8-2013

Assessing the Axis 221 Camera Onboard the UTSI Piper Navajo to Capture Manatee Images

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To the Graduate Council:

I am submitting herewith a thesis written by Coral Lee Franklin entitled "Assessing the Axis 221 Camera Onboard the UTSI Piper Navajo to Capture Manatee Images." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Aviation Systems.

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Assessing the Axis 221 Camera Onboard the UTSI Piper Navajo to Capture Manatee Images

A Thesis Presented for
The Master of Science
Degree
The University of Tennessee Knoxville

Coral Lee Franklin
August 2013

DEDICATION

This thesis is dedicated to my mom and dad for encouraging me to try new things and teaching that it's okay to fail. Thank you for your constant love and support. And to Lee Leonard, thank you for being you.

ACKNOWLEDGEMENTS

I would like to thank Dr. Stephen Corda, Devon Simmons, Sam Williams, Julien Martin, and Holly Edwards for all input and patience. I would also like to thank Dr. Peter Solies, Prof. Borja Martos, and Dr. Monty Smith for their advice and service as committee members. And finally, thank you to University of Tennessee and NOAA for this opportunity.

ABSTRACT

Researchers in Florida are attempting to improve the methods of collecting data for manatee population surveys. Standard line-transect survey methods are not appropriate for the narrow warm-water aggregations sites where these surveys are to take place. Researchers hope to obtain population estimates at three warm-water manatee refuge sites: TECO (Tampa Electric Company), FPL (Florida Power Plant, Cape Canaveral), and the Three Sisters Sanctuary (Crystal River)

The purpose of this study was to determine whether or not the Axis 221 Camera onboard the UTSI Piper Navajo is adequate for obtaining suitable images for use in population estimates. In order for the system to be determined useful, the flight tests must show that the following criteria is met. First, the video system must be capable of capturing images with sufficient quality to distinguish and count manatees while flying within the given parameters. Second, the flight team and equipment must be capable of flying the necessary flight paths while capturing the required area.

Third, the aircraft and team must be capable of flying the desired flight paths in a timely manner, to accommodate for manatee behavior and time at surface. And finally, the system must be capable of capturing surface temperature. The last two criteria (timeliness and surface temperature) are necessary information for researchers to determine a detection probability.

The data collected during two local flight tests was analyzed to assess the video system and flight team. Flight test one collected video of a parking lot and runway using objects of known size to estimate video quality. Surface temperature was also collected. Flight test two collected video over a waterway to assess the cameras field of view and the timeliness of the mission. Results indicated the flight team and video system will be sufficient for a future Florida mission at an altitude of 300 meters (about 1,000 ft).

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NOMENCLATURE

℃	celsius, degrees celsius
℉	fahrenheit, degrees Fahrenheit
Ft	feet
Hz	hertz
in.	inch
kg	kilogram
km	kilometer
m	meter
mA	milliAmp
mm	millimeter
p	roll rate
q	pitch rate
r	yaw rate
V	Volt
$\propto$	angle of attack, degrees
β	sideslip angle, degrees
Δ	change
µ	micro
θ	azimuthal angle, degrees
ρ	density, mass/volume (ie. kg/m^3)
ϕ	bank angle, degrees

ACRONYMS

AC	Advisory Circular (issued by the Federal Aviation Administration)
AGL	Above Ground Level
AHRS	Attitude and Heading Reference Sensor
ASL	Above Sea Level
AvSys	Aviation Systems
AWOS	Automated Weather Observation System
DAQ	Data Acquisition
DAS	Data Acquisition System
FS	Fuselage Station
FTE	Flight Test Engineer
GNS	Global Navigation System
GPS	Global Positioning System
ILS	Instrument Landing System
NASA	National Aeronautics and Space Administration
NI PXI	National Instruments PCI Extensions for Instrumentation
NOAA	National Oceanic and Atmospheric Administration
PB	Precision Barometer
PPT	Precision Pressure Transducer
SEPS	Supplementary Electrical Power System
UDP	Universal Datagram Packet
UMPC	Ultra Mobile Personal Computer
UPS	Uninterruptible Power Supply
UTSI	University of Tennessee Space Institute
VOR	Very High Frequency Omni-Directional Radio Range
WAAS	Wide Area Augmentation System

Introduction

The manatee has been listed as endangered since 1967 and continues to face serious threats from boat collisions and habitat destruction throughout its Florida home. This slow-moving mammal lives in both fresh and brackish waters and feeds on floating sea grasses and sub-aquatic vegetation.

Manatees tend to gather in warm-water aggregation sites when open bodies of water get colder (below 21° C). Researchers are interested in obtaining better population estimates, as well as information about how thermal preference influence manatee use of these warm-water sites.

Line-transect methods have been the predominant method for wildlife population estimates. Unfortunately, the warm-water gathering sites are narrow and irregularly shaped, making line-transects impossible.

Improved methods are being developed to tackle this problem. The study done for this paper was an attempt to contribute to the development of a faster, easier, and less expensive method to count manatees. To be specific, the study determined whether the University of Tennessee Space Institute's Piper Navajo with onboard Axis 221 Camera will be a helpful tool in future Florida manatee surveys taken at the following warm-water manatee refuge sites: TECO (Tampa Electric Company), FPL (Florida Power Plant, Cape Canaveral), and Three Sisters Sanctuary (Crystal River).

In addition, measurements of surface temperature will be collected. Surface temperature can be used to model the distribution of manatees as a function of surface temperature (probability of detection can also be modeled as a function of temperature). Finally, the imagery and temperature data could be used to assess the warm water capacity of warm water sites for manatees.

Problem Statement

Better methods of data collection are needed for manatee surveys at warm-water aggregation sites in Florida.

Requirements

- Determine if the video system is capable of capturing images with sufficient quality to distinguish and count manatees while flying within the given parameters.
- Determine if the system is capable of capturing surface temperature.
- Determine if the aircraft and team are capable of flying the desired flight paths in a timely manner.
- Determine if the flight team and equipment are capable of capturing the required area while flying the necessary flight paths.

Methods

1. Perform flight test one over a local parking lot and runway, which have objects of comparable size and shape to a manatee. Data collected will be analyzed to determine if:
    a) The video system is capable of capturing images with sufficient quality to distinguish and count manatees while flying within the given parameters.
    b) The system is capable of capturing surface temperature information.

2. Perform flight test two over a local waterway. Data collected will be analyzed to determine if:
    a) The aircraft and team are capable of flying the desired flight paths in a timely manner.
    b) The flight team and equipment are capable of capturing the required area while flying the necessary flight paths.

The work performed for this thesis was developed in response to the need of the Florida research team to acquire raw counts of manatees via georeferenced video and surface temperature. Altitude was also needed as an input for their statistical software called Distance. Flight tests were designed by the flight team (which the author was a part of); data reduction and analysis were done by the author. Pre and post-flight briefings were done to ensure the proper video and data were recorded. Microsoft Excel was used to reduce and analyze the data. Video was viewed and edited using Windows Movie Maker. Measurements of the runway markings were taken by hand using a measuring wheel, and compared to Federal Aviation Administration (FAA) standards for markings used on airport runways and taxiways. Parking lot measurements were taken with a measuring tape. Measurements were taken several times to ensure accuracy. Images were analyzed for resolvability using these measurements and considering a set of metrics developed by the author. Monitors of various size and resolution were used to view images.

Results showed that resolvability reduced with increasing altitude. Objects 1.8 meters (6 feet) long spaced at <0.6 meters (<2 feet) were resolvable at 300 meters (1,000 feet). Other altitudes tested were 600 and 900 meters (2,000 and 3,000 meters). Objects of 1.8 meters (5.75 feet) were partly resolvable at these higher altitudes. These results indicate that manatees could be counted at future Florida test locations at an altitude of 300 meters (1,000 feet).

Chapter 1 Literary Review

Chapter 1 Section 1 Manual Counting

Manatee survey methods have changed considerably over the years. Researchers in the 1970's used synoptic surveys to get an estimate of manatee population. Observers would look out an aircraft and manually count the observed manatees as the plane flew over an entire area of interest. This was costly and time consuming. Large areas needed to be covered and highly populated areas needed to be flown over several times. Reviews of the method found that the synoptic surveys did not give accurate or statistical estimates of manatee population. Instead they only gave a minimum estimate. Reviews did find that the synoptic survey method may be useful in detecting changes in population and habitat use [1,2,3].

Chapter 1 Section 2 Statistical Methods

A statistical approach known as aerial line-transects survey, was developed to deal with the negative reviews of the synoptic method. This statistical approach known as distance sampling encompasses several related methods for estimating the density and abundance of biological populations. The line-transect method appears to be the most popular among manatee researchers. Here, the observers perform a standardized survey along a series of lines, searching for manatees. When a manatee is detected, the manatee and the distance from the line to the manatee are recorded. The distance from the line then becomes a factor in statistical calculation as to the likelihood of detection [4].

A fundamental assumption of distance sampling is that all objects that are on the line will be detected. However, this is not always the case. Factors such as visibility and depth below the water make some manatees more difficult to detect. In order to deal with this dilemma, a detection function must be fit to estimate the proportion of objects missed by the observer [4]. Then, after the sample representative portion of the total study area is surveyed by flying the series of lines chosen to represent the area, the detection function is used to statistically extrapolate the density or abundance for total area [4,5,6].

Using the line-transect method, rather than synoptic surveying has the benefits of using less flight time and a lower cost. Also, the easier navigation results in less fatigue for the observer(s), and an increase in counting accuracy [5, 7, 8].

The detection function is represented as $g(x)$; where x is the perpendicular distance between the object and the transect line. In conventional line-transect theory, where it assumes that all objects on the transect line (at the distance $x=0$) are detected, this is written as $g(0) = 1$ [9].

A detection function where an object on the transect line is not necessarily spotted is written as $g(0) < 1$, or it is sometimes seen as $p(x)$, for the probability of detection at distance x. For example if a manatee on the transect line is unavailable for detection because it is underwater, then the $g(0) < 1$. This is known as an availability bias. A perception bias occurs when an observer fails to detect a manatee even when it is available for detection [9].

Capture-recapture is another method used in population studies. For this method, a sample of manatees is captured, each manatee is given a unique marker, and then released. Later, a second sample is captured. Individuals in that sample may already have a tag, because they were in the first sample, or this may be their first capture, in which case they are tagged, and the entire sample is again released. The process is repeated until the end of the study at which point all captured subjects have a capture history. For example, if there were five captures and an individual was captured on the second and third capture, its history is 0 1 1 0 0 [10].

In 1999 Schwarz and Seber published Estimating Animal Abundance: Review III. The paper reviews line-transect and capture-recapture techniques, as well as a variety of statistical models used in combination to estimate population size. They determined that a common problem with these studies is choosing an appropriate model [10].

A comprehensive review of the common population study models such as Bayesian methods, Expectation-Maximization (EM) algorithms, and Monte Carlo Markov chain methods, Horvitz-Thompson estimators, state-space models, generalized linear models, models using the concepts of over dispersion, covariates, quasi-likelihood, profile likelihood intervals, random effects models, and estimating equations can be found in Schwarz and Seber 1999. Although these concepts go beyond the scope of this introduction, it should be understood that a large number of population study models have been developed using these statistical methods [10].

In brief, model selection criteria are based on the variables believed to be factors in detection probability. Furthermore, different models create different shapes, therefore, an understanding of what shape to expect from a population study is a requirement in model development [10].

Logistic regression is often used in abundance estimation. These models are based on the assumption that if p_i can be estimated then N can be estimated. Where N is the population size and p_i is the nonzero probability that the i^{th} individual is sighted or captured [10].

A logistic function of the form found below in equation (1), is commonly used because it has the desired shape. Figure 1 is used to demonstrate the shape of logistic function.

$$\mathrm{p(x)} = \frac{e^{\Omega x}}{1+e^{\Omega x}} \qquad (1)$$

In equation (1), Ω is a parameter to be estimated and x represents distance. If equation (1), has unmodelled heterogeneity, which is the term used when the model does not factor all applicable covariates, more covariates can be factored in. Equation (2) gives an example this.

$$\mathrm{p(x,z)} = \frac{e^{\Omega_1 x+\Omega_2 z}}{1+ e^{\Omega_1 x+\Omega_2 z}} \qquad (2)$$

In equation (2), Ω_1 and Ω_2 are parameters to be estimated. They are used to estimate the variables such as distance (x) and size (z). Figure 1 shows a logistic function with two covariates, like equation (2). In figure 1, distance to the object is plotted on the x axis, size of the object is plotted on the y axis and detection probability is found on the z axis [9].

Statistical models used to estimate population from line-transect surveys hinge on the development of an accurate detection function. Many methods of doing this are mentioned above. Fortunately, a reference written by Buckland et al is widely accepted. [11]. The authors of this paper, along with several other collaborators have developed a software package called <u>Distance</u> which is documented by Thomas et al. (1998) and Thomas (1999) [12, 13].

Chapter 1 Section 3 Past Studies

Several papers discuss line-transect methods are combined with other methods. In 1998, Miller, et al. published their paper: An Evaluation Of Strip-Transect Aerial Survey Methods For Monitoring Manatee Populations In Florida [14]. In this study, the strip-transect method and statistical modeling were combined to estimate manatee population size. The Petersen mark-recapture model was then applied to their counts to correct for perception bias [15,16].

Langtimm, O'Shea, and Beck (1998) use this method for a manatee survival study. They describe the basic assumptions of the classic CJS open population model: (1) every individual has the same probability of survival between samplings; (2) every individual has the same probability of being sighted at least once during the sampling interval; (3) the sighting of an individual is not dependent on the sighting of another individual; (4) every individual is identified correctly; (5) sampling time is negligible [17, 18, 19].

In 1993 Buckland published a paper where he and his team combined the line-transect method with a logistic model, using appropriate covariates, to obtain a correction for undetected whale pods in line-transect sampling [11]. In 1998 and 1999 studies were published where researchers combined the line-transect method with multiple observer information to increase their probability of detection [20, 21, 22].

Using multiple platforms for observation was another approach to sea-life surveys [23]. Dual observers on multiple platforms could combat problems such as animals moving [23]. Hibey and Lovell used this approach when they surveyed a section of the North Sea using tandem aircraft [24].

In order to apply the line-transect method to this large area, the team first stratified the survey area into blocks using logistical constraints and accounting for existing information on the distribution and relative abundance of the species of interest. Figure 2a shows the blocks chosen for Hibey and Lovell's North Sea survey. Parallel lines along a common axis were used to further organize the survey area. Next, zigzag tracks were selected for the flight path (See figure 2b) [24, 25].

The tracks in the Hiby and Lovell studies were designed to give more mean coverage in areas of expected highest density and less mean coverage in areas of expected lowest density. Inevitably, the coverage across a block varied in response to the shape of the block boundary, but the variation was minimized by adjusting the orientation of the common axis [24, 25].

In 1999 Hiby went on to developed the very popular Hiby circle-back method, which is used to estimate g(0). In this method, standard single plane line-transect methods are modified by having the plane circle back and re-survey a portion of the track line. The criterion that initiates a circle-back can vary depending on the abundance, size, and other factors of the animal being surveyed [9].

The Beaufort Sea State Code is a scale used to describe sea conditions; it is another consideration during population surveys. For most species, Beaufort Sea state conditions from 0-4 are usable. Beaufort Sea States beyond 4 generally cause too much decline in detectability. Beaufort Sea state 0 is mirror like condition, wind speeds under 1 knot, vertically rising smoke and 0 foot waves. Sea state 1 has ripples present, wind speeds of 1-2 knots; smoke has visible motion, and 0.33 foot waves. Sea state 2 has small wavelets all over, with no whitecaps. Wind speeds are 4 - 6 knots (enough to rustle leaves and feel on exposed skin), and waves are 0.66 feet. State 3 has Large wavelets with a few white caps, wind speeds of 7-10 knots (leaves and twigs in constant motion), and waves of 2 feet. State 4 has small waves with fairly frequent white caps, winds of 11-16 knots (enough to raise loose and dust and to move small branches). Wave height is 3.3 feet. [25, 26, 27].

As mentioned above, the Hiby circle-back method was used in many studies. One study was in 2002 using the NOAA Twin Otter Aircraft to estimate the abundance of cetaceans and turtles in the North Atlantic from Long Island, New York up to the Bay of Fundy. Another circle-back study was the 2010 North Atlantic Shelf Marine Mammal and Turtle Aerial Abundance Survey; part of the AMAPPS project (Atlantic Marine Assessment Program for Protected Species). The NFSC (Northeast Fisheries Science Center) used the popular method to estimate abundance of cetaceans and turtles in waters north of New Jersey and shallower than 2000 meters [28, 29].

A secondary objective in these two studies was to investigate how the animal's distribution and abundance relate to its physical and biological ecosystem. For example, during the 2002 study, researchers also collected surface water temperature information to be used in a description of the habitat of the different species of cetaceans and turtles. Similarly, by studying manatee distribution and abundance researchers have found that manatees tend to be found in narrow, irregularly shaped bodies of water in Florida. They also congregate in warm-water outfalls of power plants and natural springs when larger bodies of water get cold. Many of these areas cannot be studied using the line-transect method, due to their size and shape [15, 16, 30 - 37].

Chapter 1 Section 4 Florida Specific Manatee Studies

Intense aerial surveys of these small, well-defined winter-aggregation sights have been used to estimate minimum population counts [3, 15, 33, 34, 38, 39, 40]. However, obtaining accurate, unbiased, or precise population is

difficult. This is because only part of the area may be sampled, so not all the manatees are present be counted [41]. Also, the area is not sampled in a random or stratified-random design, so it is impossible to extrapolate results to areas not covered in the survey. And finally, counts obtained from surveys are not adjusted to account for imperfect detection of manatees by the observers [30].

A survey by Edwards, H. et al. was conducted by making several aerial passes around the Tampa Electric (TECO) Big Bend power plant before and after the passage of major cold fronts. The team coupled these surveys with mark–resight analytical techniques, where manatees were captured and marked with unique large marker flags, which could be seen from the air [30].

Thirty minute flights were conducted in the morning and afternoon of survey days. This allowed 10 passes over the canal and observers had one minute to count manatees during each pass. The area was circled until the observer was satisfied all manatees had been counted. Photographs were not used in this study [3].

Using the counts from the flights along with some previous knowledge, the team made several estimates. They estimated the probability that a manatee will be present at the power plant, the probability that a manatee will be available to an observer, the probability that an observer in a plane will detect an available manatee, and the number of manatees presents [30].

Water temperature was an important factor in the first estimate; the probability that a manatee will be present. Manatees and dugongs are of the sirenian order, unlike whales, for example, which are of the cetacean order. Sirenian are not well adapted to the cold water (below 20 degrees Celsius). As expected the study found more marked manatees in the warm-water refuge when the mean ambient water temperatures were coldest. "The important point is the relationship between probability of use and temperature, not the absolute estimate of the probability of being present at the plant [30]."

Understanding availability is important to understanding detectability. To estimate the probability that a manatee would be available to an observer they used a dive profile method in addition to the mark-animal method. The dive profile method used time-depth-temperature recorders (TDRs) to calculate the depth and the percentage of time each manatee was deeper than 1 meter. This was similar to a study used to count dugongs [42]. Even though manatees at warm-water sites may rest on the bottom for up to 20 minutes [30, 31, 46], both methods found a high probability of detection availability, but still < 1 [30].

The team did not consider variations in detection by individual observers to be a factor when estimating the probability that an observer in a plane will detect an available manatee. They did consider weather conditions [43, 44, 30]. Due to the established observation that individual manatees often go from one group to another the detection of one individual is independent of the detection of another [31, 45, 30].

Finally, the number of manatees present at the plant was estimated using the overall detection probability to adjust the mean counts of manatees recorded during the flight. They found that the mean number of manatees present over a flight series was 45% to 96% greater than the mean of the raw counts. In actual counts this works out to an increase of 42–177 animals [30].

Chapter 1 Section 5 Unmanned Aircraft

Another development in the population studies is the use of unmanned aircraft. Although manned aircraft are very useful for wildlife surveys, they are expensive, they disturb wildlife, and safety can be an issue. Also logistics can impede surveys for a larger manned aircraft [47, 48]. UAV (unmanned aircraft vehicle) or UAS (unmanned aircraft system) surveys can be less expensive, make a smaller ecological footprint, are safer, and some are able to collect high resolution geo-referenced pictures without a human observer [47, 48].

