The effect of aerial haze on the contrast and resolution of a photographic image in direct application to a low-altitude, remote, pilotless imaging system

Todd Eric Pegelow

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THE EFFECT OF AERIAL HAZE ON THE CONTRAST
AND RESOLUTION OF A PHOTOGRAPHIC IMAGE
IN DIRECT APPLICATION TO A LOW-ALTITUDE,
REMOTE, PILOTLESS IMAGING SYSTEM

by

Todd Eric Pegelow

A thesis submitted in partial fulfillment
of the requirements for the degree of
Bachelor of Science in the School of
Photographic Arts and Sciences in the
College of Graphic Arts and Photography
of the Rochester Institute of Technology

Todd Eric Pegelow
Signature of the Author
Imaging and Photographic Science

A. Davidhazy
Certified by
Thesis Advisor

Name Illegible
Accepted by
Coordinator, Undergraduate Research
Title of thesis: The Effect of Aerial Haze on the Contrast and Resolution of a Photographic Image in Direct Application to a Low-Altitude, Remote, Pilotless Imaging System.

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THE EFFECT OF AERIAL HAZE ON THE CONTRAST AND RESOLUTION OF A PHOTOGRAPHIC IMAGE IN DIRECT APPLICATION TO A LOW-ALTITUDE, REMOTE, PILOTLESS IMAGING SYSTEM

by

Todd Eric Pegelow

Submitted to the Imaging and Photographic Science Division in partial fulfillment of the requirements for the degree of Bachelor of Science in the School of Photographic Arts and Sciences in the College of Graphic Arts and Photography of the Rochester Institute of Technology

ABSTRACT

A study of the effect of aerial haze on photographic images acquired through the use of a remotely-piloted imaging system has been completed. The project involved the design, construction, and implementation of a remotely-controlled airborne imaging system for the express purpose of collecting scientific data relating the contrast of an image to the altitude at which that image was exposed. Data was collected and analyzed and the results are presented here. The system was also evaluated with respect to its usefulness as a collector of scientific data. The conclusion drawn is that aerial haze had no effect on the contrast of an image at low altitudes (below 1000 feet) for the conditions under which the data was collected.
ACKNOWLEDGEMENTS

The author wishes to extend his most sincere thanks to his advisor, Professor Andrew Davidhazy of the Technical Photography Department at the Rochester Institute of Technology. His patience and common sense advice have been greatly appreciated.

A tremendous thank you also goes to Dr. Willem Brouwer, of the Imaging and Photographic Science Department, for his insight and his willingness to 'go to bat' for the cause. His fiery enthusiasm made the whole thing worth while.

A special thanks goes to Mr. Mike Hawkins, project pilot, of the Radio Control Club of Rochester. His undying devotion to the hobby and to helping others was an inspiration. He went beyond the call of duty on more than one occasion, and the author is proud to call him 'friend'.

Thanks go to Mr. Joe Biegel of the RIT Imaging and Photographic Science Department. His last minute proofreading and assistance with the statistical analysis was of great value. Joe went out of his way to be of help, and it was greatly appreciated.

Also deserving of thanks is Mr. Jerome Joseph of Tri-J Films. His patience, guidance and love of the hobby made the project that much easier. Jerry always came through in the clutch.

Yet another thank you goes to Lewis W. Pegelow for his understanding and his financial support. Without it, the project would literally never have gotten off the ground.

A loving thanks go to Darvin, Jackie and Tracey Pegelow. Their patience and tolerance of the perpetual mess that the project made in their household is greatly appreciated.

Thanks also go to Dr. John Schott of the Imaging and Photographic Science Department, and to Mr. Brian McGinley of American Microsystems, Inc.. Their creativity in the developmental stages of the project was invaluable.
Thanks are also due to Mr. John F. Earnst of Macedon, New York, for the generous use of his airstrip and flying field.

Special thanks also go to Ms. Jutta Middel. Her love and understanding made the 'RIT experience' bearable.

Finally, uncounted thanks go to those people special enough to call themselves "photoscience students", particularly the class of 1984 (give or take a few quarters). Their help and encouragement made the four years here a most rewarding experience. The author leaves with nothing but fond memories of all of them.
DEDICATION

This thesis is dedicated to my parents, Darvin and Jackie,
and to my sister Tracey.
Without their love, understanding, and total support,
these past four years would have been much less tolerable.

It is also dedicated to the memory of
Loyd Raymond Herriman,
a grandfather whose ingenuity, industrious spirit
and drive for perfection I had always admired.
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I. INTRODUCTION

The past several decades have witnessed the transformation of aerial photography into a very specialized area of imaging and photographic science. Most aerial photographic missions can be classified in one of two general types of aerial photography, those being surveillance (or reconnaissance) and cartographic photography. Surveillance photography is concerned with the identification of various ground features as well as specific targets, while cartographic photography is, of course, involved in the production of maps. In either case, maximum resolution of ground objects is of utmost concern. Several factors influence the attainable resolution of any aerial photographic system and include among them stability of the platform, image motion, camera format, scene reflectance, and atmospheric conditions\(^1,2,3\). Thus, careful design of airborne systems is essential for the acquisition of quality aerial photographs. It is evident that image contrast becomes of great concern, as well, since a reduction in contrast translates to a diminished ability to identify adjacent features on the ground. Contrast is defined
here in the normal photographic sense as being the change in transmission density corresponding to a change in log exposure.

Aerial photography is quite different than most other forms of photography simply by virtue of the large distance that is common between the camera and the object imaged. This being so, there exists a large volume of air which reflects light back into the camera system. The light is reflected by dust or water vapor. The air molecules themselves also contribute the aerial haze in the form of scatter. This extraneous light superimposes a uniform exposure over the film frame which decreases the contrast of the image<4>.

Although the term "haze" is rather nebulous, it describes a phenomenon that is really quite familiar to everyone. It is perhaps most evident when looking at distant scenes or objects such as mountains. Even on a clear day of normal humidity, there appears to be a thin veil over the landscape.

