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FOR HEALTH & ENVIRONMENT

LASER RANGE EVALUATION GUIDE FOR BIOENVIRONMENTAL ENGINEERS

JOHN E. BREWER, CAPT, USAF, BSC

July 1987

Final Report

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The USAFOEHL/RZ was requested by AFOMS/SGPR to develop a guide to assist base level Bioenvironmental Engineers in establishing safe range lasing operations. This report contains descriptions of potentially hazardous situations and the needed range safety controls. In addition, evaluations of lasers, both airborne and ground, of the systems currently being used throughout DOD are included.

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This guidebook is the product of many individuals' efforts. It is a collection of the experience of the past and present members of the USAFOEHL Nonionizing Radiation Services Branch, USAFSAM Radiation Sciences Division, Vulnerability Assessment Branch, and the DoD Laser Systems Safety Working Group. Some of the contributors to this guidebook are Lt Col John Burr, Major Ross Murray, Major Edward Maher, Major George Croshaw, Capt Richard Speer, Lt Burl Olson, Lt Steven Rademacher, SSgt Nancy Whitten, and Mr Jack Labo.

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I. INTRODUCTION

The use of lasers in tactical aircraft and by ground personnel on Air Force controlled weapons ranges has increased dramatically in the past decade. Because of the potential for eye and skin injuries from these lasers, Bioenvironmental Engineering Services (BES) personnel are required to perform laser hazard evaluations and recommend control procedures prior to their use on weapons ranges. Unfortunately, because of limited experience with lasers, most BES personnel must rely on other organizations (example: USAFOEHL) when performing their range evaluations. The assistance provided may fulfill the requirements stated in AFOSH Standard 161-10, Health Hazard Control for Laser Radiation, and AFR 50-46, Weapons Ranges, but does not necessarily provide the training or education needed by BES personnel to ensure that everyday range operations are indeed safe. This report is intended as an interim instructional guide on range procedures and their application. To be released concurrently with this guide, is a Z-100 and IBM PC compatible laser hazard evaluation computer program, laser range footprint calculation program, and a laser sources inventory program. Eventually, a DOD range evaluation manual will be published. Additionally, the Air Force Engineering Services Center is developing a Z-100 compatible computer program to perform some of the evaluations presented in this guidebook. Their program will contain specific details about each range, and generate a hazard plot on a map.

This guide incorporates ANSI Z136.1, American National Standards for the Safe Use of Lasers, and Tri-Service procedures as directed by Air Force Office of Medical Support to initiate uniformity in DOD laser range evaluations. To facilitate this, the following terms are now used: laser class, rather than laser category (CAT); nominal ocular hazard distance (NOHD), rather than safe eye exposure distance (SEED); and laser surface danger zone (LSDZ), rather than hazard zone. This guide supplements AFOSH Standard 161-10.

The procedures and mathematical equations for performing a laser hazard evaluation to determine laser classification, NOHD and degree of protection required (Optical Density - OD) are in AFOSH Standard 161-10, and will be available as a Z-100 compatible computer program. Therefore, they are not examined in detail in this report. In an effort to ensure that all BES personnel are using consistent laser system hazard parameters, this report contains hazard evaluations for both airborne and ground lasers presently being used by DOD forces on Air Force weapons ranges. These can be found in Appendices A and B.

II. BACKGROUND

Most lasers presently used in tactical military applications are either range finders or designators. The majority are pulsed lasers and radiate in the near infrared spectrum (700-1400 nanometers). Laser classification, NOHD, and OD required are usually well defined and will not vary from weapons range to weapons range. The variables of usual concern in laser range evaluations are the range itself (size, topography, etc.), personnel operating the laser (Air Force, Army, Navy, Reservists, etc.) and the mission (air-to-ground, ground-to-ground, etc.). To assist BES personnel in performing a range evaluation, a step-by-step procedure is presented in this report.

III. RANGE EVALUATION PROCEDURE

A laser range evaluation can be performed for a specific laser system or for a general class of lasers. The latter is recommended if available land permits and the mission is not severely impacted. To perform this general evaluation, the worst case conditions of all possible systems and missions are used. If this is too restrictive, separate evaluations for each system must be performed. In order to simplify the range evaluation procedure we divided it into five steps: The laser; the range; the target; the mission; and the laser surface danger zone.

A. **The Laser**: To evaluate a laser it is necessary to determine the hazard potential of the system. This is accomplished by determining the following:

1. Maximum Permissible Exposure (MPE) Limits: Determine the applicable MPE for the laser being evaluated.

2. Laser classification: Classify the laser using procedures in AFOSH Standard 161-10, and MIL STD 1425, 13 Dec 83, Safety Design Requirements for Military Lasers and Associated Equipment, to determine what laser control procedures are required (interlocks, warning labels, etc.).

3. Nominal Ocular Hazard Distance (NOHD): Calculate the distance from an operating laser to the point where it is no longer an eye hazard using procedures in AFOSH Standard 161-10, previously calculated data, previously measured data, or Appendices A and B. There are four types of NOHDs. They are single pulse NOHD (NOHD-S), multiple pulse NOHD (NOHD-M or simply NOHD), diffuse reflection NOHD, and NOHD for optically-aided viewing (NOHD-O). Additionally, if the laser emission can exceed the skin MPE, a Nominal Hazard Distance (NHD) is possible for skin.

4. Diffuse reflections: Determine if the laser is capable of producing hazardous diffuse reflections (Diffuse Hazard) using procedures in AFOSH Standard 161-10, previous evaluations, or Appendices A and B. Lasers which can produce hazardous diffuse reflections are classified as ANSI Class 4 and have a diffuse reflection hazard distance (t) associated with it. It is unusual for field type lasers to produce diffuse hazards (presently, only the M60 Tank and the M551 Al Sheridan Vehicle produce hazardous diffuse reflections). Normally for a diffuse hazard, the beam path up to the NOHD or point of termination (if less than NOHD), is a denied occupancy area and no objects are permitted in the beam path.

5. Optical density (OD): The degree of protection (opacity) required to reduce the incident laser energy to safe eye and skin levels must be calculated. (See AFOSH Standard 161-10.) These are also available in Appendices A and B, or previous evaluations.

6. Optical viewing: Consider the possibility of personnel viewing the beam, or reflections of the beam, through optical instruments (binoculars). The light-gathering ability of the optics can significantly increase the degree of hazard for the eyes (increase OD and NOHD). Procedures to evaluate this are in AFOSH Standard 161-10. Some evaluations are included in Appendices A and B.

7. Atmospheric attenuation: Atmospheric attenuation can be quite high for infrared lasers operating over distances of 10 kilometers or greater. It can reduce the NOHD considerably and should therefore be included in the laser evaluation. To aid in many evaluations a set of footprint tables for the PAVE SPIKE and PAVE TACK systems which use an atmospheric attenuated NOHD are included in Appendix D in addition to the tables which use the vacuum NOHD. This set of footprint tables based on atmospheric attenuated NOHD are only valid for lasing from altitudes below one kilometer (km) above mean sea level (MSL). If flight profiles include lasing from altitudes above one km, new site specific tables should be generated using the USAFOEHL footprint computer program or the tables in Appendix D based on the vacuum NOHD. As a last resort, footprint dimensions can be manually calculated using the procedure listed in AFOSH Standard 161-10 or Appendix G.

8. Laser platform stability: The stability of the laser platform must be evaluated to determine pointing accuracy of the laser system. The pointing accuracy will determine the size of the buffer angle. The largest buffer angle for airborne (aircraft) or ground based stable platforms (tripods) is 5 milliradians, while hand-held lasers require 10 milliradians (Note: this is a recent policy change from 15 milliradians). Section III.E describes the procedure for determining the buffer angle.

B. **The Range**: Both a range map and topographic map of the area are needed for the laser range evaluation.

1. Range map: The range map is essential in order to establish accurate distances from target area to range boundaries. The range map should have the boundaries and include geographic items such as roads, streams, ponds and rivers. All man-made improvements such as towers, buildings, etc., should also be on the map. Boundaries of special purpose areas such as an airstrip and the location of targets are also required.

2. Topographic map: The topographic map is important because it enables the evaluator to determine the elevation of the target area relative to the surrounding terrain. It is important that no portion of the beam which exceeds the MPE limits extend beyond the controlled area. This can be accomplished by utilizing natural geographic backstops such as hills. A topographic map is very helpful in identifying these backstops and in repositioning targets if necessary.

3. Airspace: Normally, "controlled airspace" is that airspace directly over the range up to a specified altitude. It is important that this controlled airspace and exceptions are made known. Lasing is not normally authorized outside the controlled airspace or when other aircraft are between the laser and the target. Also, if the beam is directed up, or if hazardous

reflections could exceed the height of the controlled airspace, additional controls may be necessary. See Section III.E.3.b for more information.

C. **The Target:** The size, location, and type of targets to be lased on a range are of primary importance in determining the hazard zone.

1. Optimum target: The optimum target from a safety point of view is a nonreflective surface. Flat specular surfaces must be removed or covered because reflections from them can retain high collimation. A flat specular surface is one in which you can see a relatively undistorted image. Examples of specular surfaces are windows, Army tank vision blocks, search light cover glass, plastic sheets, glossy painted surfaces, still water, clean ice, flat chrome, and mirrors. Snow is not a specular surface, but if thawed and refrozen, hazardous reflections can be found, especially at low angles of incidence. Glossy foliage, raindrops, and other natural objects are not hazardous targets. These and most other curved surfaces may be specularly reflective, but the reflected irradiance (energy per unit area) decreases quickly with distance. This is because the beam spreads as a function of the radius of curvature of the surface. The only exception to this is concave reflective surfaces. These can focus the reflected beam and cause the reflection to be more hazardous than the incident beam. Practically, these reflections are of little concern since it is improbable that the surface is perfectly concave (focuses the beam to a single point) or perfectly reflective. Additionally, the focus point(s) would probably be very close to the object (small radius of curvature) and be of little concern since people don't normally put their head close to objects and if they did, they would probably block the incident beam. Concave surfaces with a large radius of curvature which could focus at longer distances would appear nearly flat and be covered. These four types of reflections are detailed in Figure 1. Further information is provided in Appendix F.

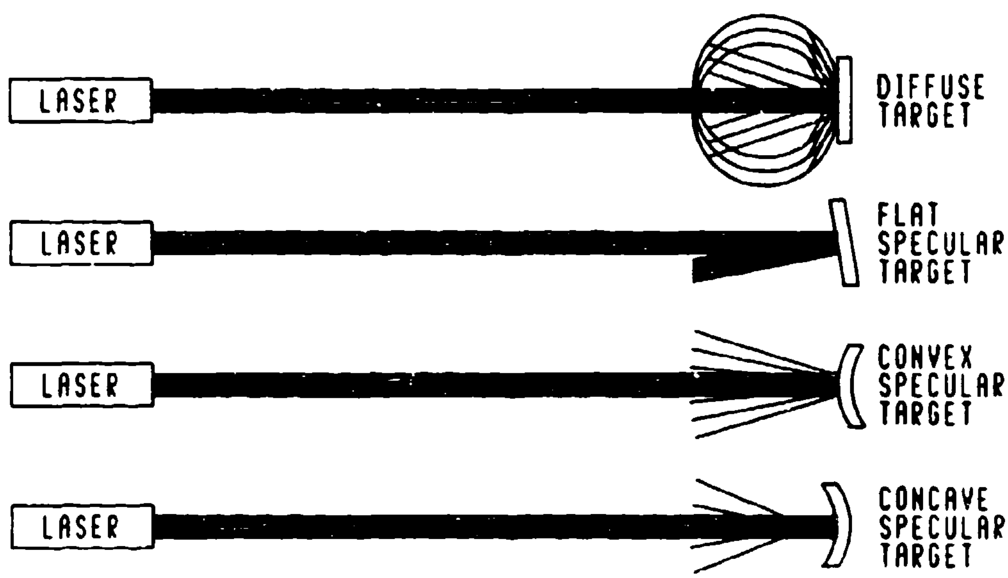


FIGURE 1. DIFFUSE REFLECTION AND SPECULAR REFLECTION

2. Size and location: The number and location of targets (distribution) will affect the size of the hazard zone. On ranges with limited space it is important that all targets be as close together as tactically feasible.

D. **The Mission:** An evaluation must be accomplished for each type of laser used on the range. The lasing mode, e.g., air-to-ground, ground-to-ground, etc., must be determined. At the present time, air-to-ground and ground-to-ground are the normal modes used by tactical forces. In the near future, training exercises will include the ground-to-air mode as more state-of-the-art airfield and ground force air defense systems are developed. The air-to-air mode is used for R&D projects and then only with special permission. Required information is listed below for each case.

1. Air-to-ground: Determine desired flight profiles. Information necessary to perform an evaluation are the altitudes, ranges, and directions of the aircraft, relative to the target, when lasing. Various terms are used to describe the aircraft direction during ordinance delivery, they include: approach track, attack heading, and run-in heading. These headings can be on a single bearing, a range of bearings, and unrestricted approach (360°). Typical mission profiles are:

a. Toss Delivery, General Profile:

Slant Range: 1,800-70,000 feet (0.3-11.5 nautical miles)
Altitude: 200-2,600 feet

b. Toss Delivery, Mode A:

Slant range: 20,000-70,000 feet (3.3-11.5 nautical miles)
Altitude: 200-320 feet

c. Toss Delivery, Mode B:

Slant Range: 10,000-25,000 feet (1.6-4.25 nautical miles)
Altitude: 1,000-3,400 feet

d. Straight and Level Delivery:

Slant Range: 1,800-30,000 feet (0.3-4.8 nautical miles)
Altitude: 1,500-3,300 feet

e. Dive Delivery:

Slant Range: 8,500-14,000 feet (1.4-2.3 nautical miles)
Altitude: 4,000-7,600 feet

2. Ground-to-ground: Determine possible laser locations and direction of lasing.

E. **Laser Surface Danger Zone (LSDZ):** Formerly called the hazard zone in the 1980 version of AFOSH Standard 161-10, the LSDZ is defined as a designated region in space where the probability of exposure to laser radiation is greater than that determined to be safe. The LSDZ considers both direct hazards (main beam) and indirect hazards (reflections). The boundaries of the LSDZ depend on which of the two overlapping zones, direct hazard zone or the indirect hazard zone, is larger. If there are no specular reflectors in the range and the laser is not a diffuse hazard there will not be an indirect hazard zone. The direct hazard zone will always exist if laser to target distance is less than the NOHD. The LSDZ includes the laser beam plus a buffer zone around the beam to account for laser platform instability. There are three types of LSDZs. The total hazard zone is called LSDZ area Z or simply the LSDZ. The area that must be cleared of specular surfaces is called LSDZ area S. For airborne lasing, it is the same as LSDZ area Z. For ground based lasing from elevated platforms where the laser projects a well defined footprint, it should equal LSDZ area Z. For ground based lasers that do not project a well defined footprint in the target area, LSDZ area S is usually defined by a circle of radius S (as specified in Appendix B of this report) around the target. Backstop areas where the energy of the incident beam is capable of producing a specular reflection hazard are also considered LSDZ area S. LSDZ area T is the diffuse reflection hazard zone, it extends to distance t, the diffuse reflection hazard distance, and will only be present for lasers capable of producing a hazardous diffuse reflection (these have a distance t associated with them). LSDZ area T is considered an exclusion zone, no one is allowed in it and nothing should be lased in it. Although a skin hazard can also be in this area, this is considered a minor concern compared to the diffuse reflection hazard.

1. Airborne lasers: Calculate the size of the beam which irradiates the ground (footprint). Normally, laser beams are circular, diverge equally in all directions, and produce cone shaped beams. The size of the beam depends on the initial beam diameter, divergence, and distance (slant range) from the source. The size of the footprint is the size of the beam plus a buffer zone. For scanning systems, the size of the beam would include all positions in the scan. The shape of the footprint depends on the angle of the beam which intersects the ground (slant angle is determined from the range and altitude). The footprint is determined by the following:

a. Determine the buffer angle: To perform an evaluation which would be adequate for most airborne lasers use 5 milliradians for the buffer angle and ignore the beam divergence since most divergences are less than 0.5 milliradians. This approach will only introduce an error of less than 5%. If this evaluation is overly restrictive (requires too much land), a system specific evaluation can be made for each laser system. The appropriate buffer angles for most systems are listed in Appendix A. To calculate a buffer angle for other systems, perform the following: When the beam divergence is equal to or greater than 1.0 milliradian, the buffer angle will be five milliradians. When the beam divergence is less than 1.0 milliradian, the following will apply:

(1) If the aiming accuracy is unknown, the buffer angle will be five milliradians.

(2) If the aiming accuracy is known, the buffer angle will be five milliradians or the absolute value of the aiming uncertainty (in milliradians) plus five times the beam divergence at the 1/e (.3679) point, whichever is less. Aiming accuracy should be contained in the system specifications.

b. Determine footprint size: There are at least two approaches used to determine the size of the footprint. If the desired flight profiles are known then the size of the footprint can be determined from these flight profiles. If the size of the range is the limiting factor, the boundaries of flight profiles can be determined which would keep the footprint within the range. These two approaches can be used independently or, typically, used together to maximize land use and minimize mission impact. The procedures for these two approaches are detailed below.

(1) To determine footprint size from predetermined flight profiles:

(a) Initially: Use the footprint tables in Appendix D to determine the footprint size from the range of flight profiles provided. These tables are based on the multiple pulse NOHD without the aid of optics. If it is possible for the laser to be viewed with optics, the NOHD for optically-aided viewing should be used. For most cases, the largest footprint is made with the longest slant range and lowest lasing altitude combination. Note that two sets of footprint tables for specific systems are provided. One set is based on the NOHD in a vacuum and the other set is valid if all lasing will be performed at altitudes below one km MSL. Additionally, Table D.5 is provided which can be used for any airborne laser system. Table D.5. is very conservative. If these tables do not cover your case, the dimensions can be calculated. The basic calculation procedure is provided in Appendix C. A computer program to make your own footprint charts using these procedures is available from USAFOEHL. These tables and calculations assume flat terrain. Corrections for terrain will come later.

1. We start the footprint determination procedure by using the following diagram to illustrate a footprint (Fig 2). Incidently, this diagram and the following diagrams are not drawn to scale in order to be easier to read.

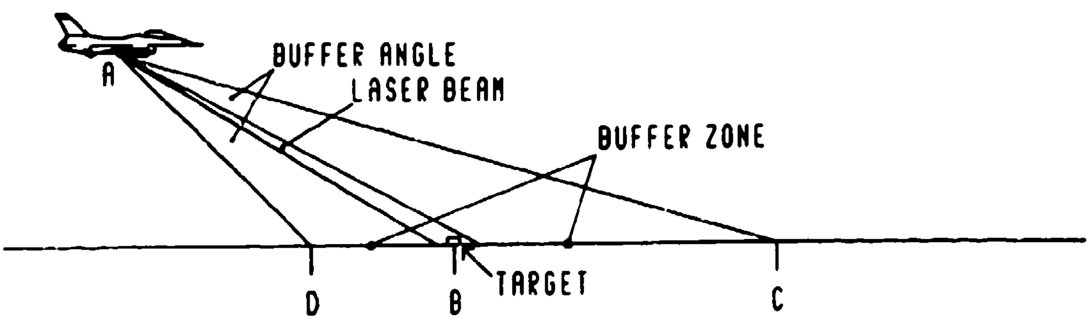


FIGURE 2. LASER FOOTPRINT WITH SINGLE TARGET

2. Figure 2 assumes that the target is small. If the target is large, or multiple targets are present in an area, the diagram would be misleading. Therefore, the diagram in Figure 3 expands the beam position to account for a large target area. For a scanning laser system, the target area shown below would be the scanned areas, while the remainder of the area from D' to C' would be the buffer zone around the scanned area.

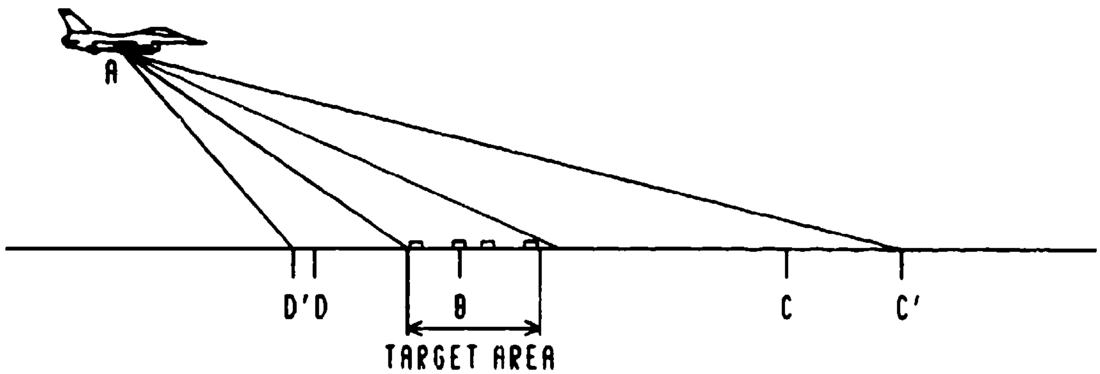


FIGURE 3. LASER FOOTPRINT WITH MULTIPLE TARGETS

3 The shape of the laser footprint on the ground is an ellipse as shown in Figure 4. This footprint will determine where LSDZ area Z, or the hazard zone is.

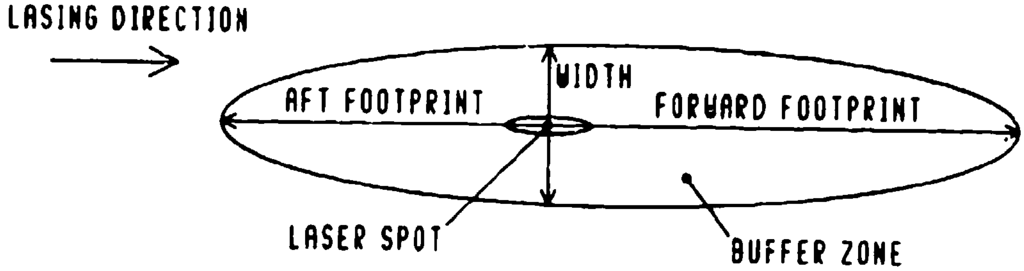


FIGURE 4. LASER FOOTPRINT

4. If the attack will only be from one direction, and the laser only fired straight ahead, the LSDZ area Z will be the size of the largest footprint dimension calculated. It can be represented as a rectangle or as an ellipse as shown in Figure 5. Normally a rectangle is used for these evaluations. The dimensions of which are listed as forward, aft, and width dimension in the footprint tables.

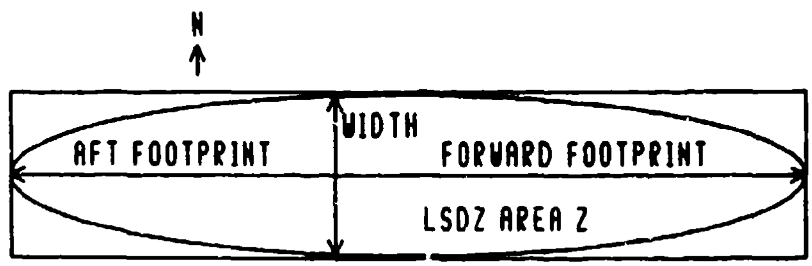


FIGURE 5. LSDZ - ATTACK BEARING 90 DEG

5. If the attack (or lasing) will be from a range of bearings, the LSDZ will be a summation of all possible footprints. This results in a LSDZ in the shape of two, pie-shaped sections. The length of these will be equal to the forward and aft footprint dimensions. The width of these pie-shaped sections will be the extremes of the attack bearings plus half the dimension of the footprint width. This is illustrated in Figure 6.

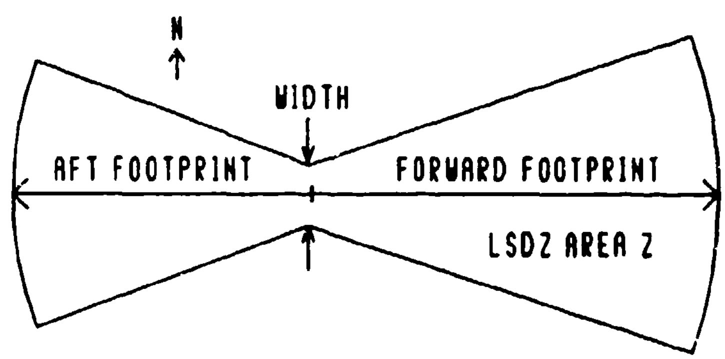


FIGURE 6. LSDZ - ATTACK BEARING 70 TO 110 DEG

6. If the attack bearings are not specified or attack from any direction is desired, the LSDZ will be a circle with a radius equal to the longest forward or aft dimension listed in the footprint table for the possible altitudes and slant ranges. This is illustrated in Figure 7.

