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A Guide to Conducting Aerial Sketchmapping Surveys

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Foreword

Sketchmapping is a skill that benefits from planning and experience. Although there are many variations in aeral survey programs, missions, and damage signatures to be captured on sketchmaps, all aerial surveys contain many of the same elements, issues, and concerns. This guide was written to address those elements, issues, and concerns.

Although this procedures guide has been written to provide those who conduct and manage insect and disease aerial surveys a basic understanding of aerial survey procedures, it cannot take the place of sound aviation management. Using aircraft to collect data has inherent risk; a good aviation program always includes a sound risk managment program. A great deal of work must be done prior to an actual aerial survey flight to ensure a safe, cost-effective, and quality mission.

Information on damage signatures in this guide are general because of the vast number of signature variations possible and because of the difficulty in reproducing quality color photographic examples of damage signatures as they would appear to an aerial observer. It is recommended that this guide be used in conjuction with local damage signatures training.

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I. Introduction

The purpose of this guide is to describe general procedures used by experienced aerial survey specialists to collect forest health data via sketchmapping. It is not intended to be a specific "how to" manual for all types of aerial surveys, nor replace training in aviation safety and management, on-the-ground field training, or apprenticeship flight time during regular aerial surveys. Rather, it is a "guide" to the aspects of flying and sketching that make up sketchmapping, presenting a comprehensive overview of aerial overview surveys and a general review of aerial survey sketchmapping methodology.

A Brief History of Aerial Surveying

In 1919, Gordon Hewitt recommended using aircraft for forest insect detection after flying over mosquito-breeding areas in parts of British Columbia. In 1920, an open-cockpit hydroplane was used to survey a spruce budworm infestation in parts of Quebec and Ontario.

One of the earliest attempts to survey forest insect damage from the air was made by J.M. Miller in 1925 over the Sierra National Forest, in California, in an open-cockpit airplane. In 1930, the Bureau of Entomology used a Forest Service airplane to survey bark beetle outbreak areas of Yellowstone National Park. In 1931, F.P. Keen, from the Portland Forest Insect Laboratory, and C.S. Cowan, Chief Fire Warden of the Washington State Fire Association, conducted the first recorded aerial survey of a forest insect outbreak in the two northwestern states when they delineated a hemlock looper outbreak in southwest Washington.

In 1947, an annual aerial survey program was instituted by the Bureau of Entomology and Plant Quarantine, USDA, cooperators from the States of Washington and Oregon, and the Weyerhaeuser Timber Company. The pioneers of the modern aerial survey, when it began in Portland, Oregon, were W.J. Buckhorn, a seasoned entomologist, and John F. Wear, a young research forester and pilot just out of graduate school after World War Two. Together, they flew aerial surveys for several years and, in 1955, wrote "Organization and Conduct of Forest Insect Aerial Surveys," the first guide to conducting aerial sketch-map surveys. Their report is still relevant today, despite the subsequent development of better maps and more powerful aircraft.

Sketchmapping: A Definition

Sketchmapping is a remote sensing technique of observing forest change events from an aircraft and documenting them manually onto a map. It is considered both an art form and a form of scientific data collection, and is highly subjective. The observer views a particular forest change event or damaged area on the forest, and delineates the affected area onto a map to record its size, shape, and location as accurately as possible. Attributes, such as host, causal agent, symptom, and an estimate of intensity or number of trees affected, are also recorded.

Aerial sketch-map surveys have been recognized for over fifty years as an efficient and economical method of detecting and monitoring forest change events over large forested areas. Since it is a relatively low cost method, it is relied upon to provide a coarse, landscape-level overview of forest health conditions. If the forest change events discovered during the overview survey are considered high priority, it can be used as the first step of a multitiered process of detection, monitoring, and evaluation, using other remote sensing and ground sampling techniques. No remotely sensed data is reliable without some amount of ground-truthing for tree species, causal agent and location.

The Beginnings of This Guide

In 1997, the Forest Health Monitoring aerial survey focus group met in Lakewood, Colorado, to develop national aerial survey sketchmapping standards. The group was made up of USDA Forest Service and state cooperators interested in coming to some agreement on standards so that the data could be shared across Forest Service Regions, states, and other artificial boundaries. One important need was identified to support new sketchmappers or sketchmappers with limited experience: there was no current guide to conducting aerial sketch-map surveys. This guide was developed to fill that need, and help anyone interested in sketchmapping understand more about the process.

No two aerial survey programs or sketchmappers are the same because of the many variables involved in planning and completing an aerial survey, but this guide can help anyone looking for general information that pertains to all aerial sketchmapping surveys. This guide is not a substitute for proper training, but serves as a resource to help, in conjunction with specific aviation safety and management training, the sketchmapper or program manager formulate, conduct, and manage an aerial survey program.

Terminology in This Guide

1. The definition of "forest health data" for this guide are the effects of insects, pathogens, or other abiotic/biotic agents on trees in the forest that can be observed from the air.
2. The following terms all mean "aerial sketch-map survey" for this guide:
   - aerial detection survey
   - insect and disease aerial survey
   - aerial overview survey
   - pest detection survey
   - annual aerial detection and monitoring survey

3. The phrases, sketchmapper, aerial survey specialist, aerial observer and observer are used interchangeably throughout this guide.

4. The terms damage, affected area, damaged area, event, change event, forest change event, signature, and area of mortality, all imply what is to be recorded by the sketchmapper. Some consider "damage" to be a normal part of forest succession and not a negative term, while others consider insects and diseases to be pests. Whatever the reader's perspective, damage is forest change and if visible, can usually be recorded from the air by sketchmapping.

II. Types of Aerial Sketchmapping Surveys

There are two types of aerial sketchmapping surveys: the overview or general survey and the more specific or special aerial survey. The intent of the overview survey is to sketch-map all new forest change events during one flight. The specific aerial survey is conducted to map primarily just one forest change event and is scheduled at peak signature of that event. A signature is what is visible in detecting "damage" or a forest change event–usually a color change from "healthy" green foliage or a perceived "texture" change in the canopy.

Aerial Overview Survey (General)

The most common overview survey is the annual aerial detection and monitoring survey. This type of survey is a landscape-level assessment of symptoms caused by insects, diseases and abiotic factors. Although large areas are covered, this type of aerial survey is still conducted systematically, so all areas of interest are adequately surveyed without large gaps of unsurveyed areas. It is intended to be a one-time "snap shot" to provide a general idea of new forest change events.

The purpose of this survey is to sketch-map most forest change events that are new since the previous year's aerial survey. The intent of the timing of the survey is that most important forest change event signatures will be visible from the air. If an important single event occurs with a signature that is not visible during the overview survey, another special survey will be necessary. The intent of the overview survey is to be cost-effective, with just one flight over an area, rather than several flights, to collect information on each forest change event. It is generally adequate, depending on the area and the events occurring each year.

One of the values of an overview survey is that it provides quick information about specific events that can be followed up with special aerial surveys, photography or ground assessment activities. Its accuracy may not be as exact as that of a special survey, but should be accurate enough to provide detection, trend, intensity and location information on the important forest change events.

The scale of map used to sketch-map for an overview survey is generally 1:100,000, 1:126,720, or 1:250,000. Some overview surveys are conducted on larger scales, such as 1:50,000, depending on desired detail and map availability. Larger scales allow greater precision, but call for lower flying altitude and require more flying hours to cover the survey area, increasing the cost of the survey and the time required to complete it.

A typical overview survey covers a lot more ground in one hour than a special aerial survey. A grid pattern aerial survey can cover as much as 480 square miles in an hour, while a contour aerial survey can cover approximately 160 square miles in an hour. The map scale must be appropriate for covering this much area. The standard for Forest Health Protection overview surveys in the lower forty-eight states is 1:100,000. The common US Geological Service (USGS) 1:24,000 topographic quadrangle map has great detail, but preplanning is required to make the maps needed manageable in the aircraft.

Event-specific (Special) Aerial Surveys

Event specific aerial surveys or special surveys are used to quantify damage caused by a unique biological agent or meteorological event in which the damage signature generally falls outside of the overview survey's optimum biological window or when more detail is desired. Special surveys are usually flown in addition to the overview survey and may take place at any time of the year. The type of aircraft, map, and survey methodology used may differ greatly from those used in a typical overview survey. A large scale map, such as 1:24,000, is commonly used for special surveys where only small areas are of concern. Other remote sensing tools, such as aerial photography, are commonly used in conjunction with or in place of sketchmapping.

Abiotic Damage Surveys

Event-specific surveys are commonly used to assess abiotic damage inflicted by events, such as, hurricanes, tornadoes, avalanches, wind storms, ice storms, fires, and floods. Most of these damage event types can be accurately mapped at any time throughout the year, often immediately following the event.

Windthrow (Blowdown) In the West, uprooted conifers following a severe wind event can be fairly easy to recognize from distances of 1.5 miles or less and from 1,000 feet or less above ground level, assuming the damage is contiguous, at least 10 acres in size, and most of the trees in the affected area are down. Blowdown is more difficult to detect from greater distances because needle color remains the same as the surrounding standing trees. Small or scattered areas of blowdown will usually go undetected, unless the flight path is very close to the damage area. In the Lake States, by contrast, much smaller areas and scattered spots are frequently mapped to identify old versus new challenges.

The difficulty in sketchmapping windthrow is in determining recent damage versus previous damage. This is because needle drop on windthrown conifers can occur either very rapidly (a few months) or very slowly (2 to 3 years, as the tree dies slowly because some roots are still intact) following a windthrow event. Therefore, it is best to schedule the survey as soon as possible after the wind event or storm.

Fire Although catastrophic fire events can be accurately mapped, mapping difficulties can occur in low intensity fires, both natural and human-caused. In the case where tree crowns are consumed but individual tree boles are only scorched or heat girdled, affected pines will fade the following year and resemble kill by bark beetles. The best way to verify cause of death is to do a low, slow pass over the damage and look for additional burn signatures, such as charred bark, branches, underbrush, or grass. Fire signatures can be mapped during both special and overview surveys.

Flood (High Water) As with fire, this signature may also be confused with that of beetle kill. Location is a key to detecting flood or high water-killed trees. This damage often occurs in drainage bottoms, near lake shores, or other low-lying areas. One other key is that it usually affects all tree species in a single location. An unusually high spring runoff or places where high beaver populations exist are often associated with forest flooding.

Main Stem Broken Stem breakage can occur from strong winds, such as hurricanes or tornados, and ice and heavy snow loads that weigh heavily on the tree tops until they break. The primary signatures of stem breakage are open canopy and the light wood color at the break of the bole. Except for breakage over a large area caused by an extreme wind event, most stem breakage signatures are difficult to detect on overview surveys. Some stem breakage can be detected, but much is missed because 1) the altitude of the aircraft, 2) exposed wood at break may not be facing the observer, and 3) the damage is scattered. Even when conducting a special aerial survey to map stem breakage, this signature is challenging to detect and map accurately.

Hail Hail damage to conifers often appears similar to defoliator-caused damage. When seen early after the event, the foliage appears thin and looks light in color because much of the bark is exposed. Later, when the remaining damaged foliage fades to red or brown, the signature may be more visible. Hail tends to occur in small concentrated areas distinct enough to indicate the path of the storm. Heavy hail damage can be picked up during an overview survey, but greater accuracy can usually be gained from a special survey.

Defoliating Insects Surveys

Depending on the part of the country, the aerial survey program, and the defoliator being monitored, some defoliator outbreaks are flown as part of overview surveys and some as special surveys. If the defoliator is considered important enough to be mapped, the following paragraphs provide some insights as to things to consider in planning aerial survey flights.

Deciduous Hosts Timing is key to mapping hardwood defoliators. For most defoliators, there is a three-week window when damage will be most apparent. Because the window is critical, regions with a lot of hardwood defoliation require a large cadre of sketchmappers and available aircraft ready to make sketchmapping a priority when conditions allow.

Don't fly too soon. Although feeding may occur over several months, peak damage doesn't occur until late in the feeding period when larvae are larger and consume more foliage. Early damage by insects which feed primarily in the lower crown may not be visible at all from the air.

Don't fly too late. As a rule of thumb, trees will refoliate if over two-thirds of their foliage has been damaged. Refoliation only takes a few weeks. Refoliated areas can be difficult to distinguish from unaffected areas, although the new foliage may be a lighter green than the surrounding foliage. Trees do not refoliate if damaged late in the growing season, but the onset of fall colors will complicate sketchmapping that is running behind schedule, especially in dry years when color change may start early. If defoliators are causing leaves to change color, sketch-map before storms knock affected leaves to the ground.

The sketchmapper should be familiar with local insect conditions prior to flight. Defoliator outbreaks come and go–even gypsy moth outbreaks don't last forever. Last year's predominant damage may have been due to forest tent caterpillar, while this year's may be due to cankerworm: the damage, however, looks the same from the air. In addition to knowing which insects are at what defoliating levels, learn what part of the canopy they prefer, where on the landscape they're likely to occur, and whether they leave yellow, brown, or lacy green leaves, or nothing at all but the midrib. The webbing of some insects may be visible from the air. Ground verification is essential if causal agent accuracy is important.

Rating. Rate the defoliation severity as "low" (less than 50 percent of susceptible foliage in the polygon is defoliated) or "high" (greater than 50 percent defoliation). Tree canopies that would be rated low, generally have a light green color. High (or heavy) damage looks browner as branches, trunks, and even the forest floor become increasingly visible, except in aspen. The sketchmapper should calibrate their eye by observing damaged stands from the air, which the sketchmapper has previously visited on the ground. Lighter defoliation often occurs in a band around heavier defoliation: thus, concentric polygons are often drawn for different severity ratings.

Know what tree species defoliating insects prefer as hosts. Typically, observers will mentally average the level of damage in a polygon, so that a polygon with heavy damage on only some trees will get the same rating as one with little damage on all the trees. The standards, however, expect the sketchmapper to consider only susceptible tree species in assigning damage ratings. This is an easier task for gypsy moth, which will eat everything but tulip poplar foliage and exposed bedrock; other defoliators are more finicky.

If susceptible species occur in a mixed stand and can be identified from the air, consider only damage to the susceptible hosts in making a severity rating decision. Don't average in the intact foliage of non-host trees. If it is not possible to differentiate the host species, additional ground checking will be necessary, but the sketchmapper should make estimates from the air whenever possible.

One example of specific-event surveys is gypsy moth hardwood defoliation surveys in the Lake States. This methodology for sketchmapping gypsy moth defoliation on hardwood forests include; grid flying with two sketchmappers, usually flying flight lines 3 miles apart at an altitude of 2,500 feet above ground level (AGL). If poor visibility exists, they may reduce the spacing of flight lines to 1.5 miles apart. Distance between flight lines has been as great as 6 miles, when there is excellent visibility and near the end of the bio-window, but isn't recommended. The standard map has a scale is

1:100,000 (30 minute by 60 minute), and usually includes USGS map features. Since the topography is very gentle in this area, efforts to include a vegetation layer to help improve accuracy is in the process. Generally, defoliation under 50 percent is considered difficult to detect, so all defoliation greater than 50 percent is rated either moderate or heavy. Both moderate and heavy fall into Forest Health Monitoring (FHM) standard of "heavy."

Coniferous Hosts

Despite the fact that conifers keep their needles throughout the year, timing is also an issue when flying sketch-map surveys in the South and West. The following are descriptions of two insects that cause damage to conifers and their seasonal effects.

Douglas-fir tussock moth. Douglas-fir tussock moth is a foliage-eating insect that defoliates Douglas-fir and some true firs in the interior dry-belt coniferous forests of western United States and Canada (Beckwith 1978). The species is characterized by extreme population fluctuations (Watt 1968). Feeding is so heavy during severe outbreaks that complete tree defoliation can take place within two months. This usually occurs in small scattered patches of trees, with surrounding areas having lesser amounts of defoliation and can result in clumps of tree mortality. This has given the tussock moth a notorious reputation as a tree-killing pest of Douglas-fir and true firs (Wickman 1978).

Early instars feed primarily on new foliage; later instars feed on new and older foliage. Tussock moth larvae are wasteful feeders, destroying much more foliage than they consume. They feed more efficiently as they mature, and become voracious feeders on all the foliage. Therefore, all foliage is considered susceptible foliage when light and heavy defoliation estimates are made from the air. Since much of the heaviest consumption of foliage occurs during the later instars, maximum defoliation usually occurs later in the summer, (e.g., mid-August). This peak signature varies with weather patterns and foliage condition, and can be missed if flown too early in the summer.

Western spruce budworm. Western spruce budworm is a foliage-eating insect that defoliates Douglas-fir, true firs, and spruce in western United States and Canada. First instar larvae overwinter, and begin spring feeding by mining old foliage and then new buds. Once new foliage has developed, later instars feed primarily on new foliage. When populations are at high levels, most or all the new foliage is quickly eliminated, forcing late instars to feed primarily on old foliage. Only new foliage is considered susceptible when light and heavy defoliation estimates are made according to FHM standards.

Large larvae cut or damage as many or more needles than they consume (Blake and Wagner 1983). By the end of the feeding period, the damaged new growth, now webbed together in clumps, turns reddish or reddish brown and is highly visible (Carolin 1959).

Because spruce budworm emerges earlier in the year than Douglas-fir tussock moth, spruce budworm's peak defoliation shows earlier as well (approximately mid-July, depending on weather). Heavy first-or second-year defoliation appears dramatically red, mostly on new foliage. However, spruce budworm defoliation is not as extensive as tussock moth defoliation: severe budworm outbreaks cause widespread damage after multiple years of defoliation, not usually during the first year, whereas heavy Douglas-fir tussock moth attacks can almost totally defoliate its host during the first or second year, appearing like a more extreme four- to six-year-old budworm outbreak.

Bare tops of either defoliator cannot be called "topkill" from the air simply because the tops appear bare. Ground surveys are required to identify and classify anything beyond a general defoliation estimate.

Sketchmapping coniferous defoliators from an aircraft requires concentration and experience. Heavily defoliated areas of dense host type are much easier to detect and record than somewhat lighter defoliation in mixed conifer stands. First, the sketchmapper should ensure that the presence of defoliation is recorded (and, if possible, the causal agent and host), whether the defoliation is light or heavy, and then whether it is continuous or discontinuous. Users of aerial survey defoliation sketch-map data need to understand that estimates made by sketchmappers from fast moving aircraft can be only a very general description of the outbreaks.

Multiple-generation Insects

Event-specific surveys are commonly done for insects that produce multiple generations in a single season, such as multivoltine bark beetles (southern pine beetle and pine engraver beetle). The damage caused by these beetles is often visible within 3 to 6 weeks following attack. Because the southern pine beetle can produce as many as 5 to 9 generations per year in the warmer climates of the southern United States, surveys may be conducted at intervals of as frequent as 4 to 6 weeks, once the first new generations' attacks become visible. Under outbreak conditions, flights are often conducted every two weeks, depending on management objectives (personal communication, Rusty Rhea). Occasionally, during outbreak years, a midwinter detection flight may be useful to locate large overwintering infestations or new spots that were initiated during the previous fall. Single-generation bark beetle damage may mimic multi-generation bark beetle damage in that attacked trees may fade before as well as after winter (Bill Schaupp, personal communication). Aerial videography is sometimes used in addition to, or in place of, sketchmapping in some areas for delineating potential treatment boundaries for southern pine beetle.

Foliage Diseases

Foliage diseases of conifers typically follow an overly wet spring, and the event signature is usually visible the following spring in the form of foliage discoloration. In hardwoods, damage peaks in the same growing season as wet weather conditions occur. If a particular foliage disease is important enough to warrant a special survey, it must be done during peak signature.

Special Forest Management Requests

Special surveys are done as a need arises. Their intensity and methodology, like most aerial surveys, is dependent on time, area and available funding. These surveys are usually done outside the scope of regularly scheduled overview and other special surveys.

Land Management Special requests from various land managers for aerial surveys are not uncommon. Often they are interim surveys for monitoring purposes of specific forest change events. They may request only certain areas to be surveyed or specific change agents, such as Douglas-fir beetle attacks on trees that are fading earlier than normal.

Research Activities One example of special surveys for research would be the survey for the Douglas-fir beetle study being conducted by the USDA Forest Service Pacific Northwest Experiment Station, National Forests and Forest Health Protection and Oregon State University. Study blocks of approximately 20 twenty square miles required exact locations of newly dead Douglas-fir trees. The survey was done in a helicopter and used USGS topographic maps at a scale of 1:24,000 to mark as accurately as possible tree mortality locations and the number of dead trees.

Cumulative Impact Surveys When aerial surveys are not being conducted to map current tree damage or mortality, an "after the fact" aerial survey can be conducted to map a particular change signature. The signature mapped is usually standing dead trees, caused by bark beetles or multiple years of heavy defoliation.

An example of a post-mortality cumulative impact aerial survey would be the special surveys done for mapping whitebark pine mortality in northwest Montana. Whitebark pine grows near the tree line in the subalpine zone, and often grow in clumps or have multiple leaders. Many of the whitebark pine in northwest Montana (and Idaho) died in the 1930s and 1940s as a result of mountain pine beetle and white pine blister rust attack. Even though mortality occurred many years ago, this tree species is often still standing, leaving a bare-tree signature than can be identified from the air and sketchmapped. The information helps those interested in the locations of whitebark pine in the forest, since often there is little forest inventory data at these higher elevation. This survey is also done using maps at a scale of 1:24,000, and can be done with either a helicopter or fixed wing aircraft.

The limitation of cumulative impact aerial surveys is that multiple species of dead trees without foliage or bark can often look very similar, and confidently assigning mortality to a specific agent can be difficult, making ground surveys and field checks necessary.

III. An Operational Aerial Survey Program

There is much more to aerial sketchmapping besides looking for damaged trees from aircraft; a great deal of preliminary work must be done before anyone is sent up in the air to do this type of work. Some of this work includes developing an aviation management plan and an aviation safety awareness program (formal or informal); providing for suitable, safe, cost-effective aircraft; and ensuring the availability of trained, qualified personnel to do the work, including experienced, qualified pilots.

Aviation Management Plan

The purpose of an aviation management plan is to provide all program participants with the appropriate information about the nature and intent of the mission and program. The plan should describe the program, its scope, and purpose; define the personnel involved and their responsibilities; and define the policies, procedures, operations, safety plan, and other pertinent documents that apply to the program. By reading the aviation management plan, anyone unfamiliar with the program should be able to quickly grasp the intent, authority, and extent of the program. The more the program is documented, the more the program can be understood by participants and their supervisors.

