Laser Registration Form (V8, 24Aug23)

Laser Clearinghouse (LCH)
US Space Command / Combined Force Space Component Command
(USSPACECOM/CFSCC)

1 Purpose

The purpose of this document is to outline the laser parameters needed to support an analysis of laser hazards to satellites. The laser owner should be able to read this document and understand what values need to be entered into the attached laser registration form (Appendix A) and how those values are defined. The information in the laser registration form is then used by the Laser Clearinghouse (LCH) and, if required, the Satellite Assessment Center (SatAC) to assess those laser parameters to determine the laser's impact on satellites and may also be used by the Department of Defense and supporting contractors to develop and test LCH and SatAC assessment and deconfliction systems. **Only the actual registration form (Appendix A) should be filled out and submitted to LCH.**

2 Background

DOD Instruction 3100.11 tasks U.S. Space Command with the responsibility to establish a process to review any proposed illumination by a laser which could project light above the horizon or in space and either provide deconfliction with key objects in space or certify a laser system's process for determining and implementing deconfliction with satellites. The U.S. Space Command is also responsible for assigning the laser to a Hazard Category.[1] Category I requires no further action on the part of the laser owner. Category III requires risk mitigation (deconfliction is one common risk mitigation approach). The laser registration data is also used for the conservative satellite susceptibility calculations performed by the Satellite Assessment Center and the Laser Clearinghouse.

3 Laser Registration

The owner/operator of a laser that requires coordination with LCH must provide information about its platform and the laser system (including its projection telescope or beam director, if any). This information is used to determine the hazard category of the laser, to analyze the laser for deconfliction if it is not Category I, and to perform susceptibility analyses for given satellites. The Laser Registration Form (see Appendix A) consists of: Laser Site, Platform Data, Platform Location, and Laser Parameters. The information required in these sections of the registration form is outlined in Sections 3.1-3.4 of these instructions. Section 3.5 will discuss the laser parameters in more detail, focusing on how they are used in laser deconfliction calculations, to provide context and clarification to the laser owner/operator. Note: The parameters, as described below, are adequate to describe many laser systems and tests. However, some lasers, platforms, and/or test scenarios may not be well described using the parameters in Appendix A. In these cases, explanatory notes should be added to fully define the laser, platform and/or test scenario, as appropriate.

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[1] DOD Instruction 3100.11, Management of Laser Illumination of Objects in Space, October 24, 2016, Under Secretary of Defense for Policy.

3.1 Contact Information

The laser owner/operator should specify contact information to the LCH in Section I of the Registration Form (Appendix A). This information is used to contact the laser owner if the LCH has information pertinent to the laser firing. The parameters with an asterisk (*), in the registration form are mandatory. The parameters without an asterisk will likely improve the laser deconfliction analysis and provide additional clarification to the evaluators but are optional.

- **Date:** The date on which the form is submitted.

- **Laser name:** A unique identifying name for the laser/beam director system. LCH will add additional identifiers to the name using standard conventions.

- **Classification:** The highest classification level associated with the laser use in the test, group of tests, exercises, or operations being registered.

- **Classification of Laser site Communicating with LCH**: The classification of the fact that the LCH is communicating with the laser site (e.g., S//NF).

- **Organization**: The name of the organization that operates (owns) the laser platform.

- **Long Facility Name**: Name of facility or program for this laser (e.g., Starfire Optical Range or Airborne Laser Program).

- **Short Facility Name**: An acronym or abbreviation for the facility (e.g., SOR or ABL).

- **Point of Contact**: Name of the person registering the laser parameters.

- **Mailing Address**: Unclassified or classified mailing address (if classified specify instructions for sending information).

- **E-mail address**: Unclassified or classified e-mail address of the person registering the laser parameters.

- **Phone Number**: Unclassified phone number of person registering the laser parameters. Alternate or backup phone numbers, where available, are often helpful and should be supplied if possible.

- **Secure Number and Type:** If applicable, a phone number for secure communications and the type of phone system that the secure communications number is for.

- **Emergency Point of Contact (POC):** Name, phone number and e-mail for a person who can be most reliably contacted for urgent issues during operations.

3.2 Platform Specifications

The following sections describe the platform parameters that are needed for the registration process. The information is entered in Section II of the Appendix A form. Mandatory parameters are indicated by an asterisk (*). Optional parameters (those not indicated as mandatory) will often improve the deconfliction analysis and provide additional clarification to the LCH.

- **Platform Name (mandatory)**: A unique “name” identifier for the laser platform or optics mount (e.g., ABL – Aircraft 1 or KTM #2). This value should be different for each platform (e.g., ABL – Aircraft 2).

- **Platform Type (mandatory)**: The type of platform that the laser will be fired from. For example, Aircraft, Ground, Space, Ground-Mobile, Missile, or other. If “other” is selected, an explanation and description should be provided.

- **Project start and completion dates**: The dates that the laser will be setup and the anticipated date the project will be complete (if applicable).

- **Typical Laser Target**: Select the type of target the laser is pointing at.

- **Orbital Platform** (if applicable): If a satellite is the platform, specify the satellite, orbital parameters, and any other information that may be appropriate (particularly for maneuvering).

3.3 Platform Location

This is the description of the boundaries that limit the positions the laser might operate from. The information is entered in Section III of the Registration Form (Appendix A). For example, if the laser is a fixed site this would be a latitude, longitude, and altitude. If the laser is on a mobile platform, then the location would be the extrema of the altitude, latitude, and longitude ranges within which the laser might be operated. For a space-based laser on an orbital platform, the location would be the space catalog number (if available) and the altitude range that the laser would be operated from.

- **Location name:** Name of the laser platform.