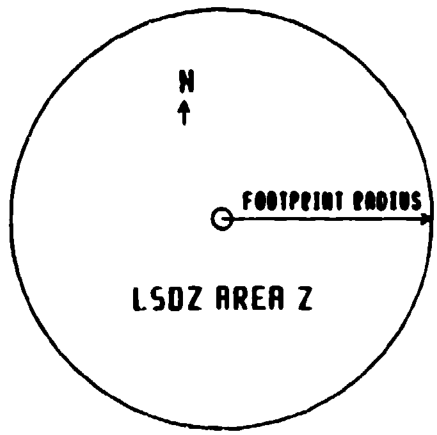


FIGURE 7. LSDZ - ATTACK FROM ANY DIRECTION

7. As a way of application, if the conditions of the three cases described above were based on the PAVE SPIKE laser fired from 200- 1000' above ground level (AGL) at ranges of 1-4 nautical miles, the longest dimensions, based on these flight profiles, are 8,500' forward, 5,960' aft, and 130' wide (see PAVE SPIKE Footprint Table D.1 in Appendix D). If the elevation were to include all types of laser systems, with the above flight profiles, the footprint dimensions would be 37,600', 9,190', and 243', respectively (See table, D.5. in Appendix D).

8. If the target and area covered by these footprint dimensions are on level ground, and no specularly reflective surfaces are present, the LSDZ or hazard zone is the size of the LSDZ determined above.

(b) If the terrain is not level: Determining footprint dimensions can get rather involved. Actual procedures vary case by case but, the following suggested general procedures are presented for common conditions. Some specific examples are shown in Appendix E.

1. Target area on rising terrain: This condition is of little concern because it makes the calculations performed above conservative. If overly conservative, the footprint dimension can be reduced. See Figure 8 for clarification.

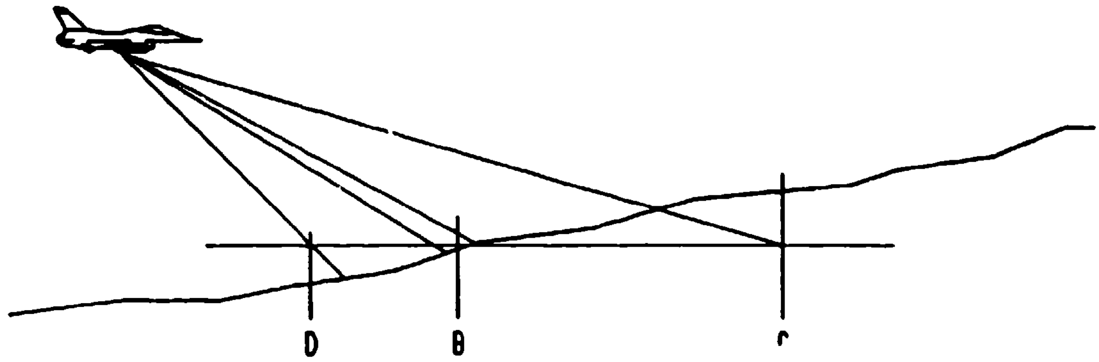


FIGURE 8. LSDZ WITH RISING TERRAIN

2. Natural Backstops: Hills behind the targets can reduce the size of the footprint as rising terrain did above. Additionally, accidental reflections and misdirected beams can be contained within the range. Effects of correct and incorrect target location and flight profiles are illustrated in Figures 9 and 10.

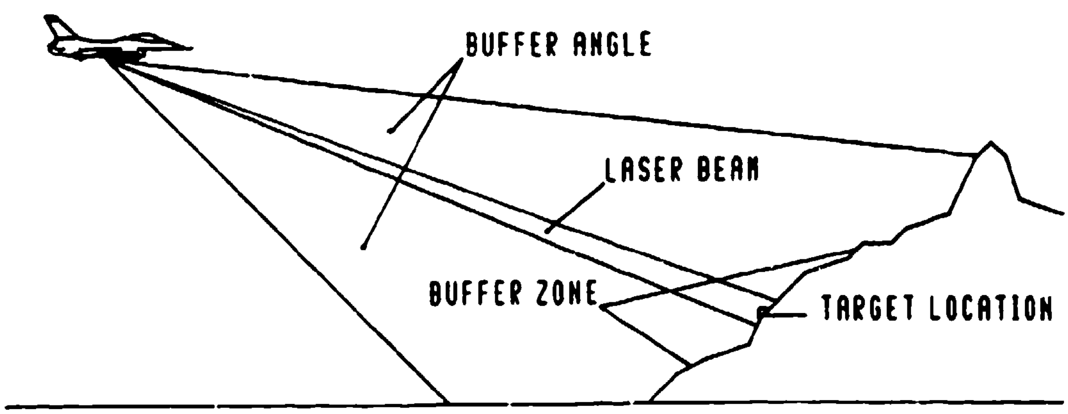


FIGURE 9. USE OF NATURAL BACKSTOPS TO CONTROL LASER BEAM

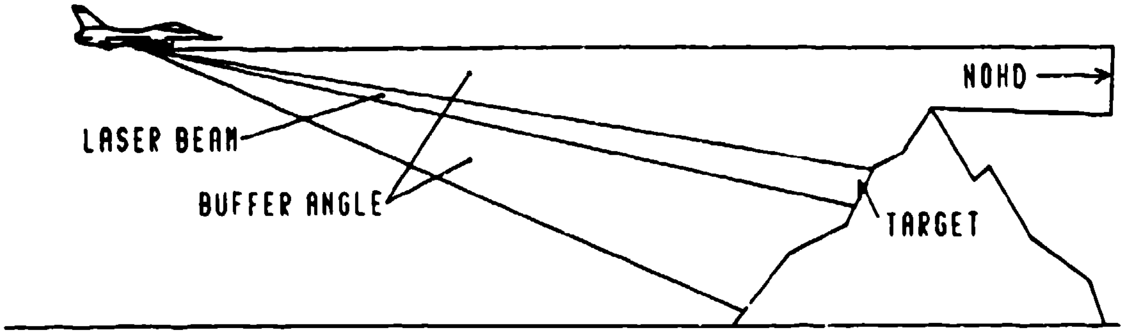


FIGURE 10. INSUFFICIENT BACKSTOP TO CONTROL LASER BEAM

3. Falling terrain in target area (or hills in the foreground): This condition requires some modifications to the previously calculated dimensions.

a. For the foreground: The height MSL, or height AGL, reference to the target of the bottom laser beam path (line AD) must be determined for all distances between the laser and target. A method of doing this is to calculate the height of the beam from the slant of AD. The slant of AD is approximately equal to the altitude divided by the difference of slant range and aft footprint dimensions. Then, these elevations are compared to the terrain height under the laser beam for all attack angles. This condition is illustrated in Figure 11.

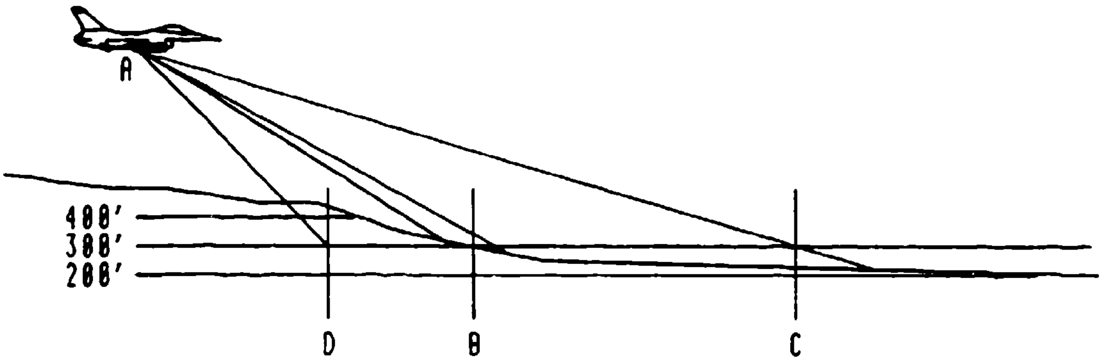


FIGURE 11. LSDZ WITH TERRAIN SLOPING DOWN RANGE < NOHD, TARGET AT 300' MSL

b. For the ground beyond the target: This condition can greatly extend the forward footprint dimension as illustrated in Figure 11. If flight profiles are not limited, the forward footprint could be as long as the NOHD as illustrated in Figure 12.

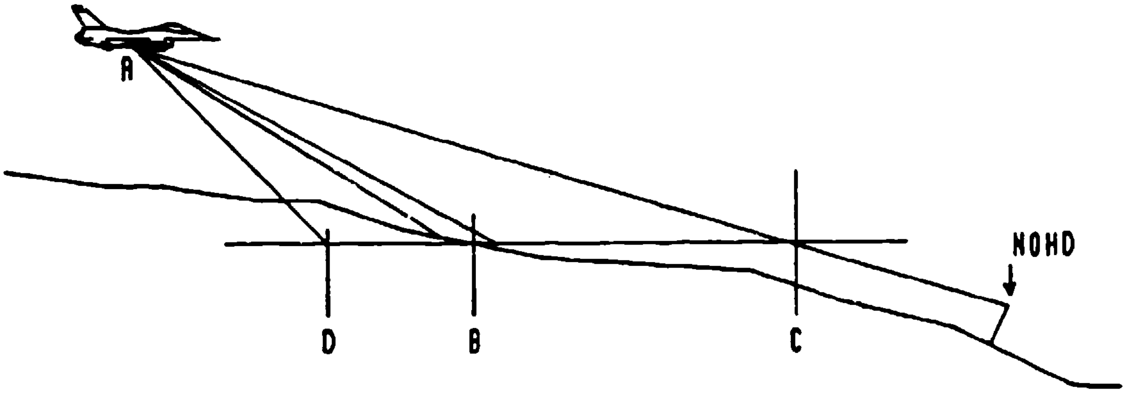


FIGURE 12. LASER SURFACE DANGER ZONE WITH TERRAIN SLOPING DOWN RANGE > NOHD

(c) Specular reflections: If the area in the footprint can be cleared of all flat specular surfaces, then the LSDZ is the size calculated above. If flat specular surfaces are within the LSDZ Area Z, these should be removed, covered, or painted. If they can't be effectively removed, the LSDZ Area Z may need to be expanded by the procedures in the following sections. Normally the LSDZ is expanded out to the single pulse NOHD (NOHD-S) rather than the multiple pulse NOHD (NOHD) when accounting for reflections. This is because the probability of multiple pulse exposures is very remote when the angle of attack, relative to the target is changing rapidly. When the angle of attack is not changing rapidly, as when lasing from long distances, the multiple pulse NOHD should be used. In actual practice when both NOHDs are used over a range of lasing distances, the NOHD-S at close ranges will give the most conservative result. In addition, if it is possible for the laser beam to be viewed with optics, the NOHD for optically aided viewing should be used.

1. Still water: Determine if the reflection from this surface can enter uncontrolled airspace or hit a hill beyond the range boundaries. These are illustrated below in Figure 13. If these are not a problem, no further controls are necessary. If this appears to be a potential problem, limit the flight profiles, move the target, or control more land or airspace. See Appendix F for more information on reflections.

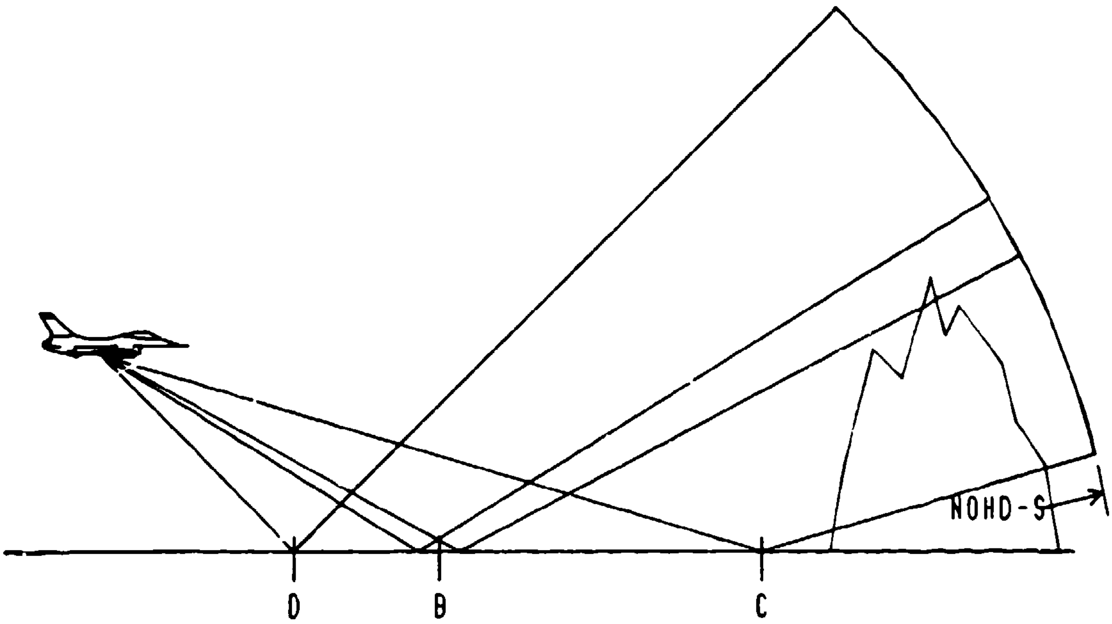


FIGURE 13. REFLECTIONS FROM STILL WATER WITHIN THE LSDZ

2. Flat specular surfaces on or near target: Aircrew, ground personnel, and the surrounding community need to be considered for this condition. If the reflectivity of the specular surfaces is known the effective NOHD can be reduced by (approximately) the square root of the reflectivity coefficient. See Appendix F for more information.

a. Aircrew: Present Air Force policy requires aircrews to wear laser protective eye wear when: flying in multiple ship formations, targets are not clear of specular surfaces, and ground based lasers are used against the aircraft. If the target area is not clear of specular surfaces, and the aircrews lase from distances less than one-half of the NOHD, aircrews are at risk of eye damage if eye wear is not used. This and other possible exposure situations are illustrated in Figure 14.

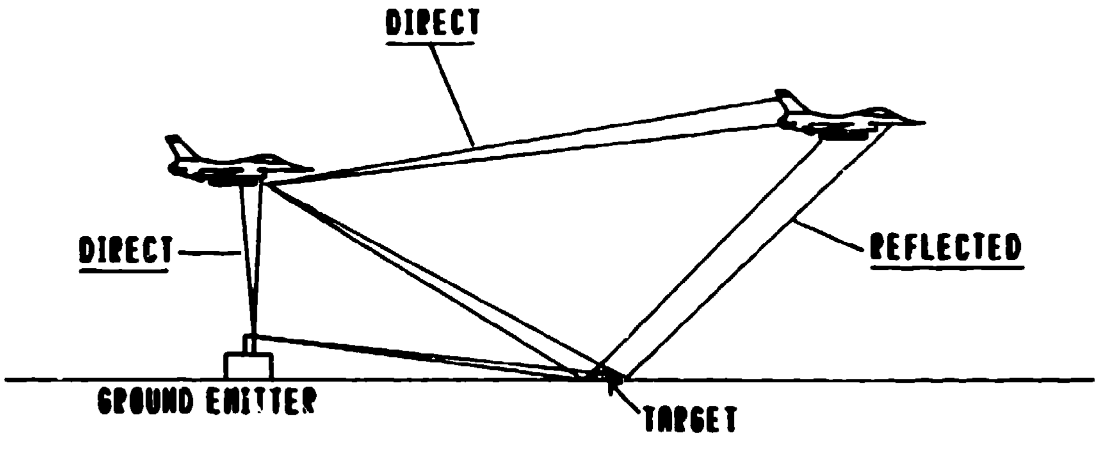


FIGURE 14. POTENTIAL EXPOSURE MODES

b. Ground personnel and surrounding community: If flat specular surfaces are near the target, the laser beam can be redirected in any direction as shown in Figures 15 and 16. Therefore, the LSDZ should be extended to a circle with a distance equal to the NOHD minus the minimum lasing distance. As with the cases described above, natural backstops and terrain may alter the shape of this area. Additionally, airspace over the range may be at an unacceptable risk. This is similar to the condition described above for standing water.

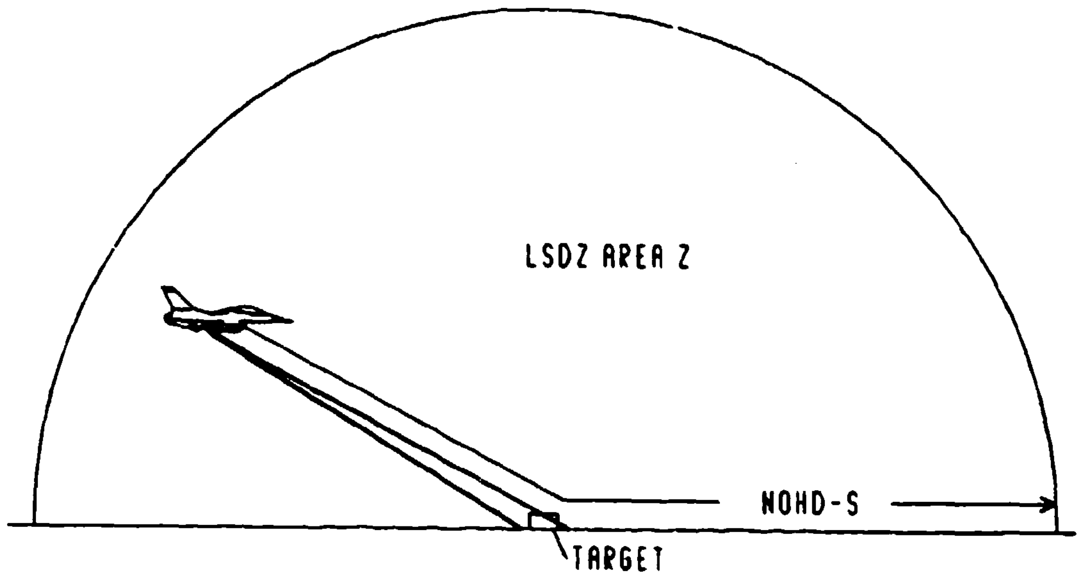


FIGURE 15. REFLECTIONS FROM FLAT SPECULAR SURFACE, SIDE VIEW

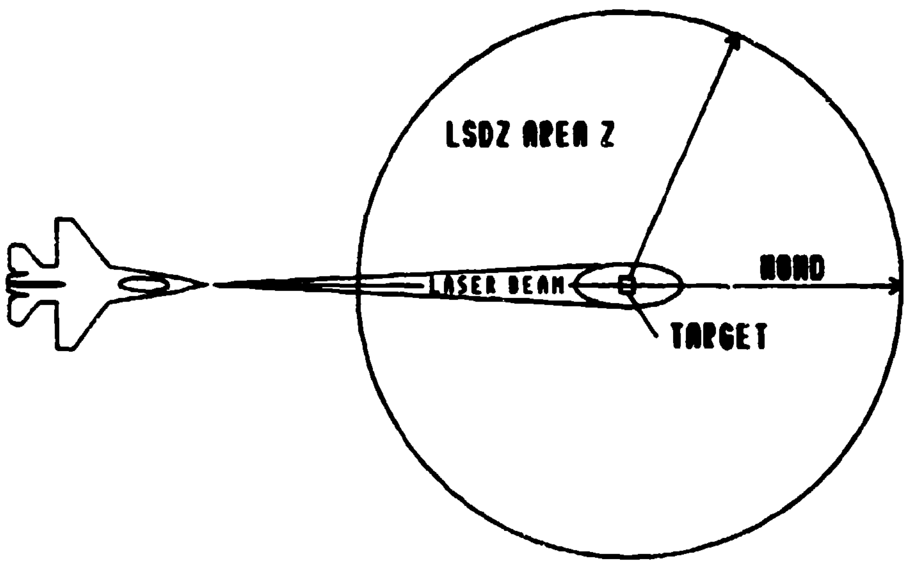


FIGURE 16. REFLECTIONS FROM FLAT SPECULAR SURFACE, TOP VIEW

(2) If the range is small and therefore is the controlling factor, we usually determine the flight profiles from the land size as follows:

(a) Determine desired target location.

(b) Draw outline of controllable range area.

(c) Measure distance from target to range boundaries.

(d) Use footprint tables or calculate flight profiles which would not cause the LSDZ to exceed the range boundaries. Procedures for this are a modification of the procedures of Section III.E.1.b.(1) above.

2. Ground Based Lasers: Ground-to-ground laser target designators and range finders are used by the Army and Marines on Air Force ranges. They are either classified as ANSI Class 3 or 4. If Class 4, hazardous diffuse reflections are possible. For these Class 4 lasers, three "hazard zones" are present. LSDZ Area S is normally the area around the target area and backstop. The size of these areas has been predetermined by the Army (or major owning service) and is listed in Appendix B. LSDZ Area Z is the area contained within the NOHD or natural backstop. LSDZ Area T is the area out to t (the diffuse reflection hazard distance). No objects are to be lased in this area because hazardous diffuse reflections are possible. Personnel are also excluded from this area because the incident laser beam's intensity usually exceeds the skin MPE. For Class 3 lasers, only LSDZ Area S and LSDZ Area Z are present. The procedures for evaluating these missions are detailed below.

a. Determine the buffer angle: The procedure for determining the buffer angle for ground-to-ground lasing is the same as air-to-ground unless the laser is hand-held. For hand-held lasers, the buffer angle will be 10 milliradians. Remember that this buffer angle is used for a horizontal and vertical buffer angle.

b. Determine the LSDZ:

(1) Normal procedures for evaluating ground based laser operations are detailed below. However, if lasing is to be performed from an elevated platform where the laser beam projects a well defined footprint, it should be evaluated using the procedures detailed above for airborne lasers.

(2) If the terrain is flat or falls off in the distance (no backstop): The LSDZ will be a cone extending out to the NOHD and cover an arc which covers the target area plus a buffer angle as illustrated in Figure 17. The width of the arc is chosen to allow lasing at any target and any point on the targets in the target area. If the targets are separated by great distances and the laser would not be used to sweep between targets, separate arcs could be established for each target.

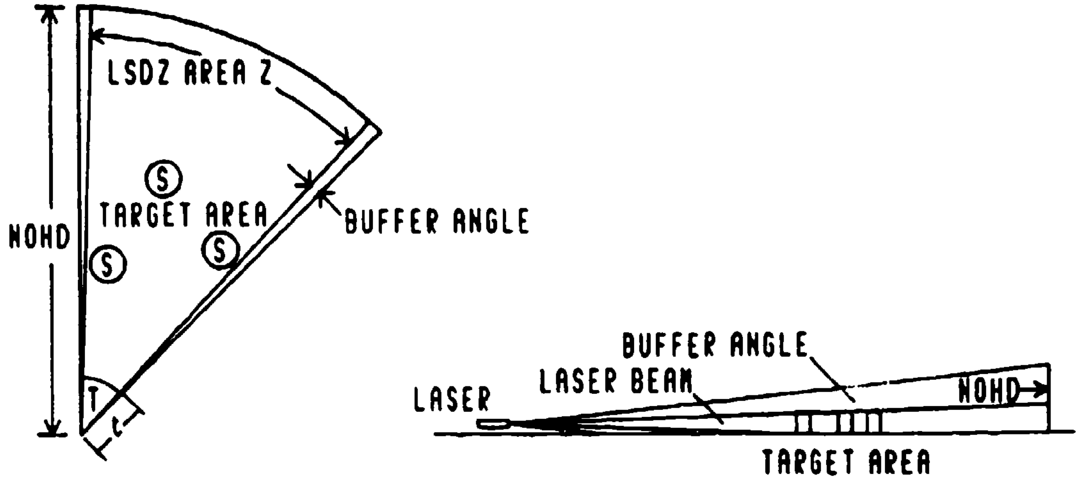


FIGURE 17. LSDZ FROM GROUND FIRED LASER - WITHOUT NATURAL BACKSTOP

(3) Terrain with natural backstops: If the beam is terminated by natural backstops within the NOHD, then the LSDZ is contained in that area. Ensure that the terrain is high enough to include the buffer angle. Figure 18 will clarify these points.