According to the USDA Forest Service, the purpose of an aviation management plan is "*to describe aviation management goals, objectives, programs and activities, and to provide strategic direction and operational guidance at each organizational level as appropriate*" (USDA Forest Service Aviation Management Plan, 1995).

The Aviation Management Plan should include:

1. A definition of the aerial survey program so that everyone involved has the opportunity to learn its scope, intent, history, and personnel involved. Explain the survey mission and its customers.
2. A list of the organization's personnel and their responsibilities.
3. Unit policies and procedures for aviation activities. These should be included in the aviation management plan, so that all rules and regulations are documented. This section could also include local or management policies more specific to daily operations. It could also include Federal Aviation Administration (FAA) regulations that may need additional emphasis.
4. A list of aircraft used in the program. A small program may list the specific aircraft to be used by aircraft tail number, while a large program may only specify the type of aircraft acceptable to conduct the aerial surveys.
5. An operations section, both daily and annual, such as aircraft procurement methods, payment processing, flight methods, flight-following procedures, and other expectations.

6. A list of required training for personnel. This can help spell out necessary prerequisites for authorization to participate in the survey program and to order appropriate aircraft.

The Aviation Management Plan should emphasize safety as its first priority. Safety considerations should be incorporated into all aspects of the plan, and outweigh any other objective.

Aviation Safety Awareness Program

The purpose of an aviation safety awareness program is to ensure that all participants understand the importance of conducting an aerial survey program safely. It is the responsibility of management to provide adequate safety awareness training and ongoing emphasis. It is the responsibility of all participants to be aware of all safety implications in an aviation program.

An important prerequisite to conducting aerial surveys is aviation safety training. Employees' safety, health and well being are top priorities to any employer. An effort to ensure a safe aviation program should be made by all involved, no matter the size of the program. Proper training should include a formal aviation safety and management course. An annual preseason training session can help get all participants thinking safety. Aerial observers and program managers would benefit from a refresher course or other training approximately every three years. Usually, all federally sponsored natural resource aviation training is available to state and county cooperators.

Certification of the sketchmapper is appropriate after aviation safety training is completed and adequate aerial survey skills are demonstrated to the program manager. Whatever the process, no one should be sent up in the air to fly aerial survey without appropriate training. The following is a list of safety considerations that should be answered by the participants before and at any point during the survey program:

Twelve Standard Aviation Questions That Shout "Watch Out!"

1. Is the flight necessary?
2. Who is in charge?
3. Are all hazards identified and have you made them known?
4. Should you stop the operation in flight due to change in conditions:

   Communications?
   Weather?
   Confusion?
   Turbulence?
   Personnel (attitudes)?
   Conflicting priorities?

5. Is there a better (simpler, safer) way to do this?
6. Are you driven by an overwhelming sense of urgency?
7. Can you justify your actions?

8. Are there other aircraft in the area?
9. Do you have an escape route?
10. Are any rules being broken?
11. Are communications getting tense?
12. Are you deviating from the assigned operation or flight?

These considerations cross all boundaries and apply to everyone involved in aerial surveys.

Personnel

Sketchmappers

The most critical element in aerial sketchmapping is also the most variable: the sketchmapper. According to Klein et al. (1983):

"Since forest pests and the damage they cause are dynamic and highly variable, the resulting data will also be highly variable. No two sketchmappers will or can be expected to record the same outbreak in exactly the same way. For this reason sketchmapping should be regarded more as an art than an exact science. It is important at the outset that this be understood, not only by conscientious sketchmappers who find that their data may not be in close agreement with their peers or with a subsequent statistically reliable aerial photo survey, but also by the forest manager, who may want to put the information to use. Sketchmapping is highly subjective, and the resulting data can be no more accurate than the competence of the sketchmapper and the conditions under which the data was obtained."

The above passage from a Methods Application Group (now the Forest Health Technology Enterprise Team) publication describes the inconsistent nature of aerial survey data. The quality of aerial survey data is directly related to the qualifications of aerial survey personnel. Sketchmapping is a skill, but it is a skill affected by non-technical factors: if the person performing the survey feels uncomfortable, unhappy, or lacks a good attitude, it will be reflected by the ensuing data. For this reason, it is very important that new sketchmappers meet certain criteria and follow a well defined apprenticeship program before venturing out on their own.

Qualifications The minimum qualification criteria (according to Wear and Buckhorn 1955) for an aerial sketchmapper include the following.

a. A desire to participate in aerial survey activities.

b. An interest in aviation.

c. Good eyesight with normal color vision and depth perception.

d. Ability to endure riding in an aircraft for 3 to 6 hours a day without experiencing the debilitating effects of motion sickness.

e. A background in forestry and the ability to identify tree species in the survey area.

f. A working knowledge of forest insects and diseases.

g. Ability to read maps and the coordination necessary for accurate aerial navigation and sketchmapping.

Training Conducting an aerial survey with a trained, experienced sketchmapper is the first and best way to assure a quality aerial survey. The process is inherently coarse in nature because of the speed and altitude. But without a qualified sketchmapper, the accuracy of the polygon location, size, attributes, and numerical estimates will be gross at best. Although forest health specialists have a variety of training in entomology, pathology, and forestry, sketchmappers will still need sketchmapping experience and training to do quality work.

While the above qualifications suggest that the candidate might be a good sketchmapper, these qualifications must be followed by the necessary training. According to Billings and Ward (1984), "*proficiency at aerial detection must ultimately come from actual experience in the air*" : in other words, there's no substitute for experience.

The four aspects of training to conduct sketchmap surveys safely and efficiently to gather quality data include: aviation safety and management, apprenticeship, annual standardization of methods and protocols, and physics-of-flight knowledge. Currently, there is no comprehensive "how-to-do-aerial-surveys" course, although this type of training would improve the learning curve of trainees and bring additional standardization to different programs.

Aviation Safety and Management. In addition to the apprenticeship process, the trainee should attend formal training offered in aviation safety and management. A variety of classes, at various levels, are offered by the Department of Interior, Office of Aircraft Services (DOI, OAS) and the USDA Forest Service. Specific training modules can be obtained to serve as helpful portions of training packages for most any agency. The USDA Forest Service's Forest Health Protection (FHP) group sponsors a customized one-week course specifically for aerial observers in the late 1990s titled "Natural Resource Aerial Survey Aviation Safety and Management" (AS2M), held at a different location at least once a year.

Apprenticeship. In addition to these basic qualification criteria, a training program should be initiated before the candidate is allowed to work independently. Because there is no opportunity to attend classroom type training on "how to do aerial surveys", traditional training efforts have come in the form of "back-seat apprenticeship training" during aerial surveys. The trainee is often referred to as the "junior observer," who learns from a skilled, competent sketchmapper, the "senior observer," while flying. At first, the junior observer concentrates only on tracking the flight path of the aircraft on the map. After becoming comfortable with tracking, the junior observer learns the different forest change signatures, polygon delineation, and then tree count and damage severity estimations. Depending upon the trainee's aptitude and intensity of flying, proficiency training can take from a few weeks to a few seasons.

Flying aerial survey is a demanding and humbling experience every day, even for the seasoned senior observer. Therefore, it is important to provide the junior observer with as much training as possible.

Standardization of Methods. A sketchmapper is always better at the end of the season than the start. According to Wear and Buckthorn (1955): "Several hours of reorientation are required by experienced observers after a break of 5 or 6 months." Reorientation is best accomplished with a short "preseason warm-up" or a "calibration and conformity" session conducted just prior to the start of the regular survey season.

This preseason exercise takes three days and involves observers who work within a similar geographical region or conduct surveys using a similar method. Day 1 is spent discussing common issues on aviation safety and management, new forest change event occurrences (such as new insect outbreaks), standardized sketchmapping techniques, and just viewing the events in a similar way. Slides or photographs of representative tree mortality or other damage are commonly viewed by the group. On Day 2, the group is split into teams of two observers per aircraft. Everyone sketch maps the same predetermined survey area with known activity to be detected and recorded. Once back on the ground all the sketchmappers share their final maps with each other and discuss the similarities and differences among various sketch maps. This helps each sketchmapper see how others capture the same events and helps each sketchmapper to "get a feel" for their personal techniques and ability to detect and record damage.

Without a 100% ground-truthing of the survey area, little can be done at this point to evaluate the accuracy of each map. So, Day 3 involves driving out to the survey area and ground-truthing affected areas that were sketchmapped. This warm-up session has proven to be a good way to "tune-up" before the actual flying begins. Without this session, at least some tune-up flying is recommended. It is recommended that the survey begin in an area that isn't extremely busy with signatures to map or of lower priority.

Physics-of-Flight Training. Aerial observers do not need to be airplane pilots, but they should be familiar with the functions and performance of the aircraft in which they fly. A "Pinch Hitters" or "Emergency Techniques for Non-Pilots" class is offered by many flight schools and some government agencies. This class allows the student to become more familiar with the aircraft and trains the student to successfully land the aircraft in the event the pilot becomes incapacitated. This is usually accomplished through a short ground school, plus actual flight time practicing the many elements of maintaining flight and landing the airplane. This training also provides the student with an improved understanding of the pilots duties and responsibilities and helps the student to be a better cockpit team player.

Aerial Survey Pilots

The pilot is a member of the survey crew and is hired or assigned to do a job for the observer. It is essential to clearly communicate your needs to the survey pilot.

It's a good day of flying when an observer has a well-qualified pilot who works as a team player to position the aircraft at the appropriate altitude, speed, and location to give the observer the best view. Depending on the program's aircraft procurement process, this can either be a regular practice or an ongoing challenge. (Remember that, when renting or leasing an airplane, you are also renting a pilot.) A good pilot can contribute a great deal to the quality of the survey or reduce the quality, effectiveness, and efficiency of the survey. The returning well-seasoned pilot is always a welcome sight at the airport.

There are many varieties of aerial surveys and there are many varieties of pilots. The FAA, the USDA Forest Service, the DOI Office of Aircraft Services, and state aviation programs have a variety of requirements for pilot qualifications. This guide is not intended to spell out all the various governmental requirements, but rather point out some of the important qualities of a good survey pilot.

Some of these important pilot qualities the observer has little or no control over, while some can be strengthened by good pilot briefings and communication.

A good pilot:

- Is motivated to perform at a high level.
- Is a team player who is service oriented.
- Maintains a positive working attitude.
- Is professional in behavior and piloting.
- Has a sense of humor.
- Understands the mission methods and goals.
- Has a sincere interest in doing the job well.
- Has an honest concern for safety.
- Checks weather, nearby airports for fuel, Notices to Airmen (NOTAMs) and other pertinent information prior to flying survey.

Flight-Following Personnel

Along with the personnel flying the aerial survey, the survey team should include someone on the ground responsible for "flight following": that is, monitoring the location of the aircraft through regular radio contact. The flight follower maintains radio contact with the flight crew in case of emergency or need to pass on other information. This person must be aware of the intended survey area, flight times, expected landing sites, aircraft type and number, and the names of the flight crew. Often, flight-following responsibilities are a part of the normal duties of agency dispatch centers.

In flight-following, the pilot or navigator calls in to the dispatch center at 15- to 30-minute intervals–depending on the agency, geographical area, and flight methods. This information is then noted by the designated flight-follower. If a dispatch center is not available, some other office or person with a suitable radio should be utilized as the flight crew's ground flight-following radio operator. It is important for the flight crew to be familiar with the necessary radio frequencies, repeaters, and tone guards associated with agency radio use.

Aircraft

Having the right tool for the job also applies to aerial surveys. Having the right aircraft is critical to the success of the survey.

Aircraft specifications can vary depending on the

- terrain,
- number of observers,
- flying altitude,
- appropriate flight speed,
- expected temperature,
- type of aerial survey,
- expected accuracy levels,
- size of survey area,
- ferry distance to survey area,
- flight pattern,
- performance capabilities,
- need for instrument flying, and
- visibility from aircraft.

Some common aircraft procurement challenges can be:

- budget constraints,
- lack of available aircraft in the general area,
- competion for same aircraft by other units,
- lack of a procurement process,
- lack of a common understanding of aircraft needs, and
- lack of awareness of aircraft types available or suitable.

This guide is not intended to provide the reader with complete information on which aircraft to select, but can help towards understanding "appropriateness" in aircraft selection.

High-wing Versus Low-wing

The high-wing airplane is generally used for most aerial surveys. It provides good visibility for observers because the wing is not in the way of the ground, except on steep turns.

Horsepower

With increased horsepower comes increased costs. A mission should not be flown with an underpowered airplane. Attempting to be cost-effective by giving up aircraft performance may not be prudent or safe. Cost-effectiveness can be accomplished by such efforts as; efficiency in the air (appropriate flight patterns, flight speed, quality sketchmappers), sound procurement methods, and reduced ferry distances.

Fixed-wing Versus Helicopter

The hourly cost of a helicopter is much higher than the cost of a fixed-wing aircraft. Helicopters have some advantages over fixed-wing aircraft, such as decreased landing zone size, hover capabilities, very slow flying speeds, and the ability to make quick altitude changes. If these attributes are not important to the survey, then there's little justification for the added expense. If the survey area is relatively small, the map scale is relatively large and data accuracy is of utmost importance, then a helicopter may be the right tool for the job. But generally, the right fixed-wing aircraft can provide an adequate platform for surveys.

Single- Versus Multi-engine Aircraft

For light loads and only VFR (Visual Flight Rules), a high-performance single-engine airplane will generally do the job. But when there is a need for IFR (Instrument Flight Rules) or heavy loads, the additional costs of a multi-engine airplane may be warranted.

For further details on the characteristics of various types and models of aircraft suitable for aerial surveys, see the section "Aerial Survey Planning," subsection "Aircraft."

Communications

Every aerial survey program is different when it comes to customers, organization, and cooperators. Communicating the intent of the aerial survey program and its goals consolidates the program's intent, efforts, and end-product. Communication can occur at many different program stages and administrative levels. Some of them include:

Preseason Notification

Prior to the start of an aerial survey season talking to the land managers, flight-following dispatch cooperators, and other involved and interested parties help orient the team as to what to expect during that flying season. This may be little more than a phone call or a proposed flight schedule sent through the mail. Then, all flight-related personnel will know you're coming, even if your schedule changes due to weather, etc.

Preflight Briefings

The day before–and even, if necessary, the day of the flight–all personnel involved should be brought up to date with details of the mission . Flight-following dispatchers need to know, at a minimum, the aircraft tail number, number of souls on board, and areas to be surveyed. Even if you don't have dispatchers to be contacted, the pilot would need to submit a flight plan with the FAA. Any experienced sketchmapper understands the importance of letting people know where they will be flying that day.

Preflight crew briefings should include the following:

- The observer in charge or "chief of party" for the flight should give two briefings before each flight.

    1. Brief the pilot on: the area to be flown using a map or good directions, explain the direction and distance from the airport to the starting point, give estimated flight time, other airports where landings may occur, type of flying to be done and any other pertinent information relative to that flight.

    2. Brief the other passengers on: your intentions for the flight, flight time, and areas to be flown, and remind them that any passenger has the right to request a flight to be terminated if they are uncomfortable or unsure about safety issues.

- The pilot should give a preflight briefing to all passengers, explaining safety equipment, door operations, emergency operations, seat belt operations, and any other particulars relative to the aircraft and flight (see Figure 1).

Figure 1: Flight crew briefing.

In-flight Communications

Crew Communication In-flight communication among crew members (regarding altitude, flight lines, impending cloud cover, etc.) is essential to the efficiency and effectiveness of the mission. The more the observer communicates to the pilot their intentions and expectations, the better the pilot can perform. Positive reinforcement works well in flight. All passengers, especially the crew, should use headsets and an active intercom system. Trying to communicate over the roar of the engine is not effective, nor is it healthy for passengers' hearing. Portable intercom systems are available, but it is best to have them built into the aircraft.

Radio Communications Poor radio communications with control towers, other aircraft, and dispatchers can be frustrating and make the flight unsafe. The pilot should ensure that communication by radio to the ground and other aircraft is unhindered. The observers should ensure that their communication with flight-following dispatchers and other aircraft is effective. Most pilots communicate with a VHF radio, using frequencies specifically designed for communication with control towers and other aircraft . A good system for observers would be having a separate FM radio with frequencies for communicating with dispatch centers.

Post-flight Communications

A post flight discussion can further improve the next mission. Immediately after a flight, especially if the pilot is new to either the mission or the observer, it is a good idea to talk about how the mission went, identifying any problems encountered, and discussing possible solutions. If there is more than one observer on the flight, they should compare maps and discuss conditions both inside and on the ground.

Post-season Communications

A post-season communication effort is also recommended. Bringing together as many of the season's program participants as possible creates an opportunity for analysis of methods and results, commendations, and procedural modifications for the next year. Depending on the program organization, the post-season meeting may include: observers, program managers, pilots, aircraft vendors, contracting officers, and dispatchers. A separate post-season meeting could also be called solely for sketchmappers and program managers as a time to talk about the missions and season while things are still relatively fresh in peoples' minds.

Schedules

A small aerial survey program may have only a few flights for the year, all occurring in one week; a somewhat larger program may have flights that last two or three weeks. Large programs may have multiple daily flights lasting all summer; and some programs will have flights throughout the summer, though the exact dates may be unknown due to unpredictable biological windows. No matter the size of the program, an attempt to provide a schedule to all involved is a good idea.

One object of communication is to avoid surprises for any of the parties involved in a cooperative effort. A honest attempt at scheduling can help this from happening. While few aerial survey schedules actually happen exactly as written due to weather, maintenance, etc., schedules provide a starting point for further coordination.

IV. Aerial Survey Planning

Aerial survey planning includes many elements. Map selection, mission planning, selection of flight patterns, selection of aircraft, and identification of the flight window all involve many steps. Good planning can make the difference between a smooth operation and a flying nightmare–or at least a flying circus. Cost-effective and efficient use of the aircraft and personnel are the result of a sound survey plan.

Map Selection

Detailed maps for flight planning and sketchmapping are key to the accuracy of an aerial survey. Aerial surveys in different parts of the country may require different map types for sketchmapping. Different surveys may require different scales depending on the size of the area to be covered and amount of detail needed. For example, flying mountainous terrain requires different map features than flying flat terrain.

Map Orientation

All aerial survey maps need to be referenced to a known latitude and longitude or other universal coordinate system. This allows for the sketch-map to be digitized to a computer file format and combined with other digital maps, if necessary.

Map Scale

When talking about relative size of scale and maps, the larger the number, the smaller the scale and the smaller the features; conversely, the smaller the number, the larger the scale and the larger the features. (Think of the "real world" at a 1:1 scale: small number, LARGE features.) So features on a 1:24,000 map will be larger than the same features on a 1:100,000 map.

Most all aerial surveys use map scales from 1:24,000 to 1:250,000. For overview surveys, Forest Health Monitoring recommends a scale of 1:100,000 or larger. Special aerial surveys often use scales 1:24,000 (USGS $7^1/_2$-minute topographic quadrangle), 1:40,000, and to 1:50,000. Much of the country has coverage available on the USGS topographic $7^1/_2$-minute maps. Also available are the USGS 15-minute (1:62,500 scale) topographic quadrangle maps. Each aerial survey program experiences the challenges of finding map bases with the appropriate scale and features for navigation and sketchmapping.

The following are some map scales and their equivalents.

Fractional Scale	Feet per Inch	Inches per Mile	Miles per Inch	Acres per Inch^2
1: 24,000	2000.000	2.6400	0.379	91.827
1: 63,360	5280.000	1.0000	1.000	640.000
1: 100,000	8333.333	0.6336	1.578	1594.225
1: 126,720	10560.000	0.5000	2.000	2560.000
1: 250,000	20833.333	0.2530	3.946	9963.907

Larger areas and overview surveys require a map base suitable for covering large areas of land. This means using a smaller map scale, so the physical map size is manageable in the cockpit of the airplane. When flying overview aerial surveys in Alaska, surveyors consider the appropriate map scale to be 1:250,000 because of the huge expanse of land that must be covered each day.

It is always best to have the proper map on hand rather than "making do" with a map at a different scale. Particularly beware of reducing a large-scale topographic map base down to a smaller scale on a copy machine, because the larger land features, when reduced, may become unreadable. For example, steep terrain is depicted as topographic contour lines drawn close together: when reduced, the lines run together into dark areas, becoming indistinguishable, and what was great detail becomes difficult to read.

Map Features

Sketchmapping is a spatial interpolation method of an observed signature pattern drawn onto a map. Only with accurate, adequate, and appropriate map features can a sketchmapper accurately depict the signature location on the map.

Map features for sketchmapping should lend themselves to what is visible from the air. Often, a good aerial survey map is not a good map for driving in the forest or ground-truthing. Each activity needs its own type of map features. With fewer features, the sketchmappers' points and polygons come less and less accurate for identifying damage on the ground. On the other hand, more features than necessary are not always better for an aerial sketchmapper because the map can be too difficult to read and important features can be difficult to distinguish.

A good aerial survey map should have features that are suitable for flying aerial survey for the specific region. Different localities require different map features, so the appropriate scale may vary across an area. Good map features provide the sketchmapper with information to continually keep track of the aircraft's position, as well as provide enough information to accurately draw the observed damage onto the map. In mountainous country, the primary features are drainage patterns, topographic contour lines, the grass/tree mosaic, and mountaintops. In flat terrain, the primary features are vegetation patterns, water, and man-made objects such as roads and structures.

Map Trends

Availability is often the determining factor for maps used on aerial surveys. Typically, there is a wide gap between the ideal flight map and the map that is readily available. Over the years, the sketchmapper has been making due with what is easily procured. Developing map bases, especially beyond the boundaries of major state and federal land owners, has been cost-prohibitive to most aerial survey programs.

For much of the past forty years in the West, overview aerial surveys were conducted using National Forest maps at a 1:126,720 (one-half inch to the mile) scale. This map base had excellent drainage information, covered the entire Forest and some of the forested lands adjacent to National Forest land, but had no topography or vegetation information. With regional needs for all forested land to be covered and additional map features now available, the old National Forest maps are no longer adequate.

