THE COVERT LASER LANDING SYSTEM FOR REMOTE OR TEMPORARY LANDING STRIPS

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ABSTRACT

The Covert Laser Landing System (CLLS) is composed of three elements: a Diode Laser Centerline Localizer (DLCL) for visual line-up guidance; a Diode Laser Glideslope Indicator (DLGI) for visual glideslope guidance; and two rows of Diode Laser Edgelights (DLE) for rollout cues. The CLLS has many advantages over existing portable airfield lighting systems. The areas with greatest advantage are size, weight, power requirement, precision, and deployability. In addition, the CLLS supplies all three elements for a fully self-contained approach and landing: centerline guidance, glideslope guidance, and landing area definition.

The CLLS was field tested. The CLLS was found to be an effective visual system for aircraft recovery onto remote or temporary landing strips. The DLCL has an effective range in excess of 10 nmi and was useful at 13 nmi, the longest range tested. The DLCL and DLGI can be used together effectively even though they use essentially the same signals for guidance. DLEs provide effective and useful flare and rollout guidance. They can be used with a maximum spacing of 400 ft, and may be turned on very late in the approach without affecting the recovery. This feature improves the low probability of intercept (LPI) nature of the system. A simple hand held GPS system can be used for guidance into the CLLS approach corridor using the two approach plates tested. The is no need, therefore, for permanent systems mounted in the aircraft or for differentially corrected GPS. The monochromatic nature of the CLLS system tested makes it probable that it will be NVG compatible.

When implemented the laser based covert portable airfield lighting system will provide precise, covert airfield lighting which will be a significant improvement over currently available systems. This system can also be used for lighting civilian airfields for disaster relief.

COVERT LASER LANDING SYSTEM

We have developed a laser based covert portable airfield lighting system, which is called the Covert Laser Landing System (CLLS) which provides the three necessary components of a self-contained approach and landing: centerline guidance; glideslope guidance; and landing area definition. The fundamental difference between this system and others that are available is the use of diode laser based visual aids for precise line-up and glideslope guidance, and for all landing area edge lights. Diode lasers are extremely efficient at converting battery power to light and the directionality of lasers allows the light generated to be placed exactly where it is needed. This significantly reduces the amount of battery power needed to operate the airfield lighting and the size of the optics needed to shape the beams precisely. The efficiency of the lasers results in a near zero thermal signature which combined with the low-scatter directional beams makes the system invisible to both FLIR and Night Vision Goggles (NVG) when viewed from outside the approach corridor. This provides a very low probability of intercept in an extremely small package. A complete airfield lighting system will fit in a single man portable package. In addition, the directionality of the system enhances stealth, and the low power consumption allows a long battery lifetime and solar cell recharging for extended remote operations.

The system is composed of three types of components: Laser Centerline Localizer, Laser Glideslope Indicator, and Laser Edge Lights. The edge lights are used to define the boundaries of the landing area. In the system there are a total of 15 edge lights, and more could be added for longer runway for large fixed-wing aircraft. An edge light is composed of a diode laser approximately 0.6 inches in diameter and 1.25 inches long. Affixed to the front of the laser is a small lens which expands the beam in a controlled fashion. In this case the beam is expanded into a rectangular pattern 9 degrees by 2 degrees in angular width. Through the use of internal baffles, light propagating outside of the 9 X 2 degree cone is eliminated. Outside of this cone the edge light cannot be seen. Other components in the edge light are: a battery for power; a radio receiver that allows the light to be turned on and off remotely; and an external antenna. The edge lights are arranged in a rectangular pattern around the perimeter of the runway. In this case there is one edge light every 400 feet or so on each side, 3 at the forward end, and 2 at the threshold. The landing area is sparsely lit, but it is more than sufficient for guiding the flare and touch down and roll out portions of the flight.