Pierce, Pearlstine and Percivel published their study on using UAVs in 2006. A significant feature of the UAV was its ability to fly low-altitude flights in small areas. UAVs can also collect highly detailed images at a more biologically distinguishable level than higher altitude manned flight images [48].

The team was able to complete over 30 missions covering an average of 13 linear km, before engine trouble caused a crash damaging the UAV. The successful missions captured high-quality, progressive-scan videos of a number of wildlife species including the Florida manatee (Trichechus manatus) [48].

The team used a prototype UAV known as the FoldBat, which was built for them by the MLB Company in Mountain View, California. The FoldBat could fly autonomously. It had a wing span of 1.5 m, flight time of approximately one hour, a 13 km telemetry range, and could fold up to be stored in a case small enough to take on commercial airlines as checked luggage. The accessories used needed a separate storage case, which was also small enough to take as checked luggage [48].

The team attached three cameras for the study; two downward looking cameras and a forward looking camera. A moving map to track the aircraft's location, speed, heading, and altitude was displayed in real time by the operating system. Live video capture was also displayed [48].

The UAV used a pusher engine to avoid noise and image interference. A laptop computer was needed for take-off and landing controls, but the majority of the flight was flown autonomously with preprogrammed software. This feature ensured more consistent flights and reduced training needed for the controller. The software allowed control of heading, airspeed, altitude, pitch, roll, and yaw. The autopilot was integrated with a Global Positioning System (GPS) receiver, an accelerometer-gyro system, and a pressure altimeter. With this system in place, the team estimated position error of less than 1 m at an altitude of 90 m. In other words, using the downward cameras they could know the images position to within 2 m (plus any GPS error) [48].

They concluded the "UAV has much promise as a scientific monitoring tool but only when combined with appropriate sensors, established sampling protocols, and statistical analysis. This study has demonstrated that videos from a UAV can be used to discern midsize vertebrates in natural areas [47]." Unfortunately, they were unable to collect geo-referenced imagery. Also, the UAV system was difficult to deploy and recapture in unimproved areas.

Martin, et al., used a UAV in their study: Estimating abundance and distribution of hidden objects with drones: from tennis balls to manatees. The group was "investigating how geo-referenced data collected with UAV technology in combination with recently developed statistical models can improve the estimation of distribution and abundance of organisms (or any object) that are temporarily undetectable (hidden), and whose distribution is determined by an environmental gradient (*e.g*., temperature, vegetation, soil type)" [46].

The team's intention was to measure the relationship between water temperature and the spatial distribution of manatees. First they conducted a test using tennis balls. They did this by sectioning of a 30 x 30, 900 cell grid (1m x 1m) and placing 329 tennis balls (1 ball per grid cell) in the area. The UAS flew over the area taking pictures. Images of the grid were taken every 2.5 seconds. The UAS made several autonomous passes over the grid at an altitude of 200 m and an air speed of 16 m/s, after each pass a ball was either covered or left uncovered. The probability of a ball being covered for each pass was 0.5. The balls in the pictures taken by the UAS were then counted by an observer who did not participate in the set up. Figure 3 is an image captured by the UAV during this study [46].

Again, an in depth discussion of the statistical method is not the purpose of this review. It is useful however to note the project as it ties in the water temperature distribution of manatees, UAS, and statistical methods introduced earlier, with the use of digital images to be addressed later. Basically, the group used three occupancy models to determine abundance. The first model assumed the probability of occupancy (ψ) is a function of the environmental gradient. The second model assumed ψ of one cell is a function of whether or not its neighboring cell is occupied. And the third assumed ψ was the same for all cells [46].

The observer counted 170-284 balls for the various passes. From there all three models determined a mean count of 328 balls, which is a very accurate estimate given the actual count was 329. Furthermore, the results indicate that the UAS technology may be used distinguishing adult wildlife from the young and perhaps even differentiating individuals, since objects as small as a tennis ball could be counted in the photographs [46].

As stated above, the first model was based on the environmental gradient. Some applications of this model related to this study will be used to gain a better understanding of how organisms distribute themselves in relation to environmental gradients and changes in use of a particular site as it relates to shifts in environmental conditions. Specifically, for manatees, the method can help determine the carrying capacity for warm-water aggregation sites based on water temperature and density [46].

Chapter 2 Description of Research Aircraft

Chapter 2 Section 1 Aircraft (Piper Navajo)

The team flew in the PA-31 Navajo (Figure 4) a cabin-class, twin-engine aircraft designed and built by Piper Aircraft, Vero Beach, Florida for the general aviation market. The aircraft has a wingspan of 40.67 feet (12.40 m), fuselage length of 32.625 feet (9.944 m), and a maximum gross weight of 6,500 lbs (2,948 kg). The UTSI Navajo can carry a maximum crew of six, nominally two pilots in the cockpit and four aircrew or passengers in the main cabin. The Navajo is powered by two turbocharged Lycoming TIO-540-A series, six cylinder, fuel injected engines rated at 310 horsepower each. An oxygen system provides supplementary oxygen for crew and passengers. The aircraft has a service ceiling of 26,300 feet (8,016.2 m). Figure 5 shows the cabin of the aircraft where the two members of the team sat to record data. A maximum of four seats can be installed in the main cabin; the individual seats can be installed facing forward or aft

The research air data system is independent of the production air data system, which consists of one pitot tube and four static pressure ports. The research air data system includes a Kiel probe, a standard total pressure probe, a static pressure mast, and a total temperature probe. The probes are mounted on the left fuselage, forward of the wing and aft of the nose baggage compartment door (Figure 6).

The data acquisition system (DAS) records over 80 parameters at 10 samples per second with the exception of the GPS signal which is logged at 1 sample per second. Increased sample rates can be obtained with a decreased number of parameters. LabVIEW software applications are available in the DAS computer to perform data acquisition tasks. Figure 7 displays the configuration of the general data acquisition system. There are blue parameters along the left side showing the input parameters. Some common parameters include air data such as airspeed, altitude and outside air temperature. Aircraft attitudes such as pitch, roll, and yaw angles are also recorded. The Reigl Altimeter, the video, the GPS and Heitronic Pyrometer information are also recorded using the DAS (Figure 8). These are discussed further in section next section, 2.2 Equipment.

One tablet personal computer (PC) and 4 ultra-mobile personal computers (UMPCs) are available for data logging and visualization. Ethernet, serial, and USB ports are available on these units. The software interface of each unit is fully configurable for individual user needs. User provided personal computers, either desktop or laptop, can also be added to the network. UMPC's were used for the flight tests of this project.

Chapter 2 Section 2 Equipment

Chapter 2 Section 2 Part 1 GPS

The aircraft is equipped with a Garmin GNS 530W mounted in the cockpit instrumentation panel. The unit is an all-in-one GPS/Nav/Comm with a WAAS-certified GPS, 200-channel ILS/VOR with localizer and glide slope, and a 2,280-channel capacity radio.

Chapter 2 Section 2 Part 2 Axis 221 Camera

The aircraft is equipped with the Axis 221 Camera. The camera is mounted under the left wing of the aircraft for downward view (Figure 9a and 9b). It is a high-performance camera originally designed for round-the-clock video surveillance over IP networks, by providing high-quality images under all lighting conditions. It has an automatic, removable infrared-cut filter and highly light-sensitive CCD sensor, enabling it to provide black and white video in dark conditions and color video when there is sufficient light. A progressive scan allows the camera to reproduce moving objects without distortion, while capturing up to 45 frames per second in VGA resolution (640x480 pixels.) Simultaneous MPEG-4 and Motions JPEG video streams optimize image quality and bandwidth efficiency. Power over Ethernet (IEEE 802.3af) supplies power via the network (no need for power cables). The camera's dimensions are 49 x 88 x 186 mm ($1^{15}/_{16}$" x $3^{15}/_{32}$" x $7^{5}/_{16}$") and it weighs 550 g ($19^{13}/_{32}$ oz) (excluding power supply). The camera and dimensions are seen in Appendix 1, Figure 10 and 11.

Chapter 2 Section 2 Part 3 Heitronics Pyrometer

The aircraft is equipped with the Heitronics Pyrometer, used to detect surface temperature. It typically has a minimal resolvable difference or +/- 0.1° C. It can detect frequencies of 2-4.5 microns, which are in the short to mid infra-red range. Accuracy of pyrometer is +/- 0.5° C plus 0.7% of the temperature difference between the housing containing the measuring instruments and the object to be measured or; value of temperature resolution. The higher value shall prevail. Accuracy is determined assuming that the emissivity has been correctly set after a warm up period of 15 minutes. Long time stability is better than 0.1% of the absolute measuring temperature in Kelvin/month. Permissible ambient temperatures range from -20° C to 70° C. Higher ambient temperatures are possible if cooling and protecting jackets are used. The Pyrometer weighs about 2.35 kg.

Chapter 2 Section 2 Part 4 Laser Altimeter

The aircraft is equipped with the RIEGL LD321, a multi-purpose laser distance meter based on precise time-of-flight laser range measurement. It uses digital signal processing enabling precise distance measurement for complex multi target situations and under bad visibility conditions. Digitizing the echo signal and analyzing it allows multi target distance measurements. Up to 5 target distances can be detected and provided.

The altimeter can be configured for various situations, such as:

- High Penetration and High Accuracy Mode for complex target situations, based on a sequence of laser shot measurements; self-adapting (rather low) data update rate.
- Fast Mode is between High Speed and High Penetration Mode, very high data update rate.
- High Speed Mode for simple target situations and extremely high data update rate.

Depending on the setting the accuracy of the altimeter ranges from +/- 20 mm to +/- 50 mm.

The integrated LAN-TCP/IP interface is used for configuration and data output. The LD321 offers separate logical data ports:

- System data port
- System configuration port
- System housekeeping port
- System error port

The logical ports can be linked to either LAN-TCP/IP ports or to a RS232/RS422 port. For simply interactive configuration via a WEB browser the LD321 offers a System WEB port. Further key features of the LD321 are:

- Short infrared laser pulses providing excellent interference immunity
- Narrow measurement beam with low divergence for excellent spatial resolution
- Measurement to almost any surface regardless of incident beam angle and surface characteristics
- Lightweight, with a stable metal housing, prepared to be used in rough industrial environments.

Chapter 3 Methods and Approach

Chapter 3 Section 1 Flight Test 1: Assessing the Video Equipment Using the Runway and Parked Cars to Represent Rivers and Manatees

Chapter 3 Section 1 Part 1 Test Objectives

The objective of this flight test was an initial assessment of the feasibility of using the Piper Navajo onboard digital video system to support the manatee aerial surveys. In flight video data was obtained at six different test points, comprised of one airspeed (115 knots) and three altitudes (300, 600, 900 meters or about 1,000, 2,000, 3,000 feet AGL) see Table 1. A rectangular pattern was flown at each altitude, to collect video at two spatial locations, over a shopping center parking lot, and over the Tullahoma Airport runway. Surface temperature was also collected to demonstrate the ability of the DAS to collect do so. Temperature collection will be an important covariate for future surveys and population modeling.

Different altitudes were chosen to allow a comparison of the video quality at each altitude. This helped to determine the highest flight altitude that would still deliver images of an acceptable quality. In addition to obtaining acceptable data quality, it was useful to determine a maximum altitude because future test sites may have varying minimum altitude limits.

The parking lot location was selected to obtain images of automobiles, providing a convenient comparison to a congregation of manatees, since a manatee and a car have comparable length scales. The average length of a manatee is approximately 3 meters (10 feet) and the average length of a car is about 3.9 meters (13 feet). The runway location was selected to provide a geometry that has some similarity to a section of a river. Furthermore, the runway conveniently had scale markers of a known length, i.e. the instrument approach landing markers on the runway surface.

Inflight display should be clearly visible and support mission requirements. The information displayed had to be sufficient for the task assigned yet not overloading for the flight test engineer (FTE). For this reason both the observer and the FTE were equipped with their own UMPC. Each UMPC was set up to display only the parameters of interest. This was intended to make it easier to quickly glance at the screen and record the information of interest.

Data collected and recorded in flight include time, elapsed time, airspeed, altitude, pitch, and surface temperature. The research air data instrument system was used to collect data. The surface temperature data was obtained using the Heitronics infrared radiation pyrometer.

An FTE and an observer were seated in the rear forward facing seats of the aircraft, next to the rear right and left windows. They were able to provide a comparison between the video on the onboard UMPCs, and their own human observation from looking out the window.

The UMPC display and the images taken from the flight and viewed on a larger monitor were qualitatively evaluated on the several metrics. These metrics are described below, they are also found in table 2 for a quick reference. The first row gives the word or metric, the second row gives the definition being used and the third row explains what the observer is analyzing the image for with respect to that metric. Results and discussion of these are found in section 4.1.

The monitor images were evaluated by considering their resolution, clarity, legibility, sharpness, acutance, definition, shape, graininess, banding, contrast, contrast ratio, color balance, brightness, sunlight, field of view, and depth of view. The UMPC images were evaluated by considering their resolution, clarity, color balance, screen size, shape, screen placement, refresh time, automatic brightness/contrast, and automatic gain.

For the purposes of the evaluations: spatial resolution is the measure of how closely lines can be resolved in an image. It depends on properties of the system creating the image, not just the pixel resolution. For practical purposes the clarity of the image is decided by its spatial resolution. This term describes image sharpness achieved by maximizing the ability of the optical system to record image detail. Clarity deals with level of contrast and definition, and how clear and easy the image is to understand. Legible refers to how easy it is for the observer to

decipher the objects in the image. For spatial resolution, clarity, and legibility the observer is trying to determine if the image is clear and legible, if the image clearly presents the desired information and if it easy to understand what the objects in the image actually are, respectively.

The images were also judged by their Sharpness, Acutance, Definition, Shape, Graininess, and Banding. Perceived sharpness is a combination of both resolution and acutance. It is a combination of the captured resolution, which cannot be changed in processing, and of acutance, which can be so changed. In photography, acutance is the edge contrast of an image. Acutance is related to the amplitude of the derivative of brightness with respect to space. Due to the nature of the human visual system, an image with higher acutance appears sharper even though an increase in acutance does not increase real resolution. A defined image is one in which the edges of fine detail are sharply distinct. For sharpness, acutance and definition the observer must determine if the objects in an image are clearly defined.

Shape refers to whether or not the objects in the image have the same shape they would have in reality. Graininess is looked at to determine if the image is grainy or smooth. And banding is an artifact of color gradation in computer imaging. When graduated colors break into larger blocks of a single color, the smooth look of a proper gradation is reduced. Here the observer looks to see if the colors of the objects in the image are blending into colors of the surrounding objects.

Next Contrast, Contrast Ratio, Color Balance, Brightness, and Sunlight are looked at. Contrast is the difference in luminance and/or color that make an object distinguishable. In visual perception of the real world, contrast is determined by the difference in the color and brightness of the object and other objects within the same field of view. The contrast ratio is defined as the ratio of the luminance of the brightest color (white) to that of the darkest color (black) that the system is capable of producing. A high contrast ratio is a desired aspect of any display.

Is the object of interest sufficiently luminesced with respect to other objects in the FOV? The contrast ratio is defined as the ratio of the luminance of the brightest color (white) to that of the darkest color (black) that the system is capable of producing. A high contrast ratio is a desired aspect of any display. Is the ratio of the luminance of the brightest color (white) to the darkest color (black) accurately represented?

Color balance is the accuracy with which the colors captured in the image, match the original scene. Is the image the same color as the actual object? Brightness is the value of a pixel in a digital image giving its value of lightness from black to white, with zero being black and 255 being white. Here the observer is looking to see if the range of illumination is sufficient and if sufficient illumination is provided. The effects of sunlight on the image are also looked at to determine if a glare was created, if the image was washed out, or if sunlight was affected by angle.

Fields of View (FOV), Depth of View (DOV), Screen Size, and Screen Placement were also analyzed. The field of view is the area that is seen at any given moment. The observer simply wants to know if the entire area of interest is available in the image. DOV is the range of items in focus in an image. This is controlled by the focal length and aperture opening of a lens. A large or wide aperture gives a shallow depth of field (not much range in focus) and a smaller or narrow aperture give a large depth of field (more range in focus). Here the observer is to decide if the objects of interest are in focus.

Considering the screen size, the observer is looking to see if the screen is small enough so that it is appropriate for the flight test, and if the screen is large enough to be effective, and if the screen display allows the FTE to view any other data. The refresh time refers to the number of times in a second that the display hardware draws the data. The observer should evaluate whether refresh rate is timely, if a flicker of smear is present, and if the picture is stable. Automatic Brightness/Contrast refers to the system's ability to automatically adjust the image brightness. For example, did it interrupt the display? Did the circuitry adequately compensated for changing light levels? And finally, automatic gain Refers to the system that is feeding back the average output signal level to adjust the gain to an appropriate level for a range of input signal levels. The gain is the mean ratio of the signal output of a system to the signal input of the same system. The observer should determine if the automatic gain disturbed the display, and if the circuitry adequately compensated for situation dynamics.

Chapter 3 Section 2 Flight Test 2: Using Flight Profiles for Manatee Congregation Sites in Florida to Practice Flights Locally

Chapter 3 Section 2 Part 1 Test Objectives

The objective of this flight test is to determine if the aircraft and team are capable of flying the desired flight paths with only insignificant deviation and in a timely manner.

Three popular manatee congregation sites in Florida include: TECO (Tampa Electric Company), and FPL (Cape Canaveral), and Three Sisters Sanctuary. Using Google Earth, the coordinates for these locations were superimposed over nearby water channels at the Tim's Ford State Park in Winchester, TN. These corresponding coordinates were used to create a flight plan in the local area that mimicked future flights over the manatee congregation sites in Florida.

Figures 12-20 show the flight plan profiles for the three manatee congregation sites. For each congregation site there is first an overall view of the flight profile. This image is an aviation chart of the area with the flight plan lines in white laid over top of the image. This is followed by a Google Earth image zoomed closer, in order to see what the area should look like. Finally, there is an image of the corresponding Florida flight profile transferred to a Google Earth image of the Tim's Ford area.

Figures 12, 13, and 14 are an image of an aviation chart and two Google Earth images used to describe the flight plans for the TECO manatee congregation sight. The TECO flight profile consists of two passes over the point of interest. The profile follows the white line in figure 12, then turns 180 degrees and follows the line back to the start. Figure 13 is the Google Earth image of the TECO congregation sight zoomed in for a closer view. As stated above, figure 14 is the same flight plan for a future TECO flight superimposed over a local area. It shows the flight path actually flown for this mission over the Tim's Ford waterway. Results and discussion are found in section 4.2.

Figures 15, 16, and 17 are an image of an aviation chart and two Google Earth images used to describe the flight plans for the FPL manatee congregation sight. The FPL flight profile consists of three passes over the point of interest. The profile can be seen by following the *shorter* white line on figure 15 (this is also the purple line in figure 17) which makes a lengthwise pass along the channel. There is an additional section for the FPL flight profile, which requires the team to set up again. This is seen by following the *longer* white line on figure 15 (the yellow line in figure 17), thus two crosswise passes will be made over the channel. Figure 16 is the Google Earth image of the FPL congregation sight in figure 15; it is zoomed in for a closer view. As stated above, figure 17 is the same flight plan for a future FPL flight superimposed over a local area. It shows the flight path that was actually flown for this mission over the Tim's Ford waterway.

Figures 18, 19, and 20 are an image of an aviation chart and two Google Earth images used to describe the flight plans for the Three Sisters Sanctuary manatee congregation sight. The Three Sisters Sanctuary flight profile also consists of three passes over the site of interest. The profile can be seen by following the horizontal white line on figure 18 from west to east: this is the first pass (it is also shown as a dotted purple line in figures 19 and 20). There is an additional section for the Three Sisters Sanctuary flight which requires the team to set up again and return along the same line, thus a second pass. (The second pass is the dotted yellow line in figure 19, and the dotted purple line in figure 20). The Three Sisters Sanctuary flight profile consists of a third pass. This requires the team to set up again and make a diagonal pass over the congregation site. This is the diagonal white line in figure 18 going in a north eastern direction. It is also the solid yellow line in figure in 19 and 20. Notice once again figure 18 is the flight plan for a future flight superimposed over an aviation chart of the Three Sisters Sanctuary. Figure 19 is the same view as figure 18, but it is zoomed in Google Earth image. And figure 20 is the same flight plan superimposed over the local Tim's Ford waterway. Figure 20 is the actual flight path used for this mission.

