Air and Ground Direction Finding

By Bruce E. Gordon

Characteristics Of The ELT And Its Signal

Most civilian aircraft are equipped with a battery-powered transmitter that is activated on impact of a crash. The power output is very small (1/16 to 1/4 watt), which makes the range over which it can be heard usually under a hundred miles (we will go into conditions later that will show you it sometimes has a range of less than a mile). These transmitters are officially called Emerfency Locator Transmitters, or ELTs, and sometimes called rescue beacons, crash locators, or beepers. The ELT is designed to transmit simultaneously on two radio frequencies, VHF (121.5 MHz) and UHF (243.0 MHz), but sometimes are damaged and only transmit on one frequency. ELTs used by the military normally operate on UHF only, Some boats are also carrying these transmitters; they have the same characteristics as those used by civil aircraft and are called Emergency Position Indicating Radio Beacons (EPIRBs). All beacons have a distinctive swept tone (usually sweeping downward in tone) with two or four sweeps per second.

Radio waves are invisible, and this sometimes makes it hard to visualize how they can be reflected, blocked, scattered and polarized. In many ways, they behave like light, and this analogy should make it easier to make sense of an otherwise confusing set of DF indications.

The ELT Location Problem

There are three parts to this problem:

1. Get to a point where the signal can be heard.
2. Establish a direction to the target or a target location.
3. Get to the target.

Execution of these steps will vary radically from incident to incident. On an airport, it may be as simple as walking out of a door, taking a single DF bearing and walking to the offending plane.

The vast majority of beacon searches so far have been non-distress or accidental. Most of these are undamaged and located in clear areas like airports. Finding them, particularly from high flying aircraft, is like "shooting fish in a barrel" and has led to exaggerated claims both for equipment and techniques. Unfortunately, the cases of real distress are also the ones likely to involve damaged beacons in awkward positions, rough terrain, wet or snowy weather, night operations, and difficult access, any or all of which will tax the best of our skills and equipment. While directed toward the ELT, the principles described apply to all types of VHF radio location and underlie the specific procedures outlined in later sections.

Under IDEAL conditions, the signal from an ELT (1) radiates equally in all directions, and (2) takes a path directly from the transmitter to the receiver. The first characteristic means that the signal strength gets stronger as the ELT is approached, regardless of the direction of approach. Signal strength or "build-fade" location patterns use this principle and work in many cases. Unfortunately, the condition of equal radiation in all directions is the one most radically violated in distress situations and this location procedure is slow at best and should never be depended upon as a primary search technique.

The second condition says that the direction to the transmitter is the same as the direction of arrival of the signal at the receiver. All direction finders use this principle.

You use this second effect constantly with light without thought. For example, if a light were turned on in a darkened room, you could easily "measure" its direction from you with your eyes and could easily "track" your way to it if required. There are two drastic differences between "optical DF" and radio DF. First, you have been practicing optical DF and becoming aware of its illusions and reflections all your life. Second, the eye has MUCH more resolution, or ability to distinguish between objects, than the radio DF antenna. A radio antenna equal to the eye's resolution would be miles in diameter and hardly portable. The small, portable or aircraft DF antenna "sees" the world in about the same way you would if your eyes were covered with 16 sheets of waxed paper. The larger portable or fixed antennas are better — like 6 or 8 sheets of waxed paper — but a long way from 20-20 vision. Even with all that waxed paper in front of your eyes, you would be able to track toward a single light in a room, though not with the precision as with no waxed paper goggles.

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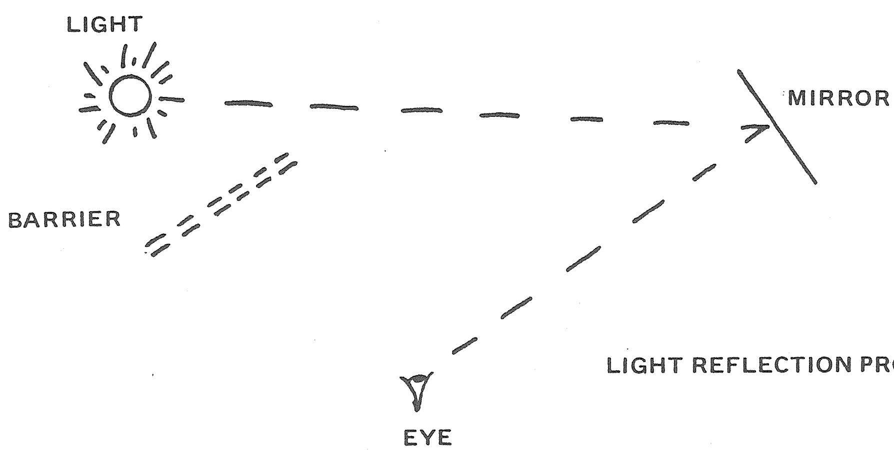
A word here about sensitivity. Sensitivity refers to the ability of a receiver to pick up a weak signal (to see a dim light). Both a good receiver and a "high gain" antenna are required for a sensitive DF. The ELT signal is weak, like a very dim light. Using a receiver with poor sensitivity would be like putting on sunglasses under the goggles or spraying them with black paint. They might still work, but you could do a lot of stumbling in the dark before first catching sight of the light. There seems to be no such thing as too much sensitivity.

If a good mirror were added and properly oriented, as shown in the sketch below, you would usually see two sources or lights of about equal brightness. The waxed paper goggles, our antenna of the moment, would averabe the two and give the impression of one light half way between. If the light were made directive, like a flashlight pointed at the mirror, or if a large obstruction (mountain) were placed between the light and your position, the apparent direction would be directly toward the mirror, even though with normal eyes, you still could see light from the side of the flashlight or light diffusing around the obstruction.



