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Infrared Field Users' Guide

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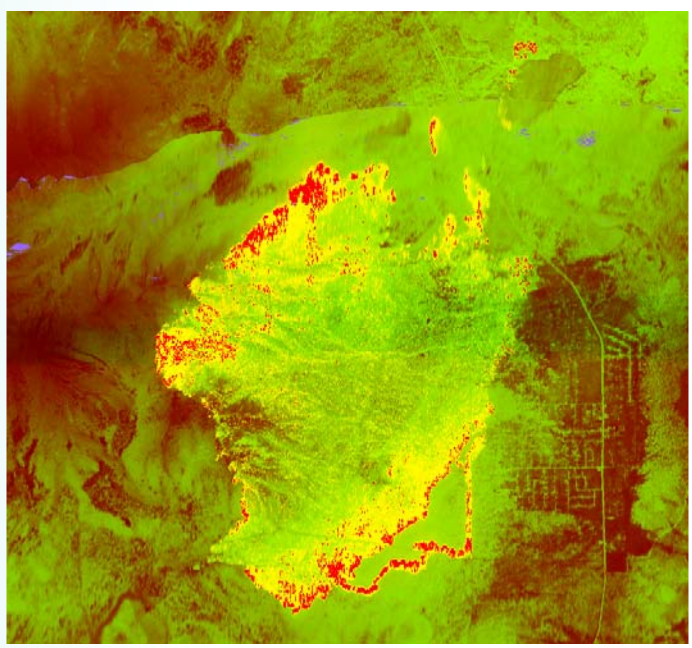

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Abstract
Infrared (IR) sensors have been aiding wildland firefighters for nearly 40 years. Originally only used for initial detection, IR sensors are now used to detect, monitor, and direct fire suppression and mop-up operations. Recent technological developments have resulted in proliferation of IR scanners at fire camps across North America. They range from small handheld units to airborne units that can cover millions of acres per hour with real-time output. Classifying IR scanners into type categories will enable incident commanders and situation unit leaders to select the proper equipment for each situation, thus avoiding waste of time and money on imagery that will not be useful. Modeled on the typing scheme used to classify helicopters, this typing scheme is easy to use and simple to understand for firefighting leaders.

Introduction

In the spring of 2001, the National Incident Commanders asked the National Infrared Operations (NIROPS) program to develop a list of infrared systems that the overhead teams could order when national infrared aircraft are unavailable. A list of IR equipment appropriate for different stages of an incident and general technical information on the fundamentals of IR were also requested. The list provides valuable information, for use during critical phases of the incident, to the fire overhead teams, Geographic Area Coordination Centers (GACC), and state and local fire organizations.

NIROPS appointed a team of specialists that included the National Interagency Fire Center (NIFC) IR technicians, IR interpreters, and Remote Sensing Applications Center (RSAC) personnel. The Department of Forestry Management at the University of Montana assisted with the final write-up. The team sought to reach national and international IR contractors, whether known or unknown by the team, by posting a Request for Information (RFI) in FEDBIZ for one month. In addition, RSAC contacted those contractors who were known to have relevant capabilities, but who did not respond to the RFI.

This report represents a unique endeavor to fulfill the intelligence needs of fire managers. Infrared sensing capabilities are categorized into one of five system types. This scheme is similar to the Overhead Fire Teams' classification scheme. A matrix of the different IR types and their characteristics is presented so fire managers can compare systems to determine which equipment type would best meet their needs.

The report includes a brief description and definition of components used to sort the IR systems into five categories. Information is presented for each company that responded to the RFI or was directly contacted to participate. For each company, information about sensor type, production rate, cost, product type, and level of accuracy is presented. This list will be updated with new information annually or sooner if needed.

The NIROPS team welcomes comments and questions; please contact Brad Quayle, RSAC RDAS Program Leader at (801) 975-3737 or e-mail at bquayle@fs.fed.us.

Infrared Basics

The four basic elements to consider in thermal IR sensing and interpretation are 1) the source (the fire); 2) attenuation by constituents interfering with the transmission of energy (ground and tree cover, smoke, and the atmosphere); 3) the sensor or detector (whether hand-held, airborne, or space-borne), and 4) the remote sensing analyst and/or image interpreter. The first three are discussed in this section. The Infrared Limitations section contains important information for both the IR analyst and the end-user of the products.