- **Fixed Site Location** (if applicable): Latitude, longitude, and altitude of the fixed laser platform location.

- **Moving Platform Location** (if applicable): Free form, but should include range of latitudes, longitudes, altitudes, and movement details. A mobile platform could include aircraft, truck, ship, etc.

- **Mobile Platform Description** (if applicable): A brief description of the mobile platform; specific vehicle, maneuver information, and other information as may be appropriate determine the possible pointing angles and locations of the laser platform.

- **Orbital Platform Description** (if applicable): the space catalog number (if available) and the altitude range that the laser would be operated from.

3.4 Laser Parameter Specifications

The following sections describe the laser parameters that are needed for the registration process. The data are entered in Section IV of the Registration Form (Appendix A). Definitions of the laser parameters are provided below so that a laser owner/operator will know how to report the parameters to the LCH for input into their tools and databases. Subsequent sections will describe how these parameters are determined.

3.4.1 Laser Parameters for All Lasers

The following information is applicable to all laser systems. Mandatory parameters are indicated with an asterisk on the registration form; optional parameters will often improve the deconfliction process but are not required. Multiple columns are provided for different modes (if applicable) or multiple lasers on a platform. Laser programs may add additional columns to the registration form to accommodate additional lasers.

LN (mandatory): Laser name within the laser system or facility. (e.g., FACET, HEL, or TILL).

LT (mandatory): Laser type: Pulsed or Continuous Wave (CW). Special laser types (e.g., ultra-short pulsed (USP)) should also be indicated. Reference and add additional notes for exotic types.

P (mandatory): Beam Director Aperture Average (Equivalent CW) Output Power (W). This is the total laser average power that is transmitted away from the final exit aperture of the optical system. For a CW laser this is equivalent to the laser *device* CW power multiplied by the throughput of the optical system including the beam director telescope. For a pulsed laser this is equivalent to the laser *device* energy per pulse multiplied by the pulse repetition frequency (PRF) multiplied by the throughput of the optical system including the beam director telescope. This power cannot exceed 100 Gigawatts (GW) if it is to be used in susceptibility calculations. Please note optical losses if used to decrement laser source power.

τ_{ATM} = *Maximum possible* laser-to-space atmospheric transmission (a value between zero and one, usually assumed to be unity for all lasers except for lasers with wavelengths heavily absorbed by the atmosphere).

$\theta_{1/e}$ (mandatory) = Minimum possible divergence half-angle, given in micro-radians, and referenced from the optical axis to the 1/e point of the beam's far field irradiance profile (i.e., to the beam radius encompassing 63.2% of the total beam power in the far field). For a pure Gaussian beam, this is also the angle between the optical axis and the point at which the irradiance profile in the far field is down to 1/e (36.78%) of the peak value on axis. This will typically be no less than the diffraction-limited beam divergence but may be larger if there is a controlled divergence angle for intentionally diverging beams.

If the laser is only operated in the focused or converging mode, then state here the measured or calculated divergence if the laser were operated in the collimated mode (i.e., focused at infinity).

The divergence associated with focusing (θ_{focus}) will be handled in a different section.

Indicate whether the divergence listed is measured or calculated. Because the minimum instantaneous value is desired (see 3.5.4 and 3.5.5), effects of platform jitter and atmospheric turbulence should not be included.

λ (mandatory) =	Center wavelength of the laser (micro-meters). (Note: If using a broadband laser, please indicate the spectral bandwidth and provide amplifying information in the free form section.) If using a multi-line laser (see 3.5.3), a power spectrum should be provided.
LW =	Linewidth (nano-meters) is defined as the width of the spectrum of the laser beam measured at full width half maximum (FWHM).
OQ =	Optical (beam) quality of the laser (defined as the ratio of the minimum linear divergence that the laser/beam director telescope combination can achieve to the diffraction-limited value). For a Gaussian beam, this is approximately M^2, where the M^2 criterion value is available. The OQ value should be for the system (i.e., from the exit aperture of the beam director telescope), not the device (unless the device's raw output is what is emitted into space). This dimensionless number will always be greater than or equal to one.
SR =	Strehl ratio of the laser (ratio of the irradiance at the beam's center at any given far-field range to the ideal, diffraction-limited value). The SR value should be for the system (i.e., from the exit aperture of the beam director telescope), not the device (unless the device's raw output is what is emitted into space). This dimensionless number will always be less than or equal to one.
t (mandatory) =	The maximum laser firing time. This is the maximum time that the laser would be "on" for a given test(s) for laser activity. It is <u>not</u> the pulse duration for pulsed lasers; it is the overall time during which the laser might operate, which, for repetitively pulsed lasers, will usually encompass many pulses.
H_{min} (mandatory) =	Minimum laser operating altitude (km). This is specified as the laser source height above WGS84 ellipsoid. If the laser would be potentially used from any point in an Earth orbit, this would be the orbit perigee. If the laser is elsewhere (e.g., deep space) provide details in an attachment.
H_{max} (mandatory) =	Maximum laser operating altitude (km). This is specified as the laser source height above WGS84 ellipsoid. If the laser would be potentially used from any point in an Earth orbit, this would be

the orbit apogee. If the laser is elsewhere (e.g., deep space) provide details in an attachment.

BT (mandatory) = Beam Type: Some combination of profile (Gaussian, Top hat, etc.), shape (circular, ellipsoidal, rectangular, square, etc.), whether annular or not, and whether collimated, focused, or intentionally defocused. If the beam is not covered by the available choices, provide a detailed, free-form description in an attachment.

BC (mandatory) = Beam Count: If the laser is composed of multiple beams or beamlets, state how many beams are used. If multiple beams are employed, add explanatory notes describing the parameters for both the individual and combined beams.

w0 = Beam waist (radius) of the laser at the laser exit aperture (cm).