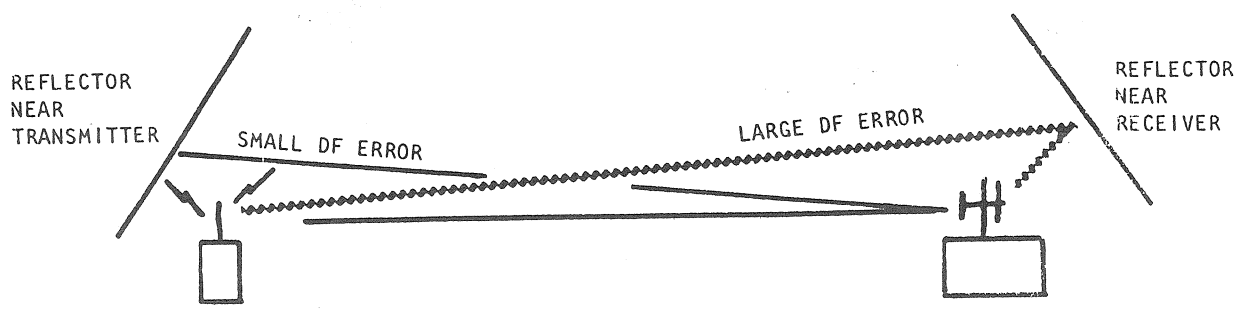
LIGHT REFLECTION PROBLEM

If the mirror, which is a very good reflector, were replaced in turn with a wrinkled sheet of metal foil, a white wall, a dark wall and a strip of black velvet, the reflection would grow progressively weaker, and at some point, our "antenna" would again "see" and point to the light from the side of the flashlight or sneaking around the barrier. Natural terrain also varies in its efficiency as a reflector. Metal is obviously a good reflector but smooth, wet snow or smooth, wet grassy hills are almost as good. Rough, dry rock is closer to the dark painted wall, while heavy tree or brush cover approaches the "velvet" class. The reflective situation can thus change with the season or even time of day. This is why some easy summer exercises have turned into winter muddles in the same place.

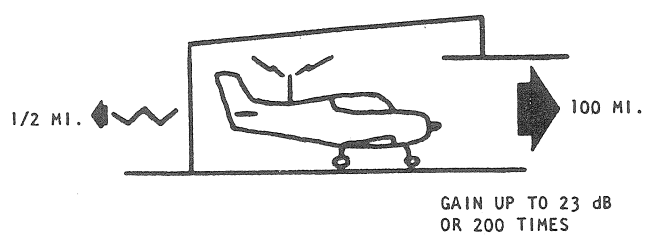
So far we have dealt with one source and one mirror. With our waxed paper goggles in place, it should not be too hard to appreciate that if several mirrors were placed at various angles all around the observer's position while keeping the direct source obscured, any direction would be very hard to determine and directions that were found would change substantially with small changes in the observer's position. The changes in direction with observer motion would be particularly large and rapid if the reflectors were very close to the observer. The directions perceived might even be due to "wrinkles in the waxed paper" (small defects of the DF receiver). The effect is rather like trying to find the sun on a very foggy morning; you know it's there because it is light, but you had better have a compass to find east! The solution to this problem is often the same as for the ELT — change position to get your head (antenna) out of the fog.

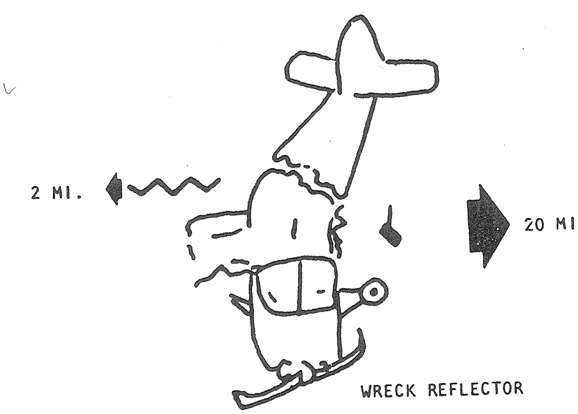
For ELT search, "getting out of the fog" usually means going higher for either ground or air search. This will both get away from nearby reflectors and improve the chance of getting a clear view of the source over the obstructions. Exceptions occur in air operations where the signal is blocked from going upward or is too weak to be heard 10,000 feet away. If climbing isn't possible or doesn't work, a methodical search will probably be required to find a place where the source can be seen clearly. In most cases, clear view is distinguished by a positive direction that does not change much as the observer moves. Before we leave our room with light and mirrors, imagine trying to find the light by plodding back and forth with an opal glass bowl over your head so that only changes of brightness could be sensed. This is essentially the build-fade location method.

The effects of obstructions in the path between the ELT and the DF set can be roughly grouped according to their location: near the transmitter, near the receiver, or at intermediate range. Objects near the transmitter affect the signal distribution or directivity of the source like the reflector of a flashlight. They affect both the ability to hear a signal at a distance and the intensity of reflections. Both objects near the receiver and at intermediate range will block or reflect the signals but those near the receiver are more visible, more severe, and often avoidable. The sketch below shows how reflectors near the receiver produce more severe errors.