Now, other map bases are being used by State and Forest Service aerial survey programs. Much of the western United States conducts overview surveys using USGS 1:100,000-scale metric topographic map. It covers 30 minutes of latitude by 60 minutes of longitude, and depicts contour elevations in meters, highways, roads, man-made features, water features, woodland areas, and geographic names.

In the past, the sketchmapper was provided a pre-printed, non-customized map. In the future, the sketchmapper will be provided with a customized map fitting a particular the geographical area, with personal preferences, utilizing satellite imagery and digital cartographic information features. With the advent of digital map bases and geographic information systems (GIS), the ultimate map base will be customized for the needs of each sketchmapper. Employing digital map bases, global positioning system (GPS), powerful personal computers, high resolution monitors and specialized software, sketchmapping will have the capability to be done on the computer monitor, rather than on a paper map.

Mission Planning

Mission planning involves identifying of the survey area, preparing maps, determining flight routes, and coordinating with ground personnel.

Survey Area Identification

Annual conditions surveys can make use of the previous year's planning. New survey areas are identified in conjunction with entomologists, pathologists, and foresters. (At times, the entomologist, pathologist, or forester may also be the survey planner and the sketchmapper, considerably simplifying communications.) The area to be surveyed is reviewed by looking at the map base. Emphasis items at this point include terrain, ferry distance, airports with fuel, possible alternative airports for breaks or emergencies, estimated time to fly the area, known outbreak areas, areas of special concern because of other aircraft traffic, and other safety concerns.

Map Preparation

Once all the necessary maps are available, several chores need to be done in preparation for sketchmapping in the airplane.

Splicing Adjoining Maps Occasionally, an observer will have the luxury of needing only one map for a planned survey area. Usually, the observer will have to work on several maps in sketching the survey area; for ease of handling, it is easier to combine maps of adjoining areas. When two or more maps are spliced, they should be put together carefully, with as little seam as possible. One method is to cut away the white margin where one map abuts the next map, match up common points on the image area, and tape the two maps together. The best way to do this is to lay the maps on a light table, upside-down, for ease of image viewing and tape the maps together with clear tape along the edges along the back side of the maps. Use enough tape to ensure the maps are seamless, supported, and have no wrinkles. Maps should not be taped on the front side because most pencils and pens that sketchmappers use won't mark well on the surface of the clear tape (anything that actually leaves a mark tends to smear afterwards).

Pre-flight Map Marking Since most maps cover more than the survey area, the survey maps should have the proposed survey area (often called a reporting area) delineated with a bold pen. Along with the survey area, especially with grid flying, many observers elect to draw the proposed flight lines on the flight map for orientation during the flight. This supports, not only the sketchmapping, but also in communicating with flight-following dispatchers. Other items that have been highlighted on flight maps include past damage areas, emergency airstrips, known military training routes, high points, ground study plots, hazards (such as power lines spanning canyons), and other areas of special interest. Because of weather and other possible reasons to change flight plans, some sketchmappers choose not to draw flight lines on their map prior to flight.

Communications for the Day

Mission planning also includes establishing details for communications between the flight crew and flight-following dispatchers. National Forests may use specific radio frequencies for this communication, use specific frequencies on different parts of the Forest, or use radio repeaters with specific frequencies and tones. These details need to be established, written down, and communicated to all affected parties prior to the actual flight. It is also good to designate specific phone numbers as alternatives in case radio communications fail.

Other information that should be kept on hand includes: the intended means of communication with ground personnel in the intended survey area; flight times; expected landing sites; aircraft number, type, and description; and flight crew names.

Flight Patterns

Flight patterns are designed to provide systematic coverage of the survey area with a favorable view of the terrain to the sketchmapper. A particular flight pattern is determined based on budget, expected level of accuracy, topography, damage signature, visibility, time allotment, and sketchmapper experience and working preferences.

The two primary types of aerial survey flight patterns are the "contour" (or "drainage") and the "grid" (or "parallel") patterns. The characteristics and variants of each are described below.

Throughout the following descriptions, working (that is: flying) methods are slightly different for aerial sketchmapping than for flying in general: specifically, in the turning direction. (For the sake of simplicity, throughout this explanation of flight patterns, the assumption will be that the principal observer is in the right front seat and the pilot is in the left front seat.) Usually, a pilot prefers to make left-hand turns, as this affords him/her with an unhindered view of the ground to the left. In sketchmapping, this preference is given to the sketchmapper in the right-hand seat, so the pilot must make (wherever possible) right-hand turns. No matter the type of pattern, the usual intent is to be systematic so that the entire area to be surveyed is covered. (If a quick view is all that is warranted, then such a systematic approach is not necessary.) No matter what type of flight pattern is used, the observers must always know the exact location of the aircraft at all times: "*If you don't know where you are, you can't sketchmap.*"

Contour (or Drainage) Flight Patterns

Contour flying follows well-defined aspects of the terrain: river drainages or ridgelines. The contour flight pattern is flown when enough topographical relief can be seen from the air to help guide the observer over the survey area. In poorly defined terrain, this method is not recommended.

The contours themselves provide the route of the aircraft. The observer directs the pilot up and down each drainage until the entire survey area is covered. The pilot flies each distinct contour in a clockwise pattern so that the drainage bottom is always on the observer's right. The airplane flies up the main drainage on the left side, turning right at the head of the drainage to fly down the drainage, keeping the bottom of the drainage, again, on the right. If there is a secondary drainage, the airplane turns right to fly the secondary drainage in the same way before completing the survey of the main drainage; tertiary drainages are completed in the same way from the secondary drainages.

During contour flying, it is important to keep the aircraft at about the same altitude so that the airplane's engine stays at about the same 'rpm'. By avoiding a lot of climbing and descending, the aircraft engine won't get overworked. As a result of maintaining a steady altitude, the airplane's altitude above ground level (AGL) will then vary greatly between the mouth of a drainage and the head of the same drainage. The AGL variation is a compromise in viewing quality and safety. It's not uncommon, when flying in the Rocky Mountains, to be as high as 3,000 feet AGL at the mouth of a drainage and as low as 500 feet AGL (the mimimum) at its head. (Obviously, the flying altitude must be worked out from the flight maps ahead of time.)

With the ability to constantly view the drainage pattern below, the observer can track the airplane's location easily on the map. When another drainage flows into the current drainage, it should be anticipated and visible on both the ground and the map.

Contour flying in mountainous terrain requires both an experienced pilot and an experienced observer who can work together well. Both people should know the status of the wind, including direction, approximate speed, and its expected behavior across the ridges, as these will affect the altitude and flight lines actually flown. Even on a clear day, winds aloft can be very strong, challenging, and at times, dangerous. Often, it is necessary to fly at an altitude that is higher and less desirable for viewing, but safer.

Some of the advantages of flying contour are:

- The crew doesn't have to concern themselves with staying on a plotted flight line (see "parallel-line flying"). As long as the observer can see the area to be sketchmapped, they are "on line."
- If an observer cannot see all the way up a minor drainage, the airplane can turn right and fly up the minor drainage, just as any other tertiary drainage. If the observer can see up the minor drainage and sketchmap based on that view, the airplane can continue on its current route without deviation.
- The observer has the opportunity to look ahead at the area to be surveyed and can adjust the flight route to fit the intensity of sketchmapping.
- This pattern has a great deal of flexibility for the observer and can be varied, depending on damage activity and survey intensity.

Within contour flying, there are two types of flight patterns, drainage flying and ridge flying. While both follow drainages, ridge flying stays over the ridges between drainages and drainage flying stays between the ridge and the bottom of the drainage.

The two types of contour flying each have their own advantages and disadvantages, the decision on which pattern to use is usually dependent on the observer's flying experience and, occasionally, the pilot's survey experience.

Drainage Contour Flying

In drainage contour flying, the right-hand turn flight pattern basically follows the overall drainage system in a counter-clockwise direction and each drainage within it in a clockwise direction. The airplane flies up each drainage from its mouth to its head between the ridge and the drainage bottom, but at an altitude higher than the ridgeline. The observer's area of view is from the bottom of the drainage (the riverbed or streambed), below, to the ridge on the opposite side of the drainage. The airplane flies up the drainage from its mouth to its head, turns around (a right-hand turn), and goes back down the same drainage, viewing the opposite side of the drainage (the side the airplane just came up). At the mouth of the drainage just flown, the airplane turns right onto the next drainage to repeat the flight pattern. See Figures 2 and 3 for representations of this pattern.

As the observer looks out to the right, the pilot is looks ahead and to the left to parallel the ridge and to find the ridge at the head or mouth of the present drainage. The airplane is never flown low in the drainage, especially going up the drainage: one reason is that, if there were a mechanical problem or loss of power, the airplane would not have sufficient altitude to make a turn within the drainage and still fly out; whereas, if flying above the drainage, there would be sufficient altitude to turn and fly out of the drainage to lower ground.

The angle of the turn at the head of the drainage depends on the size of the drainage head. In a narrow head, the turn is usually between 30 degrees and 45 degrees of bank. Again, the altitude above ground level at the turn is dependent on terrain and winds. Strong winds coming across a ridge (creating a rotor effect) on the leeward side can cause a downdraft much like a ocean wave surf breaking: the airplane should be above this wind-wave when drainage flying.

This method provides a good view of the trees for sketchmapping because the slope opposite the airplane is facing the observer. Some would consider this pattern a little less cost-effective than others because the airplane crosses its own flight path at the mouth of each drainage in order to continue up the previous drainage, creating some (albeit slight) overlap.

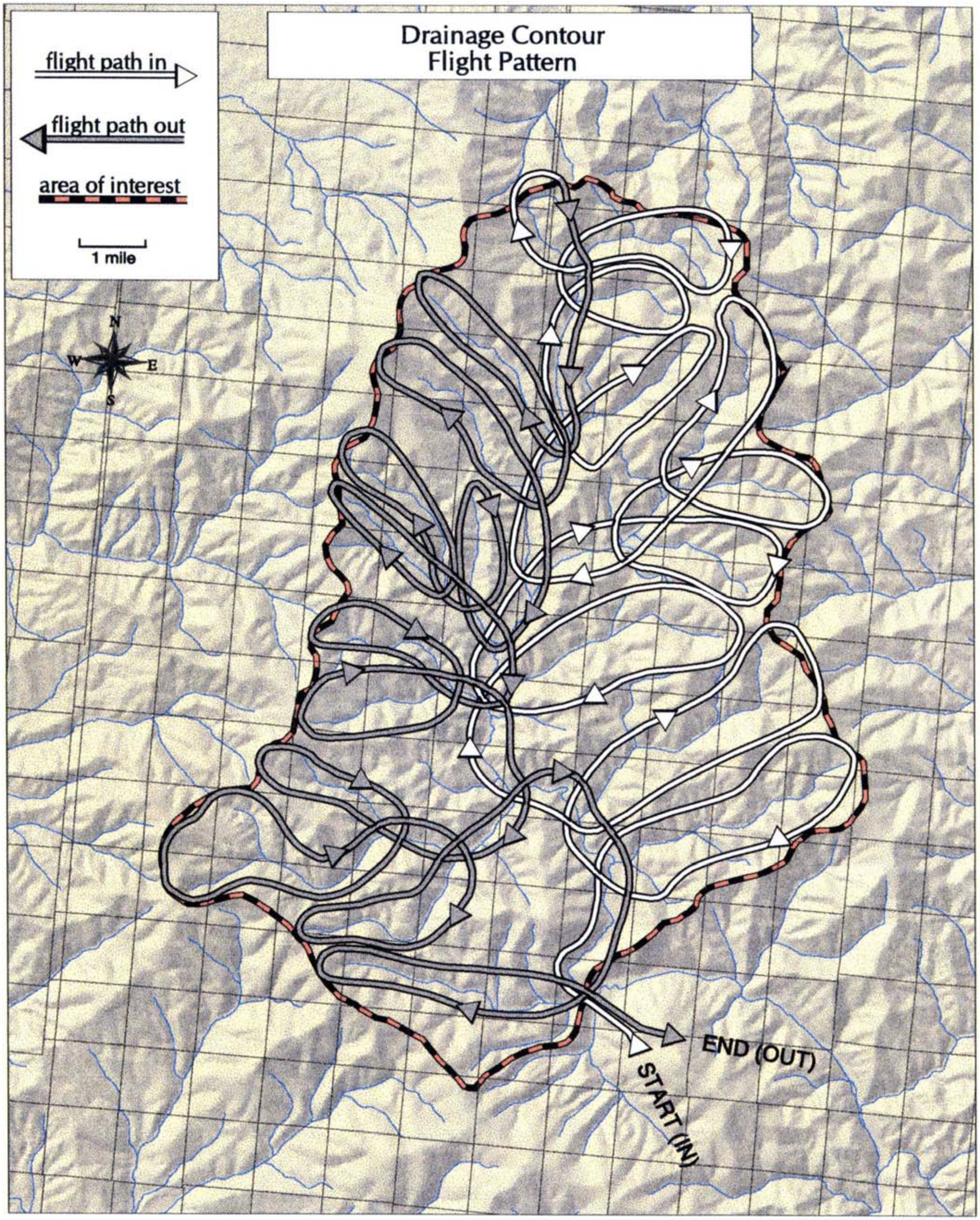

Figure 2: Drainage contour flight pattern.

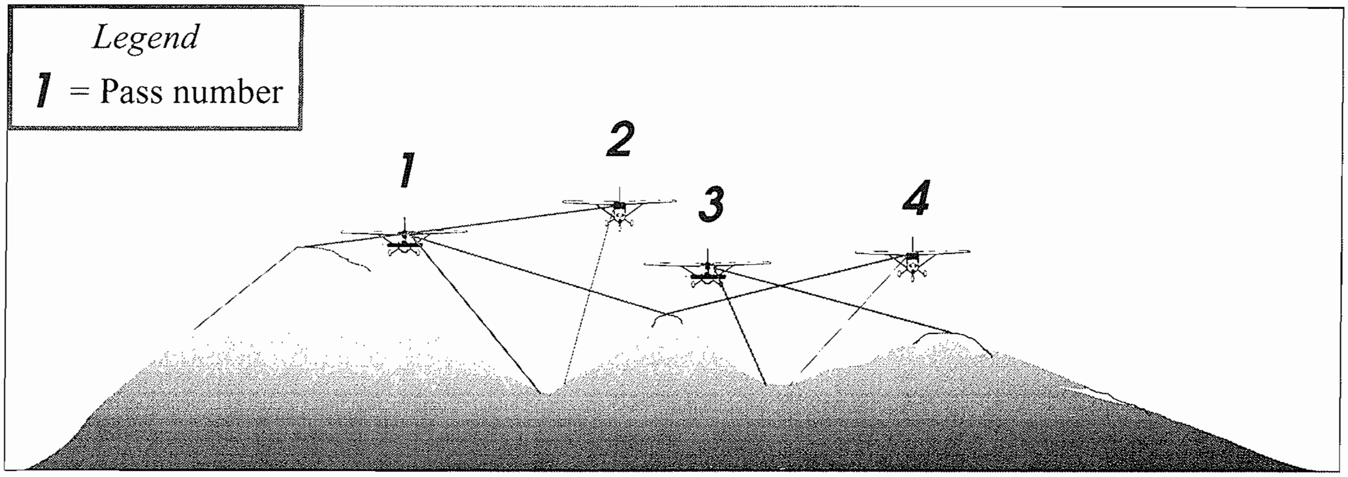

Figure 3: Contour drainage flight pattern, single-observer view responsibility.

Ridge Contour Flying

Ridge contour flying follows the general drainage system, but in a clockwise manner, and still using right-hand turns, though in a different manner. In ridge contour flying, the airplane follows the ridgeline between drainages in both directions while the observer sketchmaps, first, one drainage and then the other.

At the beginning of the survey, the airplane flies up the left-hand ridge of the first secondary or tertiary drainage on the left; the observer's viewing area is on the near slope to the right, from the ridge beneath the airplane to the drainage bottom. At the head of the drainage, the airplane makes a right turn to fly down the opposite ridge; the observer's view is from the ridge down to the same drainage bottom that the airplane just came up.

Up to this point, the flying pattern for ridge flying seems much the same as for drainage contour flying. But upon reaching the mouth of each drainage, the airplane does not go on to another ridge: instead, the airplane makes a 180-degree turn and flies back up the same ridge it has just gone down so that the observer can look from the same ridge down to the next drainage on the right, clockwise around the survey area. The 180-degree turn is done out over the mouth of the drainage, with the greatest AGL, which provides the greatest margin of safety and ease in tracking. At the head of the drainage, the airplane again makes a right turn to fly down the next ridge, and the pattern repeats itself until all ridges in the survey area have been flown. Figure 4 shows the flight pattern.

The view looks down at the trees as the terrain drops away. As the name implies, the airplane flies above the ridges between adjacent drainage bottoms. (If there are no trees on the ridge and flying conditions allow, the observer may have the pilot fly the airplane to the right of the ridge to see the slope below in more detail.) Figure 5 illustrates the view of the observer relative to the airplane and the terrain.

The 180-degree turn is usually done at a 45- to 55-degree bank. The FAA requires the crew to wear parachutes for turns of 60 degrees or more because such turns are considered aerobatic. Whether such turns are required will depend on terrain, pilot experience and familiarity with the terrain will be key to such decisions. The 180-degree turn is not recommended at a low AGL.

Ridge flying takes somewhat less flight time than drainage flying to cover the same area; but for some observers, the steep, 180-degree turn–causing two gravity ("G") forces on one's body–increases fatigue.

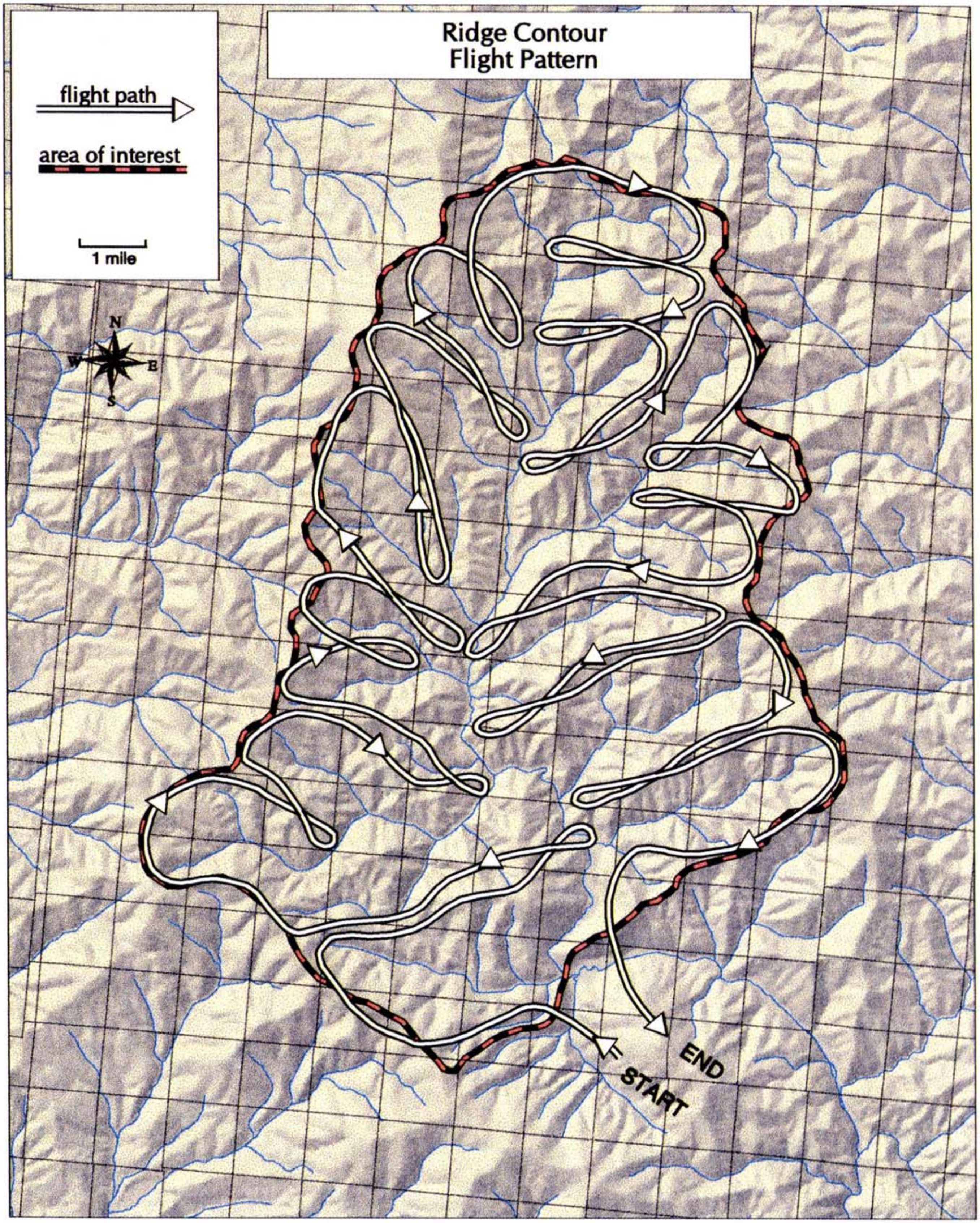

Figure 4: Ridge contour flight pattern.

