Advances in Applications for Aerial Infrared Thermography

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ABSTRACT

The farther away one can get from the subject of an infrared (IR) survey, while maintaining the needed spatial resolution and thermal sensitivity, the more usable the data becomes. This is the aerial IR advantage. Aerial IR applications can be divided into two groups; A) applications where a straight-down view and/or a large area view is needed and B) applications where long distances must be covered in a limited amount of time. Selection of aircraft, aircrew, navigational aids, avionics, infrared imaging system, analog and/or digital data acquisition systems and image processing systems are all important for successful surveying.

Keywords: Aerial, infrared, thermography, environmental impact, pollution, stormwater, animal counts, geothermal, forest fires, subsurface fires, structural fires, landfill fires, peat, coal and wood chip piles, Native American trails, high voltage electrical transmission lines, high voltage electrical distribution lines, pipelines, search and rescue (SAR), roof moisture surveys, steam lines, high temperature hot water system (HTHW), computer aided design & drafting (CADD), global positioning system (GPS), geographical information system (GIS).

1. INTRODUCTION

Almost all aerial IR is performed by the military, but there are numerous commercial applications for aerial infrared thermography, which is the focus of this paper. When a customer has need for aerial IR, he/she wants a high quality report end-product. In order to produce high quality reports, the data must be acquired, recorded and processed in an efficient and effective way. The challenge is logistics. The aerial IR operator has to get reliable aircraft and all the above-mentioned equipment along with a highly-skilled pilot and highly-skilled thermographer over a target at just the right time, under just the right conditions…and do all that at competitive rate.

2. NEEDED EQUIPMENT & CREW

2.1. Data Collection

Both helicopters and light airplanes are used to perform aerial infrared surveys. The helicopter or rotor-wing option is used if the number of targets or distance between targets is low, owing to high operating costs and slower ferry speeds. There are mounting problems with the rotor-wing platform, even when a remotely controlled turret is used. What are worse, however, are the imaging problems, like vibrations and gyrations. These problems can be offset by being able to use less expensive, smaller format imagers, especially if the aircraft can be flown close to the target. If a light airplane or fixed-wing option is used, the IR imager needs to have a much higher spatial resolution, because it must operate at higher altitudes and therefore farther away from the target, allowing for the same resolution at, for instance ~ four times the distance. There is another even more important advantage gained by using a large format imager. The field of view (FOV) is larger, making report preparation much easier and the report end-product superior. Larger lenses can improve the needed ground resolution element (GRE), or the size of one pixel on the ground, if some signal strength degradation

is acceptable, but the FOV suffers as a result. One might mosaic or paste many 'smaller' images together but this is a very labor-intensive endeavor, and often cannot be accomplished without greatly distorting the imagery. The bottom line is that it is always better to have more pixels, whether the images are stitched together or not. It is nearly impossible to get professional results with hand held imagers. Experiments have shown that midwave imagers (1.5-5 microns) produce far better IR imagery of ground objects at night, than do long wave (8-14 microns) imagers. The imager should be fixed-mounted solid (see Figure 1), turret-mounted or fixed-manually articulated. In any case, a well-maintained aircraft, experienced crew and an imager capable of the resolution required for the intended task should always be used.

Figure 1. ThermaCAM™ Phoenix® 640 x 512 InSb infrared imager with Real-Time Imaging Electronics (RTIE), fixed-mounted in a gyro-stabilized camera mount in a fixed-wing aircraft.

The type of infrared imager used dictates how images are saved. Modern infrared cameras have a variety of storage media, lens options and settings, controls must be within reach so that the camera can be moved, lenses adjusted and the images stored. Since the pilot and thermographer are busy during the flight, one or both may not see every possible anomaly, so no matter what type of imager or storage medium is used, a complete record of all the 'raw' infrared imaging should always be made.

In any aircraft operation, precise navigation is important and particularly so in nighttime aerial infrared operations. A global positioning system (GPS) is a necessity. Combining the GPS with a mobile mapping program on a computer and a video encoder-decoder (VED) is very useful, especially when large areas and/or multiple targets need to be imaged. The VED encodes the video with a continuous stream of GPS derived data (latitude/longitude, altitude, date, time and speed, etc.) and displays the information through the video signal (see Figure 2). All equipment in the aircraft must be secured with the wires labeled, shielded from electromagnetic interference and out of the way.