Chapter 4 Results and Discussion

Chapter 4 Section 1 Flight Test 1: Assessing the Video Equipment Using the Runway and Parked Cars to Represent Rivers and Manatees

Chapter 4 Section 1 Part 1 Overview of Flight

The box pattern around the airport was completed three times, collecting video and data of the parking lot and runway test points each time, data and video was also collected of the parking lot just before landing. The airspeed stayed close to 114 knots (114 +/- 4 knots), except for the data taken upon landing, which was only 93 knots. Data from the first pass shows the altitude above the shopping center was 882 meters (2,894 feet) above the parking lot and 885 meters (2,903 feet) above the runway. The second pass was 580 meters (1903 feet) above the parking lot and 582 meters above the runway. The final pass was 306 (1,004 feet) and 323 meters (1,060 feet) above parking lot and runway, respectively. The video for the parking lot taken upon final approach was taken from an altitude of 59 meters (193 feet) AGL. See table 3.

Pitch and surface temperature are also recorded in table 3. The pitch angle of the airplane refers to the up and down movement of the nose. Pitch angle is used to maintain altitude; changing the pitch angle will change the angle that the camera is facing. If this occurs, the pitch angle and the altitude of the plane will be needed to calculate the distance of the images being recorded. However, data indicate that the pitch angle was consistently small (less than 5 degrees).

For the first pass the pitch was 4.4 degrees and 3.8 degrees for the parking lot and runway respectively. For the second pass the pitch was 4.41 degrees and 4.5 degrees for the parking lot and runway respectively. For the third pass the pitch was 3.9 degrees and 4.0 degrees for the parking lot and runway respectively. The pitch on final approach was -4.5 degrees.

The temperatures for the first pass were 14° C and 15° C for the parking lot and runway respectively. They were 11° C and 15° C for pass two. And 17° and 15° C on the third pass. The parking lot temperature upon final approach was 19° C. Therefore the temperatures taken from the higher altitudes ranged from 11°C to 17 °C (14 +/- 3° C). The highest and lowest temperatures were taken over the parking lot. When the measurement taken over the parking lot from the lower altitude just before landing is included in this comparison the range increases to 11°C to 19 °C (15 +/- 4 °C). With a temperature variation of only +/- 4 °C at various altitudes and speeds, the Heitronics infrared radiation pyrometer is likely a precise instrument for surface temperature collection during future Florida manatee surveys.

Video was also being recorded during this flight test. Figure 21, 22, 23 and 24 are the parking lot digital images that correspond with the data above from table 4. An analysis follows using the metrics described in section 3.1 (table 2) to compare the image quality as a function of altitude. The results are summarized in table 4. Table 4 is set up as a quick reference to see how the images measured up at each altitude. Each altitude either has a check mark, a double squiggly line, or an x to indicate whether the image was good, fair, or poor with respect to the given metric. Following the analysis of the four parking lot images that have been transferred to a larger monitor, there is a similar analysis of the UMPC display of the moving video as seen during flight.

Chapter 4 Section 1 Part 2 Larger Monitor Display

After the flight the images collected by the camera were copied and viewed on a larger monitor. Figure 21, shows the parking lot at 306 meters AGL. Following is an analysis of this image using the metrics described earlier and in table 2. The analysis is summarized in table 4 for a quick reference. The analysis of the spatial resolution found that the image provides adequate quality to count the targets; they are easily distinguished from one another, and appear fairly clear and legible. As for clarity, the desired information is clearly presented (the targets can be easily counted). The image is mostly legible; one can glance at the image and know it is a parking lot, with cars and parking spaces. It is not easy to distinguish a car from a truck, however.

As for sharpness, acutance and definition: the image is somewhat sharp. It is easy to distinguish one car from another, and some details like car windshields can also be distinguished from the car itself. The targets in the image are the appropriate shape and the image is smooth. Banding is not an issue. The objects of interest are sufficiently luminesced with respect to other objects in the FOV; however, the darker cars are more difficult to see. The contrast ratio appears to be accurate. As for brightness, there is sufficient illumination and the range appears to be sufficient as well. Sunlight did not cause a glare or a washed out effect. As for FOV and DOV, the entire area of interest is available in the image, but the objects of interest are only somewhat in focus.

Figure 22 shows the parking lot at 580 meters AGL. Following is an analysis of the same metrics used to analyze the parking lot at 306 meters (1,004 feet). The analysis is summarized in table 4. For resolution: There is enough detail provided to count the targets. However, the targets are barely legible, they are not very clear. Some eyestrain is needed to make an accurate count. The clarity is poor, the targets can be counted, but it is difficult. The legibility has also decreased. It is only obvious that the objects are cars because it is easy to tell one is looking at a parking lot.

As for sharpness, acutance, and definition the objects are not clearly defined. They are just adequate enough that one can look closely and see where one car ends and the other begins. As for shape the viewer can determine what the target is based on the shape and surroundings. The image is smooth. Banding is beginning to become an issue. The colors are blending with surrounding colors. There is image is greyer than the previous image taken from a lower altitude.

As for contrast, the object of interest appears to have sufficient luminescence with respect to other objects in the FOV. The contrast ratio appears to be accurate. The color balance is decreasing in quality. There is adequate detail to see red, whites and blacks, but other colors appear grey. The brightness provides a sufficient range of illumination overall. Sunlight did not cause a glare or a wash out effect. The FOV encompassed the entire area of interest, but the DOV did not bring the objects of interest into focus.

Figure 23 shows the parking lot at 880 meters (2,887 feet) AGL. Following is an analysis of the same metrics used to analyze the parking lot at 306 meters (1,004 feet) and 580 meters (1,903 feet). The analysis is summarized in table 4. For resolution, the image requires significant eyestrain to count the targets. There is not enough detail provided for an accurate count of the targets. The targets are not clear and they are barely legible. The clarity is very poor. Targets cannot be counted with reliable accuracy. One can only guess to be looking at cars, based on the context of the entire image.

The sharpness, acutance and definition are poor, the cars are blurring together. The shapes are blurred, the viewer can only tell what the targets are based on the surroundings. The image is still smooth. Banding continues to be a problem the colors are blending with the colors of the surrounding objects.

The contrast and contrast ratio still appear to be sufficient and accurate. The color balance is worse; the targets appear white and black. Adequate detail is not provided to distinguish other colors. Brightness and sunlight continue to be good. The FOV encompassed the entire area of interest, but the DOV did not bring the objects of interest into focus.

Figure 24 shows the parking lot at 58 meters (190 feet) AGL. Following is an analysis of the same metrics used to analyze the parking lot at 306 (1,004), 580 (1,903), and 880 (2,887) meters (feet). The analysis is summarized in table 4. For resolution, the image is quite legible (it easy to understand what the objects in the image actually) and mostly clear (the image clearly presents desired information). However, some blurriness decreases the images the clarity. This is especially noticeable around the edges of the cars. Considering sharpness, acutance, and definition it is easy to distinguish one car from another. One can also see some things like the car windshield.

The targets in the image are the appropriate shape. There appears to be some graininess. Banding does not appear to be a problem. The contrast and contrast ratio still appear to be sufficient and accurate. The color balance of the targets is very good. Reds, yellows and blue targets are easily seen. Also, light blue and dark blues are distinguishable from one another. Brightness and sunlight continue to be good; there is a small glare which does not appear to compromise the image. The image is not washed out, nor does it appear to be affected by angle. The FOV does not encompass enough area at this altitude to include the entire strip of the parking lot. Only about half

the parking lot strip is available in the FOV. As for DOV, the objects of interest are somewhat in focus, more so than the images at higher altitudes.

Images of the runway were also qualitatively analyzed at the higher three altitudes. Figure 25 shows the runway at 323 meters (1,060 feet) AGL. In this image it is easy for the observer to distinguish between the asphalt and the concrete along the sides of the asphalt runway. One can also see the dirt patches in the grass bordering the concrete. Also, there are small circles in the concrete which are actually where the slabs come together at regular intervals. These areas stand out because they are worn and cracked, and they are easy to see at this height.

Figure 26 shows the runway at about 582 meters (1,909 feet) these. The same features discussed from figure 26 can be seen, but the color between the runway, the concrete, and the dirt patches is beginning to blend. The concrete circles are less prominent. Figure 27 is an image of the runway from 885 meters (2,903 feet). At this altitude it is difficult to determine the asphalt runway from the concrete. Some of circles can barely be seen. And the dirt is much less prominent.

Chapter 4 Section 1 Part 3 UMPC Display

The UMPC video display are analyzed next using the set of metrics described in section 3.1. There are no figure references for this UMPC analysis. Resolution, clarity, color balance, and shape had varying results for each altitude. Screen size, screen placement, refresh time, automatic brightness/contrast, and automatic gain were all consistently good at altitudes. As for the screen size and screen placement, the screen was small enough so that it is appropriate for flight tests and it was large enough to be effective. However the FTE was not able to view other information and video at the same time.

The refresh time was timely, there was no flicker of smear present, and the picture was stable. The automatic brightness/contrast did not interrupt the display, the circuitry adequately compensated for changing light levels. The automatic gain did not disturb the display and the circuitry adequately compensated for situation dynamics.

At 300 meters (984 feet) AGL the resolution in the display provided adequate quality to easily count the targets. Targets could be distinguished from one another. No eyestrain occurs to count the targets. Targets appear fairly clear and legible. As for clarity the desired information is clearly presented (the targets can be easily counted). The color balance provided adequate detail to see red, whites and blacks. Other colors appear grey. The display was large enough to show the desired area, with enough detail to count the targets. The targets on the display were the appropriate shape, but somewhat blurred. See table 5.

At 580 meters (1,903 feet) AGL the resolution in the display provided adequate detail to count the targets, with eyestrain. Targets are barely legible. The clarity is poor. Targets can be counted, but it is difficult. The color balance is also poor; the targets on the display appear to be white and various shades of grey. Some red is faintly visible. The targets on the display were the appropriate shape, but somewhat blurred. See table 5.

At 880 meters (2,887 feet) AGL the resolution in the display did not provide adequate detail to count the targets. Targets are not clear they are barely legible. The clarity is very poor. Targets cannot be counted with reliable accuracy. The color balance is also poor; the targets appear white and grey. Adequate detail is not provided to distinguish other colors. The shapes were blurred, the viewer can only distinguish what the targets are based on the surroundings. See table 5.

A comparison between an onboard observer looking out the window and the UMPC video, finds the video more useful. The observer's ability to focus due to distance was about the same as that of the video, but the aircraft's wing often obstructed the observers view. Overall the UMPC was useful in letting the observers know if the team was flying over the proper area, but the UMPC would not be good for counting manatees in flight; resolution, clarity, color balance, and shape deteriorated quickly with increased altitude. Also, in this flight, airspeed limited the observers' ability to collect data, but not the video camera's ability to collect data.

Chapter 4 Section 1 Part 4 Using the Runway to Quantify the Resolution

There are prominent measurements on the runway which were recorded at three different altitudes. These markings are seen in figure 28a. There is an arrow pointing to a. the threshold markings, b. the runway designation numerals, c. the center lines, d. the chevrons, and e. the holding position markers.

The measurements are listed in table 6, they are as follows. The threshold markings are broken down into three parts. The wider gap between at the center of the threshold markings is 3.5 meters (11.5 feet). The length of each of the threshold markings is 45.7 meters (150 feet). And the width of each threshold markings is the same as the space between each marking which is 1.8 meters (5.75 feet). Note that for the duration of this paper, length is considered the dimension running along the length of the runway and width is the measurement taken across the runway.

Figure 28b displays the measurements of the runway numerals in greater detail. The measurements are given in feet and then in brackets they are given in meters. In table 6 the runway designation numerals are broken down four ways. They are 18.3 meters (60 feet) tall, each numeral is 6.1 meters (20 feet) wide, there is 4.6 meters (15 feet) between them, and their total width is 16.8 meters (55 feet). The center line segments are 37 meters (120 feet) long and there is 24 meters (80 feet) between each of them. The chevrons are 30.5 meters (100 feet) from tip or point of one to the tip of the next one. The holding position markers are actually made up of 4 white lines each and 3 spaces between them. However, this cannot be seen in the image, because each line and each space is only 0.3 meters (1 foot) each. Therefore, the holding positions are 2.1 meters (7 feet) in height. They are spaced 1.8 meters (5.75 feet) apart, and they are 1.8 meters (5.75 feet) wide.

Figure 25 is another image of the runway from 323 meters (1,060 feet) AGL; it is used to determine which of the markings listed above are resolvable in an image taken from 323 meters AGL. Figure 26 is an image of the same runway and markings taken from 582 meters (1,909 feet) AGL; it is used to determine which of the markings listed above are resolvable in an image taken from 582 meters AGL. And finally, Figure 27 is an image of the same runway and markings taken from 885 meters (2,903 feet) AGL; it is used to determine which of the markings listed above are resolvable in an image taken from 885 meters AGL. The results are listed in table 6.

At 323 meters (1,060 feet) AGL (Figure 25) all of the markings could be resolved except the one foot spaces between the holding position markers. Therefore, from the measurements available 1.8 meters (5.75 feet) is the smallest resolvable spacing from this altitude. The 1.8 meters (5.75 feet) is the width and spaces of the threshold markings as well as the width and spacing of the holding position markers. The one foot spacing of the holding position markers was not resolvable.

At 582 meters (1,909 feet) AGL (Figure 26) the same spacing of 1.8 meters (5.75 feet) is resolvable as the width and spaces of the threshold markings, but the same spacing is not resolvable as the width and spacing of the holding position markers. Three possible reasons for this are:
1. The holding position markers are on a slight angle.
2. The holding position markers are at the edge of the FOV.
3. The holding position markers are shorter and cover a smaller area.

At 885 meters (2,903 feet) AGL (Figure 27) the smallest resolvable spacing is also 1.8 meters (5.75 feet). Once again this spacing is only resolvable on the threshold markings. Also, this spacing only somewhat resolvable, as the lines periodically blur together.

Therefore the minimum linear dimension discernible at the two higher altitudes of approximately 600 and 900 meters is 1.8 meters (5.75 feet).

A closer inspection of the runway did not show any obvious difference in the darkness of the asphalt or the brightness of the lines between the threshold markings versus the holding position markers. A higher resolution in may remedy this occurrence noted for figure 26 and 27.

Chapter 4 Section 1 Part 5 Using the Parking Lot to Quantify the Resolution

Figure 29 is an image of the parking lot taken from 306 meters (1,004 feet). There are three arrows pointing to different sections of the parking lot. Section A is pointing out the parking spaces. Each parking space has an average width of 2.9 meters or 9.5 feet (114 inches). The average length of each space is 2.1 meters or 6.8 feet (82 inches). The narrow space at the end with the bushes is only 2.1 meters or 6.8 feet (82 inches). The yellow lines making up the spaces are 0.15 meters or half a foot (6 inches) wide; the center yellow line is about 0.15 meters or half a foot (6.25 inches) wide. The end without the bushes is pointed out by the arrow labeled B. The space is enclosed by a concrete curb. The grass area plus the curb is about 6 meters or 19.8 feet (238 inches) wide, and 13.6 meters or 44.7 feet (536 inches) long.

The end with the bushes is pointed out by the arrow labeled C. The space is enclosed by a concrete curb. The grass area plus the curb is 4.3 meters or 14.2 feet (170 inches) wide and 13.3 meters or 43.75 feet (525 inches) long. It is 47.5 meters or 155.75 feet (1869 inches) from the inside curb of one end to the inside curb of the other end. It is 57.8 meters or 189.75 feet (2277 inches) from the outer curb at one end to the outer curb at the other end. The bushes vary from 1.6 meters or 5.3 feet (64 inches) to 2.1 meters or 6.75 feet (81 inches). The spaces between the bushes vary from 0.4 meters or 1.4 feet (17 inches) to 0.8 meters or 2.6 feet (31 inches). See table 7.

Figure 30 is an image of the same parking lot taken from 306 meters (1,004 feet) AGL. The parking strip described above is circled in red. All of the markings are visible at this altitude. The lines of the parking spaces, both ends, and the bushes are easy to see, and quite legible. The parking spaces are resolvable and easy to count. The bushes are also resolvable and can be counted with some effort. Therefore this image is just barely resolvable at the smallest spacing measured, which is about 0.4 meters or 1.4 feet (17 inches) to 0.8 meters or 2.6 feet (31 inches), the spacing of the bushes.

Figure 31 is an image of the same parking lot taken from 580 meters (1,903 feet) AGL. The parking strip described above is circled in red. Once again all of the markings of interest are visible at this altitude. The parking spaces can still be counted with minimal eyestrain. The bushes now blend together and are no longer resolvable. Therefore, given the measurement options, the smallest spacing resolvable is 2.9 meters or 9.5 feet (114 inches), the parking spaces. However, the previous section (which analyzed a different set of spacing) found there was resolvability for spacing as small as 1.8 meters (5.75 feet).

Figure 32 is an image of the same parking lot taken from 882 meters (2,894 feet) AGL. The parking strip described above is circled in red. All of the parking lot lines are still visible, but the thinner 6 inch lines are more difficult to see than the wider 6.25 inch center line. The narrower parking space at the end with the bushes is not distinguishable (6.8 feet). And although the parking lot lines can still be seen, portions of them are lacking the visibility to count accurately. However, the lines that are visible appear to be spaced far enough apart to count. The bushes can be seen, but they are quite blurry. Therefore five to six foot objects in images at this altitude would need to be spaced more than one to two feet apart to obtain an accurate count. This is consistent with the findings in the previous section. I showed resolvability at a spacing of 1.8 meters (5.75 feet) for longer threshold markings.

Chapter 4 Section 1 Part 6 Manatee Applications

Figure 33 is an image of an average sized adult male manatee which was adapted from image taken from the Manatee Project website. The length of the average adult male manatee is 3-3.5 meters (10-12 feet) from snout to paddle. Its axillary girth, which is the area just below flippers, averages about 2.2 meters (7.2 feet). The umbilical girth, which is the area around the belly button, is about 2.4 meters (8 feet), and the penduncal girth the area at the base of the tail where it meets the body is about 1.6 meters (5.4 feet). These areas are shown in Figure 33 and the measurements are summarized in table 8. The average adult male weighs 1,500 to 1,800 pounds. A calf will be about 0.9-1.2 meters (3-4 feet) and 60-70 lbs. Figure 34 is an image of manatees congregating around the Florida TECO sight. It is taken from Julien Martin[1],et al, Title: Estimating Abundance And Distribution Of Hidden Objects With Drones: From Balls To Manatees [48].

Even though resolution and clarity are probably the most effective tools for identifying the objects within an image, the size and shape of the object, as well as the color or hue and the value or luminance can also help make the distinction. Using the information presented in previous sections, an analysis can be made to help determine whether or not the video system will be adequate for a Florida mission.

At 306 meters (1,004 feet) the images spatial resolution, smoothness, clarity, contrast, contrast ratio, color balance, brightness, reaction to sunlight, FOV, and object shape were all of good quality. This is a positive indication that the video system will capture images of adequate quality to count manatees at 305 meters (1,001 feet) AGL.

At 306 meters (1,004 feet) the images legibility showed that it is mostly easy to understand what the objects in the image are. One can glance at the image and know it is a parking lot, with cars and parking spaces. It is not easy to determine a car (about 13 feet long) versus a truck (about 25 feet long). Therefore, it may be difficult to distinguish an adult manatee (about 10-12 feet long) from a calf (about 3-4 long) at 305 meters (1,001 feet). Sharpness, acutance and, definition indicated it was easy to distinguish one car from another. One can also see some things like the car windshield. These are all positive indication that the video system will capture images of adequate quality to count manatees at 305 meters (1,001 feet) AGL.

Results at 580 meters (1,903 feet) also indicate that the video system will capture images of adequate quality to count manatees at that altitude. However, more eyestrain would be necessary.