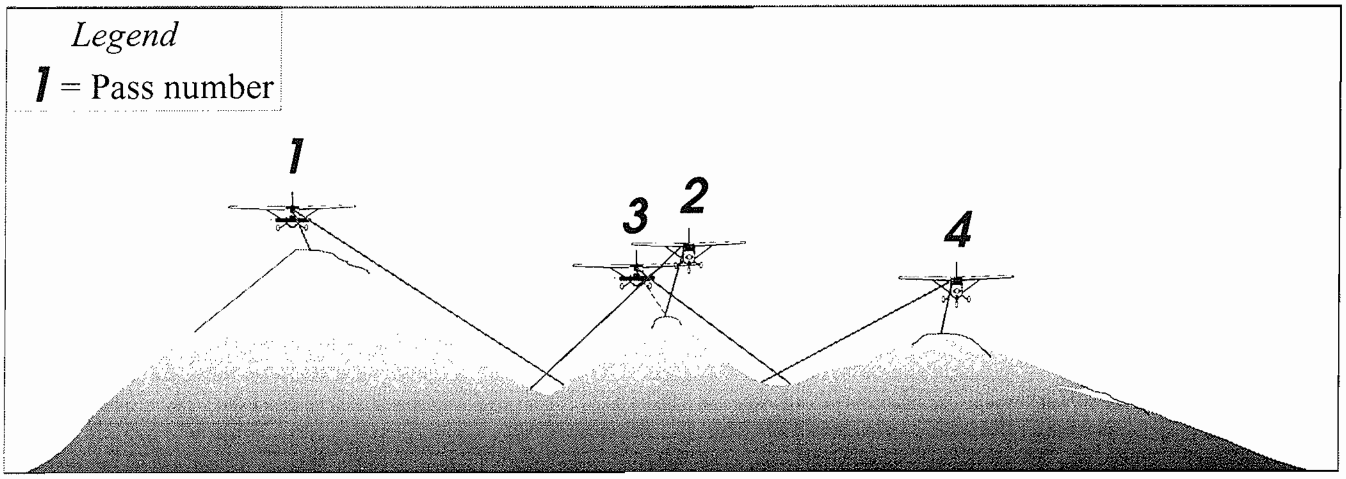

Figure 5: Ridge contour flight pattern, single-observer view responsibility.

Grid or Parallel-line Flying

Grid or parallel-line flight patterns are usually flown straight in cardinal directions in a back-and-forth pattern. The parallel-line flight pattern is generally flown in flat, poorly defined terrain, such as that in the southeast United States, or in mountainous terrain where only cursory information is desired (Klein et al. 1983) to help maintain a systematic coverage of the area. The distance between the flight lines varies with type of survey, damage intensity and signature, visibility, survey resolution, budget, time allotment, and sketch-mapper ability.

Usually, the greater the distance between flight lines, the greater the AGL because the observer needs to be higher to see farther. The more closely spaced the flight lines, the better the visibility and, therefore, the greater the accuracy. One-mile flight lines are extremely close for an airplane aerial survey, while six mile flight lines are extremely far apart for most aerial surveys. The more mountainous the terrain and the further the distance between flight lines, the less detailed the sketch-map information will be. Flying long lines is more efficient than flying short lines because there is less turning involved.

The ongoing challenge of parallel line flying is keeping the airplane on the correct heading and maintaining the predetermined flight line distance, more commonly called "staying on line." In the West, fence lines and different ownership forest cuttings along section lines can provide helpful visual references when flying lines in increments of miles.

Much effort can be spent on staying on line when the pilot relies on the principal observer for direction and guidance. The observer usually has to rely on land features ahead to point the pilot in the correct direction. Because of winds aloft, there is more to flying a straight course than just following a compass heading. The airplane can be flying the correct heading, but due to crosswinds, it can be blown off course. Conversely, the airplane could be on course, but the airplane is crabbed or turned to allow for the wind and it would appear to the crew that the airplane is heading off course.

There are two navigational aids for maintaining the correct course in the airplane; the LORAN-C, a land-based system operating on a low-AM radio frequency, and the global postioning system (GPS), a satellite-based system. The older LORAN-C has been available since World War II, and has been made obsolete by GPS. LORAN-C is not as accurate as GPS, but still helps the pilot to see if the aircraft varies from the desired latitude or longitude position displayed on the display panel.

Current GPS receivers have a number of features. Predetermined flight lines can be programmed into the GPS receiver in advance for comparison to existing position, or even programmed while in flight. GPS is a must in terrain with few land features and little relief. It provides the pilot with precise accuracy and gives the principal observer more time for reconnaissance and mapping.

Most aerial surveys do not need corrected GPS signal because of the scale at which the work is done, so the average GPS will work quite well to help keep the airplane on line.

Two-observer Flying

The parallel line flight pattern is usually the most cost-effective flight pattern because it is easily adaptable for two sketchmappers on the same flight. The principal observer usually sits in the right-hand front seat, directs the pilot, and is responsible for surveying on the right-hand side . The second observer sits in the left-hand rear seat and is responsible for the left-hand side of the airplane. The first observer is commonly responsible for terrain under the airplane because of better visibility downward from the front seats.

With parallel line patterns, 90-degree right turns are made at the end of each flight line, so the observer on the inside of the turn can continue to track the airplane's position and sketch-map along the airplane's route (see Figure 6). Again, it depends on the intent of the survey as to how effective this pattern will be to help maintain a systematic coverage of the area.

The first flight line is usually on the edge of the survey area. For the sake of this example, the first flight line is on the left-hand side of the area. The left-hand observer sketches any damage in the terrain between the airplane and the left-hand side of the survey area while the right-hand observer sketches any damage in the terrain to the right, halfway to the next flight line.

At the end of the first flight line, the airplane makes a 90-degree turn to the right, flies the gap distance decided between flight lines (3 or 4 miles), then turns right again, 90 degrees, and the second flight line is flown parallel to the first flight line, but in the opposite direction. The right-hand observer sketches any damage remaining between the first two flight lines (1.5 to 2 miles), while the left-hand observer sketches any damage halfway to the next flight line to the left. At the end of the second flight line, a 90-degree turn is made to the left, the flight line gap distance is covered, and then another 90-degree turn is made to the left and the third flight line begins (see Figure 7).

This method provides each sketchmapper with two looks across the flight line gap between flight lines: once on the way up and once on the way back. When the area is completed, each sketchmapper will have been responsible for alternate swaths across the entire flight area. Nice, efficient 90-degree turns are recommended to reduce the turning time and reduce the amount of time one observer can see nothing but sky.

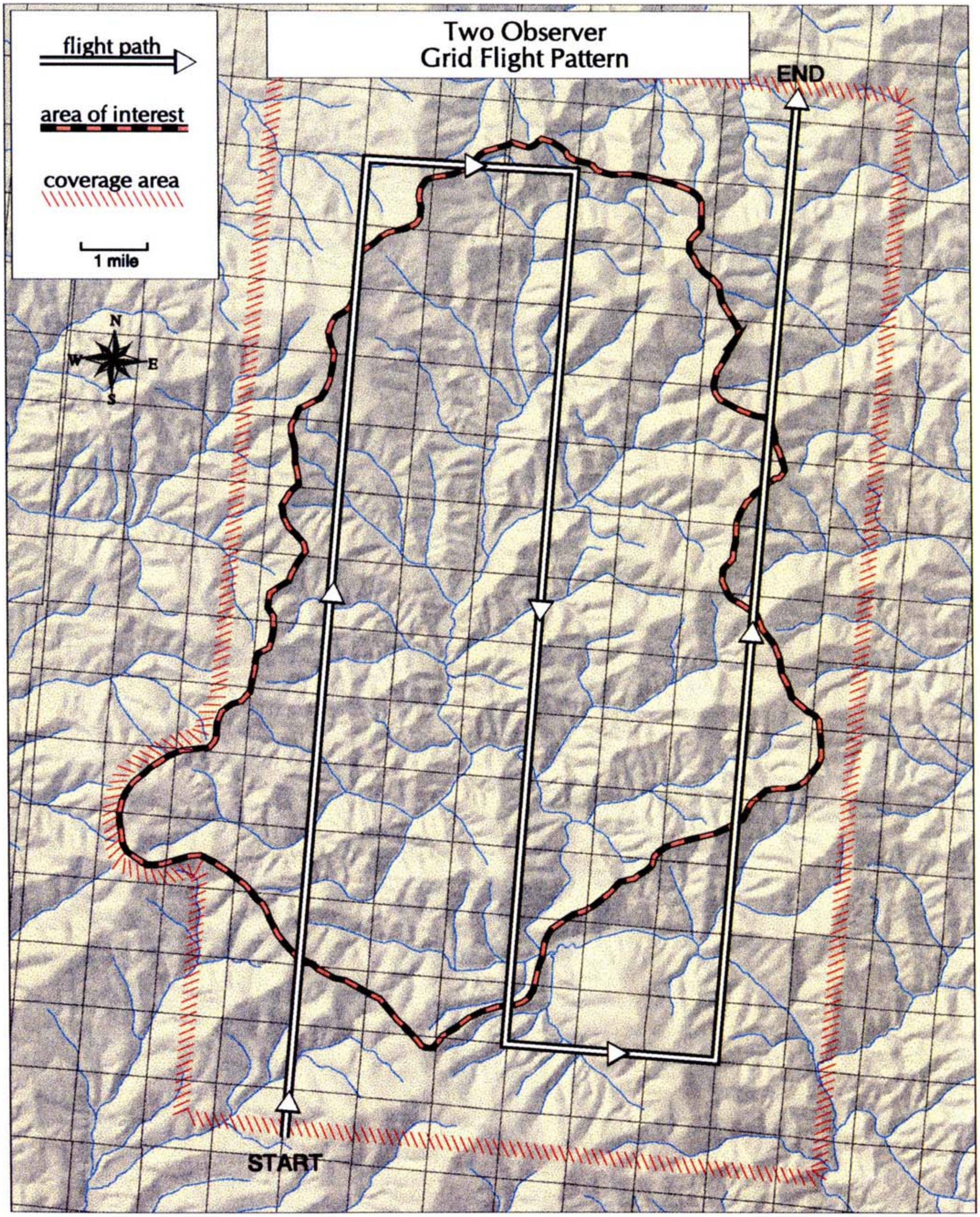

Figure 6: Grid flight pattern for two observers.

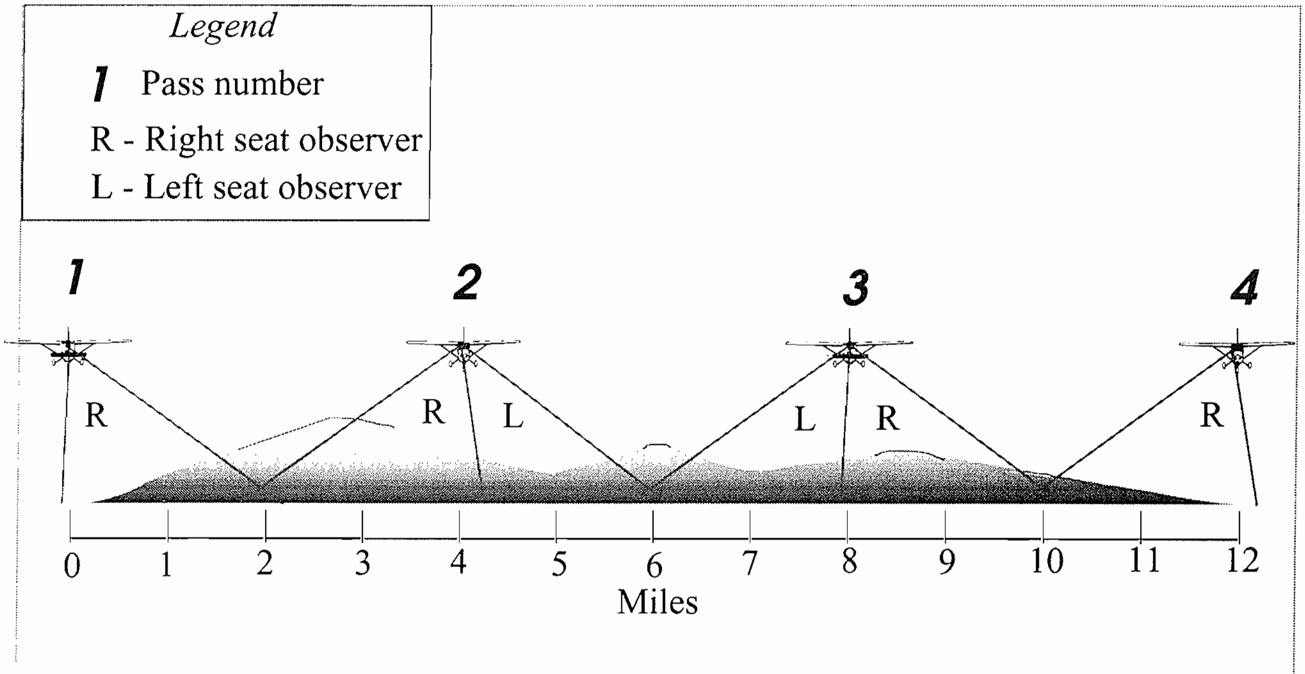

Figure 7: Grid flight pattern, two-observer view responsibilities.

The responsibility of each observer is to survey out from the airplane half the distance to the next survey line, making sure the middle portion between the two flight lines is observed thoroughly. It is common for inexperienced sketchmappers to focus on the area close to the airplane and not the full half-distance to the next flight line. Sometimes, when flying with two inexperienced sketchmappers, this tendency can be seen afterward on the final map because of the consistent gap in sketchmapped points and polygons parallel to the flight lines. If this pattern shows up, it means that greater sketchmapping experience is necessary, or that the flight lines should have been set closer together in accordance with the conditions of the day. (This gap can sometimes be avoided in flight by frequent reference to topographical landmarks that appear between the flight lines.)

In more rugged terrain, it is important to pay attention to the topography, and realize that each observer will only have one short look at each side of hills and ridges. Sometimes, this requires the observer to look beyond the half way point because it will be the only opportunity see this area clearly. Grid flying also requires great attention to looking ahead on the map and on the terrain to properly anticipate what will be coming up ahead.

In planning a parallel line pattern survey, compromises must be made in the distance between flight lines and ground speed. Annual overview surveys flown in Oregon and Washington generally use the parallel-line pattern, generally flown 4 miles between flight lines. In those two states, there are over 40,000,000 acres of forested lands to survey every summer, using only two airplanes and four observers. The entire forested area is flown in a somewhat cursory fashion due to budget and time constraints. In other parts of the country, overview surveys are done at 2- and 3-mile flight line distances because the states or forested areas are smaller and can be flown in a relatively short amount of time or require a more intensive survey.

The one flexibility in this type of flight pattern is that the speed of the aircraft can be varied depending on activity to be mapped. The airplane speed can be increased over areas of little damage and decreased (within safety parameters) where there is a lot of activity to be mapped to help give the sketchmappers sufficient time to sketch accurately.

One-observer Flying Grid flying can be done with just one observer, but the flying efficiency is reduced by half of two-observer flying. Because the observer must sketchmap on both sides of each flight line (except the first and last), each flight line must be flown twice.

Often, the area to be flown is started on the far left-hand side with the first flight line, with the survey area wholly to the right. The observer sketchmaps this edge first. At the end of the first flight, the airplane makes a 90-degree turn to the right, flies the distance between flight lines, and turns 90 degrees to the right again for the second flight line. The observer now sketchmaps the remaining area between the first two flight lines. At the end of the second flight line, the airplane makes a 180-degree turn to the right and the third flight line is flown on the same path as the second flight line, but in the opposite direction. This allows the observer to begin sketchmapping the area between the second and third flight lines. At the end of the third flight line, the airplane makes a 90-degree turn to the right and again, flies the distance between flight lines, then turns right again to begin fourth flight line, and so on (see Figure 8).

Three-observer Flying Some grid flying is done with three observers when staying on course (on line) is challenging and there is much to map. This is done with a navigating observer in the right-front seat to help direct the pilot while the two other observers sit in the back seats and each map from their respective sides of the airplane. Although this division of responsibility helps the sketchmapping observers because they don't spend their time directing the pilot, the area underneath the aircraft may not be observed because neither sketchmapper has an adequate view directly forward and downward. This can be helped by flying each flight line a small distance offset to give the one or the other sketchmapper a view of the area that was under the airplane on the previous flight line.

Combination of Grid and Contour Flying

Depending upon terrain, sometimes it is advantageous to combine grid-flying and contour-flying in the same flight. When flying relatively flat terrain that borders steep, mountainous terrain, it may be appropriate to grid-fly the flat area and contour-fly the steeper area. The contoured area is likely to be flown with one observer, so the grid portion is likely also to be flown with one observer. On the same flight, the only other alternative is to fly the grid area with two observers and, when the contour area is to be flown, the second observer could move to the right side behind the principal observer, leaving the front observer to navigate for the pilot. Again, often it is the terrain that dictates the flight pattern.

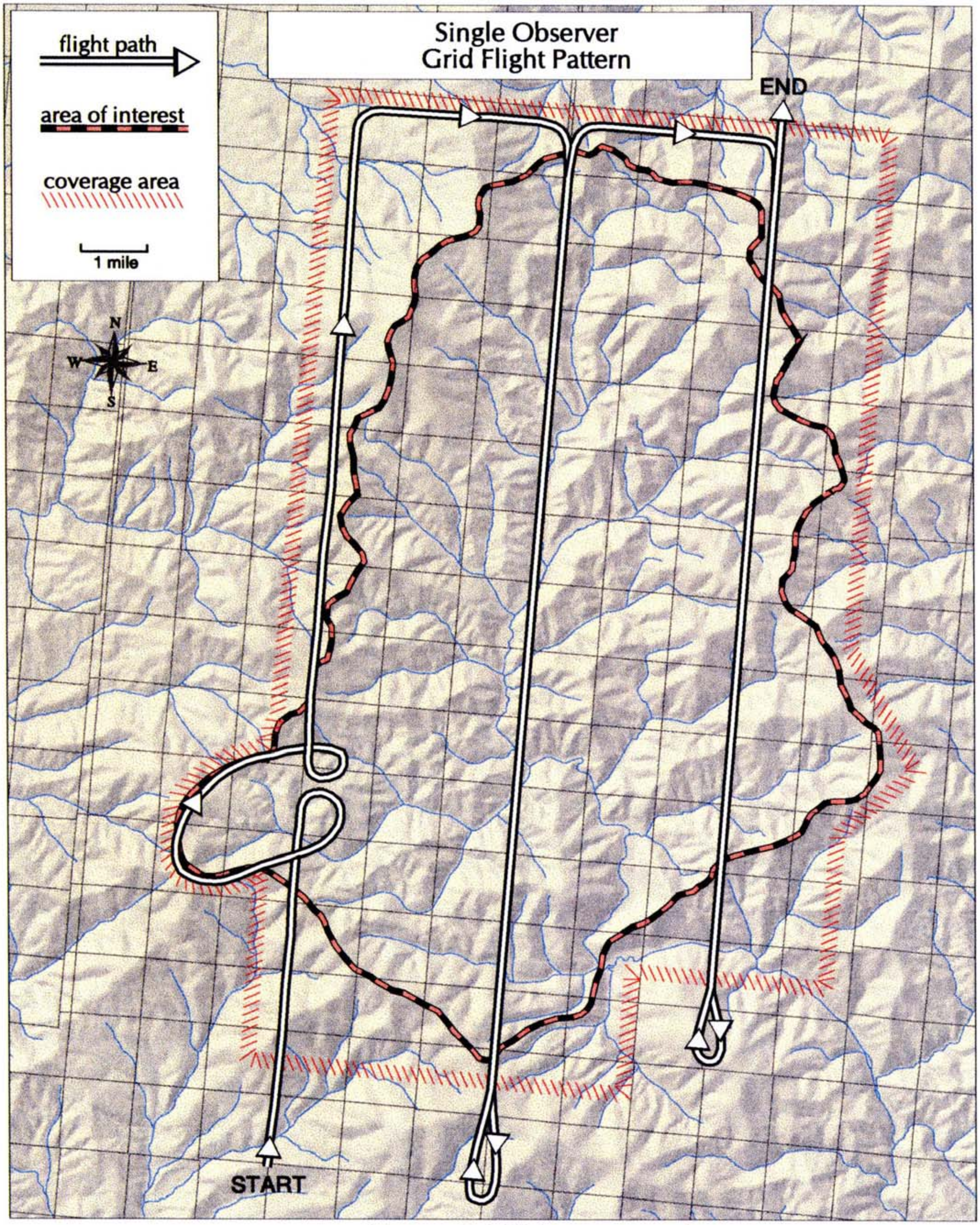

Figure 8: Grid flight pattern, one observer.

Cursory Versus Systematic Flying

Most intensive aerial surveys are done in a systematic method because it provides efficiency and thoroughness. Much like mowing a lawn, most people are systematic, no matter the pattern. This system ensures there are no skips and that the project doesn't take any longer than necessary. When a large area doesn't have to be intensively surveyed, a cursory approach can be taken. This cursory method can be very cost-effective because time isn't spend systematically covering large areas containing little or no damage. It can, moreover, provide a quick look to ensure large damage areas are not missed. If a large outbreak is detected, a more systematic method can be initiated. See Figure 9 for one example of a cursory versus systematic approach to flying a survey area.

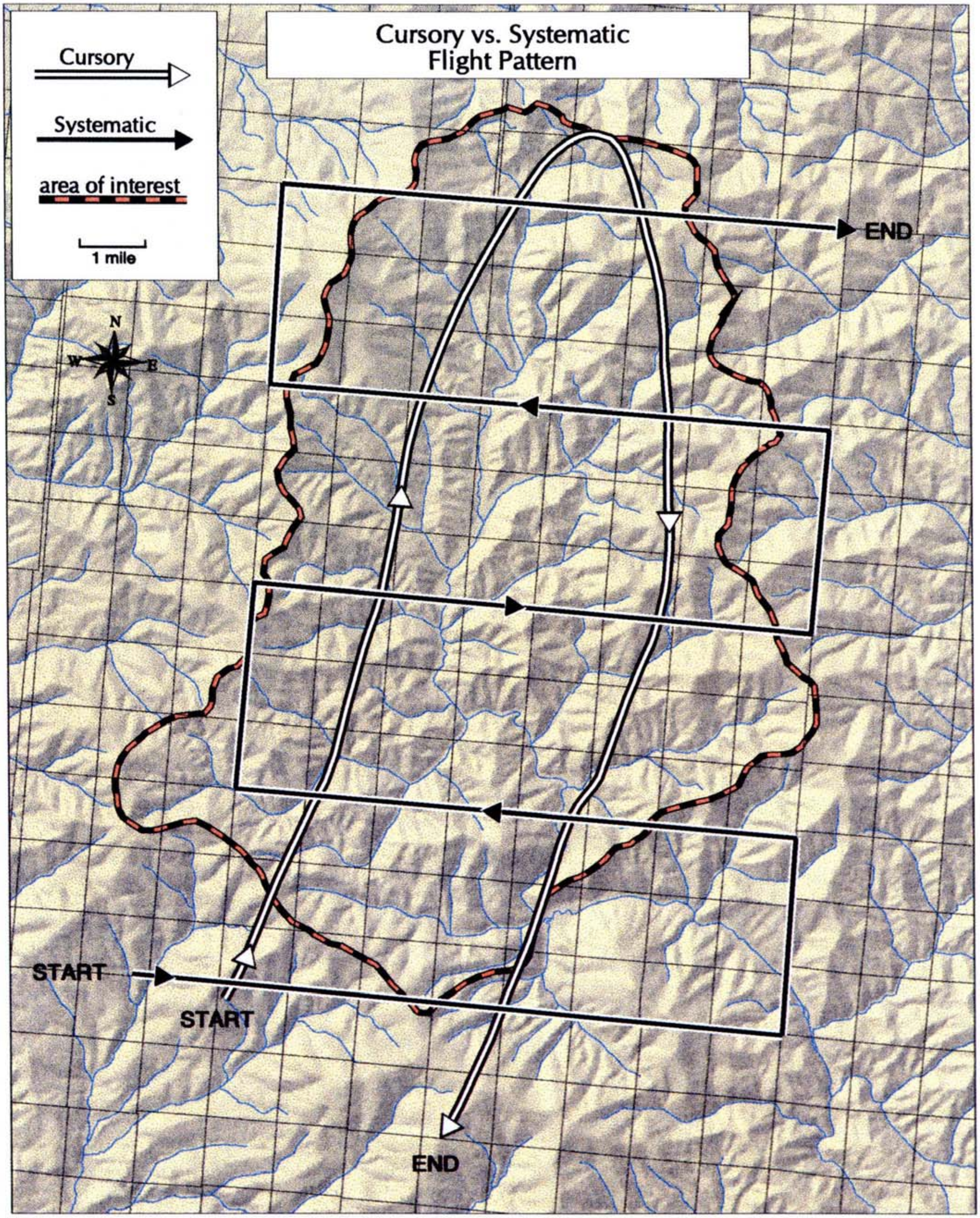

Figure 9: Cursory versus systematic flying.