Primary visual guidance to the landing area is provided by the LCL and LGI. Both devices work in a similar fashion. They project a series of fan shaped laser beams out into the approach corridor. These beams produce steady signals when the pilot is on course. Off course signals are modulated. In particular for the LCL when the aircraft is lined up to the left the pilot sees a flashing signal modulated in a pattern 'dot-dot'. On centerline is signaled by a steady laser signal, while right of centerline is indicated by a 'dot-dash' pattern. The Laser Glideslope Indicator uses a similar 'dot-dot' pattern for low on glideslope, a steady signal for on glideslope, and a 'dot-dash' signal for above glide slope. It is similar to the LCL but rotated 90 degrees. The LGI is distinguished from the LCL by its location on the ground. The physical layout of the system including edge lights, LCL, and LGI is shown schematically in Figure 1. The projected areas are an artist concept showing the coverage of the various laser beams.

To understand how this system functions let us examine the steps involved in recovering an aircraft. This system uses the directionality of laser light to achieve an extremely high level of covertness. Only an aircraft which is within the narrow field of the lasers will be aware of the presence of the airfield. When used in the field the aircraft receives its initial guidance via GPS navigation. A GPS initial point is chosen along the aircraft approach route. Upon arrival at the initial point the aircraft takes up a heading to another GPS point located along the extended centerline of the airfield. Shortly before arriving at the GPS centerline point the pilot will pass into the area of coverage of the Laser Centerline Localizer. A typical flight path is shown in Figure 2. Numerous variations on this initial approach technique are possible. At an altitude of 1000 to 1200 ft AGL the only signal the pilot will initially see is the LCL (the edge lights are off and will not be turned on until the aircraft is approximately 1/2 mile from the runway threshold and the final approach starts from level flight below the coverage of the LGI). The pilot tracks the LCL inbound until the LGI is seen, the pilot then intercepts the glideslope and descends to the landing area. Use of the LCL and LGI on approach is illustrated in Figure 3. When right or left of the centerline the pilot will see the modulated off center line signals, either 'dot dash' or 'dot dot' depending on the direction. The off course signals are indicated in this illustration by the open star, and the modulation pattern is shown in Morse code next to the star. The view on centerline is represented by the closed star which indicates a steady signal. Likewise above and below glideslope signals are shown with open stars and the appropriate Morse code. By maintaining two steady signal, one for centerline and the other for glideslope, the pilot is assured a good approach to the landing area. When the aircraft is 0.5 to 1.0 miles out the landing area edge lights are turned on by radio command. After roll out, the landing area lights are turned off.

For a normal airfield the edge lights would have to be illuminated during the entire approach to provide the pilot with line-up information; furthermore, the angular coverage of the edge lights would have to be large to accommodate intercept and tracking without precision line-up guidance. By using the LCL and LGI we have eliminated the pilots reliance of the edge lights for all but landing and roll out. This fact is used to dramatically reduce the probability of drawing unwanted attention to the landing site. During the first part of the final approach only two lights are on, the LCL and the LGI, both have very tightly contained beams. Edge lights are required only during the last 30 seconds or so of the landing. As one can see the amount of time that the landing area is exposed to view is minimal, furthermore the area where any of the landing area lights are visible is confined to a few degrees about the extended centerline.

It is extremely important to note that the aircraft needs no special equipment of its own to use this system. Virtually any aircraft, including civil aircraft, can use the system successfully. From a covert operations standpoint this is very useful since special aircraft (such as those with FLIRs or unusual sensor blisters) need not be introduced into the theater of operations where their presence might be noticed.

ADVANTAGES OF CLLS

The CLLS has many advantages over existing commercial airfield lighting systems. The areas with greatest advantage are size, weight, power requirement, precision, and deployability. In addition, the CLLS supplies all three elements for a fully self-contained approach and landing: centerline guidance, glideslope guidance, and landing area definition.

The CLLS is composed of three major components: a Diode Laser Centerline Localizer (DLCL), a Diode Laser Glideslope Indicator (DLGI), and Diode Laser Edgelights (DLE). A Photograph of the DLCL is shown in Figures 4. The CLLS is small enough to be carried in backpacks to be rapidly deployed at remote strips. The glideslope and centerline systems use diode lasers. The "proof of concept" model Diode Laser Glideslope Indicator component of the CLLS has a size of 8x9x5 inches and includes a rechargeable battery. The advanced development model DLCL has a size of 4x3x8 inches, weighs 1.8 kg, and also includes a rechargeable battery. The radio-activated edge lights, which show the outlines of the runway are in boxes which have a size of 2x7x5 inches and also contain a rechargeable battery. All components are able to operate for 6 to 12 hours when charged. The CLLS version which was tested, which includes the advanced development model of the DLCL, "proof of concept" model DLGI, and "proof of concept" model DLEs, has a total mass of 20.6 kg (45 lbs). Smaller and lighter versions are available. Advanced development models of the DLGI and DLCL would be significantly less, with an estimate of 15.6 kg (34 lbs).