Although the qualitative analysis summarized in table 4 find the clarity and resolution of the parking lot image from about 880 meters (2,887 feet) to be rather poor; figure 34 helps bring perspective to the Florida mission application. Recall the average size of a manatee is approximately the same as a car. Figure 35 is a side by side comparison of figure 23, an image of the parking lot taken with the UTSI video system from 880 meters, and figure 34, an image of manatees, in which researchers have determined the manatees can be counted. The comparison shows that the cars (from 880 meters) are of similar resolvability to that of the manatees (in an image they are deemed countable).

To further explore this comparison, arrows 1 and 2 in figure 35 have been inserted to point out some comparisons. Arrow 1 shows that the using the video system even dark cars can be seen against the dark asphalt. Arrow 2a shows where a cluster of cars are blending together, but the observer can still determine the number of cars in the cluster by knowing the size and shape of an individual car (by looking at the surrounding cars). Similarly, arrow 2b points out that a cluster of manatees that are blending together, again by using individual manatees surrounding this overlap, one can consider their size and shape and determine the number of manatees in the cluster. For example, if the area of a manatee equals n, and the cluster covers an area of 2n, there are two manatees in the cluster. This should be true provided the arrangement of the 2n area represents a shape that would be made by two manatees. This analysis also deals the non-resolvable one foot spacing issue of the holding position markers in the images taken from 324 meters (1,063 feet).

Two other useful tools presented in section 4.1.3 and 4.1.4 for determining the adequacy of the video system, are the measurements taken of the runway (table 6) and the parking lot (table 7). Nearly all runway markings were resolvable at 324 meters (1,063 feet) AGL. This is another positive indication that the video system will capture images of adequate quality to count manatees at 305 meters (1,001 feet) AGL. However, since the one foot spacing the holding position markers are not resolvable, manatees at the same distances or closer will blend together. This is blending or clustering issue is discussed later.

Findings were similar for 582 meters (1,909 feet). Except the 1.8 meters (5.75 foot) width and spacing of the holding position markers were non-resolvable. This was also true at 885 meters and therefore discussed below in that analysis.

Most of the runway markings as seen from 880 meters (2,887 feet) in figure 23 are resolvable. Notably, an analysis of this image found that the space in the runway numeral 6 is easily resolvable; it is 3 meters (10 feet) wide and 4 meters (13 feet) high. Also, the gap between the threshold markings is easily resolvable; it is 3.5 meters (11.5 feet) wide. Considering the average manatee is 3-3.5 meters (10-12 feet) long, these results are positive indicators that a manatee will be resolvable with the UTSI video system during future Florida flights from 880 meters (2,887 feet).

Furthermore, the width and the spacing of the threshold markings are partly resolvable from 885 meters (2,904 feet), and they are only 1.8 meters (5.75 feet) wide with 1.8 meters (5.75 feet) foot spacing (and150 feet long). This is another positive indication that the video system will be adequate at 885 meters. However, it must also be considered that from the same altitude, the same spacing of 5.75 feet is not resolvable for the holding position markers which are 2.1 meters (7 feet) long. In other words, in this image the separate lines appear as a single line. But the markings are actually several 2.1 meters (7 foot) white lines separated by 1.8 meters (5.75 feet) of asphalt. This brings some inconclusive results because the average axillary girth of an adult manatee 7 feet (table 8). Therefore it might be inferred that both the width and length of a manatee is resolvable and thus countable at 885 meters. However, since the manatees tend to cluster together, it may be difficult to distinguish one from another. Their shape may be difficult to distinguish as a result, and an observer must rely more heavily on the size of a cluster to calculate the number of manatees in it.

Similar to table 6, table 7 indicates which parking lot markings are resolvable. From 306 meters (1,004 feet) all parking spaces and bushes are visible and resolvable. Except for the bushes, this is also true at 580 meters (1,903 feet). Although all the bushes can be seen, they blend together. They are spacing is 0.4 to 0.8 meters (1.4 feet to 2.6 feet). This is same issue found above for the 1 foot spacing of the holding position markers. Manatees in images taken from 580 meters may blend together.

An analysis of figure 32, the parking lot from 880 meters (2,887 feet) found the following. The lines making up the parking spaces are difficult to see in some areas, they are 6 inches thick. The long center yellow line is visible at 6.25 inches. Both lines are significantly smaller than a manatee. Therefore, the information to gather from table 7 and figure 32 is not visibility, but the resolvability of the parking spaces within these pale lines. The parking spaces are resolvable at about 2.8 meters (9.5 feet) in width and 6.3 meters (20.8) feet long. Since the width and length of parking space are comparable to that the umbilical girth (8 foot) and length of a manatee (10-12 foot), and since the parking lot lines are a mere 6-6.25 inches, this result is a positive indicator that the video system will be sufficient from this altitude.

Returning to figure 35, a side by side comparison of the parking lot from 880 meters (2,887 feet) and an image deemed countable by researchers: Color (or hue) and value (or luminance) supply two more tools for a comparative analysis. The greater the difference between the color of the manatee and the color of the water, the easier it will be to count the manatees. Similarly, the greater the difference between the value of the manatee and its surroundings, the easier it will be to count the manatees. Hue and luminance create contrast in an image. The contrast in the luminance creates a more powerful distinction, than that of the contrast in hue. Table 4 indicates that the images appear to maintain contrast ratio or light/dark contrast even when color banding and color balance deteriorate at 880 meters.

This information led to a desire for a quantitative analysis of the contrast in hue and luminosity for the 880 meter parking lot image and the manatee image (figure 34). "Paint" is a common Microsoft windows program that can be used to quantify the hue and luminance contrast within the image. Tables 9a and 9b are used to summarize the hue and luminance contrast found in an image of countable manatees (figure 34) and the image of the parking lot taken from about 880 meters (2,887 feet) (figure 23).

Three samples are used in tables 9a and 9b. The first displays two color samples of the water taken from figure 34. The second shows two color samples of the manatees taken from figure 34. The third has three horizontal strips. The top and bottom strips are asphalt samples; the middle strip has a light, medium, and dark car sample. Table 9a highlights the hue and luminance of manatee and water samples from figure 34, while table 9b does the same for the asphalt and cars from figure 23.

The findings show that the average difference in hue between the manatees and the water is 18. The average difference in luminance between the manatees and the water is 6. The average difference in hue between the light car and the asphalt is 172. A large number was expected here, so this makes sense because the asphalt is nearly black and the light car is nearly white.

The average difference in hue between the medium car and the asphalt is 10. The average difference in hue between the dark car and the asphalt is 5. A low number was expected here, so this also makes sense because the asphalt and the dark car are both basically black in color. The average difference in luminance between the light car and the

asphalt is 20. The average difference in luminance between the medium car and the asphalt is 79. The average difference in luminance between the dark car and the asphalt is 63.

One very important result of this experiment is finding that the UTSI video system is capable of producing a relatively high contrast in luminance between two objects of similar hue. However, the experiment cannot definitively determine the reasons for finding consistently larger differences in contrast in the UTSI image over the countable manatee image. It may simply be that the difference in hue and luminance in the parking lot objects are greater than that of the manatees to the water. It may also be that the UTSI video system was more capable capturing these differences. Of course, overall lighting, lighting angles and reflectivity of the objects also contribute to these findings. Overall, this is positive indicator that the UTSI video system will provide sufficient contrast for producing images from 880 meters in which manatees can be counted.

There are a two more factors to consider when using cars to represent manatees. It has been stated that the average car is about 4 meters (13 feet) and the average manatee is 3-3.5 meters (10-12 feet), thus a comparable size. However the argument could be made that a manatee length of 10-12 feet is an overestimate because manatees may be partially submerged in the water. This is not an issue at 306 meters (1,024 feet), where object much less than 3 meters) 10 feet are resolvable. Also, a quick analysis of the countable manatee image (figure 34) indicates that all the manatee in the FOV appear to be the about same length. Since several of these manatees are quite close to shore, where the majority of the manatee would be exposed, this factor was not considered to be an issue.

The second factor to consider is the spacing of the manatees. Manatees may rest much closer together, or possibly overlap due to the dimension added by the water. Figure 32 and table 7 analyze the empty parking spaces. Here the 2.9 meters (9.5 feet) spaces are only separated by a 6 inch line of faded paint, and they are still resolvable at 880 meters. Furthermore, the tool of using size and shape of a manatee two count the number of manatees in a cluster (as discussed earlier) can help remedy the problem of overlap. Therefore, it was assumed that this factor only contributes a negligible error.

Overall, based on these results; images from 306 (1,024) and 580 (1,903) meters (feet) provide adequate quality to produce images in which manatees can be counted. And with further analysis using paint to investigate the luminance contrast, findings suggest images from as much as 880 meters (2,887 feet) may also provide adequate quality.

For a comparison to these findings a theoretical resolution based on pixels is used. The maximum camera resolution is 640x480 pixels. At this resolution one pixel corresponds 0.28 x 0.28 square meters (0.94 x 0.94 square feet) at an altitude of 300 meters (1,000 feet), 0.56 x 0.56 square meters (1.8 x 1.8 square feet) at 600 meters (2,000 feet), and is 0.84 x 0.84 square meters (2.8 x 2.8 square feet) at 900 meters (3,000 feet).

A manatee is approximately 3.4 meters (11 feet) long and 0.70 meters (2.3 feet) wide at the umbilicus. Using these estimates a manatee image captured from 300 meters (1,000 feet) will be 12 pixels long and 2.5 pixels wide (30 square pixels). A manatee image captured from 600 meters (2,000 feet) will be 6 pixels long and 1 pixel wide (6 square pixels). A manatee image captured from 900 meters (3,000 feet) will be 4 pixels long and less than a pixel wide (<4 square pixels).

Considering these estimates, one would expect a manatee to be resolvable in an image taken from 300 meters (1,000 feet), possibly resolvable from 600 meters (2,000 feet), and unresolvable from 900 meters (3,000 feet). This is consistent with the findings from the previous sections.

Chapter 4 Section 2 Flight Test 2: Using Flight Profiles for Manatee Congregation Sites in Florida to Practice Flights Locally

Chapter 4 Section 2 Part 1 FOV and Maintaining Flight Path

The three local flight profiles corresponding to the three Florida sites were flown. As planned, two passes were made over the Tim's Ford-TECO site, three passes were made over the Tim's Ford-FPL site, and three passes were made over the Tim's Ford-Three Sisters Sanctuary site. Data and video was obtained for each pass using the research air data instrument system.

Table 10 shows the airspeed and altitude of the points of interest during this flight test. The first pass of the Tim's Ford-TECO site was done at an altitude of 588 meters (1,929 feet) at 125 knots. The second pass of the Tim's Ford-TECO site was done at an altitude of 608 meters (1,995 feet) at 108 knots. The first pass for the Tim's Ford-FPL site was done at an altitude of 558 meters at 114 knots. The second pass for the Tim's Ford-FPL site was done at an altitude of 578 meters (1,896 feet) at 98 knots. The third pass for the Tim's Ford-FPL site was done at an altitude of 664 meters at 120 knots.

The first pass for the Tim's Ford-Three Sisters Sanctuary site was done at an altitude of 617 meters (2,024 feet) at 113 knots. The second pass for the Tim's Ford-Three Sisters Sanctuary site was done at an altitude of 612 meters (2,008 feet) at 114 knots. The third pass for the Tim's Ford-Three Sisters Sanctuary site was done at an altitude of 600 meters (1,969 feet) at 102 knots. See Table 10.

Figures 36-38 display the resultant images of the Tim's Ford waterway collected during flight. There are two images for each of the three points discussed above and summarized in table 10. The first figure for each test point (figure 36a, 37a, 38a), is a Google Earth image of the flight profile zoomed in over the Tim's Ford area. These images provide a picture of what the video equipment should capture. The images have a yellow or purple box outlining the area of interest. The second image for each test point (36b, 37b, 38b), is a compilation of digital images of the test points taken during the flight test.

Figure 36a is the zoomed in Google Earth image of the Tim's Ford waterway that represents the flight plan for a possible future flight at the TECO Florida manatee congregation sight. It also represents the area the team hoped to record during the flight test. Figure 36b is a compilation of photos taken during the flight test. The figure shows that the entire representative area needed, was successfully captured and recorded by the UTSI video system.

Figure 37a is the zoomed in Google Earth image of the Tim's Ford waterway that represents the flight plan for a possible future flight at the FPL Florida manatee congregation sight. It also represents the area the team hoped to record during the flight test. Figure 37b is a compilation of photos taken during the flight test. The figure shows that the entire representative area needed, was successfully captured and recorded by the UTSI video system.

Figure 38a is the zoomed in Google Earth image of the Tim's Ford waterway that represents the flight plan for a possible future flight at the Three Sisters Sanctuary Florida manatee congregation sight. It also represents the area the team hopes to record during the flight test. Figure 38b is a compilation of photos taken during the flight test. The figure shows that the entire representative area needed was successfully captured and recorded by the UTSI video system.

The results show the area of interest was easily captured by the cameras FOV from the flight test altitude (600 meters). The future surveys will be flown at about half that altitude (305 meters). With the focal length of the Axis 221 camera set to 8 mm (as it was during both flight tests), the FOV captured a minimum width of 360 meters (1181 feet). From an altitude of 305 meters (1,000 feet) the FOV will decrease to 183 meters (600 feet). Measurements taken in Google Earth of the Florida Manatee congregation sites show the maximum width of the water-ways to be captured is 79 meters (260 feet). Therefore the aircraft and flight team will be allowed a deviation from the flight plan of 52 meters (170 feet), or nearly .03 nm. Therefore, it was determined that the flight team and equipment are capable of flying the necessary flight paths and capturing the required area.

Chapter 4 Section 2 Part 2 Timeliness

Manatees may rest submerged at the water bottom or just below the surface, coming up to breathe on the average of every three to four minutes. When manatees are using a great deal of energy, they may surface to breathe as often as every 30 seconds. However, they have been known to stay submerged for up to 20 minutes. This behavior is important because manatees below the surface of the water might not be seen, this affects detection probability. Timeliness of the flights is therefore not only a financial concern, but can also interfere with survey results [30].

The first TECO pass took 19 seconds. The time to set up before pass two was 11 minutes and 46 seconds. The second TECO pass took 2. This gives a total of 12 minutes and 26 seconds.

The first FPL pass took 4 seconds. The crew then took 6 minutes and 25 seconds to set up. The second pass took about 1 second. Then 6 minutes and 40 were needed to set up again. The third pass also took about 1 second. This gives a total of 13 minutes and 5 seconds.

For the Three Sisters Sanctuary the first pass took 1 second. Then it took 6 minutes and 4 seconds to set up. The second pass took 1 second, then 4 minutes and 15 seconds to set up. The third pass took 1 second, for a total of 10 minutes and 20 seconds.

Thus the question is, were the necessary flight paths flown in a timely manner, such that they are useful for calculating a detection probability? To address this the times from a past survey of the TECO area are used. During the winters of 2000 – 2003 detection probability studies were done at the TECO location. Manatees were counted manually by experienced observers from a high-winged Cessna 172 aircraft. Ten passes over the canal were used for each flight, observers had one minute to count manatees during each pass. The 10-pass series lasted about 30 minutes [30].

Flight time for the Tim’s Ford area simulating the same TECO site used in this study was 12 minutes and 26 seconds. The longest flight time in this study was 13 minutes and 5 seconds for the Tim’s Ford-FPL sight. Therefore, flight time needed to simulate Florida manatee sites were less than the one half the time used in the previous accepted study (30 minutes). Furthermore, the flight team felt confident that future flights of the same path would be easier and faster.

The results indicate that the aircraft and flight team are capable of flying the desired flight paths in a timely manner, while the video system collects the area of interest.

Conclusions

Overall, the video system is capable of capturing images with sufficient quality to distinguish and count manatees while flying within the given parameters. The clarity and resolvability of the objects captured in the digital images decrease with increasing altitude. The cars are much more distinguishable at about 306 meters than they are at about 880 meters. However, even at the higher altitude, the results indicate that the UTSI video recording system will be adequate for the purpose of counting manatees in Florida. Results also show system's capability of recording surface temperature during flight. Furthermore, the aircraft and team are capable of flying the desired flight paths in a timely manner, while capturing the entire area of interest. All parameters analyzed suggest that the UTSI aircraft and video system will produce a successful Florida mission in the future.

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Appendices

Appendix A:
Figures

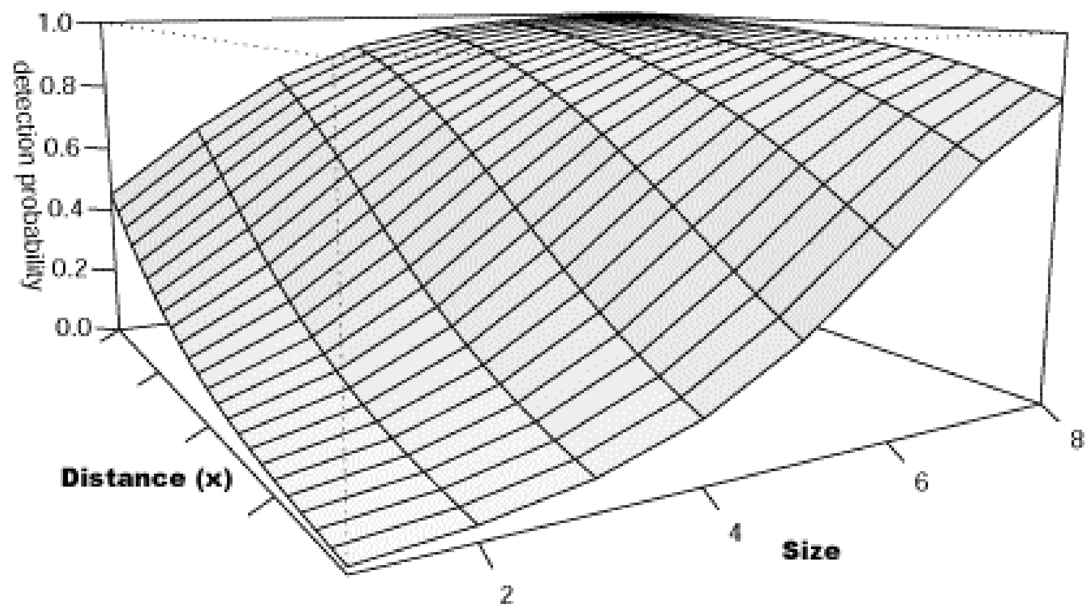

Figure 1: Example of a logistic detection probability as a function of distance (x) and group size (z): $p(x,z)=\exp(\Omega_1 x+ \Omega_2 z)/[1+\exp(\Omega_1 x+ \Omega_2 z)]$ [9].

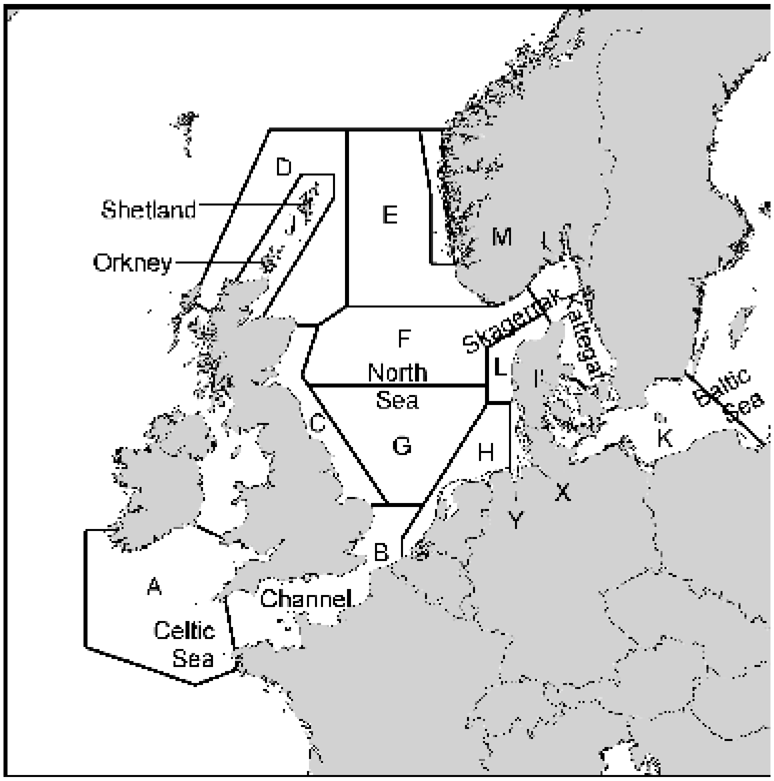

Figure 2a: The first step of the Hibey circle-back method: Blocking of the area to be surveyed [17].