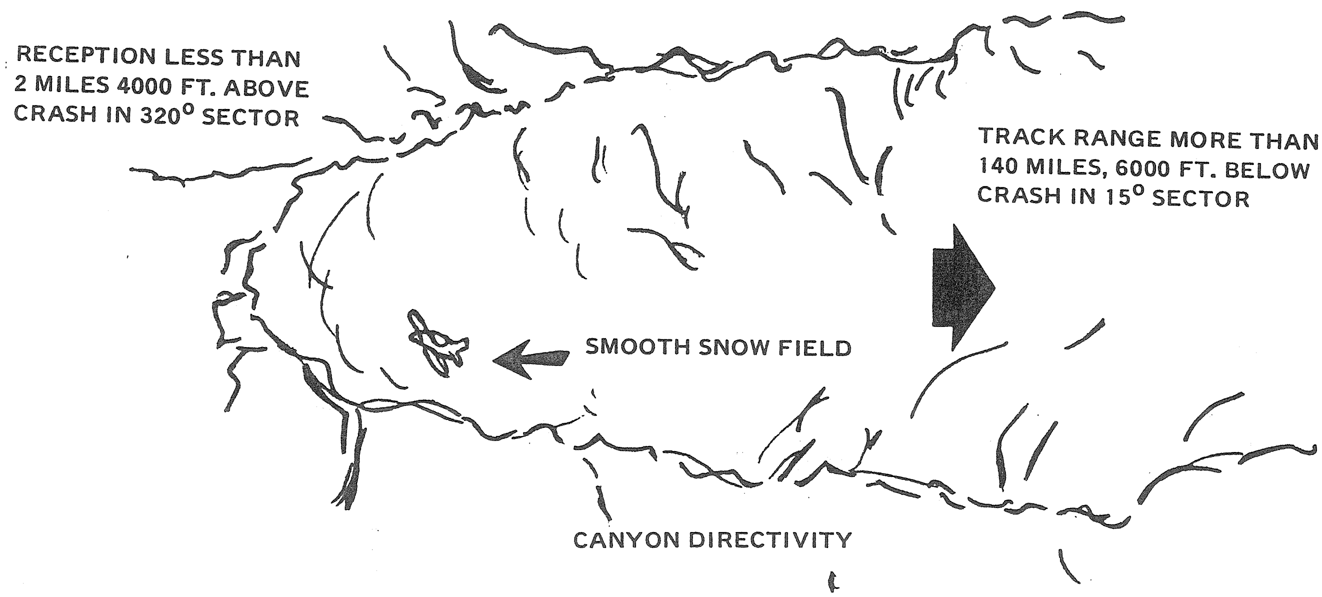


Let's take a look at some of the things near the ELT that can cause directivity. The "wreck reflector" is fairly common. The plane may come to rest on its side or back or the ELT may come loose from the plane. In any case, conductive metal parts of the airplane arranged around the antenna will sharply alter its uniform radiation pattern. In the all too common case of broken antennas, these random metal parts may actually BE the antenna. The "T" hangar reflector is an extreme example encountered during an accidental beacon search. It is difficult to deliberately build an antenna with that much directivity. An example of the vertical directivity mentioned earlier is also shown. Values were obtained from an actual wreck situation.





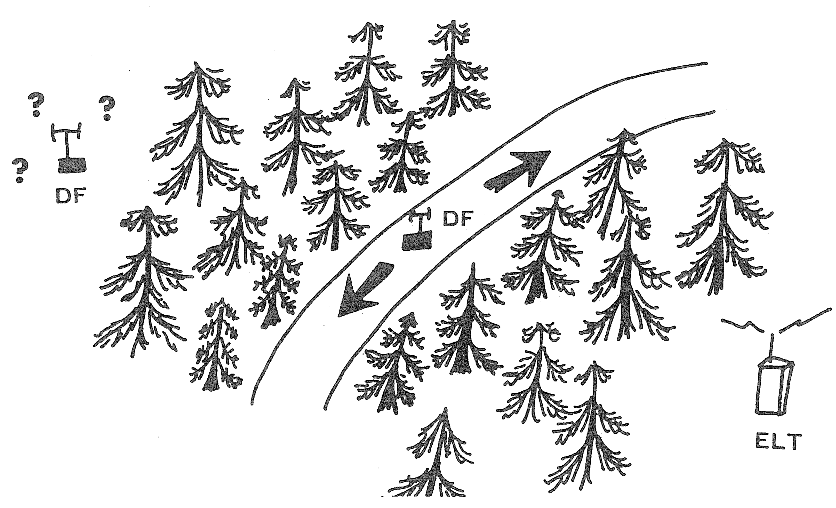
Open ground is not as good a reflector as metal as noted earlier but if there is enough of it, it can do a very good job of beaming the signal. Canyon directivity is quite common and pronounced, although it is seldom as extreme as the situation depicted in the sketch on the next page taken from a California crash.



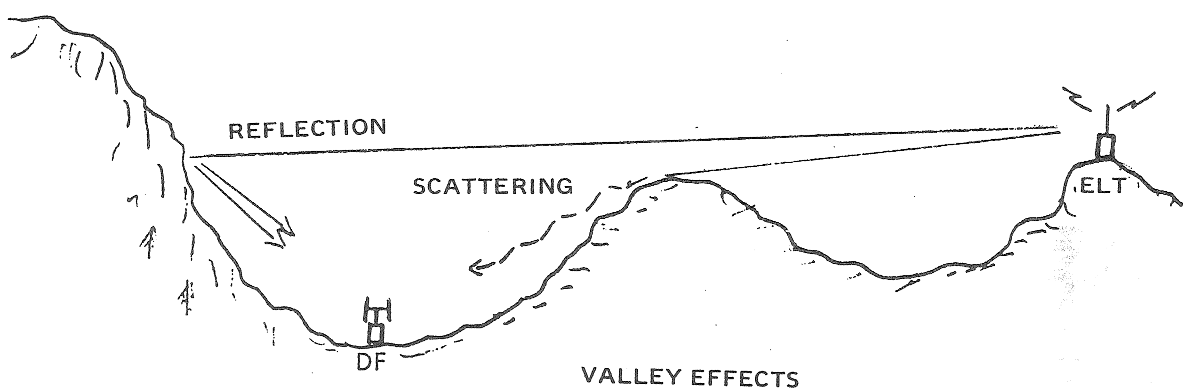
There is little we can do about the directive source except to realize how it can affect target location and perhaps avoid wrong conclusions and time-consuming detours. Poor DF environments near the receiver can be recognized and either avoided or compensated. In addition to the type of reflecting surface and amount of illumination mentioned in our light examples, the strength of a reflection depends on the angle of reflection and the distance from reflector to receiver. Fortunately, most natural objects are efficient reflectors only at small angles. The effect is rather like the reflection of the setting sun on a choppy lake surface. The reflection sparkles and shifts about a bit but the average direction is still correct. Signals scattered or diffracted over the tops of hills have this same characteristic. On the ground, wires, metal poles, vehicles, and even people near the DF antenna can produce large errors. People are not particularly good reflectors, but the tendency to gather close around the "source of the action" should be avoided. Ten-foot spacing is usually good. 20 to 30 feet spacing from vehicles and 100 feet from metal or masonry buildings is usually sufficient. Overhead wires or signs are often troublesome because more signal reaches them than gets down near ground level.

In almost all cases, interference from objects within a few hundred feet of a DF receiver will produce a significant variation in the measured direction for changes of 5 to 10 feet in the DF antenna location. This effect is due to interference or diffraction and is very useful in evaluating the quality of the bearings taken from any location.