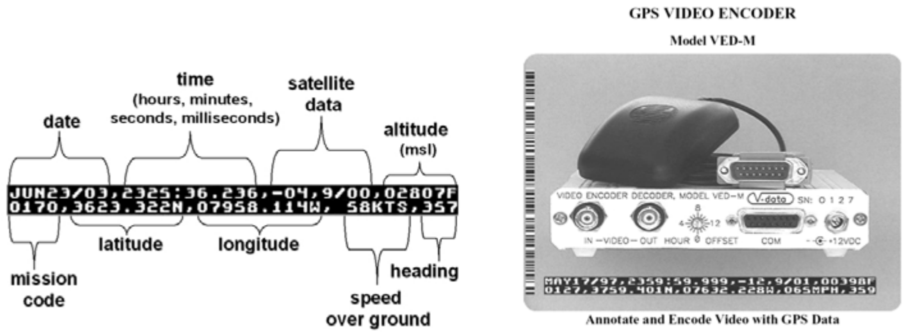

Figure 2. Video encoder-decoder (VED) and annotation guide.

Most aerial infrared imaging is performed at night because reflected and direct daylight solar radiation usually adversely affects the imagery and can damage the imager. Aerial infrared imaging is NOT a job for pilots that are not specifically trained and experienced in nighttime aerial IR operations. Likewise, airsick prone or non-professional infrared equipment operators are a liability to the operation. The work is often performed flying low and slow, while maneuvering...in the dark.

2.2. Report Generation

Upon returning from the mission, the report must be prepared. The office equipment needed to analyze imagery and produce reports can be the same as that used by a ground-based infrared thermographer. A computer workstation complete with digital thermographic and photographic imaging peripherals for handling infrared images, daylight photographs and capable of producing high quality reports in a popular format is needed. Also, specialized video capture, image processing, computer aided design & drafting (CADD) software and mapping software are required. Thermal mapping can produce giant high resolution infrared imagery in the form of mosaics. Recently, end-users are asking for more sophisticated drawings and even geo-referencing, which requires that the data be collected in a manner that allows for pixel-by-pixel orthorectification.

3. VARIOUS APPLICATIONS

3.1. Steam, High Temperature Hot Water (HTHW) & Medium Temperature Water (MTW) Systems

Steam, HTHW and MTW Systems can be imaged to find leaks and other thermal anomalies. Even from higher altitudes, steam line inspections are relatively easy applications. Thermal contrast between active underground steam lines (especially leaks) and the surrounding ground are usually good. HTHW and MTW loops, while not as brilliant as steam systems, can be imaged in the same manner. Sometimes leaks appear as cool spots because the water has come to the surface and is being cooled by evaporation.

Underground steam lines themselves are almost always readily visible with infrared imaging, even when no notable problems exist. This is due to the fact that no matter how good the insulation, there is always heat loss from the lines which makes its way to the surface. Problem areas are generally quite evident, having brighter white IR signatures that exceed the norm. Steam line faults normally appear as an overheated line or as a large hotspot (see Figure 3) in the form of a bulge or balloon along the line. If there is a leak in a tunnel or conduit, the line will heat up the whole conduit with escaping steam. If a steam line is buried directly in the ground with an insulating jacket, a leak will usually saturate the insulation, rendering it largely ineffective and will begin to transfer heat into the ground around the leak, producing the classic bulge or balloon-like hot area straddling the line. Manholes or vaults that contain leaking steam system control apparatus often heat the covers to warmer than normal temperatures.

Steam line imagery can be misleading, unless one understands and interprets the relative brightness/temperature of a given line correctly. A steam line that is the same temperature from one end to the other that passes under different surfaces and materials can exhibit a variety of temperature variations. For example, five different apparent temperatures will result from the same temperature line that runs under a grass-covered field, an asphalt parking lot, a concrete loading dock, a gravel-covered walkway and bare earth pathway.

