# POLITECNICO DI MILANO

**School Of Industrial and Information Engineering**

**POLO REGIONALE DI LECCO**

## Master's Thesis

Design and testing of heliport approach light in compliance with civil aviation rules

**Supervisor:** Prof. Emanuele Zappa

Master Thesis by:

Rubina Mahtab

Mat. No. 797014

**April 2015**

# DECLARATION

I hereby declare that this thesis, submitted to Politecnico di Milano as partial fulfilment of the requirements for the degree of Master is completely novel and has never been presented at any other University for an equivalent degree. I also certify that the document below has been exclusively done by me, with the exception of certain standardized data and technique, the source for which are appropriately cited in the references. This thesis may be made available within the university library and may be photocopied or loaned to other libraries for the purpose of consultation.

April 2015 Rubina Mahtab

# ABSTRACT

Incandescent lamps have dominated the lighting market for well over 150 years. However, recent times have seen a steady decline in their sale owing to the popularity of more compact and efficient LEDs. The high demand for LEDs can be owed to the fact that, they consume only 10% of the power required for incandescent bulbs and produce approximately no heat (1W) when compared to 25W produced by their counterpart. The initial cost of the LED is higher than incandescent but in the long run the savings can be recouped, as the need for maintenance is remarkably reduced owing to its long life of 60000hrs. Also they are highly directional, so are better suited in the situations where the area needs to be highlighted for increased visibility.

On the account of the advantages mentioned above, the airfield lighting also has been shifting focus from incandescent and halogens to LED power source. Companies have been producing non-LED luminaires for quite a long time now. Therefore, switching to LED source required remapping of the old luminaire pattern, based on the altered aviation standards better suited to the LED version.

The following study is exclusively centred on heliport approach light used to indicate the preferred approach direction through a densely populated area with low visibility of approach route. Since LED lights are more directional, they serve the purpose of highlighting the approach better than incandescent lights.

The design of the luminaire was executed using Autodesk® Inventor® and the calculations were done on Microsoft® Excel. The design process included benchmarking of the old incandescent light structure and the boundaries set by the aviation standards. The fundamental factors that influenced the structure design were the orientation of LED-lens assembly for required luminous intensity, topography of the area where the luminaire is to be installed, environmental factors, material properties and ease of availability and above all, customer requirements.

The biggest challenge was to come up with a product which was cost effective and at the same time maintain a superior quality, to be able to compete with similar products from other manufacturers.

The design was kept simplistic to ease the process of assembly and maintenance, besides lowering the manufacturing cost. To save weight and avoid corrosion, major components which were continuously exposed to sunlight and rain, were cast from aluminium. The cover encasing the optics was decided to be made by thermoforming polycarbonate sheets for the same reason.

The design of the structure has been finalised and sent for sample production. The test to affirm compliance with the standards will be run once the assembly is completed. Modifications will be made as per requirement if certain regulations are not met.

## ACKNOWLEDGEMENT

My sincerest gratitude to Professor Emanuele Zappa for the guidance he has provided throughout the project. His valuable suggestions and constructive criticism motivated me to perform better than my capabilities. I consider myself fortunate to have him as my tutor for the research as this would not have been possible without his support and guidance.

I would also like to convey my gratitude to the company supervisor Mr. Michele Romagnoli, whose extensive support and expert comments helped me to nurture my talents, and his faith in me to exclusively handle a huge assignment like this. The time and patience he devoted in tutoring me regarding the project or even in the day to day working of the company is deeply appreciated.

A special thanks to my colleagues Mr. Enrico Buzzoni, Dario Roncati, Emidio Rauli, Cesare Angeloni, Sandro Lazzari, Sergio Ferri, Cristiano Morri and Laura Scolaro for always backing me up and making me comfortable in the new workplace during my research.

I would like to thank my parents, my sister Samrina Mahtab, and my dear friend Mr. Sandip Kumar, for their kind support throughout my work and study.

And not to forget, a special mention of my extraordinary friends, Shehzad, Arijit, Dhiss, Pradeep, Bismita, Shaista, Shiba Gawar, Aye Raju, Ramu, Maddy, Geo, Vikas, Lance, Bhuvana, Libyan, Bavaria, Muhundan, Shyama, Salman, Leonardo, Liang and Sabira who never failed to boost my morale and encourage me to overcome even the most difficult situations.

Thank you all.

# LIST OF FIGURES

# LIST OF TABLES

# LIST OF GRAPHS

# TABLE OF CONTENT

# 1. INTRODUCTION

OCEM Energy Technology was established in 1943 with the objective of supplying power to laboratories and industries, with expansion to airfield in due course.

For over a duration of fifty years OCEM Airfield Technology has launched high quality products while keeping up with varying market trend. Initially the products comprised of halogen, incandescent and fluorescent light source, but now the company is moving its focus towards the more efficient LED lights.

The following research is based on the need to bring forth a challenging and innovative design to enhance the performance of the LED light structures and make them more durable. LED lights not only save power but are also long lasting when compared to other sources of light. They require low maintenance and are less susceptible to changing environmental conditions.

The second chapter discusses the regulation and standards set aside by civil aviation organisations like International Electrotechnical Commission (IEC), International Civil Aviation Organisation (ICAO) and NATO Standardisation Agency- Standardisation Agreement (STANAG). They describe in detail the rules to be followed during daily functioning of the aerodromes. These bodies also define the kind of light structure to be used, quality standards, design requirements and validation tests for the luminaires.

The optics feasibility study has been stressed upon in chapter three with the aim of finding the right mix of LED and lens assembly to optimise the power output and brightness. An iterative study was conducted on varied LED and lens combination, mounted in different orientation and numbers.

Chapter four is the most significant part as far as innovativeness of design is concerned. The idea was to come up with a unique design which is cost effective and easily manufactured at the same time. In order to launch a competitive product the final cost, time to assemble and weight of the structure needed to be toned down. A comprehensive study was performed before the design was finalised and was sent to production. The details of the design have been discussed at length in the chapter.

The last and final chapter comprises of the tests to be conducted to validate the design as defined by the regulating bodies. The tests have not been performed yet so the chapter basically consists of test results from similar light structures used on airports.

And finally the conclusion to the whole design and testing process has been outlined. It also contains justification for each trade-off and a summary of design optimisation.

# 2. CIVIL AVIATION RULES FOR LUMINAIRES

## 2.1 Introduction

In order to ensure safe landing and take-off of the airplanes and helicopters, several governing bodies have laid down a set of rules and technical specifications for their operation in the airfield. For my research the major civil aviation bodies, that specify in detail the functioning, layout and mounting of the luminaire are, NATO Standardization agency (NSA), International Civil Aviation Organisation (ICAO) and International Electrotechnical Commission (IEC). Below have been mentioned the regulations stipulated by these organizations:

## 2.2 NATO Standardization Agency (NSA) Standardization Agreement (STANAG)-3619 AMLI (Edition 4) Helipad marking and lighting

The NATO Standardisation Agency (NSA) was established in 2001 to undertake standardisation operations of North Atlantic Treaty Organisation (NATO). One of the responsibilities of NSA is to administrate and declare the Standardization Agreement (STANAG) for the process, procedures, and conditions to be implemented in both civil and military operations. This agreement STANAG-3619 deals with the standardization of helipad lighting and marking in the areas where Visual Meteorological Conditions (VMC) apply. VMC is a category in aviation flight that allows the use of Visual Flight Rules i.e., the pilots have sufficient visibility without the aid of any instrument to fly the aircraft and approach the helipad while maintaining visual separation from another aircraft or the surrounding. Currently we will deal only with the approach lights used for guiding the helicopters through populated terrains with low visibility of the landing area.

### 2.2.1 Configuration

- Approach direction lights are not to be used without landing direction lights- Landing direction lights are installed when there is need to indicate a landing direction in the procedure of touchdown or hover at the helipad.

- Approach lights should be aviation white and located in two parallel rows extending out from the landing direction lights, one row on each side of the helipad centre line extended. These lights should be installed where there is a need for approach guidance to restrict the path of approach to the helipad, or when the pilot needs additional guidance during approach.

- The two rows of elevated light fittings should be 1.5m from the helipad centre line extended. Each row is to be spaced on 15m centres over a length of 60m with the first row located 37.5m from the centre line of the row of perimeter light fittings.

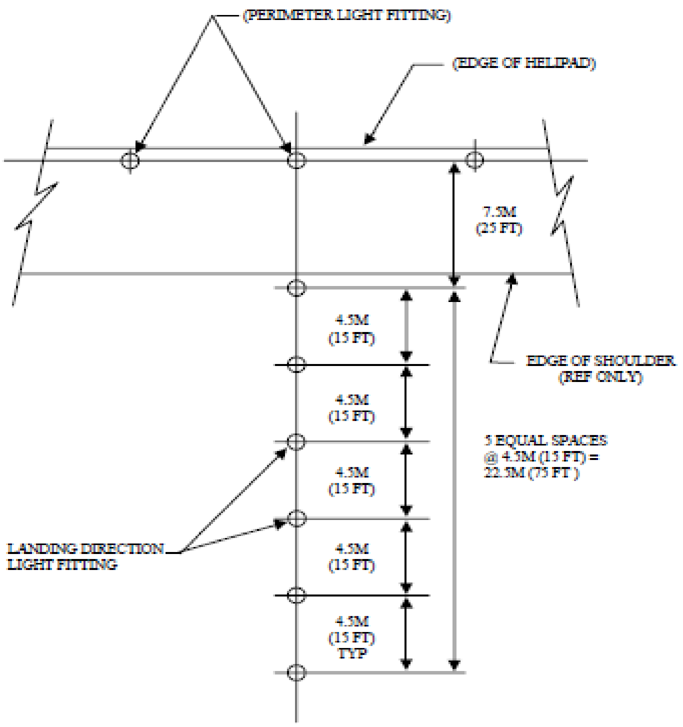



Figure 1 Landing direction light arrangement

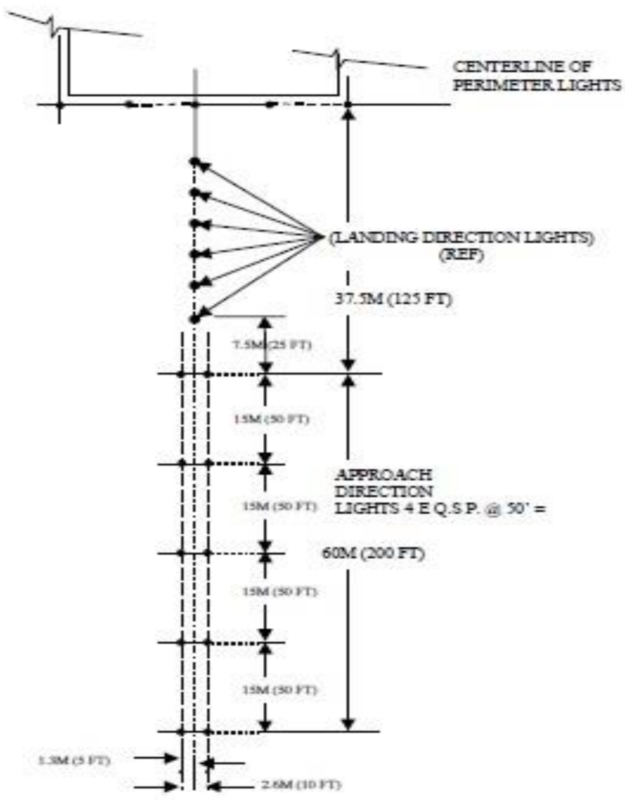



Figure 2 Approach direction lights arrangement

### 2.2.2 Construction of approach direction light fittings

- Elevated light fittings are acceptable throughout the approach system.

- Elevated light fittings are to be as light and frangible as possible.

- The light fitting should be mounted in a horizontal plane or follow the slope of the finish grade. Wherever a deviation in the axis of light beam is necessary, a tolerance of plus two percent or minus one percent in the longitudinal slope is permitted.

- If a slope is established for the landing direction lights, the same should be continued for the approach direction lights.

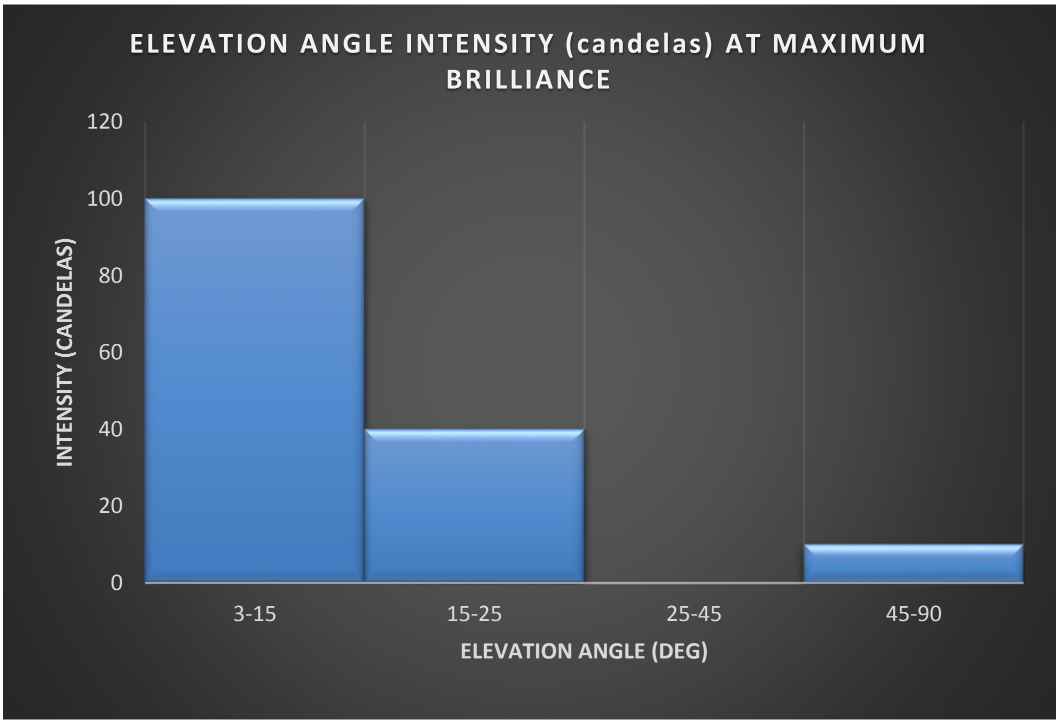
### 2.2.3 Luminous Features

- Approach light fittings are to be omni-directional.