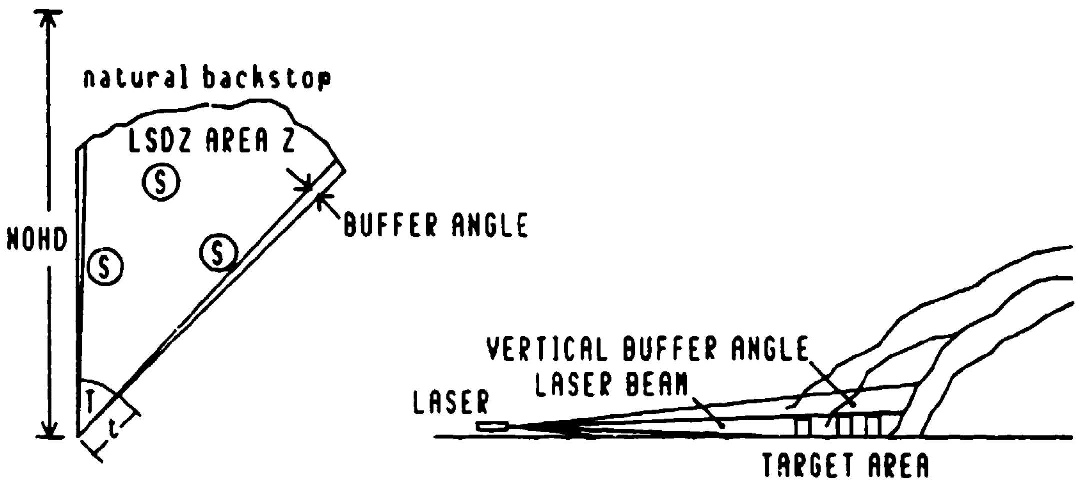


FIGURE 18. LSDZ FROM GROUND FIRED LASER - WITH NATURAL BACKSTOP

(4) Specular reflections: Normally, only the LSDZ area S and backstop areas are cleared of specular surfaces. If these areas cannot be cleared of specular reflectors, conditions as described in the air-to-ground section above need to be considered. These conditions include the laser beam hitting still water and then reflecting over the natural backstops and specular reflection extending the LSDZ to a circle with a radius equal to NOHD minus the laser to target distance. Of special concern, are aircrews flying in the area without eye protection. These are illustrated in Figures 19, 20 and 21.

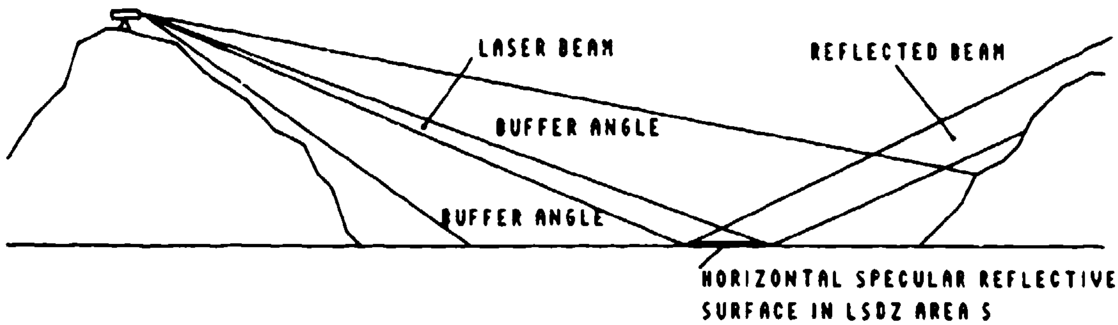


FIGURE 19. LSDZ WITH SPECULAR REFLECTIONS FROM STANDING STILL WATER

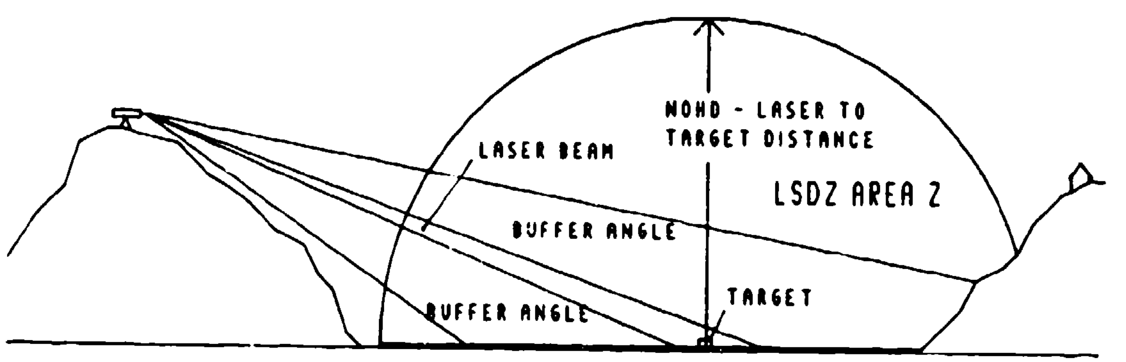


FIGURE 20. LSDZ WITH SPECULAR REFLECTIVE TARGET - SIDE VIEW

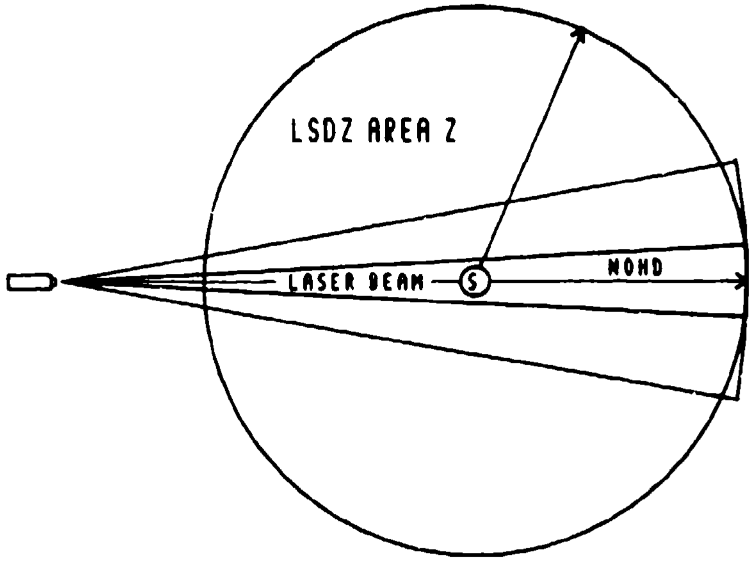


FIGURE 21. LSDZ WITH SPECULAR REFLECTIVE TARGET - TOP VIEW

c. Siting lasers and targets: As you can see from comparing Figures 9 and 10 and also 17 and 18, site selection for the lasing position and target location can be critical. If you have a choice of target location, first determine the width of the vertical and horizontal buffer zones. Then place the target that distance from the edges of the range boundaries or natural backstops. This procedure will maximize the use of natural backstops and range boundaries.

d. Atmospheric attenuation: Most lasers used by ground forces have had the NOHD established by measurement and therefore include atmospheric attenuation. If not, the procedure listed in AFOSH Standard 161-10 can be used to convert the calculated NOHD in a vacuum to the NOHD which includes atmospheric attenuation. To estimate atmospheric attenuation for 1064 nanometer lasers, a table in Appendix G provides approximate correction values. Lasers at other wavelengths require separate evaluations.

3. Other Considerations:

a. Moving targets or lasers: A moving target or laser will affect the size of the laser surface danger zone and may indicate that the single pulse NOHD is more applicable than the multiple pulse NOHD when evaluating specular reflections. This must be decided on a case by case basis. A common application of this includes evaluating reflection hazards when the angle of lasing is rapidly changing, and therefore the probability of a multiple pulse exposure is small.

b. Operating outside of controlled area: Targets should never be positioned outside the controlled area (including airspace). Airborne lasers should not be operated outside the controlled airspace if the potential for the beam striking an object outside the controlled area exists. If this risk is minimal, consider permitting lasing from uncontrolled areas under controlled conditions. Ensure the regional Flight Service Center for the Federal Aviation Administration (FAA) is notified prior to starting this operation so they can publish a Notice to Airmen (NOTAM). The FAA regulation governing this is 7930 2B, Notices to Airmen (NOTAM). Ground laser systems should never be operated outside the controlled area.

IV. RANGE CONTROL PROCEDURES AND RECOMMENDATIONS

A. **Objective:** The underlying concept of laser range safety is to prevent exposure of unprotected personnel from laser radiation in excess of the MPE. This is accomplished by determining where the laser radiation is expected to be, restricting access of unprotected personnel, and removing reflective surfaces from this area.

B. **Target areas:** Recommended target areas are those without specular (mirror-like) surfaces. Glossy foliage, raindrops, snow, and other natural objects are not considered to be specular surfaces that would create ocular hazards.

C. **Sanitized ranges:** If target areas have no flat specular surfaces, then range control measures can be limited to the control of the area where the laser beam hits directly.

D. **Lasing:** Laser devices should only be directed at targets.

E. **Unprotected personnel:** Unprotected personnel must not be exposed to laser radiation greater than the MPE.

F. **Signs:** Local procedures should provide for the placement of laser warning signs at the boundaries of the controlled areas and the access points. This is normally a coordinated process between BES, Ground Safety and the range officer. These signs should be constructed IAW MIL STD 1425. If the hazard zone is within a designated weapons and gunnery range, access controls will be established.

G. **Eye Wear:** Personnel within the LSDZ should wear laser protective eye wear. Eye wear must be approved for the wavelength of the laser system being used and must provide sufficient protection (OD). If more than one type of laser is used, protective eye wear must provide adequate protection for all wavelengths involved (OD greater or equal to the largest minimum OD required for each wavelength).

H. **Optical devices:** Magnifying daylight optical devices, without attenuation, may be used to view the target if flat specular surfaces have been removed from the target area. Specular surfaces can be viewed only if appropriate laser safety filters are placed in the optical train of the magnifying optics. Procedures for calculating the required OD are found in AFOSH Standard 161-10.

I. **Water and ice:** Still water and smooth ice can reflect laser beams, especially at low angles of incidence. Consider these potential reflections when establishing target areas. Snow is not a specular reflector.

J. **Communications:** The Range Control Officer should have positive control over all lasing operations. Direct communication with the laser operator should be maintained at all times.

V. RANGE LASER SAFETY PROGRAM

A. **AFR 50-46:** Air Force weapon ranges are operated IAW AFR 50-46. If lasing is to be authorized on a weapon range, then the guidelines in AFOSH Standard 161-10 apply. On ranges outside CONUS, specific host-user requirements must also be considered when evaluating the range. Each operating agency is required to publish a supplement to AFR 50-46 covering authorized missions and range control procedures. For lasing operations the specific authorized mission profiles, aircrew and ground laser operator training requirements, range personnel laser training requirements, medical requirements and laser range control procedures should be included in the supplement. The following list contains range control procedures that should be contained in the lasing operations supplement.

1. The size of the designated controlled area or LSDZ will be determined by an evaluation as described above. This evaluation considers the laser emission characteristics; aiming accuracy of the laser; extent of the hazards from direct, diffuse, or specular reflections; danger from exploding targets; possibility of system malfunction; potential for human error; and the topography of the target area.

2. Laser ranges or target areas will be controlled to ensure that personnel are not exposed above the MPE. Methods of controlling the target areas include warning signs at boundaries and access points, observers at strategic locations, fences, etc.

3. If possible, terminate the laser beam by a natural or man-made backstop of nonreflecting materials. This can be accomplished by making use of the terrain contour in the mission profile, and choice of target location.

4. Remove, paint, or cover specularly reflective surfaces within the LSDZ. For ground-to-ground lasing, only the LSDZ area S and backstops need to be cleared.

5. During periodic maintenance of the weapon range, the laser target area will be policed for specular reflectors.

6. All nonessential and unprotected personnel will be excluded from the LSDZ.

7. The control of airspace will be coordinated with the appropriate agency for all ground-to-ground, ground-to-air, air-to-ground, or air-to-air Class 3 or 4 laser beams transmitted through the atmosphere. See Section III.E.3.b for procedures to contact the FAA.

8. Communication with personnel in controlled areas must be maintained during laser operations.

9. Lasing of nontarget vehicles or aircraft is prohibited.

10. Personnel protection equipment commensurate with the hazard, will be provided to all personnel who must be in the hazard zone. When using magnifying devices, a greater hazard should be taken into account because more light is collected by these devices than the naked eye.

11. For maintenance and test operations involving laser designators, the beam will be oriented away from populated areas and will be terminated by a backstop.

B. **Laser Safety Training:** Laser safety training is the responsibility of the Range Safety Officer/NCO and the support Environmental Health Officer. The assigned flight surgeon and BES may also be involved in some medical aspects of this training. Specific responsibilities should be assigned according to the training/experience of assigned personnel. Initial and annual training sessions should be conducted and entered on the individual's training records (AF Form 991). Adequacy of training should be documented in the applicable shop folder. A Navy training video tape is available (Navy tape No. 800909DN, Aircrew Laser Eye Protection) through the base audio visual library.

C. **Eye examinations:** All personnel whose assigned duties are in a laser hazard zone are required to have a laser eye exam prior to and at termination of laser assigned duties. Laser eye exams are to be conducted as prescribed by AFOSH Standard 161-10. For aircrews, this requirement is met by flight physicals.

D. **Eye Wear:** All personnel entering controlled areas during lasing operations must wear the correct laser protective eye wear. Present AF policy requires aircrews to wear laser eye protection during training missions under the following conditions:

1. Exercise mission involving multiship formations.

2. Target areas not cleared of specular reflective surfaces.

3. Ground-based lasers used against aircraft.

E. **Involved agencies:** Normally, a coordinated effort between the range operating agency, BES, and the Base Safety Office is necessary to evaluate the potential hazard of laser systems operated on the range. These agencies and the Environmental Health Officer can develop an appropriate training package for range personnel.

APPENDIX A

HAZARD EVALUATIONS FOR AIRBORNE LASERS

Table A.1. AIR TO GROUND LASER TARGET DESIGNATORS

Summary of Air to Ground Laser Target Designators

Device	Wavelength (nm)	ANSI Class	NOHD-S (m)	NOHD (m)	NOHD-O (m)	OD	OD*	Buffer Angle (mrad)	Beam Divergence (mrad)
Air Force Systems:									
PAVE SPIKE (AN/ASQ-153)	1064	4	5800	10000		4.0		2.5	.35
PAVE TACK (AN/AVQ-26)	1064	4	8200	16000		4.04		2	0**
PAVE KNIFE (AN/ALQ-10)	1064	4	3100	5600		3.7		5	
PAVE SPECTRE (AN/AVQ-19)	1064	4	5000	8900		3.7		5	.33
LANTIRN POD (operational)	1064	4	7500	14800		3.8		2	0**
(Training)	1540	3b	0	0		0		NA	0**
Other Services:									
A6-E TRAM (AN/AAS-33A)	1064	4	9000	14600	58000	4.6	5.8	5	
AN/AAS-37 (OV-10)	1064	4		11200	56200	5.2	5.8	5	
TADS (AAH)	1064	4		20000	70000+	+	5.5+	5	
LAAT (AH-1S)	1064	4		5000	30000	3.4	4.8	5	

KEY:

NOHD - multiple pulse NOHD (also referred to as NOHD-M)
NOHD-S - single pulse NOHD
NOHD-O - NOHD with optical instruments
OD* - OD required in optics of viewing device (assuming 80 mm aperature)
** - Actual divergence classified, use 0 with the specified buffer angle.
+ - Pending evaluation of the production model.

APPENDIX B

HAZARD EVALUATIONS FOR GROUND BASED LASERS

Table B.1. NOMINAL OCULAR HAZARD DISTANCES AND RANGE SAFETY INFORMATION FOR FIELDED MILITARY GROUND BASED LASER SYSTEMS

Device	System	ANSI Class	Distances (m) NOHD	NOHD-O	t	s	Buffer Angle (mrad) Static	Moving
********** TANK MOUNTED **********								
AN/VVG-1	M551A1	4	10,000	80,000	10	60	2	Not Permitted
AN/VVS-1	M60A2	4	10,000	80,000	10	100	5	10
AN/VVG-2	M60A3	4	10,000	80,000	10	60	2	5
red "filter" (29 dB)			300	3,100	0	Target	2	5
green "filter" (55 dB)			0	0	0	0	NA	NA
AN/VVG-3	M1	4	7,000	35,000	0	60	2	5
********** MAN PORTABLE **********								
AN/GVT-1	SLT	1	0	0	0	0	NA	NA
AN/GVS-5		4	2,700	20,600	0	200	10 hand-held	
red filter (19 dB)			290	1,800	0	200	10 hand-held	
yellow filter (29 dB)			56	550	0	200	10 hand-held	
AN/PAQ-1	LTD	4	7,700	33,000	0	200	10 hand-held	
AN/TVQ-2 LRF mode	G/VLLD	4	8,000	40,000	0	60	2 on tripod	Not used
yellow filter (8.5 dB)			2,500+	23,000+	0	100+	5 on vehicle	--on the
AN/TVQ-2 LD mode	G/VLLD	4	25,000	80,000	0	60	2 on tripod	move in
						100+	5 on vehicle	training
AN/PAQ-3 LRF mode	MULE	4	6,500	35,000	0	60	2 on tripod	
						200	10 handheld	
AN/PAQ-3 LD mode	MULE	4	20,000	79,000	0	60	2 on tripod	
						200	10 handheld	

KEY;

+ - Pending evaluation of the production model
NOHD - multiple pulse NOHD (also referred to as NOHD-M)
NOHD-O - NOHD with optical instruments
t - diffuse reflection hazard distance
s - a predetermined (by the using service) distance around the target which must be cleared of specular reflective surfaces.

Table B.2. EYE PROTECTION REQUIREMENTS FOR FIELDED MILITARY GROUND BASED LASER SYSTEMS

Device	System	Wavelength (nm)	Built-In Safety Filter (OD)	Required Eye Protection (OD) Unaided	Required Eye Protection (OD) Total
********** TANK MOUNTED **********					
AN/VVG-1	M551A1	694.3	clip-on > 5	5.8	5.8
AN/VVS-1	M60A2	694.3	clip-on > 5	5.8	5.8
AN/VVG-2	M60A3	694.3	clip-on > 5	5.8	5.8
AN/VVG-3	M1	1,064	> 5	4.7	4.7
********** MAN PORTABLE **********					
AN/GVT-1	SLT	1,064	NA	0	0
AN/GVS-5		1,064	5	3.7	4.4
AN/PAQ-1	LTD	1,064	4	4.2	5.8
AN/TVQ-2	G/VLLD	1,064	YES	3.8	5.5
AN/PAQ-3	MULE	1,064	> 5	3.9	5.8

APPENDIX C

DESCRIPTION OF FIELDED LASER SYSTEMS

DESCRIPTION OF FIELDED LASER SYSTEMS

The following brief description of laser devices is provided for your information.

1. AN/VVS-1 Laser Range Finder mounted on the M60A2 tank.

2. AN/VVG-1 Laser Range Finder mounted on the M551A1 Sheridan vehicle.

3. AN/VVG-2 Laser Range Finder mounted on the M60A3 tank. Used with two filters, the green Eye Safe Simulated Laser Range Finder (ESSLR) filter and the red ESSLR filter. The green ESSLR is eye safe, the red ESSLR is less hazardous than the system without filters (see Appendix B).

4. AN/GVS-5 Laser Range Finder Infrared Observation Set (Handheld).

5. AN/PAQ-1 (LTD) Laser Target Designator. This is a lightweight, handheld, battery operated laser device. Forward observers use it to designate targets.

6. AN/TVQ-2 (G/VLLD) Ground/Vehicle Laser Locator Designator. This is a principle ranging and laser designating device used by Army artillery forward observers with laser energy homing munitions. It is capable of designating stationary or moving vehicular targets and may be used in a stationary, vehicle mounted, or tripod supported dismounted mode. The primary vehicle mount is the Fire Support Team Vehicle (FISTV).

7. AN/PAQ-3 (MULE) Modular Universal Laser Equipment. This is a Marine Corps laser designator used with laser energy homing munitions. The MULE is man portable and is used only in a dismounted mode.

8. Laser Augmented Airborne TOW (LAAT) mounted in the AH-1S COBRA Helicopter. The LAAT system consists of a laser range finder and reciever that is incorporated into the M65 tube launched optically tracked wire guided (TOW) telescopic sight unit.

9. Target Acquisition and Designation System with Pilot Night Vision Sight (TADS/PNVS) mounted in the Apache Advanced Attack Helicopter.

10. AN/AAS-37, Laser Range Finder Designator mounted on the Marine Corps OV-10 Observation Aircraft.

11. M55, Laser Tank Gunnery Trainer

12. Air to Ground Engagement System/Air Defense (AGES/AD) is an extension of MILES to air defense simulation.

13. AN/AAS-33A, Target Recognition Attack Multisensor (TRAM) laser system. This system is mounted on the A6-E Aircraft and has a laser target designator and forward looking infrared (FLIR).

14. Multiple Integrated Laser Engagement System (MILES). The MILES system uses low risk lasers and does not require service members to wear protective eyewear during the conduct of training with the MILES system.

15. LANTIRN System, Low Altitude Navigation and Targeting Infrared System for Night. A two pod system containing a terrain following radar (TFR), forward looking infrared (FLIR), laser designation, and later, a target recognition system. This system is designed to be flown on the F-15, F-16 and A-10. The laser operates at 1064 nm and may have a training modification to operate at 1540 nm which will be eye safe.

16. TASO (Training Aid Support Office) Rifle Marksmanship-Weaponeer-Remedial Rifle Marksmanship Trainer.

17. SHILLELAGH Conduct of Fire Trainer (SCOFT).

18. PAVE PENNY (AN/AAS-35): Laser tracker pod used on the A-10 and A-7 aircraft. Does not contain a laser.

19. PAVE SPECTRE (AN/AVQ-19): Laser tracking and designator used on C-130 gunships.

20. PAVE SPIKE (AN/AVQ-12): Laser tracking and designator pod fitted on F-4 and F-111 aircraft.

21. PAVE TACK (AN/AVQ-26): Advanced optronics pod containing stabilized turret with FLIR, laser designator and tracker used on the F-4, RF-4, and F-111F aircraft.

The following systems are not in the active inventory but are included for background:

22. PAVE ARROW (AN/AVQ-14): This was a laser tracker pod developed for use in conjunction with the PAVE SPOT laser designator used on O-2A FAC spotter planes, C-123, and was planned for use on the F-100. It was eventually merged with the PAVE SWORD program.

23. PAVE BLIND BAT: The PAVE BLIND BAT consisted of a laser target designator to illuminate targets for the PAVE WAY guided bombs. It had an effective range of 18,000 ft and was developed in part for use by AC-130 gunships to aid supporting fighter aircraft.

24. PAVE FIRE: Development of laser scanner in 1969-70 to aid F-4 Phantoms in securing proper target bearing.

25. PAVE GAT: Development of a laser range finder for use on the B-57G.

26. PAVE KNIFE (AN/ALQ-10): The original laser designator pod developed by Aeronutronic-Ford and used in combat in Vietnam 1971-73.

27. PAVE LANCE: Developmental effort to replace the PAVE KNIFE by improving night capability with the addition of a forward looking infrared (FLIR) in place of the low light television (LLTV). Superseded by PAVE TACK.

28. PAVE LICHT (AN/AVQ-9): Stablizer laser designator developed for the F-4 Phantom.

29. PAVE MACK: Development of laser seeker head for air to ground rockets. Project was also called LARS (Laser Aided Rocket System) and rockets were to be used in conjunction with FAC (Forward Air Controller) mounted PAVE SPOT designator.

30. PAVE NAIL (AN/AVQ-13): Modification of 18 OV-10 FAC aircraft with stabilized periscopic night sight and laser designator. Program coordinated with PAVE PHANTOM and PAVE SPOT.

31. PAVE PHANTOM: Addition of an ARN-92 Loran and computer to the F-4D allowing aircraft to store targeting information for eight separate positions illuminated by OV-10 PAVE NAIL.

32. PAVE POINTER: Palletized gun direction system consisting of a laser designator/range finder and low light TV employed on a C-123 and forerunner of subsequent gunship fire control systems.

33. PAVE PRISM: Aerodyne Research effort to develop IR and active laser seekers for use on the ASRAAM air-to-air missile.

34. PAVE PRONTO: Modification of AC-130 gunships for night attack including an LTV Electro systems night observation camera, AAD-4 or AAD-6 FLIR and AVQ-17 illuminator.