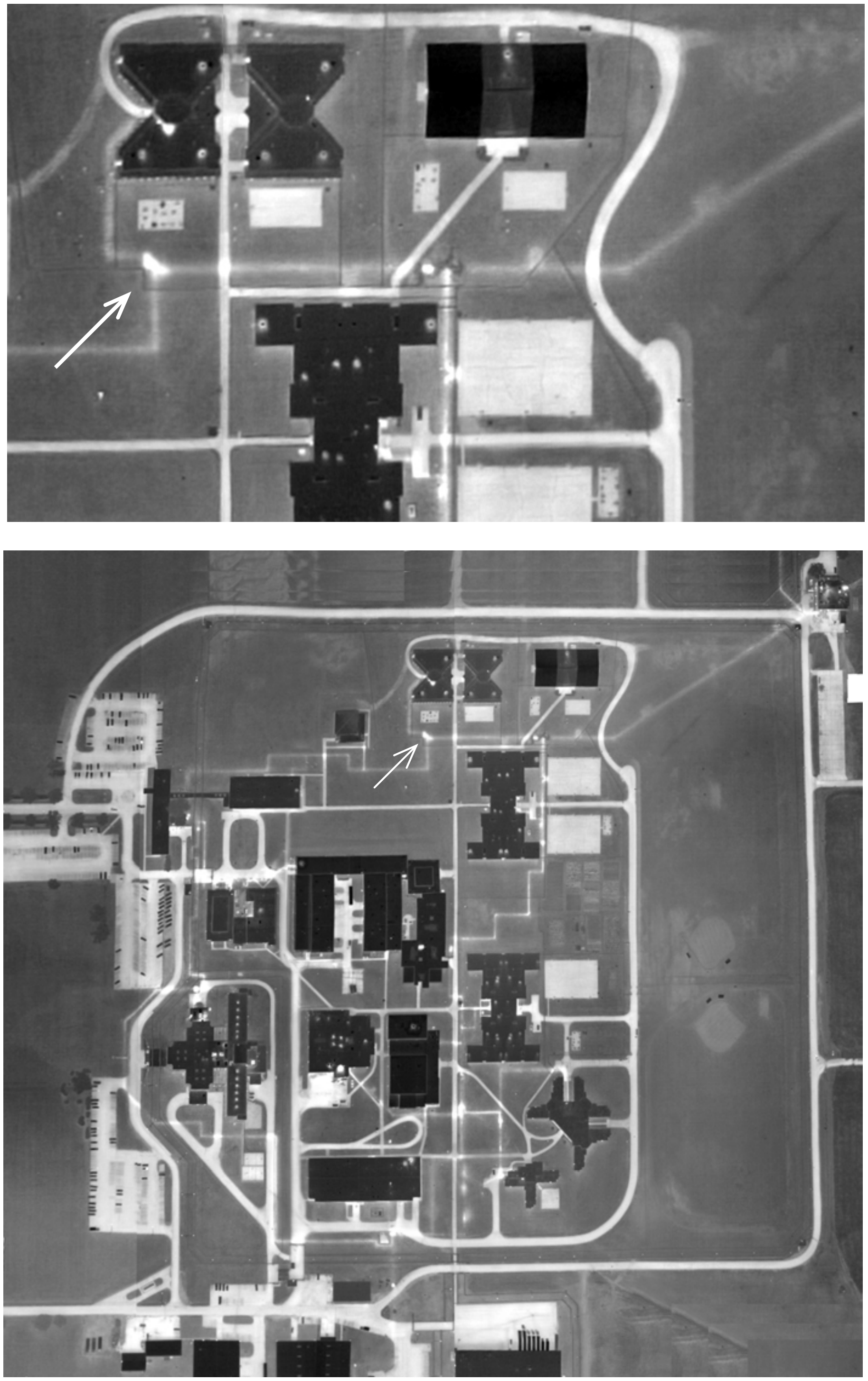

Figure 3. Steam system examples; (a) image showing steam line leak and (b) mosaic infrared image of a prison steam system.

3.2. Pipes and Pipelines

Unless there is a warm or cold liquid in the pipe, pipelines are usually difficult to survey. It depends on the depth of the pipe, the temperature of the pipe (or its contents) and the covering and surrounding ground density and temperature.

Also, shrubs, brush, water and man-made structures like bridges, roads, sidewalks and buildings often cover pipes. If a liquid is leaking from a pipe and the location of the leak is unknown, an aerial IR survey can be used to find the leak. Even if the pipe itself cannot be seen on the surface, it may be possible to see the leaking liquid and narrow the search to a relatively small area. The best results are found when the pipe is not buried deeply, has a high flow and when the difference in temperature between the liquid and the ground above is high.

3.3. Geothermal
A potential site can be flown over with aerial IR to determine if, for instance, a road or facility will be near geothermal activity. The planner can then route the road around the activity or decide if the site is unsuitable for the intended purpose.

3.4. Ancient Pathways, Concrete Structures, Buried Objects and Agriculture
Where Native American trails cross the desert, the land under the trails has been compacted. By using nighttime aerial infrared imaging, the thermographer can see this higher density differentiated from the lower density adjacent to the trails. Similarly, work is being conducted to find perform predictive maintenance on parking decks, bridges, roadways, runways. Also, work has begun to determine the effectiveness of aerial IR to find buried objects such as landmines and dead bodies. Agricultural applications include erosion control and moisture control.

3.5. Landfill Fires
Subsurface fires can also be monitored using aerial infrared thermography. Landfill fires (see Figure 4), can be hazardous to the surrounding environment. Knowing the locations, number and the extent of underground fires is useful to those in charge of containing and/or extinguishing them. Usually, maps, as CADD drawings or as geographical information system (GIS) maps are prepared indicating the extent, geometry and intensity of the subsurface fires. Similarly, peat, coal and wood chip piles can be monitored for spontaneous combustion.