- The vertical divergence and minimum intensity at maximum stage of brightness should preferably be as per graph 1.

- There is to be minimum three progressive stages of brilliancy from and including the stage required for night flying for good visibility up to full brilliancy. The lowest stage of brilliancy shall give an intensity in the normal useful portion of the beam in the order of 1.0 candelas.

- The elevation of beam peak should occur at approximately 9 degrees.




Graph 1 Elevation angle intensity

The table below represents the general values for percentage of intensity at different stages of current as per Federal Aviation Administration (FAA) EB 67D

| | **MAXIMUM STEPS** | **1** | **2** | **3** | **4** | **5** |
|---|---|---|---|---|---|---|
| **CURRENT (A)** | | 2.8 | 3.4 | 4.1 | 5.2 | 6.6 |
| **INTENSITY (%)** | | 0.15-0.7 | 1-2 | 3.9-7.3 | 16.9-31.3 | 100 |

Table 1 Brilliance stage at varying current values

## 2.3 International Electrotechnical Commission (IEC) Technical specification (TS)-61827 (EDITION 2004-05) Characteristics of inset and elevated luminaires used on aerodromes and heliports

International Electrotechnical Commission is a global organization incorporating standards for all the functions concerning electrical and electronics domain. The Technical specification 61827 deals with the requirements of system components and elevated and inset luminaires deployed in Aeronautical Ground Lighting (AGL). The kind of lighting used depends on aerodrome layout and operation, traffic density, and certain other environmental factors that may affect the visibility owing to the weather or topography of the aerodrome.

### 2.3.1 Terms defined

- Luminaire: Apparatus which distributes, filters and transforms the light transmitted from one or more lamps and includes all parts necessary for supporting, aiming fixing and protecting the lamps (but not the lamps themselves), and circuit auxiliaries with the means of connecting them.

- Elevated Luminaire: Luminaire more than 40mm above the ground and designed to break, distort or yield on impact so as to present minimum hazard to the aircraft.

- Base: Fastened into the pavement possessing structural strength equal to the surrounding pavement and able to transfer heat from the luminaire and the load imposed by the standing or moving aircraft.

- Standard useful lamp life: The operating time of a lamp, installed in the luminaire and powered at rated current or voltage, beginning at a given instant of time and ending when the photometric intensity becomes unacceptable.

- Constant Current Regulator: An apparatus that provides a current output at a constant RMS value independent of variations in the constant current series circuit load, input voltage and service conditions. The International Standard specifies the requirements for a CCR having a nominal output of 6.6A for use in aeronautical ground lighting (AGL) constant current series circuit.

## 2.3.2 General requirements

- Dimensional requirement: The overall height of an elevated luminaire intended for use at the heliports should not exceed 250mm above the pavement. The height could be increased with the approval of the competent aerodrome authority

- Interface requirement: The luminaire should be equipped with a 2” 11 TPI GAS (60mm O.D.) or a 2” 11 TPI BSP (60mm O.D.) or a 2” 11.5 TPI NPT (60mm O.D.) interface to fit with a straight loose fit thread

- Drainage requirement: The luminaire shall comply with the requirements of Section 9 IEC 60598-1, have a degree of protection IP24 (preferred IP47) and if necessary, be provided with a drain hole with a diameter of at least 5mm.

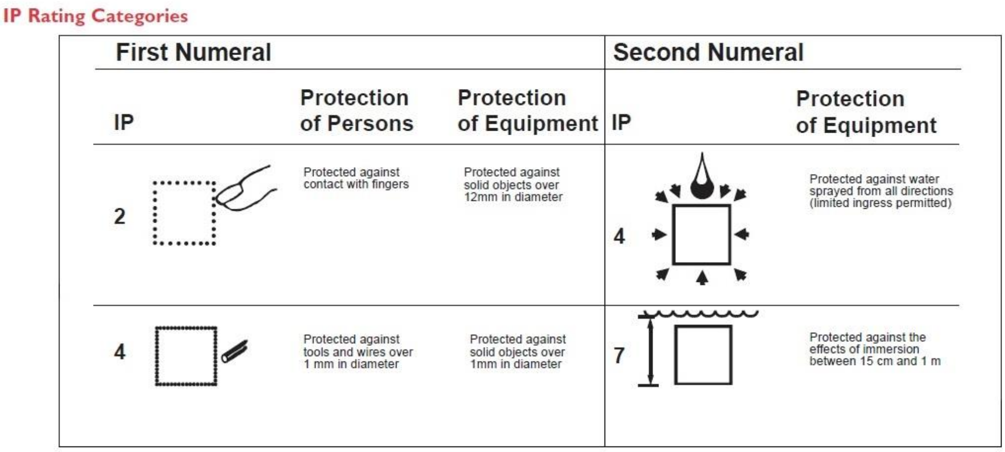



Figure 3 IEC Standard 60529- IP Code

- Photometric requirement: The luminaires shall meet the photometric performances as specified by ICAO Annex 14 for the colour of the emitted light and isocandela diagrams of the intensity which has been described in section 2.4.2.

- Lamp life requirement: The lamp life while installed and operated at rated current or voltage in the corresponding luminaire in the mounting configuration, which simulates the actual installed condition, shall not be less than 500hrs.

- General test requirement: The luminaire powered by a series circuit should be tested using constant current regulators (CCR) or an equivalent power source providing identical or better performances from the output current stabilisation point of view.

## 2.3.3 Environmental tests

The luminaire should be powered by a series circuit using a CCR or equivalent power source providing identical or better performances from the output current stabilisation point of view. All tests must be done at the ambient temperature of 20℃ ± 5℃ unless otherwise specified

#### 2.3.3.1 High temperature test:

The luminaire shall be installed in a normal configuration and operated throughout the test with the rated current. This test shall be run with the highest wattage lamp and lowest transmissivity filter to be qualified. The luminaire is energized for 24hrs continuously at the ambient temperature of 55℃ ± 2℃. Any deterioration shall be cause for rejection.

#### 2.3.3.2 Low temperature test:

The luminaire shall be subjected to a 24h period at -55℃ ± 2˚C and shall be operated 5 minutes at the beginning and 5 minutes after the end of the test period at the rated current or voltage. Any deterioration of materials shall be cause for rejection

#### 2.3.3.3 Thermal shock:

The luminaire shall be run with the light unit equipped with the most powerful lamp for each filter combination the fitting has been designed for and powered at the maximum current level at an ambient temperature until its temperature is stabilised. It shall be sprayed with water at a temperature of 15℃ ± 2℃ lower than the normal ambient temperature during which no cracking, damage or functional defect shall be observed. The droplet size shall be between 2mm and 4.5mm and produce a rainfall of 9m/s. The rain shall start slow and achieve 9m/s in 15s.

#### 2.3.3.4 Corrosion:

A salt fog test shall be conducted on assembled luminaire according to IEC 60068-2-11. If the luminaire is protected by a coating, a cross shall be cut through the coating, until the base metal is reached prior to running the test. Any evidence of functional damage caused by rust, pitting or corrosion shall be cause for rejection.

**IEC 60068-2-11**

**Test chamber**

- The chamber for this test shall be constructed of such materials that will not influence the corrosive effects of the salt mist
- No direct spray should impinge upon the specimen during the test
- Accumulated drops on the chamber walls shall not drip on the specimen
- The chamber shall be vented to prevent pressure build up and allow uniform distribution of salt fog.
- Atomizer used shall produce finely divided, wet, dense mist and the atomizer material should be non-reactive to salt solution

**Salt mist**

- The salt used for the test should be high quality Sodium Chloride (NaCl) containing not more than 0.1% Sodium Iodide and 0.3% of total impurities, when dry.
- pH value =6.5-7.2 @ 35˚± 2℃
- The salt solution concentration shall be 5 ± 1% by weight

**Air supply**

- The compressed air entering should have a relative humidity of at least 85% to prevent the atomizer from clogging.

- The humidification of air is done by passing it through a tower containing water at 35℃
- the air shall be free from impurities such as oil and dust

### 2.3.3.5 Moisture:

The elevated luminaire, with drain hole plugged, shall be tested as specifies in Section 9 of IEC 60598-1 to determine the degree of protection of the luminaires. Elevated luminaires shall at least have a degree of protection IP24.

**IEC 60598-1**

**General requirement**

- Before the test for the second characteristic numeral, the luminaire complete with lamps shall be turned on and brought to stable operating temperature at rated temperature
- The water temperature for the test shall be 15℃ ± 10℃.
- The luminaire shall be wired and mounted in the most unfavourable position
- Fixing screws of covers, other than hand-operated fixing screws of glass covers, shall be tightened with a torque as specified.
- After the completion of test there shall be no deposit of talcum powder in dust-proof luminaires
- There should be no trace of water on current carrying parts.
- For luminaires without drain holes, there should be no water entry

**Test procedure**

- Solid-object proof luminaires (1st numeral 4) shall be tested at every point, with a probe and the applied force should be as indicated by table2 below.
- The luminaire, whilst still operating is placed with the minimum disturbance in the dust chamber.
- The chamber door is closed and the blower is turned on
- After 1 minute the luminaire is turned off and allowed to cool for 3hrs whilst the talcum powder remains in suspension
- Water tight luminaires (2nd numeral 7) are switched off and immersed for 30 minutes in water, so that there is at least 150mm of water above the top of the luminaire and the lowest portion is subjected to at least 1m head of water

| | Test probe according IEC 61032 | Probe wire diameter | Application force N |
|---|---|---|---|
| First IP numeral 3 | C | $2,5\ ^{+0,05}_{-0,00}$ mm | 3 ± 10 % |
| First IP numeral 4 | D | $1\ ^{+0,05}_{-0,00}$ mm | 1 ± 10 % |

Table 2 Solid- object proof luminaire test

### 2.3.4 Structural tests

The structural tests are performed to check for the mechanical strength of the luminaire and its ability to withstand jet blast and wind loading. The test also verifies the frangibility of the structure to impact from a moving aircraft.

#### 2.3.4.1 Jet blast:

Elevated luminaire shall withstand a force corresponding to jet blast of 480kmph. The test shall be performed with the elevated luminaire fully assembled at nominal height and mounted to a rigidly secured support structure with the load applied perpendicular to the mounting surface at a point just below the lens, no faster than 220N/min until the minimum bending moment of 408Nm is achieved

#### 2.3.4.2 Frangibility:

Luminaire should be frangible as specified by ICAO Annex 14. Frangibility test is continued from jet blast test. After the luminaire sustains the jet blast test, the loading shall continue at the same rate until fracture occurs. The test shall be repeated on a total of five luminaires. Fracture shall be reached before a bending moment of 678 Nm is achieved. The yield point shall be no more than 37mm above the ground and shall give way before any other part of the fixture is damaged.

### 2.3.5 Functional tests

Functional tests are a way of examining the luminous intensity of the light as well their compliance with chromaticity requirement.

#### 2.3.5.1 Photometry:

Type tests are performed to ascertain that one or more luminaires, made to certain design, meet applicable specification. The tests performed should be in accordance with ICAO annex 14 specified in section 2.4.2. Each luminaire should be tested with each type of filter, lamp and optical system to be used in the luminaire

The horizontal photometric axis runs through the centre of the luminaire and is parallel to the runway centreline. The vertical axis runs through the centre and along the height of the luminaire. Before beam intensity testing, the luminaire unit shall be energized at the rated current and/or voltage until its properties have stabilised.

The photometric test distance shall be greater than 50 times the largest dimension of the luminaire optical aperture. In case of luminaire less than 5cd, a shorter test distance of less than 50 times may be applied to avoid the increase of error caused by low illumination measurement. The test shall be performed using three sets of different lamps supplied by the manufacturer installed in the same luminaire. For omni-directional luminaires, the vertical beam spread shall be measured at least every 30 degrees of the horizontal beam width.

#### 2.3.5.2 Chromaticity:

The luminaire fitting is operated at rated current and/or voltage until its characteristics have stabilised and then the chromaticity is measured, with a filter if designated to be equipped, and shall be confirmed to satisfy the specifications in ICAO Annex 14 specified in section 2.4.2.

### 2.3.6 Endurance test

The following tests are performed to know the accelerated life and standard useful life of the lamps. The test procedure has been mentioned below

#### 2.3.6.1 Accelerated life test:

The luminaire operated in ambient temperature of 55° ± 2℃, shall be continuously illuminated at rated current and/or voltage for 250 hrs and then subjected to a beam intensity and chromaticity test. Upon completion of testing, the luminaire unit should have a luminous intensity of at least 80% of the minimum average value and should be free of physical defects

#### 2.3.6.2 Standard useful life test:

The test shall consist of minimum 10 luminaires with the corresponding lamps installed. The light system shall be operated at lamp rated voltage and/or current using an A.C. power supply having 1% regulation. The duty cycle shall consist of 20 hrs of lamp operating time and 4 hrs de-energised. Testing shall continue until 90% of all original lamps have reached the end of lamp useful life or 5000 hrs, whichever comes first. End of useful life may be determined by use of spot meter or photocell. A daily log shall be maintained at the test site.

## 2.4 International Civil Aviation Organisation (ICAO) Annex 14 Volume II- Heliports

ICAO is a United Nations agency responsible for the codification of the techniques and principles of international air transportation to ensure safe navigation.

### 2.4.1 Terms defined

- D-value: The largest overall dimension of the helicopter when rotors are turning measured from the most forward position of the main rotor tip path plane to the most rearward position of the tail rotor tip path plane or helicopter structure

- Final approach and take-off area (FATO): A defined area over which the final phase of the approach manoeuver to hover or landing is completed and from which the take-off manoeuver is commenced. Where FATO is to be used, any helicopters, the defined area includes the rejected take-off area available

- Take-off distance available (TODAH): The length of the FATO plus the length of the helicopter clearway declared available and suitable for helicopters to complete the take-off

- Rejected take off distance available (RTODAH): The length of the FATO available and declared suitable for helicopters to complete a rejected take-off.

- Landing distance available (LDAH): The length of the FATO plus any additional area declared available and suitable for helicopters to complete the landing manoeuver from a defined height.

