LASER LIGHT LANDING SYSTEM (L3S)

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Abstract

One of the most important problems for pilots, is landing on runways in dense foggy nights, that visibility is very poor i.e. less than 50 meters. Even with the help of navigational systems like ILS, radar, etc… from point of psychological view of the problem, it is difficult for a pilot to land when he or she can not see landing runway even the indicators show the correct course i.e. center line of runway and glide angle. On the other hand many countries like England, most of times have dense foggy weather and this problem forces an inordinate amount of expenses for airlines due to delays and landing in alternate airports, etc...

On the other hand dissatisfaction and probable economical losses for passengers are some of other profiles of above mentioned problem. L3S or laser light landing system provides a very efficient, with no harm in any conditions for pilots eyes, illumination of runway, touch down point and edges of runway before decision altitude i.e. about 400 feet. For the sake of security in the following calculations the decision altitude is recognized 200 meter or about more than of 600 feet, i.e. the pilot will see the illuminations at 200 meter altitude and has enough time to decide to land or not. It should be emphasized that, there will be no direct interception of light beam of laser to the pilot's eyes that the potential of any harm to the pilot's eyes reduces to zero probability.

1 Introduction

L3S or Laser Light Landing system is a number of collections of several arrangements or light Geometries that provide illuminating signs on touch down point and edges of runway, so it can prevent any psychological hesitation of pilot during landing in very poor visibility**.**

2 Light Geometries

There are several arrangements of laser lamps that in which, there is never any direct interception of light beam and pilot's eyes. A detailed discussion about penetrating of light in fog, dense fog and even in clouds will be provided after this section.

2.1 Simple Geometry

In this geometry the edges and the center line of runway is illuminated, (figures 1,2 and 3) when the aircraft follows landing procedures and is located in glide angle , i.e. in about more than 200 meter altitude and about 2-3 kilometers (depending on glide angle of specific airport) away from touch down point.
Directional beams of lights from edges of runway signs edges for pilot and when aircraft reaches more close to touch down point vertical beams of light in center line illuminates the touch down point and still the edges of run way is distinguished by edge light, and because that aircraft is located in glide angle by precision instruments like ILS, there is no possibility of direct interception of runway edge lights by pilot. Following pictures are depictions of light geometry, that is observed by pilot , when aircraft is reached to about altitude of 200 meters and also 2-3 kilometers away from touch point, by ILS or

any precision landing system. It is important to notice that , L3S is used with landing system instruments like ILS and can be optional, i.e. lights can be turned on by pilot , like tower light, to satisfy pilots with any decision regime, i.e. a pilot may follow landing procedures with the help of only ILS or intends to use L3S simultaneously to be confined psychologically or even use the system after decision altitude.

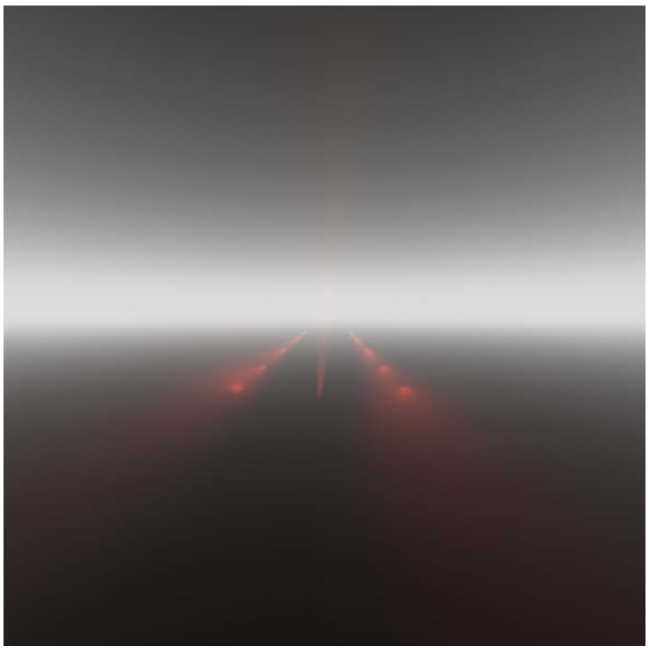

Figure.1.Runway illumination in day time Observed by pilot at decision altitude

It is important to notice that because diode lasers consume only some hundreds of milliwatt each, and totally a number of them consume some tens of watts by accounting the driving circuits, hence employing the laser lights instead of any other approach lights, has its own economical views, that is recognized and analyzed later in this paper.