The CLLS allows greater precision for guidance than is possible with the incandescent lighting systems. This is due to the use of lasers for the illuminating source. The spatial coherence of the laser causes the light to appear to come from a single point source rather than the distributed source common to incandescent, florescent, or arc lights. Thus, it is possible to define the edge of a particular corridor as sharply as the limits of diffraction will allow. From the pilot's perspective, this means that the transition from corridor to corridor is abrupt and clean with the CLLS. Consequently the transitions between corridors are readily apparent and recognition time short.

Diode lasers are extremely efficient at converting battery power to light and the directionality of the lasers allows the light generated to be placed exactly where it is needed. This significantly reduces the amount of battery power needed to operate the airfield lighting. The CLLS is operated from small, lightweight batteries. Coherence of the laser allows small optical elements to be used. Combining this with the small physical sizes of the diode laser and the battery permits extremely small, lightweight packaging. Because of the small volume and mass, the entire CLLS can be contained in a single-man carry case. Because of the small size and mass, no vehicle would be required for rapid deployment. The CLLS can be deployed as nearly as rapidly as the personnel can travel over the runway, while taking only a few seconds to set each DLE. While precision placement and alignment could take a substantial amount of time (i.e. 2 hours), adequate placement and alignment can be obtained in 10 to 15 minutes by pacing out distances and alignment by eye.

An edge light needs to be placed so that its beam projects into the approach corridor and also into the landing area. The edgelights work best when their azimuthal alignment was such that the outside edge of the beam projected out of the runway area approximately 2 degrees, so that most of the coverage was towards the inside of the runway where it could be seen during rollout. This azimuthal angle can be easily set to adequate precision with a two man team by using 30 paces away and 1 pace outwards. Adequate azimuthal angle is obtained at night with a single person by looking at the reflection of the beam and judging when about 1/4 of the beam was aimed out of the runway edgeline. Precision alignment in ascensional angle is easily accomplished with a bubble level on the top of the units.

Because of the precision centerline guidance of the CLLS, the pilot's reliance on the edge lights are eliminated for all of the approach except landing and roll out. Thus, the angular coverage of the edge lights do not need to be large to accommodate intercept and inbound tracking. This dramatically reduces the probability of drawing unwanted attention to the landing site. During the first part of the approach, only the centerline and glideslope guidance components are on, and both of these components have very tightly controlled beams which are not visible outside of the proper approach corridor. Edge lights are required only during the last 30 seconds or so of the landing. The amount of time that the landing area is exposed to view is minimal. Furthermore, since the edge lights are only on during the final portion of the approach, their angular coverage is much smaller than for the other portable systems. These two factors, smaller angular coverage and limited time on, provides for extremely covert operation.

Because of the very small electrical load, the CLLS has an extremely small thermal signature. Furthermore, the power using element, the laser itself, is mounted at the bottom of its box. Insulation above and a heat sink below direct the waste heat into the ground. The monochromaticity of the laser helps reduce the system's detectability. Most incoherent light sources are composed of a wide spectrum of emission wavelengths, which often include broad band infrared, thus making the lights themselves bright to heat seeking devices. The lasers used here are single wavelength and contain no components at any other wavelengths. Thus the visible lasers would be invisible to any infrared seekers. Similarly, any infrared lasers would be visible only to equipment designed to detect in a band which includes that wavelength. Thus for example, a NVG compatible laser would not be visible to humans or visible detectors or to long wavelength heat detectors. Also remember that because the laser light appears to come from a single point source, there is very little scattered light and that is suppressed with a baffle. Consequently the detector would not only have to be sensitive to the laser wavelength, but be pointed directly into the beam in order to detect it.