- Touchdown and lift-off area (TLOF): An area on which a helicopter may touchdown or lift-off.

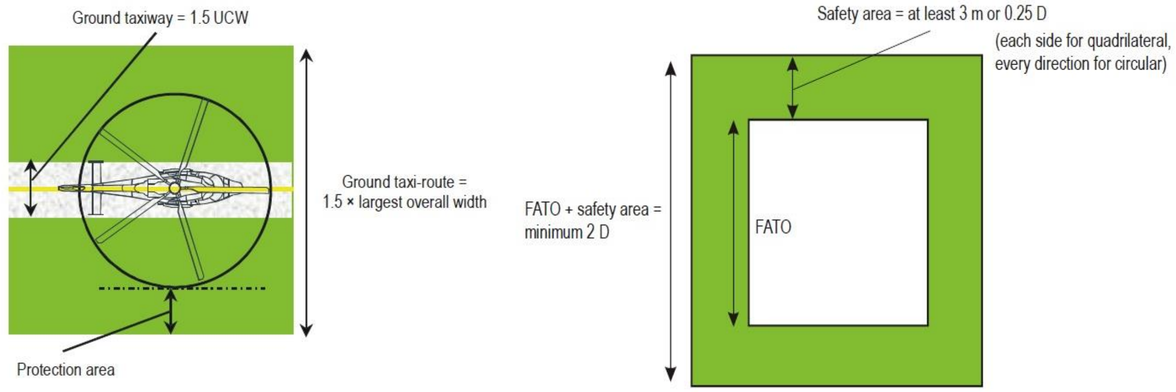



Figure 4 FATO and safety area

## 2.4.2 Location

- An approach lighting system shall be located in a straight line along the preferred direction of approach.

- It should consist of a row of three lights spaced uniformly at 30m intervals and of a crossbar 18m in length at a distance of 90m from the perimeter of the FATO as shown in the figure below

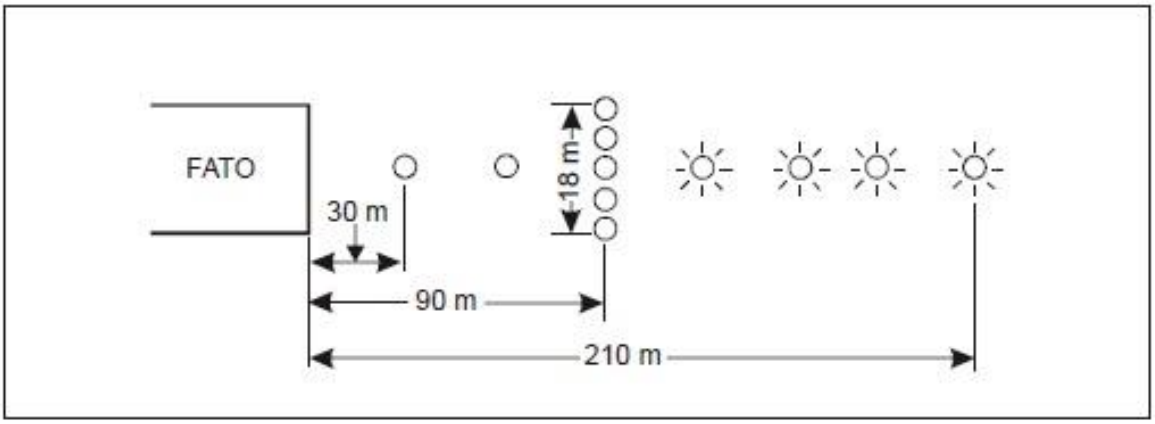



Figure 5 Approach lighting system location

- The lights forming the crossbar should be as nearly as practicable in a horizontal straight line at right angles to, and bisected by, the line of the centre line lights and spaced at 4.5m intervals.

- Both sequenced flashing lights and steady lights should be omni-directional white lights

- The following brilliancy control should be incorporated to allow for adjustment of light intensity to meet the prevailing conditions: steady lights-100%, 30%, 10%; flashing lights- 100%, 10%, 3%

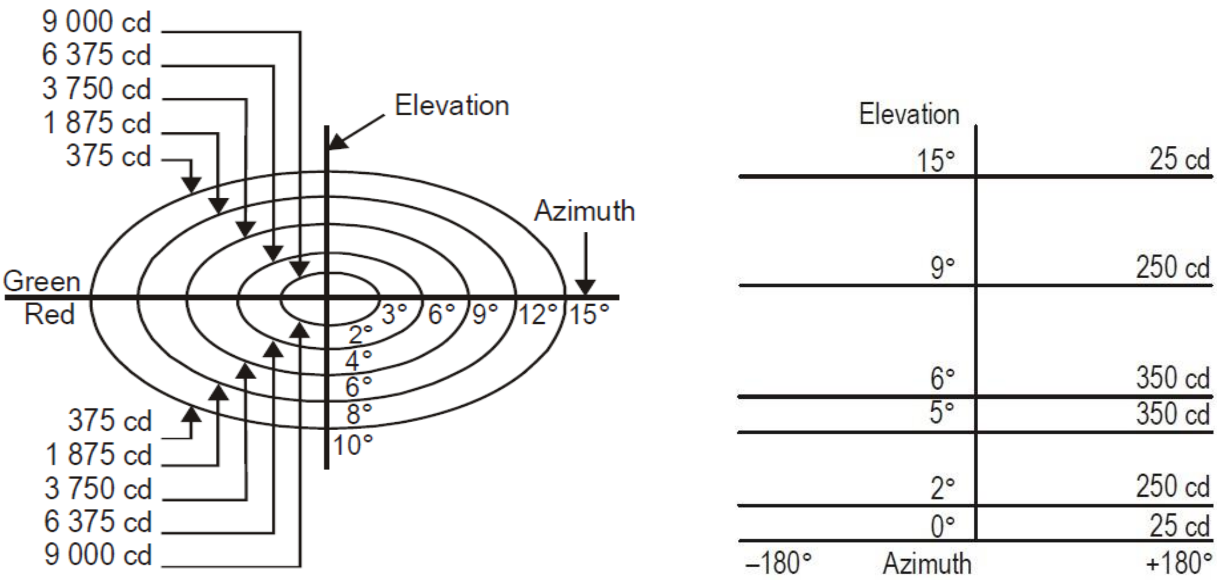



Figure 6 Iso-candela diagram

### 2.4.3 ICAO-9157 Frangibility

When subjected to envisaged environmental loads, the deflection of the structure should be such that the deflection of the light beam does not exceed ±2 degrees in the vertical axis and ±5 degrees in the horizontal axis.

#### 2.4.3.1 Frangibility requirement:

A frangible structure should be designed to withstand the static and operational wind or jet blast loads with a suitable factor of safety but should break, distort or yield rapidly when subjected to the sudden collision forces of a 3000kg aircraft borne and travelling at 140kmph or moving at the ground at 50kmph. Frangible structures should include concepts such as low-mass members, brittle or low toughness members and connections, and/or suitable break away mechanisms.

Types of frangible connections: It include neck-down or fuse bolts, special material or alloy bolts, countersunk rivets or tear through fasteners, and gusset plates with tear-out sections. Non-metallic materials can be specially designed to provide excellent frangibility characteristics. However their structural behaviour is difficult to analyse because of their uncertainty about their elastic modulus or material isotropy.

Electronic components and supports should also be designed to be frangible, while ensuring that their operational functions are not degraded. It is therefore recommended to place the electronics below the ground. The electrical conductors should be designed such that they do not rupture but break at predetermined points within the limits for frangibility of the structure. This is accomplished by the provision of connectors that require a low tensile force to separate then that required to rupture the conductor

#### 2.4.3.2 Design criterion for frangibility:

It should be ensured that elevated runway and taxiway lights are capable of withstanding jet blast velocities from aircraft at around 480kmph for all high and medium intensity lights and 240kmph for all other elevated fixtures.

Each elevated light fixture should have a yield point near the position where the light attaches to the base plate or mounting stake. The yield point should be no more than 38mm above the ground surface and should give away before any other part of the fixture is damaged. The yield point should withstand a bending moment of 204J without failure but should separate cleanly from the mounting system before 678J.

The design wind pressure can be calculated as below

$P= 0.0000475*V^2$

Where P- Pressure (kPa)

V- Wind speed (kmph)

Static tests are considered adequate for verification of frangibility of visual aids of low mass having an overall height equal to or less than 1.2m. All tests should be performed with the light unit fully assembled at nominal height and mounted to a rigidly secured base plate. The load should be applied just below the lens, no faster than 220N/min until the minimum bending moment is achieved. If the light unit sustains this load without damage, the loading should continue at the same rate until yielding at the yield point occurs

# 3. OPTICAL FEASIBILITY AND DESIGN

## 3.1 Introduction

Optics study is one of the major areas of concern in the luminaire design, as even the slightest variation in light intensity from the specified limit can lead to a major disaster as far as aerodrome safety is concerned. The two major terms that need to be defined are chromaticity and photometry. The details of which have been discussed below.

## 3.2 Terms defined

- Luminous flux: It is the measure of total power of light in the visible spectrum, as perceived by the human eye, also referred to as the luminous power. It is adjusted to factor in the sensitivity of human eye, which varies depending upon different wavelengths of which the light is composed of. The S.I. unit for luminous flux is lumen (lm)

- Luminous intensity: It is a measure of wavelength-weighed power per unit solid angle in a given direction from the light source. It is measured in candela (cd). Candela= $\frac{lumen\ (lm)}{steradian\ (sr)}$

- Luminance: When luminous intensity is described in terms of per unit area of the light travelling in a given direction, it is known as luminance. It describes the transmission and reflection of the amount of light from a particular area, and falls within a given solid angle. It is measured in $cd/m^2$

- Luminance factor: The ratio of the luminance of an illuminated body measured under specific conditions to that of a perfect diffuser under the similar conditions is known as luminance factor

- Spectral power distribution: Spectral power distribution in photometry describes the power per unit area per unit wavelength of an illumination

- Color rendering index: It is a comparative measure of the representation of colors of various objects as seen under the given light source and that of an ideal light source. A high CRI value corresponds to the closeness to ideal condition and is desirable in Color-critical applications. The value is measured between 1 and 100

- Luminosity function: Luminosity function or luminous intensity function describes the average spectral sensitivity of human visual perception of brightness. It is based on subjective judgements of which of a pair of different-coloured lights is brighter, to describe relative sensitivity to light of different wavelengths

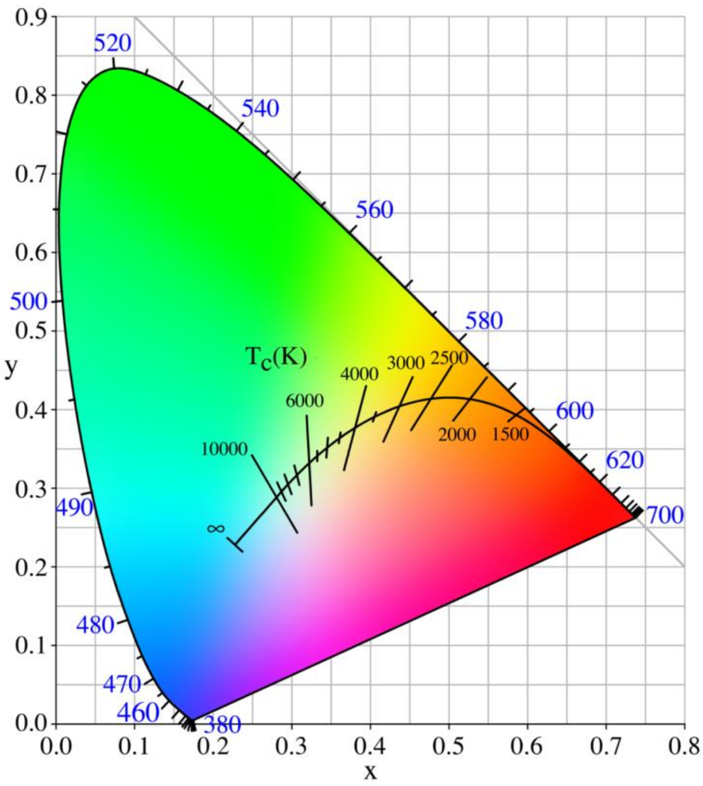
- Color temperature: For a given light source the color temperature signifies the temperature of a black body at which it radiates light of similar colour to that of the given source

- Efficiency: It is given by the ratio of the amount of light exiting the lens to the amount of light entering

## 3.3 Chromaticity

Chromaticity is a measure of color quality irrespective of the luminance. It is possible for two different colours to have same level of chromaticity but different luminance value. Hue and colourfulness are the two parameters generally used to describe chromaticity. The latter is alternatively called saturation, Chroma, intensity, or excitation purity.

In photometry, for an illuminant or a source of light, the white point is a neutral reference characterized by a chromaticity. Polar coordinates are used to define all other chromaticity in relation to this neutral reference. The hue is the angular component, and purity is the radial component, normalized by the maximum radius for that hue




Graph 2 CIE 1931 xy Chromaticity Space

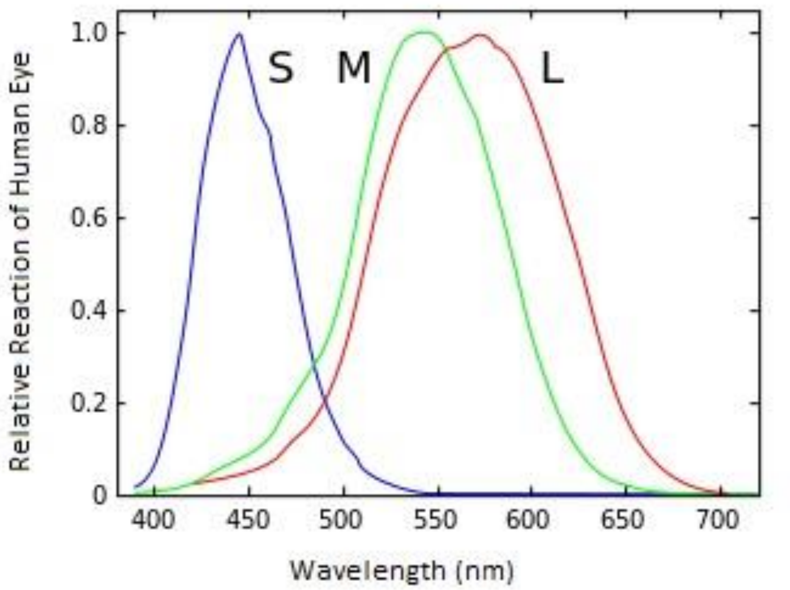
### 3.3.1 CIE Color space

'Color Space' was created by a body called CIE or the International Commission on Illumination, in 1931. The CIE 1931 Color Space articulates the physical pure colors in the visible spectrum of the electromagnetic wave with the colors as perceived by human physiology. They allow to translate different physical responses to visible radiation into a universal human color vision response.

