantage of kites while reducing the complexities of model airplanes/helicopters. The disadvantage of a powered parasail is that it is dependent on fuel or limited duration batteries for engine operation.

During the initial design stage of a remote controlled powered parachute I became aware that a company in Illinois, AirFoil Aviation, had just begun producing an R/C model powered parachute that fit the characteristics I was looking for in this platform. I purchased a 1/4 scale model with an advertised lifting capacity of .68 - 1.3 k (1.5 - 3 lb), a potential speed of 24 kph (14 mph), and a flight time of 45 minutes (Figure 95) (AirFoil-Aviation 1998).
On the first flight of the Airfoil Aviation powered parachute (CAST I) its greatest weakness became apparent when the fuselage snapped in two while landing. The problem was that the manufacturer had choose to build the fuselage out of aircraft grade spruce that was not strong enough to survive a hard landing. In addition to the weakness of the fuselage the propeller used was a traditional wooden design which also broke or was damaged easily.

The repair process of the fuselage began a long cycle of rebuilding and modifying the powered parachute platform. Because one of the goals of this project was to create an aerial platform that was capable of
being flown by novice flyers the fuselage needed to be built strong enough to survive crashes and be field repairable.

The powered parachute went through three major design stages. A significant problem that was encountered was that the airspeeds that the powered parachute was capable of generating during crashes, which were frequent, could easily break the wood frame. The fuselage was rebuilt out of heavier wood, which was reasonably durable, but still broke under extreme conditions and with the increased weight of the wood it left no weight capacity for carrying a payload. The fuselage was then constructed out of aircraft grade aluminum but was so heavy that while it could fly, and was durable, it had no extra capacity for carrying a payload.

The final version of the powered parachute was CAST IV (Figure 96). CAST IV was constructed using lighter weight aircraft grade aluminum for the fuselage and a fiberglass prop protector with plastic push-prop. The design proved to be exceptionally durable and easily handled several very rough crash landings.

An unknown obstacle during the testing of all of these models of the CAST powered parachute was the design of the parachute initially provided by Airfoil Aviation. It was not until the final stages of flying CAST IV that I became aware of the variety of kite types used by hobbyists which might prove to be more stable. After consulting with other kite fliers I determined the they style of kite that was being used for the powered parachute, which is derived from a parachutes style that was being used was more for acrobatic sport flying, was likely not the best choice for my goal of a very slow moving stable platform.
Unfortunately before a different kite parachute could be tested on CAST IV the powered parachute was lost in a flying accident which also proved to be a learning lesson. While performing the final pre-camera flight test I was eager to get the powered parachute up even though winds were out of a different direction than usual and much stronger than usual. From what Airfoil Aviation had advised the weather was still within the operational range of the powered parachute. What I learned was that while wind speeds at ground level might be acceptable, the winds associated with a weather front, can vary dramatically in as
little as 150 m. CAST IV was caught in a strong wind and when I realized it was being pushed out of the limits of my radio I forced it to gain altitude by accelerating to give me time to track it. Even with the aid of a Columbus police department helicopter I was not able to locate CAST IV.

Because of the difficulty in building, maintaining, and flying the powered parachute I choose to stop that path of research. I then began to look at applying traditional kites to aerial photography for archaeology projects which comprises the bulk of this thesis.

**Challenges of Remote Controlled Powered Parachutes**

I did learn several valuable lessons from the endeavors with the CAST powered parachutes. The first thing I became very aware of was that fuel based R/C engines are very messy. Because the fuel has an oil additive it does not fully evaporate like auto fuels. As a result if the fuel is spilled anywhere a difficult to remove oily residue is left after initially wiping it off. A byproduct of the fuel is that the exhaust is also very oily and if there is any spatter from the exhaust, especially from chaotic wind during flight, keeping camera equipment free from the fuel is difficult.

Powered parachutes use a "push" configuration of the engine with the propeller being located at the back of the fuselage with no protection from the propeller blades. Without assistants to hold the parachute above the intake force of the propeller the shroud lines are easily pulled into the wash, or pushed in by a random burst of wind, and cut by the propeller. I experimented with different types of shroud line, including Kevlar, and all types suffered about the same degree of failure. Kite line must be kept at precise lengths so when a line was cut field repairs could be time consuming. Exhaust spray was another problem during launches and it frequently would coat the porous kite line.
Starting a fuel based engine can be very problematic, especially if the weather conditions are cold. Often while working with CAST powered parachutes in cold weather I would have to keep the car running and warm the engine in the cab of the car. I would then need to start the engine near the car, to prevent it from cooling down to much, and transport it with the engine running to the launch point.