Source

The energy from fires, called heat, is emitted as electromagnetic energy within specific wavelength bands. Most of the energy emitted by heat from wildland fires is in the thermal IR portion of the spectrum. Figure 1 shows the wavelength bands of thermal energy detectable by various receptors (such as the human eye, photographic film, and multi-spectral and thermal sensors). While the human eye detects energy in the short wavelength range of 0.3 - 0.7 microns (μm), energy from fires is emitted at wavelengths an order of magnitude longer (nominally, 2 - 14 μm). For example, consider the wavelengths of energy from a typical earth-surface background versus those from fires with four, fire-relevant combustion temperatures (table 1).

Therefore, most heat or fire-mapping applications utilize long-wavelength, thermal remote sensors. The higher the temperature of the heat source, the more energy is emitted and the shorter the wavelengths that can be used to detect and map that source.

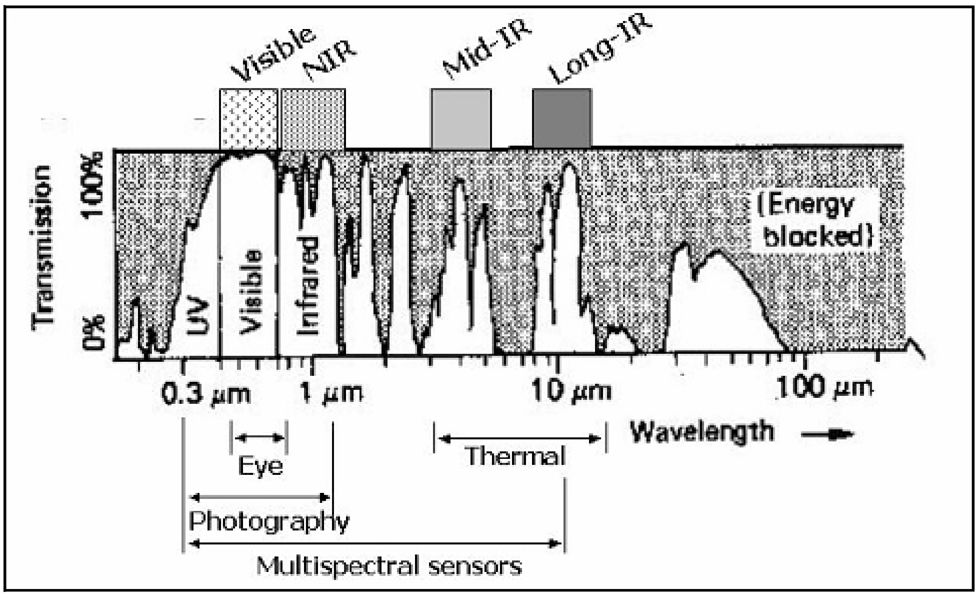

Figure 1—Wavelengths and transmission through the atmosphere (a high percentage of transmission is called a “window”) of various wavelength ranges of energy, including visible, near-infrared (NIR), mid-wave infrared (Mid-IR), and long-wave infrared (Long-IR).

Table 1—Wavelengths and Temperature Relationships

Source	**Temperature (C)**	**Nominal Wavelength (μm)**
Background	25	10
Fuel ignition	275	5
Glowing	550	4
Cool fire	725	3
Hot fire	1200	2

Attenuation

Certain wavelengths of energy are attenuated by water vapor, solid particle aerosols, and compounds occurring naturally in ambient air. Other wavelengths are relatively free from the effects of scattering and absorption; these are called atmospheric “windows.” Figure 1 shows these windows as the percentage of energy transmitted through the atmosphere to a sensor. The dark-hatched areas in Figure 1 indicate “blocked” wavelength regions. Generally, attenuation has two effects of concern. First, short wavelength energy is more affected than longer wavelength energy; this allows us to “see through” smoke at long thermal wavelengths. Second, when attempting to determine temperatures of heat sources, remotely-derived estimates will tend to be lower than the actual (kinetic) temperatures.