"Haze is the optical turbidity of the atmosphere. It may be caused by dust, smoke, water vapor, irregular temperature distribution, or even by dry air. In fact, any atmospheric material which tends to diminish the transparency of the space it occupies may be said to be a source of haze. There are many types of haze. At times it is stratified near the ground or at high altitudes, and at other times it extends uniformly to a great height. Its quality or color also varies, not only with the varying sources of haze but also with the size of the suspended particles it may contain. Haze,
therefore, is due to a light-scattering medium, and creates a veiling glare between the camera and the subject, causing not only a brightening of it but also a great reduction in contrast.

The determination of the distribution, the quantity, and the quality of haze is possible only by observations from aeroplanes at various altitudes and under different weather conditions, and, since these important factors must be considered from a photographic viewpoint, photographic methods are employed. Therefore, it is necessary to frame a definition of haze in terms of its measurable effects upon the developed photographic material. This definition is based upon the two obvious effects. The suspended materials in the atmosphere scatter sunlight and hence send back light to the camera, which adds to the exposure creating an image of the subject..."<5>

Often it has been said that we can visually perceive objects by virtue of the light that they reflect. It is, however, more precise to state that the perception of objects is, for the most part, dependent on the differences in the amount of light that they reflect. If consideration is given to the perception of an object that is the same color as its background, it is obvious that perception is impossible. When, however, there is a difference in the amount of light that is reflected due to either illumination differences or color differences, perception becomes possible<6>.

If this concept is extended to the production of photographic images, the same situation holds true. Detail in an image cannot be produced from a scene where
these differences in reflected light do not exist, or are not significant. Aerial haze degrades photographic images by serving to reduce such intensity differences.

"...Any diminuation of the contrast between the different parts of a subject will diminish the ability of the observer to discriminate detail; and, since the object of aerial photography is the discrimination of detail in the subject photographed, the effect of haze is to produce a most serious loss in the efficiency of the process. The study of haze...thus becomes of primary importance for aerial photography."<7>

Figure 1. Haze Causing Airlight<8>.
Figure 1 illustrates light reflecting in the atmosphere and adding to the reflected energy from the ground scene (from Lillesand and Kiefer's Remote Sensing and Image Interpretation). Notice that the total incident radiation is composed of sunlight, that light which penetrates the atmosphere without scattering, and skylight, or that radiation which reaches the ground after being scattered in the atmosphere. The light that scatters in the atmosphere and travels upward into the camera system is caused by particles in the air, and is the light that produces the unwanted extra exposure<9>.

The scattering depicted in Figure 1 may be of several types. Rayleigh scatter is a major cause of aerial haze. It is produced when radiation encounters atmospheric particles smaller than the wavelength of the illumination. Another type is known as Mie scatter and is caused by particles roughly the same size (in diameter) as the wavelength of the interacting radiation. Yet a third type, and perhaps the worst of the three, is called nonselective scatter. This is caused by interaction of radiation with particles larger in diameter than the wavelength of that radiation. Water droplets and dust particles are examples of those particles that may cause nonselective scatter. Each of these contributes to aerial haze<10>. 
As illustrated in Figure 1, and as discussed above, aerial haze serves to add a uniform exposure in addition to the energy from the ground scene. Consideration of a simple example will demonstrate just how this diminishes contrast. If a certain reflectance step tablet contains two patches, one with a luminance of 600 foot-lamberts and the other with a luminance of 200 foot-lamberts, the contrast between the two would be 600/200, or 3:1. Now, if extraneous radiation of 200 foot-lamberts caused by haze is uniformly exposed across the film frame, the contrast is reduced to 800/400, or 2:1. If the atmospheric luminance were 400 instead of 200 foot-lamberts, the contrast between the two patches would have been 1000/600, or 5:3. This simple example not only demonstrates the reduction in contrast caused by aerial haze, but the non-linearity of the reduction as well<11>.

This study focuses its concern on the effect of aerial haze in low-altitude aerial photography (in this instance, one-thousand feet or less). Although a substantial amount of the remote sensing and aerial photography being done today is at higher altitudes, there are still a large number of low-altitude applications. Examples of such situations include rural property surveys, on-site progress reports, stockpile inventories<12>, water pollution studies of streams, ponds and reservoirs through infrared surveys,
photographic journalism, and wildlife studies. Another use for low-altitude photography is in what Lillesand and Kieffer refer to as "multistage remote sensing". Figure 2 is an illustration of the multistage remote sensing concept. "In the multistage approach, satellite data may be analyzed in conjunction with high altitude data, low-altitude data, and ground observations. Each successive data source might provide more detailed information over smaller geographical areas. Information extracted at any lower level of observation may then be extrapolated to higher levels of observation."<13>

Figure 2. Multistage Remote Sensing<14>. 
Ground and low-altitude data may be used, for example, to detect, identify, and analyze forest disease and insect infestations. This data may then be used to formulate a model using the optical characteristics of the image to remotely detect that disease. This first stage model is then tested on larger areas using higher altitude systems. Eventually, the model may be extended to large scale implementation using satellites to collect the data. Thus, low-altitude data collection lays the essential foundation upon which large-scale remote sensing may be built.

Just as aerial haze is a limiting factor in higher altitude photography, so it may be in lower altitude studies. If the effects of haze at lower altitudes is not studied and accounted for in low-altitude data collection, such as the multistage approach, the errors incurred could affect the quantity and quality of information not only within that image, but in the model which is built upon that image.

Not only is this project concerned with haze effects at low altitudes, but it is also concerned with collecting the data using a low-altitude, remotely-piloted imaging system (LARPIS), and evaluating the system in terms of usefulness, ease of use, and its inherent limitations. That is, the data that has been collected in this experiment was done so by a radio-controlled camera system. There are several
reasons for using a system of this type, not the least of which is cost. The system provides the means for collecting atmospheric data on a daily basis at a very reasonable cost. It is also a highly maneuverable system, thereby extending its usefulness to a multitude of applications. In the multistage concept, the LARPIS system could be used at either the ground observation stage (particularly if the "ground" happens to be in the middle of a pond or river) or the low-altitude stage.