35. PAVE SCOPE: Target acquisition aids for jet fighter aircraft such as the Eagle Eye (LAD) AN/AVG-8, and TISEO.

36. PAVE SHIELD: Classified project undertaken by Aeronautical Research Associates.

37. PAVE SPOT (AN/AVQ-12): Stabilized periscopic night vision sight developed by Varo for use on the O-2A FAC. The system was fitted with a Korad laser designator (Nd: YAG) and first went into service in 1970 over Vietnam.

38. PAVE STRIKE: A related group of air-to-ground strike programs including PAVE TACK and IR guided bombs.

39. PAVE SWORD (AN/AVQ-11): Laser tracker designed to pick up energy from targets illuminated by O-2A spotter planes. Used on F-4, and bore sighted with its radar set.

40. PAVE WAY: Code name for a wide variety of guided bomb projects, also refers to AN/AVQ-9 laser designator developed by Martin Marietta in the late 1960s for use on the F-4 Phantom.

APPENDIX D

FOOTPRINT TABLES FOR COMMON AIRBORNE SYSTEMS

Table D.1
LASER FOOTPRINT TABLE for: PAVE SPIKE (USING VACUUM NOHD)

Table based on: Flat terrain, Buffer= 2.5 mrad, Divergence= .35 mrad
NOHD= 10000 meters (32800 feet or 5.4 nautical miles)

Table values are FOOTPRINT dimensions(feet and meters)

ALTITUDE (feet)	FOOTPRINT	SLANT RANGE (nautical miles, feet, and meters)								
		1.0 NM 6080 ft 1850 m	2.0 NM 12200 ft 3700 m	3.0 NM 18200 ft 5560 m	4.0 NM 24300 ft 7410 m	5.0 NM 30400 ft 9260 m	6.0 NM 36500 ft 11100 m	7.0 NM 42500 ft 13000 m	8.0 NM 48600 ft 14800 m	9.0 NM 54700 ft 16700 m
100	FORWARD	1180 ft	5850 ft	14600 ft	8500 ft	2420 ft	0 ft	0 ft	0 ft	0 ft
		359 m	1780 m	4440 m	2590 m	737 m	0 m	0 m	0 m	0 m
	AFT	850 ft	2980 ft	5970 ft	9580 ft	13600 ft	18000 ft	22600 ft	27500 ft	32500 ft
		259 m	909 m	1820 m	2920 m	4150 m	5490 m	6900 m	8380 m	9900 m
200	FORWARD	537 ft	2360 ft	5880 ft	8500 ft	2420 ft	0 ft	0 ft	0 ft	0 ft
		164 m	719 m	1790 m	2590 m	737 m	0 m	0 m	0 m	0 m
	AFT	457 ft	1700 ft	3570 ft	5960 ft	8780 ft	11900 ft	15400 ft	19200 ft	23100 ft
		139 m	518 m	1090 m	1820 m	2680 m	3640 m	4700 m	5840 m	7040 m
300	FORWARD	348 ft	1460 ft	3540 ft	6720 ft	2420 ft	0 ft	0 ft	0 ft	0 ft
		106 m	450 m	1080 m	2050 m	737 m	0 m	0 m	0 m	0 m
	AFT	312 ft	1190 ft	2550 ft	4330 ft	6480 ft	8940 ft	11700 ft	0 ft	0 ft
		95 m	362 m	777 m	1320 m	1970 m	2730 m	3560 m	0 m	0 m
400	FORWARD	257 ft	1070 ft	2530 ft	4720 ft	2420 ft	0 ft	0 ft	0 ft	0 ft
		78 m	328 m	771 m	1440 m	737 m	0 m	0 m	0 m	0 m
	AFT	237 ft	913 ft	1980 ft	3400 ft	5130 ft	7150 ft	0 ft	0 ft	0 ft
		72 m	278 m	604 m	1040 m	1560 m	2180 m	0 m	0 m	0 m
500	FORWARD	204 ft	845 ft	1970 ft	3630 ft	2420 ft	0 ft	0 ft	0 ft	0 ft
		62 m	258 m	600 m	1110 m	738 m	0 m	0 m	0 m	0 m
	AFT	191 ft	742 ft	1620 ft	2800 ft	4250 ft	5950 ft	0 ft	0 ft	0 ft
		58 m	226 m	494 m	852 m	1290 m	1810 m	0 m	0 m	0 m
600	FORWARD	169 ft	696 ft	1610 ft	2950 ft	2420 ft	0 ft	0 ft	0 ft	0 ft
		52 m	212 m	491 m	900 m	738 m	0 m	0 m	0 m	0 m
	AFT	160 ft	625 ft	1370 ft	2380 ft	3620 ft	5100 ft	0 ft	0 ft	0 ft
		49 m	190 m	418 m	724 m	1100 m	1550 m	0 m	0 m	0 m
700	FORWARD	144 ft	592 ft	1360 ft	2490 ft	2420 ft	0 ft	0 ft	0 ft	0 ft
		44 m	180 m	416 m	758 m	738 m	0 m	0 m	0 m	0 m
	AFT	138 ft	539 ft	1190 ft	2070 ft	3160 ft	4460 ft	0 ft	0 ft	0 ft
		42 m	164 m	362 m	630 m	963 m	1360 m	0 m	0 m	0 m
800	FORWARD	126 ft	515 ft	1180 ft	2150 ft	2420 ft	0 ft	0 ft	0 ft	0 ft
		38 m	157 m	361 m	655 m	738 m	0 m	0 m	0 m	0 m
	AFT	121 ft	475 ft	1050 ft	1830 ft	2800 ft	3960 ft	0 ft	0 ft	0 ft
		37 m	145 m	319 m	557 m	854 m	1210 m	0 m	0 m	0 m
	WIDTH	33 ft	65 ft	98 ft	130 ft	163 ft	195 ft	228 ft	260 ft	293 ft
		10 m	20 m	30 m	40 m	50 m	59 m	69 m	79 m	89 m

FOOTPRINT FORWARD- distance beyond target.
FOOTPRINT AFT- distance from target toward aircraft.
FOOTPRINT WIDTH- total width at target.
NOTE: -99 indicates an impossible alt./range combination

Table D.2
LASER FOOTPRINT TABLE for: PAVE SPIKE (INCLUDING ATMOSPHERIC ATTENUATION FOR LASING FROM ALTITUDES BELOW 1 km MSL ONLY)

Table based on: Flat terrain, Buffer= 2.5 mrad, Divergence= .35 mrad
NOHD= 8200 meters (26896 feet or 4.4 nautical miles)

Table values are FOOTPRINT dimensions(feet and meters)

ALTITUDE (feet)	FOOTPRINT	SLANT RANGE (nautical miles, feet, and meters) 1.0 NM 6080 ft 1850 m	2.0 NM 12200 ft 3700 m	3.0 NM 18200 ft 5560 m	4.0 NM 24300 ft 7410 m	5.0 NM 30400 ft 9260 m	6.0 NM 36500 ft 11100 m	7.0 NM 42500 ft 13000 m	8.0 NM 48600 ft 14800 m	9.0 NM 54700 ft 16700 m
100	FORWARD	1180 ft	5850 ft	8670 ft	2590 ft	0 ft	0 ft	0 ft	0 ft	0 ft
		359 m	1780 m	2640 m	790 m	0 m	0 m	0 m	0 m	0 m
	AFT	850 ft	2980 ft	5970 ft	9580 ft	13600 ft	18000 ft	22600 ft	27500 ft	32500 ft
		259 m	909 m	1820 m	2920 m	4150 m	5490 m	6900 m	8380 m	9900 m
200	FORWARD	537 ft	2360 ft	5880 ft	2590 ft	0 ft	0 ft	0 ft	0 ft	0 ft
		164 m	719 m	1790 m	790 m	0 m	0 m	0 m	0 m	0 m
	AFT	457 ft	1700 ft	3570 ft	5960 ft	8780 ft	11900 ft	0 ft	0 ft	0 ft
		139 m	518 m	1090 m	1820 m	2680 m	3640 m	0 m	0 m	0 m
300	FORWARD	348 ft	1480 ft	3540 ft	2590 ft	0 ft	0 ft	0 ft	0 ft	0 ft
		106 m	450 m	1080 m	790 m	0 m	0 m	0 m	0 m	0 m
	AFT	312 ft	1190 ft	2550 ft	4330 ft	6480 ft	0 ft	0 ft	0 ft	0 ft
		95 m	362 m	777 m	1320 m	1970 m	0 m	0 m	0 m	0 m
400	FORWARD	257 ft	1070 ft	2530 ft	2590 ft	0 ft	0 ft	0 ft	0 ft	0 ft
		78 m	328 m	771 m	790 m	0 m	0 m	0 m	0 m	0 m
	AFT	237 ft	913 ft	1980 ft	3400 ft	5130 ft	0 ft	0 ft	0 ft	0 ft
		72 m	278 m	604 m	1040 m	1560 m	0 m	0 m	0 m	0 m
500	FORWARD	204 ft	845 ft	1970 ft	2590 ft	0 ft	0 ft	0 ft	0 ft	0 ft
		62 m	258 m	600 m	790 m	0 m	0 m	0 m	0 m	0 m
	AFT	191 ft	742 ft	1620 ft	2800 ft	4250 ft	0 ft	0 ft	0 ft	0 ft
		58 m	226 m	494 m	852 m	1290 m	0 m	0 m	0 m	0 m
600	FORWARD	169 ft	696 ft	1610 ft	2590 ft	0 ft	0 ft	0 ft	0 ft	0 ft
		52 m	212 m	491 m	790 m	0 m	0 m	0 m	0 m	0 m
	AFT	160 ft	625 ft	1370 ft	2360 ft	3620 ft	0 ft	0 ft	0 ft	0 ft
		49 m	190 m	418 m	724 m	1100 m	0 m	0 m	0 m	0 m
700	FORWARD	144 ft	592 ft	1360 ft	2490 ft	0 ft	0 ft	0 ft	0 ft	0 ft
		44 m	180 m	416 m	758 m	0 m	0 m	0 m	0 m	0 m
	AFT	138 ft	539 ft	1190 ft	2070 ft	0 ft	0 ft	0 ft	0 ft	0 ft
		42 m	164 m	362 m	630 m	0 m	0 m	0 m	0 m	0 m
800	FORWARD	126 ft	515 ft	1180 ft	2150 ft	0 ft	0 ft	0 ft	0 ft	0 ft
		38 m	157 m	361 m	655 m	0 m	0 m	0 m	0 m	0 m
	AFT	121 ft	475 ft	1050 ft	1830 ft	0 ft	0 ft	0 ft	0 ft	0 ft
		37 m	145 m	319 m	557 m	0 m	0 m	0 m	0 m	0 m
	WIDTH	33 ft	65 ft	98 ft	130 ft	163 ft	195 ft	228 ft	260 ft	293 ft
		10 m	20 m	30 m	40 m	50 m	59 m	69 m	79 m	89 m

FOOTPRINT FORWARD- distance beyond target.
FOOTPRINT AFT- distance from target toward aircraft.
FOOTPRINT WIDTH- total width at target.
NOTE: -99 indicates an impossible alt./range combination

Table D.3
LASER FOOTPRINT TABLE for: PAVE TACK (USING VACUUM NOHD)

Table based on: Flat terrain, Buffer= 2 mrad, Divergence= 0 mrad
NOHD= 16000 meters (52480 feet or 8.6 nautical miles)

Table values are FOOTPRINT dimensions(feet and meters)

ALTITUDE (feet)	FOOTPRINT	SLANT RANGE (nautical miles, feet, and meters)								
		1.0 NM 6080 ft 1850 m	2.0 NM 12200 ft 3700 m	3.0 NM 18200 ft 5560 m	4.0 NM 24300 ft 7410 m	5.0 NM 30400 ft 9260 m	6.0 NM 36500 ft 11100 m	7.0 NM 42500 ft 13000 m	8.0 NM 48600 ft 14800 m	9.0 NM 54700 ft 16700 m
100	FORWARD	841 ft	3930 ft	10500 ft	23000 ft	22100 ft	16000 ft	9950 ft	3870 ft	0 ft
		256 m	1190 m	3190 m	7010 m	6740 m	4880 m	3030 m	1180 m	0 m
	AFT	658 ft	2380 ft	4870 ft	7950 ft	11500 ft	15400 ft	19600 ft	24000 ft	28600 ft
		201 m	724 m	1480 m	2420 m	3500 m	4690 m	5960 m	7300 m	8710 m
200	FORWARD	393 ft	1680 ft	4060 ft	7800 ft	13300 ft	16000 ft	9950 ft	3870 ft	0 ft
		120 m	512 m	1240 m	2380 m	4040 m	4880 m	3030 m	1180 m	0 m
	AFT	348 ft	1320 ft	2810 ft	4750 ft	7080 ft	9740 ft	12700 ft	15900 ft	19300 ft
		106 m	401 m	857 m	1450 m	2160 m	2970 m	3870 m	4850 m	5890 m
300	FORWARD	257 ft	1070 ft	2520 ft	4700 ft	7720 ft	11700 ft	9950 ft	3870 ft	0 ft
		78 m	327 m	769 m	1430 m	2350 m	3570 m	3030 m	1180 m	0 m
	AFT	237 ft	911 ft	1980 ft	3390 ft	5120 ft	7130 ft	9400 ft	11900 ft	14600 ft
		72 m	278 m	602 m	1030 m	1560 m	2170 m	2860 m	3630 m	4450 m
400	FORWARD	190 ft	786 ft	1830 ft	3360 ft	5440 ft	8130 ft	9950 ft	3870 ft	0 ft
		58 m	240 m	557 m	1020 m	1660 m	2480 m	3030 m	1180 m	0 m
	AFT	179 ft	696 ft	1520 ft	2630 ft	4010 ft	5620 ft	7460 ft	9500 ft	11700 ft
		55 m	212 m	464 m	803 m	1220 m	1710 m	2270 m	2900 m	3580 m
500	FORWARD	151 ft	621 ft	1430 ft	2620 ft	4200 ft	6220 ft	8720 ft	3870 ft	0 ft
		46 m	189 m	437 m	798 m	1280 m	1900 m	2660 m	1180 m	0 m
	AFT	144 ft	563 ft	1240 ft	2150 ft	3290 ft	4640 ft	6180 ft	7910 ft	9810 ft
		44 m	172 m	378 m	656 m	1000 m	1410 m	1880 m	2410 m	2990 m
600	FORWARD	126 ft	513 ft	1180 ft	2140 ft	3420 ft	5040 ft	7030 ft	3870 ft	0 ft
		38 m	156 m	359 m	653 m	1040 m	1540 m	2140 m	1180 m	0 m
	AFT	121 ft	473 ft	1040 ft	1820 ft	2790 ft	3950 ft	5280 ft	6780 ft	[illegible]30 ft
		37 m	144 m	318 m	555 m	852 m	1200 m	1610 m	2070 m	2570 m
700	FORWARD	107 ft	437 ft	1000 ft	1810 ft	2890 ft	4240 ft	5880 ft	3870 ft	0 ft
		33 m	133 m	305 m	553 m	880 m	1290 m	1790 m	1180 m	0 m
	AFT	104 ft	408 ft	902 ft	1580 ft	2430 ft	3440 ft	4610 ft	5930 ft	7390 ft
		32 m	124 m	275 m	481 m	740 m	1050 m	1400 m	1810 m	2250 m
800	FORWARD	94 ft	381 ft	870 ft	1570 ft	2500 ft	3660 ft	5060 ft	3870 ft	0 ft
		29 m	116 m	265 m	479 m	761 m	1110 m	1540 m	1180 m	0 m
	AFT	91 ft	358 ft	795 ft	1390 ft	2140 ft	3050 ft	4090 ft	5270 ft	6580 ft
		28 m	109 m	242 m	424 m	654 m	928 m	1250 m	1610 m	2000 m
	WIDTH	24 ft	49 ft	73 ft	97 ft	122 ft	146 ft	170 ft	194 ft	219 ft
		7 m	15 m	22 m	30 m	37 m	44 m	52 m	59 m	67 m

FOOTPRINT FORWARD- distance beyond target.
FOOTPRINT AFT- distance from target toward aircraft.
FOOTPRINT WIDTH- total width at target.
NOTE: -99 indicates an impossible alt./range combination

Table D.4

LASER FOOTPRINT TABLE for: PAVE TACK (INCLUDING ATMOSPHERIC ATTENUATION FOR LASING FROM ALTITUDES BELOW 1 km MSL ONLY)

Table based on: Flat terrain, Buffer= 2 mrad, Divergence= 0 mrad
NOHD= 12000 meters (39360 feet or 6.5 nautical miles)

Table values are FOOTPRINT dimensions(feet and meters)

ALTITUDE (feet)	FOOTPRINT	SLANT RANGE (nautical miles, feet, and meters) 1.0 NM 6080 ft 1850 m	2.0 NM 12200 ft 3700 m	3.0 NM 18200 ft 5560 m	4.0 NM 24300 ft 7410 m	5.0 NM 30400 ft 9260 m	6.0 NM 36500 ft 11100 m	7.0 NM 42500 ft 13000 m	8.0 NM 48600 ft 14800 m	9.0 NM 54700 ft 16700 m
100	FORWARD	841 ft	3900 ft	10500 ft	15100 ft	8980 ft	2900 ft	0 ft	0 ft	0 ft
		256 m	1190 m	3190 m	4590 m	2740 m	885 m	0 m	0 m	0 m
	AFT	658 ft	2380 ft	4870 ft	7950 ft	11500 ft	15400 ft	19600 ft	24000 ft	28600 ft
		201 m	724 m	1480 m	2420 m	3500 m	4690 m	5960 m	7300 m	8710 m
200	FORWARD	393 ft	1680 ft	4060 ft	7800 ft	8980 ft	2900 ft	0 ft	0 ft	0 ft
		120 m	512 m	1240 m	2380 m	2740 m	885 m	0 m	0 m	0 m
	AFT	348 ft	1320 ft	2810 ft	4750 ft	7080 ft	9740 ft	12700 ft	15900 ft	19300 ft
		106 m	401 m	857 m	1450 m	2160 m	2970 m	3870 m	4850 m	5890 m
300	FORWARD	257 ft	1070 ft	2520 ft	4700 ft	7720 ft	2900 ft	0 ft	0 ft	0 ft
		78 m	327 m	769 m	1430 m	2350 m	885 m	0 m	0 m	0 m
	AFT	237 ft	911 ft	1980 ft	3390 ft	5120 ft	7130 ft	9400 ft	11900 ft	0 ft
		72 m	278 m	602 m	1030 m	1560 m	2170 m	2860 m	3630 m	0 m
400	FORWARD	190 ft	786 ft	1830 ft	3360 ft	5440 ft	2900 ft	0 ft	0 ft	0 ft
		58 m	240 m	557 m	1020 m	1660 m	885 m	0 m	0 m	0 m
	AFT	179 ft	696 ft	1520 ft	2630 ft	4010 ft	5620 ft	7460 ft	9500 ft	0 ft
		55 m	212 m	464 m	803 m	1220 m	1710 m	2270 m	2900 m	0 m
500	FORWARD	151 ft	621 ft	1430 ft	2620 ft	4200 ft	2900 ft	0 ft	0 ft	0 ft
		46 m	189 m	437 m	798 m	1280 m	885 m	0 m	0 m	0 m
	AFT	144 ft	563 ft	1240 ft	2150 ft	3290 ft	4640 ft	6180 ft	0 ft	0 ft
		44 m	172 m	378 m	656 m	1000 m	1410 m	1880 m	0 m	0 m
600	FORWARD	126 ft	513 ft	1160 ft	2140 ft	3420 ft	2900 ft	0 ft	0 ft	0 ft
		38 m	156 m	359 m	653 m	1040 m	885 m	0 m	0 m	0 m
	AFT	121 ft	473 ft	1040 ft	1820 ft	2790 ft	3950 ft	5280 ft	0 ft	0 ft
		37 m	144 m	318 m	555 m	852 m	1200 m	1610 m	0 m	0 m
700	FORWARD	107 ft	437 ft	1000 ft	1810 ft	2890 ft	2900 ft	0 ft	0 ft	0 ft
		33 m	133 m	305 m	553 m	880 m	885 m	0 m	0 m	0 m
	AFT	104 ft	408 ft	902 ft	1580 ft	2430 ft	3440 ft	4610 ft	0 ft	0 ft
		32 m	124 m	275 m	481 m	740 m	1050 m	1400 m	0 m	0 m
800	FORWARD	94 ft	381 ft	870 ft	1570 ft	2500 ft	2900 ft	0 ft	0 ft	0 ft
		29 m	116 m	265 m	479 m	761 m	885 m	0 m	0 m	0 m
	AFT	91 ft	358 ft	795 ft	1390 ft	2140 ft	3050 ft	4090 ft	0 ft	0 ft
		28 m	109 m	242 m	424 m	654 m	928 m	1250 m	0 m	0 m
	WIDTH	24 ft	49 ft	73 ft	97 ft	122 ft	146 ft	170 ft	194 ft	219 ft
		7 m	15 m	22 m	30 m	37 m	44 m	52 m	59 m	67 m

FOOTPRINT FORWARD- distance beyond target.
FOOTPRINT AFT- distance from target toward aircraft.
FOOTPRINT WIDTH- total width at target.
NOTE: -99 indicates an impossible alt./range combination

Table D.5

LASER FOOTPRINT TABLE for: ANY LASER SYSTEM WITH BEAM DIVERGENCE < 0.5 mrad

Table based on: Flat terrain, Buffer= 5 mrad, Divergence= 0 mrad
NOHD= 100000 meters (328000 feet or 54.0 nautical miles)

Table values are FOOTPRINT dimensions(feet and meters)

ALTITUDE (feet)	FOOTPRINT	SLANT RANGE (nautical miles, feet, and meters)								
		1.0 NM 6080 ft 1850 m	2.0 NM 12200 ft 3700 m	3.0 NM 18200 ft 5560 m	4.0 NM 24300 ft 7410 m	5.0 NM 30400 ft 9260 m	6.0 NM 36500 ft 11100 m	7.0 NM 42500 ft 13000 m	8.0 NM 48600 ft 14800 m	9.0 NM 54700 ft 16700 m
100	FORWARD	2650 ft 808 m	18800 ft 5740 m	188000 ft 57200 m	304000 ft 92600 m	298000 ft 90700 m	292000 ft 88900 m	285000 ft 87000 m	279000 ft 85200 m	273000 ft 83300 m
	AFT	1420 ft 432 m	4590 ft 1400 m	8690 ft 2650 m	13300 ft 4060 m	18300 ft 5580 m	23500 ft 7180 m	28900 ft 8820 m	34400 ft 10500 m	40000 ft 12200 m
200	FORWARD	1090 ft 332 m	5300 ft 1620 m	15300 ft 4650 m	37600 ft 11500 m	95900 ft 29200 m	292000 ft 88900 m	285000 ft 87000 m	279000 ft 85200 m	273000 ft 83300 m
	AFT	801 ft 244 m	2830 ft 863 m	5710 ft 1740 m	9190 ft 2800 m	13100 ft 4000 m	17400 ft 5300 m	21900 ft 6680 m	26700 ft 8130 m	31600 ft 9630 m
300	FORWARD	685 ft 209 m	3090 ft 941 m	7950 ft 2420 m	16500 ft 5040 m	31200 ft 9500 m	56500 ft 17200 m	104000 ft 31600 m	207000 ft 63200 m	273000 ft 83300 m
	AFT	559 ft 170 m	2050 ft 624 m	4250 ft 1290 m	7010 ft 2140 m	10200 ft 3110 m	13800 ft 4200 m	17600 ft 5380 m	21800 ft 6630 m	26100 ft 7950 m
400	FORWARD	499 ft 152 m	2180 ft 663 m	5380 ft 1640 m	10600 ft 3230 m	18600 ft 5670 m	30500 ft 9300 m	48300 ft 14700 m	75300 ft 22900 m	118000 ft 36000 m
	AFT	429 ft 131 m	1600 ft 488 m	3380 ft 1030 m	5660 ft 1730 m	8360 ft 2550 m	11400 ft 3480 m	14800 ft 4500 m	18400 ft 5600 m	22200 ft 6770 m
500	FORWARD	393 ft 120 m	1680 ft 512 m	4060 ft 1240 m	7800 ft 2380 m	13300 ft 4040 m	20900 ft 6380 m	31500 ft 9590 m	46000 ft 14000 m	66000 ft 20100 m
	AFT	348 ft 106 m	1320 ft 401 m	2810 ft 857 m	4750 ft 1450 m	7080 ft 2160 m	9740 ft 2970 m	12700 ft 3870 m	15900 ft 4850 m	19300 ft 5890 m
600	FORWARD	324 ft 99 m	1370 ft 417 m	3260 ft 995 m	6170 ft 1880 m	10300 ft 3140 m	15900 ft 4850 m	23400 ft 7120 m	33100 ft 10100 m	45800 ft 14000 m
	AFT	293 ft 89 m	1120 ft 341 m	2400 ft 733 m	4090 ft 1250 m	6140 ft 1870 m	8500 ft 2590 m	11100 ft 3390 m	14000 ft 4270 m	17100 ft 5220 m
700	FORWARD	276 ft 84 m	1150 ft 352 m	2730 ft 832 m	5110 ft 1560 m	8420 ft 2570 m	12800 ft 3910 m	18600 ft 5660 m	25900 ft 7880 m	35100 ft 10700 m
	AFT	253 ft 77 m	971 ft 296 m	2100 ft 640 m	3600 ft 1100 m	5420 ft 1650 m	7530 ft 2300 m	9910 ft 3020 m	12500 ft 3820 m	15400 ft 4680 m
800	FORWARD	240 ft 73 m	999 ft 304 m	2340 ft 714 m	4350 ft 1330 m	7120 ft 2170 m	10800 ft 3280 m	15400 ft 4690 m	21200 ft 6470 m	28400 ft 8650 m
	AFT	222 ft 68 m	858 ft 262 m	1860 ft 568 m	3210 ft 977 m	4850 ft 1480 m	6770 ft 2060 m	8930 ft 2720 m	11300 ft 3450 m	13900 ft 4250 m
	WIDTH	61 ft 19 m	122 ft 37 m	182 ft 56 m	243 ft 74 m	304 ft 93 m	365 ft 111 m	425 ft 130 m	486 ft 148 m	547 ft 167 m

FOOTPRINT FORWARD- distance beyond target.
FOOTPRINT AFT- distance from target toward aircraft.
FOOTPRINT WIDTH- total width at target.
NOTE: -99 indicates an impossible alt./range combination

APPENDIX E

SAMPLE RANGE EVALUATION A, AIR TO GROUND MODE, GENERAL CASES, FLAT TERRAIN

SAMPLE RANGE EVALUATION B, AIR TO GROUND MODE, SPECIFIED APPROACH TRACK, FLAT TERRAIN

SAMPLE RANGE EVALUATION C, AIR TO GROUND MODE, SPECIFIED FLIGHT PROFILE, COMPLEX TERRAIN

SAMPLE RANGE EVALUATION D, GROUND TO GROUND MODE, COMPLEX TERRAIN

SAMPLE RANGE EVALUATION A

AIR TO GROUND MODE, GENERAL CASE, FLAT TERRAIN

1. Given: Figure E.1 shows a bombing range with an area labeled target area. The target to be lased is in the center of the target area. It has no reflective surfaces exposed. The larger area outlined is the controlled range area. The range owner wants to allow Air Force and Navy units to lase this target and wants no restrictions on attack angle.