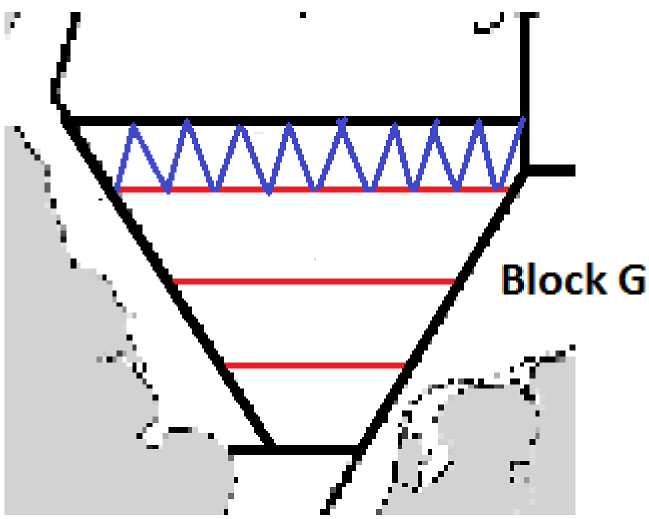

Figure 2b: Block G of from figure 2a zoomed in to show the parallel lines in red and the zigzag lines in blue [adapted from 17].

Figure 3: Experimental setup taken from the UAV at an altitude of 200m. Red circles indicate the corners of the grid; inset shows a section of the photograph enlarged. Blue circle indicates a tennis ball available for detection [46].

Figure 4: Piper Navajo [49].


Figure 5. Main cabin seating arrangement (view looking forward) [49].

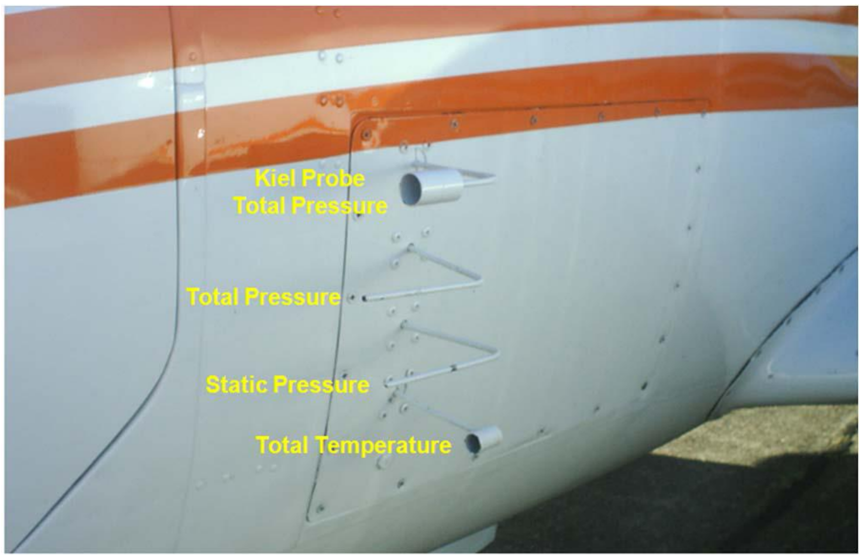

Figure 6. Research air data system probes [49].

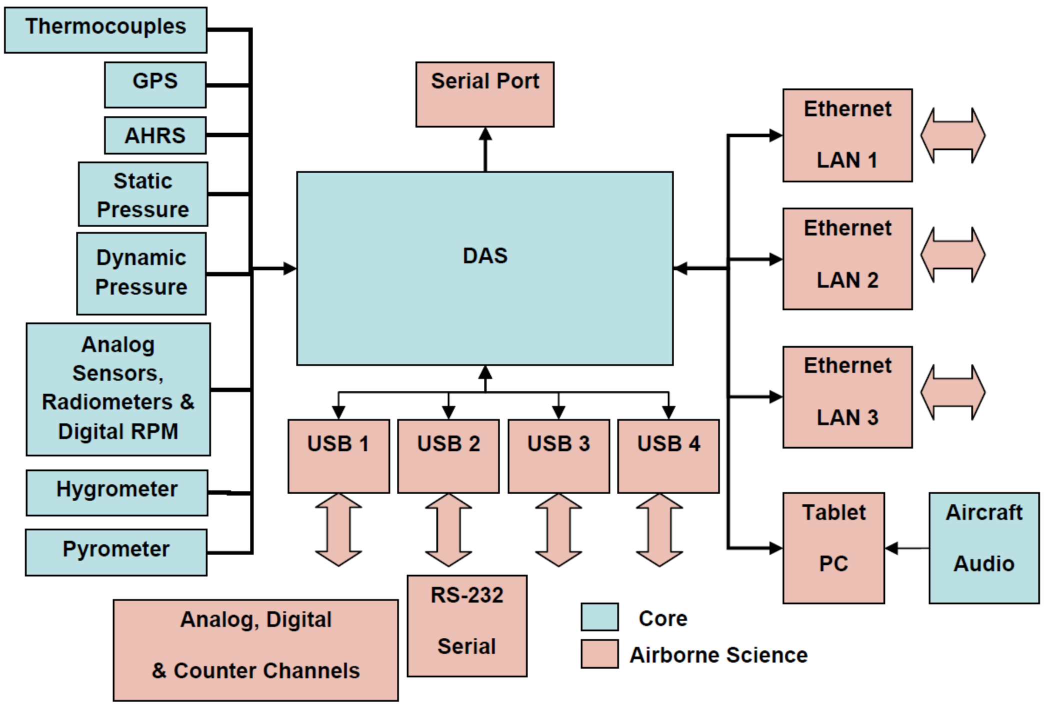

Figure 7: DAS functional diagram [49].

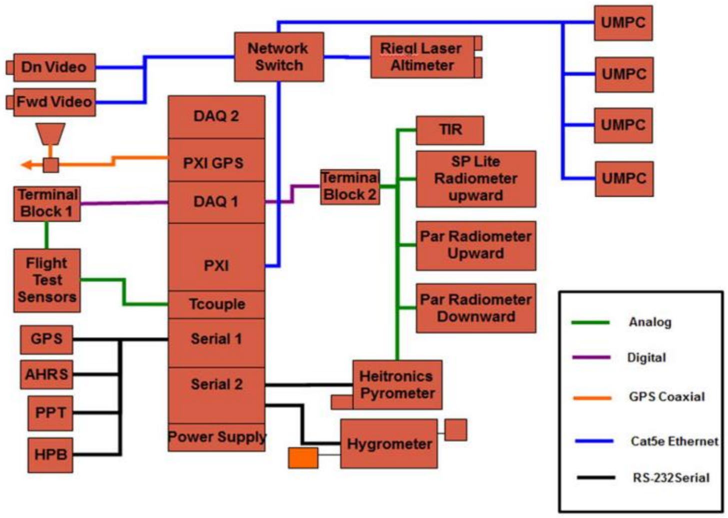

Figure 8. DAS signals overview [49].

Figure 9a: The Axis 221 camera mounted under the left wing of the Navajo.

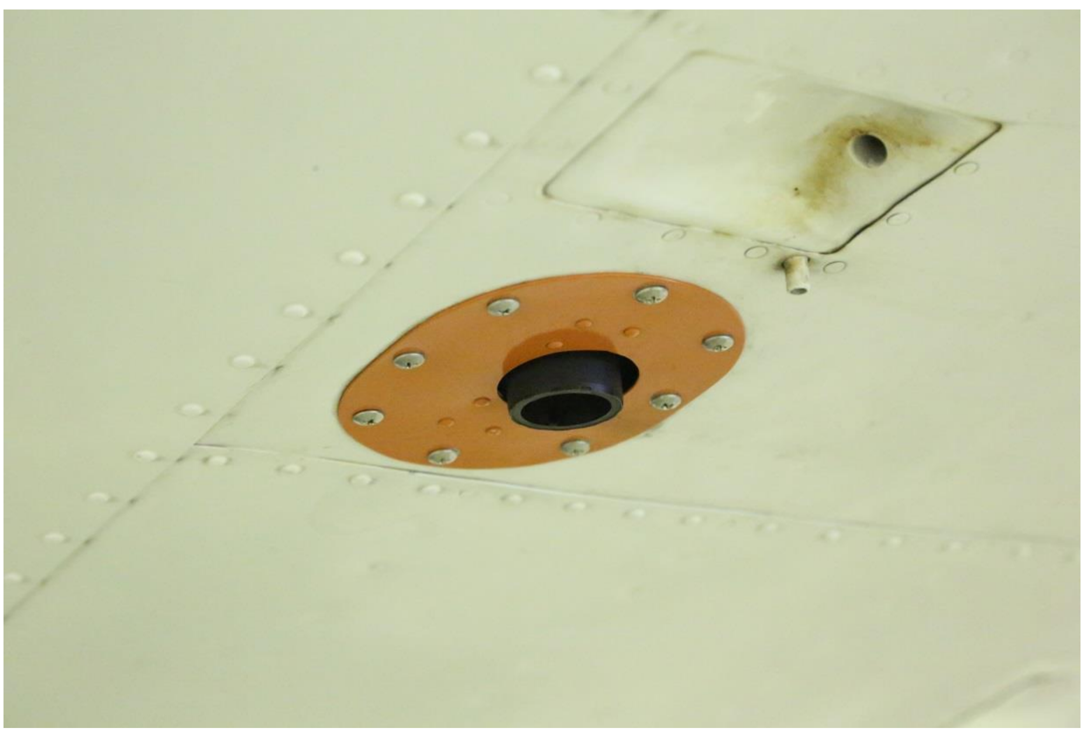

Figure 9b: The Axis 221 camera mounted under the left wing of the Navajo (close up).

Figure 10: The Axis 221 Camera [49].

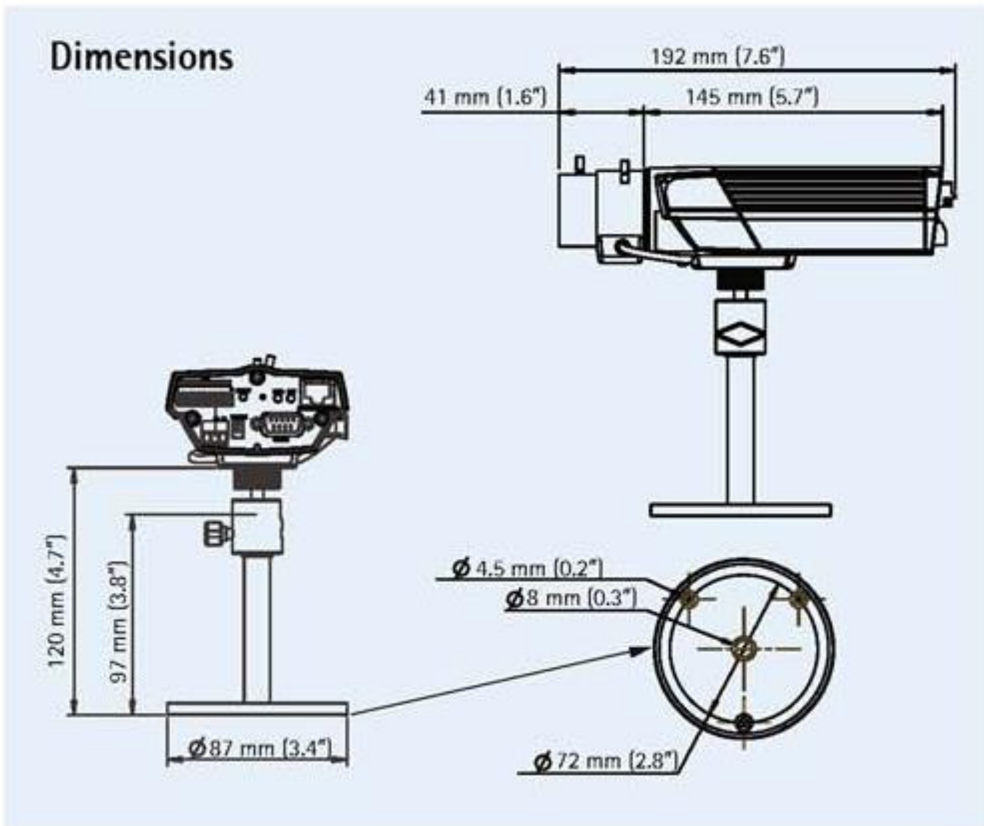

Figure 11: The Axis 221 Camera dimensions [49].

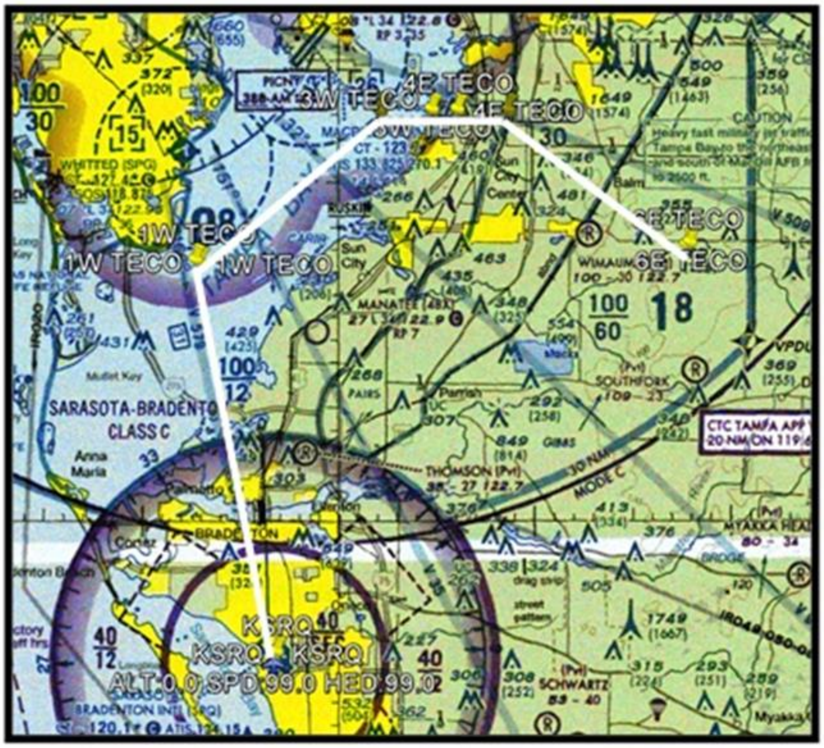

Figure 12: An Aviation Chart image of the TECO flight profile (in white).

Figure 13: A Google Earth image of the TECO flight profile zoomed in.

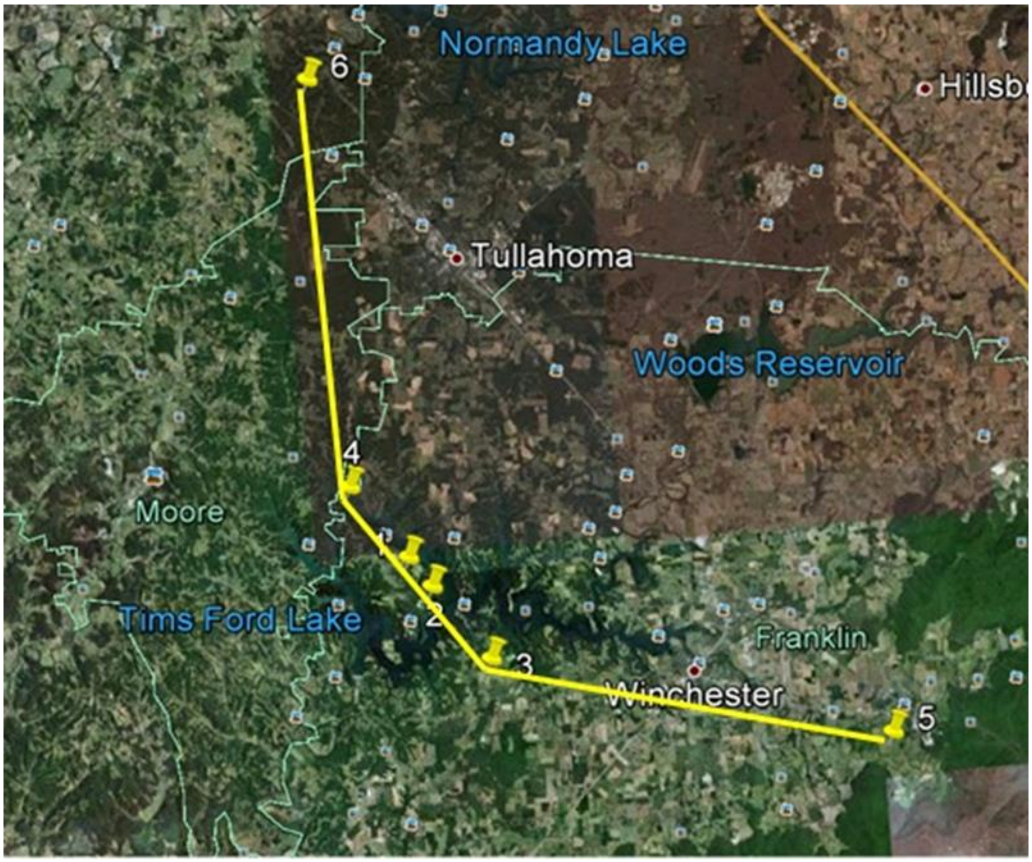

Figure 14: A Google Earth image of the TECO coordinates superimposed over Tim's Ford area.

Figure 15: An Aviation Chart image of the FPL flight profile.

Figure 16: A Google Earth image of the FPL flight profile zoomed in.

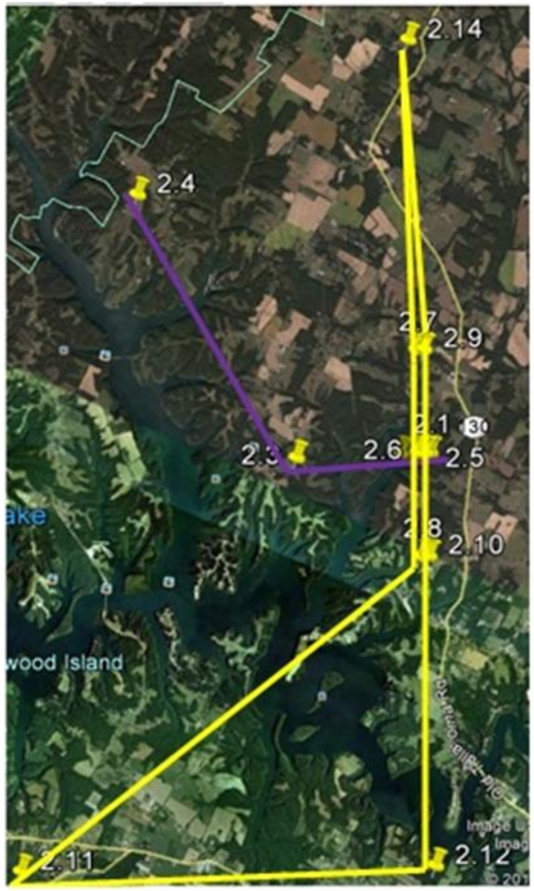

Figure 17: A Google Earth image of the FPL coordinates superimposed over Tim's Ford area.

Figure 18: An Aviation Chart image of the Three Sisters Sanctuary flight profiles (in white).

Figure 19: A Google Earth image of the Three Sisters Sanctuary flight profile zoomed in.