Looking now at the specific components of the system, a 35mm Konica FS-1 auto-advance camera has been mounted in the fuselage of a J-5 Enterprises Loadmaster radio-controlled airplane. The plane has a wingspan of 93.25 inches (2.37 meters), and a flying weight of 23 pounds (10.89kg). The plane is powered by a 35cc Quadra model aircraft engine (basically a modified chainsaw motor) and fueled by a 20:1 mixture of regular gas and two-cycle engine oil. The large wingspan and large engine enable the craft to easily support the weight of the camera and ensure a relatively stable platform for the camera. In comparison, it far exceeds the capabilities of similar unmanned low-altitude systems such as kites and hot-air balloons. The maneuverability of the aircraft makes it a much more practical choice for many low-altitude situations.

As stated, the second part of the project is an evaluation of the data collection system itself. It was
surprising to learn in the initial literature survey and in discussion with those involved in remote sensing and technical photography, that no reference to systems of this type could be found in the publications of the scientific community in the United States\textsuperscript{15,16,17}. Although several references were found in hobby publications, only one scientific reference to a similar system was found, and that was in the Canadian Journal of Remote Sensing. It was published in December of 1983, four months after the beginning of this project.

"Early in 1982, BC Research began to evaluate the feasibility, advantages and limitations of using Remotely Piloted Aircraft (RPA) to acquire small format aerial photography in environmental applications. A three-metre wingspan model aircraft was modified to carry a remotely-operated 35mm camera system. The aircraft was controlled from the ground by a seven-channel radio transmitter, and could be operated from land or water... Remotely piloted aircraft are useful in a wide variety of forestry applications including insect and disease surveys, nursery monitoring, post-fire mapping and regeneration surveys..."\textsuperscript{18}

Project AERIE (an acronym for Airborne Equipment for Remote Imaging of the Environment) was basically a system evaluation of miniature, remotely piloted aircraft for aerial data acquisition. Table 1 displays a comparison of the specifications of the AERIE system and the LARPIS system designed, constructed and utilized in this project.
<table>
<thead>
<tr>
<th></th>
<th>BC RES.</th>
<th>PPHS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>AERIE</td>
<td>LARPIS</td>
</tr>
<tr>
<td>wingspan</td>
<td>2.7</td>
<td>2.37</td>
</tr>
<tr>
<td>length (overall)</td>
<td>2.24</td>
<td>1.65</td>
</tr>
<tr>
<td>fuselage width</td>
<td>0.15</td>
<td>0.19</td>
</tr>
<tr>
<td>fuselage height</td>
<td>0.15</td>
<td>0.25</td>
</tr>
<tr>
<td>payload</td>
<td>4.5</td>
<td>4.54</td>
</tr>
<tr>
<td>weight (empty)</td>
<td>11.4</td>
<td>8.1</td>
</tr>
<tr>
<td>engine</td>
<td>35.0</td>
<td>35.0</td>
</tr>
<tr>
<td>ceiling</td>
<td>* limited to line of sight</td>
<td></td>
</tr>
<tr>
<td>camera format</td>
<td>35</td>
<td>35</td>
</tr>
<tr>
<td>manufacturer</td>
<td>Canon</td>
<td>Konica</td>
</tr>
<tr>
<td>model</td>
<td>AE-1</td>
<td>FS-1</td>
</tr>
<tr>
<td>cost (system)</td>
<td>$ na</td>
<td>&lt;1,000</td>
</tr>
</tbody>
</table>

Table 1. System Specifications for BC Research's Project AERIE<19> and the PPHS LARPIS system.

Several other "camera planes" have been written about in the hobby magazines. One of these articles was written by Frank Heppner and published in the March 1978 issue of RC Modeler. Heppner discusses his attempt at mounting eight millimeter movie cameras atop a 96 inch-wingspan model. Heppner is an ornithologist by trade, and used the system to study the formation of Canadian Geese in flight. He had no problem with the weight of the cameras, and no apparent vibration problems<20>.

Another system was described by Larry Sribnick in an article published in the August 1983 issue of Popular Photography. Sribnick mounted a Kodak Disc 4000 camera in an electrically powered glider<21>. His results were
surprisingly good given the format of the Disc film and the pre-set shutter speed of the camera. A third article was found in Model Aviation Magazine (August 1982). Luther Hux describes his work on the 'Snapshot Twin', a modified twin engine aircraft carrying a 35mm camera. One of the images produced by the system is now a postcard for the National Geographic Society<22>.

Although vibration was not reported to be a problem in the aforementioned articles, it was suggested that it would be a severe problem, and that it might render the images useless<23,24>. A study undertaken at the Air Force Avionics Laboratory by Y. C. Sun in October of 1967 indicated that resolution decreases with increasing vibrational amplitude<25>, but is less affected by vibrational frequency<26>. As a result, several precautions have been taken in the modification of the model aircraft to filter the destructive vibrational effects.

Briefly restated, the goals of this project were to design, produce, and use a low cost, remotely-controlled imaging system for the purpose of studying the effects of aerial haze at altitudes below 1000 feet. The results of the study shall be discussed later, but the basic method of data collection shall be outlined here. A twenty-four foot by eight foot tri-reflectance step tablet was imaged from the ground
and from various altitudes, with the hypothesis that a trend in contrast reduction with increasing altitudes would be apparent.
II. EXPERIMENTAL

A. System Design:

At the outset of the experiment, several performance requirements were set down, and the system designed around them. Several of the requirements of the system deal with the performance of the aircraft, others deal with the imaging system, and still others involve the interaction between the two. These requirements, as put forth in the proposal, include the following:

1. The craft must be slow so as to avoid any possible degradation of the image due to camera motion.

2. It must be easily and highly maneuverable, or an acceptable compromise thereof. Flight should be achievable with a minimum of training and practice.

3. The vehicle must be stable and sturdy, and able to withstand the stresses of weather extremes and turbulence.

4. The vehicle should be able to support and carry the weight of a 35mm SLR camera and necessary accessories. An SLR is preferred over an automatic advance pocket 35mm camera for reasons of flexibility, interchangable lenses, cable release provisions, and the characteristically higher degree of optical quality associated with SLR's.

5. The camera should be as light as possible and as dimensionally small as possible without giving up the necessary features
such as a cable release (although one is probably not crucial to the instrumentation), a motorized film advance, and a lens with a focal length between 30mm and 200mm.

6. If at all possible, the camera should provide the option to change lenses, thus increasing the number of possibilities for its use.