The Sensor or Detector

An ideal sensor design considers the wavelength(s) of the sources it is designed to measure, the atmospheric windows for those respective wavelength(s), and the most suitable materials with which to build the actual detector. These three factors produce typical thermal infrared detector systems designed to bracket specific bands, or ranges, of wavelengths. The two most common wavelength bands for remote sensing of fires are 3 to 5 µm and 8 to 12 or 14 µm. Note in Figure 1 that these wavelength bands are consistent with both the wavelengths of typical fire sources and good atmospheric windows. Detectors or sensors that operate at shorter wavelengths “see” color and not heat; this, coupled with atmospheric attenuation, limits the utility of shorter wavelength, or optical, systems to map heat.

Infrared Limitations

Infrared energy and the sensors used to detect and map heat sources have limitations of which the analyst and the user must be aware. These may generally be broken down into four categories: atmospheric effects/attenuation, solar radiation effects, source temperature, and saturation.

Attenuation

The atmosphere influences which wavelengths are chosen to detect heat, and affects the ability to detect heat and determine the actual temperature of the heat source (which may be useful in assessing severity and intensity).

- IR energy can be emitted or reflected. For most fire/heat-mapping applications, we are interested in long wavelength IR energy.
- Water and water vapor absorb IR energy; therefore IR sensors cannot see through dense water vapor (e.g., clouds or fog).
- The atmosphere is a good transmitter of IR energy only in certain wavelength regions, called windows. IR remote sensing is usually restricted to the windows of 3 - 5 µm and 8 - 14 µm in wavelength.

Solar Radiation

- Reflected sunlight may also mix with the emitted IR energy; thus, highly reflective surfaces (rock outcrops, water, snow, bare ground, metal roofs) may appear hot in an IR image. This can create false positives (i.e., the sensor detects fire where there isn't one). This problem can be mitigated by utilizing more than one IR band or looking at the object from multiple angles to see if it is truly on fire.

- Often long-wavelength IR (8 - 14 µm) data is collected to portray background areas around the heat source. Because smoke does not prevent this long wavelength energy from passing through, we can see the background at these wavelengths. Conventional remote sensing (photos, visible bands of Landsat) cannot see through the smoke because it scatters and absorbs short wavelength energy. (Note that heavy, moist smoke also attenuates IR data.)

Heat Source Temperature

- The amount of energy emitted by a fire or heat source depends on the temperature of the object; the higher the temperature, the more energy is emitted. The temperature of an object also affects the wavelength it emits. "Hot" fires can be detected in the 3 - 5 µm range, while "cool" fires can only be seen in the longer portion of the IR spectrum (8 - 14 microns).

- Fires are not perfect emitters of IR energy. Therefore, when IR sensors map the temperatures of heat sources, the apparent temperature of the object will normally be lower than its kinetic temperature. In other words, a measurement of a fire using a thermometer would be 7 to 10 percent higher than the remotely-sensed temperature.

- Emitted energy can also be absorbed by a heavy canopy or over-story. The ability to detect heat beneath a canopy may be reduced by heavy smoke, vegetation, or water vapor. This effect will generally make an object appear cooler than it really is. Also the higher the sensor is above the ground, the more likely this reduced temperature effect is to occur.

- Remote sensing of thermal energy can only detect heat ***on the surface*** of the targets because that is where the energy is emitted. Therefore, heat beneath surface material (e.g., duff, litter, or organic matter) cannot be detected unless it raises the surface temperature enough to cause an increase in long-wavelength IR energy. Note that many surface materials, such as duff, are good insulators.

Saturation

- Very hot objects or heat sources may saturate a sensor, creating low contrast in an image. Therefore, images are best collected when the thermal contrast is highest, which is in the morning or evening. Maximum surface cooling will typically occur near or just after dawn.

- Hot gasses may cause "blooming" in an IR image due to their high temperature. This can happen when a fire flares up and emits a convective fire column that includes gasses hot enough to saturate the sensor, thereby rendering portions of the image unusable.

Figure 2—An example of a fire flare-up that can cause saturation or blooming in an infrared sensor.

Infrared Typing System

In the past, IR systems have been used on fires without prior knowledge of the system's ability to meet the objectives of the fire managers. This has resulted in use of products that may not meet the needs of the fire team.

During the past decade, a number of advancements in thermal IR remote sensing have occurred, and a growing number of these systems are available in aircraft for use in fire management. The IR typing system is a guideline designed to help incident command teams determine the best system for their situation. The typing system informs fire managers about the capabilities and limitations of the available IR systems. They can then use this information to choose a system that will be cost-effective for their situation. Choosing the right IR system ensures that this valuable fire intelligence is obtained in a safe, timely, and cost-efficient manner.