El_{min} = The minimum elevation angle at which the laser might emit radiation (in degrees) Note: zero is the local horizontal and 90 is zenith. For a space-based laser -90 is defined as pointing towards the center of the earth and the local horizontal is in the direction of its velocity vector. For earth-based lasers at high altitudes the horizon will be at a negative elevation below local horizontal.

El_{max} = The maximum elevation angle at which the laser might emit radiation (degrees). Note: zero is the local horizontal and 90 is zenith. For a space-based laser -90 is defined as pointing towards the center of the earth and the local horizontal is in the direction of its velocity vector. For earth-based lasers at high altitudes the horizon will be at a negative elevation below local horizontal.

Turbulence = If the laser will only be firing during atmospheric conditions characterized by some minimum level of atmospheric turbulence, specifying that minimum turbulence value may improve the deconfliction process (the default value is vacuum propagation for beam irradiance purposes). Units are free form since there are several different ways to define turbulence, including the C_n^2 ($m^{-2/3}$) value (index of refraction structure function) at some altitude (h), or the Fried coherence length parameter r_o at some wavelength λ (m) and others.

Orbital Lasers (mandatory, if applicable)

APO (mandatory) = Apogee is the point in the orbit of an object orbiting the Earth that is at the greatest distance from the center of the Earth minus the Earth's radius 6,738 km.

PERI (mandatory) =	Perigee is the point on the orbit of an object orbiting the Earth that is at the nearest to the center of the Earth's radius 67,38 km (km±).
INC (mandatory) =	Inclination measures the angle between the orbital plane of the satellite and a reference plane (usually the plane of the equator of the celestial body). It determines the tilt of the orbit with respect to the equatorial plane (degrees).
OAD (mandatory) =	Operational Altitude Differential (km) is the maximum possible difference in altitude between the laser-capable asset and its intended target.
OSD (mandatory) =	Operational Separational Distance (km) identifies how far apart the laser-capable asset is from its intended target when emitting laser energy. Specify if this is a singular distance or a range.

Circular Beams (mandatory, if applicable)

D =	Primary aperture (exit pupil) **diameter** of the laser telescope.
D_{obs} =	If there is a central circular obscuration, the diameter of the obscuration (cm). If the obscuration is not central circular, specify in the notes of the configuration.
w_{AP} =	$1/e^2$ (and/or 1/e; specify which) beam **radius** at aperture (Gaussian and truncated Gaussian beams only).
Z =	Distance of the final beam waist from the final exit aperture of the optical system (cm); positive in the direction of propagation. If the waist is at the final aperture of the optical system, then Z = 0 and $w_0 = w_{AP}$. If elsewhere (e.g., at the Rayleigh Range), then w_0 and Z must be specified.

Ellipsoidal Beams (mandatory, if applicable)

A =	Major axis of primary aperture (cm).
B =	Minor axis of primary aperture (cm).
a =	Major axis of central obscuration (if any; cm). If not central ellipse, specify in notes.
b =	Minor axis of central obscuration (if any; cm). If not central ellipse, specify in notes.
θ_{OBS} =	Angle between major axis of obscuration and major axis of exit pupil (degrees; default 0). If not central ellipse, specify in notes.

w_a =	$1/e^2$ (and/or $1/e$; specify which) semi-major beam axis (Gaussian and truncated Gaussian beams).
w_b =	$1/e^2$ (and/or $1/e$; specify which) semi-minor beam axis (Gaussian and truncated Gaussian beams).
θ_{BEAM} =	Angle between major axis of beam and major axis of exit pupil (degrees; default 0).

Rectangular Beams (mandatory, if applicable)

X =	Long dimension of primary aperture (cm).
Y =	Short dimension of primary aperture (cm).
x =	Long dimension of central obscuration (if any; cm).
y =	Short dimension of central obscuration (if any; cm).
θ_{OBS} =	Angle between long dimension of obscuration and long dimension of exit pupil (degrees; default 0). If not central rectangular, specify in notes.
d_x =	$1/e^2$ (and/or $1/e$; specify which) long half-dimension of beam (Gaussian and truncated Gaussian rectangular beams).
d_y =	$1/e^2$ (and/or $1/e$; specify which) short half-dimension of beam (Gaussian and truncated Gaussian rectangular beams).
θ_{BEAM} =	Angle between long dimension beam and major axis of exit pupil (degrees; default is 0).

Square Beams (mandatory, if applicable)

X =	Dimension across primary aperture (cm).
x =	Dimension across central obscuration (if any; cm). If not central Square, specify in notes.
θ_{OBS} =	Angle between diagonal of obscuration and diagonal of exit pupil (degrees; default is 0).
d =	$1/e^2$ (and/or $1/e$; specify which) half-dimension of beam (Gaussian and truncated Gaussian square beams).

Note: If the beam director telescope mixes shapes (e.g., a circular exit pupil with a square obscuration), the appropriate boxes for each can be filled in, but, for such combinations, conservative “equivalent” dimensions of the obscuration will be used to match the exit pupil shape, unless a sufficiently detailed assessment is required to merit the use of wave optics codes.