One must differentiate between the pilot being able to see a light and the quality of the guidance information being provided. For example, seeing a light provides the pilot with the direction of the airfield, but fails to provide the pilot with any information on the final heading or the degree of deviation from the runway centerline. Also for example, being able to see light from a PAPI does not mean that the aircraft position with respect to the proper glideslope is discernible at that range. This is because the PAPI requires that the pilot be able to resolve the pictorial presentation to interpret his position with respect to glideslope. Therefore, the range at which optical resolution of the PAPI provides useful information is much smaller than the range at which any light from the PAPI is observable. The presentations used in the CLLS do not require optical resolution by the pilot, thus are useable at a much longer ranger than the PAPI.

This feature also implies that the CLLS signals would be functional in marginal weather where systems such as the PAPI would be obscured. This is because the pilot does not need to optically resolve the light source, but only needs to note its general location and temporal frequency. The monochromaticity of the lasers is an asset because the wavelength (color for visible portion) is well defined, even in the presence of atmospheric haze. The monochromatic nature of the light permits easier recognition.

APPROACH PATH FLIGHT PROFILES

Two types of GPS entries were tested: over the top; and entry point from an arbitrary angle. For the over the top type of GPS entry, the GPS defined point, labeled as the "Initial Point", is at the touchdown zone. The aircraft is navigated to the Initial Point, past it on the Initial Leg, turn downwind, go downwind on the Downwind Leg for a specified distance, turn left to Base Leg, then follow the CLLS in with a turn to the Final Leg and the final approach. For the entry point technique, GPS is used to navigate to a point which is inside of the approach corridor at the range equivalent to the turn to final. At the entry point, the pilot turns using the CLLS centerline guidance until on the final bearing. Then the pilot follows the CLLS guidance to touchdown.

The azimuthal coverage of the Diode Laser Centerline Localizer (DLCL) component of the Covert Laser Landing System (CLLS) is shown schematically as viewed from above in Figure 5. In this figure the corridor width is plotted as a function of range from the touchdown zone (TDZ) with the lines representing the corridor transitions. When a pilot is within the region, i.e. corridor, which is indicated as "on" the on-centerline signal is visible to the pilot on final approach. When a pilot is within the region, i.e. corridor, which is indicated as "right" the right of centerline signal is visible to the pilot. When a pilot is within the region, i.e. corridor, which is indicated as "left" the left of centerline signal is visible to the pilot. The angular coverage of the DLCL in azimuth is given in degrees outside of the right hand axis; the tics on this axis correspond to the left hand axis, not the angular coverage. The location of the DLCL with respect to the TDZ is given in the lower left hand side of the figure; in this case it is exactly on the centerline and 300 ft from the TDZ towards the approach end.

The ascensional coverage of the Diode Laser Centerline Localizer (DLCL) component of the Covert Laser Landing System (CLLS) is shown schematically as viewed from the side in Figure 6. In this figure the corridor height is plotted as a function of range from the touchdown zone (TDZ) with the lines representing the top and bottom of the corridors. When a pilot is within the region, i.e. corridor, which is between these lines, then one of the DLCL signals is visible to the pilot on final approach. The angle of the DLCL corridor bottom edge with respect to horizontal is given in degrees outside of the right hand axis; the tics on this axis correspond to the left hand axis, not the angular coverage. The angle of the DLCL corridor top edge with respect to horizontal is given in degrees at the top, center of near the top axis; the tics on this axis correspond to the bottom axis, not the angular coverage. The location of the DLCL with respect to the TDZ is given in the top left hand side of the figure; in this case it is at the same elevation as the touchdown zone and 300 ft from the TDZ towards the approach end. The nominal glideslope angle for the landing field is shown in the lower left hand corner. A typical approach path which uses the nominal glideslope angle is shown schematically with a dashed line.