Infrared systems are a combination of the detector, data recorder and processor, Global Positioning System/Inertial Navigation System (GPS/INS), platform, and operator. These components determine which mission profiles the system can accomplish effectively. Infrared systems can be classified in various ways; we have classified them in a manner relevant to the wildland firefighter. The following four components are used to sort the various IR systems into five categories (see Table 2).

Table 2—Infrared System Types

Components	Multiple Incident/Large Fires		Single Incident		
	Type 1	**Type 2**	**Type 3a**	**Type 3b**	**Type 3c**
Mount	Nadir	Nadir	Gimbaled	Gimbaled	Hand
Geocorrected Products	Yes	Yes	Yes	Optional	Optional
Thermal Band(s)	2+	1	1	1	1
Production Rate (acres per hour)	100,000	10,000	1,000	500	100

Mount

Infrared systems can be mounted in several different ways: nadir, gimbaled, semi-permanent fixed, or hand. Hand-held units are designed to be operated as one would use a camcorder. With gimbaled mounts, widely known as forward-looking IR (FLIR) balls, the IR sensor is mounted on a stabilized turret that can be pointed in nearly any direction not blocked by the aircraft. With nadir mounts, the sensor is pointed directly below the aircraft.

Geo-corrected Products

The deliverable product(s) are corrected for applicable sensor distortions and set to a specified map projection with associated map coordinates. Typically, an IR interpreter or image analyst manipulates the data to a point where it can be integrated into an incident's GIS. It is important to check with the infrared provider to determine if an infrared interpreter or extra GIS specialist will be needed.

Thermal Bands

IR sensors can detect a number of thermal bands, or ranges, within the electromagnetic spectrum between 3 - 5 µm and 8 - 14 µm. Systems that detect more than one thermal band are better suited to reject false positives that occur when flying over hot rocks, a metal roof, etc. (See Infrared Basics section for more details.)

Figure 3—Hand-held infrared imager *(left);* gimbaled-mounted turret FLIR system *(middle),* and nadir-mounted line scanner *(right).*

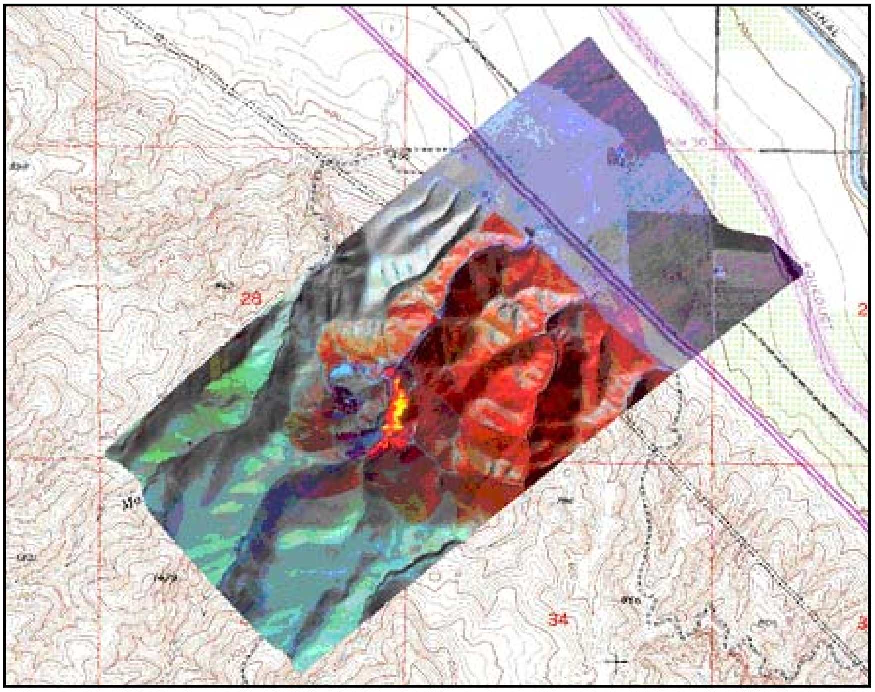

Figure 4—Output from the NASA Airborne Infrared Disaster Assessment System (AIRDAS), a type 1 line scanner, draped over a Digital Raster Graph (DRG). The bright orange and yellow area is an active, controlled burn.