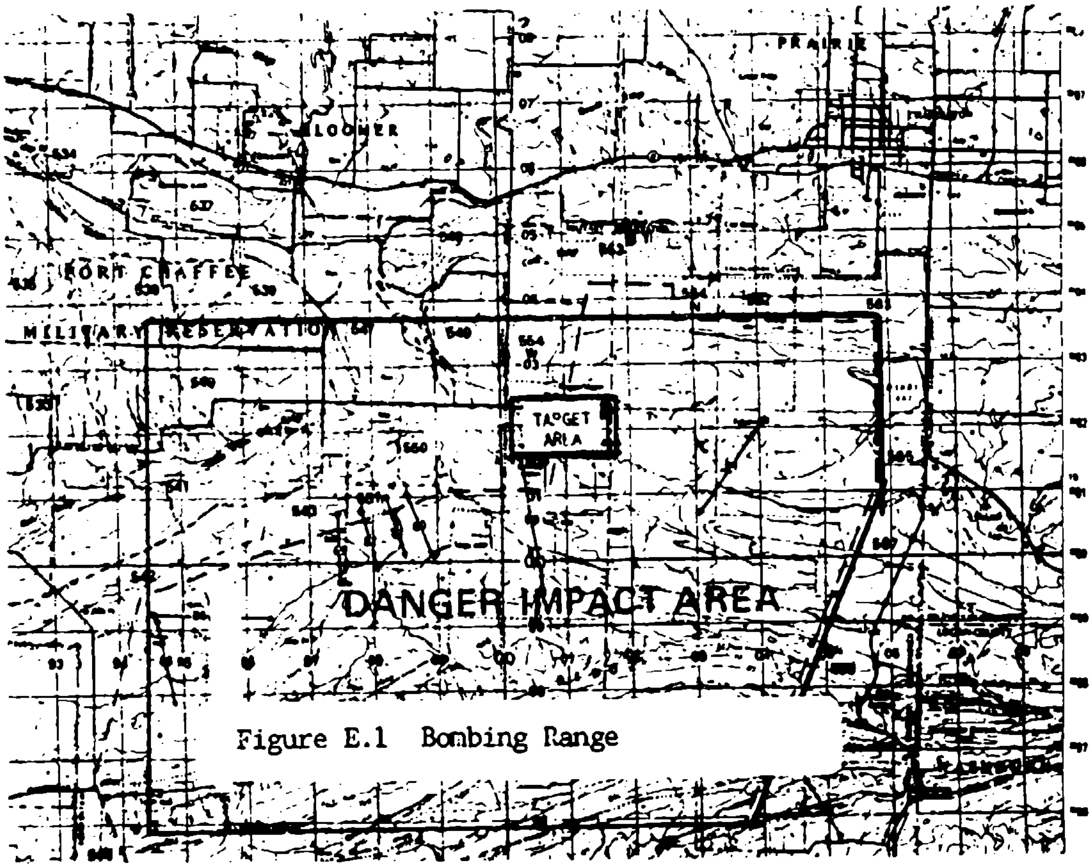


Figure E.1 Bombing Range

2. The first step in evaluating this situation would be to evaluate each laser to be used on the range. If this information is not readily available, or you want to make the evaluation general enough to allow any laser system to be used on the range, a conservative evaluation can be performed. For this evaluation a five milliradian (mrad) buffer zone is used. Since almost any laser target designator will have a divergence of less than 0.5 mrad, the divergence can be ignored.

3. The range and target locations are shown on the map above. Since the size of the range will be the controlling factor, the largest LSDZ will be drawn on the map and the allowable flight profiles determined from its dimensions. Since the attack will be from any direction, the LSDZ will be a circle as shown on Figure E.2.

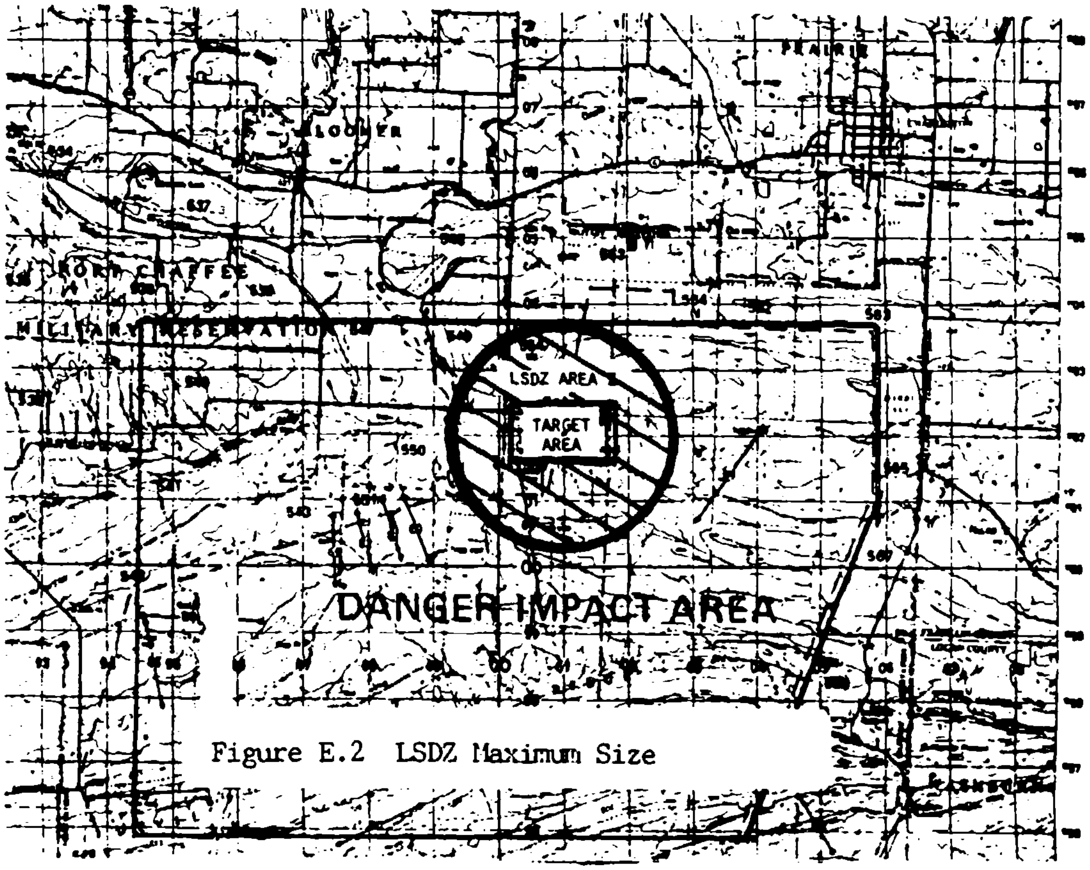


Figure E.2 LSDZ Maximum Size

4. The grid on this map is 1000 meters. Therefore, the controlling footprint dimension will be approximately 1700 meters (5576 feet). From the footprint Table D.5 in Appendix D, for lasers with a beam divergence less than 0.5 mrad and a 5 mrad buffer angle the following flight restrictions can be found:

Altitude	Maximum Range (km)
100	1
200	2
300	2
400	3
500	3
600	3
700	4
800	4
900	5
1000	5

5. If these flight restrictions are acceptable to the range operator, then any laser system with a beam divergence less than 0.5 mrad can be used on this range under the flight restrictions listed above. Additionally, the LSDZ area Z outlined on the map above must be cleared of specularly reflective surfaces and unprotected personnel excluded from the area.

6. If these flight restrictions are too severe, the following alternatives are available:

a. Restrict the approach bearings to make the most use of the available land.

b. Perform a separate evaluation for each laser system to be used on the range.

c. Move the target to the center of the range.

d. Buy more land.

e. Find another range.

SAMPLE RANGE EVALUATION B

AIR TO GROUND MODE, SPECIFIED APPROACH TRACK, FLAT TERRAIN

1. Given:

Laser System: PAVE TACK

Flight Profile:

Range: 1-9 km
Altitude: 100-500 feet AGL
Run-in heading: from west and southwest along the track shown below

Targets: six separate targets in one area as shown on Figure E.3.

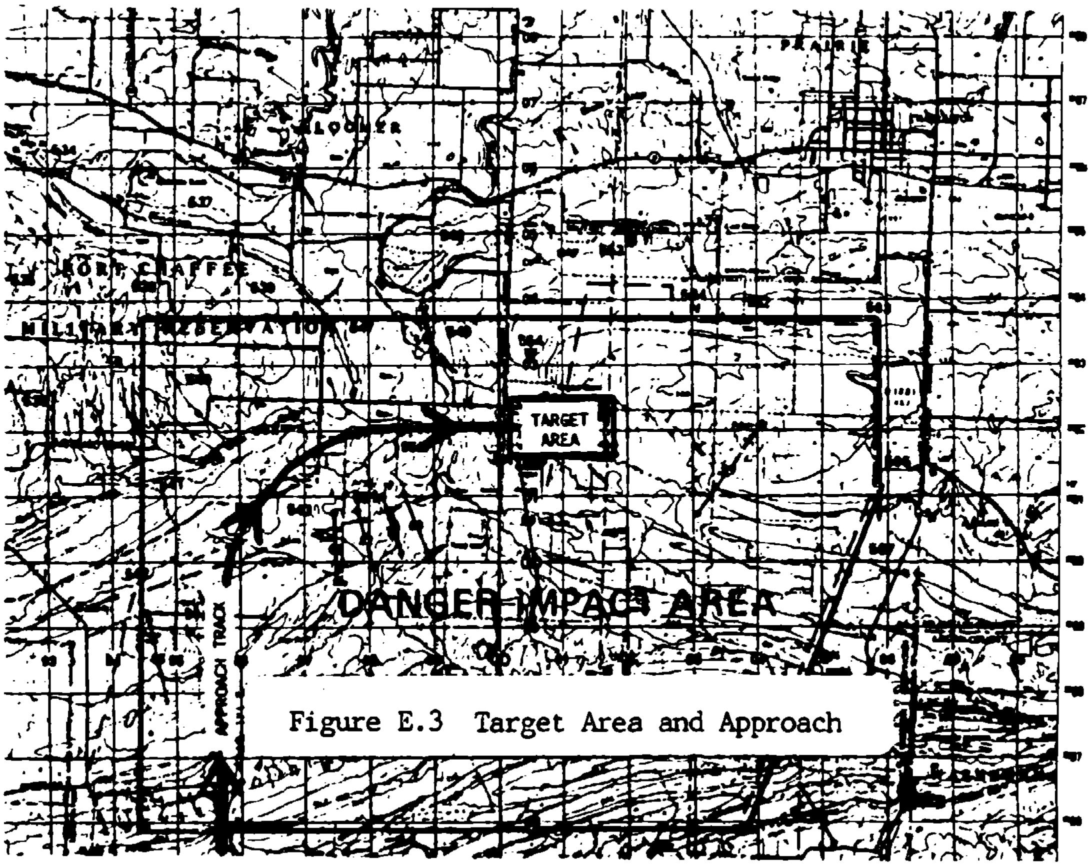


Figure E.3 Target Area and Approach

2. The following information is shown in Appendix A for the PAVE TACK system:

Wavelength: 1064 nm
ANSI Class: 4
Single Pulse NOHD: 8241 m
Multiple Pulse NOHD: 16000 m
OD Required: 4.04
Buffer Angle: 2 mrad
Beam Divergence: 0 (actual divergence is classified and is contained in the buffer angle)

From this information we see that the laser is not eye safe, eye protection required to view the laser beam directly must have an OD of 4.04 at 1064 nm, the hazard distance excluding atmospheric attenuation is 16,000 meters, the beam divergence is classified, and zero may be used for the divergence when using the 2 milliradian specified buffer angle. For this evaluation, we used the 16,000 meter NOHD, which does not include atmospheric attenuation. Using the NOHD which includes atmospheric attenuation would be more appropriate in actual practice.

3. The range is shown in Figure E.3. Since the ground is fairly flat, extensive modification of the flat terrain determined LSDZ will not be required. Note the proximity of the town of Charleston and small size of the range. These factors will cause the flight profiles to be limited.

4. The target area location is shown on the Figure E.3.

5. To determine the size of the LSDZ and the limits of flight profiles, footprints were drawn on maps to see where the laser beam was expected to hit. This was done at discrete altitudes and ranges along the flight path. Figures E.4 through E.8 represent the footprints as boxes. The lines connected to the boxes show the locations of the aircraft for that footprint. The numbers at the end of the lines indicate the distance to the far edge of the target area in kilometers.