Aircraft Considerations

Appropriate Altitudes and Aircraft Speeds

Altitude Maintaining the appropriate altitude during an aerial survey requires constant adjustment between flying too high and too low. Flying high gives the observer a good view for tracking the aircraft's route and location, but may be too high for detecting forest change signatures. Flying low gives the observer a good view of the nearby signatures, but may be too low for tracking the aircraft's location and seeing further away from the aircraft.

Survey flight altitude is dependent on many variables, including: type of signature, sketchmapper experience, type of survey, topography, type of aircraft, safety considerations, sun light, sun angle, haze, distance between flight lines, wind, and cloud cover. For safety reasons and legal reasons, the survey should never be conducted below 500 feet above ground level (AGL). Generally, the greater the altitude, the greater the margin of safety.

With so many variables affecting survey flight altitude, only a rough estimate of altitude can be given in this guide. Sometimes, due to winds, the pilot would prefer to work at a higher altitude than the observer. The pilot's preference is usually safety-driven, and should be adhered to at all times. It is better to err on the "high" side, rather than the "low." If necessary, two or three passes over an area prior to sketchmapping can help give the observer an idea of the appropriate flight altitude. If the observer feels that the airplane needs to fly low for long periods of time, but the conditions for the day are not conducive to it for safety reasons, the mission should be rescheduled.

Below are some general suggestions for appropriate flight altitudes for grid and contour flying. These are only estimations and are subject to the many variables found in aerial survey flying. In mountainous areas, the AGL will vary with the terrain. The airplane should maintain specific altitude and not vary a great deal from that planned altitude, reducing the need for gaining and losing altitude. Gaining altitude by increasing the power setting of the airplane can be hard on the engine and it is usually better to plan ahead and anticipate necessary altitude changes using flaps and trim.

Grid Flight Altitudes. The following are general recommendations for flight altitudes used in flying grids. The altitudes are related to several factors, all of which may be interrelated.

Flight Line Distance	Flight Map Scale	Terrain Types	Flight Altitude
2 miles	1:24,000	gentle to mountainous	500 - 1000 feet
3 miles	1:24,000 to 100,000	gentle to mountainous	1000 - 1500 feet
4 miles	1:50,000 to 100,000	gentle to mountainous	1000 - 2000 feet
5 miles	1:62,500 to 126,720	gentle to rolling hills	1500 - 2000 feet
6 miles	1:100,00 to 250,000	gentle to rolling hills	2000 - 2500 feet

Contour Flight Altitudes. Flight altitude in contour flying is dictated more by safety concerns involving terrain, winds, light, and damage signatures. Although this type of flight requires a more experienced observer, it provides the greatest flexibility for conducting aerial surveys. The observer can ask for whatever AGL is necessary to provide adequate viewing of the terrain below. This demands more communication between the observer and the pilot, so both the pilot and the observer must have a common understanding of the mission's intent.

Since contour flying is usually conducted over rolling hills or mountainous terrain, the terrain elevations vary greatly. To maintain safe flying conditions:

- The airplane should be kept at an altitude that requires only slight power changes or little additional circling to gain altitude.
- Whenever an airplane starts to follow a drainage upstream, an adequate AGL should already be met.
- NEVER start flying up a drainage below the ridgetops on either side of the drainage mouth.
- NEVER be below 500 feet AGL at the head or terminus of the drainage (or any other time for that matter).
- ALWAYS compromise on the side of more altitude, especially when following the drainage upstream. Relatively less altitude can be acceptable when flying downstream because the terrain is dropping away.

Aircraft Speeds

The velocity of an aircraft is measured two ways; true air speed and true ground speed. Ground speed is a measure of the distance the aircraft is moving relative to the ground. Air speed is the speed the aircraft is moving through the air. It is aircraft ground speed that is important to the observer because the observer is relating what is seen on the ground to what is on the map. The pilot will be concerned with both types because they relate to aircraft performance (flight physics). Winds are the reason that there are two different speeds. A tailwind comes from the rear of the airplane and gives the airplane a push, so the ground speed is faster than the air speed. Conversely, a headwind slows down the airplane's ground speed, but the air speed would indicate the airplane is flying faster.

It is best to maintain a consistent ground speed when flying aerial survey. A consistent ground speed helps to track the airplane route and provide a sort of timing rhythm to the observer. Experienced observers get accustomed to various ground speeds, much like a regular drum beat.

An aerial survey should be flown as fast as possible while still providing the observer time to track, detect, identify, sketch, and attribute all intended change signatures. For some observers that speed may be 90 m.p.h. and for others is could be 120 m.p.h. Try to choose an aircraft with an optimum operating speed that matches the intended survey speed. The upper end speed depends on the signature activity and the skill of the sketchmapper; the lower-end speed depends on safety concerns. Airplanes must fly fast enough to maintain lift: if a safe minimum flying speed isn't met, the airplane may stall.

It is important that the observer know the performance capability of the airplane and talk to the pilot about appropriate flying speeds relative to temperature, altitude, winds, and aircraft performance. Airplane engines are air cooled, so flying slow and changing power settings often can cause the engine to run hotter than normal, which is not good for the engine. If an airplane is expected to fly less than approximately 80 m.p.h., then perhaps the airplane isn't the "right tool for the job" and a helicopter should be ordered.

Grid. There are two observers with most grid-flying. Maintaining a constant ground speed helps the observers track the flight route by making upcoming landforms more predictable. Again, one of the few flexibilities of grid-flying is that the ground speed can be adjusted to meet the ongoing signature activity. When there is little to map, the flight speed can be increased and, conversely, when there is a lot of activity, the airplane can be slowed down to give the observers more time.

Contour. One of the challenges of contour flying is to maintain a continuous ground speed because the airplane is routinely turning and changing altitudes. Depending on the aircraft, flying upstream usually means gaining altitude, which will slow down the airplane. Flying downstream usually means losing some altitude, which will cause the airplane to speed up. It is difficult to slow down an airplane losing altitude. More powerful engines can make gaining altitude easier, while lowering wing flaps, landing gear, and "throttling back" can help slow down most airplanes descending in altitude.

Tracking (Flight Path Navigation)

Following the flight path of the aircraft on a map and relating this to features seen on the ground is referred to as "tracking" or "flight path navigation." This is probably the most difficult element for the novice sketchmapper to learn. If you do not know your location on the map, you cannot record the insect and disease information you are observing. The best aid to tracking is a good map base. For tracking purposes, USGS topographic maps complete with a grass/tree mosaic layer are among the best available in the United States when there is some topographic relief in the survey area.

An important point to remember while tracking is to not spend too much time looking at the map. After all, the reason for the flight is to observe forest conditions *outside* of the aircraft. As a general rule, the observer should be looking outside of the aircraft 75% of the time, and at the map and other cockpit details 25% of the time. This is easier said than done at first, but with some practice and patience, it will come.

Most sketchmappers orient their map to the same direction the aircraft is flying. This provides continuity between ground features and map features. This is true in contour- and grid-flying. Even scrolling maps are oriented in the direction of flight. Looking ahead, both on the ground and on the map, can be done much easier when the map is oriented with the direction of flight.

Grid Pattern Tracking the aircraft's position while flying a grid pattern on a predrawn or predetermined flight line is made significantly easier with a good pilot using GPS for navigation. Once the pilot is "locked" on the appropriate flight line, all the observer has to do is determine where on that flight line the airplane is located. Looking out the window, it is best to "key in" on natural land features. It is important to know the date of the flight map, because new roads are often not on old maps and vice versa. This is why land features are the best key because they seldom change, except for reservoirs.

Rivers, major canyons, and large mountains are primary features, and when present, make flight path navigating easier. The difficulty comes when only secondary features are available, such as small streams or minor topographical changes. In this case, moving your fingers or pencil along the flight line on the map at a rate consistent with that of the aircraft's path over the ground can be an effective tracking method.

After some practice, the observer will develop a habit of tracking current position across the map with "finger speed" while grid-flying over poorly defined terrain. One caveat to this is that the speed of the aircraft over the ground may change dramatically with any change in heading, due to wind velocity. So, for example, if east and west grid lines are being flown, the speed over the ground flying eastbound might be 120 knots and the speed over the ground flying westbound might be 80 knots at the same throttle setting. To compensate for this change in speed, the observer should communication with the pilot, who must adjust the airspeed of the aircraft to maintain a constant speed over the ground.

Contour Pattern While flying a contour pattern, tracking is best achieved by visually following creeks and rivers within the drainages being flown. Direct the pilot so the creek being followed is within your sight and never directly under the airplane. With the creek in sight, the observer can follow its many twists and turns and correlate this with the similar twists and turns on the map, knowing exactly where the aircraft is at all times. Because contour flying usually takes place in steeper terrain, where distinct land forms are present, flight path navigation is generally not as difficult as with grid-flying.

Efficiency and Cost-Effectiveness

Planning is very important when it comes to conducting an aerial survey efficiently and effectively. The expense of using aircraft to conduct surveys requires the need to be very cost conscious. The more the survey is logistically organized, the better use of flight time is made. Again, there is a constant balance between cost-effective use of the aircraft and accuracy, and compromise must be made to accommodate both. This compromise can be better made when there is a common understanding of the survey resolution, needs and goals. Besides good planning and communication, other factors that can contribute to efficiency and cost-effectiveness include: aircraft selection, ferry time, fuel stops, and alternate plans.

Ferry Time Ferry time is the time it takes from takeoff to the starting point of the aerial survey, and from the ending point of the aerial survey back to the airport. Often, there is little that can be done about ferry time because of the aircraft provider's location and the location of the survey area. Ferry time is often a major factor when long distances prevail between survey areas and airports: whenever possible, survey crews should work from suitable airports closest to the survey areas.

Fuel Stops A major factor that affects the planning process is airport location and fuel availability. All fueling opportunities should be known and considered in advance of the survey. Even timing of the fuel stop can be important to the cost-efficiency of the mission. Most survey crews prefer to fuel at the normal midday break. Running low on fuel and then having to ferry a long distance to get fuel suggests that the day's flying was not adequately planned.

It is best to land at an airport that provides quick and easy fueling. A busy airport with a control tower and an unmotivated fixed base operator (FBO) who sells fuel can cause a delay much greater than landing at a smaller airport that has very motivated FBO and will fuel the airplane quickly. The refueling schedule and its effect on the sketchmapping of an area is one more consideration that needs to be worked out between the pilot and the sketchmapper.

Alternate Plans Because of weather changes and other factors, it is important, when possible to have an alternate area planned. This would require informing other survey participants like flight-following dispatchers and the land managers, in addition to bringing flight maps for the alternate areas.

Aircraft Selection

Aircraft selection should be based on the flight parameters established in the flight planning stages. The aircraft selected should be the one that best fits the flying requirements of speed and altitude. However, not all types and models of aircraft are available to every National Forest, so safety concerns become the minimum requirement for the aircraft selected and cost-effectiveness becomes the maximum requirement: the aircraft must be able to fly the survey safely, but not at a price that is prohibitive to the program. The following addresses terms of procurement and type for selecting the appropriate aircraft.

Procurement Procuring aircraft is an important aspect of cost-efficiency. Never compromise safety to save money. Here, there must be a balance between procuring the most suitable aircraft and paying the standard rate. If there are several vendors available with the same type of aircraft, costs can be quite reasonable, whereas, if there are few vendors, the cost could be higher. If an aerial survey program is relatively large in terms of area to be flown and number of hours flown each year, a long-term contract may be the most cost-effective. A small aerial survey program may also have to pay more per hour because of the limited use of the aircraft. Procurement price is less of an issue if the program uses the aircraft provided by the agency.

Selecting the Appropriate Aircraft When several types of aircraft are acceptable to conduct an aerial survey and everything else is equal, such as pilots, then selecting the least expensive aircraft would be the most cost-effective. There is no reason to use a Bell 206 Jet Ranger at $500 per hour when an Cessna 182 airplane at $185 per hour can do the job quite well. It is the responsibility of the program manager to procure the appropriate aircraft for the mission. The following are the basic models of high-wing airplanes used in aerial surveys

Single-engine Aircraft

Aircraft	Horsepower	Cruising Speed (in m.p.h.)	Seating
Cessna 180	230	125	4
Cessna 182	230	150	4
Cessna 182 RG	235	180	4
Cessna 185	285-310	150	4
Cessna 206	285	130	6
Cessna 206 Turbo	285	160	6
Cessna 207	285	130	6
Cessna 210	285	190	6
Cessna 210 Turbo	285-310	210	6
de Havilland Beaver	450	110	6
Cessna 172	150	120	4

Twin-engine Aircraft

Aircraft	Horsepower	Cruising Speed (in m.p.h.)	Seating
Partenavia P-68	200	135	6
Partenavia Observer	200	135	6
Partenavia Turbo	200	150	6
Cessna 337 Skymaster	210	170	4

General Comments The following are general observations regarding aircraft capabilities. These characteristics will not be the only factors affecting aircraft selection, but may help guide selection among many suitable models.

Cessna 172. Only recommended for a crew of two at lower elevations in good weather. Not recommended for mountain flying or contour flying. Not used in the West.

Cessna 180. A fine mountain airplane for a crew of three or fewer. Best performance when temperature is below 80° F and altitudes are below 6,000 feet. Has "tail-dragger" landing gear.

Cessna 182. A good survey plane below 7,000 feet for a crew of two, a third crew member is okay when temperatures are low and the maximum working altitude is below 7,000 feet.

Cessna 182 RG. The "RG" stands for "retractable gear." It has a Lycoming engine, works well to an altitude of 12,000 feet, and is an excellent survey plane for a crew of three, or for point-to-point flying with four people on board. See Figure 10 for a view of the airplane.

Cessna 185. Considered the best mountain and backcountry airplane below 10,000 feet. Same fuselage as the 182, but has a larger engine and "tail dragger" landing gear. Good for a crew of three or fewer. Not turbo-charged.

Cessna 206. The "pickup truck" of single-engine Cessnas. A very stable plane: it can be overloaded (though not recommended) because of the large body. Okay to an altitude of 10,000 feet.

Cessna 206 Turbo. Like the 206, but able to work at higher altitudes. Has the large carrying capacity but, like the 206, has a wide body, making it more difficult for the pilot to see out the observer's side.

Cessna 207. A stretch version of the Cessna 206.

Cessna 210. Same size as a 206, but has no wing strut; retractable landing gear.

Cessna 210 Turbo. A fast airplane, good for higher altitudes, and good for a crew of four.

de Havilland Beaver. Has good lift and flies slow (both good for survey work), but is expensive to operate and noisy. A long-proven, dependable workhorse; often used with floats or skis.

Partenavia P-68. Good survey plane, especially for grid-flying at lower elevations. Performs well and climbs well, even at slower speeds. Can maintain 5,000 feet altitude on one engine with a crew of three.

Partenavia Observer. Excellent survey plane because the front of the fuselage is clear plastic, much like a Hughes 500 helicopter; designed specifically for survey work. Performs like the P-68. See Figure 11 for a view of the airplane.

Partenavia Turbo. The best of the three Partenavia airplanes at the higher working altitudes.

Cessna 337 Skymaster. A "push/pull" design, with one engine in the front and one in the back. A good survey plane, but noisy, and has smaller windows than single-engine planes, especially if equipped with a pressurized cockpit.

Other Things to Consider

There are other single-engine and twin-engine aircraft available. Always be familiar with your aircraft's performance capabilities. This information is meant to provide general information, not exact characteristics. When dealing with aircraft, here are a few old axioms to remember:

Power. Generally speaking, the higher you go (past optimum altitude), the lower the power. There is no substitute for horsepower.

Seating. Under ideal conditions, each passenger seat may be filled. Under mission conditions, such things as weight, temperature, fuel on board, and working altitude must be considered. Mission flights should carry only necessary personnel so that aircraft performance is not reduced.

Turbo Engines. The turbo pumps more air into the engine (that's why fuel must be "leaned out"), and so helps maintain aircraft power at higher altitudes. They are no help on a low-elevation takeoff. Turbo engines must be operated properly, as they can overheat easily. Turbo engines are also more expensive to maintain.

Substitution. While compromises in aircraft choice are sometimes necessary, there is no substitute for altitude and airspeed.

Runway Length. Be sure you have enough: the runway behind the plane is no good to you on takeoff or landing.

Figure 10: Cessna 182 RG.

Figure 11: Partenavia P68 Observer.

Other Technology and Tools for Aerial Surveys

Global Positioning System (GPS)

The Global Positioning System is a worldwide radio navigation system formed from a constellation of 24 satellites and ground receiving stations. The satellites and ground stations are used to calculate positions accurate to a few meters. The GPS receiver triangulates it's position by measuring the distance of four separate satellites using the travel time of the radio signals. The satellites travel precise orbits that are carefully monitored by the Department of Defense (DOD), using ground stations to correct the positions of the satellites in response to gravitational anomalies.

Most of the errors involved with GPS are due to atmospheric and physical distortion, which deflects and alters the path of radio signals. Also, there is intentional "noise" in the clock data used by the satellites that creates encoded errors in position calculation to hamper military use of the GPS by other countries. Only U.S. military receivers are capable of decoding all these errors and maintaining a "corrected" signal for complete accuracy. However, use of differential GPS (DGPS) eliminates many of these errors.

DGPS uses a reference station of known location in addition to the 24 satellites and DOD ground stations to calculate radio travel time errors. DGPS then transmits this "error correction factor" information to the roving GPS receiver. In the past, companies had to build a reference station in order to generate their own error correction factor; now, the U.S. Coast Guard and other international agencies are establishing these reference stations all over the world, which can be used for a relatively low cost–some even at no cost.

The Federal Aviation Administration (FAA) is in the process of building it's own monitoring system separate from the DOD system. The FAA system will transmit satellite position corrections *immediately* to aircraft. This is basically a continental DGPS system termed "Wide Area Augmentation System" (WAAS). This is accomplished by using a geosynchronous satellite transmitting instant corrections to aircraft on a GPS frequency. The FAA has estimated that, with about 24 reference receivers scattered across the United States, they could gather correction data for most of the country accurate enough for "Category One" landings (i.e., very close to the runway, but not at zero visibility). To complete the system, the FAA will establish "Local Area Augmentation Systems" (LAAS) near runways. With these reference receivers in place, aircraft will soon be able to make "Category Three" landings (zero visibility).

Of course, aerial surveys are flown under generally good weather conditions, and single engine airplanes are not used in natural resource work under "Instrument Flight Rules" (IFR) conditions (needing navigational instruments to land survey aircraft). By providing more precise navigation tools and accurate landing systems, GPS not only makes flying safer, but also more efficient. With precise point-to-point navigation, GPS saves fuel and extends an aircraft's range by ensuring pilots don't stray from the most direct routes to their destinations. The current system of aircraft navigation using VOR (Very High Frequency Omnidirectional Range) stations, is being phased out by the FAA, leaving GPS as the primary navigational system in aviation.

GPS is of great value to aerial surveyors. GPS enables the pilot to stay on precise flight lines for grid-flying and photo missions. Aviation GPS units can store locations of most airport and landing strips around the world. The airport information is usually updated every few months. When fuel is needed or a lunch break is required, a button is punched, bringing up a list of the closest airports. Another button is punched, and you now have a heading and estimated time of arrival to that airport. At the lunch break or the end of the day, when it is time to return to the airport, another button is punched to mark the ending location, so after lunch or the next morning, the GPS unit efficiently guides the pilot back to the ending location waypoint on a direct line from the airport. Latitudes and longitudes of mapped areas can be recorded by GPS and later plotted on a map using software that comes with some newer GPS units. Always knowing the aircraft's location means delivering accurate position reports to flight-following dispatchers, thus, increasing the crew's safety in the event of an emergency.

Automated Flight-Following

While in flight, position reports radioed to a flight-following dispatch unit are required by all USDA Forest Service, Department of Interior, and some state agency personnel. This is known as "flight-following." Flight-following gathers up-to-the-minute aircraft position information for search and rescue efforts in the event of an emergency landing. Currently, flight-following is achieved by a radio check-in from the aircraft to the ground every 15 to 30 minutes.

The requirement for frequent radio check-in is most important for safety reasons; however, it can break the concentration of the pilot, the sketchmapper, or both, depending on who is responsible for radio communication. Oftentimes, communicating using FM radios are less than ideal due to variables in the distance to the dispatch unit, the power of the radio, the need of a direct "line of sight" to a radio repeater (aerial sketchmapping often requires much lower flight altitudes than "point-to-point" flying), and the need for the dispatcher to be continuously attending the base radio.