3.4.2 Laser Parameters for Pulsed Lasers

For a pulsed laser the following items must also be defined:

Pulse Format (mandatory) =	Describes the laser temporal format, with special emphasis on "non-standard" pulsed lasers, such as double pulsed systems, micro/macro pulse systems (in which a macro-pulse burst of energy might be made up of numerous micro-pulses), or variable pulsed systems that might change their pulse rates throughout a laser firing. If needed for a complete description, this should include plots of pulse formats.
E_{PULSE} (mandatory) =	Amount of energy in each laser pulse exiting from the beam director/telescope (Joules/pulse).
Pulse Shape (mandatory) =	Specify square, saw-tooth, Lorentz, etc., and describe special details (e.g., 80% of energy in 10 ns spike, with 1 μs of "noisy" tail containing 20% of energy). If initially not available, please provide as much detail as possible.
t_{PULSE} (mandatory) =	Pulse duration (s) and criterion (beginning to end, full width half max (FWHM), etc.).
PRF (mandatory) =	Pulse repetition frequency (kHz).
P_{INST} (mandatory) =	Instantaneous single pulse peak power exiting from the beam director/telescope (W) – Redundant for clarity. For a Gaussian temporal shape this will be equal to the laser *device* energy per pulse divided by the pulse FWHM duration.
P_{EQUIV_CW} (mandatory) =	Equivalent CW Power or Average Power exiting from the beam director/telescope (W) – Redundant for clarity. Typically equivalent to the laser *device* per pulse multiplied by the pulse repetition frequency (PRF).

3.4.3 Laser parameters for Focused Lasers

If a laser focuses at a point in space or target rather than trying to provide a culminated beam that focuses at infinity, then the laser owner/operator should specify the following information. Note: If the same system is used both as a collimated and focused system (without hard or soft stops) this section is N/A. If a beam is focused, then it will go through a minimum at the focus distance and diverge from that point with a half-angle divergence $\theta_{FOCUS\ DIV}$ generally greater than the diffraction limited divergence $\theta_{1/e}$. If the laser beam director is other than round, then the largest span across it should be used (e.g., a diagonal for a rectangular aperture). Thus, for an aperture 0.80 m x 1.2 m, the appropriate diameter would be 1.4422 m.

D_{MAX} (mandatory) =	Maximum laser aperture (exit pupil) dimension (cm; for a circular aperture, this is the diameter; for a rectangular aperture, this is the diagonal).
$R_{FOCUS\ MIN}$ (mandatory) =	*Minimum* possible focus range (km). Specify whether this is the true range of focus (to beam minimum) or the radius of curvature of the output beam. If collimated only, specify N/A.
$R_{FOCUS\ MAX}$ (mandatory) =	*Maximum* possible focus range (km). If collimated, specify infinity or N/A.

3.5 Laser Parameter Definitions and Clarifications

This section describes the laser parameters of power, divergence, atmospheric effects, and platform jitter in detail.

3.5.1 Output Power

The laser system output power is expressed in Watts projected from its beam director exit pupil or aperture. For continuous wave (CW) lasers, the CW power is specified as P on the registration form.

For pulsed lasers, both the instantaneous peak power P_{INST} and the equivalent CW or average power P must be specified. The instantaneous power P_{INST} for a single pulse can be estimated from the energy per pulse (E_{PULSE}) and the pulse duration t_{PULSE}, if known, by:

equation (1)

$$P_{INST} \cong \frac{E_{PULSE}}{t_{PULSE}}$$

In many cases, pulsed laser power is specified by energy per pulse and pulse repetition frequency (PRF). The equivalent CW power (P_{EQUIV_CW}) for the laser pulse train is given by:

equation (2)

$$P_{EQUIV\_CW} = E_{PULSE} \cdot PRF$$

In some cases, pulse temporal profiles will not lend themselves well to such simple analyses. If a pulse has, for example, a leading spike followed by a noisy "tail," the peak power of the spike, if known, should be used.

3.5.2 Beam Divergence

Because the 1/e radius of a beam contains about 2/3 of the energy, and the peak-to-average ratio of a Gaussian beam within its 1/e radius is 1.5:1, a reasonable and conservative estimate of the peak radiant intensity in the far field is given by:

equation (3)

$$J(W/sr) \cong \frac{P_{MAX}}{\pi\theta_{1/e}^2}$$

where:

P_{MAX} = Instantaneous peak power (CW power for CW lasers; W)

π = pi; 3.14159265…

$\theta_{1/e}$ = Minimum 1/e half-angle (rad)

Beam divergence can be specified in many ways; for purposes of uniformity, we define it to be the angle between the optical axis and the equivalent Gaussian 1/e radius of the beam in the far field. Specifically, this is defined as that half-angle which encompasses 63.2% of the beam's total power. For a circular Gaussian beam, this is also the half-angle at which the irradiance at any given range is down to 1/e (36.8%) of its peak, central irradiance value.

For diffraction-limited top hat beams in the far field, the 1/e beam radius is half of the Airy radius. The half-angle divergence, for top hat beams, is the angle between the optical axis and the 1/e beam radius in the far field given by:

equation (4)
$$\theta_{1/e} = 0.5 \cdot 1.22 \cdot \frac{\lambda}{D}$$

For diffraction-limited Gaussian beams, the half-angle divergence is the angle between the optical axis and the 1/e beam radius in the far field given by[2]:

equation (5)
$$\theta_{1/e} = \frac{\lambda}{\pi \cdot \sqrt{2} \cdot w_0}$$

If the beam director is known to be consistently less than diffraction-limited, then this can be included in the beam divergences via an optical quality factor:

equation (6a)
$$\theta_{1/e} = 0.5 \cdot 1.22 \cdot \frac{\lambda}{D} * OQ \ \ (Flat\ Top)$$

equation (6b)
$$\theta_{1/e} = \frac{\lambda}{\pi \cdot \sqrt{2} \cdot w_0} * OQ \ \ (Gaussian)$$

Note: For most beams, OQ ≈ 1/(√SR). If the beam has a known divergence, the laser owner/operator should provide this value on the laser registration form and indicate whether this is a measured or theoretically calculated value.