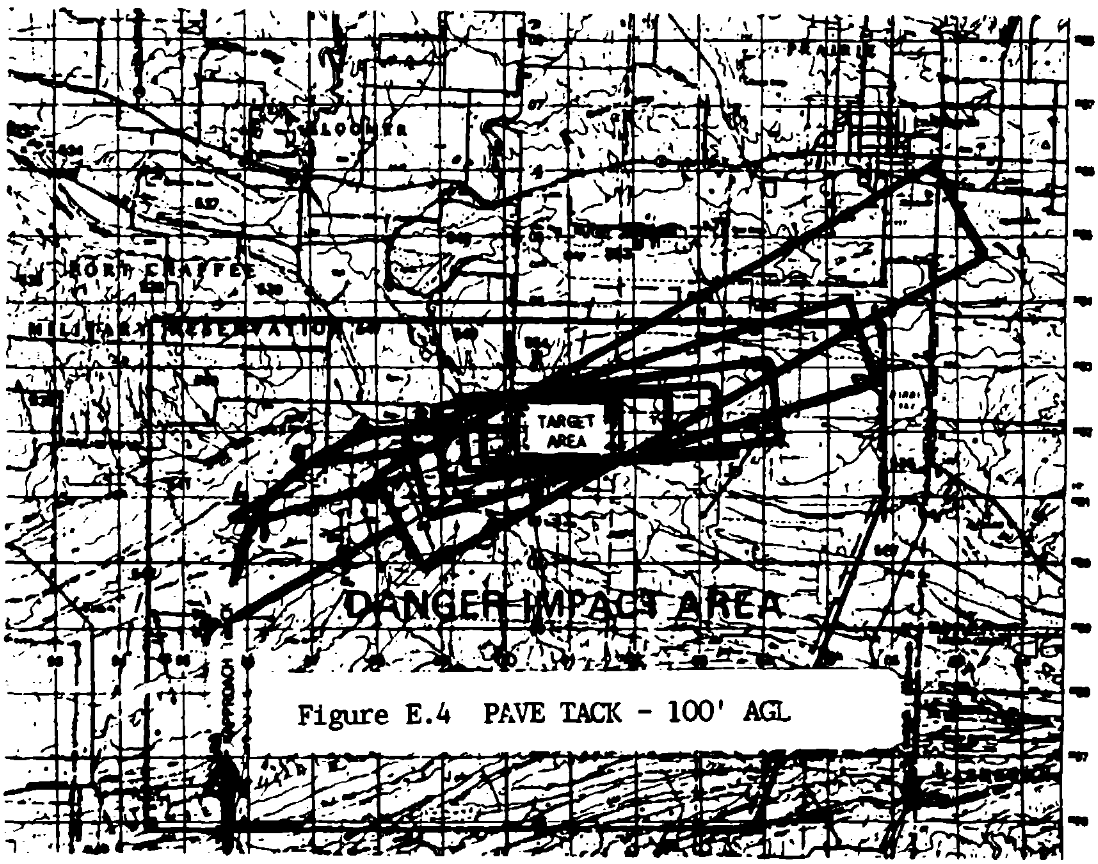


Figure E.4 PAVE TACK - 100' AGL

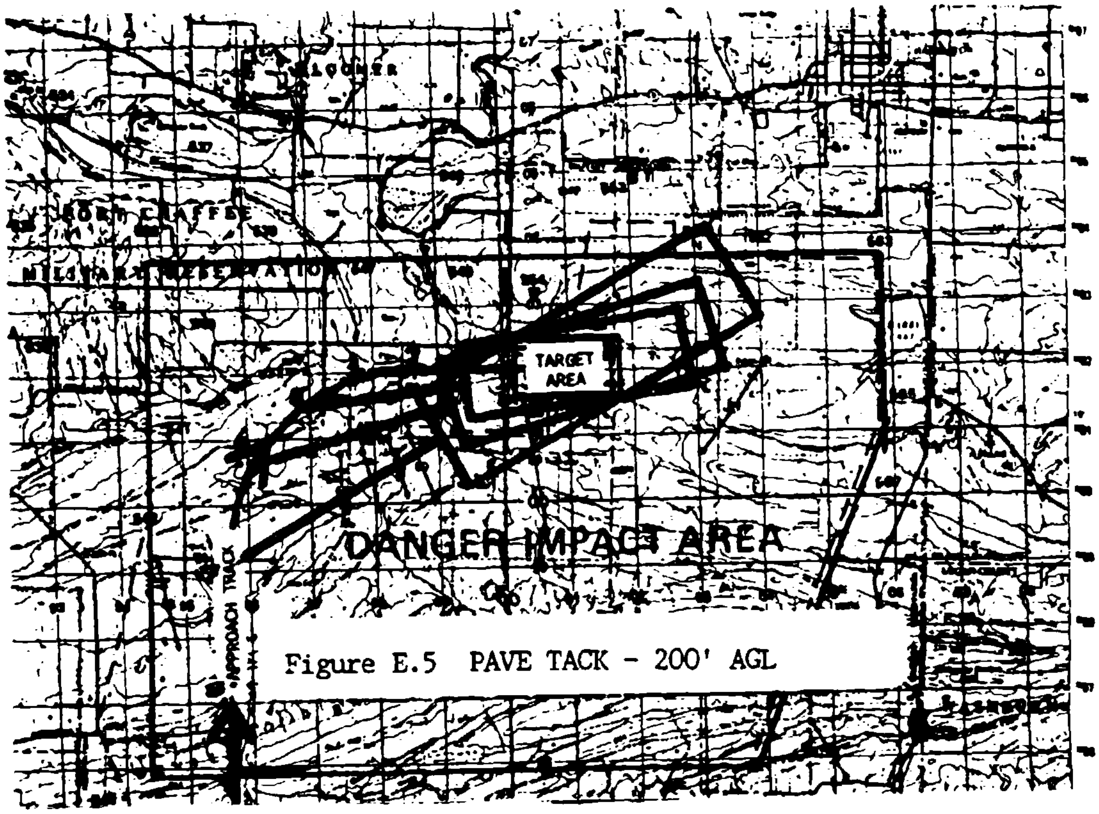


Figure E.5 PAVE TACK - 200' AGL

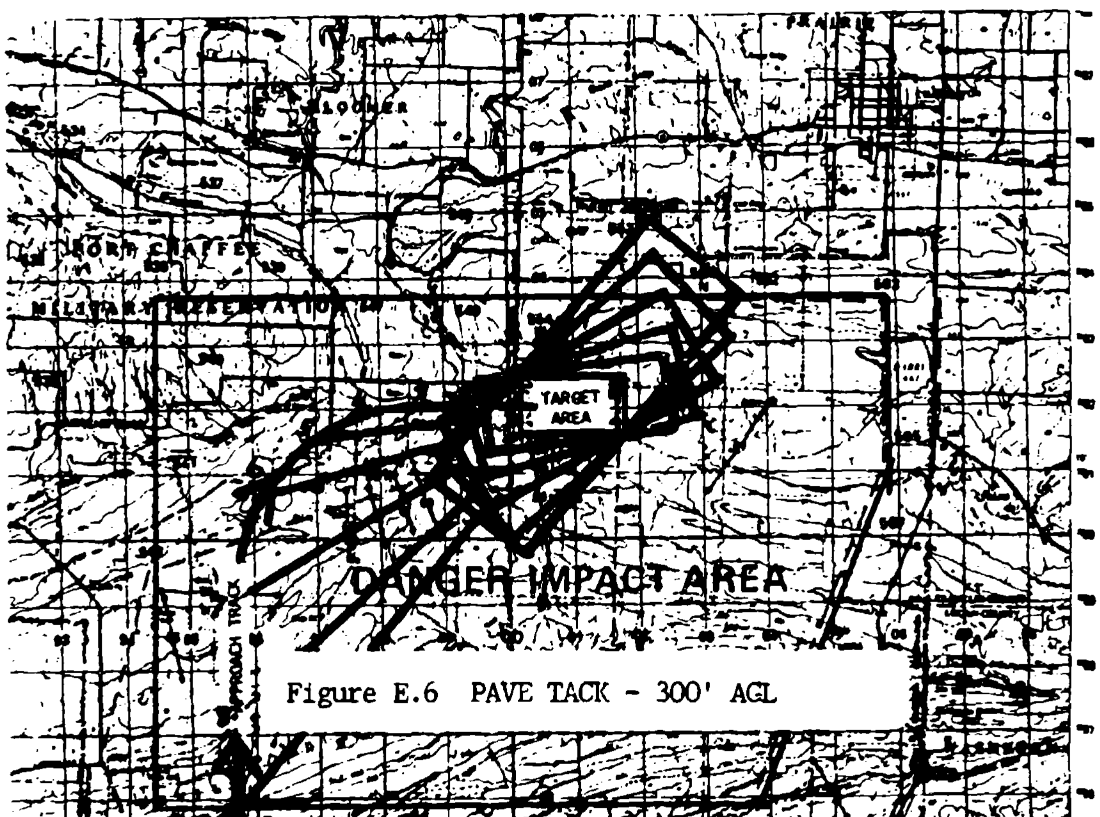


Figure E.6 PAVE TACK - 300' AGL

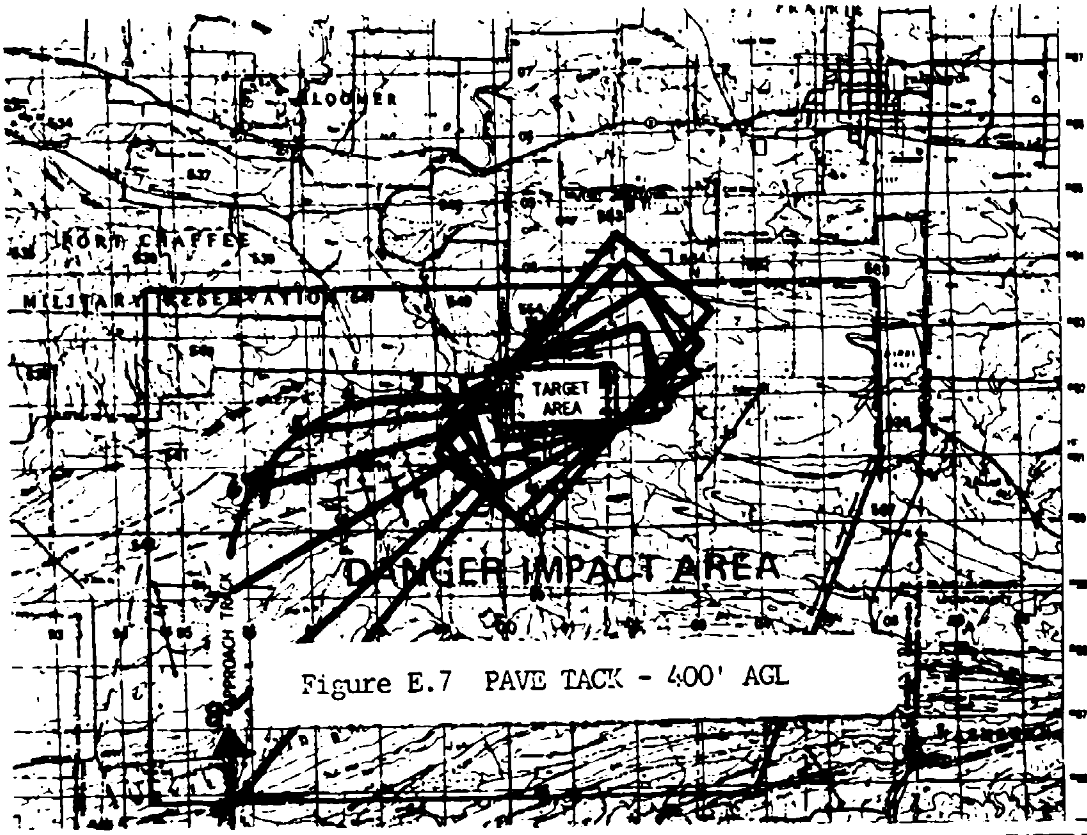


Figure E.7 PAVE TACK - 400' AGL

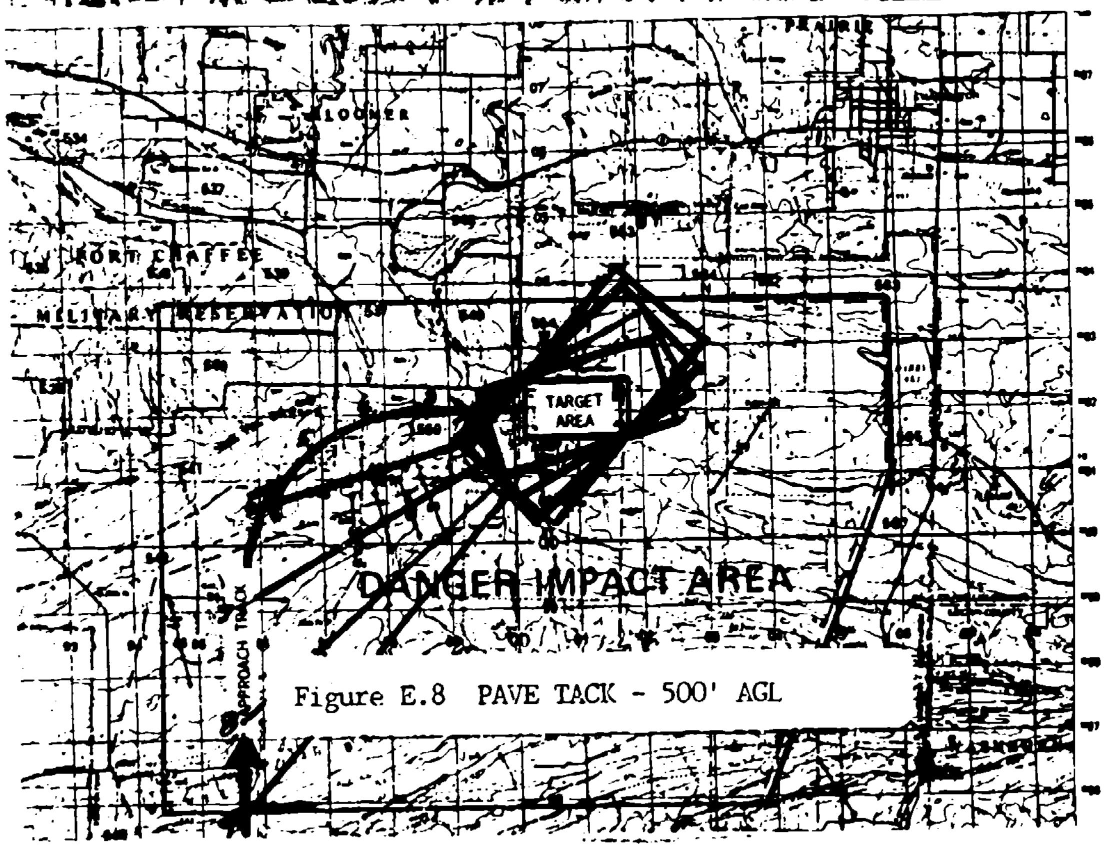


Figure E.8 PAVE TACK - 500' AGL

6. As you can see, the further the aircraft is from the target, the larger the footprint gets. The further south the aircraft is, the more likely the footprint will not fit within the laser range. The following table summarizes the maximum lasing distance for each altitude to keep the laser beam within the laser range. These distances will be the limitations placed on the flight profiles.

Altitude (AGL in feet)	Max Range (km)
100	5
200	6
300	7
400	7
500	7

7. The LSDZ for the example would be the union of all the footprints found within the laser range. This area is shown on Figure E.9. This area must be cleared of all specular surfaces and unprotected personnel excluded.

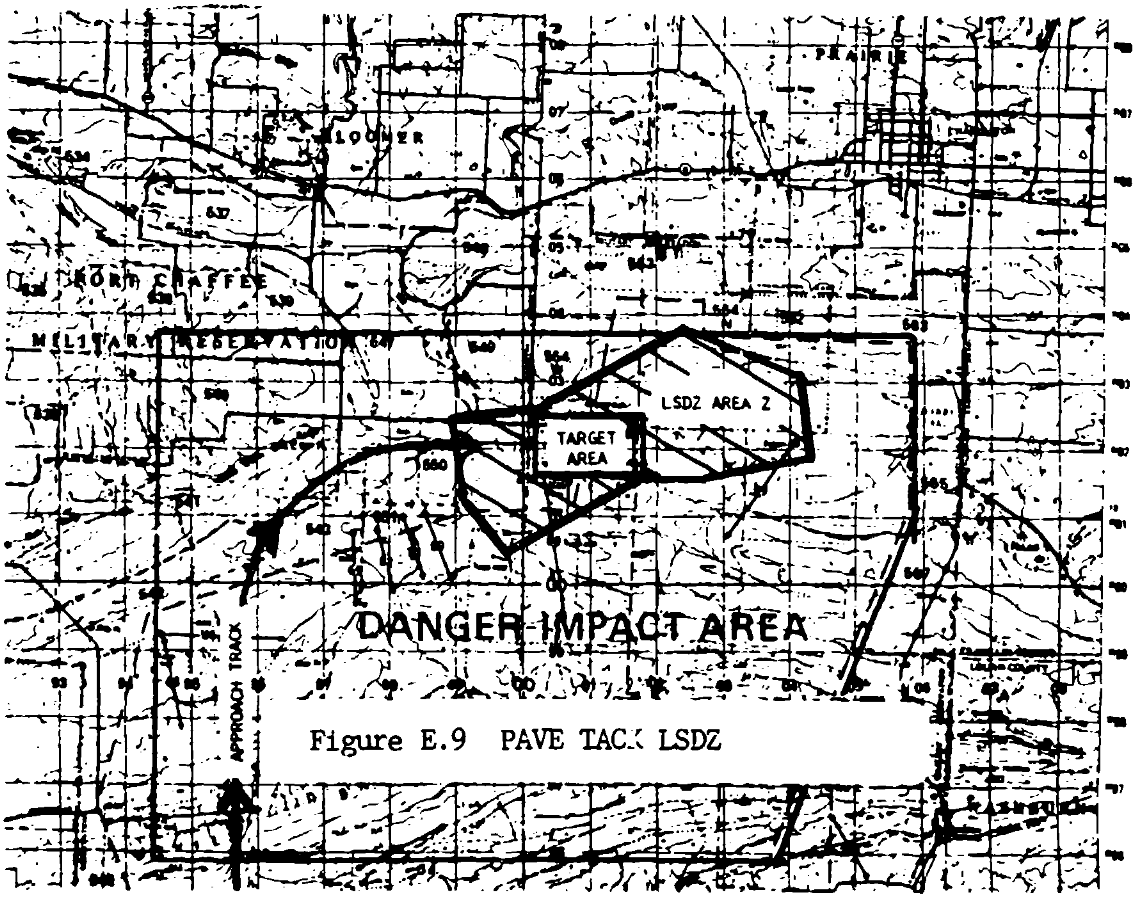


Figure E.9 PAVE TACK LSDZ

SAMPLE RANGE EVALUATION C

SPECIFIED FIGHT PROFILE, COMPLEX TERRAIN

1. Given:

Laser System: PAVE SPIKE

Flight Profiles:

Range: 1-4 nautical miles
Altitude: 200-400 feet AGL
Run-in Heading: 60-90 degrees

Target: Tank with no reflective surfaces

2. The first step in this evaluation is to evaluate the laser system. Appendix A lists the following information about the PAVE SPIKE system:

Wavelength: 1064 nm
ANSI Class: 4
Single Pulse NOHD: 5807 m
Multiple Pulse NOHD: 10406 m
OD required: 4.02
Buffer Angle: 2.5 mrad
Beam Divergence: .35 mrad

From this information we see that the laser is not eye safe; eye protection required to view the laser radiation safely must have an OD of 4.02 at 1064 nanometers, the hazard distance for most conditions is 10406 meters, the aiming accuracy allows a 2.5 milliradian buffer angle (rather than 5 milliradians), and the beam divergence is 0.35 milliradians.

3. The range is shown on Figure E.10. Note that the ground is not flat. This will require an extra evaluation step.

4. The target location is also shown on Figure E.10. From the given information we know that it has no reflective surfaces. The target altitude is 2,900 feet MSL.

5. The given mission information was an attack from a run-in heading of 60-90 degrees, a range of 1-4 nautical miles, and the altitude will be 200-400 feet above ground level reference to the target. Figure E.11 outlines the run-in heading and target location.

6. To determine the LSDZ area we must determine how large the laser beam is when it strikes the ground for all flight profile conditions. For this evaluation, we had to produce an additional footprint table (Table E.1) in addition to the ones in Appendix D because the lasing altitudes (target altitude, MSL, plus aircraft altitude, AGL) exeed one km MSL. It was produced with the Z-100/PC compatible program available from USAFOEHL. It includes

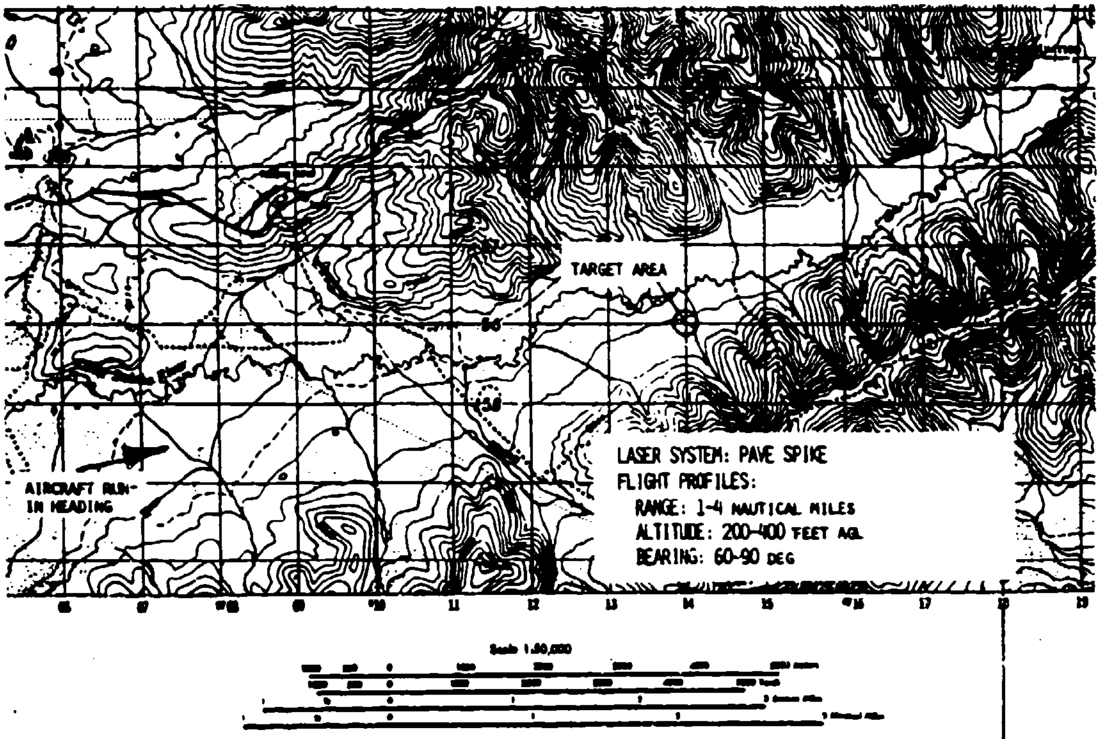


Figure E.10 Laser Range and Target Area

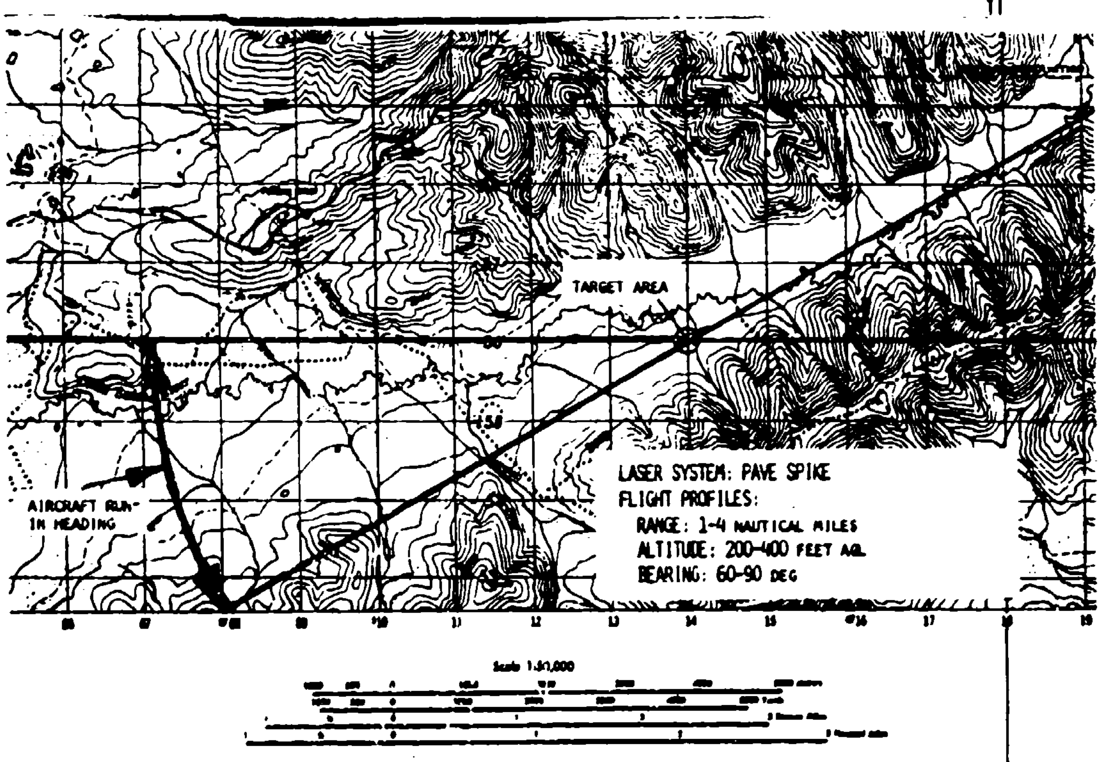


Figure E.11 Attack Headings

atmospheric attenuation and lasing altitudes (MSL). Lasing altitudes are calculated by the program by adding the target altitude (MSL) to each aircraft altitude (AGL reference to the target altitude).

7. Footprint Table E.1. shows the largest footprint dimension for the given flight profiles for each case as follows:

Footprint	Excluding Atmospheric Attenuation	Including Atmospheric Attenuation
Forward	2990 m	1790 m
Aft	1820 m	1820 m
Width	40 m	40 m

From this information we see the effects of atmospheric attenuation. Note that the largest forward dimension is usually produced for the lowest altitude and the longest slant range. Also note for Table E.1. where the NOHD is reduced, the largest forward footprint dimension is not produced at the longest slant range. This is because the forward footprint dimension is truncated by the length of the NOHD at the longest slant range. This concept is further explained in Appendix C. Also note that the sum of the slant range and forward footprint length is approximately equal to the NOHD at low altitudes. From these footprint dimensions, we can draw the outline of the LSDZ based on flat terrain. These areas are drawn on Figure E.12 showing the effect atmospheric attenuation has on these evaluations.

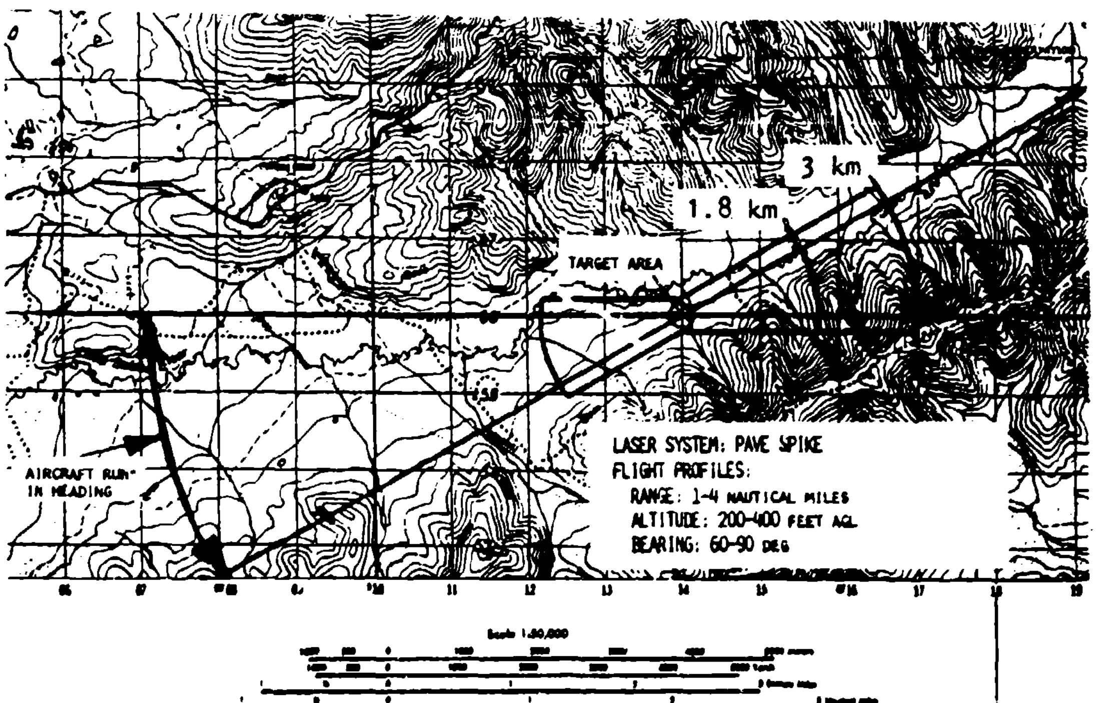


Figure E.12 Initial LSDZ Outline

8. The area outlined by the two pie-shaped sections would be the LSDZ for flat terrain. Since the ground is not flat, we must determine if the laser beam actually hits this area and if any other areas are hit. To do this we determine the height of the laser beam at all distances from the aircraft out to the NOHD and compare it to the ground elevation as explained in the text of this report and in Appendix C. Then we adjust the size of the LSDZ to account for the effects of terrain. In our example, the mountains behind the target, at bearings of approximately 70-90 degrees, are taller than the highest portion of the laser beam and therefore terminate the beam prior to reaching the length of the LSDZ based on flat terrain. The point where the beam is terminated is found by first finding the height of the top of the buffer zone at the target. This is approximately half the footprint width or 20 m AGL. This height is compared to the terrain height near the target. For distances beyond the target, this height is reduced by the slope of the lowest lasing angle which is approximately 200 feet for each four nautical miles. At 2 km beyond the target, the height is 66 minus 50 or 16 feet AGL reference to the target elevation. From 60-70 degrees the ground is not high enough to terminate the laser beam nor low enough to extend it. Since the ground in the aft section of the LSDZ is approximately the same height as the target, the LSDZ will be the area determined for flat terrain. Additionally, a ridge about five km from the target in the lower portion of the map is a possible area of concern. It intersects the possible area that the laser beam may pass for the given flight profiles. It may be appropriate to include this area as part of the LSDZ but may also be excluded. In actual practice it is really of little concern because when the laser beam could strike the ridge, the pilot could not see the target and therefore should not be lasing. Figure E.13 shows the result of this evaluation. The double hatched area is the additional area needed for the LSDZ if the value of the NOHD in a vacuum were used rather than the NOHD including atmospheric attenuation. In practice you would use the NOHD including atmospheric attenuation if it was available and not have two areas. Both are shown here to display the difference in results of including or not including atmospheric attenuation.

9. The LSDZ determined above should be cleared of specularly reflective surfaces and unprotected personnel. The river must be inspected to see if it has sections that are very still and could produce hazardous reflections. This river could also become a hazardous reflective surface when frozen and smooth. If these conditions exist, the hazardous reflections could extend to the NOHD, which is beyond the length of this map. This is illustrated in Figure 13 of the text.