7. The camera should be as inexpensive as possible, again without passing up the important features.

8. Some provision should be made for optically placing vital information onto a small portion of the film plane (altitude, temperature, time, date, and tilt).

9. Of course, the optical component of the system should be of the highest possible quality for the cost. The lens will be focused at infinity for the duration of its life as an airborne imaging system, so close focus capability is not a concern.

10. Film loading should be the epitome of simplicity. The mounting of the camera in the transport vehicle, therefore, should allow film loading and unloading without requiring the dismantling of the entire project.

11. And finally, the cost of the entire system should be well within the budget of the small businessperson or firm. A cost of two-thousand dollars seems reasonable, but a price tag of a thousand or less should be the ultimate goal without sacrificing significant amounts of data. The lower the cost, the greater the market for such a device. But again, information should not be forfeited in lieu of the all important dollar, lest the usefulness for purposes of engineering be lost.

An attempt was made to meet as many of these requirements as possible within the restrictions of a bachelor's thesis. Table 2 summarizes the component
selection.

Imaging system:

<table>
<thead>
<tr>
<th>Component</th>
<th>Choice</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>camera</td>
<td>Konica FS-1</td>
<td>$170.00</td>
</tr>
<tr>
<td>lens</td>
<td>Konica 50mm f/1.8</td>
<td>60.00</td>
</tr>
<tr>
<td>shutter release</td>
<td>Konica electronic cable</td>
<td>14.50</td>
</tr>
</tbody>
</table>

Aircraft:

<table>
<thead>
<tr>
<th>Component</th>
<th>Choice</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>airplane</td>
<td>J-5 Enterprises Loadmaster(kit)</td>
<td>74.00</td>
</tr>
<tr>
<td>engine</td>
<td>Quadra 35cc</td>
<td>126.50</td>
</tr>
<tr>
<td>radio system</td>
<td>Futaba 6 channel</td>
<td>186.00</td>
</tr>
</tbody>
</table>

Table 2: System Component Listing.

The Konica FS-1 system was chosen for its light weight, compact nature, its auto-film-advance and auto-film-loading features, as well as its relatively low cost as 35mm camera systems go. The electronic cable release allowed for easy mounting of the radio-controlled servo that is necessary to trigger the mechanism, and as a result, the easy mounting and dismounting of the camera system in the fuselage. The J-5 Enterprises Loadmaster was chosen for its simple, yet functional, design, its large payload volume and weight capacity, and its large
physical size. The craft is capable of carrying a ten pound payload when equipped with the 35cc Quadra, and its large physical size contributes to stable flight characteristics.

B. System Construction:

1. Airplane construction:

   a. Framework:

      The first major task, after the accumulation of components, was the deciphering of the kit blueprints. They left something to be desired as far as clarity goes (at least for a first-time builder). That accomplished, roughly 150 hours were devoted to the frame construction and strengthening process. The kit is entirely made of hardwoods, and was not always easy to work with. Epoxy and white glue were used for the majority of the construction.

   b. Radio Control System:

      With the wooden skeleton completed, the battery pack (rechargeable nickel-cadmium) was mounted along with the receiver, antenna, and control servos. Five servos were mounted in all, one for the ailerons (roll control), one for the elevators (pitch control), one for the rudder (yaw control), one for the throttle, and a fifth for the shutter release mechanism. Control rods linking the servos to the control surfaces (ailerons, elevators and
rudder) were then mounted and tested.

c. Engine Mounting and Vibration Isolation:

The 35cc quadra was mounted onto the fuselage in an inverted fashion. Three layers of 3/8 inch plywood, each separated by two sheets of rubber, were placed between the firewall of the fuselage and the engine. The rubber sheets were used in an attempt to reduce the vibration travelling from the engine to the fuselage, and ultimately to the camera system.

d. Covering:

The final stages of the aircraft construction involved the addition of the skin. A lightweight, heat-shrinkable, self-adhesive material was used to cover the wings, providing the airfoil surfaces, and the fuselage and tail sections.

2. Camera Mounting:

a. Shutter Orientation:

The camera was mounted in the plane so that the shutter travels in a direction parallel to the line of flight. This was done in an attempt to minimize the blur due to image motion across the film plane.

b. Vibration Considerations:

As discussed in the Introduction section of this document, vibration was anticipated to be a major problem. In an attempt to reduce the effect of the vibration, not only was the fuselage isolated from the engine by rubber,
but the camera mounting frame was isolated from the fuselage by four vibration isolators. These are basically cubical pieces of medium hard rubber with threaded rods embedded in them. The threaded rods are oriented on opposing faces of the rubber cube, and are not connected in the center of that cube. Thus, whatever is attached to one side of the isolator is filtered from vibration that may be present on the other side. These isolators are used to support a rectangular frame by attaching it to the fuselage walls. The camera is mounted to this frame by a tripod bolt, and is insulated from the frame by a 1/4 inch thick sheet of rubber. Thus the camera system is triple-isolated from the engine vibration. It was hoped that this would reduce the effects of the vibration to an acceptable level.

c. Shutter Release Mechanism:

The remote release of the camera's shutter is accomplished, as are all of the other controls, from a radio transmitter on the ground. The receiver activates the fifth servo which swings a small arm across the release button of the electronic release. A simple throw of a switch on the transmitter results in one exposure.

C. Target Construction:

A reflectance stepwedge was constructed in order to facilitate the evaluation of the contrast of each
image. The target was made from six sheets of particle board, each being four by eight feet in size. Each of the three patches of the wedge required two of these sheets, thus each patch was eight by eight feet in size. One patch was painted with a low gloss white, one with a flat gray, and the third with a flat black paint. Sand was mixed into the paint for each of the colors to provide an approximation to a Lambertian surface. This approximation was analyzed, and the results will be discussed later.