3.5.2.1 Focused Beams

3.5.2.1.1 Beam has Known Divergence

If the laser beam is intentionally broadened to a divergence larger than the diffraction limit ($\theta_{1/e}$ in equations 6a and 6b), or the divergence is otherwise known, then this larger divergence ($\theta_{diverged}$) can and should be used as $\theta_{1/e}$.

If the divergence is specified by other than the 1/e point as defined here, then it must be converted. If the beam is roughly a Gaussian, but its divergence is specified in terms of the one-sigma half angle, the 1/e

[2] This is the standard formula for a Gaussian beam ($Pz^2/\pi w_0^2$), using the fact that the 1/e radius is the 1/e^2 radius (w) divided by the square root of two.

half-angle is the square root of two times this value. If the beam is roughly a Gaussian, but its divergence is specified in terms of the full-width, half-maximum (FWHM) half angle, then the 1/e half-angle is 1.185 times the FWHM half-angle. To obtain the 1/e half-angle divergence from the $1/e^2$ half-angle divergence of a Gaussian beam, divide the $1/e^2$ half-angle by the square root of two.

3.5.2.2 Total Beam (Half Angle) Divergence

Given the discussion above for diffraction, optical quality, focusing, known divergence, and beam shaping, the laser owner must specify the least possible total divergence. This value is used to determine the highest possible laser irradiance that a satellite could encounter on orbit. If a laser is collimated and focused at infinity by high quality optics, then the minimum possible instantaneous total divergence will simply be the diffraction limited value, increased for poorer optics by the optical quality (OQ) or $\theta_{1/e}$ as defined in Equation 6. If the laser is focused, then the total divergence is based on the focused divergence (0.795 x $\theta_{FOCUS\ DIV}$) plus the beam divergence ($\theta_{1/e}$). If the laser has a known, larger divergence then the total divergence is the defined divergence for that laser ($\theta_{diverged}$). For purposes of filling out the laser registration form the laser owner should specify the beam divergence angle ($\theta_{1/e}$). During the calculation of laser energy at a satellite the total divergence will be used.

3.5.3 Atmospheric Transmission

Note: A transmission value of 1 (unity) is the default value. If the atmospheric transmission will be less than unity, then read this section.

The term τ_{ATM} in the laser radiant intensity formula plays a significant role in the calculation; yet may be among the most difficult for a laser owner/operator to determine. Several physical phenomena need to be considered to establish τ_{ATM}. The term is very wavelength dependent and can vary considerably based on the initial assumptions one uses. The use of sophisticated computer models such as FASCODE (FASt transmission CODE), developed by the Air Force Geophysical Lab in the 1980s, are typically required. However, for deconfliction purposes, the transmission of interest is the ***maximum value that might be seen at any moment during a test or laser activity***. In the case of visible wavelength lasers, this is generally so close to unity that unit transmission is assumed. For many infrared lasers, the value will be less, but may still be as high as 80 to 90% in at least some circumstances, however rare, so that more detailed calculations usually need not be made, and unity can be assumed. In some cases, a more detailed calculation might be enough to assign the laser to Category I, and these calculations should be made. In general, however, only lasers ***invariably*** subject to heavy attenuation by the atmosphere (e.g., HF lasers, which operate at 2.7 μm) should routinely include less-than-unity atmospheric transmission in their sure-safe calculations. For such lasers, a ground-to-space transmission calculation using a model such as FASCODE can be made, assuming the lowest possible values for water vapor and the highest possible visible range (i.e., minimum aerosols), for laser emissions assumed to be at the highest possible beam director elevation.

Note:It is not adequate to use models such as MODTRAN, MOSART or LOWTRAN for these calculations, as their spectral resolutions are inadequate to accurately estimate gaseous absorption, which is the primary parameter of interest for establishing the highest possible transmission at the wavelength of interest. A laser line model such as FASCODE must be used. Additionally, some lasers spread their power over multiple lines (wavelengths). In these cases, unless the actual power distribution spectrum of the laser is known, the line with best atmospheric transmission will be assumed for deconfliction purposes. If specific features of the test or laser activity conditions are known in advance, these can be incorporated into the calculation. For example, if it is known that laser operation will only be conducted if there are at least 10 g/m^3 of water vapor in the air, there is no need to compute propagation for a lower absolute humidity.

3.5.4 Atmospheric Turbulence

Note: If the laser firing will take place only during conditions with some minimum level of atmospheric turbulence, read this section.

The beam divergence value provided by the laser owner/operator should NOT include divergence due to atmospheric optical turbulence. Optical turbulence causes beam spread because the atmosphere is not homogeneous but, rather, consists of numerous small “eddies” of air which are warmer (less dense) or colder (more dense) than the surrounding air. Similarly, albeit less important, some parcels of air may have greater or lesser humidity than nearby parcels. These factors are associated with index of refraction variations which can bend light as it propagates through. Over a long path, these refractions of light can cause significant effects; it is atmospheric turbulence that causes the “twinkling” of stars at night. Over time, these eddies disrupt the beam from moment to moment, which changes the beam's shape, size, and spatial radiance profile. Over time, these shifting movements of individual “rays” within the beam can average to a larger beam size, as well as cause gross motion of the beam (wander), and cause instantaneous and shifting patterns of hot and cold spots.

Computing the effects of optical turbulence in detail requires sophisticated calculations and depends critically on the value of the optical turbulence all along the propagation path. Fortunately, for deconfliction purposes, such calculations are not necessary. Because damage to Electro-Optical (EO) satellite systems can take place in microseconds or less, the worst-case effect of turbulence will generally involve no time averaging. Furthermore, even in high turbulence conditions, the atmosphere can demonstrate momentary “still” conditions, in which the turbulence, briefly, has little or no effect on beam spread. Thus, the "worst case" condition for deconfliction purposes is that there is no turbulent beam spread at all. Calculations for divergence which include turbulence effects should therefore be redone without such effects for purposes of deconfliction calculations.