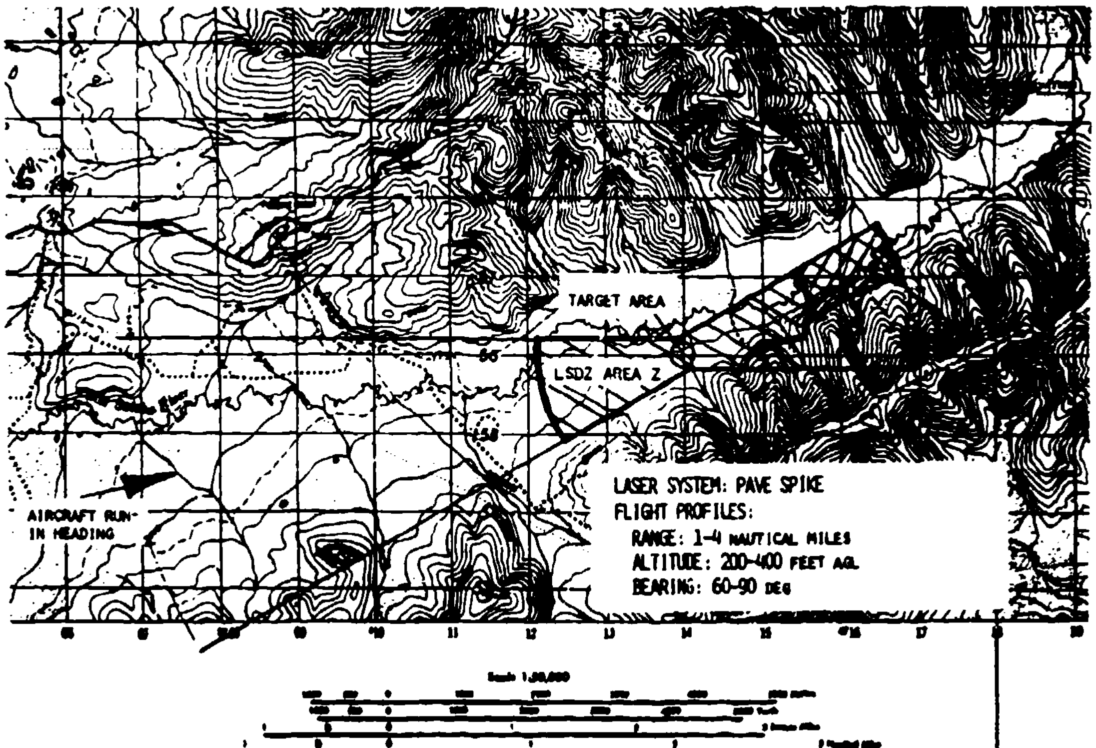


Figure E.13 PAVE SPIKE LSDZ

Table E.1.
LASER FOOTPRINT TABLE for: PAVE SPIKE (INCLUDING ATMOSPHERIC ATTENUATION - TO BE USED WITH RANGE EVALUATION C ONLY)

Table based on: Flat terrain, Buffer= 2.5 mrad, Divergence= .35 mrad
NOHD in vacuum= 10400 meters= 34112 feet= 5.6 nautical miles
OD= 4.02 and target altitude= 2900 feet MSL

Table values are FOOTPRINT dimensions(feet and meters)

ALTITUDE (feet)	FOOTPRINT	SLANT RANGE (nautical miles, feet, and meters) 1.0 NM 6080 ft 1850 m	2.0 NM 12200 ft 3700 m	3.0 NM 18200 ft 5560 m	4.0 NM 24300 ft 7410 m	5.0 NM 30400 ft 9260 m	6.0 NM 36500 ft 11100 m	7.0 NM 42500 ft 13000 m	8.0 NM 48600 ft 14800 m	9.0 NM 54700 ft 16700 m
100	FORWARD	1180 ft	5850 ft	8520 ft	2450 ft	0 ft	0 ft	0 ft	0 ft	0 ft
		359 m	1780 m	2600 m	745 m	0 m	0 m	0 m	0 m	0 m
	AFT	850 ft	2980 ft	5970 ft	9580 ft	13600 ft	18000 ft	22600 ft	27500 ft	32500 ft
		259 m	909 m	1820 m	2920 m	4150 m	5490 m	6900 m	8380 m	9900 m
200	FORWARD	537 ft	2360 ft	5800 ft	2450 ft	0 ft	0 ft	0 ft	0 ft	0 ft
		164 m	719 m	1790 m	745 m	0 m	0 m	0 m	0 m	0 m
	AFT	457 ft	1700 ft	3570 ft	5960 ft	8780 ft	11900 ft	0 ft	0 ft	0 ft
		139 m	518 m	1090 m	1820 m	2680 m	3640 m	0 m	0 m	0 m
300	FORWARD	348 ft	1480 ft	3540 ft	2450 ft	0 ft	0 ft	0 ft	0 ft	0 ft
		106 m	450 m	1080 m	745 m	0 m	0 m	0 m	0 m	0 m
	AFT	312 ft	1190 ft	2550 ft	4330 ft	6480 ft	0 ft	0 ft	0 ft	0 ft
		95 m	362 m	777 m	1320 m	1970 m	0 m	0 m	0 m	0 m
400	FORWARD	257 ft	1070 ft	2530 ft	2600 ft	0 ft	0 ft	0 ft	0 ft	0 ft
		78 m	328 m	771 m	791 m	0 m	0 m	0 m	0 m	0 m
	AFT	237 ft	913 ft	1980 ft	3400 ft	5130 ft	0 ft	0 ft	0 ft	0 ft
		72 m	278 m	604 m	1040 m	1560 m	0 m	0 m	0 m	0 m
500	FORWARD	204 ft	845 ft	1970 ft	3180 ft	0 ft	0 ft	0 ft	0 ft	0 ft
		62 m	258 m	600 m	968 m	0 m	0 m	0 m	0 m	0 m
	AFT	191 ft	742 ft	1620 ft	2800 ft	4250 ft	0 ft	0 ft	0 ft	0 ft
		58 m	226 m	494 m	852 m	1290 m	0 m	0 m	0 m	0 m
600	FORWARD	169 ft	696 ft	1610 ft	2950 ft	0 ft	0 ft	0 ft	0 ft	0 ft
		52 m	212 m	491 m	900 m	0 m	0 m	0 m	0 m	0 m
	AFT	160 ft	625 ft	1370 ft	2380 ft	3620 ft	0 ft	0 ft	0 ft	0 ft
		49 m	190 m	418 m	724 m	1100 m	0 m	0 m	0 m	0 m
	WIDTH	33 ft	65 ft	98 ft	130 ft	163 ft	195 ft	228 ft	260 ft	293 ft
		10 m	20 m	30 m	40 m	50 m	59 m	69 m	79 m	89 m

FOOTPRINT FORWARD- distance beyond target.
FOOTPRINT AFT- distance from target toward aircraft.
FOOTPRINT WIDTH- total width at target.
NOTE: -99 indicates an impossible alt./range combination

The footprint table above is based on atmospheric attenuation reduced NOHDs. These are shown in the table below.

ALTITUDE	NOHD(meters)	NOHD(feet)	NOHD(nautical miles)
100	8155.488	26750	4.402567
200	8155.488	26750	4.402567
300	8155.488	26750	4.402567
400	8201.22	26900	4.427255
500	8378.049	27480	4.522712
600	8503.049	27890	4.590191

These are based on OD= 4.02 and target altitude= 2900 MSL

SAMPLE RANGE EVALUATION D

GROUND TO GROUND MODE, COMPLEX TERRAIN

1. Given: A handheld AN/PAQ-3 MULE Laser System used to designate three targets.

2. The first step in this evaluation is to evaluate the laser system. Appendix B lists the following information about the MULE system:

Wavelength: 1064 nm
ANSI Class: 4
Multiple Pulse NOHD: 20,000 m (79,000 m with optics)
OD Required: 3.9 (5.8 with optics)
Buffer Angle: 10 mrad
Distance S: 200 m

From this information we see that the laser is not eye safe; eye protection required to view the laser radiation safely must have an OD of 3.9 at 1064 nm. The hazard distance for unaided viewing is 20,000 meters and the buffer angle is 10 mrad.

3. The range is shown on Figure E.14. Note the location of the ground based laser station and the three target sites. Also note, the laser is located on a hill over 2000' MSL and the targets are at approximately 1000' MSL. These locations allow the laser beam to be terminated by the ground behind each target.

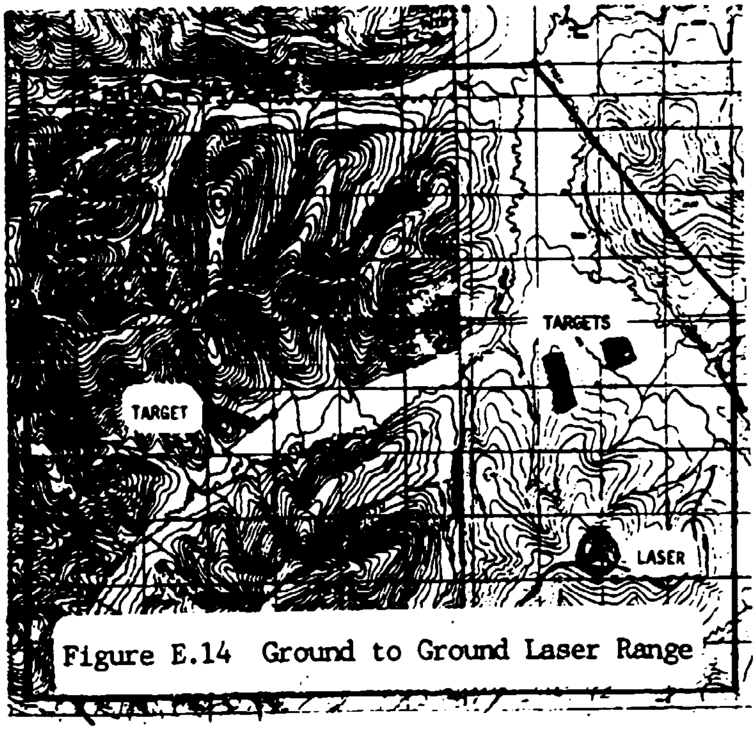


Figure E.14 Ground to Ground Laser Range

4. Since lasing will be limited to three pre-selected targets, the area for the LSDZ Area Z will only include the zone where the laser will pass while designating these targets. This zone includes every position of the laser on each target plus a 10 mrad buffer angle. If the laser will not be turned off between lasing each target, the area between these targets will be included in the LSDZ Area Z.

5. To determine the LSDZ a separate analysis is done for every target site.

a. The width of the LSDZ includes the width of the laser beam on any part of the target plus a 10 mrad buffer angle. These regions are shown on Figure E.15 for each target.

b. All regions within this buffer region and between the laser and target are designated as part of the LSDZ. Regions beyond the target within the buffer zone are also designated as the LSDZ if the distance from the laser is within the 20,000 m NOHD and the laser beam isn't terminated by the terrain.

c. If laser system elevation is approximately the same as the target elevation, the laser beam should always be fired horizontally. For this situation an adequate back stop would be a hill of a slightly higher elevation. If the target and laser system are at different elevations as in this case, then the slope of the buffered hazard zone must be calculated. Once this slope is evaluated, one may calculate elevations where the beam will intersect the ground and terminate the laser beam.

6. Shown in Figure E.15 is the completed analysis of this range. The LSDZ Area Z is annotated as cross-hatched lined areas. The two targets on the right were combined into one LSDZ because of their proximity. If the operators would not turn off the laser when switching from one target to another, the areas between these two areas would be included in the LSDZ.

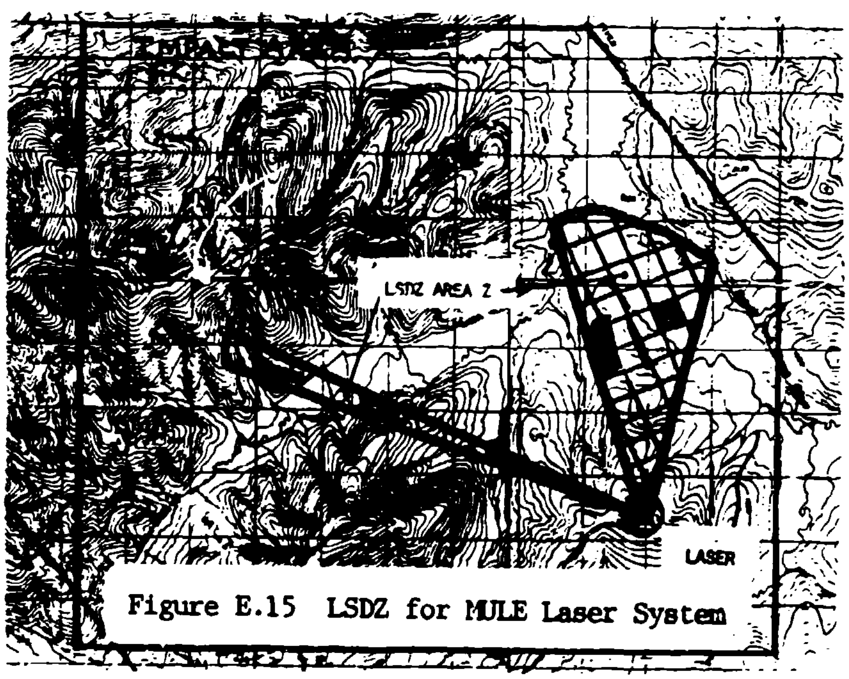


Figure E.15 LSDZ for MULE Laser System

7. The LSDZ Area S is a circle with a radius of 200 meters around each target. This dimension is provided in Appendix B. This area and the backstop areas must be cleared of specular reflections prior to laser operations.

APPENDIX F

DERIVATION OF FOOTPRINT FORMULAS

DERIVATION OF FOOTPRINT FORMULAS

1. The following diagram is used to illustrate the calculations.

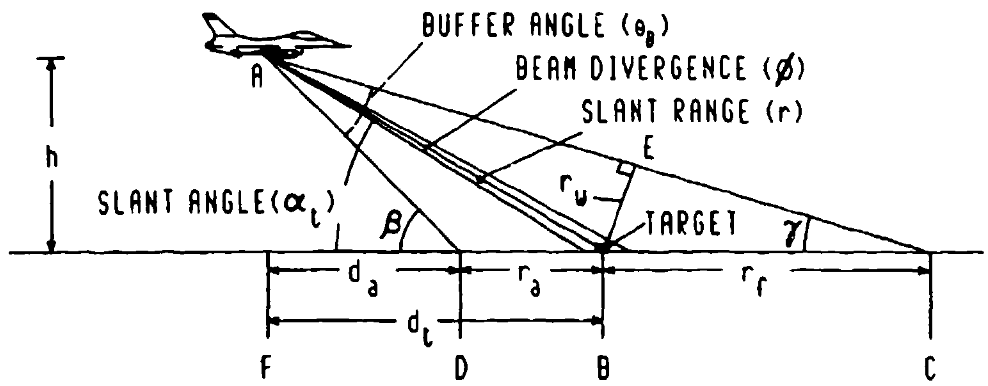


FIGURE F.1. LSDZ WITH SINGLE TARGET

2. Flight profiles are normally specified as range and altitude. We consider the range to be the slant range and have labeled it as r. It is normally given in nautical miles (one nautical mile equals 6076.1155 feet). The altitude can be specified as above ground level (AGL) or above mean sea level (MSL). For our calculations, we must use the altitude above ground level reference to the target altitude. It is normally given in feet. The following derivations are provided to assist you in understanding how we have calculated footprint dimensions.

a. <u>Mathematical Symbols Used</u>

r = slant range
h = height above ground
d_t = horizontal distance from aircraft to target
d_a = horizontal distance from aircraft to aft footprint boundry
r_a = aft radius of ground hazard
r_f = forward radius of ground hazard
r_w = the width of one-half of the laser beam plus the buffer angle at distance r
ϕ = divergence angle of laser beam (full angle)
θ_B = buffer angle of laser beam
α_t = slant angle
β = angle of aircraft to aft beam radius
γ = angle of aircraft to forward beam radius

b. Aft Footprint Dimension

Problem: Find distance r_a in terms of θ, ϕ, r, h

$$r_a = d_t - d_a \qquad (1)$$

Solve for d_a-

$$d_a = h/\tan(\beta) \qquad (2)$$

where -

$$\beta = \alpha_t + \theta_B + \phi/2 \qquad (3)$$

and

$$\alpha_t = \arcsin(h/r) \qquad (4)$$

substituting (3) and (4) into (2) gives

$$d_a = h/\tan\,(\arcsin(h/r) + \theta_B + \phi/2) \qquad (5)$$

Solve for d_t -

$$d_t = (r^2 - h^2)^{1/2} \qquad (6)$$

substituting (5) and (6) into (1) gives final solution

$$r_a = (r^2 - h^2)^{1/2} - h/(\tan(\arcsin(h/r) + \theta_B + \phi/2)) \qquad (7)$$

c. Forward Footprint Dimension

Problem: Find distance r_f in terms of θ, ϕ, r, h

$$r_f = r_w/\sin(\gamma) \qquad (8)$$

Solve for r_w -

$$r_w = r\ \sin(\theta_B+\phi/2) \qquad (9)$$

Solve for γ

$$\gamma = \alpha_t - \theta_B - \phi/2 \qquad (10)$$

combining (4) and (10) gives

$$\gamma = \arcsin(h/r) - \theta_B - \phi/2 \qquad (11)$$

substituting (11) into (8) gives the final solution:

$$r_f = r\ \sin(\theta_B+\phi/2)/\sin\,(\arcsin(h/r)-\theta_B-\phi/2) \qquad (12)$$

d. Footprint Width

Problem: Find total width (distance w) in terms of θ, ϕ, r, h

Since w is equal to $2r_w$ (if r_w were rotated about line r, 90°, it would represent half of the elipses width).

Therefore, we can rewrite formula (9) as:

$$w = 2 r\sin(\theta_B + \phi/2)$$

3. The formulas above are fine for most conditions if the footprints are within the NOHD and are on level ground. Exceptions to these formulas are listed below by category:

a. NOHD greater than AC (distance from aircraft to far edge of forward buffer zone): No change, see above.

b. NOHD less than AC and:

(1) Greater than r: Forward footprint length reduced, aft and width dimensions unchanged. This condition normally occurs when the slant range is long and is therefore, approximately equal to d_t. Then:

$$r_f = NOHD - r$$

(2) Less than r but greater than AD: This condition eliminates the forward footprint (the ground is still illuminated by the laser beam but the intensity is below the MPE). Part of the aft footprint exceeds the MPE (the part closest to D). Its shape is dependent on the attack headings and range of flight profiles. Usually, we choose not to reduce r_a, the aft footprint dimension or the width for this condition.

(3) Less than r and less than AD: This condition eliminates the ground hazard zone (all exposures on the ground are below the MPE).

c. Footprint not on level ground (or ground not at same height as target):

A general procedure for this condition is described in the main text of this report. Basically, to determine the footprint size on unlevel ground, the height of the beam and the slope of the extremes of the buffer zone extremes (line AC and AD) must be determined. Then, the AGL referenced to the target is found and compared to the terrain level. The height of the beam is approximately half of the footprint width. Derivation of the slopes of the buffer zone extremes are as follows.

(1) For low slant angles ($r \cong d_t$)

$$\beta \text{ (slant of AD)} = h/(r - r_a)$$

$$\gamma \text{ (slant of AC)} = h/(r + r_f)$$

APPENDIX G

REFLECTIVITY INFORMATION

REFLECTIVITY INFORMATION

1. When a laser beam hits a surface, three things can happen to the beam. It can be absorbed in the material, transmitted through the material, and reflected off the surface. Reflected laser energy is a major concern on laser ranges. If it is uncontrolled, the potential for eye damage may be greatly increased.

2. Reflective surfaces fall into three categories. These three categories are: diffusely reflective, flat specularly reflective, and curved specularly reflective surfaces. These are illustrated in Figure 1 in the text of this report. Examples of these surfaces are listed in the table below.

a. The first and of least concern is diffusely reflected surfaces. Reflections from these surfaces are not collimated and essentially spread out according to the inverse square law.

b. Surfaces that produce specular reflections are the greatest concern. If the surface is flat, the laser beam may just be redirected when it strikes the surface. Usually some of the beams energy is absorbed. The magnitude of the reflected beam is dependent on the reflectivity coefficient of the surface. Typical plate glass will reflect about 8% (4% per surface) of incident light if it is perpendicular to the surface while plastics may reflect more depending on the index of refraction. At near grazing angles, nearly all of the incident energy will be reflected. This is illustrated in Figure G.1. A curve drawn for water would be similar with the reflectivity for normal incidence at two percent and the polarizing angle at 53 degrees. Figure G.2 shows the effect on the reflected beam for the various possible incidence angles.

c. If the specular surface is not flat, the reflected beam spreads rapidly dependent on the radius of curvature of the surface (for concave reflective surfaces, the beam focuses then spreads). Therefore, they produce hazardous reflections only very near the surface. This is the case with most natural objects. As a general rule, if the laser beam is safe to view for diffuse reflections, it will be safe to view at distances of one meter from curved reflective surfaces such as water droplets and natural foliage.

TYPICAL REFLECTION SURFACES

Diffuse Reflectors	Flat Specular Reflectors	Curved Specular Reflectors
dry foliage	flat glass	wet foliage
rocks	vision viewblocks	beer bottle
camouflage	calm water	turbulent water
soil	vehicle mirrors	glossy paint
matte paint	instrument gauges	optical sights
aluminum cans	flat windows	curved windows
old ordnance	detector windows	automobile bumpers
snow	clean ice	rain drops
	flat chrome	

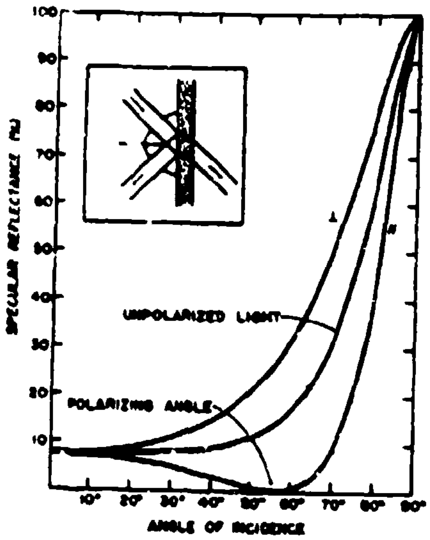


Figure G.1: Specular reflectance from both surfaces of plate glass having an index of refraction of 1.5.

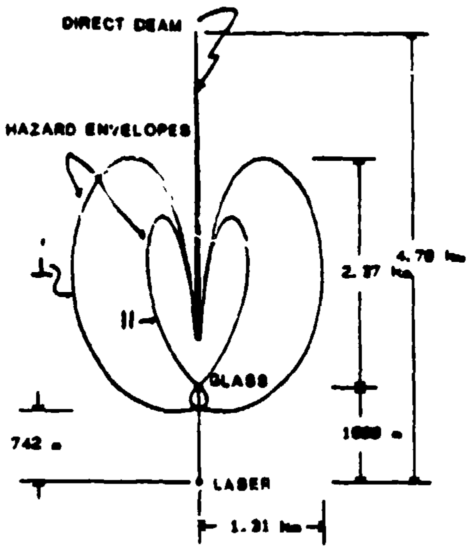


Figure G.2: Hazard envelopes created by a laser beam incident upon a vertically oriented flat (30 cm x 15 cm) glass surface.

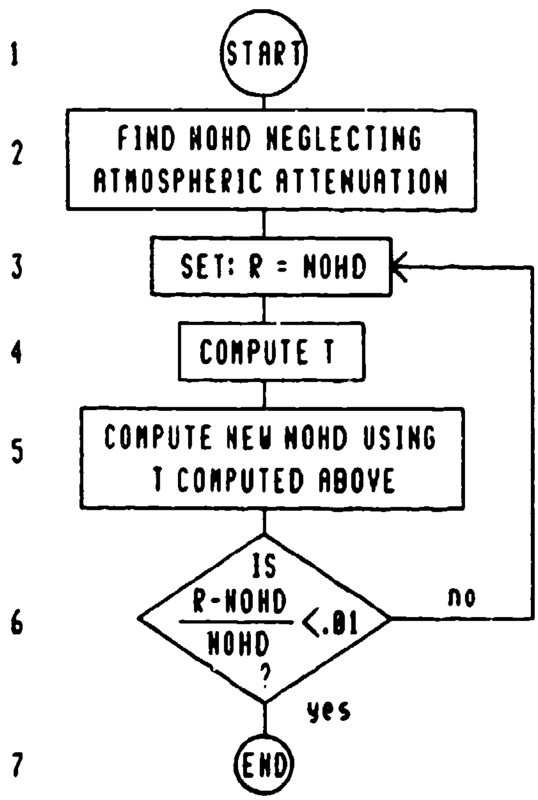
3. As way of application, if the reflectivity can be determined, this term can be treated as a transmission coefficient in the NOHD formula. An example of the use of this formula is provided in Appendix H.

APPENDIX H

ATMOSPHERIC EFFECTS

1. Several procedures are available to include the effects of atmospheric attenuation on the NOHD. Ground based lasers have this effect included in their NOHD. For airborne lasers, the simplest is to use the footprint tables which includes these effects. However, they do not apply to all cases. A specific table for your range and conditions can be generated with the USAFOEHL computer program. This program uses atmospheric extinction coefficients for mid latitude, summer, clear day. These coefficients can be modified for your condition. Alternate manual methods are detailed below.