2.2 Hybrid Geometry

It is one of the basic features of laser diodes that a laser with scanning device illuminates a large area of space, consuming only some tens of watts. (Figure.4)

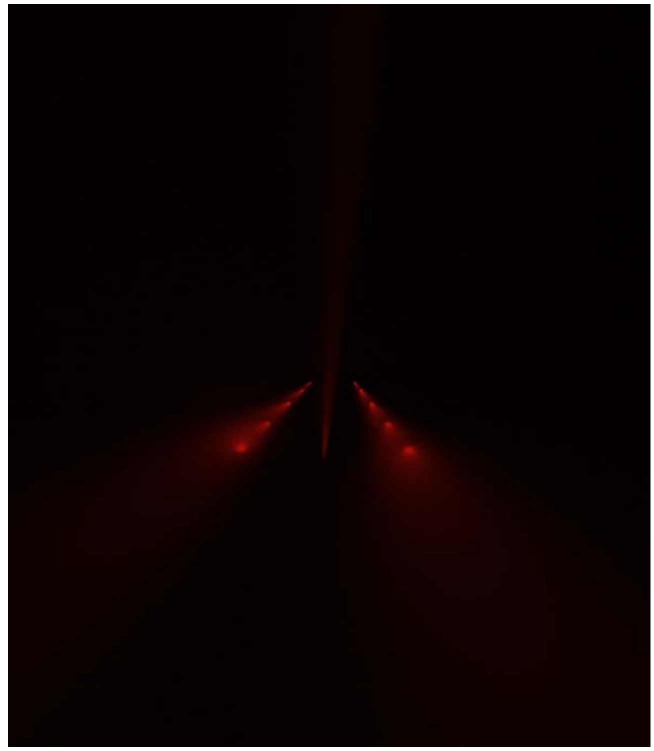

Figure.2. Runway illumination in night observed By pilot at decision altitude

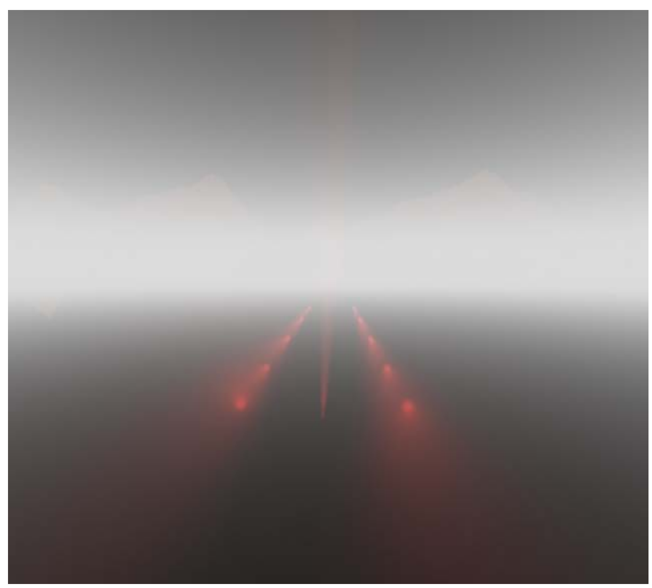

Figure.3. Runway view when pilot is some Hundreds of meters to touch down

A laser beam employed with a scanning device can scan a large amount of space and still seems to be continuous light. Of course using one or some tens of diode lasers, that consume some watts of power and provide some hundreds of milliwatts light flux equal to illuminating power of lamps of some thousands of lumens flux, will be a perfect economical solution for illumination in low visibility conditions or even in normal visibility conditions. Laser diodes are very economical devices that produce light beams; they are about some tens of dollars and long life, shock resistance, low heat generator light sources that can be used for illuminating and signage purposes.

Figure.4. vertical scanning laser light [1]

As depicted in figure 4 a laser diode or some diode lasers with power consumption of several watts when employed with an electronic scanner, can illuminate a very large area of space just because of our very famous visual neural property that is called spatial flicker effect that we see the whole area as continuous illuminated area.