The ascensional coverage of the Diode Laser Glideslope Indicator (DLGI) component of the Covert Laser Landing System (CLLS) is shown schematically as viewed from the side in Figure 7. In this figure the corridor height is plotted as a function of range from the touchdown zone (TDZ) with the lines representing the transitions between the corridors. When a pilot is within the region, i.e. corridor, which is indicated as "on" the on-glideslope signal is visible to the pilot on final approach. When a pilot is within the region, i.e. corridor, which is indicated as "high" the above glideslope signal from the DLGI is visible to the pilot. When a pilot is within the region, i.e. corridor, which is indicated as "low" the below glideslope signal is visible to the pilot. The angular coverage of the DLGI in ascension is given in degrees outside of the border in the upper right hand corner; the tics correspond to the left hand and bottom axes, not the angular coverage. The location of the DLGI with respect to the TDZ is given in the top left hand side of the figure; in this case it is at the same elevation as the touchdown zone, at the same axial location as the touchdown zone, and 80 ft from the centerline of the landing field towards the port side. The nominal glideslope angle for the landing field is shown in the lower left hand corner. A typical approach path which uses the nominal glideslope angle is shown schematically with a dashed line.

The azimuthal coverage of the Diode Laser Glideslope Indicator (DLGI) component of the CLLS is shown schematically as viewed from above in Figure 8. In this figure the corridor width is plotted as a function of range from the touchdown zone (TDZ) with the lines representing the corridor edges. When a pilot is within the region, i.e. corridor, which is between these lines, then one of the DLGI signals is visible to the pilot on final approach. The angle of the DLGI corridor edge with respect to the centerline of the landing field is given in degrees outside of the right hand axis; the tics on this axis correspond to the left hand axis, not the angular coverage. The location of the DLGI with respect to the TDZ is given in the lower left hand side of the figure; in this case it is at the same axial location as the touchdown zone and 80 ft from the centerline of the landing field towards the port side.

CLLS FLIGHT TESTS

The covert laser landing system is designed to provide a very low probability of intercept (LPI) method for remote or temporary airfield lighting. The system is composed of three major components all of which were used during this test period. Those components are: Diode Laser Centerline, Localizer (DLCL), Diode Laser Glideslope Indicator (DLGI), and Diode Laser Edgelight (DLE). The DLCL is design to provide long range precision visual line-up information, the DLGI is designed to provide visual glideslope guidance from prior to tip-over to about 1/4 nmi, and the DLEs provide airfield boundary lighting for the final phases of flare, and landing rollout. The system is designed to work in conjunction with GPS. GPS is used to navigate the aircraft into the approach corridor. Once inside the approach corridor the pilot uses the laser lighting system to navigate to a landing on the airfield.

The CLLS was placed on the abandoned and otherwise unlit runway 34 at our test site in Ephrata, Washington. The CLLS consisted of 14 DLEs, a DLCL, and a DLGI. The DLCL was 275 ft. from the threshold of the landing piste. The DLGI was at the right hand approach end corner of the piste and placed approximately 40 ft from the edgelight line. The DLEs were placed at 400 ft intervals, and the first DLEs were placed 400 ft uprange from the approach end threshold, i.e. 400 ft uprange from the position of the DLGI. The edgelights were arranged to form a landing field 2800 ft in length. One additional DLE was placed near the DLCL, but facing backwards to provide a reference point for back taxing before take off.

The aircraft were C-172 and C-182 single engine light aircraft. Special onboard equipment was a Magellan 5000A hand held GPS receiver with a PC type laptop computer (DX2/50) running Mentor LapMap software. The Magellan 5000A was programmed to accept GPS Initial Points (IP) and GPS Centerline Points (CP). The final bearing to this landing strip was determined using GPS to be 160 degrees magnetic with a reciprocal bearing of 340. The IP and CP points were entered into the GPS unit by transcribing the TDZ GPS coordinates into the unit and using the waypoint projection function to establish the new point. The IP was set by projecting the TDZ coordinate out 10 nmi on a bearing of 350 degrees, this gave a 10 degree lead in to the extended centerline. The CL point was established by projecting the TDZ out 7.5 nmi on a bearing of 340 degrees. The antenna for the GPS system was attached to the windscreen in the area of the forward glareshield. Two different pilots flew these aircraft, each was familiar with the aircraft (approximate total flight times were 3800 and 1800 hours).