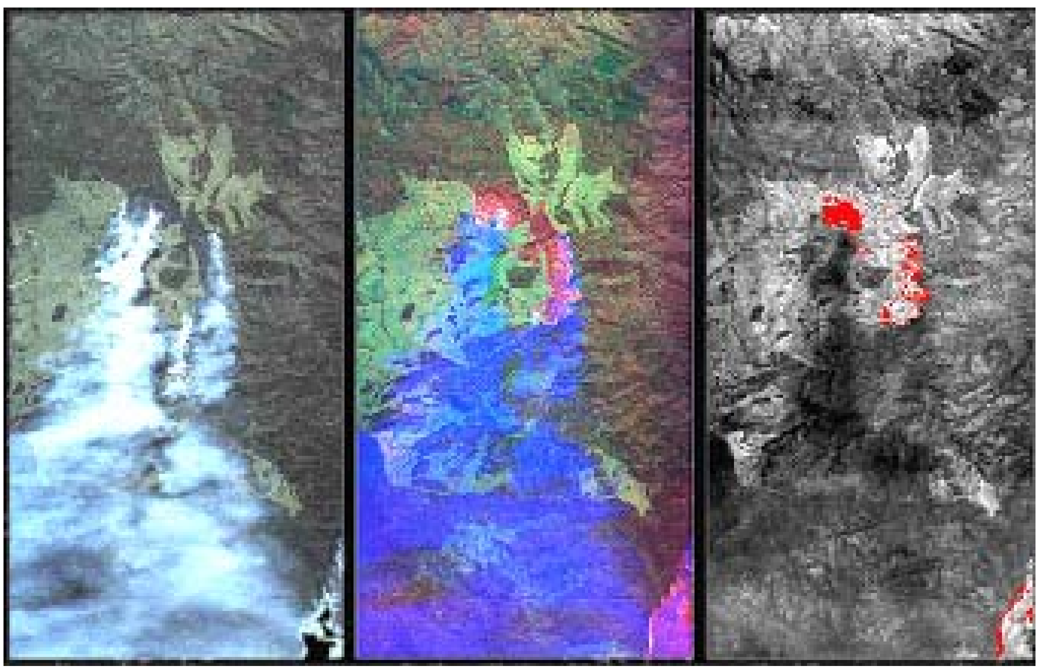

Figure 5—The same fire seen with visible bands *(left),* near- and mid-infrared bands *(center),* and thermal bands *(right).* Notice how the smoke obscures the fire in the visible bands; the fire scare shows well in the near- and mid-infrared, and the active fire is highlighted with the thermal bands. (Image courtesy of Airborne Target Systems, Australia)

Production Rate

The production rate is the area the sensor can cover in one hour stated in acres per hour. Note that the stated value for a particular sensor is the best case and will decrease significantly due to turns, flight-line overlap, mission type, etc. Production rates are determined by the instrument's field of view (FOV) in conjunction with the aircraft's speed and altitude. The values listed for production rates do not include the amount of time it takes to deliver and process the imagery.