2. A method frequently used to calculate the NOHD including atmospheric attenuation involves calculating the atmospheric attenuation over the range of NOHD in a vacuum, then iteratively recalculating the NOHD including this attenuation, and then recalculating the attenuation over the new NOHD. This process is outlined in the flow chart below.



$$NOHD = \frac{(4QT/\pi MPE)^{.5} - a}{\phi} \text{ cm}$$

where:

Q = laser energy
T = atmospheric attenuation
MPE = maximum permissible exposure limit
a = beam diameter (cm)
ϕ = beam divergence

$$T = e^{-uR} \quad \text{and} \quad u = \sum_{j=1}^{N} u_j R_j$$

where:

u = atmospheric extinction coefficient (average)
R = test range (m)
N = # of layers of atmosphere
j = atmosphere level

Figure H.1. Atmospheric Attenuation Flow Chart

3. The following example illustrates this procedure:

a. Given: PAVE SPIKE laser system fired from 2000' AGL. The parameters for PAVE SPIKE are as follows:

Wavelength	=	1064 nm
Energy/Pulse	=	168 mJ
Pulse Width	=	0.015 µsec
PRF	=	10 Hz
beam diameter	=	3.59 cm
beam divergence	=	0.35 mrad
Multiple Pulse MPE	=	1.581 E-6 J/cm^2

b. Calculating the NOHD neglecting atmospheric attenuation (step 2) gives:

$$\text{NOHD} = \frac{(4 \times 0.168 \times 1 / \pi \times 1.581\ \text{E-6})^{.5} - 3.59}{0.35 \times 10^{-3}}$$

$$= 1040700\ \text{cm}$$

c. Table H.1 gives atmospheric extinction coefficients (μ) for various wavelengths and altitudes. For our case μ is equal to 5.89 E-7 cm^{-1}.

d. By setting R = NOHD (step 3) and calculating T (step 4) gives:

$$T_{\lambda,R} = e^{-(5.89\ \text{E-7})\ (1040700)}$$

$$= 0.542$$

e. The new NOHD (step 5) including this factor gives

$$\text{NOHD} = \frac{(4 \times 0.168 \times 0.542 / \pi \times 1.581\ \text{E-6})^{.5} - 3.59}{0.35 \times 10^{-3}}\ \text{cm}$$

$$= 763{,}450\ \text{cm}$$

f. Step 6 shows this solution needs further refinement.

g. The following iterations gives these results

T	NOHD (m)
0.638	8290
0.614	8130
0.619	8169

h. The last result is within ten percent of the previous, therefore, it will be used as the NOHD including atmospheric attenuation. We rounded off this value and the NOHD in a vacuum for the tables in Appendix D.

TABLE H.1. ATMOSPHERIC EXTINCTION COEFFICIENTS*

Extinction Coefficients μ (cm^{-1})
Midlatitude Summer - Clear Day (23 km Visibility)

WAVELENGTH

H(km)	337.1 nm	488.0 nm	514.5 nm	632.8 nm	694.3 nm	860 nm	1.06 µm	1.536 µm	3.392 µm	10.591 µm	27.90 µm	337.0 µm
0	3.22 E-6	1.95 E-6	1.83 E-6	1.46 E-6	1.96 E-6	1.07 E-6	8.85 E-7	6.47 E-7	1.86 E-5	3.68 E-6	3.00 E-4	2.03 E-4
0-1	2.39 E-6	1.35 E-6	1.26 E-6	9.85 E-7	1.40 E-6	7.18 E-7	5.89 E-7	4.30 E-7	1.81 E-5	3.32 E-6	3.00 E-4	1.60 E-4
1-2	1.39 E-6	6.69 E-7	6.15 E-7	4.58 E-7	7.10 E-7	3.22 E-7	2.60 E-7	1.89 E-7	1.71 E-5	1.91 E-6	3.00 E-4	9.66 E-5
2-3	9.68 E-7	3.62 E-7	3.23 E-7	2.21 E-7	3.63 E-7	1.45 E-7	1.14 E-7	8.16 E-8	1.65 E-5	1.16 E-6	3.00 E-4	5.58 E-5
3-4	7.51 E-7	2.33 E-7	2.03 E-7	1.36 E-7	1.92 E-7	7.49 E-8	5.67 E-8	3.93 E-8	1.60 E-5	7.64 E-7	3.00 E-4	2.87 E-5
4-5	6.42 E-7	1.83 E-7	1.57 E-7	9.19 E-8	1.19 E-7	5.08 E-8	3.74 E-8	2.54 E-8	1.54 E-5	5.58 E-7	3.00 E-4	1.50 E-5
5-6	5.64 E-7	1.53 E-7	1.31 E-7	7.39 E-8	7.96 E-8	3.92 E-8	2.81 E-8	1.87 E-8	1.54 E-5	4.90 E-7	3.00 E-4	7.17 E-6
6-7	5.01 E-7	1.33 E-7	1.13 E-7	6.32 E-8	6.11 E-8	3.27 E-8	3.32 E-8	1.53 E-8	1.46 E-5	3.77 E-7	3.00 E-4	3.97 E-6
7-8	4.54 E-7	1.23 E-7	1.05 E-7	5.91 E-8	5.30 E-8	3.12 E-8	2.24 E-8	1.48 E-8	1.52 E-5	3.04 E-7	2.95 E-4	2.17 E-6
8-9	4.12 E-7	1.14 E-7	9.70 E-8	5.59 E-8	4.77 E-8	3.02 E-8	2.18 E-8	1.45 E-8	1.41 E-5	2.40 E-7	1.32 E-4	1.12 E-6
9-10	3.72 E-7	1.04 E-7	8.92 E-8	5.20 E-8	4.35 E-8	2.85 E-8	2.08 E-8	1.40 E-8	1.43 E-5	1.97 E-7	5.77 E-5	5.72 E-7
10-11	3.35 E-7	9.51 E-8	8.17 E-8	4.81 E-8	3.98 E-8	2.68 E-8	1.97 E-8	1.33 E-8	1.40 E-5	1.59 E-7	2.33 E-5	2.75 E-7
11-12	3.03 E-7	8.79 E-8	7.59 E-8	4.55 E-8	3.75 E-8	2.60 E-8	1.93 E-8	1.31 E-8	1.39 E-5	1.26 E-7	5.87 E-6	8.43 E-8
12-13	2.74 E-7	8.11 E-8	7.04 E-8	4.30 E-8	3.55 E-8	2.50 E-8	1.88 E-8	1.28 E-8	1.37 E-5	9.73 E-8	1.16 E-6	2.05 E-8
13-14	2.43 E-7	7.33 E-8	6.38 E-8	3.95 E-8	3.28 E-8	2.34 E-8	1.76 E-8	1.21 E-8	1.34 E-5	8.52 E-8	2.78 E-7	5.44 E-9
14-15	2.14 E-7	6.58 E-8	5.76 E-8	3.64 E-8	3.04 E-8	2.19 E-8	1.68 E-8	1.16 E-8	1.36 E-5	8.88 E-8	1.28 E-7	2.50 E-9
15-16	1.89 E-7	5.89 E-8	5.17 E-8	3.32 E-8	2.79 E-8	2.04 E-8	1.57 E-8	1.09 E-8	1.28 E-5	8.66 E-8	8.51 E-8	1.64 E-9
16-17	1.69 E-7	5.36 E-8	4.74 E-8	3.10 E-8	2.62 E-8	1.94 E-8	1.51 E-8	1.05 E-8	1.20 E-5	8.53 E-8	6.37 E-8	1.23 E-9
17-18	1.51 E-7	4.93 E-8	4.38 E-8	2.92 E-8	2.50 E-8	1.87 E-8	1.45 E-8	1.02 E-8	1.14 E-5	8.63 E-8	4.67 E-8	9.03 E-10
18-19	1.33 E-7	4.35 E-8	3.87 E-8	2.61 E-8	2.23 E-8	1.67 E-8	1.31 E-8	9.23 E-9	1.09 E-5	8.70 E-8	3.84 E-8	7.30 E-10
19-20	1.15 E-7	3.54 E-8	3.14 E-8	2.09 E-8	1.78 E-8	1.33 E-8	1.04 E-8	7.26 E-9	1.00 E-5	9.04 E-8	3.18 E-8	5.89 E-10

*McClutchey, R. A., Fenn, R. W., Selby, J. E. A., Volz, F. E., and Garing, J. W. (1972) Optical Properties of the Atmosphere (Third Ed), AFCRL-72-0497, ERP 411.

4. An alternate approach suitable for computer application has recently been developed. The first step is to calculate the atmospheric attenuation at increments of distance and compare the attenuation with the OD required for a specific laser system at each distance increment. Then, find at what distance the atmospheric attenuation is equal to the OD required. This distance is the NOHD including the effects of the atmosphere. This procedure has been incorporated into the USAFOEHL footprint computer program.

5. Formulas used to calculate the OD and attenuation are provided in AFOSH Standard 161-10. Unfortunately many system parameters are needed, which may be classified. However, it is possible to express these formulas in terms of NOHD, OD, extinction coefficient (μ), and range. These formulas, provided below, allow you to calculate the atmospheric attenuation and OD without using classified parameters. The derivation is left to the reader. Each is expressed as a logrithmic value for easy comparison.

$$OD(r) = \log_{10} [10^{OD} (1 + (r/NOHD) (\sqrt{10^{OD}}-1))^{-2}]$$

$$\text{Equivalent Optical Density due to Atmospheric Attenuation } (r) = \log_{10}[e^{100\mu r}]$$

where μ is expressed in cm^{-1} and distance, r is expressed in meters.

6. The following example illustrates the procedure discussed above.

a. Given: PAVE SPIKE laser system, fired from 2000' AGL at a target 400' MSL.

b. From the previous example we know the NOHD in a vacuum is 10,400 m and the OD required at the operators is 4. From table H.1, we see the atmospheric extinction coefficient is 5.89 E-7 cm^{-1}

c. To find the distance where the OD of the atmosphere is equal to the OD required by the laser at a distance, insert the NOHD excluding atmospheric attenuation and the OD required at the aperture into the formulas given in paragraph 4 above. Then, use these formulas at various ranges to find when they are equal. The table below lists several attempts at "guessing" the correct distance.

r	OD	Atmospheric OD
0	4	0
10407	1.035E-07	.266
9000	.124	.230
8000	.225	.204
8100	.125	.207
8200	.204	.209
8150	.209	.208

d. The first two lines confirm the formulas are correct at the aperture and that zero OD is required at the NOHD. The succeeding guesses appoach the NOHD when the two ODs are close. This result is close to the previous example. This result was rounded off and used in the tables at Appendix D. It was also calculated by the USAFOEHL computer program and is shown in Table E.1.

7. Table H.2. provides the approximate reduction in NOHD for 1064 nm lasers when used below one kilometer in altitude (MSL). It is based on an atmospheric extinction coefficient of 5×10^{-7} cm^{-1}.

8. This table would reduce the PAVE SPIKE NOHD to include atmospheric attenuation to approximately 8200 m, which is close to the two previous examples.

Table H.2. Table to Reduce NOHD for Atmospheric Attenuation (units of kilometers)

NOHD(v)	NOHD	NOHD(v)	NOHD	NOHD(v)	NOHD	NOHD(v)	NOHD	NOHD(v)	NOHD	NOHD(v)	NOHD
0.10	0.10	4.80	4.31	9.50	7.81	52.00	26.70	99.00	38.10	560.00	78.60
0.20	0.20	4.90	4.39	9.60	7.88	53.00	27.00	100.00	38.30	570.00	79.00
0.30	0.30	5.00	4.47	9.70	7.95	54.00	27.30	110.00	40.20	580.00	79.50
0.40	0.40	5.10	4.55	9.80	8.02	55.00	27.60	120.00	42.00	590.00	79.90
0.50	0.49	5.20	4.63	9.90	8.09	56.00	27.90	130.00	43.70	600.00	80.40
0.60	0.59	5.30	4.71	10.00	8.20	57.00	28.20	140.00	45.20	610.00	80.80
0.70	0.69	5.40	4.79	11.00	8.80	58.00	28.50	150.00	46.70	620.00	81.30
0.80	0.78	5.50	4.87	12.00	9.50	59.00	28.80	160.00	48.10	630.00	81.70
0.90	0.88	5.60	4.95	13.00	10.10	60.00	29.00	170.00	49.40	640.00	82.10
1.00	0.98	5.70	5.03	14.00	10.70	61.00	29.30	180.00	50.70	650.00	82.50
1.10	1.07	5.80	5.11	15.00	11.30	62.00	29.60	190.00	51.90	660.00	83.00
1.20	1.17	5.90	5.18	16.00	11.90	63.00	29.90	200.00	53.10	670.00	83.40
1.30	1.26	6.00	5.26	17.00	12.50	64.00	30.10	210.00	54.20	680.00	83.80
1.40	1.35	6.10	5.34	18.00	13.00	65.00	30.40	220.00	55.30	690.00	84.20
1.50	1.45	6.20	5.41	19.00	13.50	66.00	30.70	230.00	56.30	700.00	84.60
1.60	1.54	6.30	5.49	20.00	14.10	67.00	30.90	240.00	57.30	710.00	84.90
1.70	1.63	6.40	5.57	21.00	14.60	68.00	31.20	250.00	58.30	720.00	85.30
1.80	1.72	6.50	5.64	22.00	15.10	69.00	31.40	260.00	59.20	730.00	85.70
1.90	1.82	6.60	5.72	23.00	15.60	70.00	31.70	270.00	60.10	740.00	86.10
2.00	1.91	6.70	5.80	24.00	16.10	71.00	31.90	280.00	61.00	750.00	86.40
2.10	2.00	6.80	5.87	25.00	16.50	72.00	32.20	290.00	61.80	760.00	86.80
2.20	2.09	6.90	5.95	26.00	17.00	73.00	32.40	300.00	62.60	770.00	87.10
2.30	2.18	7.00	6.02	27.00	17.50	74.00	32.70	310.00	63.50	780.00	87.50
2.40	2.27	7.10	6.10	28.00	17.90	75.00	32.90	320.00	64.20	790.00	87.90
2.50	2.36	7.20	6.17	29.00	18.30	76.00	33.20	330.00	65.00	800.00	88.20
2.60	2.45	7.30	6.24	30.00	18.80	77.00	33.40	340.00	65.70	810.00	88.50
2.70	2.53	7.40	6.32	31.00	19.20	78.00	33.60	350.00	66.50	820.00	88.90
2.80	2.62	7.50	6.39	32.00	19.60	79.00	33.90	360.00	67.20	830.00	89.20
2.90	2.71	7.60	6.47	33.00	20.00	80.00	34.10	370.00	67.90	840.00	89.50
3.00	2.80	7.70	6.54	34.00	20.40	81.00	34.30	380.00	68.60	850.00	89.90
3.10	2.88	7.80	6.61	35.00	20.80	82.00	34.60	390.00	69.20	860.00	90.20
3.20	2.97	7.90	6.68	36.00	21.20	83.00	34.80	400.00	69.80	870.00	90.50
3.30	3.06	8.00	6.76	37.00	21.60	84.00	35.00	410.00	70.50	880.00	90.80
3.40	3.14	8.10	6.83	38.00	22.00	85.00	35.20	420.00	71.10	890.00	91.10
3.50	3.23	8.20	6.90	39.00	22.30	86.00	35.40	430.00	71.70	900.00	91.50
3.60	3.31	8.30	6.97	40.00	22.70	87.00	35.70	440.00	72.30	910.00	91.80
3.70	3.40	8.40	7.04	41.00	23.00	88.00	35.90	450.00	72.80	920.00	92.10
3.80	3.48	8.50	7.11	42.00	23.40	89.00	36.10	460.00	73.40	930.00	92.40
3.90	3.57	8.60	7.19	43.00	23.70	90.00	36.30	470.00	74.00	940.00	92.70
4.00	3.65	8.70	7.26	44.00	24.10	91.00	36.50	480.00	74.50	950.00	93.00
4.10	3.73	8.80	7.33	45.00	24.40	92.00	36.70	490.00	75.00	960.00	93.30
4.20	3.82	8.90	7.40	46.00	24.80	93.00	36.90	500.00	75.60	970.00	93.60
4.30	3.90	9.00	7.47	47.00	25.10	94.00	37.10	510.00	76.10	980.00	93.80
4.40	3.98	9.10	7.54	48.00	25.40	95.00	37.30	520.00	76.60	990.00	94.10
4.50	4.07	9.20	7.61	49.00	25.70	96.00	37.50	530.00	77.10	1000.00	94.40
4.60	4.15	9.30	7.68	50.00	26.10	97.00	37.70	540.00	77.60	2000.00	110.00
4.70	4.23	9.40	7.75	51.00	26.40	98.00	37.90	550.00	78.10	3000.00	126.60

APPENDIX I

SOURCES FOR LASER PROTECTIVE EYE WEAR

Table I.1. LASER EYE WEAR DATA FOR 1060/1064 nm WAVELENGTH

Manufacturer	Type	CAT. No.	PN/Description	OD	LTM	Cost
Energy Tech. Inc.	Spectacle/7400 Series		NDGA-7448-1	14	45	106.00
Energy Tech. Inc.	Goggle/B-Series		LGB Broad Spectrum	4	45	193.00
Energy Tech. Inc.	Goggle/7400 Series		NDGA-7448-1	14	45	106.00
Energy Tech. Inc.	Spectacle/VL Series		NDGA	14	45	106.00
Energy Tech. Inc.	Goggle/A-Series		LGA Broad Spectrum	20	20	193.00
Energy Tech. Inc.	Spectacle/7400 Series		NDGA	14	45	106.00
Energy Tech. Inc.	Goggle/VL Series		VL-NDGA	14	45	106.00
Energy Tech. Inc.	Softie/LGS Series		NDGA	14	45	106.00
Energy Tech. Inc.	Goggle/LGS Series		LGS-NDGA	14	45	106.00
Energy Tech. Inc.	Spectacle/A-Series		7400-A Broad Spectrum	20	20	193.00
Fish-Schurman Corp	Goggle/Spectacle	AL-1060-9	Nd-Doped Glass/YAG	9	63	80.00
Fred Reed Optical	Spectacle/7400 Series		NDGA-7448-1	14	45	106.00
Fred Reed Optical Co.	Spectacle/B- Series		7400-B Broad Spectrum	4	45	193.50
Fred Reed Optical Co.	Goggle/VL Series		VL-NDGA	14	45	106.50
Fred Reed Optical Co.	Goggle/CL Series		CL-NDGA	14	45	98.00
Fred Reed Optical Co.	Goggle/A-Series		LG-A Broad Spectrum	20	20	193.00
Fred Reed Optical Co.	Spectacle/A-Series		7400-A Broad Spectrum	20	20	193.50
Fred Reed Optical Co.	Goggle/LGS Series		LDS/NDGA	14	45	106.50
Fred Reed Optical Co.	Goggle/B-Series		LGS-B Broad Spectrum	4	45	193.50
Glendale	Goggle/LGS Series	2200	LGS/NDGA	14	45	106.50
Glendale	Spectacle/7400 Series	2205	NDGA-7448-1	14	45	106.00
Glendale	Spectacle/A Series	2193	7400-A Broad Spectrum	20	20	193.00
Glendale	Goggle/A Series	2198	LGA Broad Spectrum	20	20	193.00
Glendale	Spectacle/B Series	2197	7400-Broad Spectrum	4	45	193.00
Glendale	Goggle/B Series	2199	LGB Broad Spectrum	4	45	193.00
Glendale	Spectacle/VL Series	2183	VL-NDGA	14	45	106.00
Physitec	Eye Shield	04-0058	Nd-YAG	7	70	335.00
Physitec	Eye Shield	04-0054	Nd-YAG (Pulsed, Q-Switched)	8		495.00
Physitec	Eye Shield	04-0059	Nd-YAG (CW,Pulsed,Q-Switched	8	80	345.00
Rockwell Assoc. Inc.	Spectacle-Glass Filter	YAG:LEPD-13-S	Nd-YAG	>4		120.00
Rockwell Assoc. Inc.	Goggle-Glass Filter	YAG:LEPD-13-G	Nd-YAG	4.5		91.00
Rockwell Assoc. Inc.	Spectacle-Glass Filter	YAG:LEPD-13-S	Nd-YAG	>8		140.00
Rockwell Assoc. Inc.	Goggle Glass Filter	YAG:LEPD-13-G	Nd-YAG	>4.5		111.00
US Laser Corp.	Goggle	USL-1075-1	Nd-YAG/ND-Glass Lasers	>6	60	83.00

KEY:

LTM - Luminous Transmission
OD - Optical Density
Cat. No. - Catalog Number

Table I.2. MILITARY STOCK LISTED EYE WEAR

Type	Stock No.	Manufacturer	Federal Supply Code	P/N	Cost
Ground Crew	4240-00-620-0054	Glendale	16561	LGS-NDGA	73.33
Air Crew	1680-01-169-3151		(MIL-S-8550) No FSC avail.	KG-3 Lens	96.00

ORDER INFORMATION

EDU-1/P Neodymium Laser Protective Spectacles with Corrective Lenses

The base optometrist shall prepare a DD Form 771 indicating the required refraction and specifying "Aviation (KG-3)" in "Special Lenses or Frames" block and submitted under cover letter from the Commanding Officer of the squadron or activity. The optometrist shall sign DD Form 771 in the "Prescribing Officer" block and the Commanding Officer of the squadron or activity shall sign "Approving Authority" block.

Forward the letter and DD Form 771 to:

Commanding Officer
NOSTRA
Yorktown VA 23691

Provide an information copy without the enclosure to Code 60B1, Naval Air Development Center, Warminster PA 18974-5000.

EDU-1 Neodymium Laser Protective Spectacles with Plano Lenses

NSN 1RD 1680-01-169-3151LX $96.00
Part # 1368AS101-1
Aviation Supply Office
700 Robbins Avenue
Philadelphia PA 19111

AUTOVON 442-4360

EEK-3/P Neodymium Laser Protective Visors

NSN 1RD 8475-01-115-1711LX $180.00
Part # 765AS310-2
Aviation Supply Office
700 Robbins Avenue
Philadelphia PA 19111

AUTOVON 442-4361

APPENDIX J

DEFINITIONS

DEFINITIONS

The following terms are not found in AFOSH Standard 161-10 and are therefore included in this guide.

Footprint - The area on the ground where the laser beam will probably hit. This includes the laser beam and a buffer zone.

Laser Class - ANSI classification for lasers.

Laser Surface Danger Zone (LSDZ) - The ground area that requires control during laser operation. Sometimes called the Laser Safety Danger Zone.

LSDZ Area S - That surface area within the LSDZ Area Z where the energy or power level of the laser beam is capable of delivering a specular reflection hazard to the aided or unaided eye. Area S is equivalent to the footprint for elevated laser platforms, such as aircraft, which project a well defined (localized) laser footprint on the range. For ground based lasers that do not project a well defined footprint in the target area, Area S is usually defined by a circle of radius, r, around a target area where r is defined for each laser system based on typical operational parameters. Backstop areas where the energy of the laser is capable of producing a specular reflection hazard are also considered Area S. Area S defines the area in which all spectral reflectors must be removed before lasing may begin, i.e., circular area around targets used by ground emitters, footprints from airborne emitters and backstops where the beam path length is less than the Nominal Occular Hazard Distance (NOHD).

LSDZ Area T - That space (area) within the LSDZ Area Z where the energy or power level of the laser beam is capable of delivering a direct hazard to the skin or a diffuse reflection hazard to the aided or unaided eye. This zone usually extends out distance t from the laser aperature.

LSDZ Area Z - This is the total envelope defined as the LSDZ.

Nominal Occular Hazard Distance (NOHD) - The distance from the operating laser at which the radiant exposure or irradiance within the beam equals the maximum permissible exposure limit (i.e., safe distance from laser).

Nominal Hazard Distance (NHD) - The hazard distance for skin exposure.

APPENDIX K

REFERENCES

REFERENCES

AFOSH Standard 161-10, Health Hazard Control for Laser Radiation

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AFR 50-46, Weapons Ranges

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APPENDIX L

ABBREVIATIONS

LIST OF ABBREVIATIONS

a	diameter of laser beam
AGL	Above ground level
ANSI	American National Standards Institute
BES	Bioenvironmental Engineering Services
d_a	horizontal distance from aircraft to aft footprint boundry
d_f	horizontal distance from aircraft to target
h	Laser height, AGL
LSDZ	Laser surface danger zone (also LSDZ area S, T, and Z)
MPE	Maximum Permissible Exposure
MSL	Mean Sea Level
NHD	Nominal Hazard Distance
NOHD	Nominal Occular Hazard Distance (also NOHD-S and NOHD-O)
NOTAM	Notice to Airmen
OD	Optical Density
Q	energy of laser pulse
R	range used in atmospheric attenuation calculations
r	slant range
r_a	radius of footprint - aft of target
r_f	radius of footprint - forward of target
r_w	radius of footprint - to the side of target
S	radius of LSDZ Area S for ground based lasers
T	atmospheric attenuation term
t	diffuse reflection hazard distance
w	width of footprint
α_t	slant angle

β	angle of aircraft to aft beam radius
γ	angle of aircraft to forward beam radius
θ_B	buffer angle
λ	wavelength
μ	atmospheric extinction coefficient
ϕ	beam divergence

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