D. Processing Characterization:

The film chosen for use in this project was H&W VTE Panchromatic film. It was chosen for its high resolution characteristics, wide exposure latitude, and availability within the Imaging and Photographic Science Department. The process time was extrapolated from H&W's recommendations. The film was developed for four minutes at twenty-four degrees centigrade. In order to study the variability of the photographic processing, sixteen sensi-strips (strips of film exposed in a sensitometer to a transmission step wedge containing, in this case, twenty-one steps) were processed under identical conditions. These strips were evaluated on both a MacBeth TD-504 densitometer and a ROSCOE microdensitometer (RIT Imaging and Photographic Sciences Remote Sensing Laboratory). The resulting step densities were then
plotted as a function of the log exposure (log lux-seconds) that they received, thus producing the film's characteristic curve. The log exposure of each step in the ground target would be determined using this relationship and the densities of each of the steps in the image.

E. Imaging Set-Up:

1. Step Tablet and USAF Resolution Target Layout:
   
The reflectance step tablet was laid out on the airstrip in such a manner that its largest dimension was oriented in the same direction as the width of the film frame. This was in done an attempt to increase the chances of imaging the entire target. Also placed in the target vicinity was a standard Air Force Resolution Target. It was used in an attempt to evaluate the resolution capabilities of the system.

2. Aircraft Alignment for Imaging:

   The aircraft was flown over the designated target area in such a manner that when the plane was directly overhead, the pilot could look up through the clear plate on the bottom of the fuselage and through a clear plate on the top of the fuselage. When sky could be seen through these windows, the airplane and camera were satisfactorily oriented over the target. The shutter release was activated as soon as sky could be seen and continued until
it could no longer be seen through the airplane.

F. Data Analysis:

1. ROSCOE Microdensitometric Determination of Control Densities:

   The three patches of the reflectance step tablet were photographed on the beginning of each roll at ground level. The camera was then mounted inside the fuselage at the same shutter and aperture settings used in making the ground level images. These images would be used later for control and cross reference.

2. ROSCOE Microdensitometric Determination of Density Within Each Image:

   The ROSCOE microdensitometer was also used to evaluate the image of the step tablet in each frame. The ROSCOE has a sensor diameter of 150 micrometers at a system magnification of 1.0. At the various altitudes, the microdensitometer was used to read the transmission density of each step in the image of the ground target.

3. Microscope Observation of Resolution:

   As stated, a standard USAF resolution target was placed on the airstrip near the reflectance wedge. A microscope was used to perform a qualitative analysis of the resolution capabilities of the system as a whole. This was intended to aid in the evaluation of the system as a tool for the collection of scientific data, and is in no way meant to be a conclusive statement. Since resolution depends on optical quality, film and developer
combination, and image speed, the resolving power for specific photographic missions is left up to the investigator of each particular job.

4. Curve Fitter Analysis:

Curve Fitter is a statistical software package for the Apple II+/e computer (Curve Fitter by Paul K. Warme; copyright 1980, Interactive Microware, Inc.)(Apple is a registered trademark of the Apple Computer Corporation). It was used, in this case, to plot the resultant density on each step of the sensi-strip against log exposure. Curve Fitter also allowed the quick determination of the log exposure resulting from the ground target given the densities of the steps within each image.

5. Photogrammetric Altitude Determination:

Altitude was calculated by photogrammetric means. That is, given the focal length of the lens, the target size on the ground, and the size of the image of the target, altitude can be calculated.

\[
\text{Altitude (feet)} = \frac{\text{focal length (mm)} \times \text{object size (mm)} \times 3.283 \text{ ft/m}}{\text{image size (mm)} \times 1000 \text{ mm/m}}
\]

The image size was measured with the aid of a micrometric scale (produced by the Graphic Arts Research Center,
Rochester Institute of Technology) and an 8x loupe.

6. All of this data now collected, Curve Fitter was utilized once again to determine the relationship between contrast and altitude. A least squares linear regression was used on the data since a simple relationship between variables was not expected. A trend is noticed and analyzed. It was the determination of the existence, or non-existence for that matter, of this trend that was the main objective of the thesis.
III. RESULTS

The data collected and presented here is the result of many flights on very few days. Several problems were encountered and shall be discussed in detail shortly. The data collected concerning the effect of haze on the image contrast was incomplete with respect to temperature and humidity, and no attempt is made at drawing a relationship between these variables and image contrast. Data was collected that enables some analysis where the effect of altitude is concerned, however. The amount of data collected is not sufficient to derive a predictive relationship, but a general trend common in the several data sets acquired is apparent. Some minor problems were also encountered with the system, and an analysis of its characteristics and uses is offered.

A. Problems:

Several problems were encountered during the course of the project; the most severe of which was the infamous Rochester weather. Initial test flights were accomplished during a lull in the winter weather between 14 February and 25 February, 1984. The first flight made apparent a slight downward warp in the trailing edge
of the right wing that quickly sent the craft into a left roll. That problem satisfactorily solved, the first images were made. The day was extremely overcast and with the low ASA of H&W film (approximately 50), the negatives were underexposed (since the shutter speed was set at 1/125 second). With the shutter speed that slow, blur due to image motion was evident. The overall quality of the images, even given the fact that they were slightly underexposed and some blur was evident, was surprisingly good. As discussed, vibration had been expected to be a real problem. The blur in the images, however, was very directional in nature, indicative of image-motion blur. Blur from vibration would have been evident had the entire image been blurred in all directions.

The weather subsequently deteriorated into a severe winter storm that lasted nearly four weeks. When the weather finally broke, and after some scheduling delays, less than two weeks remained in which to complete the data collection and analysis. When the weather finally cleared, and flying once again became a possibility, five consecutive days (all nearly identical as far as temperature and humidity are concerned) were spent collecting data. These flights were not without problems, however, as on the first test flight a rough landing destroyed the eighteen inch propellor and further flying was postponed until another could be found. By
the end of those five days, four rolls of film were exposed. The first roll was image after image of grass and more grass. A thorough analysis of the imaging procedure indicated premature tripping of the shutter. That is, as the craft was flying overhead, the shutter was released before the camera was over the target. Compensating for this problem proved effective as the next three rolls of film contained many images of the ground target. In this short period of time, 40 useable frames were found, evaluated, and analyzed.

It is also suggested that for most applications a 50mm focal length lens is too long and that a 35mm lens might better fit a wider variety of needs. Photographing the target proved to be somewhat of a problem since the field of view limited the chances of imaging the ground target, especially at very low altitudes.