### 3.3.2 Tristimulus values

There are three kinds of cells present in the human eye. These cells respond to light with spectral sensitivity peaks lying in short, middle and long wavelengths regions. The corresponding wavelength value for these three cells, varies from 420-440nm for short (S), 530-540nm for middle (M) and 560-580nm for long (L).

The tristimulus values are obtained by integrating the product of the power spectrum of the total light source with individual spectral sensitivities of the three cone cells over the visible spectrum range. These three parameters can be indicated using a 3-Dimension space, called color space.




Graph 3 Normalized spectral sensitivity of cone cells for short, medium, and long wavelengths

### 3.3.3 CIE standard observer

The cone cells in the human eye are not evenly distributed. This causes the dependence of the tristimulus value on the viewer's field of view. To overcome this difficulty the CIE defined a color mapping function known as the "standard observer". A standard observer is a reference for an average human's chromatic response within a 2 degree arc inside the fovea (part of the human eye where the cone cells reside). The standard observer is characterised by three color matching functions.

### 3.3.4 Color matching functions

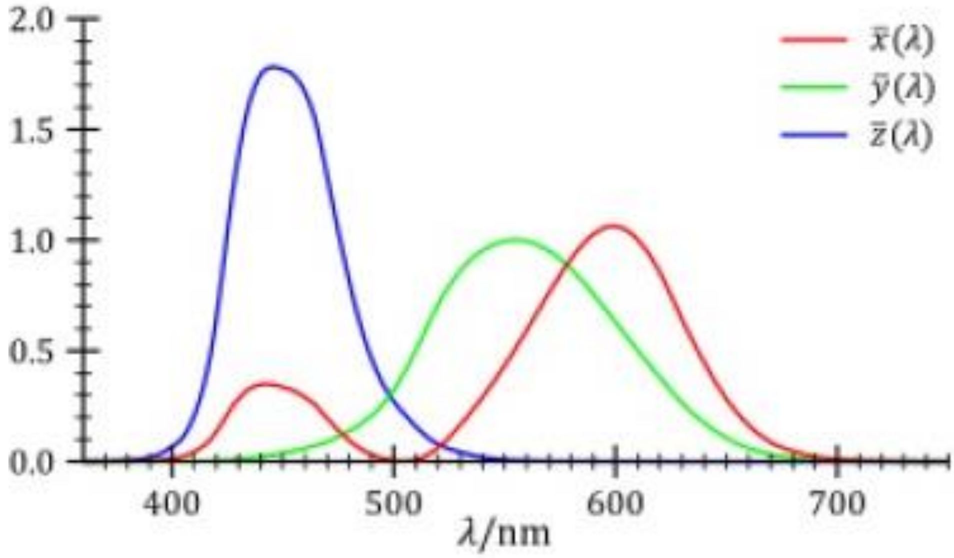
The chromatic response of an observer is outlined numerically in terms of color matching functions $\bar{x}(\lambda), \bar{y}(\lambda)$ and $\bar{z}(\lambda)$. They can be thought of as spectral sensitivity curves of three linear light detectors yielding the CIE tristimulus values X, Y, Z. The X, Y, Z tristimulus values are represented below in terms spectral power distribution $I(\lambda)$ of a color and the color matching functions:

$$X = \int_{380}^{780} I(\lambda)\bar{x}(\lambda)d\lambda$$

$$Y = \int_{380}^{780} I(\lambda)\bar{y}(\lambda)d\lambda$$

$$Z = \int_{380}^{780} I(\lambda)\bar{z}(\lambda)d\lambda$$

Where λ is the wavelength of the equivalent monochromatic light in nanometres




Graph 4 CIE Standard observer colour matching function

### 3.3.5 CIE xy chromaticity diagram and xyY color space

The notion of color cannot be explained on a diagram, as the plot of the three different sensors in human eye will result into a three-dimensional figure. For simplification two parameters were identified which could sufficiently define a colour- brightness and chromaticity. For example, the chromaticity of grey and white is same but the brightness of white is more than that of grey.

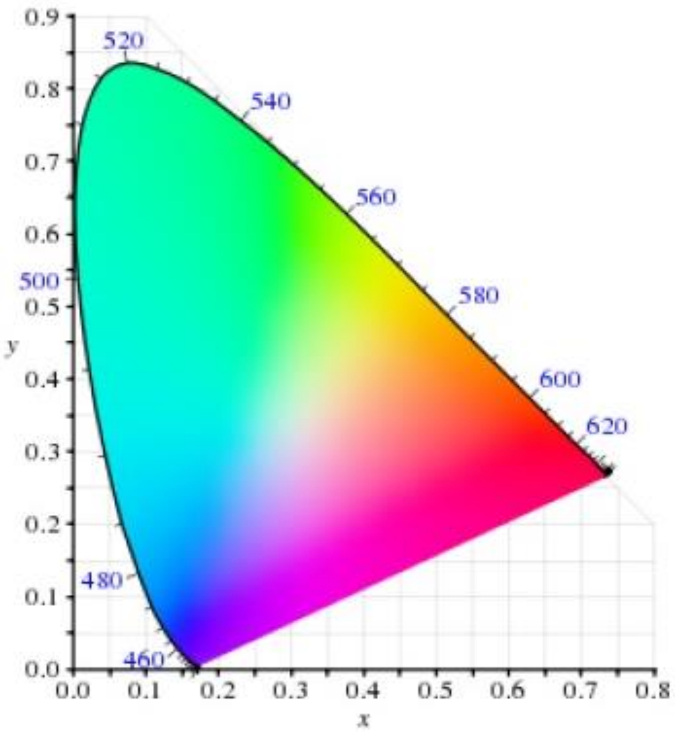
The brightness or luminance of a color is determined by the parameter 'Y'. Two more parameters, x and y, were derived from the tristimulus values and normalized to represent the chromaticity of a color.

$$x = \frac{X}{X+Y+Z}$$

$$y = \frac{Y}{X+Y+Z}$$

$$z = \frac{Z}{X+Y+Z} = 1 - x - y$$

The derived colour space specified by x, y and Y is known as the CIE xyY colour space.




Graph 5 CIE xyY Colour Space

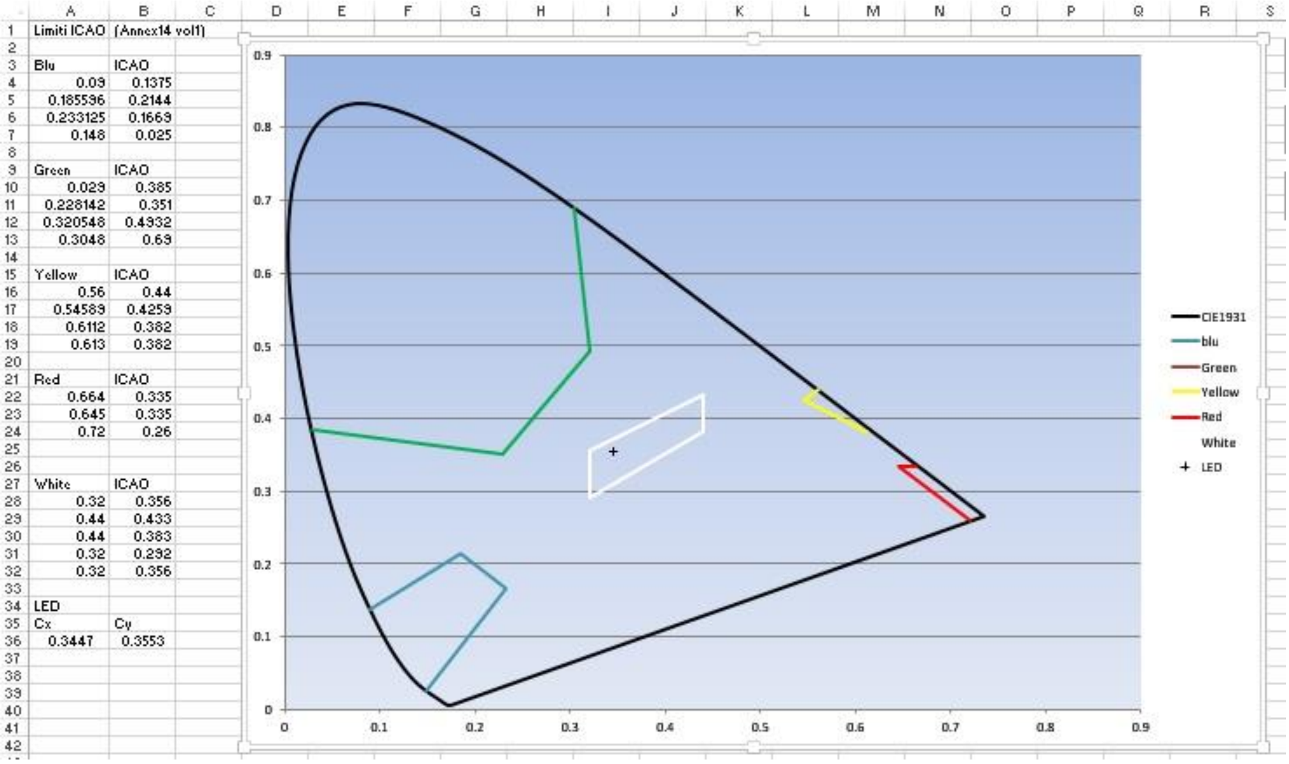
The curved outer boundary corresponds to monochromatic light and is known as the spectral locus, specifying the wavelength in the visible spectrum in nanometres. All the maximally saturated colors that are physically possible are represented on the above CIE Color Space.

### 3.3.6 Boundary conditions

The following are the boundaries defined by ICAO for chromaticity limit of colors for aeronautical ground lights. It is important that the eye illumination be well above the threshold of perception, that the color not be greatly modified by selective atmospheric attenuations and that the observer's color vision be adequate.

| | | |
|---|---|---|
| Red | Purple boundary | y=0.980-x |
| | Yellow boundary | y=0.335 |
| Yellow | Red boundary | y=0.382 |
| | White boundary | y=0.790-0.667x |
| | Green boundary | y=x-0.120 |
| Green | Yellow boundary | x=0.360-0.080y |
| | White boundary | x=0.650y |
| | Blue boundary | y=0.390-0.171x |
| Blue | Green boundary | y=0.805x+0.065 |
| | White boundary | y=0.400-x |
| | Purple boundary | x=0.600y+0.133 |
| White | Yellow boundary | x=0.440 |
| | Blue boundary | x=0.320 |
| | Green boundary | y=0.150+0.643x |
| | Purple boundary | y=0.050+0.757x |

The above coordinates were used to plot a standard curve on excel so that a range of values can be iterated within the given boundaries.



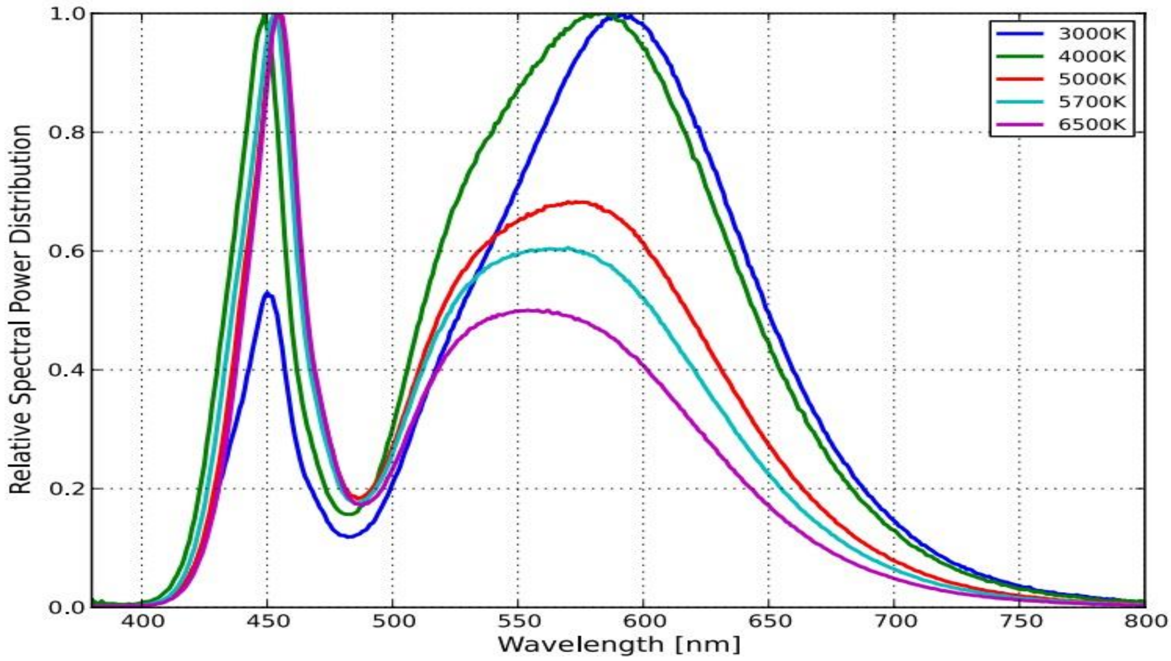

Graph 6 ICAO Chromaticity boundary conditions

ICAO Annex 14 Volume II and STANAG 3619 specify the use of white LED for approach lights. There are basically three kinds of white- Cool, warm and neutral white. Color temperature over 5000K are called cool colors (bluish white), generally used when a bright and clear light is required. While lower color temperatures from 2700-3000K are called warm colors (yellowish white through red). It mimics the daylight color which is similar to the light emitted by a 60W incandescent bulb. Neutral colors lie between warm and cool colors at around 4000K.