A truly remote site primary reference must depend on reference to instruments due to darkness and lack of visually navigational reference. Therefore it is essential that full instrument techniques be adequate for entry into the CLLS visual reference system. Two techniques were tested and each was satisfactory. The first technique requires two pilots. The primary pilot fly to the base leg on instruments with reference to the onboard GPS. Ten to fifteen degrees off of the final bearing the second pilot begins to watch for the DLCL signal. Upon seeing the flashing DLCL signal the second pilot informs the first pilot who begins an instrument rate turn to the final bearing. Once established on the final bearing the first pilot looks out and acquires the lasers. At the response "I'm on the lasers" the first pilot takes over visually while the second pilot keeps track of altitude and range. At the response "I'm on the glideslope" the first pilot continues to fly visually while the second pilot keeps track of airspeed. This allows a relatively low workload approach. For single pilot operation, the pilot proceeds along the base leg until the present position differs from the final bearing by 10 degrees. The first pilot then turns to 45 degrees to the final bearing. When the present position is within 5 degrees of the final bearing (as indicated by GPS) the pilot begins to include the outside world into the scan. When the DLCL signal is noticed the pilot turns to the final bearing. Once on the final bearing the pilot must maintain a semi-normal instrument scan, including the DLCL until the glideslope is intercepted. The pilot may then proceed visually, with airspeed held in the scan. The single pilot technique is acceptable with the two pilot technique being preferred.

Approaches were flown with typical turn-ins of 6 to 4 miles on nights when the weather was clear and the visibility was unrestricted. A down wind leg was typically flown at a heading of 170 degrees magnetic until the aircraft was approximately 7 miles from the TDZ. In addition, approaches were flown directly to the IP from an arbitrary heading The aircraft was then turned to a base leg heading of 070 degrees until the DLCL could be seen. From that point the DLCL and DLGI were used to navigate to the TDZ. Most approaches were to full stop. A total of 25 recorded approaches were made in this test program.

The edgelights were not turned on until the aircraft was within 0.5 miles of the TDZ. If the DLEs are left on continuously, they were faintly visible at range (5-7 miles) while in their area of coverage and gave the appearance of a light red haze in the landing area. Due to the geometry of their coverage, they become clearly visible at about 1.5 miles. The brightness and definition of the landing area was good. The fact that they were left on produced no real interference with the DLCL and DLGI.

CONCLUSIONS

(1) CLLS is an effective visual system for recovery onto remote of temporary landing strips.
(2) The DLCL has an effective range in excess of 10 nmi and was useful at 13 nmi, the longest range tested.
(3) The DLCL and DLGI can be used together effectively even though they use essentially the same signals for guidance.
(4) DLEs provide effective visual cues for late stage line-up and useful flare and rollout guidance. They may be turned on very late in the approach without affecting the recovery. Leaving the DLEs on during the entire approach did not reduce the visibility or performance of the DLCL and DLGI.
(5) A GPS receiver can be used for guidance into the CLLS approach corridor. There is no need for differentially corrected GPS.
(6) The monochromatic nature of the CLLS system tested makes it probable that it will be NVG compatible.

In conclusion, this laser based airfield lighting system provides full airfield lighting in a man portable system with an unprecedented degree of covertness.

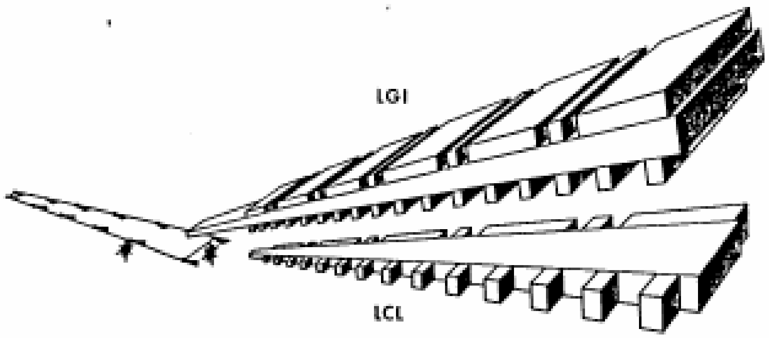

Figure 1 Corridors of the Covert Laser Landing System, which consists of a Laser Centerline Localizer (LCL) for line-up guidance, a Laser Glideslope Indicator (LGI) for glideslope guidance, and Diode Laser Edgelights (DLE) for flare and rollout cues.