Growing trees and high brush, especially if wet, can strongly absorb radio signals in the same way they absorb light from the setting sun. In dense foliage, most of the ELT signal, like most of the light, will come from overhead and no reliable direction sensing will be obtained. Even less obvious is that readings taken from a cut for a power line or road through heavy tree cover will have a strong tendency to line up with the cut, regardless of the direction to the ELT. This latter condition will give apparently good bearings. Find a more circular clearing a few hundred feet in diameter.

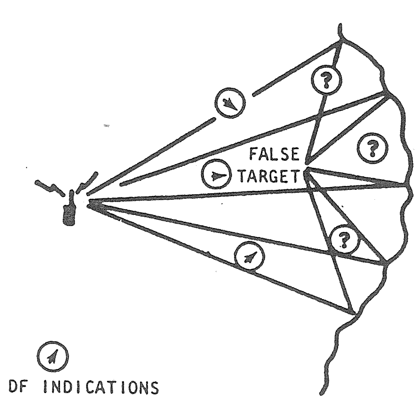


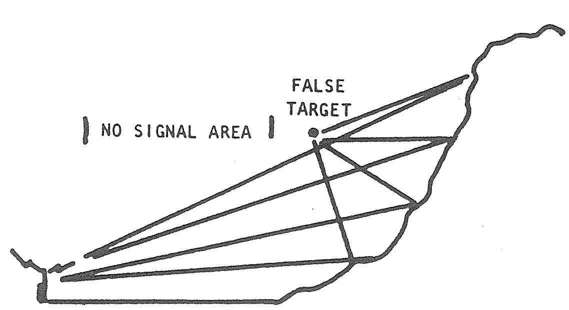
The last of the "near receiver" effects concerns reception at the bottom of valleys or canyons. If the canyon is nearly aligned with the direction of the signal, it will act like the cut in the trees mentioned above. This is not so bad because that is where the best access route is likely to be anyway. If the direction is closer to right angles to the canyon, the signal may be reaching the receiver EITHER by scattering or diffraction over the canyon wall toward the source OR reflecting off the wall OPPOSITE from the ELT's direction. The first case is like seeing the glow over a ridge after the sun has set behind it. The second is like seeing the sunlight hitting a high ridge after the valley has fallen into shadow. The first effect will usually predominate in shallow, dry valleys while the second is most likely to be found in deep canyons with wet or snow-covered ridges. Scattering, which gives a correct bearing, will usually give a constant compass heading over distances of a few feet to a mile or more. The reflection, which is in the wrong direction, will usually give bearings that swing about by more than $\pm 45^{\circ}$, but the swinging is not so rapid with distance as where the reflecting surface was closer to the receiver. Full swings may take several hundred feet of travel in large canyons. A third possibility which should not be overlooked is that the ELT is IN the canyon. In this case, bearings will be fairly steady but will converge on a geographic point rather than on a compass heading. This case will produce much stronger signals. If the scattered and reflected effects produce about the same signal strength, no bearing may be obtained at all. The solution, as before, is to pick a new location, preferably higher and clearer.



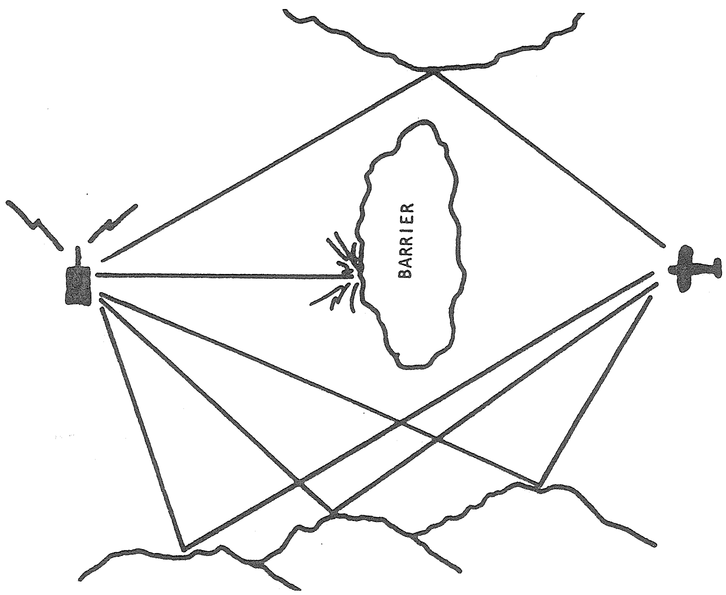
VALLEY EFFECTS

Reflecting objects near the receiver are not a major concern to airborne DF mainly because the aircraft is not so close to reflecting objects and its motion automatically averages rapidly changing bearings. There are both vertical and horizontal focusing effects caused by large terrain features which can generate false targets as illustrated below. DF instruments will point to these false targets over a substantial area, causing unkind comment on the instrument quality. If the false target can be approached, it disappears like the ghost that it is, instead of increasing in strength and DF sharpness like a true target. The effect also disappears at high altitudes but light aircraft may not be able to go high enough. Many ELTs produce patterns of spotty reception over a wide area. Unfortunately, there appears to be no reliable way to distinguish between a false target and a weak signal from a damaged ELT if the ground cannot be approached, although the vertical sensors being used on some aircraft should help. Certainly, an aircrew should continue and extend their search if their first target is weak and diffuse. The target location should be marked before departure for later return if necessary, because a real target in a snow-covered valley may present the same indications.