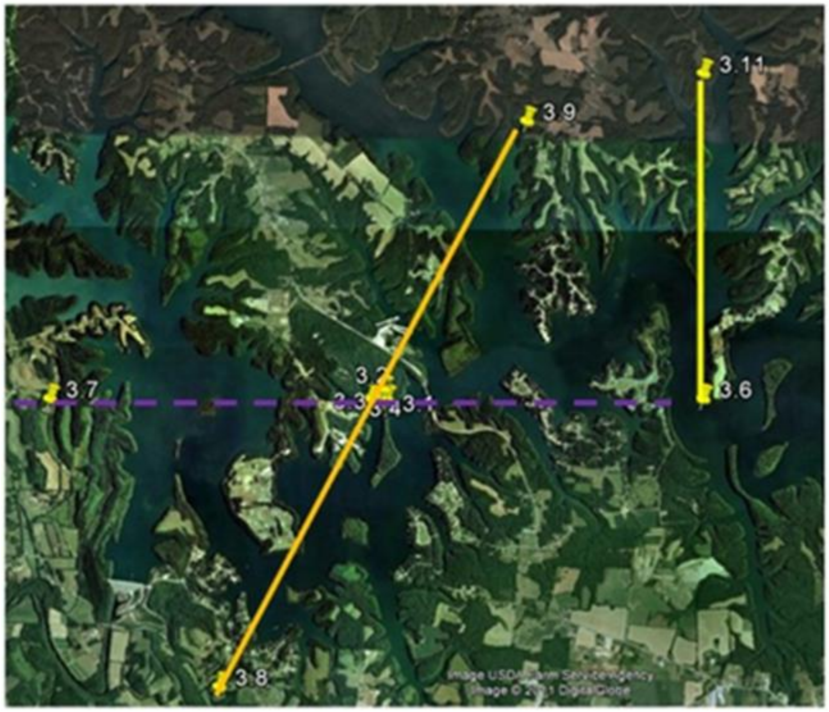

Figure 20: A Google Earth image (zoomed in) of the Three Sisters Sanctuary coordinates superimposed over Tim's Ford.

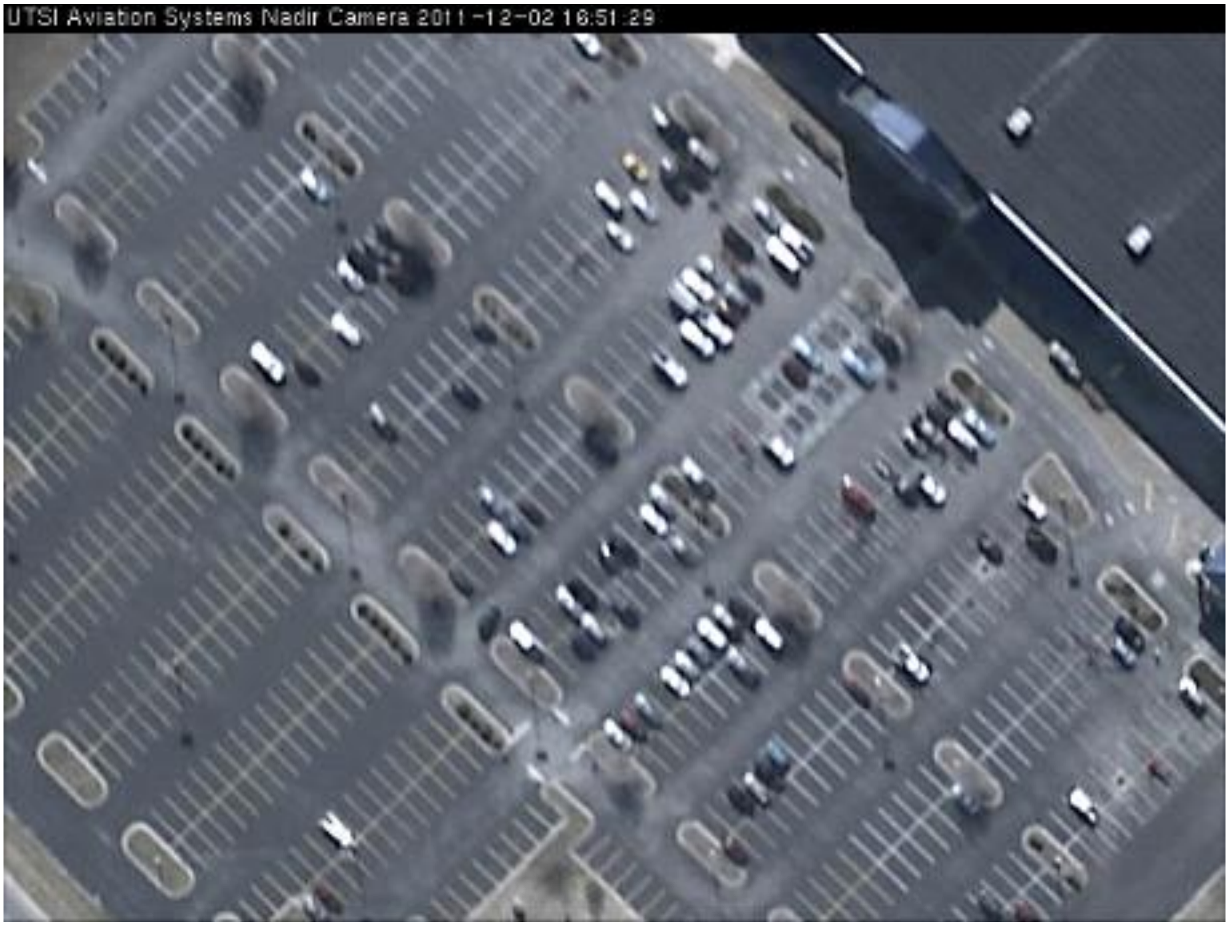

Figure 21: Parking lot from 306 meters.

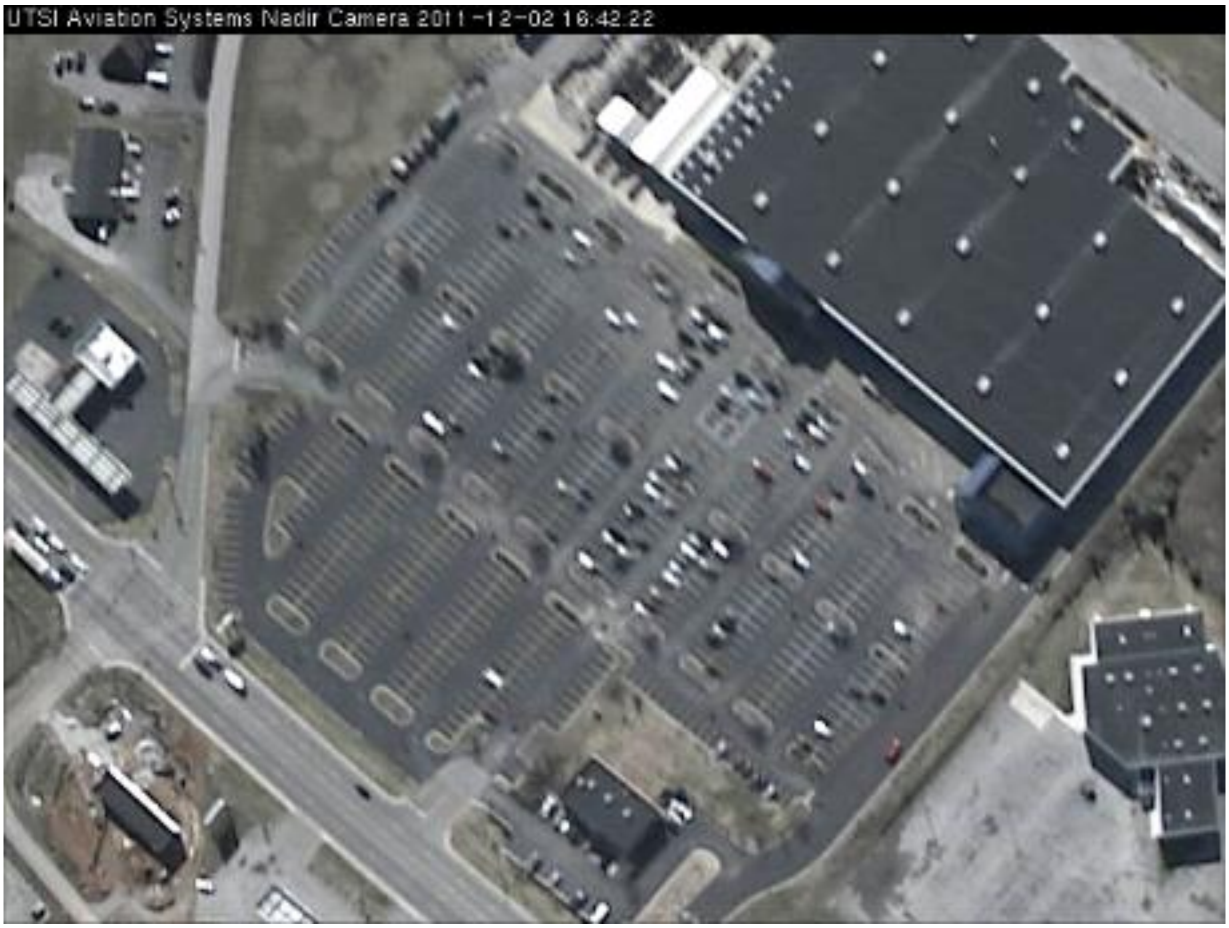

Figure 22: Parking lot from 580 meters.

Figure 23: Parking lot from 880 meters.

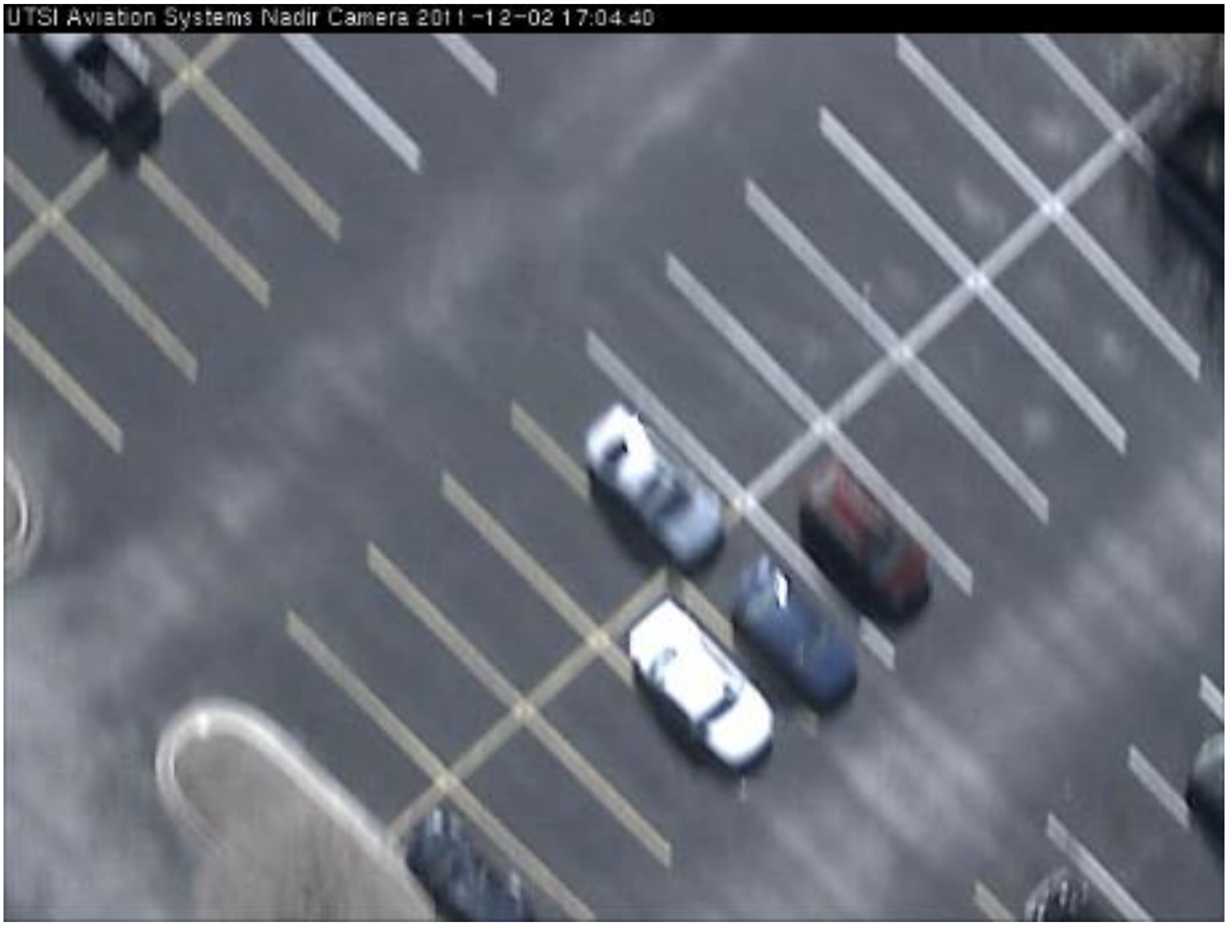

Figure 24: Parking Lot from 58 meters during Final Approach and Landing.

Figure 25: Runway markings from an altitude of 323 meters AGL.

Figure 26: Runway markings from an altitude of 582 meters AGL.

Figure 27: Runway markings from an altitude of 885 meters AGL.

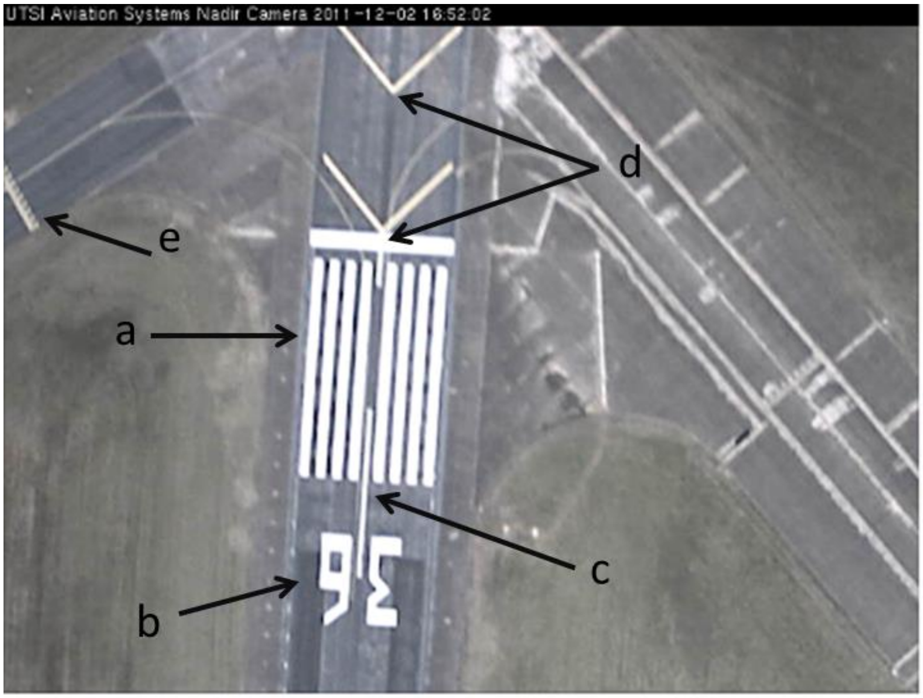

Figure 28a: Image of the runway from 323 meters AGL used to indicate measurements.
a. the threshold markings,
b. the runway designation numerals,
c. the center lines,
d. the chevrons,
e. the holding position markers.

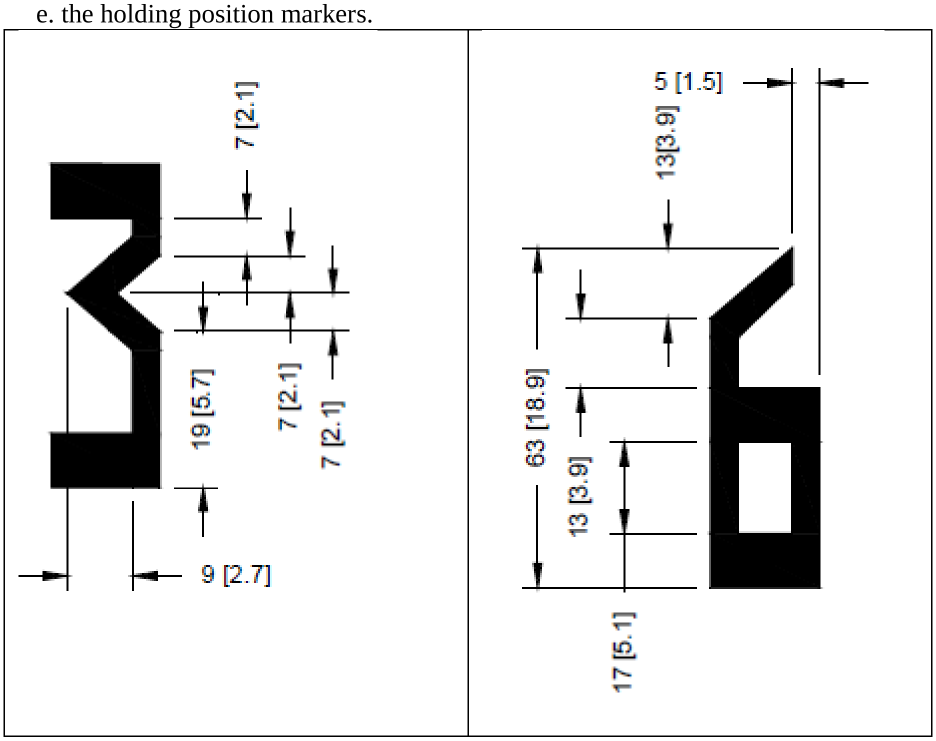

Figure 28b: Measurements of the runway numerals given in feet and meters in brackets [50].