So cool white was an obvious choice for its higher illumination as compared to warm or neutral whites. The white LED is derived from Blue LED coated with a layer of phosphor. These are called phosphor based LEDs. The thickness of the film determines whether the white will be cool or warm. The higher the thickness of the film, lower will be the luminous power as more light is absorbed by the surface.

In order to get a ‘cool white’ light from the lens and LED assembly it was important that the correlated colour temperature of the light be 5000K at a nominal value of 70CRI (colour rendering index).

For the selected Luxeon TX LED the standard wavelength v/s relative spectral density curve is shown as below




Graph 7 Relative spectral power distribution v/s wavelength curve for Luxeon TX LED

## 3.4 Photometry

Unlike chromaticity, photometry is the study of light in terms of brightness as perceived by human eye. The human eye is not equally sensitive to all wavelengths of visible light. Photometry attempts to account for this by weighing the measured power at each wavelength with a factor that represents how sensitive the human eye is at that wavelength. The standardized model of the eye's response to light as function of wavelength is given by the luminosity function.

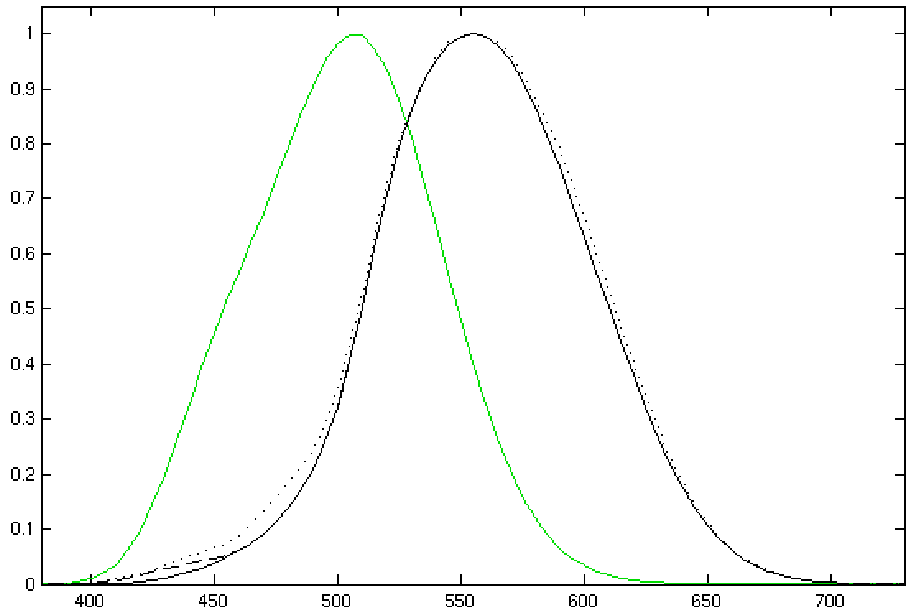
$$F = 683.002 \frac{lm}{W} * \int_0^\infty \bar{y}(\lambda)\, J(\lambda)\ d\lambda$$

Where F- luminous flux (lm)

J (λ) - spectral power distribution of the radiation (W/m)

$\bar{y}(\lambda)$- Standard luminosity function a.k.a V (λ)

λ- Wavelength (m)

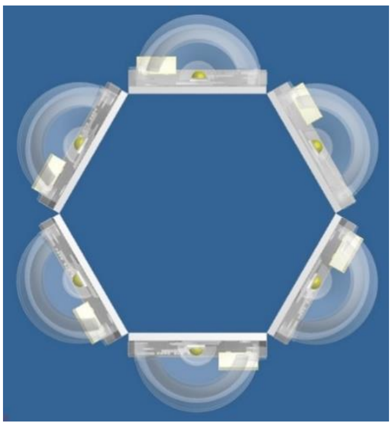


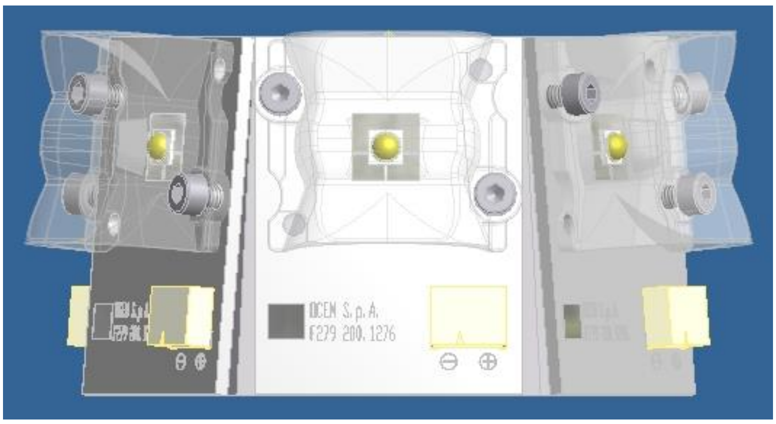

Graph 8 Photopic (black) and scotopic (green) luminosity function

In order to achieve the specified brightness value described in ICAO, STANAG and IEC, simulation was performed with different lenses in varying combination using TracePRO® software.

It was decided to use a combination of 6 LEDs with each LED mounted on a single LED Board along with the lens. If the total number of LED was less than six, it would leave dark spaces at the point of intersection of the boards. The LED boards were placed at an angle of 60 degrees from each other and inclined at an angle of 5 degrees to the vertical. Vertical inclination is given so that the point of maximum intensity from the LED lies between 5-6 degrees from the azimuth as specified in the rule.

It was decided to use a polycarbonate top cover over the previous glass design to reduce the cost of production as well as the weight of the overall assembly.





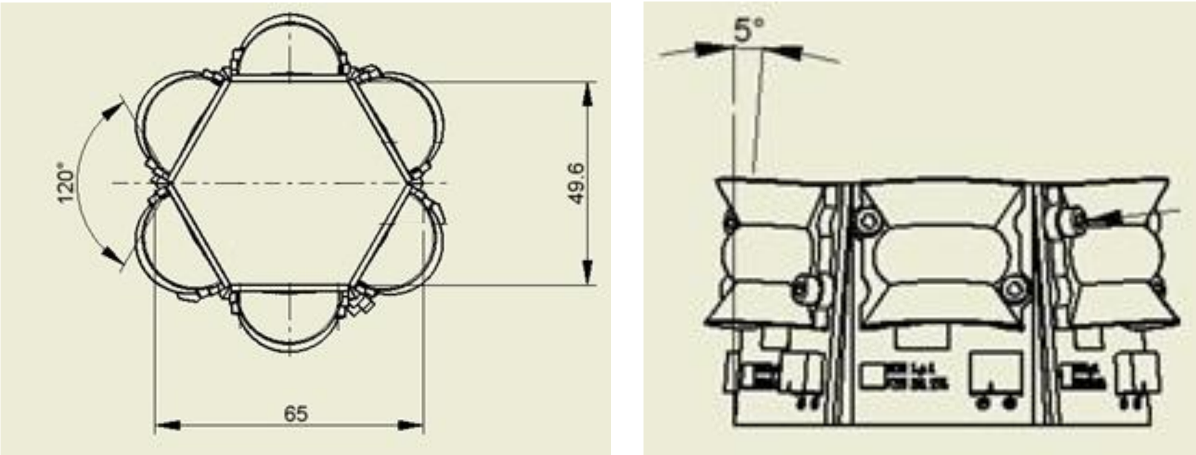



Figure 7 LED board assembly

### 3.4.1 Simulation data

#### 3.4.1.1 Test 1

6 LED Z 5000 K
Flux = 130 lm at 500mA
Lens Ledil CA11266 with polycarbonate casing
Efficiency = 82%
=106 lm flux source for simulated photometry lens
(4% absorbed and 14% reflected, only 82% of the light is transmitted)