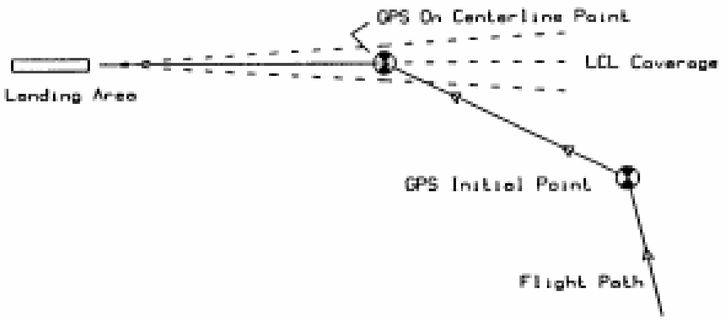

Figure 2 Typical flight path using navigation data from GPS to provide initial entry into the coverage of the CLLS and the lasers for final guidance.

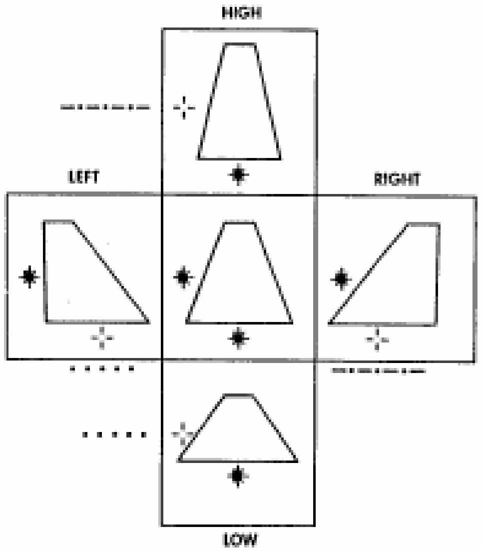

Figure 3 Views and corresponding signals that a pilot would receive on final approach to the CLLS.

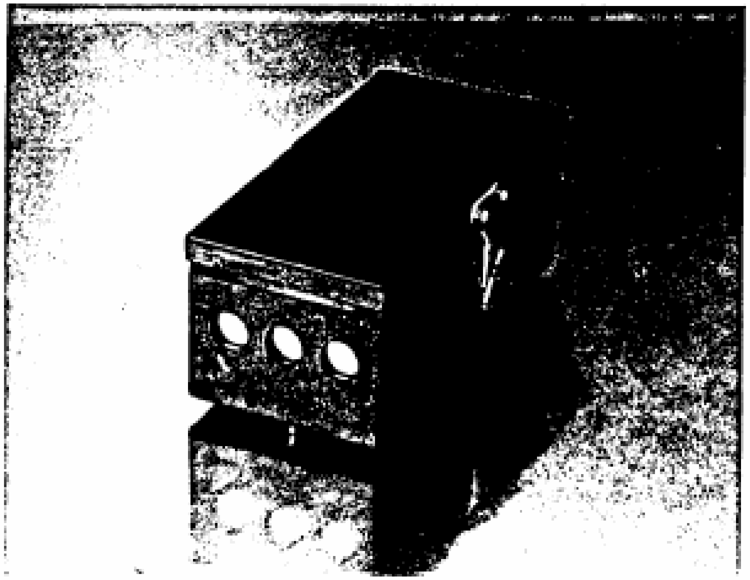

Figure 4 The Diode Laser Centerline Localizer (DLCL) is 3 by 4 by 8 inches and weighs 1.84 kg.

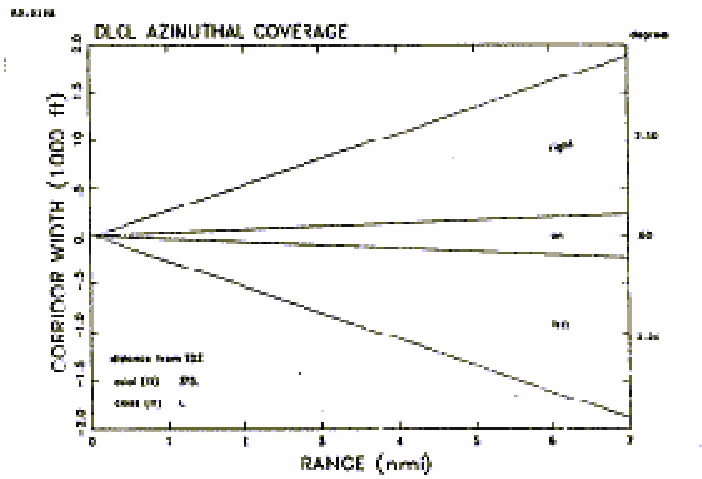

Figure 5 Azimuthal coverage of the Diode Laser Centerline Localizer.