Dealing with these factors may add flight time to the survey in order to climb to a higher altitude for radio transmission, to re-fly a survey area as a result of the climb, to circle until radio communication is achieved, or to fly to an airport and make a phone call to the dispatch unit because radio communication was unclear or broken. These delays become very expensive when aircraft costs can be $200 per hour or more. Moreover, the periodic check-ins provide only the location and direction of the survey airplane at that point in time: flying an aerial survey at 100 miles per hour or faster means the airplane can quickly be in a different location that what was reported.

Point-to-point flights are only required to report when and where they take off and when and where they land (usually defined ahead of time in the flight plan). The aircraft would be reported missing only after the expected arrival time had passed, which may be several hours after the aircraft made an emergency landing.

There is help on the horizon, though, in the form of GPS automated flight-following. GPS automated flight-following is a technology that uses a roving GPS receiver in an airplane and a transmitter that transmits current GPS positions back to a tracking office. At the tracking office, a computer complete with a GIS map base displays flight path and real-time aircraft position information on the map base as well as by spatial coordinates. The map can be a vector or scanned map; it can even be a three-dimensional display map.

The three basic components of a GPS tracking system are: the GPS receiver, a communication channel, and a geographic information system (GIS) map display system. The GPS receiver provides the location of the aircraft. The communication channel provides the means to transfer the GPS location to the dispatch unit. This is usually a one-way digital radio signal (the communication could be two-way, though this would require an additional dedicated frequency for the response signal).

The communication channel usually does not carry voices, however. Voice communication needs to take place on a separate frequency and/or a separate radio.

Data transfer can be achieved by radio (HF, VHF, UHF), cellular communication, commercial radio wireless communication, or satellite communication. A single dispatch unit can track several aircraft on one computer at the same time, and specific features can be designed into the system, such as an audible alarm or "panic switch" that is activated when an aircraft stops moving somewhere other than at a landing strip. If a two-way communication system is in place, the dispatch center can send a message back to the aircraft via the monitoring computer. Various automated flight-following systems are being tested and implemented in North America. With the support of multiple government agencies, a high-quality, safe system will soon be available.

Computerized Sketchmapping

Computerized sketchmapping systems are being developed for aerial surveys. This technology is the union of GPS, GIS software, a digital map base, a powerful computer with on-screen pen-sketching capability, and customized software to integrate them all. The system will place the aircraft location on the digital map base displayed on the monitor and offer a pen-based digitizing capability with pull-down attributing windows: in essence, replacing the paper map with an electronic one that scrolls as needed to help the observer sketch continuously and accurately.

In 1998, most systems were in the prototype stage, and are still under development. The expected advantages to this type of system are that they will allow the sketchmapper to view the aircraft's exact location on-screen in relation to the landscape, in turn, helping to sketch the polygon's relative position more accurately, and create a GIS file that can be downloaded to the unit's computer after the flight and incorporated into an overall map of the forest, avoiding the need for post-flight map processing. Although this system is being developed for sketchmapping, the technology could be used for other natural resource activities as well.

No matter what the new technology, it should be said that sketch-mappers must still know their location within the survey area in order to follow the map and accurately draw affected areas. Nevertheless, the flight map remains a critical part of the accuracy of the aerial survey, whether it is a digital or paper map, and should be the best flight map available.

Noise Cancelling Headsets

Aerial sketchmappers expose themselves to dangerous noise levels every time they get into an airplane or helicopter to do a survey. The Occupational Safety and Health Administration (OSHA) determined that 90 decibels (dB) is the maximum sound level a human can safely tolerate without risk of injury. The sound levels inside aircraft cockpits widely vary. Typically, this is 80 to 95 dB, but the levels may be higher or lower depending on the size and location of the engine(s) and the degree of sound insulation. Ear plugs are simple, effective and inexpensive protection devices and will reduce the sound intensity by 15 to 20 dB. The next step up in aviation hearing protection is the noise-attenuating headset which can reduce the noise levels by about 20 to 25 dB.

Noise-attenuating headsets achieve noise reduction using a rigid cup that encloses the ear and a cushion that seals the cup to the side of the head. These headsets passively attenuate noise by insulation, and hearing protection is provided by a rigid wall between the ear and the noise. To allow pilots to communicate while wearing these headsets, a speaker is mounted within the cup and a microphone, attached to a boom, is positioned in front of the pilot's face.

In a carefully designed headset this passive attenuation is very effective at reducing a broad spectrum of audio noise, but it does not achieve high attenuation for low frequencies below 200 Hz. This is unfortunate, because many aircraft generate very high sound levels at low frequencies.

Fortunately, a system has been developed which reduces this low frequency noise: the Electronic Noise Cancellation headset. Noise can be cancelled by generating a signal identical in sound pressure level, but exactly reversed in phase to the offending noise: broadcasting this opposing signal in the presence of the noise effectively cancels the noise.

To do so, a miniature microphone is placed in the ear cup next to the earphone element and as near as possible to the entrance to the ear canal. This microphone senses the external noise as it approaches the ear. The signal developed by the sensing microphone represents the noise that has penetrated the passive attenuation barrier, composed of predominately low-frequency sound. This signal is fed to a circuit in which it is inverted in phase, amplified, and fed back into the headset, thus creating an anti-noise signal that cancels the intruding noise. Electronic noise cancelling headsets reduce the noise of a booming engine to a low rumble!

Good ear protection not only guards against hearing loss, but reduces the debilitating effects of noise fatigue. Fatigue, irritability, poor morale, and reduced productivity are products of exposure to excessive noise. Noise cancelling headsets currently cost about $700 a pair, but investing in these headsets will pay for themselves through increased efficiency alone, not to mention the physiological protection it affords to sketchmappers.

Timing of Surveys and Biological Windows

The ideal time to fly an aerial survey is when damage signatures are the most visible. Special surveys are always conducted at "damage signature peak" to best capture the essence of the event. This peak will depend on weather, life cycle of the damage agent, etc., and so should be determined with the aid of an entomologist or pathologist. An aerial survey flown at an inopportune time is not only inaccurate, but potentially a waste of time. For example, a single annual overview survey in southeastern United States is not adequate to capture all the southern pine beetle-caused mortality in a year, so several flights per growing season are necessary to capture the ongoing mortality.

Typical annual overview aerial surveys should be timed so that most of the major damage signatures are visible during flight time. Knowing that not all damage signatures peak at the same time, a compromise must be made to be able to map most of the damage, or at least the highest priority damage. Bark beetle caused mortality may be flown at the same time defoliation is flown, so both signatures can be mapped concurrently.

Signature Biological Windows for Foliage Diseases

Disease	Causal Agent	Host(s)	Observation Period Apr May Jun Jul Aug Sept Oct
Pine needle casts			
	Lophodermella concolor	Lodgepole pine	------------------
	Lophodermella arcuata	Whitebark pine, lodgepole pine	------------------
	Dothostroma pini	Ponderosa pine, western white pine	------------------
	Elytroderma deformans	Ponderosa pine	------------------
Fir needle cast			
	Rhabdocline needle cast	Douglas-fir	------------------------
	Swiss needle cast	Douglas-fir	-----------------
Larch needle cast			
	Meria laricis	Larch	----------------- (and sometimes later)
Larch needle blight			
	Hypodermella laricis	Larch	-----------------
Hardwood Fungi			
	Anthracnose	Hardwoods	dependent on weather
	Oak wilt	Oaks	------------------------------------

Signature Biological Windows for Insects

Region	Causal Agent	Host(s)	Observation Period						
			Apr	May	Jun	Jul	Aug	Sept	Oct
WEST									
	Mountain pine beetle	Pines				----	----	----	
	Western pine beetle	Ponderosa pine			----	----	----	----	----
	Ips beetles	Pines		----	----	----	----	----	----
	Douglas-fir beetle	Douglas-fir			----	----	----	----	----*
	Fir engraver beetle	True firs				----	----	----	----
	Spruce beetle	Spruce				----	----	----	----
	Jeffrey pine beetle	Jeffrey pine		----	----	----	----	----	----
	Spruce budworm	Douglas-fir, true firs, Engelmann spruce, western larch				----	----**		
	Douglas-fir tussock moth	Douglas-fir, true firs				----	----		
	Hemlock looper	Western hemlock, Douglas-fir, true firs, spruce					----	----	
	Lodgepole pine needle miner	Lodgepole pine				----	----		
	Larch casebearer	Western larch		----	----				
CENTRAL, LAKE and NORTHEAST									
	Spruce budworm	Balsam fir, spruce				----			
	Gypsy moth	Hardwoods'			----	----			
	Forest tent caterpillar	Hardwoods			----				
	Fall cankerworm	Hardwoods			----				
	Elm spanworm	Elm, oak, maple, hickory, ash			----				
	Pear thrips	Hardwoods (maple)			----				
	Saddled prominent	Beech, maple, birch					----		
	Cherry scallop shell moth	Wild cherry, chokecherry					----		
	Hemlock woolly adelgid	Hemlock		----	----	----			
	Southern pine beetle	Southern pines		----	----	----			
SOUTHEAST									
	Southern pine beetle	Southern pines			----	----	----	----	
	Ips beetle	Southern pines			----	----	----	----	
	Forest tent caterpillar	Hardwoods	----						
	Balsam woolly adelgids	Fraser fir, balsam fir			----	----	----		
	Poplar tentmaker	Cottonwood						----	
	Fall cankerworm	Hardwoods		----					
	Elm spanworm	Hardwoods		----					
	Oak leaf tier	Hardwoods		----					

* May have late summer faders the year of attack, as well as faders the following summer

** Up into October in California

V. Sketchmapping

Aerial sketchmapping is difficult. To most sketchmappers, the activity is a humbling experience, every flight. Because the aircraft is moving at a high rate of speed, the land features are constantly changing, making observations (detection and identification) and documentation (sketching) an ongoing challenge. No two sketchmappers will map exactly alike and no one sketchmapper will map exactly the same way two days in a row. Management and sketchmappers alike must understand that this unique method of documenting forest change event signatures is far from perfect. But the "bird's eye view" can offer a lot to those interested in forest change events that can be viewed from the air.

Much of aerial survey limitations relate to sketchmapper experience and survey methodology. Like any other forest monitoring method, much effort must be put in to training, standardization and protocols. The old cliche "you get what you pay for" is very applicable in aerial sketchmap surveys. There can be a huge difference between a well conducted aerial survey and a poorly conducted survey. Aviation safety should be the highest priority of any program.

Although sketchmapping is not perfect, when conducted in the best manner possible, it can provide a great deal of very good information. It is up to the sketchmappers to communicate to management personnel that they require proper training, aircraft, maps and a mission plan in order to produce what is expected. It is up to management to ensure that people being sent up into the air are prepared and ready to do their job properly. It is important that the sketchmapper is trained and experienced enough to do the job properly.

The sketchmapper should always attempt to collect as much data with as much detail and accuracy as the survey methodology allows. If the question is asked "should I or should I not record this?", the answer should be "record as much as possible, you can always delete, but you can't add after the flight".

Using a large scale map and a helicopter, an aerial survey can be very precise. But helicopters are expensive, fly relatively slow compared to airplanes and the amount of time to conduct an aerial survey over a large area would be unrealistic. Conversely, flying high and fast in a jet, using a small scale map, over a large area, also would not be realistic. Aerial surveys become an ongoing compromise between budget, time and size of survey area. Proper mission planning and program management is critical to the success of any aerial survey program. Again, a program can be well managed, but if there is not a good, qualified sketchmapper, the information collected will be marginal at best.

Damage Categories

Program managers must recognize that their survey coverage is a part of a larger national effort, and they should ensure that their program fits at the national level. Most events that affect trees in a forest will fit into one of the following "damage type" categories (organized into "primary" and "secondary" damage types), used by the National Forest Health Monitoring Program (FHM). They include:

- Mortality,
- Defoliation,
- Discoloration,
- Dieback,
- Topkill,
- Branch breakage,
- Main stem broken or uprooted,
- Branch flagging, and
- Other.

Although the many and varied aerial survey programs around the country prioritize these categories differently, at a minimum, recording and reporting mortality and defoliation should be done during all overview surveys.

Primary Damage

Mortality The definition of mortality used for the FHM Program is "standing dead trees which have died since the last survey." This implies that if an aerial survey is flown annually that each year the new dead trees will be detected and mapped. Special surveys (for example, for southern pine beetle damage) are conducted as frequently as necessary to capture faders that are new since the previous survey. This may require as many survey flights as the bark beetle has generations per year.

Main stem breakage and uprooting can cause tree mortality, but since this type of damage usually implies the tree or portions of the tree are laying on the ground, the signature is very different from standing dead trees, and is therefore considered to be in the "stem broken or uprooted" category.

The standard for attributing sketchmapped mortality is to include:

- Host,
- Causal agent, and
- Number of dead trees, whenever possible.

Defoliation The definition of defoliation is "damage which results in physical or functional removal of foliage, partially or wholly by some agent."

The standard for attributing sketchmapped defoliation is to include:

- Host,
- Causal agent,
- Severity by low (<50% of susceptible foliage in polygon is defoliated) and high (>50% of susceptible foliage in polygon is defoliated), and

- Damage pattern, whether continuous or discontinuous within each polygon.

It is understood that different aerial survey programs can have different priorities and thresholds due to different tree species and management objectives. But whenever mortality and defoliation damage has been mapped, it is important for the programs to meet the above standards so the data can be assimilated into the national effort. These national standards are in an ongoing process of refinement and will likely evolve over time.

Secondary Damage

Although the majority of aerial survey mapped tree damage is mortality and defoliation, other damage categories defined by FHM include: discoloration, dieback, topkill, branch breakage, mainstem broken or uprooted, branch flagging, and other. These categories are the same used in FHM ground plot data recording. To standardize ground data and aerial survey data, most aerial survey programs will follow the FHM definitions. These other categories are usually associated with changes to the forest, such as windthrow, ice storms, pollution damage, cankers, etc. If these categories are to be reported nationally, the FHM mapping and reporting standards should be met.

Discoloration FHM definition: Foliage is a color other than green, such as yellow, red, purple, black or brown.

Dieback FHM definition: Distal portions (tips of branches) in upper part of crown killed since the last survey, with dead or dying (yellow, red, or brown) foliage. Non-distal portions of these branches have visible green, live foliage.

Topkill FHM definition: Top portion of the tree, including the terminal and all branches in that area, killed since the last survey, with dead or dying foliage visible (yellow, red, or brown). Stem is not broken. This type of damage is usually associated with conifers; it can, however, be seen in hardwoods that have a distinctive main stem and terminal.

A word of caution when trying to map topkill from an aircraft: bare tops in conifers does not necessarily mean "topkill." One must consider the causal agent and the length of time defoliation or other damage has been occurring; topkill mapping almost always requires ground-truthing.

Branch breakage FHM definition: Broken branches in any portion of the crown since the last survey or breakage that has occurred recently. Broken branches are identified by either a missing or a dangling distal portion; exposed wood at the break is bright white or another light color (exposed wood on breaks older than one year has usually darkened). Non-distal portions of these branches have visible green, live foliage.

Main stem broken or uprooted FHM definition: Main stem broken at any point or uprooted since last survey or that has occurred recently. Tree is no longer vertical above break or uprooting. Trees that have been recently uprooted or broken have green or fading foliage, and exposed wood at break is bright white or lightly colored (exposed wood in breaks older than one year has usually darkened).

This category is intended for windthrow or blowdown and ice or heavy snow damage.

Branch flagging FHM definition: Some, but not all, branches on the tree have red or yellow (dying) foliage since last survey; remaining branches are green.

Other FHM definition: A type of damage other than described in the above categories.

Mapping

Delineation of Affected Area

Most sketchmapping delineation of an affected area is done by either placing a point or drawing a polygon on a flight map. It is inferred that the sketchmapper will draw on a map what they see on the ground as accurately as possible. Mapping without points or polygons, does not provide spatial information that can be processed after the flight. For example, notes alone written on a map cannot be used for much of anything except notes for the sketchmapper.

Points Damage areas are recorded on the flight map as either points or polygons. A small polygon of two acres on the ground becomes a point to a sketchmapper drawing with a pen or pencil on a map with a scale of 1:100,000. This is the finest resolution a sketchmapper can accomplish with this method of mapping at that scale. Throughout this guide, the word polygon also infers points.

Polygons Shape and size are critical to the accuracy of polygons drawn by a sketchmapper. The affected area seen on the ground (trees forming an area feature) should be delineated in the same shape and size ratio onto the map. Good sketchmappers do not draw circles to indicate the presence of damage onto a map; they draw polygons that match the shape and size of the affected area. Delineation should be as fine as allowed by map scale, observer experience, aircraft speed, pen thickness, map feature detail and visibility of affected area signature. If the affected area is 600 acres, the polygon should correspond to 600 acres in size on the sketchmap. All affected areas should be delineated as accurately as possible, no matter the size of the polygon and the map scale.

Inexperienced sketchmappers tend to delineate in a more general fashion than experienced sketchmappers. Inexperience can lead to less than accurate mapping. Inexperienced sketchmappers or an unmotivated experienced sketchmapper can "broad brush" an affected area onto a map. Broad brush implies delineation with a general approach, rather than fine detail. This usually occurs because the sketchmapper cannot quickly delineate an affected area accurately and chooses to get something down onto the map in a more general way.

Nested Polygons "Nested" polygons are often referred to as "doughnut hole" polygons. Nested describes a polygon inside of a larger polygon. The nested polygon is drawn by the sketchmapper to display what has been seen on the ground inside the larger polygon. Often, a nested polygon is drawn to show unaffected areas inside a larger affected area. An unaffected nested polygon is called an "out" or "null". An example of a null could be mapping a large mortality area, while delineating out a clear cut patch or area of non-host within the mortality area. In large affected areas, nested polygons are often used to display multiple affected causal agents inside an area of a single causal agent affected area. For example, in a large area mapped as defoliation, a smaller mortality area is drawn. This smaller area may be attributed as just mortality or double attributed for mortality and defoliation. It depends on the size of the smaller polygon and how the sketchmapper intends to report the damage. It is important for the sketchmapper to understand how this data will be spatially displayed and summarized.

Lumpers and Splitters Each sketchmapper develops their own style in drawing what they see onto the map. Commonly, sketchmappers are put into two categories: the "lumpers" and the "splitters." Splitters tend to draw many small polygons and show as much detail as possible across the landscape. Splitters are usually very experienced and have the ability to detect and delineate quickly. The risk in splitting polygons out too much is that so much time is being spent drawing that some or a lot of the damage on the ground may be missed. Lumpers tend to look at the same area and draw larger and fewer polygons. Lumping has its advantages when there is a great deal of activity to be mapped. Often what dictates lumping or splitting is the amount of activity detected and map scale. Again, the point of sketchmapping is to "capture the essence" of a forest change event. Whichever style the sketchmappers use, when the survey data is digitized and summarized, the total acres and trees should both be in the same "ball park" and telling a similar story if the pattern is noted and understood.

Attributing and Coding Systems

Simply put, attributing is the description of a drawn point or polygon. Attributing is usually done in the form of some labelling code to improve efficiency. Different aerial survey programs usually have different coding systems. Any coding system will work, as long as the codes can be deciphered when the maps are processed in the next step. Some coding systems use numbers, some use letter abbreviations, and some use colored pencils and pens. For example, writing the phrase "Douglas-fir tussock moth" takes too much time and space, so various survey programs code it as "17" or "TM," or they delineate the area with a purple colored pen. Another example is mountain pine beetle coded as "6" or "MPB," or draw the line in red. Whatever system works in the airplane can be adjusted on the ground at map processing time. The best coding system would be the one that uses the least amount of time to write and the least amount of space on the map while in the airplane.

Some coding systems include both the causal agent and the host. An example of this would be "6L," denoting mountain pine beetle in lodge pole pine. But since many causal agents are host-specific, coding the host may not be necessary. For example, Douglas-fir tussock moth feeds mainly on Douglas-fir and true fir species, while hemlock looper feeds mainly on hemlock. There would be no need to spend extra time in the airplane coding host as well as causal agent.

Polygons should be labeled with no more than three causal agent codes. Marking a map with more than three agents sacrifices spatial detail, and is burdensome to GIS processing. If more than three agents are active in the survey area, multiple sketchmappers or multiple surveys should be used to capture the damage information.

Polygon attributes should have three pieces of information within each code. They include; causal agent, host, and intensity.

Causal Agent The FHM definition of "causal agent" is "any biotic or abiotic agent that causes damage to a tree, or other plant of concern." When mapping forest change events, the causal agent (when known) should always be included in the attribute.

There are times in which the cause of events cannot be determined from the air. For this situation, the sketchmapper should indicate the unknown causal agent with a question mark or other type notation (such as "unknown bark beetle" or "unknown defoliator").

Generally, mortality and defoliation should have the causal agent included by the time a final map is produced or before GIS processing is begun. Depending on the forest type and experience of sketchmapper, the causal agent may be more generally recorded as "bark beetle" rather than "mountain pine beetle." Not all polygons can be ground-checked, so the better the estimate during flight by the sketchmapper, the better the overall data quality. Whenever possible, the more exact the recording of causal agent, the better. For unknown causal agents, the more information about the signature, the greater the possibility of determining the correct causal agent after the flight.

Host The FHM definition of "host" is "a tree or other plant species (e.g. longleaf pine), species group (e.g. true fir), forest type (e.g. pinyon-juniper), or tree type (e.g. hardwood) showing damage." The trees affected by the causal agent are the hosts. Most biotic causal agents have fairly specific host trees. Abiotic causal agents such as ice storms, wind throw, and high-water damage may affect all tree species. The sketchmapper should use the most specific host designation possible.

Intensity Besides attributing the causal agent and host, when possible, the number of dead trees should be counted or estimated, the severity of the defoliation should be estimated, and the pattern of defoliation should be described.

Counting or estimating affected conifer trees for mortality. When mortality is delineated on the map due to bark beetles or other common causal agents, the number of dead trees should be counted.

A small spot with only a few trees, can usually be counted during an aerial survey.

When the number of trees and the size of the affected area are very large, the tree count becomes an estimate. Estimating the number of dead trees requires both sketchmapping experience and ground-truthing experience.

Different experienced sketchmappers have different methodologies for estimating the number of dead trees in a polygon. Some look at the size, pattern, and species composition, and then estimate the total number dead in the polygon. Others look at the same elements and estimate the number of dead trees per acre in the polygon. In some sketchmapping programs, sketchmappers are only required to estimate the percentage of trees affected with in the polygon.