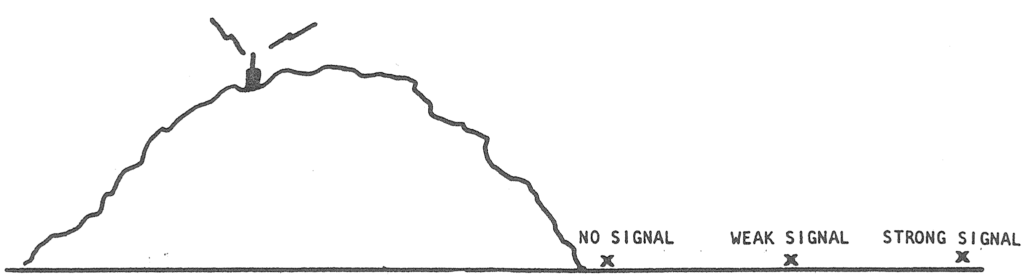




The sketch below illustrates, from an airborne standpoint, the most prominent effect of intermediate range obstructions. This situation is the same as the blocked light and mirror discussed earlier. If only the reflections from the mountains to the bottom of the sketch were strong, the initial DF indication will be toward the reflecting hills and may be diffuse and swing about. When the aircraft gets to the reflecting hills, the ELT comes in sight, overpowers the reflections and provides a correct new course. The indicated course often swings wildly for a minute or two during this transition. The aircraft arrives at the target, but by a curved path. This illustrates a basic difference between homing and triangulation. Reflections of the type described, DF instrument errors (like not having the course lined up with the airplane), and even wind drift will cause the course to the target to be curved, but not much longer than a straight shot. The effect of reflection and DF errors on a triangulation plot are often drastic. This is the primary limitation of the triangulation technique.



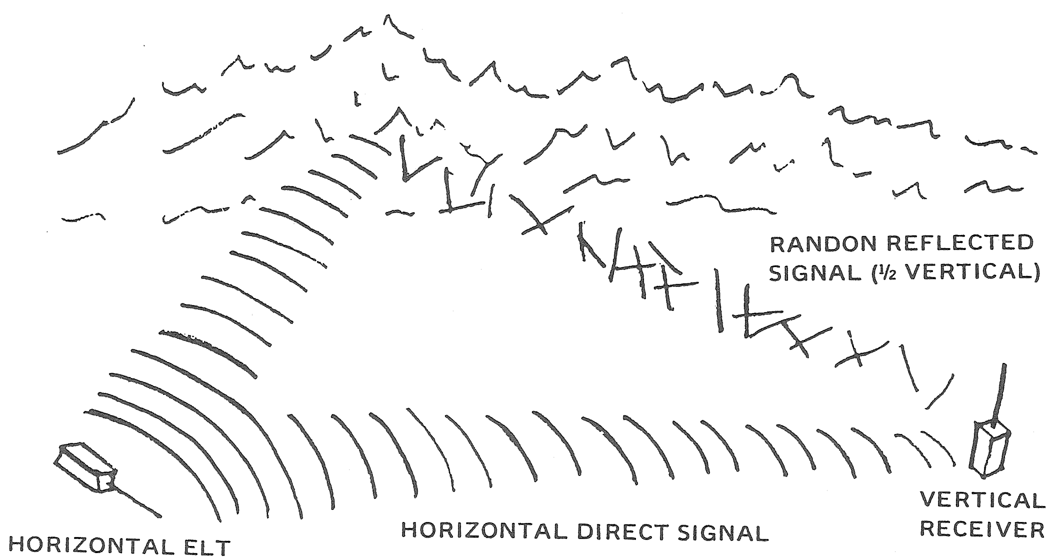
An effect particularly important for ground operations is blockage or shadowing by hills and how this affects signal strength as the DF team moves. Radio waves will bend or scatter around hills to some degree but the signal rapidly weakens as the angle of bend gets large. In the sketch below, the signal will fade and completely disappear even though the DF team is headed directly toward the ELT. Not recognizing this situation and not having the confidence to continue to pursue a set of good bearings through a signal fade has been responsible for a lot of wasted motion. Once understood, shadowing can be a help rather than a hazard. For instance, if the ELT had been on the near face of the hill rather than on top or on the back side, the signal strength would have increased as the hill was approached rather than fade out. Ground DF teams should listen continuously while traveling and note where the signal is heard and where it is lost. The shadows of an ELT, like the shadows of the sun, can be a good indication of direction.



Hill Shadows

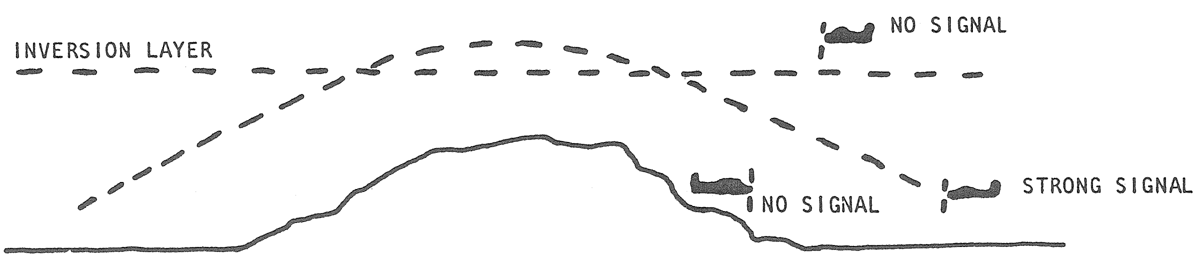
All of the discussion so far has been about one signal and its reflections. Multiple, simultaneous ELT signals do occur and if they are about the same strength at the receiver, will act like strong reflections. Three differences: (1) two ELTs will produce confused bearings over a much wider area than terrain reflections, (2) climbing usually makes the situation worse, and (3) the situation can be recognized by listening for two unsynchronized tone sweeps. Note that both ear fatigue and severe reflections can cause a single ELT signal to sound funny; rather like a fading short wave signal, but two separate sweeps produce a distinctly different sound. As with reflections, the usual solution is to find a location where one signal predominates and clear bearings can be obtained. This is one place where the larger ground antennas have an advantage because they may be able to resolve the two signals.

Both radio and light waves have a property called polarization. Most light sources are of random polarization, but light can be polarized by passing through a special filter. If the light then passes through a second filter oriented the same way, not much happens. If the second filter is turned 90^{o} (cross-polarized), most of the light is blocked. Radio antennas are usually polarized. Most amateur, aircraft, CB, and commercial 2-way radio antennas are vertically polarized (antenna rods vertical); TV and FM broadcast are horizontal (antenna rods horizontal). The important thing is that for best performance, the transmitting and receiving antennas should be turned the same way. Most reflections from natural objects scatter and rotate the original polarization, so if a vertical antenna is used to receive a signal from an ELT lying on its side, the cross polarization effect can act the same as a barrier in the direct path and emphasize the reflection. This effect can be overcome by rotating the DF antenna for maximum signal reception. It is impractical to do this for an airplane, but the bend in the usual receiving whips helps some.