B. The Effect of Aerial Haze:

The data and results are presented in Figures 3, 4, and 5. They represent data collected on three different flights. The contrasts of each of the frames within each separate data set was normalized to unity. Each data set was normalized so that it could be plotted directly against the others as shown in Figure 6. The normalization was necessary since the contrasts of the ground target at zero altitude (the control exposures)
were not the same in each series. Data tables corresponding to these graphs are found in Tables 3, 4, and 5 respectively.

Series #5:

<table>
<thead>
<tr>
<th>ID#</th>
<th>Altitude</th>
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<tbody>
<tr>
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<td>500 feet</td>
<td>.5266</td>
</tr>
<tr>
<td>04</td>
<td>500</td>
<td>.5282</td>
</tr>
<tr>
<td>05</td>
<td>500</td>
<td>.5399</td>
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<tr>
<td>06</td>
<td>500</td>
<td>.5282</td>
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<tr>
<td>07</td>
<td>300</td>
<td>.4916</td>
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<td>08</td>
<td>546</td>
<td>.5700</td>
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<td>09</td>
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<td>10</td>
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<td>.5770</td>
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<td>12</td>
<td>250</td>
<td>.5770</td>
</tr>
<tr>
<td>13</td>
<td>316</td>
<td>.5568</td>
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<tr>
<td>14</td>
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<td>.5685</td>
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<tr>
<td>15</td>
<td>890</td>
<td>.5298</td>
</tr>
<tr>
<td>16</td>
<td>429</td>
<td>.5391</td>
</tr>
<tr>
<td>17</td>
<td>445</td>
<td>.6034</td>
</tr>
</tbody>
</table>

Table 3. Contrast as a Function of Altitude (unnormalized) for Series 5.
Figure 3. Plot of Contrast as a Function of Altitude for Series 5.

Series #6:

<table>
<thead>
<tr>
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<tr>
<td>18</td>
<td>400 feet</td>
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<tr>
<td>19</td>
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<td>.5310</td>
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<td>20</td>
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<td>22</td>
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<td>.5194</td>
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</table>

Table 4. Contrast as a Function of Altitude (unnormalized) for Series 6.
Figure 4. Plot of Contrast as a Function of Altitude for Series 6.
Series #7:

<table>
<thead>
<tr>
<th>ID#</th>
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<th>Contrast</th>
</tr>
</thead>
<tbody>
<tr>
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<td>546 feet</td>
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<td>28</td>
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<td>.5339</td>
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<td>.5627</td>
</tr>
<tr>
<td>40</td>
<td>800</td>
<td>.5416</td>
</tr>
</tbody>
</table>

Table 5. Contrast as a Function of Altitude (unnormalized) for Series 7.

Figure 5. Plot of Contrast as a Function of Altitude for Series 7.
Figure 6. Plot of Relative Contrast as a Function of Altitude- Series 5, 6 & 7 Combined.

<table>
<thead>
<tr>
<th>Data Set</th>
<th>Slope</th>
<th>Standard Deviation</th>
<th>3-sigma limits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Series 5</td>
<td>-3.310E-5</td>
<td>.02822</td>
<td>.08466</td>
</tr>
<tr>
<td>Series 6</td>
<td>-1.741E-5</td>
<td>.01109</td>
<td>.03327</td>
</tr>
<tr>
<td>Series 7</td>
<td>-4.287E-5</td>
<td>.01679</td>
<td>.05037</td>
</tr>
<tr>
<td>Composite</td>
<td>-4.652E-5</td>
<td>.03868</td>
<td>.11603</td>
</tr>
</tbody>
</table>

Table 6. Least Squares Linear Regression Statistics
Figure 7: Photograph of Imaging Scene.
Figure 8: Resolution Target From 320 Feet.

Figure 9: Resolution Target From 545 Feet.
C. System Evaluation:

The system, as a tool for the collection of scientific data, has many advantages over conventional methods and other forms of low-altitude data collection (i.e. balloons and kites), as well as some limitations. The ease-of-use aspect of the analysis must be looked at first as it is perhaps the first feature a prospective user would evaluate. After all, if the system is impossible to use, what good is it? The system is only fair with respect to ease of use. The talent required to fly a model aircraft must not be underestimated. A novice cannot simply walk onto a flying field, pick up the transmitter and fly. An experienced pilot is an absolute must. Another possible alternative would be to
devote several months with an experienced pilot learning to fly. With the tight time restrictions of a project of this nature (refering to the work presented here and not the future uses of the system), months of training after months of building was just not possible.

With respect to the usefulness of the system, any serious consideration for use of this system must include several restrictions. First, the control of the system is limited to the line of sight. Altitudes above 1000 feet or so are not only fatiguing to the pilot, but very hard to maintain due to the difficulty in discerning the attitude of the craft. Radio interference is also a major consideration (as well as the force that a twenty plus pound object has upon impact at a velocity of nearly sixty miles per hour). The danger involved with losing control of the aircraft due to radio interference must be seriously considered when evaluating a site for aerial photography. After stating that, it must also be said that loss of control due to radio interference is not a frequent occurrence. Thus, the risks must be weighed against the benefits of the system on any given mission. A job in farm land should be less of a concern than a job over a housing development, for example.

The resolution limits of the system are demonstrated in pictoral form above. Figure 8 is a micrograph of the image of the USAF resolution target taken from approximately 320 feet. The ground resolution
observed in this instance is slightly over 0.56 inches. Figure 9 is a similar micrograph of a negative made at about 545 feet, and demonstrates a ground resolution of 1.0 inch. These images were produced using a shutter speed of 1/1000 second. The ground resolution obtained is quite impressive considering the system and the camera, and the fact that it is a first generation system.

Overall, the system performed reasonably well for a first generation remote imaging system, and as will be discussed, is a useful tool in the collection of aerial data at low altitudes.
IV. DISCUSSION

At first glance, the data appears to be a real disaster. Upon closer inspection, however, it may not be as bad as it looks. Noting how the y-axis of each plot is scaled, it can be seen that although there is a good deal of variation in the data at similar altitudes (x-axis), the variance appears to be larger than it really is due to the range and the scaling of that axis. The slope of the least squares linear regression line in Figure 3 (series 5 data), for example, is only -3.31E-5 although it visually appears much steeper. The slopes of the lines in Figures 4 and 5 are -1.74E-5 and -4.29E-5 respectively. The magnitude of these slopes are so small that they can effectively be considered to be zero. Also notice (see Table 6) that that in all cases, a 95% confidence interval about the slope would include zero.