As it is mentioned, when the airplane is located in 200 meters altitude, it is about 2-3 kilometers away from touch down point. Starting from this point and locating the first scanning laser as a vertical illumination light source, then pilot intercepts the first vertical illuminating plane in space at this point and if other scanning light sources is located in each 100 or 50 meters, the pilot intercepts this planes one after another and before reaching to final plane, the touch down point is illuminated by dense light in the root of last plane. It should be reminded that all above visual signs should be a help for precision landing systems like ILS, and such above systems indicators should be checked simultaneously by the pilot.

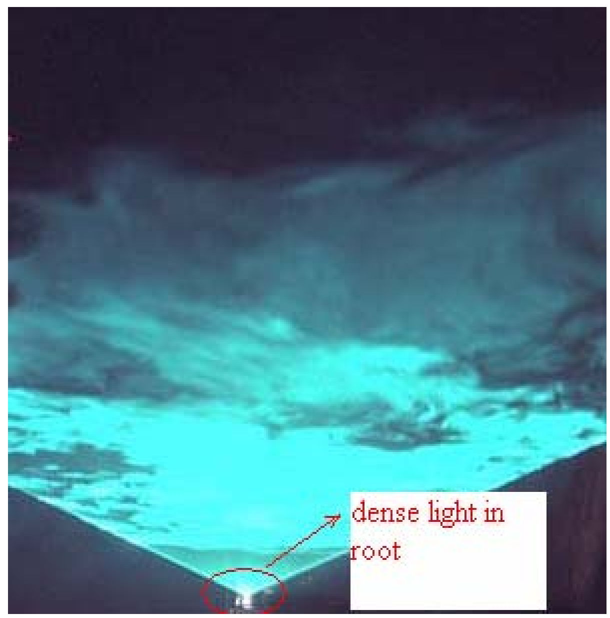

Figure.5. Dense Light in the Root of Illuminated Space Plane

Figure.6 depicts a more clear visualization of hybrid geometry using a number of scanning laser lights producing red partially-circular signs in space having a column of blue light by another laser lamp, that exhibits the center line path. It is important to take notice that all above geometry should be compliant with STAR (standard arrival) procedures of specific airport that may have any procedures of circling or straight approach, before touch down on the runway.

Of course if it is intended that, the hybrid illumination geometry to be used optionally by pilot, he or she should turn on the system before reaching to decision altitude just like tower light.

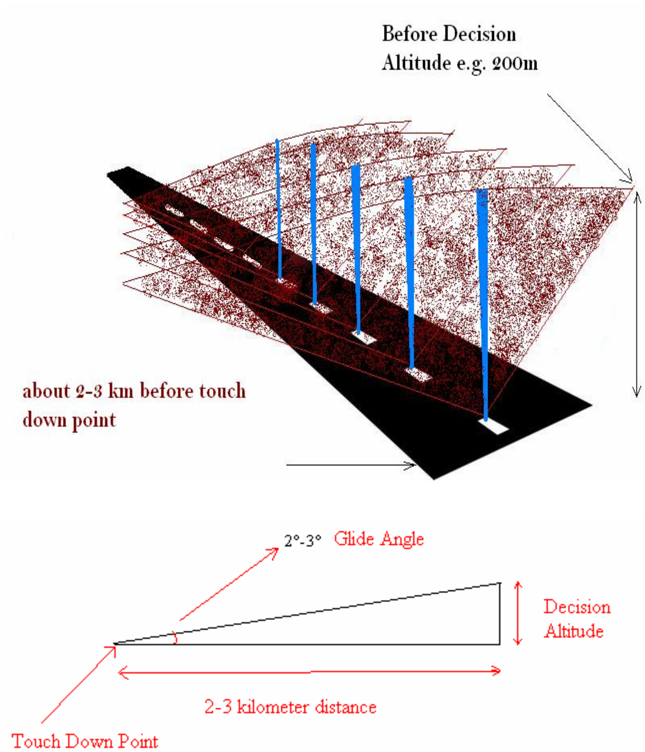

Figure.6. Hybrid Illuminating Lighting System

It should be mentioned that, it is possible to use mobile lamps, depending on air traffic controlling managements, in emergency cases or any other approved policies. (Figure.7)
Also it should be recognized that, with the help of scanner systems it is possible to illuminate any geometry of space like a funnel, cone, cylinder-Plane, partially circular plane, semi circular plane etc… with avoiding of any direct interception of light by pilot eyes, i.e. illuminating a portion of space or runway on the ground just as signage guide for landing of aero planes in dense foggy nights.
recently improving laser technologies, provides the possibility of penetrating visual laser light in dense clouds.[2] as depicted in figure.8.