CROSSED POLARIZATION

Temperature inversions, where the air temperature goes up with increasing altitude, can hold radio waves as well as smog close to the earth. The effect is most common over water and near coastal regions and can make reception possible at ranges and in locations far beyond that normally expected. VHF communications has been established a number of times between California and Hawaii using this effect. The effect is often unstable so that signal strength varies substantially over times as short as 10 or 15 minutes. Bearings, when obtained, are usually dependable.



When listening to an ELT or any other VHF signal from a moving car, the signal will often be heard to "flutter," or vary rapidly in strength. If this kind of flutter is observed when the DF receiver is held fixed, either the ELT or a reflector in the path between is moving. This can be a key item in finding an accidentally-activated ELT in a car or a mail sack. In at least one search, a valuable initial heading was obtained by noting that a fluttery ELT signal was received as an airliner passed over a ridge of intervening hills. The airliner was acting as a moving reflector!

In the beginning, the three elements of the ELT search were stated as: (1) get to a point where a signal can be heard, (2) establish a direction to the target or a target location, and (3) get to the target. Let's now look at some procedures for accomplishing these steps based on the "rules" of ELT signal propagation.

If the weather conditions permit, aircraft with trained crews can rapidly localize an ELT and direct ground teams at least close enough to hear the signal and finish the track from the ground. Because of the high work load, two pilots should be used for all IFR DF flights. A safety pilot is a good idea even in VFR. In extremely bad weather where aircraft cannot be used, multiple ground teams coordinated in their efforts can use triangulation to establish an approximate location to start close-in tracking. This is usually a slower procedure than air search. In all cases, DELIBERATE speed and efficiency are important, both to increase the chances of any survivors and to locate the ELT before its batteries expire (48 hours in low temperatures). Safety and organization should never be sacrificed for speed. A few minutes planning can save hours of milling about the field, or even catastrophe from convergence of uncoordinated efforts. Remember that the job of the rescue unit is to assist in the recovery from a disaster, not to become a part of it!

In general, ELT searches are started either from the report of an overdue aircraft from flight plan or family information, or from the reception of ELT signals from one or more passing aircraft. Fastest response is obtained when both conditions are present. Records of the Air Force RCC indicate that most crashes occur within a few miles of the pilot's intended course, so if the course is known, a route search is a first priority. Weather data and satellite photos may suggest the most likely points to begin on a long route. An optimum altitude for first search seems to be about 4,000 feet over the terrain, particularly if no reports from high altitude aircraft have been received. If more aircraft are available, several parallel tracks at 4,000 feet and one at 10,000 feet can be flown. Both VHF and UHF should be monitored if the aircraft are so equipped. If more than one plane is used, a leader and communications between planes that can be maintained while tracking is in progress should be established for information and bearing exchange and to avoid dangerous congestion over the target if one is located. Don't forget to keep your eyes open too, in the event the ELT didn't work.

All civilian and military aircraft have been requested to report to FAA any beacons heard, giving their altitude, place first heard, place loudest, and place where contact is lost. DF-equipped search aircraft can use these reports to select a place and altitude where initial reception of the signal is most likely. Preference should be given to lower altitude reports.

Ground teams usually operate over a smaller geographic area than aircraft. It is desirable that they have good, accessible DF sites "staked out" in advance. People with access keys, and funny little back roads, are a lot easier to find on a sunny weekday than a rainy Saturday night. Choice of initial DF sites should be based on their time for access and field of view as well as the mission data described above. Because of the more limited range of ground DF, this initial hunt for a signal can be both time consuming and frustrating. Where this search does not involve unacceptable recovery times, it probably should be used even if air support is available. The provision for central coordination of ground teams and their measurements is probably even more important than for aircraft. When selecting potential DF sites, care will be required to avoid loss of sensitivity and errors due to other transmitters which occupy the tops of most easily accessible mountains. On these mountains, walking 50 to 100 yards down the side in the suspected direction often yields better sensitivity and bearings than can be obtained on top because it gives some separation from the high-powered transmitters.

Aircraft Procedures

The following procedures assumes an aircraft with properly functioning left-right, or homing, DF equipment.

When the signal is first heard, it will normally build up or "fade in" over a period of a minute or two. Continue the original course and altitude until a fairly strong signal and/or a positive DF needle indication is obtained. Resist the urge to turn and immediately follow the needle. Make a full 360° turn at no more than 30° bank. The DF needle should cross zero only twice on headings about 180° apart. If more than two crossings are noted, try again with a shallower bank. If more than two crossings are still observed, the bearings are unusable. More on this in a moment.

The DF needle of a homer, when deflected from zero, always shows the direction to turn the airplane to track toward the transmitter. The amount of deflection has little significance and can be set to the taste of the pilot with a sensitivity control on most units. If the initial 360° turn showed the desired two cross overs, turn in the indicated direction until the needle centers, note the magnetic heading, and fly the heading. The DF needle will often wander back and forth around zero at 10 to 30 second intervals. This is caused by flying through weak reflections. If the variations are not too large, fly a course that averages left and right swings like flying the needle of the needle-ball instrument in rough air. Don't try to "chase" the needle. If there is ever a doubt about the quality of the course, make another 360° turn to verify two crossovers. A "clean" DF track will result in a gradual increase of signal strength and DF needle sensitivity.

If the DF needle is steady, the aircraft should be yawed or turned 5 or 10 degrees one way or the other to see that the needle still gives an indication to turn back to get on track. For example, if a yaw to the right produces a deflection to the left, you are still on the way to the target. If the needle goes to the right instead, you have passed the target. Target passage is usually accompanied by substantial needle flutter and sharp signal strength changes, particularly if the DF antennas are top-mounted on the plane. It is difficult to cross a target so accurately that no needle deflection occurs. Target crossing should be verified by recrossing from several angles. After crossing, fly outbound for about a minute before starting a turn so that the new inbound course is well stabilized. If conditions permit, descend to a lower altitude to improve the target location. In VFR conditions, a transfer to visual search will probably be made after 2 or 3 good crossings. Precise crossing should then be avoided to let the observers see. Some aircraft installations employ a second antenna pair to improve the accuracy of station passage indication. It is a very slow and unreliable technique when the receiver is far from the ELT, particularly if there is a directive source. Very close in (less than ½ mile) the rapid change of strength (brightness) with distance is a good way to complete the target location. Many DF sets provide for both strength and DF indications for this reason.