There appears to be a downward trend in density with increasing altitude. There may be some question, however, as to just how valid that conclusion is when the spread of data about those lines is considered. The linear regression is obviously not the best fit to the data, but is meant to illustrate a possible trend. Again, the way in which the data is presented (i.e. scaled on the y-axis) may be a bit misleading. The
standard deviation of the data about those linear regressions provides a good deal more information than a visual analysis of the graphs. The standard deviation is 0.028 for series 5 (Figure 3), 0.011 for series 6 (Figure 4), and 0.017 for series 7 (Figure 5). If attention is given to the composite presentation of the data (Figure 6), the slope of the least squares linear regression fit is -4.652E-5 while the standard deviation of the distribution of data about that line is 0.039.

An analysis of variance (ANOVA) was performed on the data in Tables 3 and 5 with the null hypothesis that contrast remains the same with varying altitude for those altitudes investigated. The alternative hypothesis is, then, that contrast changes with altitude. The test resulted in the failure to reject the null hypothesis, or that altitude did not affect contrast. In order to determine whether or not the data in these two tables is consistent (i.e. the means are the same), a paired T-test was performed. The null hypothesis was that the difference in the means was zero, while the alternative was that the difference in the means was non-zero. The result here was that the null was rejected. So, from these tests it was concluded that although the different series did not yield results with the same mean contrast (possibly due to differences in exposure, processing, or a combination of several factors), it was shown that contrast did not change with altitude. More succinctly,
aerial haze did not affect the contrast of aerial images exposed between (roughly) 250 feet and 900 feet.

The next logical step in the analysis is to determine the practical and statistical significance of the slight downward trend that is noticed throughout the data. After a comparison of the range of the data collected (referred now to Figure 6 and the composite representation of the three data sets) with respect to the three-sigma confidence interval about the least squares regression of that data, it is obvious that all of the data lies well within those limits, and that the change in the data represented by the slope of the line is not significant. From a practical standpoint, it is readily evident that a contrast change on the order of ten to the minus five means nothing to a piece of photographic material, and is for all practical purposes insignificant. Thus, when statistical scrutiny is focused on each of these data sets, as well as the composite representation of all three of the data sets, it cannot be stated that a relationship exists between contrast and altitude that indicates the reduction of contrast with increasing altitude at these low altitudes, and under the weather conditions present at the time.

The fact that a trend is observed through three data sets is interesting, though, and may suggest either a true underlying relationship between contrast and altitude (perhaps due to Rayleigh scatter), or that there
may be some other factor influencing the data in a repeatable manner. In an attempt to determine the significance of processing variability with respect to the data observed, a comparison of the variance about the mean of the regression (contrast as a function of altitude; Figure 6) and the variance about the characteristic curve of the film used in the experiment is done. Noting that the three-sigma confidence limits about the regression is 0.11603 while the same confidence interval about the characteristic curve is 0.0759, it can be asserted that the error incurred in processing is not wholly responsible for the variation observed in the data. Other factors have been considered as contributing to the variation, such as the repeatability of the timing mechanism in the camera's shutter. This aspect of the imaging system was not evaluated, and to get a better grasp of the error involved in the study, it should be proposed as future work.

Analysis of the validity of the assumption that the reflectance step wedge (ground target) is a Lambertian surface yielded further information. A spectrophotometer was used to determine the relationship between reflectance and angle of view (or incidence), and it showed that the assumption deteriorated at about fifty degrees from normal to the surface (source placed normal to the surface). With the solar angle a constant for all of the data collected, about twenty-two degrees, the
reflectance of each of the steps turned out to be a constant, and the influence of the solar angle "comes out in the wash", so to speak. It is doubtful, then, that angle of illumination of the step wedge contributed significantly to the variance in the data.

Figures 8 and 9 above contain the results of the investigation into the resolution capabilities of the system. They are micrographs (photographs made with the aid of a microscope) of two of the images of the resolution target. The first image was exposed at roughly 320 feet, while the second was exposed at 545 feet. The photographs demonstrate a rather remarkable capability in resolution, much greater than anticipated. It should be noted, however, that the resolvability of details within the image is directly related to the direction in which those details lie with respect to the line of flight of the aircraft. Analysis of the images presented above make this point evident. It is clear that the plane travels in the direction in which the most easily resolved bars point. That is, the line of flight was parallel to the long dimension of the most easily resolved bars.

It should be intuitive that at such low altitudes, image blur is of more concern than it is at higher altitudes. Even using the fastest shutter speed available, there will be some finite amount of image motion resulting in image blur. The amount of image blur
is of particular interest in that it places yet another restriction on the resolution capabilities of the system. It can be derived from first principles that:

(1) Object Movement-

\[ \text{delta-x} (\text{mm}) = V \times t \times k1 \]

where: \( \text{delta-x} \) is the object movement in mm  
\( V \) is the ground speed of the aircraft in miles per hour  
\( t \) is the shutter speed in seconds  
\( k1 = 447.04 \ (\text{mm x hours})/(\text{seconds x miles}) \)

(2) Image Movement-

\[ \text{delta-x}' (\text{mm}) = \frac{k2 \times f \times V \times t}{A} \]

where: \( \text{delta-x}' \) is image motion in millimeters  
\( V \) = ground speed in miles per hour  
\( t \) = shutter speed in seconds  
\( f \) = focal length in millimeters  
\( A \) = altitude in feet  
\( k2 = 1.4667 \ ((\text{feet x hours})/(\text{miles x seconds})) \)

(3) The ratio of image to object movement is-

\[ \frac{\text{delta-x}'}{\text{delta-x}} = \frac{k3 \times f}{A} \]

where: \( \text{delta-x}' \) is image motion in millimeters  
\( \text{delta-x} \) is object motion in millimeters  
\( f \) = focal length in millimeters  
\( A \) = altitude in feet  
\( k3 = 3.2809E-3 \ (\text{feet/millimeter}) \)
These equations assume that the precise focal length is known. It is not always valid to assume that the focal length marked on the lens is accurate, however. The actual focal length of the lens used in this experiment was found to be 50.9mm, an error of 1.8%. For the purposes here, it was assumed that the focal length was 50mm since at most, the error incurred was sixteen feet. The data collected indicated that an error of only sixteen feet was insignificant. At higher altitudes, however, that 1.8% could become significant. Notice from the third equation that as altitude increases, image blur becomes less significant. Thus, at these low altitudes, it is a prime concern in the performance of the system.