3.5.5 Platform Jitter

The beam divergence value provided by the laser owner/operator should NOT include the time-averaged beam spread due to jitter. Vibrations in or near a laser device can cause small angular deflections of the laser beam at the source. Over long propagation distances, these small deflections can translate to significant motion of the spot at the target. High frequency vibrations will statistically cause the ***time-averaged*** beam to appear broader at the target; low frequency vibrations usually affect the pointing of the laser beam. However, as with turbulence, because damage to Ultra-violet (UV)/EO/InfraRed (IR) sensor focal planes can occur in a period short compared to the characteristic times associated with most jitter, it is the instantaneous spot size that is of interest, not the time-averaged size. Thus, calculations which include jitter, except that of components at MHz and higher rates, should therefore be redone without such effects for purposes of deconfliction calculations.

4 Summary of Parameters

The laser owner/operator should provide laser parameters to the Laser Clearinghouse that are representative of the way the parameters will be used in the satellite risk analysis. **Most lasers (even some hand-held) other than low power, wide-divergence sources pose a potential threat to some**

satellites. This is because at least some UV/EO/IR sensors might be at risk of permanent damage from even low power laser systems.

Appendix A: Laser Registration Form

Laser Registration Form

CSpOC/SPD
Attention: LCH
816 13th St, Building 7000, Room A217A
Vandenberg Space Force Base, CA 93437
Unclassified Phone: (805) 605-4763
DSN: 605-4763 or(805) 606-7410 / DSN: 606-7410

In registering your laser and requesting Laser Clearinghouse (LCH) assistance, your organization is confirming that the operation of your laser does not raise an issue of compliance with arms control treaty obligations and does not raise an issue of compliance with other international or legal obligations**.**

If your laser is NOT assigned to Category I, further coordination with LCH is required. A formal Deconfliction Plan must be in place and signed through USSPACECOM/CFSCC prior to support from LCH.

Category I lasers are required to re-register every two years or when parameters change, whichever occurs first. Category III lasers are required to re-registered whenever parameters change.

The laser and platform values specified in this document must be "worst-case" values such that the values will not exceed the specified parameters. For example, the specified average laser power must not exceed the value stated. For further information about these laser parameters, please see the instructions for the form. Any changes that cause the information to exceed the specified value(s) requires a new laser registration form submitted to LCH.

A separate laser registration form must be filled out for each platform. It is encouraged that you use a single form for a platform with many lasers and laser locations. If a single platform is transportable to other locations, please list these locations and ensure a unique name is given to each location. Also, use a single form to list multiple modes of a single laser. Columns can be added to the tables below to account for more than two laser modes or lasers on a single platform.

SECTION I
Laser/Point of Contact Information

Date: 2025 Jan 13

Laser Name/Modes:
Classification of Laser:

Arete Laser Guide Star	
Unclassified	

Classification of Laser Site Communicating with the LCH: Unclassified

Organization: Lick Observatory

Long Facility Name: University of California/Lick Observatory

Short Facility Name: Lick

Point of Contact:

- **Name:** Elinor Gates
- **Mailing Address:** Lick Observatory, PO Box 85, Mount Hamiton, CA 95140
- **E-mail address:** egates@ucolick.org
- **Phone (commercial, unclassified):** 408-238-9610
- **Phone (DSN, unclassified):** N/A
- **Secure Phone #/Type:** N/A
- **Emergency POC (name, phone, and e-mail):** Elinor Gates, mh-laser@ucolick.org, 408-238-4274

SECTION II
Platform Data
(Each field is mandatory)

Platform Name: Arete

Platform Type (check all that apply):

X Fixed ☐ **Surface-Mobile** ☐ **Airborne** ☐ **Space-Based**

☐ **Other, explanation** ______________________________

Project Start Date: 2025 April 15

Project Completion Date: 2025 December 31

Typical Laser Target (check all that apply):

☒ **Look-Angle** ☐ **Missile** ☒ **Star** ☐ **Satellite** ☐ **Balloon** ☐ **Aircraft**

☐ **Other, explanation** ______________________________

Test objectives/scenario: Achieve laser guide star adaptive optics correction on astronomical targets with the 3-m Shane Telescope and compare results with existing Lick Laser Guide Star.

Will multiple lasers be incident on the target at the same time? No

Comments:

SECTION III
Platform Location

The following specifies the location information for the laser platform. Please see the instructions for this form for the formats and types of information needed for each platform type (i.e., fixed, aircraft, space, etc.).

If the laser will be operated from multiple locations, please provide as many geodetic locations and unique location names as are known using a separate attachment.