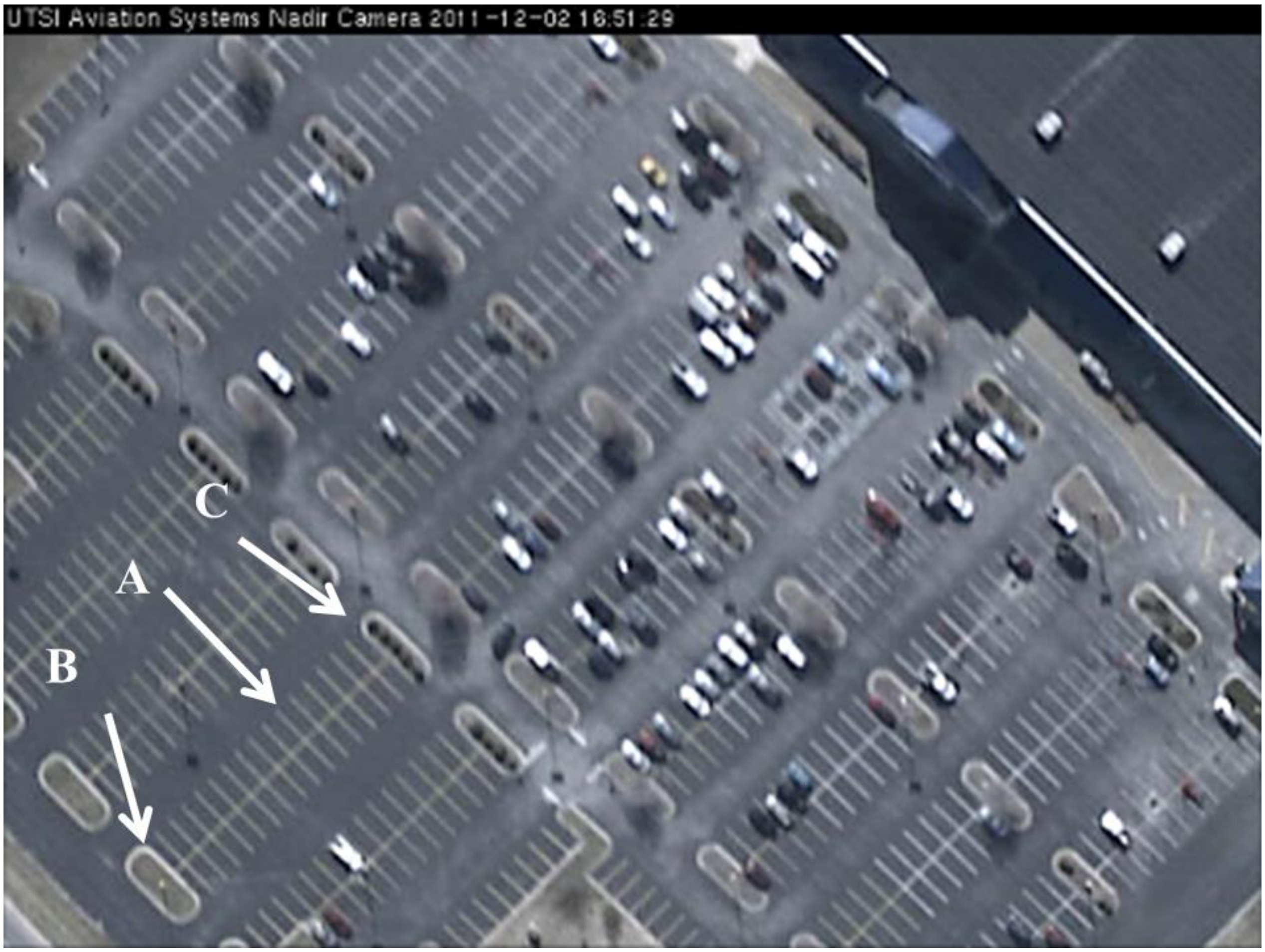

Figure 29: The parking lot from 306 meters AGL. A. The parking spaces, B. End without bushes
C. End with bushes

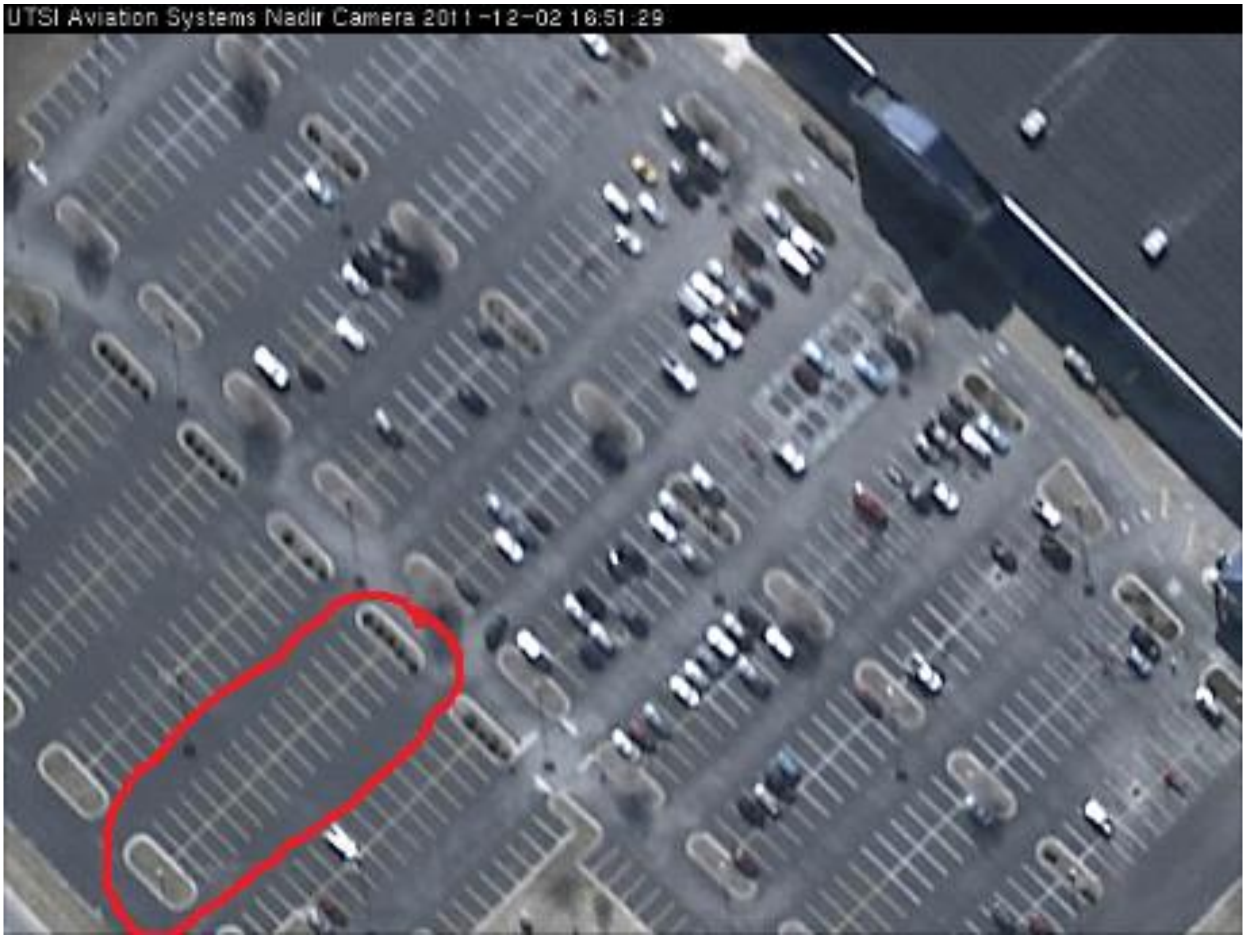

Figure 30: The parking lot from 306 meters AGL.

Figure 31: The parking lot at 580 meters AGL.

Figure 32: The parking lot at 882 meters AGL.

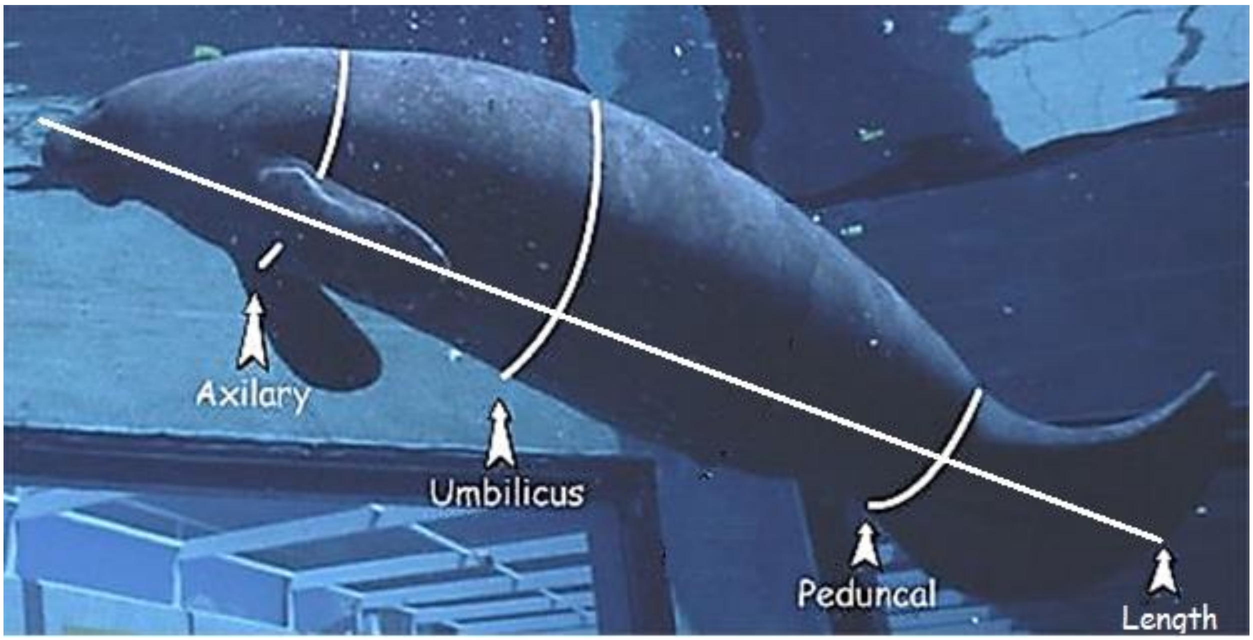

Figure 33: Average sized manatee [51].

Figure 34: An image of the TECO manatee congregation [48].

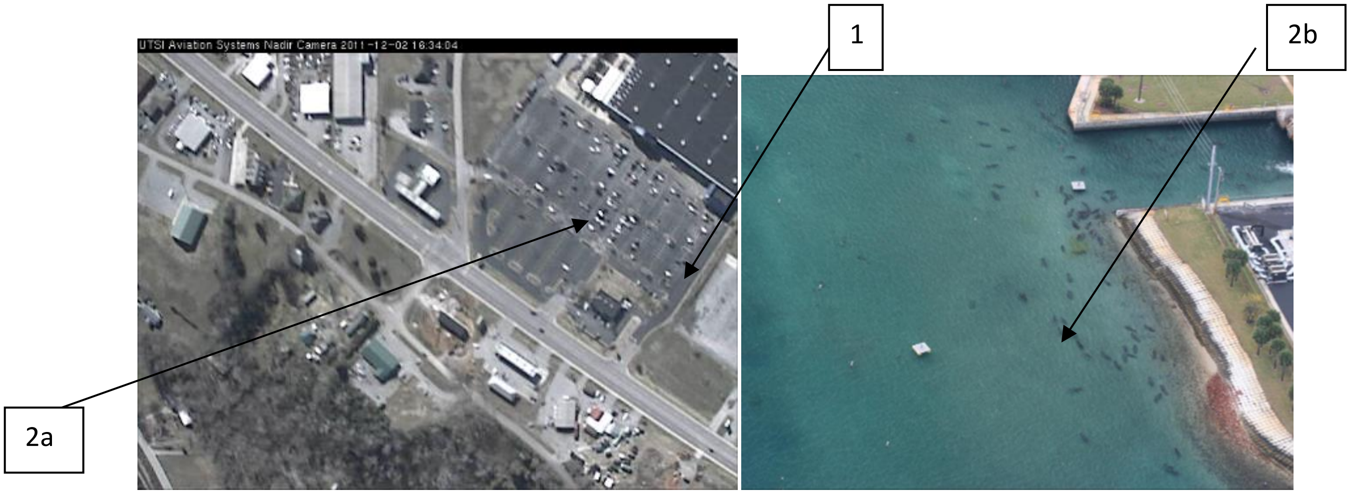

Figure 35: A comparison of the parking lot at 880 meters (figures 23) and an image of countable manatees (figure 34)

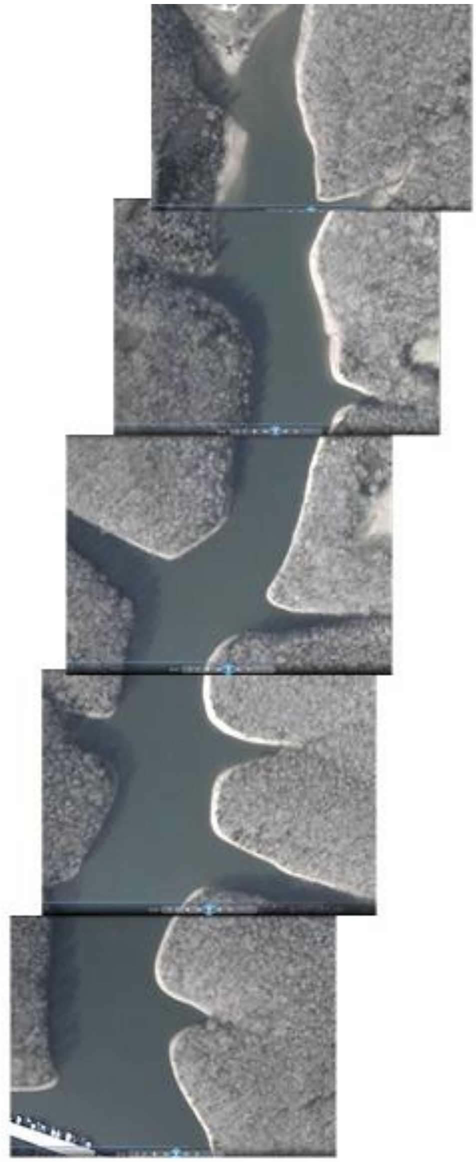

Figure 36a

Figure 36b

Figure 36a: Google Earth Image of Tim's Ford-TECO test point to be captured (Left).
Figure 36b: A compilation of digital images of the Tim's Ford-TECO test point taken during flight. (Right)

Figure 37a: Google Earth image of Tim's Ford-FPL test point to be captured.

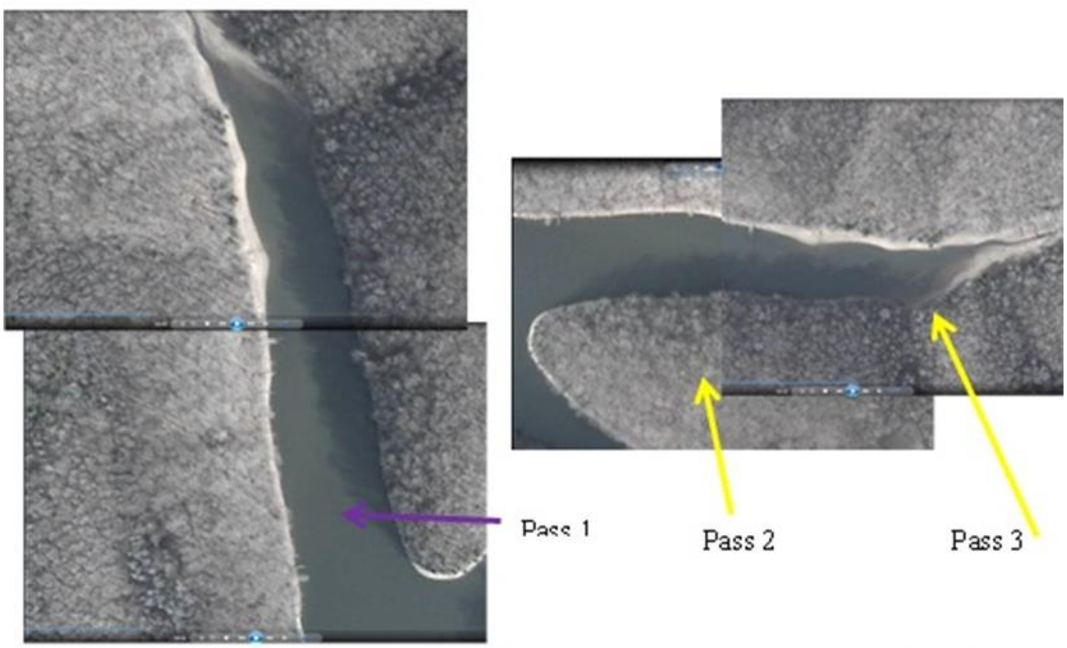

Figure 37b: A compilation of digital images of the Tim's Ford-FPL test point taken during flight.

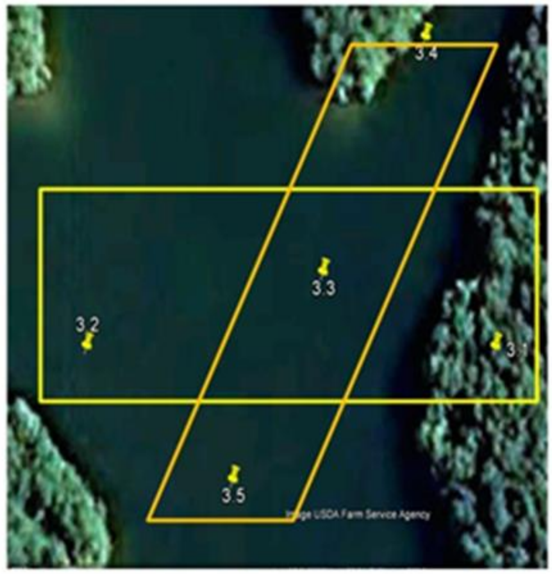

Figure 38a: Google Earth image of Tim's Ford-Three Sisters Sanctuary test point to be captured.

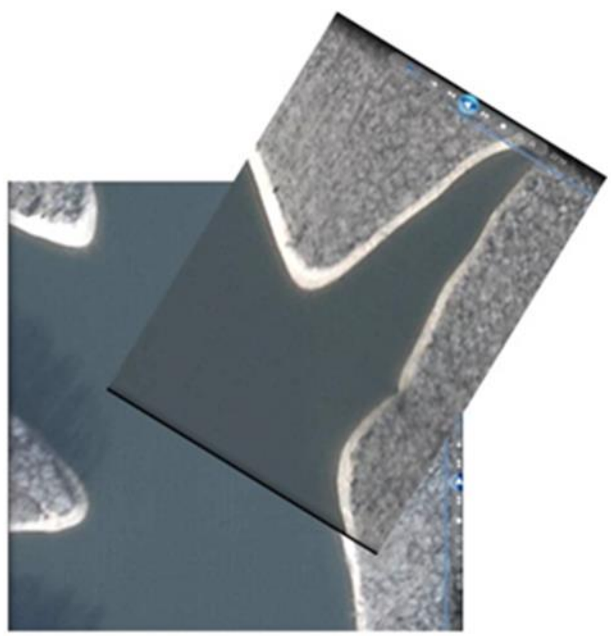

Figure 38b: A compilation of digital images of the Tim's Ford-Three Sisters Sanctuary test point to be captured.

Appendix B:
Tables

Table 1. Altitude and airspeed test points.

Altitude AGL (feet)	**Altitude AGL (meters)**	**Airspeed (kts)**
3,000	900	115
2,000	600	115
1,000	300	115

Table 2: A list and description of the metrics used to analyze the digital images, as well as what the observer is looking for with respect to that metric.

Metric	Description	Question for Metric
Spatial Resolution	How closely lines in an image can be distinguished from one another.	Is the image is clear and legible.
Clarity	Deals with level of contrast and definition. Clear, easy to understand.	Does the image clearly present desired information?
Legible	Capable of being deciphered with ease.	Is it easy to understand what the objects in the image actually are?
Sharpness	Perceived sharpness is a combination of both resolution and acutance. It is a combination of the captured resolution, which cannot be changed in processing, and of acutance, which can be so changed.	Are the objects in an image clearly defined?
Acutance	Edge contrast in an image, which can be changed in processing. Related to the amplitude of the derivative of brightness with respect to space. High acutance gives impression of higher resolution.	Are the objects in an image clearly defined?
Definition	The edges of fine detail are sharply distinct.	Are the objects in an image clearly defined?
Shape	The shape of the objects in the image.	Are the objects of interest the proper shape?
Graininess	Having a granular appearance	Was the image smooth or grainy?
Banding	An artifact of color gradation in computer imaging. When graduated colors break into larger blocks of a single color, the smooth look of a proper gradation is reduced.	Are the colors of the cars blending into colors of the surrounding objects?
Contrast	Contrast is the difference in luminance and/or color that makes an object distinguishable.	Is the object of interest sufficiently luminesced with respect to other objects in the FOV?
Contrast Ratio	The contrast ratio is defined as the ratio of the luminance of the brightest color (white) to that of the darkest color (black).	Is the ratio of the luminance of the brightest color (white) to the darkest color (black) accurately represented?
Color Balance	The accuracy with which the colors captured in the image, match the original scene.	Is the image the same color as the actual object?
Brightness	Value of a pixel in a digital image giving its value of lightness from black to white, with 0 being black and 255 being white	Is the range of illumination sufficient? Did it provide sufficient illumination?
Sunlight	Effect of the sunlight on the image.	Did it create a glare or did it wash out the display. Was this affected by angle?

Table 2 Continued

FOV	The field of view is the area that is seen at any given moment.	Was the entire area of interest available in the image?
DOV	The range of items in focus in an image. This is controlled by the focal length and aperture opening of a lens. A large or wide aperture gives a shallow depth of field (not much range in focus) and a smaller or narrow aperture give a large depth of field (more range in focus).	Are the objects of interest in focus?
Screen Size	The size of the UMPC screen that displays the image.	Is screen small enough so that it is appropriate for flight tests? Is it large (small) enough to be effective? Does the display allow the FTE to view any other data?
Screen Placement	Refers to the where the screen is (the placement of the screen on the UMPC).	Is it easily viewed? Does it interfere with other information?
Refresh Time	The refresh time refers to the number of times in a second that display hardware draws the data.	Was the refresh rate timely? Was a flicker or smear present? Was the picture was stable?
Automatic Brightness/ Contrast	Refers to the system's ability to automatically adjust the image brightness.	Did it interrupt the display? Did the circuitry adequately compensated for changing light levels?
Automatic Gain	Refers to the system that feeding back the average output signal level to adjust the gain to an appropriate level for a range of input signal levels. Where gain is the mean ratio of the signal output of a system to the signal input of the same system	Did it disturb the display? Was circuitry adequately compensated for situation dynamics?

Table 3. Airspeed, altitude, pitch, and surface temperature at test points collected during flight test #1.