This option captures more flexible usage of above mentioned system when a runway is covered by thick dense clouds, like cumulonimbus clouds and there is an essential emergency for landing of aircraft in such conditions, like technical fatal failures, or lack of enough fuel, etc…

Figure.7.A Mobile Light Module

Cloud penetrating laser light needs very precise Landing procedures and format to be written by air traffic controlling experts.

Figure.8. Cloud Penetrating Laser. [2]

3. Laser beam propagation losses in fog and Haze weather and the effect of above Conditions for selection of the geometry.

In this section the efficiency of diode lasers which is used to produce required illumination in space is discussed. because modern laser diodes produce about several hundreds of milliwatt light intensity and if it is proved that one or a lamp comprised of several tens of diode lasers can provide such or more intensity in very dense fog, then there will be an opened option that provides so many advantages: because laser diodes are very cheap, very small and light, low heat generators, very compact, easy to be controlled with a fairly cheap and small scanning and power supply electronic systems.

3.1 Weather Conditions

Visibility is a function of weather condition, the following table illustrates weather conditions and the attenuation of laser light of about 700 nanometer (dark red). Atmospheric attenuation can be vary from .2 dB/km in exceptionally clear weather to 310 dB/km in very dense UK fog.[3,4]

weather	Visibility km	Attenuation dB/km
Dense Fog	0.05	340
Thick Fog	0.5	85
Moderate Fog	0.2	34
Light Fog	1	14
Thin Fog	2	7
Haze	5	3
Light Haze	10	1
Clear	10>	0.5

Table.1. Weather Conditions and Attenuation Factors [6]

3.2 Laser Diode implementations

As it is seen in table.1, in dense fog weather condition, a laser signal of about 0.7 micrometer is attenuated about 340 dB per kilometer. If it is assumed that illuminating power of .01 watt that is very good illuminating intensity, because a lumen is equal to 1.496×10^{-10} watt [5].

Hence it can be written that for 200 meters or 0.2 kilometer is equal to

$$20 \log \frac{10^{-2}}{P_0} = -(340\times 0.2) = -68 \text{ dB} \quad (1)$$

Then P_0 or light intensity of laser source should be about 4 watt and this amount is in the range of a series of some diode lasers, hence it is possible to implement diode lasers for illumination in hybrid geometry. In the case of simple geometry, there are two options, first option is turning on the system before decision altitude, that there is about 2 kilometers distance between aero plane to touch down point, (or the first laser lamp) and substituting -68 dB in above equation, apparently P_0 will be much more than laser diodes rated output power, and other kinds of lasers should be implemented. As second option, laser diodes can be used when aircraft reaches to about several hundred meters of touch down point with the help of ILS but with visual confirmation in final several hundred meters. Of course as it is seen in Figure.9, it is possible to use laser diodes in thick, moderate and light (not dense) fog conditions in hybrid and simple geometries, because when the