Whichever method is used, when the final data summary is completed, the different methods should have similar estimates. A 40-acre polygon with 80 dead trees can also be described as a 40-acre polygon with 2 dead trees per acre. Both descriptions would have the same numbers of dead trees in a data summary after processing: recording them simply depends on the sketchmapper's style and situation. No two sketchmappers will consistently make the same estimate, but they should be "in the same ballpark." Most ground-truthing surveys have shown that sketchmap surveys tend to underestimate the number of dead trees and also over estimate affected area. The more work the sketchmapper does on the ground to check their estimates, the better they will do in future efforts. Estimations are affected by

- crown size,
- canopy structure,
- species composition,
- size of outbreak, and
- other stand dynamics.

When estimating the number of trees recently killed by bark beetles in a heavily defoliated area, it should be noted that the number of dead trees observed is dependent on the amount of foliage remaining on the dead trees to provide a good visible signature. Without faded foliage present to provide a signature, mortality estimates will likely be very low compared to the actual mortality. Conversely, attempting to map all dead, with no or little foliage, as recent dead would likely highly inflate the number of dead.

When estimating the number of dead trees per acre, the sketchmapper should be aware of how much the delineated polygon includes openings and non-host areas. Assigning a trees per acre designation to these areas would lead to an overestimation of the mortality figure. When estimates of dead trees are done with less accuracy than hoped, the numbers can still show general intensity levels from one polygon to another.

Estimating severity of defoliation. The first step in sketchmapping defoliation is to delineate on the map what is visible from the air.

Detecting very light defoliation can be difficult depending on the defoliator, host species composition, time of flight, and sun angle. Once the area defoliated has been delineated, different aerial survey programs usually require some kind of severity rating.

Forest Health Monitoring standards require that defoliation estimates be recorded as "light" or "heavy." Estimating defoliation severity from a fast-moving aircraft is difficult. The more categories of defoliation intensity that are called for, the more opportunity there is for estimation error. The more that is asked of the sketchmapper beyond delineation of defoliation, the greater the risk of not accomplishing the highest priority goal: delineation.

There are many variables that affect the appearance of defoliation from the air, and when attempting to estimate the severity of damage, the sketchmapper should be aware of them. The biggest variable is how the defoliation was indicated: the larger the polygon, the more general the estimate. Seldom is the amount of defoliation of host type contiguous across a stand, let alone across the landscape, so the more the defoliation is represented by smaller and more numerous polygons, the greater the effort of the sketchmapper to delineate the true edges of the damage and also make severity calls on each polygon. Other variables include the time of year it is flown, the direction and angle of the sunlight, the slope aspect, and the altitude of the aircraft.

Damage pattern of defoliation. The Forest Health Monitoring Program requires that defoliation be classified according to pattern: that is, as either continuous or discontinuous. The primary reason for including the pattern is to explain differences between the work of different sketchmappers. Some sketchmappers (the "lumpers") draw very large polygons of discontinuous defoliation, while other sketchmappers (the "splitters") draw several smaller polygons of continuous defoliation. When the two maps are combined, the differences in the way defoliation is recorded on the can be explained in order to more fully understand conditions on the ground.

Some programs feel the sketchmapper is burdened by having to add pattern to the attributes of polygons, therefore reducing overall accuracy. Such programs may elect to consider the discontinuous pattern as the default, and the sketchmapper must indicate a continuous pattern before that particular pattern is assigned.

Sketchmapping with Ink or Pencil

Often the type of survey will dictate the use of ink and/or pencil to sketch and attribute. Usually, the decision is made by program policy or the sketchmapper's personal preference. Both have their advantages and disadvantages as to clarity. Whichever is used, line thickness and readability after the survey are important to accuracy, and should be considered in advance.

Lead Pencil Sketchmappers often need to redraw or reattribute their first efforts. Using a lead pencil offers that flexibility, and a darker, softer lead is easily read and can be easily erased. The lead point should be small enough to draw and write in detail, yet large enough so the point doesn't poke holes in the paper map. Penciled maps can be inked over in color during post-processing. This eliminates the need for light-table transfer of work onto another map.

When using a lead pencil, it is important to ink the map as soon as possible after the flight because pencil lead can smear or wear off the paper map, reducing the readability of the flight map. Another reason for inking in the map as soon as possible after the flight is because all of the information is still fresh in the mind of the sketchmapper, who can thus resolve any ambiguous or unclear entries.

Ink Pen The best kind of ink pen to use for aerial surveys is the type that dries immediately, doesn't smear, and has a relatively fine point. It's nice to be able to draw polygons in one color and attribute in a second color, but time and damage activity doesn't always permit the use of multiple colors. Most ink pens are not easily erasable. This can make for a messy map if the sketchmapper decides to edit a particular sketch or attribute (in which case, a second color may be useful to make corrections easier to interpret). Inked maps are sometimes retraced during post-processing.

Colored Pencil Some sketchmappers prefer using multiple colored pencils for drawing polygons to indicate causal agent and/or host. This can be more efficient than drawing a polygon and then attributing. When drawing small nested polygons of bark beetle mortality inside large polygons of defoliation, a second color can help enterpret the differences. Changing colored pencils for each causal agent may take as much time as attributing and, in areas with many common causal agents, there may not be enough different colors to match causal agents.

Factors Affecting Sketchmapping Accuracy

Many factors contribute to the accuracy of aerial survey data. The following items are a partial list of factors that can contribute to or detract from the overall quality of the data. The difference between a quality aerial survey program and an inadequate aerial survey program can be found in the management of the following factors.

Human Factors

One of the easiest ways to ensure an aerial survey program fails is to put someone up in an airplane that cannot adequately do, or does not want to, perform the job. Once the human factors are met, the program management challenges can be addressed.

Vision The following are vision-related factors that should be known before assigning a sketchmapper to a survey program.

Color perception. Most forest change signatures relate to color, and much of the detection process of an aerial sketchmap observer is done by recognizing the subtle color differences between green trees and faded trees. To be a good sketchmapper, one must have normal color perception. Without good color perception, the forest colors (green, red, orange, brown and yellow) are not apparent and the primary signature is lost.

Nearsightedness. While much time is spent looking out the window of the aircraft, there is also time spent reading the fine detailed features on the flight map. If the sketchmapper can't physically read the map, they can't track the path of the aircraft or know where to accurately draw the polygon. Some sketchmappers find themselves needing reading glasses to read the map. This often requires the need for bifocal lenses, so that the observer can still see the ground out the window as well as read the map.

Farsightedness. The aerial observer must have good farsighted vision to detect subtle changes to the forest from the aircraft. Thin crowns and other texture differences are common signatures that require good eyesight to detect. Farsightedness can also be helpful for spotting other aircraft in the vicinity of the survey aircraft.

Aptitude

Not everyone can be a good sketchmapper. The following are some aptitude factors that are important to sketchmapping.

Personal comfort in an aircraft. Not everyone is comfortable flying in small aircraft, especially for long periods of time and at relatively low altitudes. Fear of flying, motion sickness, and an inability to focus on a single task for hours without a break are primary factors that affect comfort levels of aerial observers or trainees. Even seasoned aerial survey veterans often need a few days of flying to adapt their body to the physical demands of flying. A new observer that has high anxiety about flying will have difficulty concentrating and performing at the high level needed to sketch map. Flight time experience can improve the observers' awareness, which is why apprenticeship time in the back seat is so important. Contour flying requires a great deal of turning to follow drainages. Some people will be comfortable in grid flight patterns, but when flying contour patterns, become uncomfortable.

Sketching and drawing ability. A sketchmapper must have some level of artistic ability to be able to draw on a map what they view below on the ground. Not only must the affected area be drawn on the map in a similar pattern, but it must be drawn on the map in the correct place and drawn to the correct scale. This process can be quite challenging for people unless they have good hand-eye coordination. Much of drawing is simply the skill of looking and visualizing. This skill can be taught, but is easier when the observer has the aptitude.

Attitude. The aerial observer must have a sincere interest in not just doing the job, but doing it at a high level of performance. The observer must have a positive attitude just to try and do this difficult task as well as possible. Sketchmappers do not work alone, so their attitude must be that of a team player. Even an experienced sketchmapper must have a sincere interest in doing the job well.

Experience and Training

The aerial survey program is only as good as its sketchmappers, and experience and training are critical to the success of an aerial observer and an aerial survey program. While some previous education in forestry, mapping experience, and training in a related discipline can be good background for sketchmapping, the combination of all three is rare. It is therefore necessary to emphasize specific skills when evaluating the performance of a sketchmapper.

Knowledge of forest conditions. Factors causing visible changes in the forest canopy vary from year to year, month to month, and locality to locality. Sketchmappers should be personally knowledgeable about current local conditions or should have been in contact with others who are knowledgeable prior to flying the survey.

Map reading skills. Above all other skills, map reading is the most critical for a sketchmapper. Sketchmapping requires a constant balance between following landscape features outside of the airplane window and correlating land features with map features. The observer must be able to read and understand every map feature at a glance in order to sketchmap as accurately as possible. The sketchmapper must, moreover, be constantly aware of the ever-changing speed of the airplane in order to anticipate upcoming geographic features: this is very different than reading a map on a day hike in which the landscape will "stand still" until features can be identified.

Tracking the aircraft's location. If you don't know the location and heading of the aircraft, you won't know where to draw an affected area onto the map. This skill should be demonstrated prior to a person's being approved as a lead sketchmapper, for the lead observer is also responsible for following the mission's route. An individual may know much about forestry and the interaction between causal agents and hosts, but if they can't keep track of the aircraft's location, they cannot be an effective sketchmapper.

Understanding sketchmapping techniques. The flight map is the sketchmapper's canvas. The sketchmapper must know where to work on that canvas. They must be able to, not just detect the forest change signature, but to interpolate that area onto the map. The sketchmapper must understand that this process is not perfect. Aircraft speed, altitude, and time allotted for viewing and drawing are constantly changing. Compromises must be made for the sake of getting a decent product completed. When there is loud radio traffic on two frequencies at the same time, it is hot and bumpy, the aircraft is flying a little too fast, it's the third hour in the air, there are strong winds aloft, there is other air traffic in the area, the crew is hungry, and there are very busy damaged areas on the forest below, the sketchmapper must understand that this is all just part of sketchmapping and do the job.

Fatigue

Once a trained, experienced sketchmapper, with all the right aptitudes and positive attitude is conducting an aerial survey, there are still other human factors that effect the accuracy of the survey. These factors are the responsibility of the individual sketchmapper to recognize and manage appropriately. A "brain dead" sketchmapper (one who stares glassy-eyed out the window, recording little of anything) is not very effective.

Noise fatigue. All motorized aircraft are extremely noisy. Every effort should be made to reduce the noise by the flight crew. Ear plugs and good head sets are the primary equipment to do this. Often not recognized as a fatigue factor, noise can add up to stress and pressure, just as listening to any other loud noise, such as highly amplified music or traffic.

Motion fatigue. The old question "Why should I be so tired? I simply sat in an airplane all day," is easy to answer for an experienced sketchmapper. The only smooth flights occur on a jet airliner. The turning and bumping in air pockets make for constant pressure to the human body. Motion fatigue is part of flying, just as it is in driving an automobile on a winding, two lane highway. The crew should remember to take a break from flying, when reasonable and time-efficient.

Heat fatigue. Much of the time spent conducting aerial surveys occurs in the heat of the summer months. This is compounded by the greenhouse effect in the aircraft: the sun shines strongly into the cabin through the windows, but the cabin may have little fresh air moving through it. The result is a hot and stuffy working environment. Heat fatigue is very common in aerial survey, but can be managed by drinking lots of water, dressing in lighter-weight clothing, flying at hours outside of the highest heat of the day (though this is not usually practical), and using all possible ventilation devices in the aircraft short of taking the door off the fuselage. Some crews may also take a "time-out" in the air for a juice break.

Sunlight fatigue. Most aerial surveys are conducted in direct, bright sunlight, which can also be a fatigue factor. The crew should wear sunglasses and billed caps: the sunglasses are an absolute necessity, while the billed caps will not only reduce the amount of sunlight shining in the crew's eyes, but also reduce the glare reflecting off of sunglasses within the cabin.

Altitude effects. Working at higher altitudes can be a factor affecting fatigue. Much of it has to do with the elevation the observer lives and commonly works. Someone who lives at sea level and flies aerial survey at an altitude of 9,000 feet will likely feel the affects of that altitude, whereas someone who lives and works at 5,000 feet and flies survey at 3,000 feet elevation will not be affected. Flying above 10,000 feet, lack of oxygen becomes a factor. Again it is all relative to the individual. A sedentary smoker and an active nonsmoker who hikes in higher elevations would likely not be affected equally by altitude. Oxygen is recommended in an nonpressurized aircraft while working at or above an altitude of 10,500 feet for more than 30 minutes. Fortunately, most aerial surveys are conducted below 10,500 feet, except in the Rocky Mountains and for special photography flights.

Hours flown. Aerial sketchmapping is difficult, challenging work that requires a great deal of concentration. It can be very tiring for some people. Endurance levels between sketchmappers varies greatly. Each observer should know their own limits, because once you become fatigued, it is difficult to concentrate. For some a flight of two hours is long, for others a flight of 3.5 hours is about maximum. There is no specific amount of time that determines the flight time. It all relates to the many human factors previously mentioned.

Some sketchmappers fly five to seven hours a day. Five hours is usually considered a productive day, where seven hours may be on the "pushing it" side of a long day. It is the responsibility of the sketchmapper and the pilot to know when "enough is enough." Know when to say "when!"

Aviation

Besides the many human factors that can affect sketchmapping accuracy, the aviation aspects are, by definition, important to the success of the survey.

Flight Pattern Flight pattern is one of the most important factors when it comes to accuracy. It also affects the cost of the survey because it determines the amount of flight time spent over the survey area. In mountainous terrain, the contour flight pattern generally provides for better results than the grid pattern, and when flying grid patterns, 3-mile flight lines generally provide for more detailed results than 4-mile flight lines.

Flight Altitude The "right" altitude is one that is safe and provides enough height to see out as far from the aircraft as necessary. The higher one flies, the less forest change detail will be seen. Conversely, the higher one flies, the easier it is to track the flightpath. Flight altitude is an ongoing adjustment, especially in mountainous terrain. When surveying flat terrain, a relatively constant altitude should be maintained to provide for consistency and ease in tracking the aircraft's position.

Flight Speed Fly too fast, and the time to view the ground becomes so short, sketchmapping cannot capture all the visible forest change. Fly too slow, and the survey becomes less cost-effective or worse: it affects the performance of the airplane. The sketchmapper is responsible for having the aircraft slow down or speed up, which requires an awareness of the aircraft's capabilities.

Visibility Not all airplanes are equal when it comes to visibility. Windows should be large, NOT tinted, and always clean. Bubble windows are good for viewing terrain directly below the airplane, but can cause some distortion. High-wing (vs. low-wing) airplanes are a must. Helicopters provide great viewing from the front seat, but not from the rear.

Flight Crew Interaction The aerial observer and the pilot must work together as a disciplined team. Each must understand and communicate his/her responsibilities. A good, motivated pilot who knows his/her role in the mission can be an asset to the sketchmapper, but it is the responsibility of the sketchmapper to ensure the pilot understands what is expected of the mission.

Aircraft Traffic in the Area Encountering other aircraft during aerial surveys is common. But when the sketchmapper is more concerned about other aircraft in the survey area than detecting and sketching forest changes below, accuracy and detail decrease. Watching for other aircraft is the responsibility of all crew members. Depending on the flight pattern and location of the survey area, the crew should work out a system that will ensure that the sketchmapper can concentrate on sketchmapping. Once other aircraft are spotted, the pilot can usually maintain visual contact with that aircraft, and the sketchmapper can continue focusing on the ground. Other airspace management activities should include checking of aeronautical charts, flight service stations and agency dispatchers for active military training routes, restricted airspace, and military operation areas.

Other Hazards A regular effort should be made before and during the flight to ensure that the survey crew is aware of any other known local hazards to aviation. This may come in the form of an agency hazard map or by contacting dispatchers or aviation management personnel in other groups or agencies about other aviation activities in the survey area.

Meteorological Conditions

Even with a trained sketchmapper, a good pilot, and the ideal aircraft, if meteorological conditions are not favorable, the accuracy of the aerial survey could be greatly reduced. Time constraints usually dictate that many surveys must be flown under less than ideal conditions. The sketchmapper must often choose between surveying under marginal conditions and not conducting the survey at all.

Sun Angle Time of year is very important to getting the best sun angle to fly. Summer months in North America provide the highest sun angle, which provides the best light to view damage signatures. This is also when most signatures appear.

Time of day is also very important for optimal viewing. The best time to fly is during the three to four hours before and after noon, as bright sunlight is best for viewing subtle color signatures. However, terrain can play a part in the timing of the day's flight: east-facing ridges can be flown earlier in the morning because they face the morning sun and, conversely, west-facing slopes may be flown later in the day.

Cloud Cover Clouds reduce the amount of sunlight, but are not always detrimental. A high cirrus cloud layer can diffuse sunlight, reducing shadow and producing even lighting on the ground. This type of cloud layer can sometimes even be of help to the observers' viewing by reducing lighting contrast, making viewing some damage types easier to see. Cumulus clouds, on the other hand, cause dark shadows to fall on the ground, contrasting with bright sunlight in adjacent areas: these highly contrasting areas make consistent sketchmapping difficult.

Winds and Turbulence High winds in mountainous terrain can cause high anxiety to a sketchmapper and possibly to the pilot because they can be dangerous to the functionality of the aircraft. Anything that reduce the sketchmappers' ability to concentrate will effect accuracy. Strong turbulence can cause such a rocking and bumping motion that the sketchmapper has a difficult time drawing polygons and attributing accurately. Turbulence can also occur in cumulus cloud conditions because of the contrast between shaded descending cool air and rising sun-warmed air.

Precipitation Aerial surveys have been flown during falling rain and falling snow. Often, this is because it is near the end of the day or end of the season. Sometimes, this only occurs for a short time during small weak storm cells, and then the sky is sunny again. Generally, dark rainy days do not provide good sun light for aerial surveys, and the rain on the windscreen reduces visibility. Under these conditions, there is an ongoing debate between getting the work done and waiting for better conditions before continuing. Sketchmapping aircraft should never fly near a hail or lightning storm (level 3 or greater cumulus cloud): these are very dangerous because of downdrafts, potential hail damage, and possible direct lightning strikes.

Haze Haze can come in the form of smoke, smog, dust, or moisture. Haze is a common problem in states with a humid climate. All other conditions may be favorable for an aerial survey, but the presence of haze can make for a less than an ideal day. On hazy days, the compromise may be a shorter distance between flight lines or to make up for limiting visual conditions. Smoke can be a problem during forest fire season. If the observer can't see adequately, the survey should be postponed or moved to another area with less smoke, and the skipped area flown on a more favorable day.

Fog Maybe its a beautiful day, with a strong high pressure zone over the survey area, but ground fog covers the intended aerial survey area. Fog will postpone an aerial survey as abruptly as any other meteorological condition. It is illegal under Federal Aviation Rules (FAR) 135 to fly over large expanses of ground fog (a "solid deck") with a single engine airplane because, if there is an on-board emergency, the pilot cannot see through the fog to fly safely to a safe landing spot. If the fog is not solid but broken, as during dissipation, then the flight can proceed with caution.

VI. Quality Assurance

Quality assurance is performed on sketchmaps after a flight to determine that:

- damaged areas have been detected,
- damaged areas are mapped in the correct location,
- mapped polygons are the correct size, and
- the correct attributes have been assigned to mapped polygons.

The amount of quality assurance review should be dependent upon the objective of the aerial survey mission. Ground-truthing has gone hand-in-hand with sketchmapping from its very beginning, but the concept of quantifying sketchmap accuracy is still in its infancy. It's safe to say that, as the need for accuracy increases, the effort to implement quality assurance will also increase. For example, a survey intended to document the magnitude of a problem requires less accuracy than one which will direct the location of salvage operations.

In addition, as the variability of the damage increases, so will the difficulty of mapping and the chances for errors. A survey of heavy gypsy moth defoliation, which tends to be uniform in affected areas, will require less checking than a survey of forest decline which may include; discoloration, dieback, topkill, and mortality in various combinations and patterns.

Whatever method is used, ground-truthing or check surveys must be done before tree conditions change: before browned foliage drops, before insect life stages disappear, before hardwoods refoliate or drop their leaves, etc. Ideally, checks should be done within a few weeks of the original survey.

Checks can be done to refine and correct the original map, or simply to quantify their accuracy. If the objective is to refine and correct data, updating the processed maps after digitizing, printing, and reporting can be a challenge. Moreover, it will be necessary to decide whether the corrections should be applied to specific areas or to the entire survey.

Ground-truthing

Ground-truthing is the best way to verify that polygons have been correctly delineated and attributed. Following a transect across the mapped area is an efficient way to check location and size. The survey should evaluate crowns of dominant and co-dominant trees within the damaged area and check damage type, host, and causal agent, as well as damage severity. If trees are not in the upper canopy, do not consider them since they were not visible to the sketchmapper. Also note if there is any difference in damage severity between upper and lower crowns.

Which polygons should be visited? If the objective is to correct and refine the original maps, focus on the areas that are typical of all polygons with the same attributes. Sketchmappers are helpful in identifying polygons which are representative and accessible.

Overlap

Overlap, or sketchmapping the same part of the survey area twice, is a good method of checking that damaged areas are detected and mapped. It also helps to establish the repeatability, if not the accuracy, of polygon size estimation and damage attribution. Overlap can be done by re-flying the survey area with a different crew, on closer flight lines, on perpendicular lines to the original lines, or at a slower speed over the previously flown area. Because differences in observers' sketchmapping styles are probably the largest source of variability in sketchmapping, quality assurance by overlap will most often be done with a different crew. But by flying the same area more than once with the same sketchmapper, repeatability by individuals can also be assessed.

To compare the two surveys, the maps can be evaluated in their original form or through their GIS-processed images. Using GIS, points or polygons on a grid can be compared visually, or the software can be instructed to check for polygons from one survey that intersect polygons from another survey.