	Avgerage GPS Ground Speed (kts)	Altitude From Laser Altimeter (meters)	Avgerage Aircraft Pitch Angle (deg)	Avgerage Heitronics (deg C)	Time
Parking Lot 1	113	882	4.373	14	16:51:29
Parking Lot 2	117	580	4.351	11	16:42:22
Parking Lot 3	118	306	3.889	167	16:34:04
Landing Parking Lot	93	59	-4.466	19	17:04:40
Runway 1	118	885	3.818	15	16:34:35
Runway 2	115	582	4.532	15	16:42:53
Runway 3	110	323	3.988	15	16:52:01

Table 4: An overview of the digital images at 59, 306, 580, and 880 meters displayed on a monitor, (check mark=good , wavy lines=fair, and x=poor)

Metric	59 m	306 m	580 m	880 m
Spatial Resolution	✓	✓	≈	⊗
Clarity	✓	✓	≈	⊗
Legible	✓	≈	≈	≈
Sharpness, Acutance, Definition	✓	≈	≈	⊗
Shape	✓	✓	≈	≈
Graininess	✓	✓	✓	✓
Banding	✓	✓	≈	⊗
Contrast	✓	✓	✓	✓
Contrast Ratio	✓	✓	✓	✓
Color Balance	✓	✓	≈	⊗
Brightness	✓	✓	✓	✓
Sunlight	✓	✓	✓	✓
FOV	⊗	✓	✓	✓
DOV	≈	≈	⊗	⊗

Table 5a: Analysis of the UMPC display of the parking lot at 306 meters.

Metric	Question for Metric	Answer
Spatial Resolution	Is the image is clear and legible?	The image provides adequate detail to easily count the targets. Targets could be distinguished from one another. No eyestrain occurs to count the targets. Targets appear fairly clear and legible.
Clarity	Does the image clearly present desired information?	The desired information is clearly presented (the targets can be easily counted)
Color Balance	Is the image the same color as the actual object?	There is adequate detail to see red, whites and blacks. Other colors appear grey.
Screen Size	Is screen small enough so that it is appropriate for flight tests? Is it large (small) enough to be effective? Does the display allow the FTE to view any other data?	Yes, the display on the UMPC an appropriate size. Yes. It was large enough to capture the desired field of view. It was small enough that it did not get in the way. No.
Shape	Are the objects of interest the proper shape?	The targets on the display were the appropriate shape, but somewhat blurred.
Screen Placement	Is it easily viewed? Does it interfere with other information?	Yes. Yes, only the video or the parameters could be viewed at one time.
Refresh time	Was the refresh rate timely? Was a flicker or smear present? Was the picture was stable?	Yes. No. Yes.
Automatic Brightness/Contrast	Did it interrupt the display? Did the circuitry adequately compensated for changing light levels?	No. Yes.
Automatic Gain	Did it disturb the display? Was circuitry adequately compensated for situation dynamics?	No. Yes.

Table 5b: Analysis of the UMPC display of the parking lot at 580 meters.

Metric	Question for Metric	Answer
Spatial Resolution	Is the image is clear and legible?	There is enough detail provided to count the targets, with eyestrain. Targets are barely legible, they are not clear.
Clarity	Does the image clearly present desired information?	The clarity is poor. Targets can be counted, but it is difficult.
Color Balance	Is the image the same color as the actual object?	The targets on the display appear to be white and various shades of grey. Some red is faintly visible.
Screen Size	Is screen small enough so that it is appropriate for flight tests? Is it large (small) enough to be effective? Does the display allow the FTE to view any other data?	Yes, the display on the UMPC an appropriate size. Yes. It was large enough to capture the desired field of view. It was small enough that it did not get in the way. No.
Shape	Are the objects of interest the proper shape?	The targets on the display were the appropriate shape, but somewhat blurred.
Screen Placement	Is it easily viewed? Does it interfere with other information?	Yes. Yes, only the video or the parameters could be viewed at one time.
Refresh time	Was the refresh rate timely? Was a flicker or smear present? Was the picture was stable?	Yes. No. Yes.
Automatic Brightness/Contrast	Did it interrupt the display? Did the circuitry adequately compensated for changing light levels?	No. Yes.
Automatic Gain	Did it disturb the display? Was circuitry adequately compensated for situation dynamics?	No. Yes.

Table 5c: Analysis of the UMPC display of the parking lot at 880 meters.

Metric	Question for Metric	Answer
Spatial Resolution	Is the image is clear and legible?	The image does not provided adequate detail to count the targets. Targets are not clear they are barely legible.
Clarity	Does the image clearly present desired information?	The clarity is very poor. Targets cannot be counted with reliable accuracy.
Color Balance	Is the image the same color as the actual object?	The targets appear white and grey. Adequate detail is not provided to distinguish other colors.
Screen Size	Is screen small enough so that it is appropriate for flight tests? Is it large (small) enough to be effective? Does the display allow the FTE to view any other data?	Yes, the display on the UMPC an appropriate size. Yes. It was large enough to capture the desired field of view. It was small enough that it did not get in the way. No.
Shape	Are the objects of interest the proper shape?	The shapes were blurred, the viewer can tell what the targets are based on the surroundings.
Screen Placement	Is it easily viewed? Does it interfere with other information?	Yes. Yes, only the video or the parameters could be viewed at one time.
Refresh time	Was the refresh rate timely? Was a flicker or smear present? Was the picture was stable?	No. Yes. Yes.
Automatic Brightness/Contrast	Did it interrupt the display? Did the circuitry adequately compensated for changing light levels?	No. Yes.
Automatic Gain	Did it disturb the display? Was circuitry adequately compensated for situation dynamics?	No. Yes.

Table 6: Measurements of prominent runway markings.

Markings	Distance	Height 324 meters AGL	Height 582 meters AGL	Height 885 meters AGL
a. Threshold markings				
Gap between the threshold markings	**11.5'**	Resolvable	Resolvable	Resolvable
Length of the threshold markings	**150'**	Resolvable	Resolvable	Resolvable
Width and spaces	**5.75'**	Resolvable	Resolvable	Partly Resolvable
b. Runway Designation Numerals				
Height	**60'**	Resolvable	Resolvable	Resolvable
Width per numeral	**20'**	Resolvable	Resolvable	Resolvable
Spacing	**15'**	Resolvable	Resolvable	Resolvable
Total width	**55'**	Resolvable	Resolvable	Resolvable
c. The center lines				
Length	**120'**	Resolvable	Resolvable	Resolvable
Spacing	**80'**	Resolvable	Resolvable	Resolvable
d. Chevrons				
from tip to tip	**100'**	Resolvable	Resolvable	Resolvable
e. Holding Position Markers				
Height-Wise Spacing 4 lines and 3 spaces 1' each	**1' each (blends into a 7' strip)**	The 1' spaces are Not Resolvable	The 1' spaces are Not Resolvable	The 1' spaces are Not Resolvable
Width and spacing	**5.75'**	Resolvable	Not Resolvable	Not Resolvable

Table 7: Parking lot measurements, see Figure 29.

What is being measured	Inches/feet	Altitude (AGL)		
		306 meters	580 meters	882 meters
A. The parking spaces		Resolvable	Resolvable	Somewhat Resolvable
Average Width	114"/ 9.5'	Visible	Visible	Intermittently Visible
Average Length	250"/ 20.8'	Visible	Visible	Intermittently Visible
Narrow space at far end	82"/ 6.8'	Visible	Visible	Barely Visible
Yellow Lines	6"/ .5'	Visible	Visible	Intermittently Visible
Center Yellow Line	6.25"/	Visible	Visible	Visible
B. End without bushes				
Width	238"/ 19.8'	Visible	Visible	Visible
Length	536"/ 44.7'	Visible	Visible	Visible
C. End with bushes				
Width	170"/ 14.2'	Visible	Visible	Visible
Length	525"/ 43.75'	Visible	Visible	Visible
Bushes/Spaces		Resolvable	Not Resolvable	Not Resolvable
Bush 1	64"/ 5.3'			
Space 1	27"/ 2.25'			
Bush 2	67"/ 5.6'			
Space 2	20"/ 1.7'			
Bush 3	68"/ 5.7'			
Space 3	17"/ 1.4'			
Bush 4	81"/ 6.75'			
Space 4	31"/ 2.6'			
Bush 5	79"/ 6.6'			
Length from B to C (inside to inside)	1869"/ 155.75'	Visible	Visible	Visible
Length from B to C (outside to outside)	2277"/ 189.75'	Visible	Visible	Visible

Table 8: Measurements for an average sized adult male manatee [51, 52]

Area	**Measurement for a (Average Male Manatee)**	
	Meters	**Feet**
Length (snout to paddle)	10-12	3.0-3.7
Axillary Girth (just below flippers)	7.2	2.2
Umbilical Girth (around the belly button)	8	2.4
Penduncal Girth (the base of the tail where it meets the body)	5.4	1.6

Table 9a: A comparison of hue and luminance for the image of countable manatees (fig 34). *Scale/Spectrum range is 0-240, no units*

Sample (Fig 34)	Left Sample	Right Sample	Average	Water vs Manatee
 Water	Hue 122	Hue 119	Hue 121	Hue 18
	Luminance 94	Luminance 114	Luminance 104	
 Manatee	Hue 139	Hue 139	Hue 139	Luminance 6
	Luminance 96	Luminance 99	Luminance 98	

Table 9b: A comparison of hue and luminance for the parking lot image (fig 23) taken from 880 feet. Two samples of asphalt are used (top and bottom strips) and three car samples are used (middle strip). *Scale/Spectrum range is 0-240, no units*

Sample (Fig 23) 	Hue	Luminance
Average Asphalt	137	98
Light Car	38	185
Difference from Light Car and Asphalt	172	20
Medium Car	147	177
Difference from Medium Car and Asphalt	10	79
Dark Car	142	35
Difference from Dark Car and Asphalt	5	63

Table 10: Airspeeds and altitudes at test points for Flight Test 2 over Tim's Ford.

Area	Altitude (meters)	GPS Ground Airspeed (kts)
Tim's Ford-TECO First Pass	588	125
Tim's Ford-TECO Second Pass	608	108
Tim's Ford-FPL First Pass	558	114
Tim's Ford-FPL Second Pass	579	98
Tim's Ford-FPL Third Pass	664	120
Tim's Ford-Three Sisters First Pass	617	113
Tim's Ford-Three Sisters Second Pass	612	114
Tim's Ford-Three Sisters Third Pass	600	102

Appendix C:
Technical specifications – AXIS 221 Network Camera

(From www.axis.com)

Camera	
Image sensor	1/3" Progressive scan RGB CCD
Lens	Varifocal 3.0 – 8.0 mm, F1.0, DC-iris, CS mount Angle of view, horizontal: 35° – 93°
Minimum illumination	Color: 0.65 lux, F1.0 B/W: 0.08 lux, F1.0
Shutter time	1/25000 s to 2 s
Video	
Video compression	MPEG-4 Part 2 (ISO/IEC 14496-2) Motion JPEG
Resolutions	160x120 – 640x480
Frame rate MPEG-4	Up to 30 fps at 640x480, 60 fps at 320x240
Frame rate Motion JPEG	Up to 45 fps at 640x480, 60 fps at 480x360
Video streaming	Simultaneous MPEG-4 and Motion JPEG Controllable frame rate and bandwidth VBR/CBR MPEG-4
Image settings	Compression, rotation, color, brightness, sharpness, contrast, white balance, exposure control, exposure area, backlight compensation, fine tuning of behavior at low light Text and image overlay Privacy mask
Network	
Security	Password protection, IP address filtering, HTTPS encryption, IEEE 802.1X network access control, user access log
Supported Protocols	IPv4/v6, HTTP, HTTPS, QoS Layer 3 DiffServ, FTP, SMTP, Bonjour, UPnP, SNMPv1/v2c/v3 (MIB-II), DNS, DynDNS, NTP, RTSP, RTP, TCP, UDP, IGMP, RTCP, ICMP, DHCP, ARP, SOCKS

System Integration	
Application Programming Interface	Open API for software integration, including VAPIX® from Axis Communications available at www.axis.com
Intelligent video	Video motion detection, active tampering alarm
Alarm triggers	Intelligent video, IR-cut filter, temperature and external input
Alarm events	File upload via FTP, HTTP and email Notification via email, HTTP and TCP External output activation
Video buffer	9 MB pre-and post alarm
General	
Casing	Metal (aluminum)
Processors and memory	ETRAX 100LX, ARTPEC-2, 32 MB RAM, 8 MB Flash
Power	7 – 24 V DC, max 5.5 W 10 – 24 V AC, max 7.5 VA Power over Ethernet IEEE 802.3a, Class 2
Connectors	RJ-45 for 10BASE-T/100BASE-TX, DC jack Terminal block for 2 alarm inputs, 1 output and RS485 D-sub for RS-232
Operating conditions	0 – 50 °C (32 – 122 °F) Humidity 20 – 80% RH (non-condensing)
Approvals	EN 55022 Class B, EN 55024, EN 61000-3-2, EN 61000-3-3, EN 61000-6-1, EN 61000-6-2, FCC Part 15 Subpart B Class B, VCCI Class B, C-tick AS/NZS CISPR22, ICES-003 Class B, EN 60950-1 Power supply: EN 60950-1, UL, cUL
Weight	550 g (1.2 lb.)
Included accessories	Installation Guide, CD with User’s Manual, recording software, installation and management tools, mounting and connector kits, power supply, Windows decoder 1-user license

Appendix D:
Technical Specification for Infrared Radiation Heitronics Pyrometer KT19II

(From http://www.heitronics.com/en/infratot-messtechnik/)

Technical Specification		
Value	Range I	Range II
Temperature measuring range	-50 – 300 °C	150 – 1000 °C
Spectral sensitivity	8-14 µm	3.9 µm
Field of View	7.4 at 420 mm	5.8 at 390 mm
Measuing field marking	Laser marker and through-the-lens-sighting	
Lens	S977 (Zinc Selenide)	
Detector	Pyroelectric	
Analog Output	0… 20 mA, 4…20 mA, 0…1V, 0…10 V The output signal is linearly to the measuring temperature r linearly to the measuring radiation, depends on setting.	
Resolution of the analog output	12 bit	
Digital Inerface (RS232C)	9600 – 115,200 bps	
Response time (90%) (variable by programming)	0.02 °C	
Permissible ambient temperature	0.03, 0.1, 0.3, 1, 3, and 10 s	
Storage temperature	23 °C +/- 3 °C	
Operating voltages	-20 … +70 °C	
Current consumption	24 VAC +/- 10%, 48-400 Hz, 22-30 VDC	
Weight	200 mA RMS	
Type of protection	1.5 kg	
	IP65 (NEMA4 equivalent)	

Appendix E:
Laser Altimeter Spec Sheet

(From UTSI Piper Navajo Airborne Science Experimenter's Handbook)

Technical Data LD321

Performance Examples

High Penetration and High Accuracy Mode	LD321-A20	LD321-A40
Measurement range [1] for natural targets, ρ ≥ 80% for natural targets, ρ ≥ 10% reflector foil [2] & plastic cat´s-eye reflector	 up to 500 m up to 150 m up to 2200 m	 up to 900 m up to 300 m up to 2400 m
Minimum range	2 m	2 m
Measurement accuracy [3) 4)]	typ. ± 20 mm	typ. ± 20 mm
Measurement rate [5]	typ. 100 Hz	typ. 100 Hz
Max. number of targets	5	5

Fast Mode	LD321-A20	LD321-A40
Measurement range [1] for natural targets, ρ ≥ 80% for natural targets, ρ ≥ 10% reflector foil [2] & plastic cat´s-eye reflector	 up to 250 m up to 80 m up to 1200 m	 up to 470 m up to 160 m up to 2200 m
Minimum range	2 m	2 m
Measurement accuracy [3) 4)]	typ. ± 30 mm	typ. ± 30 mm
Measurement rate	2500 Hz	2500 Hz
Max. number of targets	3	3

High Speed Mode	LD321-A20	LD321-A40
Measurement range [1] for natural targets, ρ ≥ 80% for natural targets, ρ ≥ 10% reflector foil [2] & plastic cat´s-eye reflector	 up to 200 m up to 60 m up to 1000 m	 up to 390 m up to 130 m up to 1900 m
Minimum range	2 m	2 m
Measurement accuracy [3) 4)]	typ. ± 50 mm	typ. ± 50 mm
Measurement rate	10000 Hz	10000 Hz
Max. number of targets	2	2

1) The following conditions are assumed
   - target is larger than foot print of laser beam, • normal incident angle, • visibility 10 km
   - typical values for average ambient brightness conditions. In bright sunlight, the operational range is considerably shorter than under an overcast sky. At dawn or at night the range is even higher.
2) Reflecting foil 3M DG4090 or equivalent, dimensions ≥ 0.45 x 0.45 m^2.
3) One sigma standard deviation @ 50 m range under *RIEGL* test conditions.
4) Plus distance depending error ≤ ± 20 ppm.
5) With self adapting measurement time selected, the effective data update rate depends on the number of targets and their reflectivity and distance.

Technical Data LD321

Laser Specifications

	LD321-A20	LD321-A40
Wavelength	near infrared	near infrared
Beam divergence [1)]	2.7 x 0.2 mrad	1.2 x 1.8 mrad
Laser safety class according to IEC 60825-1:1993+A1:1997+A2:2001 The following clause applies for instruments delivered into the United States: Complies with 21 CFR 1040.10 and 1040.11 except for deviations pursuant to Laser Notice No. 50, dated July 26, 2001.	Laser Class 1 CLASS 1 LASER PRODUCT	Laser Class 1M INVISIBLE LASER RADIATION DO NOT VIEW DIRECTLY WITH OPTICAL INSTRUMENTS CLASS 1M LASER PRODUCT Viewing the laser output with certain optical instruments designed for use at a distance (for example, telescopes and binoculars) may pose an eye hazard.

1) 1mrad corresponds to 10 cm beam width per 100 m distance.

RIEGL
LASER MEASUREMENT SYSTEMS

Appendix F:
Techincal Specifications for the Piper Navajo

(From UTSI Piper Navajo Airborne Science Experimenter's Handbook)

Basic Dimensions

Wing Span, ft (m)	40.67 (12.39)
Wing Area, sq ft (sq m)	229 (21.3)
Length, ft (m)	32.63 (9.946)
Height, ft (m)	13.00 (3.962)
Wing Loading, lbs per sq ft (kg per sq m)	28.4 (139)
Power Loading, lbs per HP (kg per watt)	10.5 (0.00639)
Propeller Diameter, in (m)	80 (2.0)
Turning Radius (Nose Wheel), ft (m)	28 (8.5)

Weights

Ramp Weight, lbs (kg)	6,536 (2,965)
Gross Weight, Takeoff, lbs (kg)	6,500 (2,948)
Gross Weight, Landing Max	6,200 (2,812)
Empty Weight (standard, six-place), lbs (kg)	4,387 (1,990)
Useful Load (standard, six-place), lbs (kg)	2,113 (958)

Power Plant

Engine Type Lycoming TIO-540-A	
Rated Horsepower, HP (Watts)	310 (231,167)
Rated Speed (rpm)	2,575
Bore, inches (m)	5.125 (0.1301)
Stroke, inches (m)	4.375 (0.1111)
Displacement, cubic inches (cubic m)	541.5 (0.008873)
Compression Ratio	7.3:1
Dry Weight, lbs (kg)	535.0 (242.67)

Vita

Coral Franklin was born in Emporia, Va, to the parents of Jim and Beth Franklin. She graduated from Digby Regional High School in Digby, Nova Scotia and ICT Northumbland College in Halifax, Nova Scotia. She graduated Summa Cum Laude from East Tennessee State University (ETSU) in Johnson City, TN earing her Bachelor of Science degree with a major in Physics and minor in Mathematics. While at ETSU she worked as a research assistant and completed an undergraduate thesis "Infra-Red Colors of Normal Nearby Spiral Galaxies with Respect to Hubble Type." She submitted her poster and participated in participated in the "Galaxy Wars Conference" in Johnson City and the Women in Science Conference at Duke University. She also completed an Undergraduate Student Research Project (USRP) as a student intern at the NASA Langley in Va. She is continuing her education with a Masters of Aviation Systems at the University of Tennessee Space Insitute.