In addition to studying the effect of aerial haze, this thesis demonstrated that a low-cost system of this type can, indeed, be used for a variety of scientific and practical applications. Figure 7 is a photograph of the entire imaging set-up. Notice the details in the pickup truck (especially the dash, where a roll of tape is readily evident) and in the shadows of the bicycles to the top-center of the photograph. Recall also, that the resolution of the print is not only a function of the detail in the negative, but also a function of the resolution limits of the enlarger and the print paper. Undoubtedly, some of the detail evident in the negative is lost in printing.
V. CONCLUSIONS

The data collected in this experiment leads to the conclusion that the effect of aerial haze on the contrast of a photographic image made at low altitudes was insignificant for the weather conditions at which they were made. Varied weather conditions did not avail themselves within the time restrictions of this experiment, and it consequently made the study of aerial haze as a function of temperature and humidity impossible. Data was taken that enabled a study of the relationship between contrast and altitude. It was found that the analysis failed to prove any significance in the effect of aerial haze, although a trend of slightly decreasing contrast as a function of altitude was noted. It was proposed that some other error was most likely present, although variability in the processing does not appear to be wholly responsible for the variance in the data. Another possible source of error might be the repeatability of the camera's shutter creating variations in exposure.

The system produced in the experiment has significant potential as a data accumulation tool as is evident from Figures 7, 8 and 9. It is suggested, however, that a 35mm lens be used rather than the 50mm lens used here. The field of view of the 50mm lens
proved to be too limiting, and the chances of imaging the intended target were seriously decreased. Although the system requires an experienced pilot to be of any use, model aviation clubs exist across the country, and if the Rochester club is any indication, there would be numerous individuals interested in such a project. The quality of the images retrieved were acceptable, especially for a first generation system. The concern over vibration fostered a rather elaborate vibration isolation system, and as a result, vibration was not found to be a serious problem in the images obtained.

The resolution of the system as a whole was found to be remarkable. At an altitude of 320 feet, features of the magnitude of 0.56 inches were discernable, while at 550 feet, the resolution was 1.0 inches. It was observed, however, that the resolution depended on the direction of travel of the system. As expected, details perpendicular to the line of flight are blurred due to image motion. Those details parallel to the line of flight are most easily resolved. An optical bench was again used, this time to investigate the resolution capabilities of the Konica lens. As shown in Figure 10, the resolution is somewhat low for large aperture size due to aberrations. It increases to a maximum at f/4 and then decreases due to diffraction. The aperture used in this experiment was 2.8, due to shutter time restrictions, and thus maximum resolution of the system
was not realized.

Suggestions for future work, in keeping with the original goals of the project, would include filling in the data with respect to the effects of varying temperature and humidity. If this system is to be implemented for scientific purposes where detailed information of ground features is a necessity, the significance of aerial haze at low altitudes should be known. A faster speed film is also recommended for most applications as it would allow faster shutter speeds at lower aperture settings. The shutter speeds used in this experiment were 1/1000th second to 1/500th second, and proved to be fast enough to minimize blur due to image motion and vibration.
IV. REFERENCES


3 Dr. J. Schott, Rochester Institute of Technology, Imaging and Photographic Science Department, personal communication, 6 October, 1983.


5 ibid., p.36.

6 ibid., p.15.

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9 ibid., p.373.

10 ibid., p.10.


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15 Prof. A. Davidhazy, Rochester Institute of Technology, Technical Photography Department, personal communication, 20 December, 1983.

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Dr. W. Brouwer, Rochester Institute of Technology, Imaging and Photographic Science Department, personal communication, 20 December, 1983.


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F. Heppner, "This Plane is for the Birds", RC Modeler, 64 (March, 1978).


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Sun, pp.39-45.

ibid, pp.62-70.

APPENDIX A

The following is a list of the equipment utilized in this experiment. Thanks go to all of those who made the use of this equipment possible.

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<thead>
<tr>
<th>ITEM</th>
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<td>Kodak Process Control Sensitometer Model 101</td>
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<td>Sensitometer Step Wedge</td>
<td>101-163</td>
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<td>MacBeth TD-504 Densitometer</td>
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<tr>
<td>ROSCOE microdensitometer</td>
<td>RIT Remote Sensing Lab</td>
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<td>United Detector Technology Spectrophotometer Model 80X</td>
<td>131934</td>
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<tr>
<td>Bausch &amp; Lomb microscope with Polaroid Land camera attachment</td>
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Table 7: Equipment List.
APPENDIX B

Film Evaluation:

Film Type
Processing
--
developer: H&W Panchromatic VTE
development time: 4 minutes
development temp: 24 degrees centigrade
processing method: reel tank processing
10sec continuous initial
6sec every 30sec thereafter

Table 8: Processing Specifications.

Figure 11: Characteristic Curve of H&W VTE Given Processing Parameters.
APPENDIX C

Figure 12 contains four illustrations of the mid-construction stage of the system. The wingspan of the model is 93.25 inches, while the length from firewall to rudder is 58 inches.
Figure 13 is an illustration of the completed aircraft in its flight-ready state.
VITA

Todd Eric Pegelow was born in Canandaigua, New York in March of 1962. He was raised in the Rochester area and attended Fairport Senior High School in Fairport, New York. Strong in math and science, and playing varsity baseball and basketball, he further pursued his educational and athletic careers at the Rochester Institute of Technology in Rochester, New York. Majoring in Imaging and Photographic Science, he also played two years of intercollegiate basketball and two seasons of intercollegiate baseball. With particular interest in the semiconductor industry, he has accepted an employment offer and plans a career with American Microsystems, Inc. of Santa Clara, California.