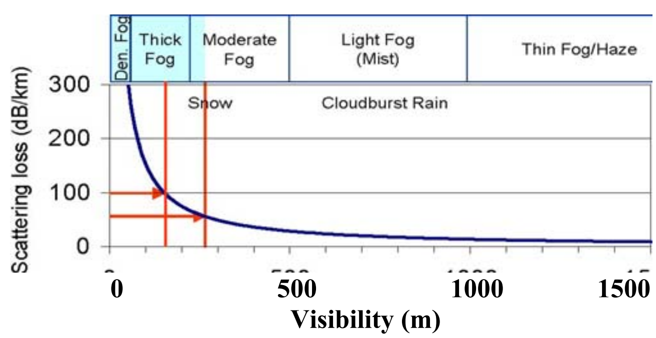

Fig.9. Power loss of laser light versus visibility

Regarding table.2, and equation (1), it is easy to calculate source intensity and easily conclude that laser can furnish these ranges of intensity in all weather conditions except dense fog weather. when aero plane is located at decision altitude it is about 2 to 3 km distance between it and touch down point (or the first lamp) and power loss is 2×85=170 dB (for thick fog) or less (for better weather conditions), and if p= 0.1 mw ,and considering (1), then series of several laser diodes producing several tens of watts is acceptable level of illumination. It should be mentioned that snowing weather is recognized equal to thick fog or moderate fog depending on amount of snow falling and cloud burst rain is equal to light fog or mist (figure.9) [6]. As another option, it is possible to use diode lasers, with above geometries for illumination of bound boarders and or for landing instead of runway approach light with the advantage of low power consumption for lighting purposes. The last option for using diode laser is that pilot can follow IFR rules and approaches using ILS, MLS, etc…and when reaching to 200-300 meters of touch down point (of course after decision altitude) then uses laser light illumination to give psychological satisfaction to pilot.

3.3 Implementation of Power Lasers of other Kinds except than Laser Diodes

There is no required intensity restriction for using such lasers but , there are some disadvantages, like big size, rather difficult operation, sensitivity to environmental conditions, and price, etc… but having enough power to satisfy any kind of geometry or even penetrating in thick clouds. as it is seen in figure.9. Probable implementation of various simple geometry conditions depicted in table.2. It should be emphasized that in hybrid geometry, aero plane receives its light form sources about 200 meters (and less) bellow, in simple geometry source light is located about 2-3 km distant.

3.4 Simple Geometry Implementations

All discussed conditions is depicted in table.2.

		Attenuation	Possible methods
Dense Fog	1 ------- 2	2km×340dB/km ------------------- 0.3km ×340db/km	C -------- D, C
Thick Fog	1 ------- -2	2km×85 dB/km ------------------- .3km×85 dB/km	C ----------- D, C
Moderate Fog	1	2Km×34 dB/km	D is preferred
Light Fog	1	2km×14 dB/km	D is preferred
Thin Fog	1	2km×7 dB/km	D is preferred
Haze	1	2km×3 dB/km	D is preferred
Light Haze	1	2km×1 dB/km	D is preferred
clear	1	2km×0.5 dB/km	D is preferred

Table.2. Power losses in various weather Conditions

C: commercial power lasers
D: Diode Lasers
1: Observing light before decision altitude about 2-3 km before touch down point
2: Observing about 200 to 300 before touch down

There are other options, which to use vertical cylinder light of laser diodes to distinguish possible areas like the edges of runway and /or the center line of it, but all should be in compliant with *IFR-STAR rules* and *avoiding direct interception of light by pilot geometry.*

3.4 Hybrid Geometry Implementation

This type of geometry can be implemented by laser diode in any weather conditions. Because of very short distance between aircraft to light sources.

4 Probable hazards for pilots' eyes

As a fundamental principle:
"Only direct interception of laser light beam by eyes can harm to them" and by implementing above geometries, there is absolutely no direct interception of light beam by pilots' eyes and just an illumination of light is the sole perception by pilots' eyes.

5 The wave length dependence of Atmospheric attenuation

Above mentioned attenuation coefficients are experimented and concluded for very high wave length of visible spectrum. Using various kinds of light sources, is equal to implementation of various colors i.e. various wave lengths of light hence a more precise verification of all visible spectrum is required.
When an electromagnetic wave is passing through a medium there should happen several phenomena like scattering, absorption, reflection, etc… in the case of passing light beams the main interaction responsible for attenuation is scattering of light photons by varied-size disorder molecules of water with lower density than ordinary water.
The attenuation of laser light through atmosphere is described by exponential Beers-Lambert law[7]

$$\tau(R) = \frac{P(R)}{P(0)} = e^{-\sigma R} \qquad (2)$$

Where:
τ (R) is transmittance at range R,
P(R) is laser power at R,
P(0) is laser power at source, and
And σ is attenuation or total extinction Coefficient (per unit length)

Typical attenuation coefficient are: clear air=0.1 (43 dB/km) ; haze = 1 (4.3 dB/km) and fog = 10 [6].
The attenuation coefficient has contributions from the absorption and scattering of laser photons by different aerosols and gaseous molecule in the atmosphere. Of course for about 700 nm of wavelength the contribution of absorption to total attenuation coefficient are very small. [6] The effects of scattering, therefore, dominate the total attenuation coefficient. The type of scattering is determined by the size of the particular atmospheric particle with respect to the transmission laser wavelength. This is described by a dimensionless number called the size parameter α [8].