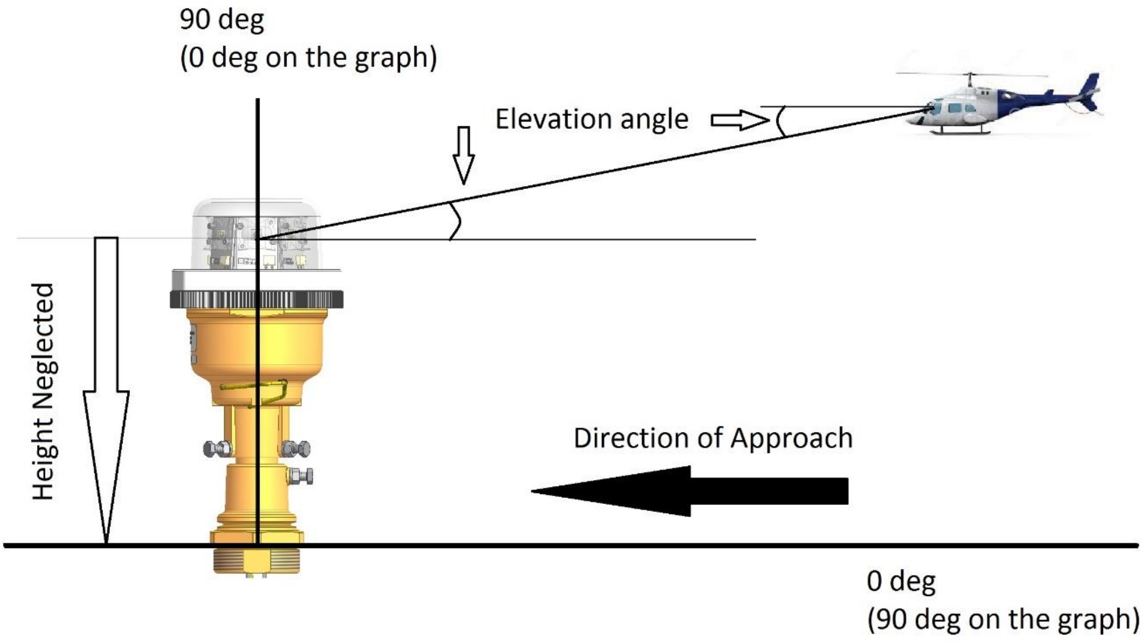



Figure 8 X-axis Representation

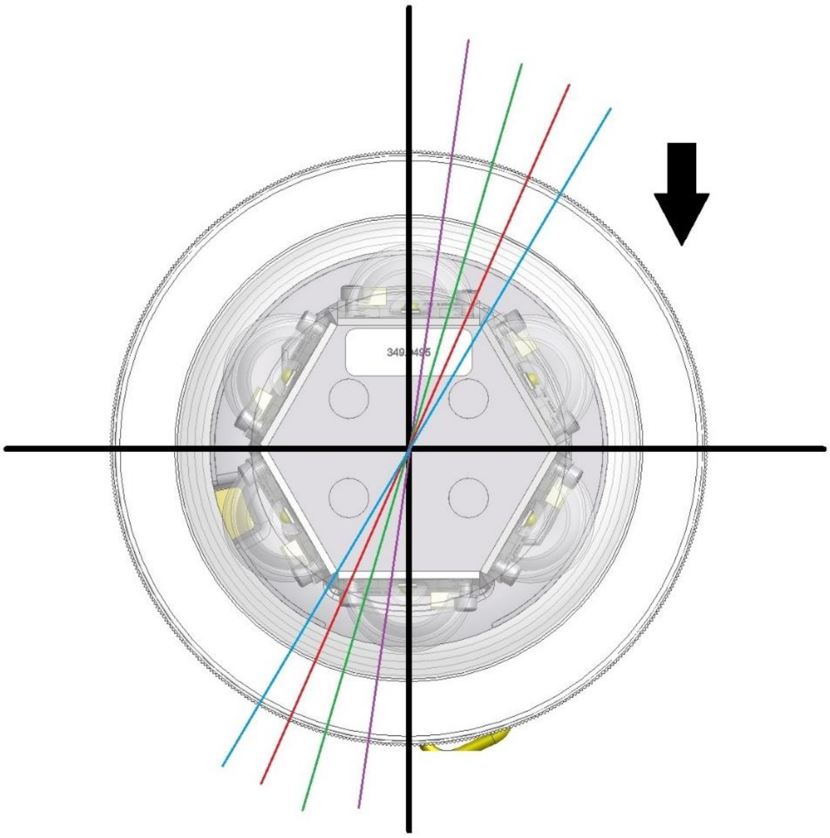
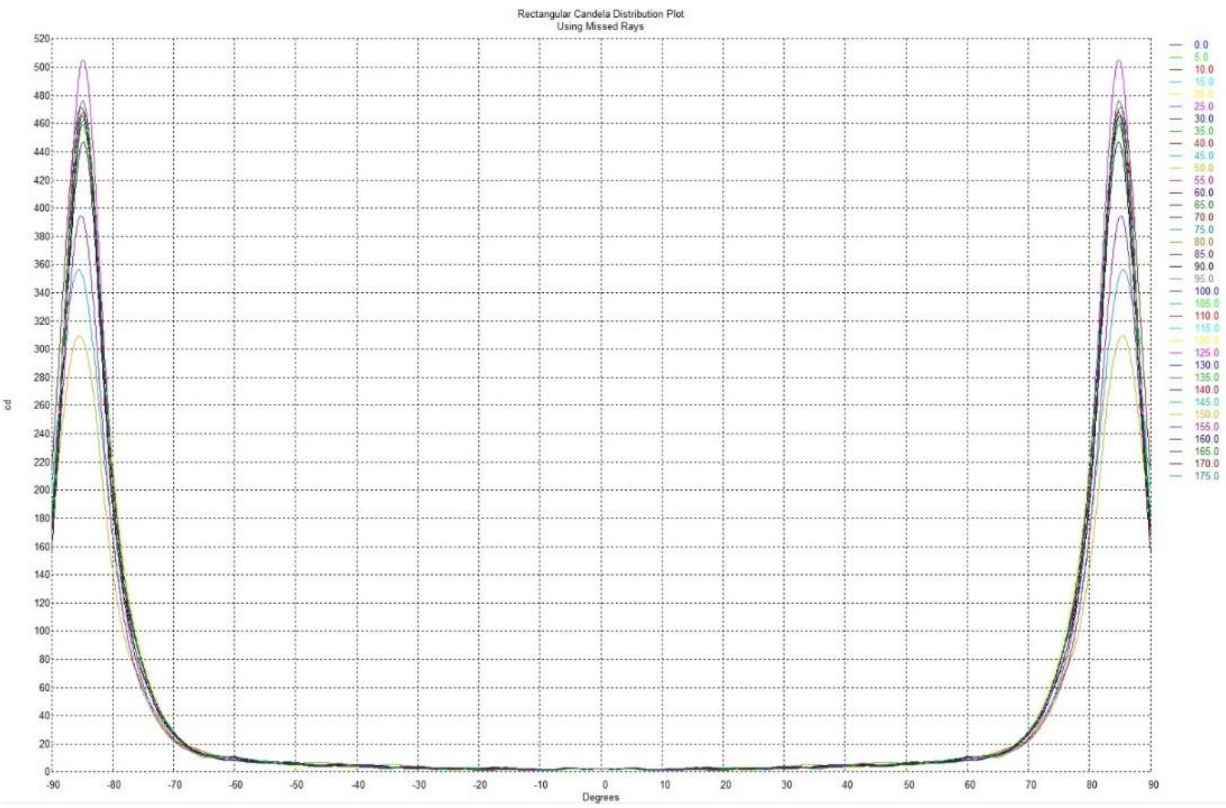
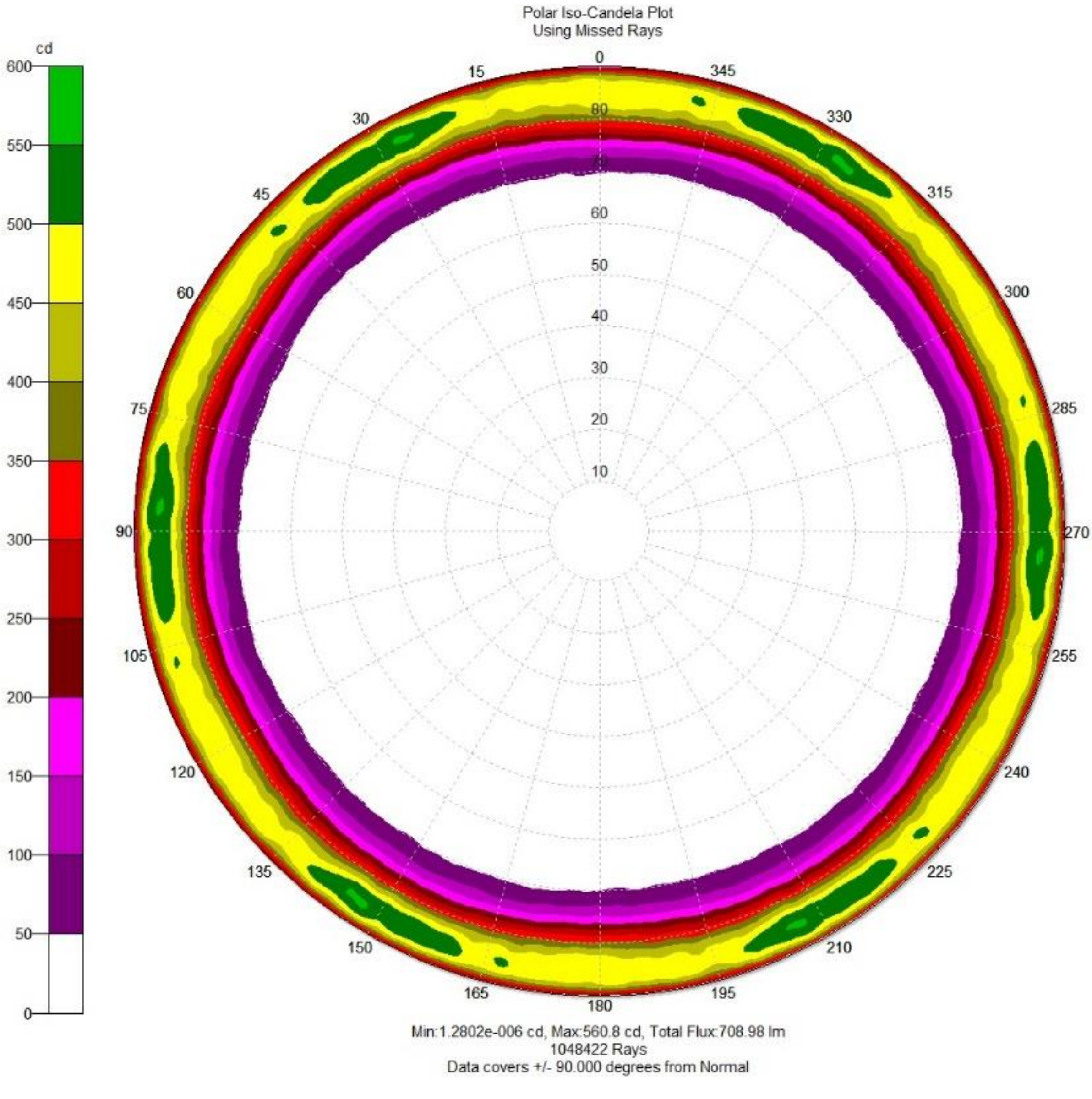


Figure 9 Y-axis representation along with vertical planes around the axis as viewed from the top




Graph 9 Six LED Z 5000K performance

Graph 5 shows the spread of light from LED Z 5000K. The Y- axis represents the luminous intensity of the light for all the planes passing through the vertical axis of the light. The X-axis denotes the elevation angle that the pilot's line of sight makes with light structure, in degrees. For simplicity the distance between the centre of the LED to the ground is neglected. To be able to represent all the planes on the graph the vertical was considered at 0˚and the 90˚on the horizontal, as a requirement in TracePRO®.




Graph 10 Polar iso-candela plot from top view

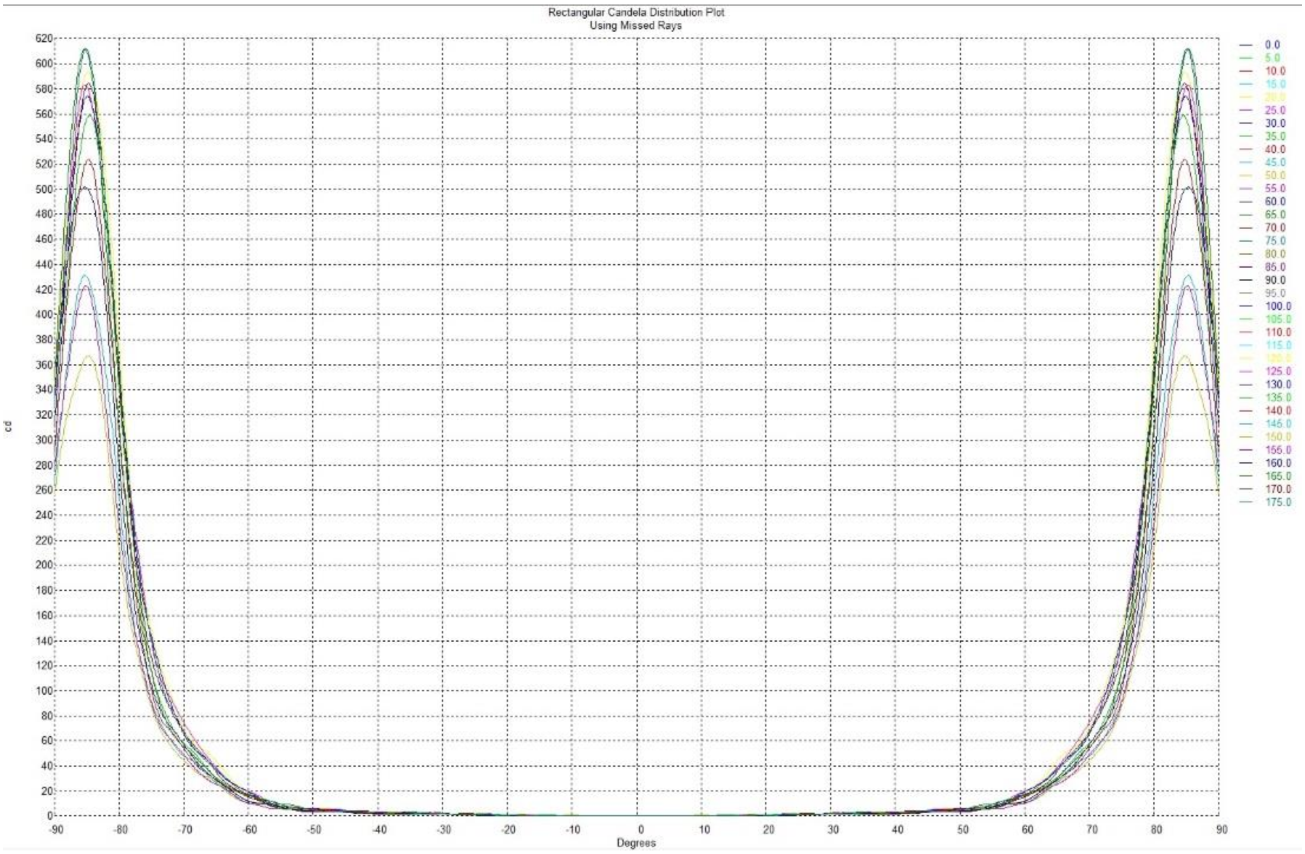
The graph shows a considerable difference in intensity of the light along the planes at different angles. At an elevation angle of 5 degrees the intensity varies from a minimum of 310 cd (peak value along 50 degree plane) to 505 candela (peak value along 25 degree plane). This is because the lens is not able to spread the beam uniformly around the vertical which causes the presence of areas between two LEDs with intensity lower than 350 cd. This lens corresponds to poor horizontal uniformity and as well as low intensity.

For better understanding Graph 5, Graph 6 can be referred to check for luminous intensity values at different planes as viewed from the top of the luminaire. The green color represents high intensity while red and purple are in reduced intensity range. The values on the boundary of the circular plot shows the angular position of each vertical plane from the central axis.

The six green zones are the areas where the LEDs are mounted. So it is characterised by high luminous intensity. The low intensity zones are between two LED boards where the spread of the light is not sufficiently received.

#### 3.4.1.2 Test 2

6 LED 5000 TX
Flux = 195 lm at 500mA
Lens Ledil CA11266 with polycarbonate casing
Efficiency = 82%
=160 lm flux source for simulated photometry lens
(4% absorbed and 14% reflected, only 82% of the light is transmitted)

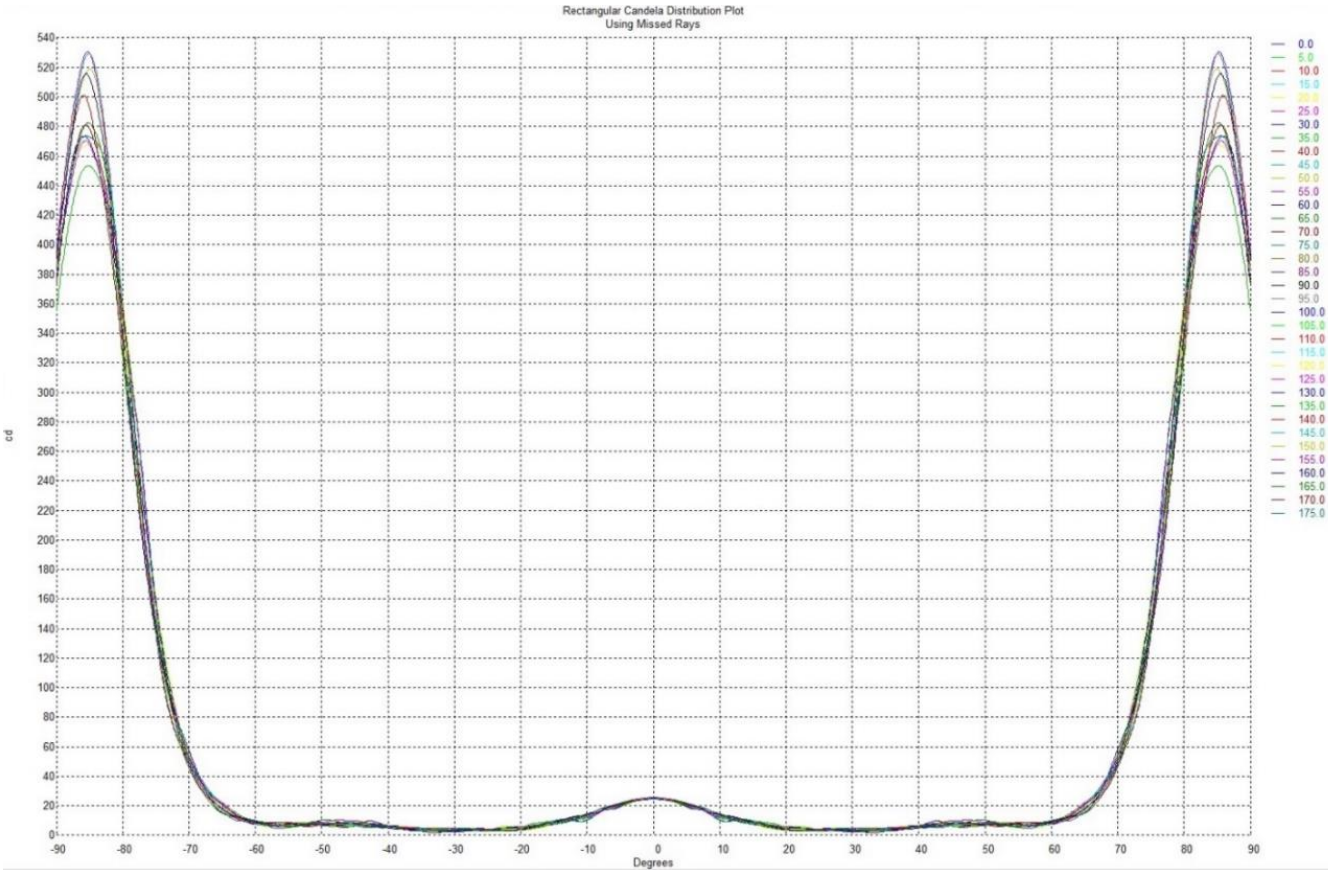



Graph 11 Six LED TX 5000K performance

The TX-version lens has higher peak intensity values for all planes compared to the Z-version. But the problem of uniformity and intensity still persists. As can be seen from Graph 7 that the minimum peak intensity value, i.e., 365 cd, falls along the plane lying at 80 deg. And the maximum peak for plane at 65 degrees is 610 cd.  This LED suffices the condition for 350 cd between 5-6 degrees, but the request for 250 cd between 2-9 degrees is not completely satisfied. Regions with intensity lower than 250 cd can be seen from the curve.