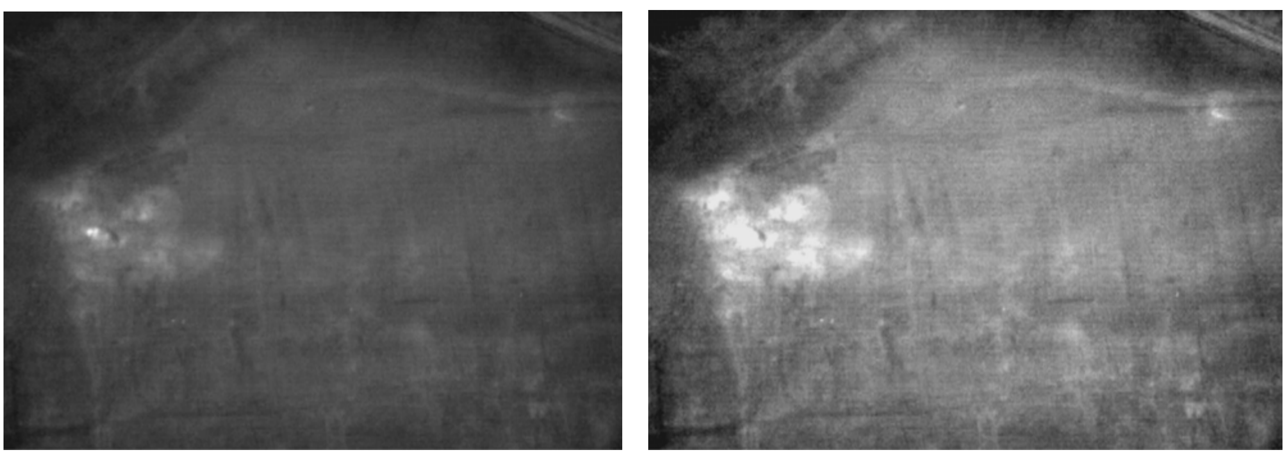

Figure 4. Thermographs of a landfill are shown. The hot spot on the left is a subsurface fire.

3.6. Forest Fires
The U.S. Forest Service uses aerial infrared imaging to monitor forest fires. Very accurate mosaic infrared maps of active fires can be made to help with fire management and suppression efforts. This information can be sent immediately to those in charge of controlling fire lines. Thermal intensity is resolved to classify the hottest sections of the active fire, therefore pinpointing the areas of most intense thermal energy. These digital aerial maps are loaded to hand held GPS devices to enable ground teams to navigate directly to the hot spots rapidly, either by walking, driving or flying. Thermal IR provides an important visual reference locator by identifying the hot spots with respect to terrain features in the thermal imagery. Positive identification of hot spots is rapid even through dense smoke.

3.7. Structural Fires

Aerial infrared can be helpful to the firefighters of structural fires especially on large, single story buildings. Often the smoke escapes the building from a different location other than the hottest part of the fire. These areas can be imaged and the firefighters informed as to the location of the hottest areas. Also, runoff from the water used to extinguish the fire can be followed to reduce its environmental impact.

3.8. Waterways and Drainage Systems

The flow of a liquid into the body of another liquid can be identified using infrared thermography if there is a temperature difference. Typically, liquids flowing into a body of water appear warm as compared to the surface water in a creek, stream, river or lake, particularly during cooler times of the year, due to the relative warmth of the ground a short distance below the surface. Leaks from nearby water, sewer and/or stormwater lines and direct run-off from a sloped surface can be detected because the warm plume flowing over the ground toward the water and the liquid joining and flowing downstream with the body of water are visible in the thermal infrared spectrum. In most parts of the US, late fall, winter and early spring are well suited to this type of inspection because the difference between water temps (ground and surface waters) is present and because interference to view due to overhanging foliage is minimized. The waterway is flown and infrared images are saved with exact location information of each thermal anomaly (see Figure 5a). A map is created with exact latitude/longitude of each marked area (see Figure 5b). The system operator then takes a hand held GPS device to each location and tests the outfall for signs of contamination. If necessary, the outfall is traced back to its source.