Photography

Comparison of sketchmaps with aerial photographs is the best way to assess the accuracy of detection, polygon size, location and attributes of signatures. Individual polygons derived from these images are almost always smaller than the same polygons sketched from the air, and tree counts are usually lower as well.

VII. Post-flight Operations

After the flight is completed, there are still several activities and processes that should be done to ensure data accuracy, comprehension, and usefulness. The job isn't done when the airplane lands. Once a survey has been flown, it is very important to protect the completed flight map from damage or loss.

Flight Map Processing

Properly processing the flight map after the survey is flown is critical to the accuracy and success of the program. Some flight maps come out of the airplane folded or torn. Usually the attributing is written in all directions, relative to the top of the map, because the survey is flown in many directions and the map was turned to reflect the direction of the airplane. Only the sketchmapper can make sense out of all the attributing, combined polygons, notes, and other "chicken scratches" that fill the survey area. It is the responsibility of the sketchmapper to personally ensure that all point, polygons, attributes, and additional information are readable to those who use and process the map afterwards. A flight map that is unreadable or incorrectly read becomes a waste of time and money. See Figure 12 for an example of a sketchmap that just came out of an airplane.

The sketchmapper is responsible for either "cleaning up" the original flight map by inking the flight map or copying the information onto an unmarked flight map for processing. The intent is to make the remaining map processing as easy as possible for the assisting cartographer. Processing the flight map includes such things as:

- Taping tears and holes on the back with clear tape. Never use clear tape on the front because it is difficult to write on (unless all inking is complete). Never use masking tape to tape tears because the light table doesn't penetrate the tape to show the inked polygons,

- Inking over penciled polygons and rewriting attributes with the map oriented to the north. It is best to ink polygons in one color and attributes in another color so that there is no confusion among points, polygons and attributes. After all inking is completed, erase the pencil work. If the polygons were entered in ink in the airplane, it usually means the information will need to be transferred to another map, either by placing the maps on a light table and tracing the polygons from the original to the new map, or transcribing by eye,

- Checking the map over thoroughly for omissions and mistakes, close all polygons, and ensure that all polygons and notes are distinct and legible. Remember: only the sketchmapper can make the call as to what was observed and recorded.

See Figure 13 for an example of a redrawn map.

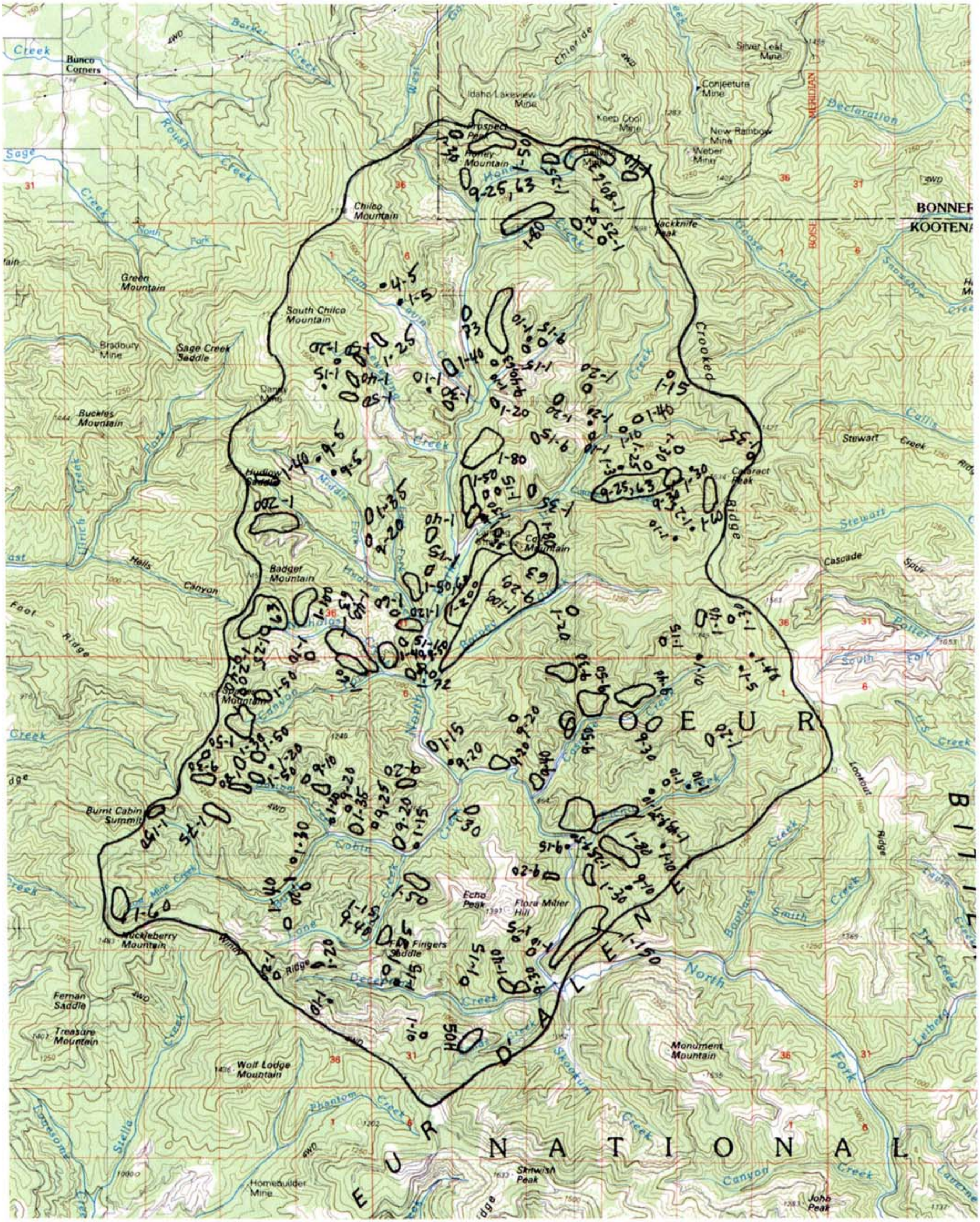

Figure 12: Example of a rough flight sketchmap.

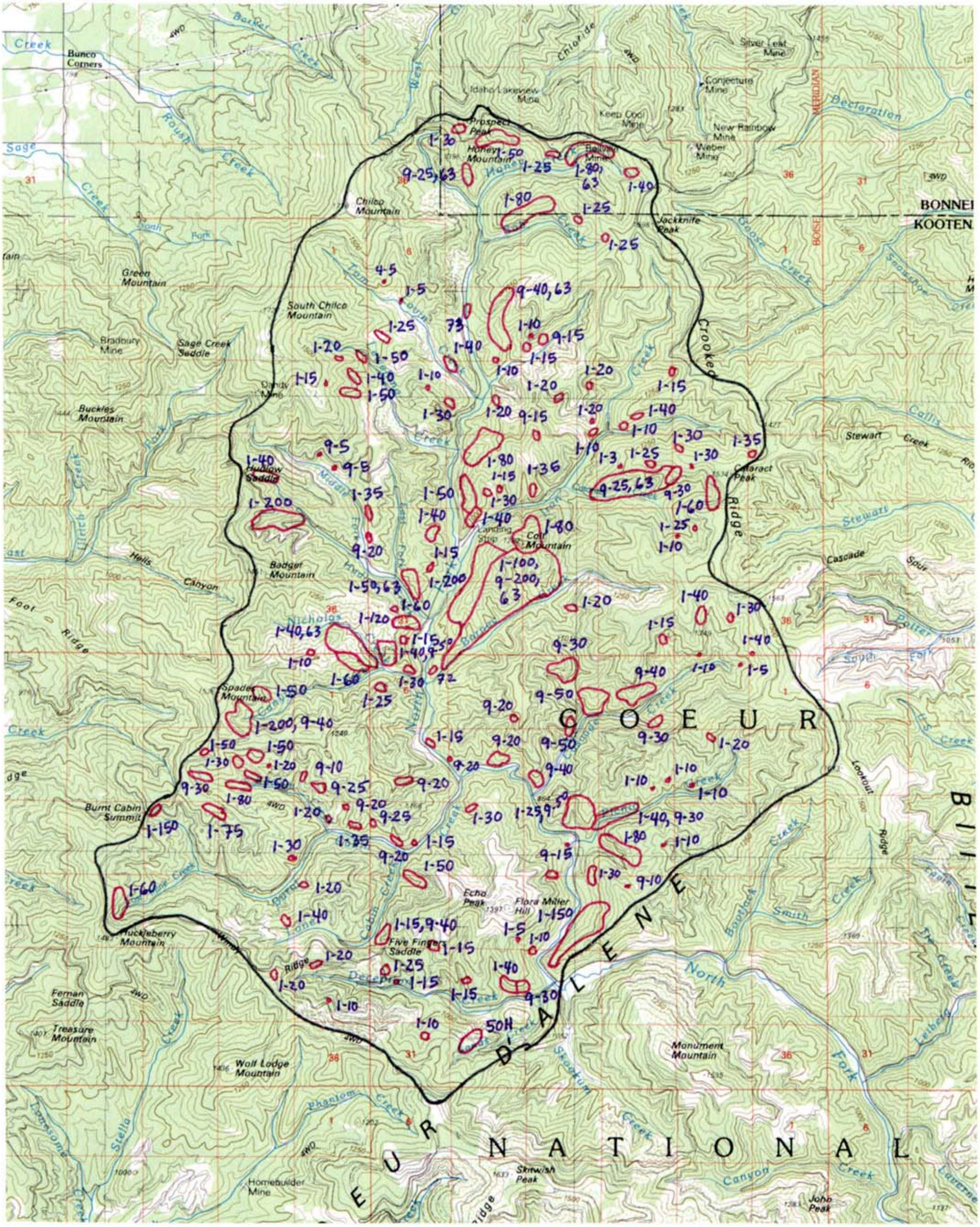

Figure 13: Cleaned-up flight map (preliminary final map).

If the flight map was originally sketched in pencil, the polygons and attributes could be traced in ink, and then the pencil marks erased. If the flight map was originally done in ink, then the polygons and attributes could be traced onto a new, overlying map using a light table. The cleaned-up, redrawn map is then ready for copying to a digitizable mylar flat map or ready for digitizing on a digitizing table, depending on the required post-processing prodedures. Prior to these procedures, the redrawn map, when copied on a copy machine, can provide customers with a preliminary map almost immediately.

Once the flight map is cleaned up or redone, proper and accurate post-processing can be done. This post-processing may consist of tracing the flight map onto a fresh map for digitizing or it may consist of tracing polygons on a scanning table for scanning purposes. The sketchmapper should consider their final flight map a personal art piece and can be proud of the work that was done to create it. See Figure 14 for an example of a completed map after post-processing.

Documentation and Metadata

Documentation accompanying the sketchmap allows subsequent viewers to understand the "what," "why," "how," "when," and "who" of the specific aerial survey. This information, the "metadata," should be written on every aerial survey flight map, along with any other pertinent information. Much of the metadata information is captured during GIS processing, but it is furnished by the sketchmapper. It is important for the sketchmapper to provide the processing cartographer or GIS personnel with information about the survey flight.

Each sketchmapper is also responsible for documenting what part of the survey was flown–the "where." The intent here is to document what was flown and was not flown so that, when large areas with no polygons are present, the end user can differentiate between an area that wasn't surveyed and an area that was surveyed but where no change signatures were found. Flown/not flown designations can either be on the flight map or on another corresponding map of reasonable scale carried specifically for documentation.

Aerial Survey Map Information Sharing

Every aerial survey program should know its map and data users (that is, its customers). Aerial surveys have been conducted for over fifty years, and there have been many different users in that time. Early users were entomologists and land-managing foresters; today, these are still very important aerial survey customers. With national and worldly interest in forest change, additional customers are being recognized. It is important for the aerial sketchmapper to understand the reasons for conducting a particular aerial survey.

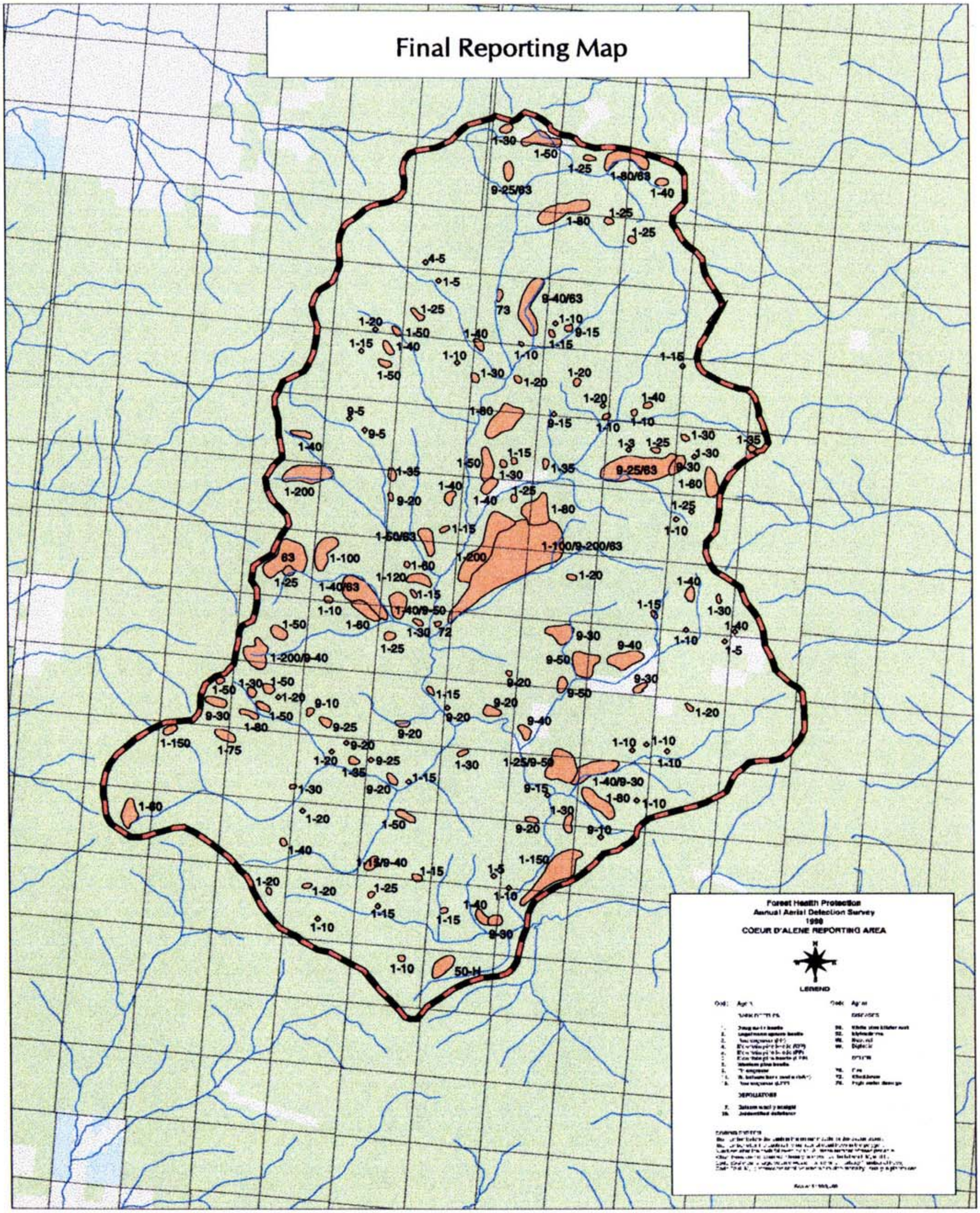

Figure 14: Final reporting map.

Overview surveys have somewhat different purposes than special surveys, but they are all collecting data by aircraft. Most always, an aerial survey conducted for land managers and historical records are more than adequate for other customers, such as national reporting efforts. But maps and data should be processed in such a manner as to accommodate all customers from local silviculturists to Forest Health Monitoring. Common aerial survey customers today include:

- Land managers from federal, state, and county agencies
- Large timber companies
- Small private wood lot owners
- Cooperating researchers from agencies and universities
- National level organizations
- Land managers in adjacent states and countries
- Log home companies, and
- Historical documentation interests.

Established aerial survey programs have a larger customer base than new aerial survey programs. These newer programs can develop their customer base by working to share the data that has been collected. Often, a potential customer doesn't know the product is even available. The value of aerial surveys extends well beyond national reporting because of the value the data has to so many others.

VIII. Helpful Hints to the Sketchmapper

This section contains tips on conducting aerial surveys that may be helpful to a new sketchmapper.

1. Properly tinted sunglasses are very helpful for detecting color change or contrast by enhancing colors on the ground. Red to rose to amber tinting does wonders for highlighting the contrast between red and green foliage. Beware of very dark sunglasses because they make it difficult to read the map inside the aircraft cockpit, and never wear green-tinted sunglasses as these obscure differences in foliage color on the ground.

2. Wear a solid-colored, dark shirt and hat to reduce unwanted glare off the window of the airplane. Never wear red or a red-and-white shirt because of the color distraction. A baseball cap-style visor reduces the glare on your sunglasses.

3. Wear a fly-fisherman's, photographer's, or similar vest, preferably black or another dark, solid color. A sketchmapper needs several pockets for pencils, pens, pocket notebooks, radio frequency lists, attribute code lists, ear plugs, facial tissue, candy, erasers, etc.

4. Consider wearing a kneeboard. On it, have a list of all pertinent radio frequencies and attribute codes for your flight. The kneeboard also provides a stable platform for writing and drawing on your map.

5. Note, have with you, maintain, and monitor the radio frequencies necessary and appropriate for your survey.

6. Usually, the area to be surveyed is larger than a single map: this requires the use to two or more maps. It is better to have one large folded map than several small maps, requiring you to go back and forth from one to another. The best way to prepare the flight map is to cut and tape multiple maps together prior to the flight, as follows:

   - Cut the map along the edges to be matched with scissors or a sharp blade.
   - When connecting two separate map edges together, turn the two maps over, face down, on a light table; match map features and edge nodes; then tape, first, the center, and then the remaining matched edges. Always use clear tape. Do not put tape on the face-side of the map. Tape tears from the back as well.
   - Repeat the previous step until all maps are taped into one large map. This process will ensure that no tape is on the writing surface and that the finished flight map can be used on a light table for tracing, if necessary, after the flight.

7. Sketch and attribute in pencil; then, during post-flight processing, ink the polygons and attributes in contrasting colors with the attributes entered right side up.

8. Always try to procure an aircraft with a built in intercom system for pilot and crew.

9. If you smell something burning, you're probably right. This would be a good thing to share with the pilot.

10. Don't sketch tired. Fatigue produces poor quality and low productivity.

11. To reduce the physical strain of flying as the day wears on, fly the mountainous terrain in the morning and save the more gentle terrain for the afternoon if the situation allows.

12. Pace yourself: if you have a choice, plan to fly the busy areas when you are fresh.

13. Help the pilot help you: tell the pilot of your intentions. Direct the pilot during the first part of the survey so that the pilot can learn your system and method; the pilot will need less direction later in the survey.

14. Pilots like to monitor local airport radio frequencies, as well as 122.9 MHz: a designated air-to-air frequency. Learn how to tune it in yourself.

15. Keep the cockpit free of clutter. Beware of wires, cords, belts, notebooks, water bottles, etc.

16. The entire crew should contribute to the safety, efficiency and effectiveness of the survey. If you are in the airplane, you are part of the crew.

17. For flight-following, look at your watch when you do your first check in and note the time. It's good to try to do your 15-minute check-ins on the quarter hour because its easier to remember the interval. (You've got plenty of other things to be thinking of when you're flying survey). Consider a watch with a loud alarm that can be set to go off every 15 minutes. Be aware that not all flight-following personnel on the ground use a timer.

18. Look out the window more. It is easy to "get behind" by spending more time at the map than at the window. Watch the drainage patterns or another predictable feature to orient yourself. Remember to look ahead as well as out perpendicular away the aircraft.

19. Be careful of strong winds aloft and downdrafts. Be careful when attempting to gain altitude on a hot day; when climbing

from at a low AGL, fly into the wind (look for the direction the clouds are coming from for the wind direction).

20. Draw only what you see. Draw the disturbance pattern just as it appears from the air (just like delineating areas in aerial photo interpretation).

21. The lower you fly, the more you'll see. But don't fly below 500 feet AGL in an airplane.

22. Maintain proper flying altitude for the expected disturbance signature. Fly too high, and you can't determine host or causal agent (e.g., adelgids); fly too low, you can't see far enough away from the aircraft for the coverage, and you may be at an unsafe flight altitude.

23. To be efficient and effective, when possible, fly fast through areas with little or no activity and fly slower in busy areas. But don't have the pilot continually change the speed of the aircraft. Maintaining a constant speed helps tracking because the rhythm and the flow of passing land features related to the flight map becomes predictable.

24. If you are tired, there's a good chance your pilot is too. Tune in to how your pilot is feeling. A fatigued sketchmapper risks poor quality data; a fatigued pilot risks a lot more.

25. Know where to find daily dependable weather forecasts for your area. Use the "Pilot Brief" on-line at many airports for current radar and satellite images (these are updated frequently).

The Sketchmapper's Check List

The following is a checklist of items that should be accounted for before the beginning of each season and each flight.

- ___Aviation Management Plan - read
- ___Plan for the day - read
- ___Weather for the day - checked
- ___Briefing completed, including from pilot, to pilot and to crew
- ___Suitable flight map, cut , taped, and folded properly
- ___Pens, pencils, and erasers
- ___Red- to amber-tinted sun glasses
- ___Solid dark (not red) shirt, with pockets, if available
- ___Dark billed cap
- ___Vest
- ___Headset
- ___Pocket notebook to record flight times, area flown, and other pertinent information
- ___List of important radio frequencies
- ___List of important telephone numbers
- ___All necessary personal contacts were made prior to flight
- ___Attributing code list
- ___Camera (with film)
- ___Backup hand-held radio
- ___Cell phone for convenient calling (on the ground) and for potential emergency situations
- ___Water
- ___Lunch
- ___Snacks
- ___Jacket or coat
- ___Minimum emergency/survival kit (should fit in your pockets), including: waterproof matches/fire starter kit, hand held radio, hard candy, water purification tablets and water bottle. Each person should decide what their personal needs might be for the area they will be traversing in the event of an emergency landing.

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