Location Name: Lick Observatory, Shane 3-m Telescope Dome

Fixed Site Location (if applicable):

Lat 37.3417 **(deg N) Long** 121.6428 **(deg W) Alt** 1.3 **(Km)**

Moving Platform Location (if applicable; free form, but should include range of latitudes, longitudes, altitudes, and movement details):

Mobile Platform Description (A brief description of the mobile platform; specific vehicle, maneuver information, and other information as may be appropriate determine the possible pointing angles and locations of the laser platform):

Orbital Platform Description (A brief description of the orbital platform; specify planned nominal satellite and orbital parameters):

Item	**Description**	**Constraints**	**Laser 1**	**Laser 2**
*LN	Laser Name/mode			
*APO	Apogee is the point in the orbit of an object orbiting the Earth that is at the greatest distance from the center of the Earth minus the Earth's radius (km±)	> -6378.150		
*PERI	Perigee is the point on the orbit of an object orbiting the Earth that is at the nearest to the center of the Earth's radius (km±)	> -6378.150		
*INC	Inclination measures the tilt of an object's orbit around a celestial body (deg°)	0° - 360°		
*OAD	Operational Altitude Differential is the maximum possible difference in altitude between the laser-capable asset and its intended target (km)	≥ 0.0 -or- Min - Max		
*OSD	Operational Separational Distance identifies how far apart the laser-capable asset is from its intended target when emitting laser energy. Specify if this is a singular distance or a range (km)	≥ 0.0 -or- Min - Max		

Comments:

SECTION IV
Laser Parameters

The following information is applicable to all laser systems. The parameters with an asterisk (*) are mandatory whereas the parameters without an asterisk will assist analysis and likely improve deconfliction but are optional.

If the laser system includes more than two lasers or modes, you may create a spreadsheet attachment of the laser parameters with columns for each laser/mode. Alternately, the tables below may be reproduced to enable data for all laser/modes to be captured. Note that each laser needs to have a unique name for each table of information; also, all values must be within the value range, number of significant figures, and exponentiation range for the double datatype.

NOTE: Input all numerical entries below in an exponential format, e.g., 6.12E-06 would be correct vs. 0.00000612 which is the same number but not the correct format for this form.

Item	Description	Constraints	Laser 1	Laser 2
*LN	Laser Name/mode		Arete	
*LT	Laser Type	Pulsed or CW	CW	
*P	Beam Director Aperture Average (Equivalent CW) Output Power (W). This is the total laser power that is transmitted away from the optical system	> 0.0	12	
τ_{ATM}	Maximum possible laser-to-space atmospheric trans-mission (usually assumed to be unity)	$0 < \tau_{ATM} < 1$	1	
*$\theta_{1/e}$	Divergence half-angle measured in micro-radians from the optical axis to the equivalent circular Gaussian 1/e point (i.e., that beam radius encompassing 63.2% of the total beam power). This will typically be either the diffraction-limited beam divergence for a collimated beam, or the controlled divergence angle for intentionally diverging beams, whichever is larger. For lasers operated only in the focused mode, stated here the diffraction-limited beam half-angle divergence if the laser were operated in the collimated mode (i.e. focused at infinity) (µrad)	> 0.0, Indicate if measured or calculated List both $1/e^2$ and 1/e values	$1/e^2$	$1/e^2$
			1.0 calculated	1/e
*λ	Center wavelength of the laser (µm)	> 0.0	5.89159E-01	
LW	Linewidth of the laser beam (nm) (FWHM)	> 0.0	2.82E-01	
OQ	Beam quality (multiple of linear divergence above diffraction-limited value)	≥ 1.0	<1.2	
SR	Strehl ratio: ratio of irradiance at beam's center to diffraction-limited value	≤ 1.0		
*t	The maximum laser firing time. In other words, this would be the maximum time that the laser would be on for a given test (sec)	> 0.0	2.88E04	
*H_{min}	Minimum laser operating altitude (km). Specified as the height above/below WGS84 ellipsoid where the laser is originating from; If space-based this should be the APO	> -6378.150	1.3	

<table>
<tr><th>Item</th><th>Description</th><th>Constraints</th><th>Laser 1</th><th>Laser 2</th></tr>
<tr><td>*H_{max}</td><td>Maximum laser operating altitude (km). Specified as the height above/below WGS84 ellipsoid where the laser is originating from; If space-based this should be PERI</td><td>> -6378.150</td><td>1.3</td><td></td></tr>
<tr><td>*BT</td><td>Beam Type (Specify one from each column, or use free form description for more detail)
<table>
<tr><td>Top Hat (uniform)</td><td>Circular</td><td>Clear</td><td>Focused</td></tr>
<tr><td>Truncated Gaussian</td><td>Ellipsoidal</td><td>Annular</td><td>Collimated</td></tr>
<tr><td>Hyper-Gaussian</td><td>Rectangular</td><td></td><td>Defocused</td></tr>
<tr><td>Pure Gaussian</td><td rowspan="2">Square</td><td rowspan="2"></td><td rowspan="2"></td></tr>
<tr><td>Other</td></tr>
</table></td><td>N/A</td><td>Top Hat
Circular
Clear
Collimated</td><td></td></tr>
<tr><td>*BC</td><td>Beam Count (If multiple beams are used)</td><td>> 1</td><td>1</td><td></td></tr>
<tr><td>El_{min}</td><td>The minimum elevation angle that the laser could be pointed to (deg°); zero is the local horizon and 90° is zenith)</td><td>$-90^{o} \leq El_{min}$ ≤D 90^{o}</td><td>45</td><td></td></tr>
<tr><td>El_{max}</td><td>The maximum elevation angle that the laser could be pointed to (deg°); zero is the local horizon and 90° is zenith)</td><td>$-90^{o} \leq El_{max}$ ≤D 90^{o}</td><td>90</td><td></td></tr>
<tr><td>θ_{error}</td><td>Maximum laser pointing uncertainty and the slew angle the laser emits radiation during an emergency shut-off in inertial space (not relative pointing). Half angle (deg°)</td><td>> 0.0^{o}</td><td>8.3E-02</td><td></td></tr>
<tr><td>Turbulence</td><td>Specify if laser will only be used during conditions with some minimum level of atmospheric turbulence</td><td>> 0.0^{o}</td><td></td><td></td></tr>
<tr><td>w_0</td><td>Beam Waist (cm). (Required for Gaussian beams)</td><td>> 0.0</td><td></td><td></td></tr>
</table>

Comments:

<u>Circular Beams.</u> For circular beams, provide the following information as mandatory entries, provide additional comments below if necessary.