#### 3.4.1.3 Test 3

6 LED 5000 TX
Flux = 195 lm at 500mA
Lens Ledil CA10932 Flare-B with polycarbonate casing
Efficiency = 93%
=190 lm flux source for simulated photometry lens
(4% absorbed and 3% reflected, 93% of the light is transmitted)




Graph 12 Six LED TX 5000K performance with increased efficiency

Good uniformity and efficiency top of this lens allows you to gain the light. The lenses Flare-B have dimensions 29x23x13 mm, placed horizontally at 60 ° from each other in a circle of radius 22 mm.

### 3.4.2 Conclusion

Six LEDs need to be used as any number lower than that will leave dark areas in patches around the vertical axis. To reduce such a situation a hexagonal arrangement is preferred with each LED board at an angle of 60 degrees from the vertical plane.

Now out of all the possible range of LEDs made available to us we chose LED TX with the flux of 700 mA at 85°C color temperature and 260 lm, placed at a vertical tilt of 5°. This lens has high transmissivity of 93% and a much more uniform distribution of the light around the central axis. It also satisfies the photometry requirement based on the isocandela chart to provide luminous intensity in the range of 25cd from 0-15˚, 250cd from 2-9˚ and 350cd from 5-6˚.

Teaming the LED with Lens Ledil Flare-B, C10932 provides maximum uniformity with high intensity spread of light. The distribution of light around the axis is more homogenous as the flare in the lens is capable of propagating the light in a larger area.

# 4. LUMINAIRE DESIGN

The design of the luminaire should be in-line with the rules specified by the governing bodies and at the same time keep the cost of production to minimum. This can be achieved by designing the part which can be easily cast and do not require extensive machining, and by selecting the material available in the European market. The description of the target, design process and the final outcome of the luminaire have been discussed below in detail.

## 4.1 Target

To design a mechanical structure or luminaire for housing the lens assembly and electronic systems for heliport approach light. The structure should be able to withstand wind loads both static and dynamic, but should break or yield when impacted upon by a moving airplane or helicopter in order to dissipate the impact energy to cause minimum damage to the aircraft.

## 4.2 Constraints

For many years the company has been relying on halogen lamps to aid the aircraft during approach, landing and take-off. But as the market has been swiftly shifting towards the more efficient LED lights, this has compelled the engineers to design a new housing structure that abides by all the norms, while keeping the cost of production to minimum.

## 4.3 Design process

### 4.3.1 Benchmarking

The halogen luminaire version is known as HEOL (Heliport Elevated Omnidirectional Lights). On field they are designed to be connected in parallel circuit. Generally a parallel circuit is only employed when there are only few fittings existing in the circuit and accurate intensity balance is not critical.

#### 4.3.1.1 Final assembly and parts

1. Clear top lens for encasing the lamp with metallic ring
2. 100W halogen lamp, 24V
3. E27 lamp holder- (E27- ‘Edison screw’ with 27mm diameter measured across the peaks of the thread on the base)
4. Stainless steel clamp for fastening the top lens with the lower assembly
5. O-ring for lens
6. Fixture body
7. Standard breakable coupling for approach fixture
8. Cable lead with plug

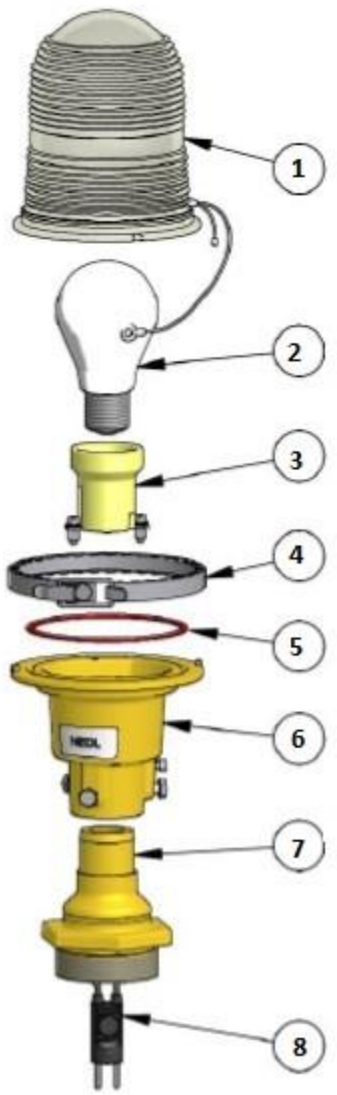



Figure 10 HEOL general assembly exploded view

#### 4.3.1.2 Characteristics

- The main body of the assembly is made of Cast aluminium to minimize the weight but still maintain high strength to weight ratio.
- The clear top cover is a symmetric Fresnel lens, attached to the main body by means of a stainless steel clamp. A Fresnel lens is preferred in order to have a large aperture and short focal length, with reduced mass and thinner walls as compared to conventional lens with comparable optical properties. The surface of the lens is carved into concentric annular sections of same curvature as that of a standard lens with stepwise discontinuities between them.
- The top cover is provided with a metalling ring so that during maintenance at height it can remain suspended in air, while being attached to the main body, when there is a need to change the lamp.
- The lens is made of heat resistant glass to withstand thermal shock that may occur due to constant change in temperature.
- In order to ensure water tightness, a silicon O-ring is provided between the body and the lens without the need for any sealant.
- A frangible coupling connects the fixture body to the mounting base. The coupling is made of cast aluminium with a yield point to ensure breaking when impacted upon by a moving aircraft. Three

screws are used to connect it to the fixture for easy removal and assembly. The coupling is provided with 2” GAS male thread for a proper installation. For varying the height of the light for approach, a suitable pole up to a length of 2m is inserted between the main fixture and the coupling.

- In compliance with IEC 61823, the power requirement is sufficed by using two cable leads or a cable lead with plug.
- A suitable grounding screw is provided
- Easy installation and maintenance as no optical adjustment is necessary after the lamp or the lens have been replaced

#### 4.3.1.3 Lamp requirements

- ICAO- color of the lamp-clear;100W
- STANAG- color of the lamp-clear;100W

#### 4.3.1.4 Overall dimension

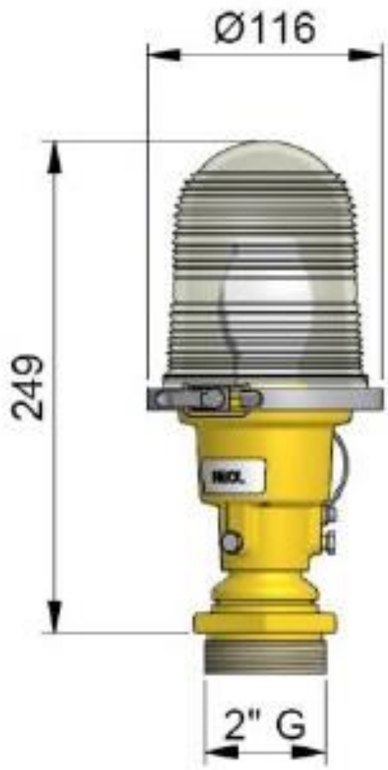



Figure 11 HEOL overall minimum dimension

### 4.3.2 Design approach

Initially two design approaches were considered. Either to modify the old taxiway edge luminaire to accommodate the LED assembly or to design an entirely new product. As the cost of an all new product would have been quite high, it was decided to go with the former approach. Also, since it is a multi-part structure, it would be advantageous to retain the main structure, while designing only the parts compatible with LED version. It was also decided to avoid heavy machining on old parts and instead produce a new in place.

### 4.3.3 New design 1

The following are the parts to be tailored for the luminaire:

- Breakable coupling
- Mounting pole
- Main outer body
- Electronic housing
- Top cover
- LED mounting base

#### 4.3.3.1 Electronic housing

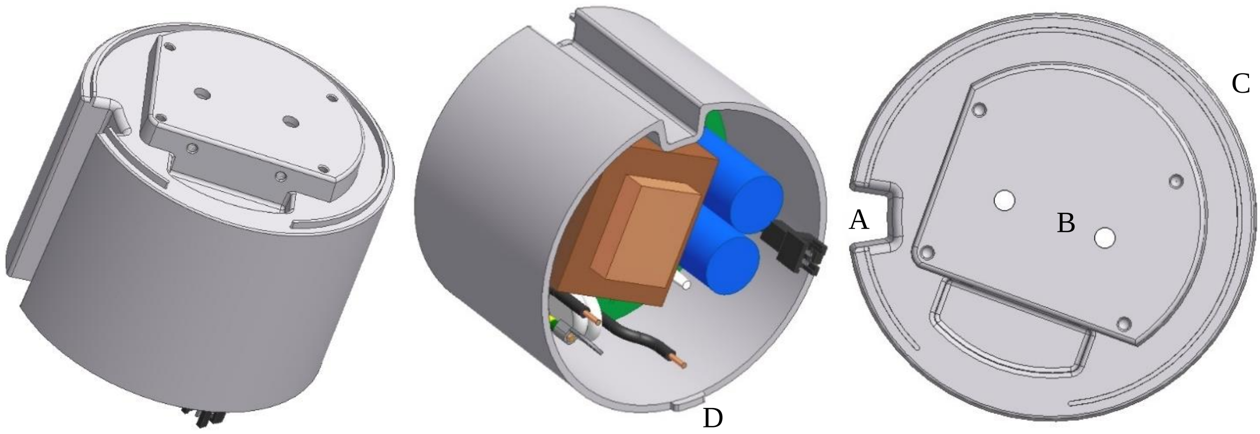



Figure 12 Electronic Housing

The electronic housing was developed bearing in mind the units to be packaged inside the body. The housing contains electronics to power the LED, mounted on a printed circuit board.

The material selected for the production is aluminium ANSI/AA 380.0-F (AlSi8Cu3Fe) Die cast alloy. It is by far the most commonly used aluminium alloy, preferred for its ease of production and superior material properties. It has high flowability which easily fills up the die to form thin and intricate shapes and exhibits anti-soldering property to the die during casting as compared to other alloys of the aluminium family. The finished product undergoes anodic oxidation to provide 10 microns of oxide layer to protect the surface from corrosion and to increase wear resistance and also to ensure that the surface becomes non-conductive to protect from electrical surge during installation or maintenance.

The groove marked in the picture as position A, is provided to rout the wires from the LED board mounted on the top face of the housing, to the power board inside the housing. Position B is branded with holes to facilitate the attachment of 'LED mounting base'. The ridge around the circumference marked as position C is provided to align the gasket on the surface between the housing and the transparent cover to encase the LED Assembly. Provisions are made inside the housing to screw in the nylon support, used to hold the printed circuit board in place. M4x0.7 internal threads are drilled for fastening MSCBS-4-01 supports produced by Essentra Components. A key is protruded at position D for proper orientation of the housing inside the main external body.

In the past, it was noticed that the some components of electronic assembly came loose due to vibrations incurred by the moving aircraft. So to keep the assembly intact in its position, it was sealed with thermally conductive silicone resin. TPC (Thermally conductive potting compound), is a kind of thermal interface material that provides a balance between low thermal expansion and high thermal conductivity. Apart from providing resistance to vibrations and thermal conductivity, it also works as electrical isolator and prevents current leakage. The material possesses the ability to flow before curing, which makes it easier to fill in the gaps between the hot electronic components and the adjacent heat sink. After curing it is dry and sets as a thermally conductive elastomer. TPC cures at room temperature in a duration of 8 hours and the hardened material possesses a hardness value of 50(shore A) and a thermal conductivity of 1.3W/mK.

The circuit board is attached to the housing using MSCBS-4-01 nylon supports. The Metric Studded Circuit Board Support (MSCBS-4-01) is made of Nylon 6/6 material rated as UL 94 V-2. UL 94 is a safety standard to measure flammability characteristics of plastic materials. The vertical rating, V-2 signifies that the test for flammability was conducted in vertical position and the flame was self-extinguished after the removal of source, within a specified time duration. It also takes into consideration, whether the flame dripping is able to ignite a cotton indicator placed under the sample. The supports with grade UL 94 V-2 was chosen as it stops burning after the removal of the source within 60 seconds and flame drips are not hot enough to initiate burn.