"Clean" signal DF with good equipment is relatively easy and straightforward. What distinguishes the good DF operator—air or ground—is his ability to understand the situation and locate the target rapidly under adverse conditions.

Let's return now to the initial signal acquisition and examine some problem situations. If the initial 360° turn showed more than two crossovers and was made at a considerable distance from a plotted signal location, the best procedure would be to continue on toward the original destination at the original altitude, trying turns at strong signal points every 10 minutes or so until clean bearings are obtained. If the turn was made at the plotted location, or if no plot exists, change altitude by 2,000 feet—preferably up—and try the circle again. Move the pattern over a mile or two on the odd chance of being directly over the target. If no reliable bearings result or if the signal is lost, a second climb and turn may be useful, but this is about a limit. If the aircraft is equipped with UHF, both VHF and UHF bearings should be taken, and the best ones used. In areas where both VHF and UHF signals are heard, but they give substantially different headings, treat the resulting bearings with some caution, but keep in mind that two different ELTs could be involved.

Even though the left-right DF is usually more efficient, wing shadowing should not be overlooked if the left-right needle gives unreliable results. Shadowing is less susceptable to some polarization problems. A signal strength meter is very handy for this procedure, although if the signal is not too loud, the squelch or background noise in the receiver can be used as an audible strength reference. To use this procedure, an antenna aligned with the wing is needed. In a steep banked turn, the received signal will show a drop in strength when the wing comes between the ELT and the antenna.

In mountainous terrain, examine the terrain under you by sight or map while doing the circles for features such as high mountains or ridge lines that could cause focusing or for major barriers nearby that could shield a signal. If a likely terrain feature is present, use it to determine the most probable direction to the source (but not back the way you came). If no such features are present, continue your original course. In any case, use the altitude which gave the strongest signals. Continue on this selected course for at least 25 miles or until a terrain feature is crossed which would have prevented reception at the initial fix.

If another fairly strong signal area is encountered, repeat the turn and act on the result if clean bearings are indicated. If not, the same altitude change and terrain examination as before should be repeated. In fact, a continuous watch should be kept on the terrain for clues to what is causing the reflections. A third possibility is that the signal will fade out after leaving the original fix and not return. If this happens, return to the original fix, turn 90° in either direction and try again. Return to the fix on a parallel course to give wider coverage. It will be a rare but not unprecidented situation if the above procedure is completed with no useful bearings obtained. The most likely reason is that the ELT is near the original fix and situated in such a way as to prevent tracking. In IFR conditions, ground support should be called. If visibility permits, radio shadows of hills around the fix can be used to narrow down the possible location. This requires flying below the hilltops and close to the sides of the hills to be effective and can be hazardous. Flying close to the ground and behind hills is one of the few procedures that can be used to separate two simultaneous ELT signals so that they can be tracked down one at a time. The fact that the ELT can be heard near the ground usually confirms that the ELT is nearby and that the fix is not a false target from a distant transmitter. If the area around the fix where the signal can be heard is not too large, a small scale grid search using a signal strength meter may be successful without using too much time. To the author's knowledge, no ELT that has remained on the air has failed to yield to these procedures.

Once a good initial bearing is obtained, the signal may be lost for distances of 15 to 25 miles on the way to the target. Failure to believe and hold a good heading for the required time, particularly if the signal gave some "funny" readings as it faded away, is a major cause of lost motion in ELT search. Another is a tendency to track and report every test ELT signal that comes on the air. Real signals do not appear abruptly for a few sweeps and then cut off again. Reacting to every test can tie both the pilot and the entire search organization in knots and destroy a methodical search. Another waste of time, particularly early in the search, is chasing after strange noises and "mike clicks" that are often reported. While it is possible for an ELT to be damaged in a way that it will send out a very non-ELT type sound, no actual case has been verified.

At its limits of sensitivity, a good DF set will track signals too weak to hear. This has been useful in rapid initial signal acquisition, but it must be remembered that the DF set will point to ANY source of signal, including noisy powerlines and stray signals from radio stations on hilltops. For the same reasons noted for ground teams, air DF on weak signals should be avoided in the vicinity of mountains crowded with radio stations.

Ground Search

Ground search involves weaker and more obstructed signals than air search with less freedom of movement or maneuver. These disadvantages can be partially overcome by triangulation, particularly if multiple teams are available, but triangulation is more affected by measurement and reflection errors as we have seen so the evaluation of bearing quality becomes an important skill. Regardless of the type of equipment used, its performance on "clean" signals should be thoroughly in mind so changes in field performance can be evaluated.

Taking and evaluating a bearing has three steps:

1. Find an approximate heading and change the antenna polarization from vertical to horizontal and note which produces the strongest signal. If there is a large difference (6 dB or more) use the orientation that gives the strongest signal for the following steps. If the difference is small, do the following steps twice, once with each polarization to see if any big differences in indicated direction result. If the bearings differ by less than 20°, use vertical polarization. If a large difference shows up, report and plot both until either the difference disappears or it becomes apparent which polarization is producing converging bearings.

2. While standing in one place, swing the DF antenna through a full circle. If signal strength sensing is being used, a single maximum and one or two nulls depending on the antenna characteristics should be obtained. The sharpness of the maximum and position of the nulls should be judged against the particular antenna's performance with a "clean" signal. If no defined maximum or more than one are obtained or if the nulls are in a much different position with respect to the maximum than normal, the bearings at that point are probably unusable. If left-right homing is used, the left-right indicator should center at two headings about 180° apart. More than two center readings in a full circle indicates unusable bearings.