<table>
<tr><td>D</td><td>The primary aperture (exit pupil) diameter of the laser telescope (cm)</td><td>> 0.0</td><td>25</td><td></td></tr>
<tr><td>D_{obs}</td><td>The diameter of a central, circular obscuration (if any) (cm)</td><td>$0.0 \leq D_{obs} \leq D$</td><td>0</td><td></td></tr>
<tr><td rowspan="2">w_{AP}</td><td rowspan="2">$1/e^2$ (and/or $1/e$, indicate which) beam radius at the exit pupil (Gaussian, truncated Gaussian beams) (cm)</td><td rowspan="2">> 0.0</td><td>$1/e^2$</td><td>$1/e^2$</td></tr>
<tr><td>$1/e$</td><td>$1/e$</td></tr>
<tr><td>Z</td><td>Distance from aperture to Beam Waist (cm)</td><td>Any Value</td><td></td><td></td></tr>
</table>

Comments:

<u>Ellipsoidal Beams.</u> For ellipsoidal beams, provide the following information as mandatory entries, provide additional comments below if necessary.

	Major axis of primary aperture (cm)	> 0.0		
B	Minor axis of primary aperture (cm)	> 0.0		

Item	Description	Constraints	Laser 1	Laser 2
a	Major axis of central obscuration (if any; cm)	> 0.0		
b	Minor axis of central obscuration (if any; cm)	> 0.0		
θ_{OBS}	Angle between major axis of obscuration and major axis of exit pupil (deg)	> 0.0		
w_a	$1/e^2$ (and/or 1/e, indicate which) semi-major beam axis (Gaussian and truncated Gaussian beams) (cm)	> 0.0	$1/e^2$	$1/e^2$
			1/e	1/e
w_b	$1/e^2$ (and/or 1/e, indicate which) semi-minor beam axis (Gaussian and truncated Gaussian beams) (cm)	> 0.0	$1/e^2$	$1/e^2$
			1/e	1/e
θ_{Beam}	Angle between major axis of beam and major axis of exit pupil (deg)	> 0.0		

Comments:

<u>Rectangular Beams.</u> For rectangular beams, provide the following information as mandatory entries, provide additional comments below if necessary.

X	Long dimension of primary aperture (cm)	> 0.0		
Y	Short dimension of primary aperture (cm)	> 0.0		
x	Long dimension of central obscuration (if any; cm)	> 0.0		
y	Short dimension of central obscuration (if any; cm)	> 0.0		
θ_{OBS}	Angle between long dimension of obscuration and long dimension of exit pupil (deg)	> 0.0		
d_x	$1/e^2$ (and/or 1/e, indicate which) long half-dimension of beam (Gaussian and truncated Gaussian rectangular beams) (cm)	> 0.0	$1/e^2$	$1/e^2$
			1/e	1/e
d_y	$1/e^2$ (and/or 1/e, indicate which) short half-dimension of beam (Gaussian and truncated Gaussian rectangular beams) (cm)	> 0.0	$1/e^2$	$1/e^2$
			1/e	1/e
θ_{Beam}	Angle between long dimension beam and major axis of exit pupil (deg)	> 0.0		

Comments:

<u>Square Beams.</u> For square beams, provide the following information as mandatory entries, provide additional comments below if necessary.

X	Dimension across of primary aperture (cm)	> 0.0		
x	Dimension across central obscuration (if any; cm)	> 0.0		
θ_{OBS}	Angle between diagonal of obscuration and diagonal of exit pupil (deg)	> 0.0		

Item	Description	Constraints	Laser 1	Laser 2
d	$1/e^2$ (and/or $1/e$, indicate which) half-dimension of beam (Gaussian and truncated Gaussian square beams) (cm)	> 0.0	$1/e^2$	$1/e^2$

Comments:

Other Laser Parameters

Pulsed Lasers. For pulsed lasers, provide the following information as mandatory entries:

Item	Description	Constraints	Value 1	Value 2
Pulse Format	Description of the laser pulse format (e.g. single pulse, repeating pulse, double pulse, etc)	N/A		
E_{PULSE}	Energy per pulse from the beam director telescope (J/pulse)	> 0.0		
Pulse Shape	Rectangular, sawtooth, spike + tail (including energy fractions in each), etc.	N/A		
t_{PULSE}	Pulse duration (sec) and criterion (FWHM, beginning-to-end (BE), etc)	> 0.0		
PRF	Pulse repetition frequency (kHz)	> 0.0		
*P_{INST}	Instantaneous single pulse peak power from the beam director telescope (W)	> 0.0		
P_{EQUIV_CW}	Equivalent CW Power or Average Power from the beam director telescope (W)	> 0.0		

Comments:

Focused Lasers. If a laser focuses to a point in space rather than trying to provide a collimated beam that focuses at infinity, then the laser operator must specify the following information:

Item	Description	Constraints	Value 1	Value 2
*D_{MAX}	Maximum laser beam director exit pupil dimension (cm)	> 0.0		
$R_{FOCUS\ MIN}$	***Minimum*** focus range (km). Specify true focus or radius of curvature at output aperture	> 0.0		
*$R_{FOCUS\ MAX}$	***Maximum*** focus range (km). Specify true focus or radius of curvature at output aperture	$R_{FOCUS\ MAX} \geq R_{FOCUS\ MIN}$		

Comments:

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DECON Mission Name :

PRM Name Format :

Final Divergence Calculation :

Type	Divergence (μrad)
Diffraction Limited	
Focus	
Other	
Total	