$$\alpha = \frac{2\pi r}{\lambda} \qquad (3)$$

where r = radius of scattering particle,
λ = laser wavelength

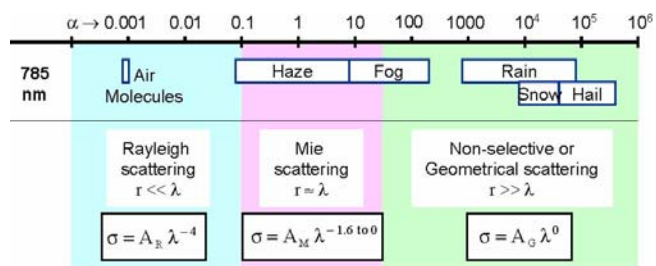

Figure.10. σ = Scattering coefficient; AR, AM , AG = constants; λ = wavelength

Type	Radius	Size Parameter α
	(µm)	785 nm
Air Molecules	0.0001	0.0008
Haze particle	0.01 - 1	0.08 - 8
Fog droplet	1 to 20	8 - 160
Rain	100 to 10000	800 to 80000
Snow	1000 to 5000	8000 to 40000
Hail	*5000 to 50000*	*40000 to 800000*

Table.3. laser transmission of wavelengths 785

As it is seen the attenuation coefficient or atmospheric particles depends on their size called Rayleigh scattering for small size particles. Mie scattering, for middle size particles and Non-selective or geometrical scattering for large size particles of water in atmosphere.

Profound discussion of above criteria is out of scope of this paper but the results are important.

$$\sigma = A\lambda^{-q} \qquad (4)$$

Where σ is defined in figure10. an expression can be derived for A from definition of visual range and q can be determined from experimental data, resulting in:

$$\sigma = \frac{3.91}{V}\left(\frac{\lambda}{550nm}\right) \qquad (5)$$

Where: $\sigma =$ scattering attenuation (or scattering) Coefficient

V = is visibility in (km)

q = the size distribution of scattering particles

= 1.6 for high visibility (V> 50 km)

= 1.3 for average visibility (6 km < V< 50 km)

$=0.585V^{1/3}$ for low visibility (V< 6 km)

This form of calculation is very handy because it depends on visibility that can be obtained from airport or weather data.

The result is depicted in table.4 [6]. This table gives very good idea and or practical equations to calculate attenuation factor and finally power implementation of the type and Number of diode lasers in a lamp or using of commercial power lasers and also choosing the geometry or even a combination of both depending to air traffic rules like STAR for specific airport, air traffic management design, goals and weather conditions pattern for specific airport.

6 Geometrical spreading of Laser Beam

In the case of simple geometry when laser beams of edges of bound after 2 km distance reaches to aircraft and according to the inherent characteristic of laser beam, there is a spreading angle for lasers about 1 mrad then after 2 km it spreads to a circle of radius r:

r = 2000 × tg (1 mrad) = 14 cm

Visibility (km)	dB/km 785 nm	Weather
0.05	315	Fog
0.2	75	
0.5	29	
1	14	
2	7	Haze
4	3	
10	1	Clear
23	0.5	

Table.4. weather attenuation coefficient versus Visibility

is illuminated by edge lights. The illuminated area is about 0.6 square meter which is acceptable surface of illuminating because can be distinguished by pilot easily. It is obvious with using a number of laser diodes and cascading them in a lamp and using various lenses depending to application any surface area with desirable illumination intensity can be produced.

7 Conclusion

In spite of using very precise and complicate systems, for observing, human is still depended on his senses primarily, and psychologically can accepts easily, with no hesitation , every thing that can see, even if what is seen is not correct or is affected by aberration or other phenomena. This system provides an effective and pleasant method to insure pilots to land with self confidence and no hesitation hence provides a good means of psychological assertion for pilots not hesitate and to land with no psychological stress.

This means less delay and less psychological stress for Pilots that leads to considerably reduction of the expenses due to delays or landing in alternate airports for airlines and passengers and providing more convenient psychological conditions for pilots, passengers, crews etc…

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