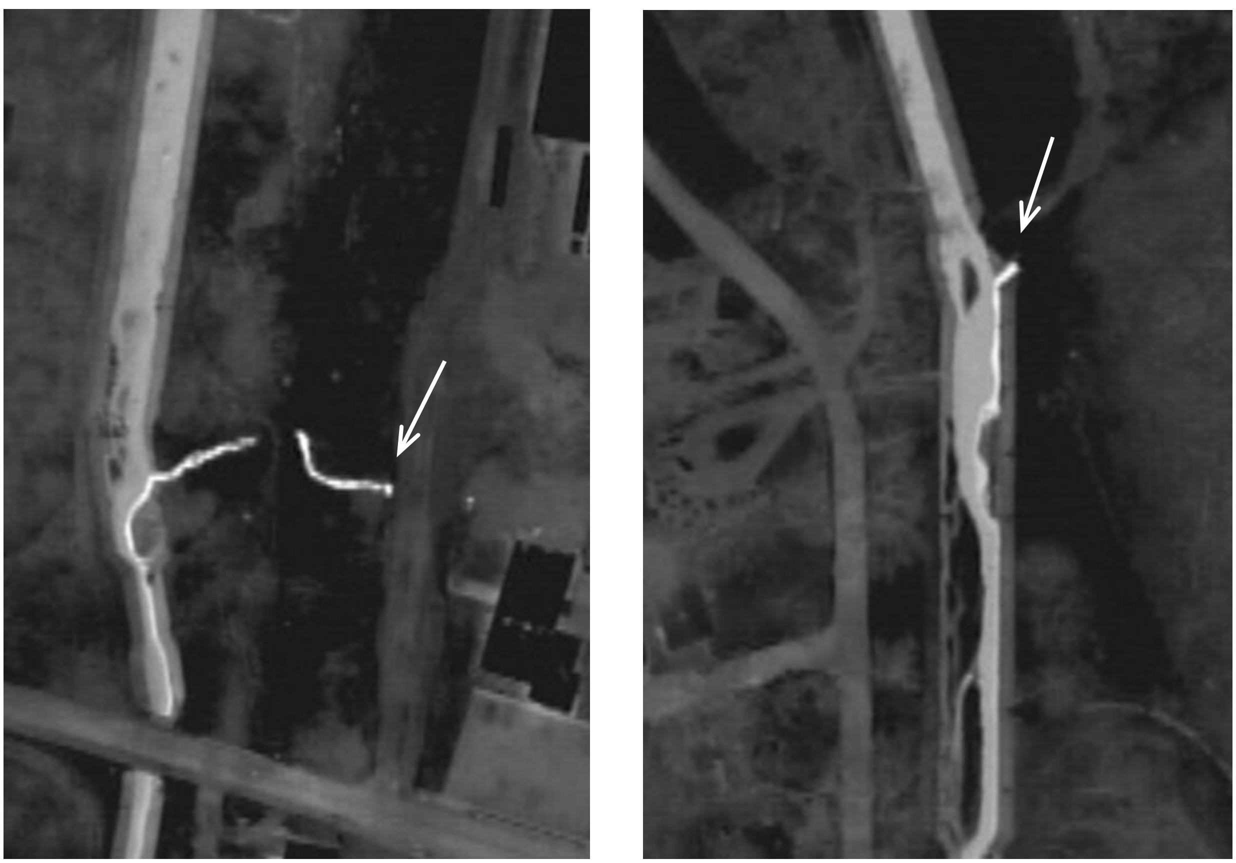

Figure 5a. Creek survey examples with two thermographs of outfalls.

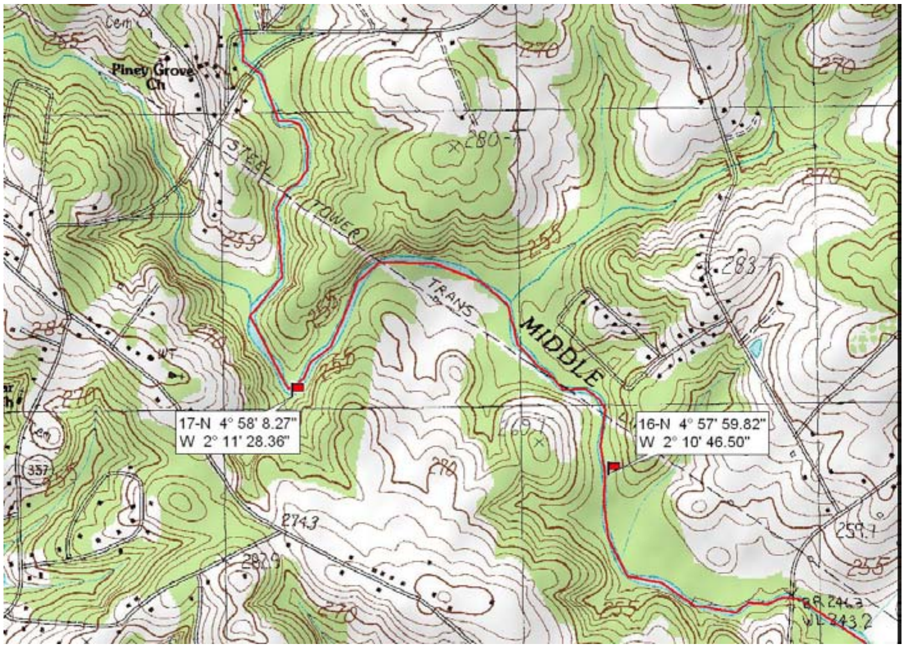

Figure 5b. Topographical map showing exact locations of outfalls.