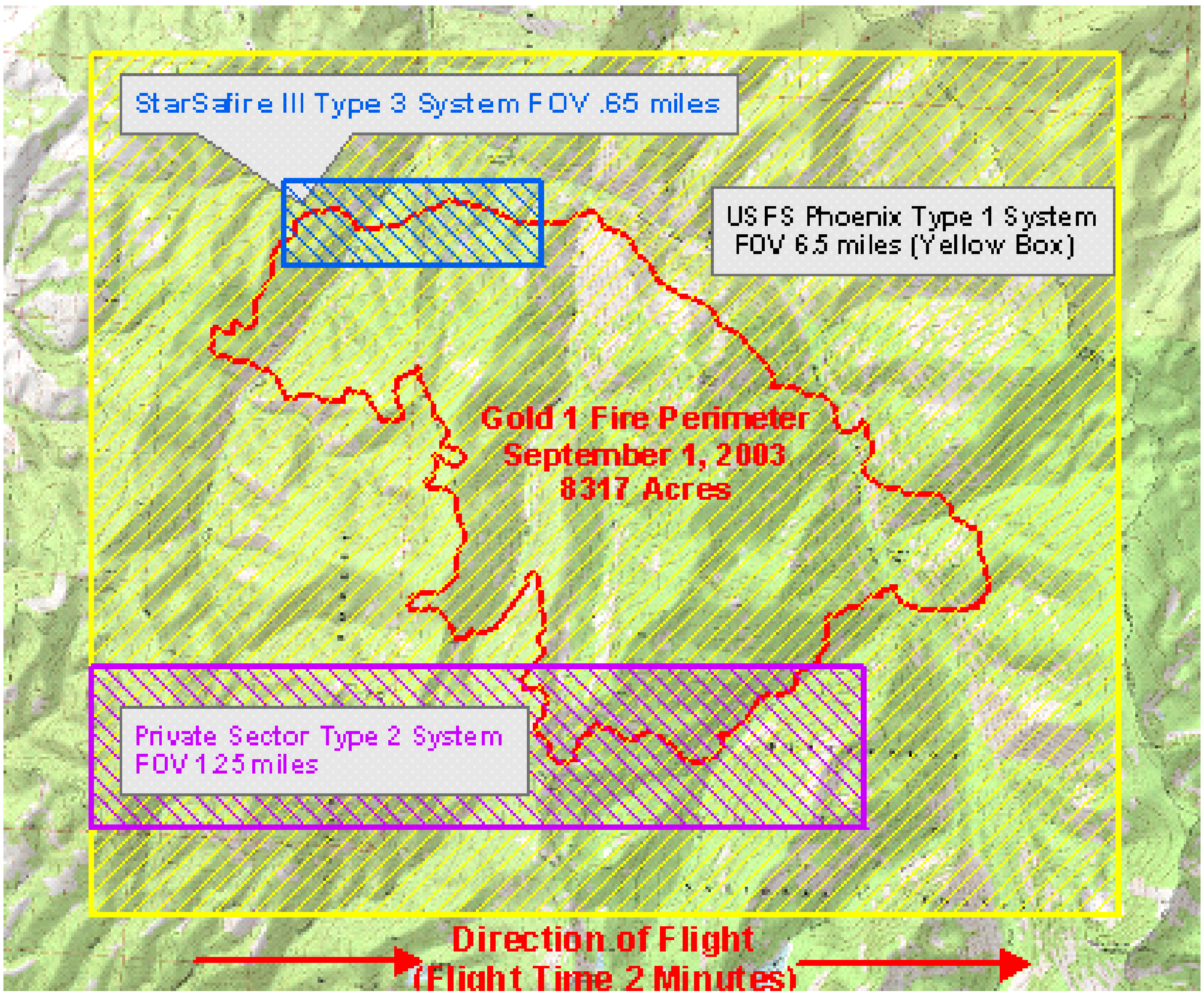

Figure 6—This figure illustrates the production rate of three infrared sensors. The Phoenix type 1 line scanner, mounted on a twin turboprop or jet, is capable of covering the fire in two minutes with a one-mile buffer on each side of the fire, enabling the interpreter to identify spot fires that have jumped containment lines. The private-sector type 2 system mounted on a piston twin-engine aircraft would require seven passes and six turns, which would take nearly 40 minutes, to cover the same amount of ground. The time could be reduced to 32 minutes if the same sensor were mounted on a twin turboprop. A helicopter-mounted type 3 system would take 90 minutes to accomplish the same task (normally type 3 systems are flown much lower so that they can pick up very small heat sources and view critical areas from multiple angles).

Figure 7—The NIFC Citation Bravo and the Phoenix line scanner, type 1 platform and sensor.

Type 1

These systems are best used to detect very small heat sources distributed over vast areas and to map large fires. Type 1 systems are capable of imaging a large incident quickly so that fire managers get a snapshot of the situation. Strategic information may be gathered for planning and general assessment of conditions over large areas. They are also useful for a final look before an incident is turned over to the local agency. These systems, mounted on twin-engine or jet aircraft, can cover large areas quickly.

Type 2

These systems are best for gathering data for tactical and near-real-time decision making and should be coupled with products that do not require an on-the-scene IR interpreter. These systems can often be used for multiple purposes, including infrastructure and forest condition mapping and burned area assessment. Unless specifically stated by the vendor, a qualified analyst is required to create the desired data products. Possible platforms are fixed-wing aircraft or helicopters.