3. If the results of step 1 are OK, that a continuous reading or individual readings at 5' intervals for up to 50' along a line at right angles to the indicated radio direction. If the various bearings differ from one another by more than $\pm 45^{\circ}$, a different DF site should be selected. If the bearings vary by less than $\pm 45^{\circ}$, an average can be taken which should be accurate to about 1/5 of the observed variation. Example: 10 readings with variations of $\pm 25^{\circ}$ average should be accurate to $\pm 5^{\circ}$. Readings with variations more than $\pm 20^{\circ}$ should be treated with some suspicion. Less than that indicates no serious accuracy degradation due to NEARBY objects, but effects of obstructions in the intermediate range may still be present.

If an interferometer antenna system is available, it should be used instead of the averaging procedure of step 3. The limits of site usability still hold and these results should still be recorded or sent to a central poltting point for evaluation. The interferometer acts like a very large antenna and can average out the effects of nearby reflections better than the procedure of step 3. One degree accuracy is regularly obtained under field conditions. The procedure is not suitable for vehicles or aircraft.

Each bearing that is taken should be plotted on a map, preferably a topographic or other map that shows detailed terrain features whether or not multiple teams are involved. Different colors can be used to denote bearing quality and polarization. A good quality mapping compass with built-in protractor will be invaluable in doing this job without error. A magnetic north grid ruled or placed over the map will eliminate magnetic variation calculation errors. Also to be avoided are bearings taken with the compass laying on a car hood or against a radio speaker. Obvious? Yes, but even sillier things have happened without prior practice. For quick "how goes it" bearings, prominent landmarks can also be used for reference. Another obvious but critical point: the bearing will be only as good as the DF team's ability to specify accurately its own location. Compass and map reading skills and a common reference system between teams is needed.

Theoretically, just two bearings taken from different locations will define a source location. In practice, 10 or 20 may be required to get a reasonable average estimate. In most cases, the eye is quite good at estimating the point of highest probability in a grouping of DF intersections. The number of bearings taken will depend largely on the difficulty of getting to the indicated point. The more difficult the access, the more time can profitably be spent on refining the predicted location. Both the evaluation of bearing quality by the measuring team and terrain over which the indicated bearing falls should be considered in making this estimate.

In summary, the following general points are the basis for most ground search.

1. Use air direction to probable area if available. Prior coordination on communications is desirable. Do not depend on accuracy better than 15 miles (north-south) by 30 miles (east-west) from satellite (SARSAT) information.
2. Head for high ground in the suspect area. Walk around hilltops, checking all possible sides.
3. Make multiple DF readings along a line at right angles to received signal. Average results.
4. Listen while traveling in low country. Stop and take additional bearings if signal is heard.
5. Try to bracket target from high points before attempting detailed search.
6. Make notes of the quality of DF and the nature of surrounding terrain at each point as an aid for possible later data re-evaluation.
7. Request assistance of other agencies (law enforcement, forestry, etc.) and private individuals for access as required.
8. Use multiple teams with radio communications between them for initial triangulation.

Short Range and Non-DF Location

Most operating ELTs have been and will probably continue to be non-distress or accidentally activated. Most are on airports. To complete the job, pilots are often required to do some ground search. The equipment designed for long-range ground search is very efficient in this environment. The aircraft DF can often be used to taxi to the proper side of the airport. With a simple procedure, any $20 to $30 transistor radio tuning the aircraft band, or even the FM band can be used to finish the job. Tune FM radios to 100.1 instead of 121.5 or as close to that as possible while missing strong broadcast stations.

The trick is to adjust the radio so that the ELT signal is audible, but quite weak or noisy so that the radio's automatic volume control doesn't cover up the changes in strength that indicate direction or target approach. This is done by retracting the antenna and tuning the radio away from the ELT frequency until the desired noisy reception is obtained. Hold the radio a few inches from your body at belt line with the antenna vertical and turn a full circle. The signal will be loudest when you are facing the ELT and weaker when your body blocks the signal path. If no direction is obtainable, this same radio setting can be used as a signal strength memory to find the ELT by looking for the strongest signal. The further the receiver is tuned from 121.5 MHz, the stronger the signal. When standing next to the offending aircraft, most simple receivers will receive some ELT signal from one end of the dial to the other. Several articles have appeared describing screens or loops that can be attached to these receivers to enhance their directivity. In most cases, body shielding described above works better. This is particularly true of loops, which suffer both from polarization errors and 180° ambiguity.

What To Do After Finding The ELT

If you are in the air, notify the nearest FAA facility or your operating organization by radio of the situation. If an airport is nearby, you can then land and complete the search on the ground with a hand DF.

On the ground, the detailed procedure to follow upon locating an activated ELT will depend on the circumstances and the policies of your organization. One primary job should be to shut off the beacon, or failing that, reduce its transmission range so that it will not prevent reception of other distress or emergency communications. In an actual wreck, this, of course, is secondary to care of the survivors, but should be accomplished before leaving the site. Failure to do this simple step has caused a number of false searches with attendent risk and time loss. Find out what ELTs look like and where they are located as part of your training. Disturb the wreckage as little as possible when deactivating the beacon and make thorough notes of what was done for later use by accident investigators. For non-distress activations, it is common to find the beacon inside a locked airplane or building. Assistance of the local law enforcement or airport manager should be obtained to locate the owner or otherwise gain access to the ELT. Neither FAA, FCC, CAP, or other search organization has special entry authority in non-distress situations. If access cannot be obtained to a parked aircraft, the signal can be reduced by wrapping the external antenna with aluminum foil. Take a piece of foil 12" wide and about 5' long. Place the tip of the antenna in the center of the foil, being careful not to punch a hole in it. Fold the foil down on both sides of the antenna and let the ends lay flat on the fuselage. Tape the foil to the fuselage and fold the two sides together to completely enclose the antenna. See sketch below.

ELTs have a variety of switch mechanisms. Most are plainly labeled. Switch malfunction is fairly common, so always check the result with a receiver. If the switch can't be found or doesn't work, the unit can be disabled by removing the batteries. This operation often requires hand tools, but it is a positive method to disable the beacon. Any time an aircraft or ELT is worked on, be sure to leave a warning note in a prominent place for the owner if he was not present. Do not depend on the airport operator or the police to pass the word. Also, notify the nearest FAA facility or your organization's controller of the time the beacon was shut off; the aircraft type and number, if any; ELT make, model, and serial number; owner's name; and circumstances causing activation, if known.