Aerial IR can also be used to detect illegal dumping and/or discharges, track pollution such as waste spills or oil spills, monitor sewage treatment plant discharges, manage heated water from power plant cooling towers, monitor ground water seepage into rivers, streams and lakes and measure the amount of fresh water from ground sources that are introduced into an estuary.

3.9. Animal Census

Animals such as deer (see Figure 6), moose and large migratory birds are among the many warm-blooded animals which can be found and counted from the air. In the case of deer, aerial IR is far more accurate than any other method and is used primarily by government agencies. Population density information is used to monitor and control the population of these animals on city, county, state and federal lands.

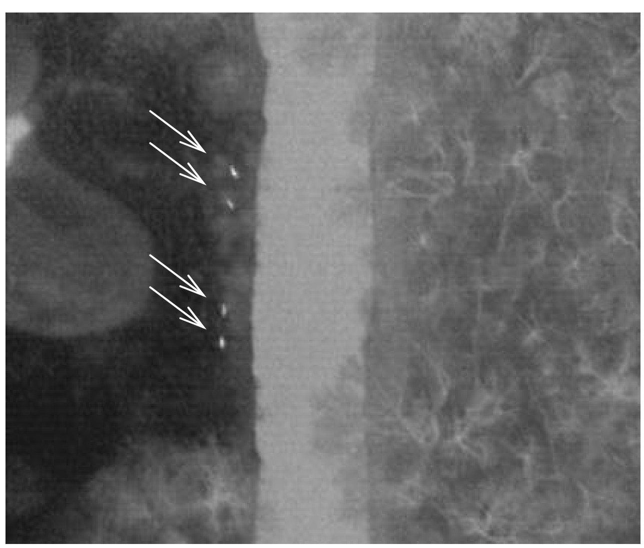

Figure 6. Thermograph shows four deer in a forested area (indicated by the four arrows).

3.9.1. Flight Methodology

These counts are flown at an average altitude of 1,500 feet above ground level. The camera view directly below the airplane from that altitude is ~400 feet wide on the ground surface. Flight lines are spaced an average of 350 feet apart to allow for image overlap and 100 percent coverage of the study area. A 'bread crumb' feature of the mobile mapping software used for the flight allows for tracking the flight path and helps guide the pilot along predetermined flight lines to assure complete coverage. The data acquisition device is normally paused during the turns outside the study area.

3.9.2. Analysis Methodology

After the flight, analysis is done by reviewing the flight lines with two monitors. As the recorded data moves forward, the VED decodes the bar-coded GPS signal that was received from the GPS during the flight and recreates the original GPS signal, sending it to the mobile mapping software so that the software 'thinks' it is receiving a live signal. The mapping software shows the moving position of the airplane superimposed on a map on one computer screen while the imagery of the area below the airplane is visible on the other. The GPS updates the airplane position once per second throughout the flight and at the same rate during the post-flight analysis. Each deer's position is placed on the map as a dot (see Figure 7). Deer usually appear as a fairly bright white dot or narrow line (similar to a grain of rice) in the infrared imagery.

Figure 7. Maps indicate (a) flight lines and (b) deer populations (red dots).

3.10. Search and Rescue (SAR) and Security

SAR operations are often 'rush' jobs where ambient conditions are less than ideal and availability of aircraft, IR equipment and pilot may be limited. Aerial infrared SAR is better than ground-based SAR in most instances; however it is still highly overrated. People targets either do not want to be seen, are disabled and unable to move to an area where they can be seen, or are trying to keep the warmth of their body close by insulating themselves, so they cannot be seen.

3.11. High Voltage Electric Utility Transmission and Distribution Lines

Detecting electrical faults on high voltage electrical transmission lines can be accomplished rapidly from the air. However, even from short distances, accurate temperature measurements of electrical faults are impossible to *measure* [quantify]. There are several problems associated with temperature measurement from the air. These include spot size to target distance ratios, reflection of the objects surveyed, weather conditions and having a sufficient load on the line at the time of the survey. Utility company specification writers have not yet realized the seriousness of these problems and continue to ask for quantitative data on fault areas. The fact is that infrared cameras that are in general commercial use today cannot measure accurate temperatures on small objects from distances of 50 feet...much less from reliably safe