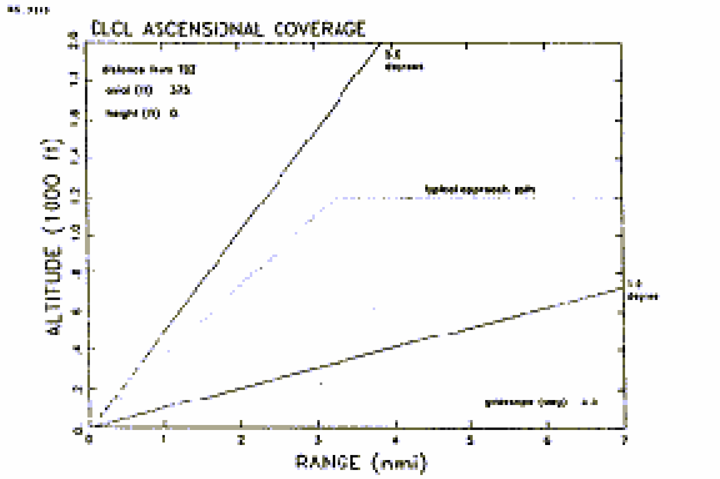

Figure 6 Coverage of the Diode Laser Centerline Localizer in ascension.

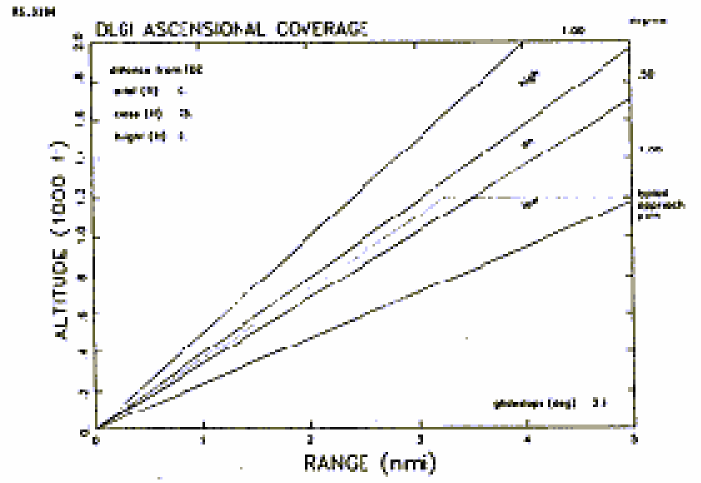

Figure 7 Coverage of the Diode Laser Glideslope Indicator in ascension.

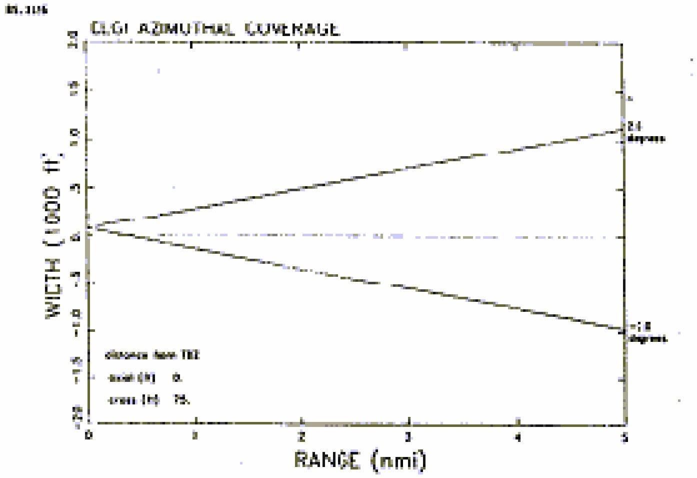

Figure 8 Azimuthal coverage of the Diode Laser Glideslope Indicator.