The R/C powered parachute was advertised as being capable of launching like the full size versions. The challenge is that this almost always required assistants to help hold the parachute while the operator controlled the engine speed. The model was advertised as being able to be hand launched, but to be consistent this required an assistant also.

All models of CAST that used wooden propellers experienced a high failure rate of propellers breaking, even during non-traumatic landings. When the powered parachute touched down and if blade dipped low enough to touch the ground a section of it could be knocked off, if not broke. Because a propeller needs to be properly balanced even a small piece missing would require a prop change. The propellers used were also not a kind found routinely as hobby shops. With the engine oriented backwards to a typical airplane configuration the propellers used are “push” propellers and have a different design than a standard propeller. In a pinch a standard propeller could be used, but with a greatly reduced amount of torque.

As an alternative to wooden propellers I experimented with plastic propellers. Plastic propellers produce more thrust and are more durable and better able to withstand light impacts. The tradeoff is that plastic propellers have a very sharp edge and more easily cut kite lines and do serious bodily injury if a body part contacts the blade.

There are a number of batteries to be concerned about for all of the parts of the system to work properly. If any of these fails to hold a charge it can ruin a photo shoot and limits this platforms appeal for remote
location use. The traditional battery packs used on R/C platforms also takes up a significant portion of the limited carrying capacity of the powered parachute. Since the testing of the CAST Models Lithium Polymer (LiPo) batteries which are much lighter, and carry a greater charge than traditional batteries, have become available which might negate some of these concerns. The disadvantage to LiPo batteries is that they are still quite expensive and require very precise charging systems.

I conclude that gasoline powered parachutes, when configured properly and operated by an advanced hobbyist with a support team does have an applications in aerial archaeological reconnaissance. The ability to fly untethered is an appealing asset, as is the potential to fly predictable flight patterns over a project area. The disadvantages discussed above though preclude me being able to recommend the powered parachute as a aerial platform suitable for a project of limited finances, or time to learn. If an environment exists where KAP, BAP or related technologies will not work it might be useful to explore.

The potential for an alternative to the R/C fuel based powered parachutes does exist with the advent of the LiPo batteries. R/C airplanes are able to get 15 minutes of flight time on a single fast charge of the engines battery.

The battery powered engines offer several advantages over the fuel engines. The lack of fuel and its by products is a huge asset to getting high quality images, and keeping the camera equipment intact. The electric engines also provide an "instant on" power which negates trying to start cold fuel engines and keep kite line free while the engine is brought through its warm up process.
Chapter 11. Conclusions

This thesis consisted of a survey of Kite Aerial Photography (KAP) systems as a fast, easy to implement, low cost, near earth aerial photo system using consumer cameras for archaeology excavations and surveys in a variety of environmental areas and conditions. Archaeologists routinely need time sensitive aerial images of excavations or survey areas but the cost or logistics of using manned airplanes/ helicopters, R/C blimps or R/C airplanes makes these options unusable.

This thesis demonstrates that with limited training and investment an archaeologists can acquire highly detailed aerial imagery of a survey area at a variety of altitudes. Because of the ease of use of KAP it is an ideal tool for all levels of archaeology from field schools through Cultural Resource Management operations.

A traditional R/C KAP kit which includes an R/C transmitter and receiver has many applications in archaeology but it is limited in broad application for several reasons. A traditional KAP is more technically complicated, requires frequent recharging, and needs at least two operators for a safe and successful flight. A basic autoKAP kite consisting of a kite, line, picavet and CHDK camera is an exceptionally accessible approach to quickly gathering aerial photos of an archaeology project. Because of the low weight, easy of transport, and limited battery requirements a basic KAP kit is also applicable for very remote survey and excavations. A variation of the AutoKAP kit, the recently developed KAPerchief, is the most portable of all KAP systems and is useful in acquiring aerial images where only plan or limited oblique views are necessary.

The KAP equipment described in this thesis can be put together for under $600 providing a research group with a fully functional and easy to operate KAP system. A great strength of this system is that be-
cause it is straightforward to operate a number of individuals with moderate technical skills can be quickly trained to accurately use the KAP kit. This allows a research project to easily aerially document a project's progress before, during, and after research. In certain cases a KAP can even be used for feature level documentation during an excavation. While it is possible to use KAP to create georectified images (Peel and Willis 2008) this thesis did not cover that topic.

There is no one single near earth aerial photography platform that will fit the needs of all situations an archaeologist might encounter. But KAP is an economical and accessible technology that is ready for broad use in archaeology.
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