flying distances. A one-inch (relative size of a transmission line splice) target cannot be *measured* from that distance, plain and simple, although it can be *detected* (see Figure 8). These spot sizes are unmanageable and inaccurate on any target that does not have a large homogeneous heat signature. The GRE is critical to the measure of spatial resolution in aerial infrared thermography. Nyquist's frequency theorem states that an object less than two times the size of a sensor's GRE cannot be resolved for measurement, so a 3x3 pixel or GRE spot is needed for reliably obtaining measurements. This shortcoming may be addressed by using a more powerful lens to reduce the GRE for a given distance, but then the sensor's FOV is reduced, limiting the area covered over a given period of time. So, if one is using a small format IR camera, say, 256x256 pixels, in a helicopter only 50 feet away from a 1 inch hot spot, it is impossible to obtain accurate temperatures using a standard lens. The smallest hot spot that could be accurately measured with one of these imagers even at that extreme short distance is over 2". Also, from the air, using a more powerful lens does not work well because vibration is more evident in the form of image 'shaking'. Image 'smearing' may also occur due to an increase in the apparent speed of the sensor's view across the scene. In the air, there are few substitutes for a large pixel array, but even using large format detectors, one cannot and should not profess to *measure* temperatures on very small objects. These anomalies can be seen, and by comparing them to similarly loaded equipment, potential problem areas can be identified, saved and marked on a map. Quantitative data in this application should not be specified, but if it is absolutely necessary, a ground-based verification team should be used to inspect each hot spot from the ground (cloudy nights are best) and quantify the findings of the aerial IR survey. The ground-based thermographer will be close to the target and with a powerful lens on a stable surface mount; much more accurate measurements can be obtained.

Because they are smaller, lower to the ground and often run through populated areas, high voltage electrical distribution lines are much more difficult to see against all the thermal clutter on the ground such as trees, street lights, people, animals, etc., than transmission lines. Therefore they are best left to ground-based infrared thermographers.

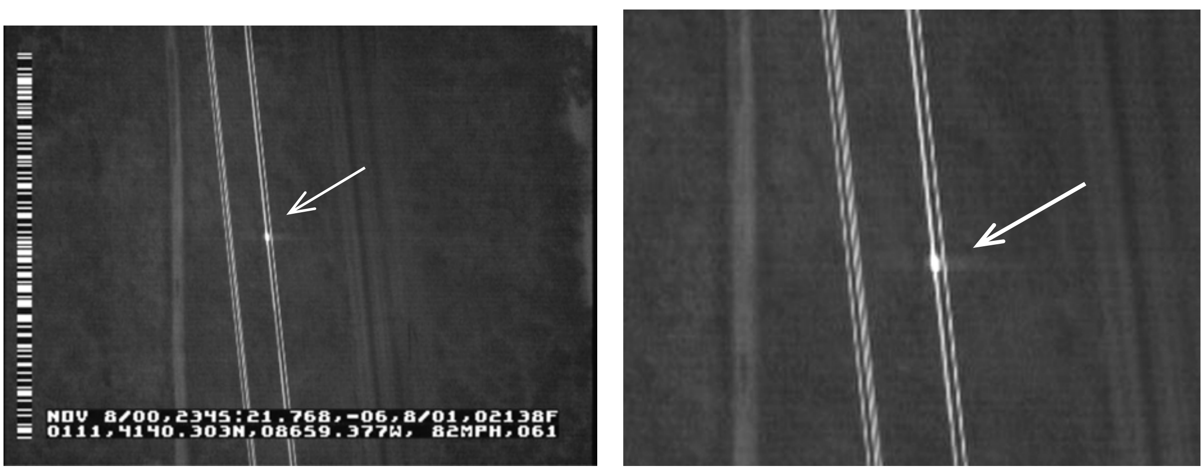

Figure 8. Thermographs of a high voltage transmission line splice fault.

3.12. Roof Moisture Surveys

Regularly scheduled infrared surveys help building owners assess their roof's general condition at all stages of its service life, because they can make repair decisions based on actual roof moisture data by quantifying and tracking areas of moisture (water) contamination in insulated flat or low-sloped building roofs (see Figure 9). Accurate scaled drawings of roof moisture also allow the owner to produce a bid document for repairs, so that surgical removal of wet insulation and repairs can be specified. Almost all roof materials sent to landfills in the US annually…are dry.

No other application better illustrates the advantage of aerial infrared thermography over ground-based infrared than roof moisture surveys. Straight down aerial imagery is much more useful to the owner than on-roof imagery because aerial infrared images are plan view and because large areas can be seen in one image. Areas of roof moisture contamination manifest themselves as warmer areas, commonly found in linear or puddle-like shapes. They may be nebulous and sometimes mottled in appearance. The linear shapes many times follow low areas, drainage routes, roof edges and seams. Puddle-like round or oblong shapes often form around roof penetrations such as mechanical

equipment, standpipes, vents and drains. The wet areas are warmer at night because the latent heat (from daylight sunshine) in the trapped water mass is greater than in the dry, functioning insulation or roof substrate. After sunset the roof structure cools down, except for areas where the roof insulation is wet.