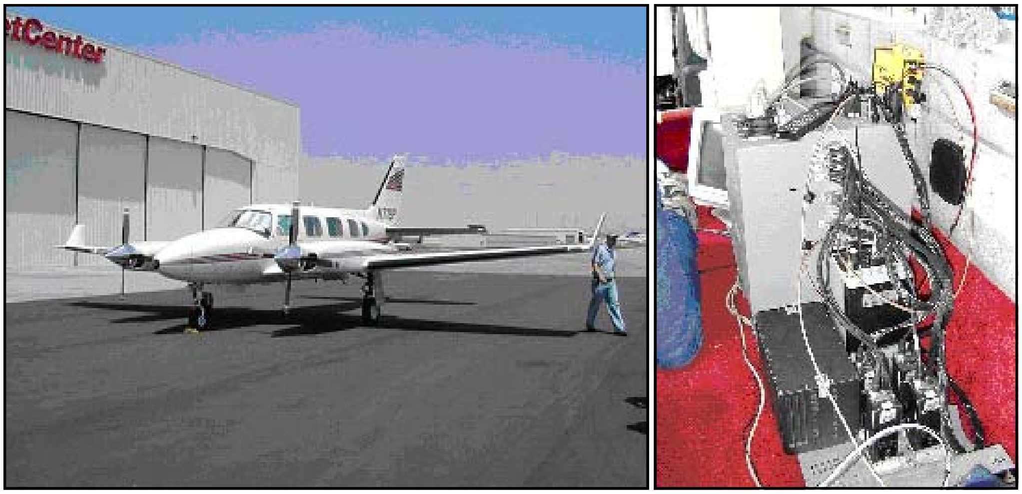

Figure 8— An example of a private sector, type 2 aircraft and its sensor.

Figure 9—A FLIR system mounted on a fixed-wing aircraft.
Source Lassen National Forest.

Type 3

These systems are valuable for close-in IR viewing, coupled with visual observation and judgment by on-the-scene fire managers. Type 3 systems are very useful for fire-line mapping and mop-up operations. Because these systems are gimbaled mounted, they can typically view an object from multiple angles, thus detecting heat that may elude nadir-mounted systems. Type 3 systems are generally mounted on helicopters that travel with their own processing centers but a few are mounted on fixed winged aircraft.

Table 3 classifies IR venders by these three types. These vendors have voluntarily submitted their information through RFI-AG-84N8-S-08-0039. This information has been checked for technical feasibility by NIROPS and RSAC staff. This list of vendors does not constitute an official evaluation, conclusion, recommendation, endorsement, or approval by the Forest Service of any product or service to the exclusion of others that may be suitable.

Table 3—Infrared Vendors Listed by Type. Page numbers refer to the Vendor Listings Appendix

Type	Company Name	Thermal Bands	Mount	Hourly Acquisition Rate (Acres per hour)	Fire Experience	Platform(s)	Page
I	**USDA-FS National Infrared Operations**	2	Nadir	750,000	Yes	BE200, Cessna Citation Bravo	1
	Range and Bearing	1	Nadir	2,1000,000	Yes	Piper Cheyenne II	1
	VeriMAP PLUS Inc	1	Nadir	550,000	Yes	Piper Navajo PA-31	1
2	**Fuhr Flying Services**	1	Nadir	400,000	Yes	Piper Navajo PA-31	2
	Icaros Inc	1	Nadir	—	Yes	Light aircraft, ex. Cessna 170	2
	GeoVantage Inc.	1	Nadir	20,000	Tests	Light aircraft, ex. Cessna 170	2
3a	**Fireball International Services Corp.**	1	Gimbaled	9,400	Yes	Bell 206 Jet Ranger	3
	Patriot Technologies Group LLC	1	Gimbaled	—	Yes	Jabiru J-430	3
	Aspen/Veteran's Emergency Technical Services	1	Mounted	9,200	Yes	Bell 206L3, Bell 407	3
	Avwatch Inc.	2	Gimbaled	—	Tests	Light aircraft, ex. Cessna 182	4
	Vision Air Research	1	Gimbaled	21,000	Tests	Cessna 206	4
	HeloAir Inc.	1	Gimbaled	—	Yes	Bell 206B, Bell 407	4
3c	**Fireball International Services Corp.**	1	Hand		Yes	Various	5
	Henderson Aviation	1	Gimbaled	9,100	Yes	Bell 206B3, L3, L4	5