Aerial is by far the best platform for performing infrared roof moisture surveys for several reasons. First, straight down, high-resolution aerial imagery captures large areas at once, making the report easier and less expensive to produce, while lessening reflection and perspective problems and eliminating all of on-roof infrared's logistical evils, such as access to multiple levels and dealing with security, manpower and safety issues. Secondly, plan view imaging (see Figure 10) allows for the precise, accurate marking of areas of suspect roof moisture contamination on computer aided design & drafting (CADD) drawings (see Figure 11). Visual, infrared and CADD drawings can be reconciled closely, making the report accurate, clear, concise and easy to understand. Perhaps the biggest advantage of aerial infrared is not its use on roofs that have well-defined areas of moisture at all, but on those roofs that are the most difficult to image from any distance or angle. I am referring to the roofs that, for instance, have a lot of ballast, are covered with reflective coatings, have multiple layers or that for whatever reason are difficult or impossible to image while standing on the roof. With high-resolution aerial imagery, slight nuances of temperature differences can be seen from far enough away to actually trace the patterns of heat.

Figure 9. Raw thermograph of a flat roof showing moisture (lighter areas) entrained in the insulation.

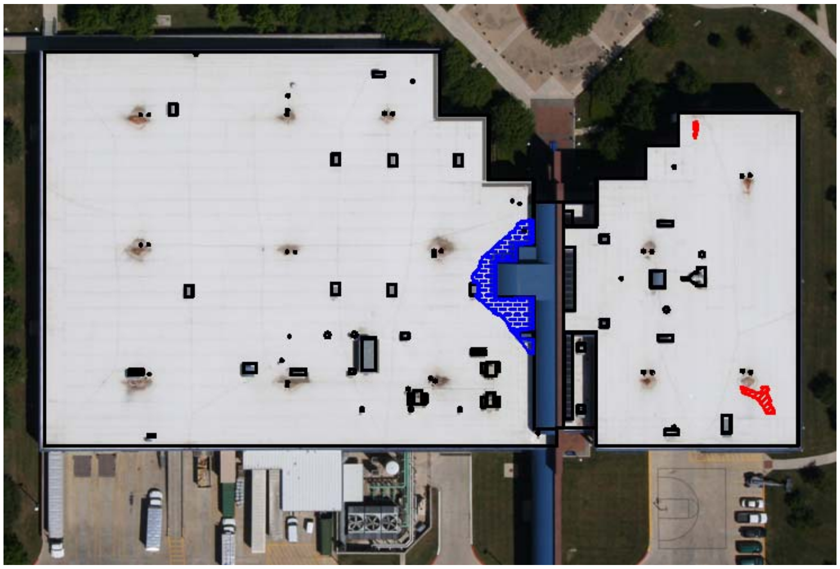

Figure 10. Aerial photograph with CADD overlay.

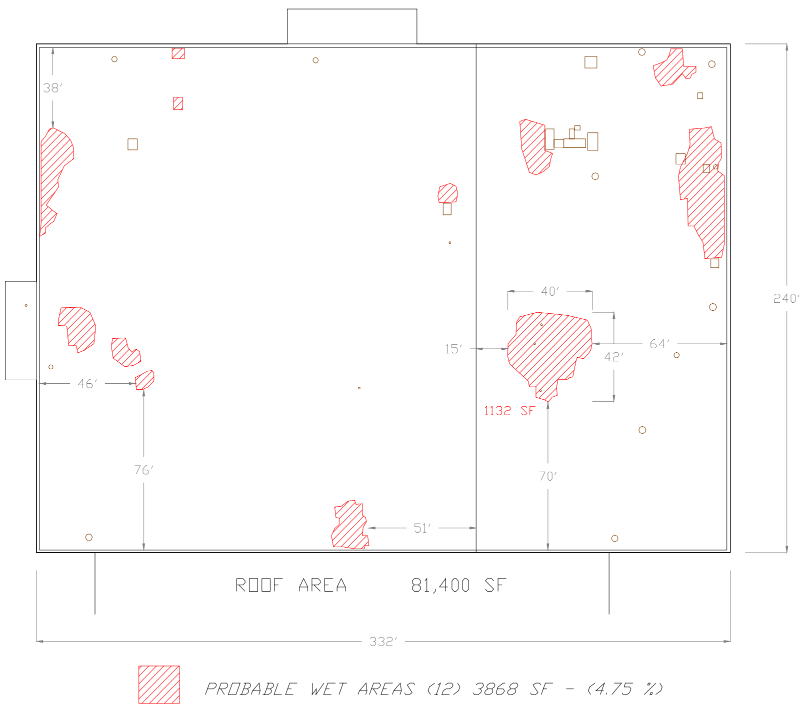

Figure 11. Scaled CADD drawing with areas of roof moisture contamination marked.

4. SUMMARY

As outlined above there are many commercial uses for aerial infrared thermography. The aircraft, imager and crew must be capable of performing the tasks and providing professional results. With improvements in photographic and thermographic camera quality, flight and image-processing and mapping methodology, aerial infrared thermography will increasingly be the preferred method of IR imaging of ground objects.