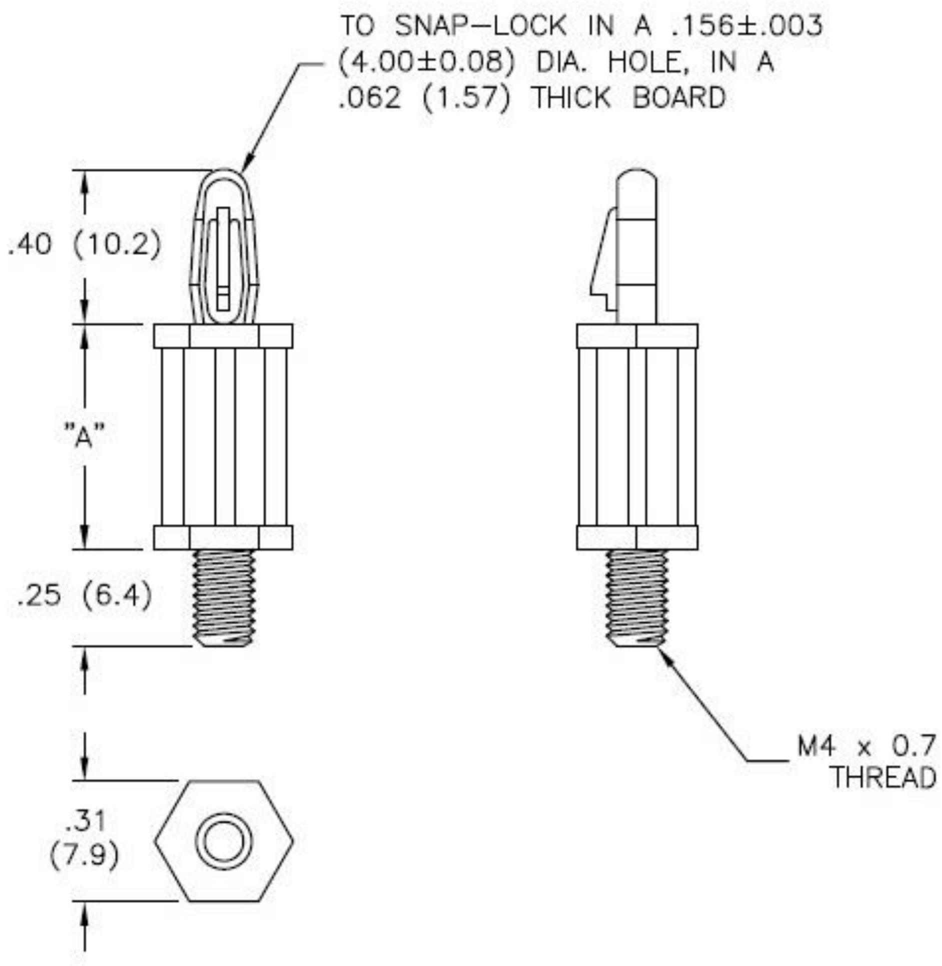



Figure 13 Nylon supports for PCB

| NYLON 6/6 UL 94 V-2 (RMS-01) COLOR: NATURAL PART NO. | "A" |
|---|---|
| MSCBS-4-01 | 1/4 (6.4) |
| MSCBS-6-01 | 3/8 (9.5) |
| MSCBS-8-01 | 1/2 (12.7) |
| MSCBS-10-01 | 5/8 (15.9) |
| MSCBS-12-01 | 3/4 (19.1) |
| MSCBS-14-01 | 7/8 (22.2) |
| MSCBS-16-01 | 1 (25.4) |
| MSCBS-18-01 | 1-1/8 (28.6) |
| MSCBS-22.5-01 | 1-13/32 (35.7) |

Table 3 Reference table for nylon supports

#### 4.3.3.2 Main outer body

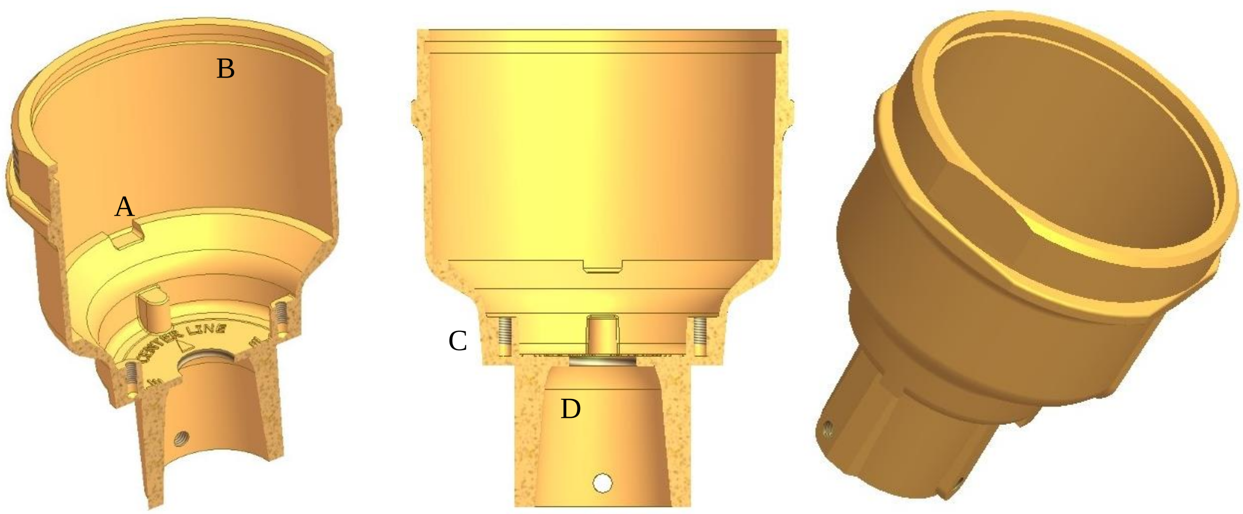



Figure 14 Main outer body

The design of the main outer body was based on the external dimension of the electronic housing. The whole part was decided to cast from aluminium ANSI/AA 380.0-F (AlSi8Cu3Fe) Die cast alloy. In order to align the bottom of the electronic housing perfectly with the surface of the external body, a key slot has been machined at position A. The key is shown in Figure 17, position D of the electronic housing. Figure 20 below shows the correct alignment position. Once the housing has been placed in right orientation, it is locked into position using a circlip. A groove around position B marks the placement of the internal circlip used to arrest the housing in vertical direction as shown in figure 21 below. In order to reduce the number of parts as well as shave off weight from overall assembly the circlip was used to retain the housing inside the exoskeleton.

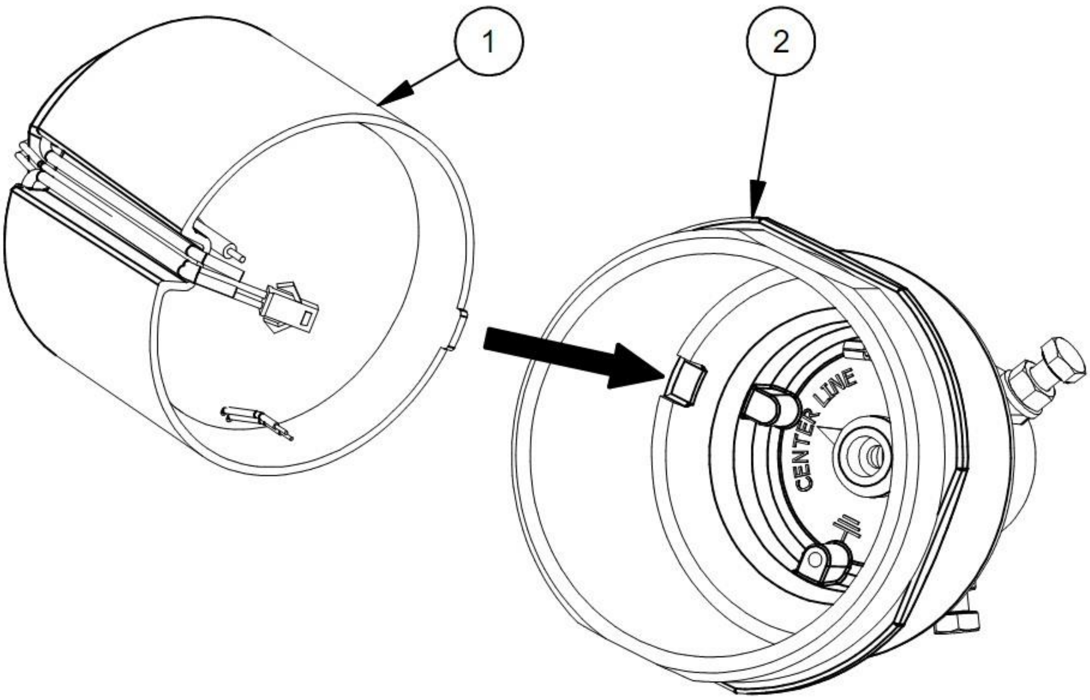



Figure 15 Alignment Position of Electronic Housing in the main body

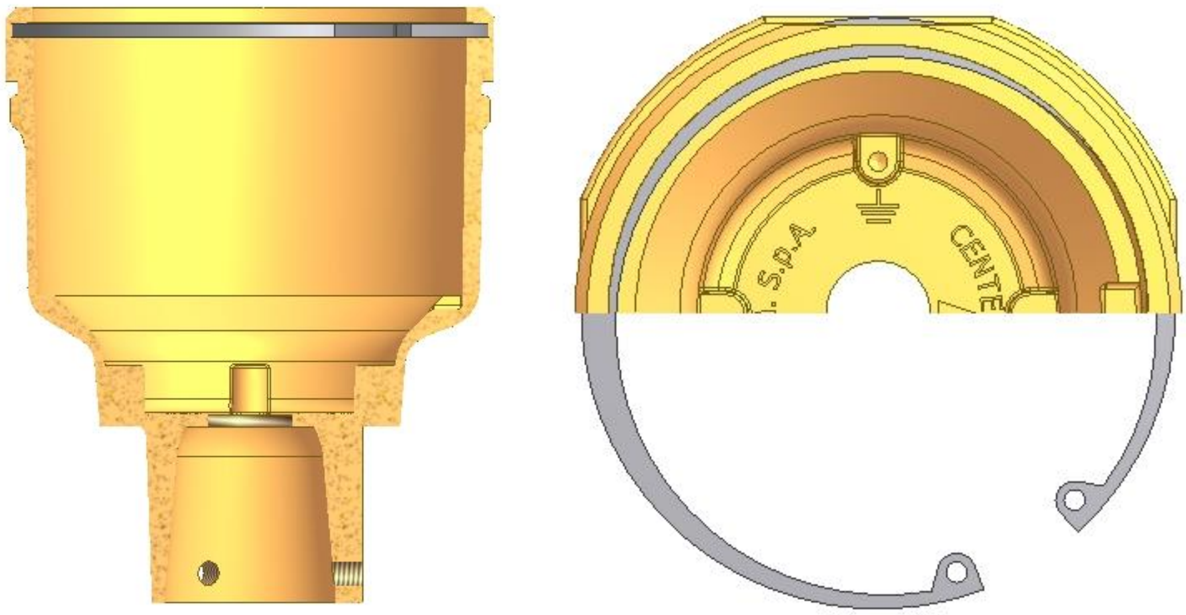


Figure 16 Circlip placement

Position C in figure 19 contains drill and tap for fastening of the ground cable, which runs through the assembly to the base burrowed in the ground, for power supply. The hollow space in the vertical direction is provided for the insertion of the mounting pole. The pole provides a connection between the breakable coupling and the main body. The hollow space at position D is arched at an angle of 5degrees inwards from the vertical to provide compliance to the pole mounting. As mentioned in FAA 150-5345-46D "at least 4degrees of adjustment must be provided in all directions to allow levelling of the fixture after installation". It ensures reduced stiffness between the two bodies, necessary during assembly and degree of freedom at high altitude to withstand lateral wind load.

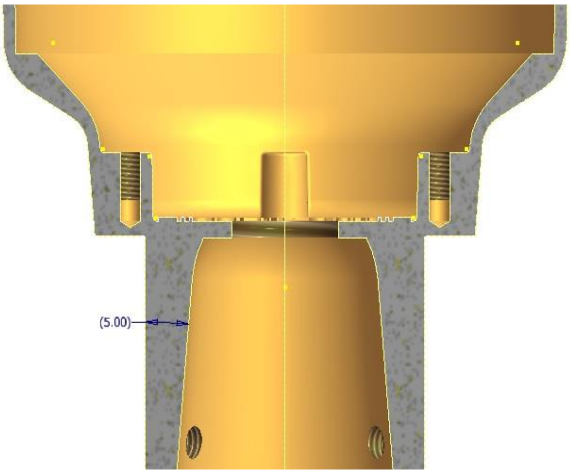



Figure 17 Inclination of inner walls

#### 4.3.3.3 Mounting pole

The EMT 1" cylindrical pole with wall thickness of 1.4mm is provided to alter the height of the luminaire based on the requirement of the heliport. It also provides a connection point between the breakable coupling and the main body. The pole is fixed using three M6 UNI 24017 levelling screws on both top and bottom. Levelling screws were introduced, to ensure easy removal and remounting during maintenance. It was also ensured that the mounting pole remains unworked at both ends so that the length can easily be tailored to the required height in the field.

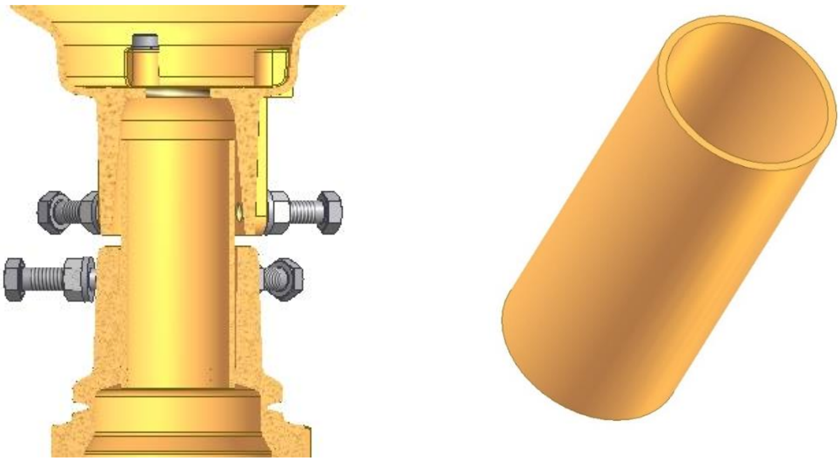


Figure 18 Mounting pole and levelling screws

#### 4.3.3.4 Breakable coupling

Breakable coupling or the yield device on the luminaire, is an obligatory requirement to prevent the aircraft from damage in case it comes in contact with the light structure while moving at high speed.

Frangibility is defined as the quality of a structure to break, yield or distort in the event of a collision, with the objective of dissipating the impact energy. In the absence of the yield device the Kinetic energy generated during the impact will be transmitted back to the aircraft, thereby causing serious damage. So the smaller structure is designed to be frangible to minimise the effects of time dependent dynamic impact and the amount of damage incurred by the bigger object.

The device should be designed so as to be frangible to impact load but should be rendered harmless when normal operational or environmental loads are acted upon. The design of the base was conceived, with the top end (Figure 24 position A) free to fit in the mounting pole and a provision at the bottom end to mate with the installation base. At position D, three M6 holes at an angle of 120 degrees around the vertical, have been machined to insert the fastener for joining together the mounting pole and yield device.

The part is made by casting aluminium ANSI/AA 380.0-F (AlSi8Cu3Fe) into the required shape. The bottom end is cast to have 2" GAS male thread (Figure 24 Position B) to couple with the female fitting machined in the base.

As specified in the rules, the yield point can be no higher than 37mm above the ground as per STANAG and 38 mm above the ground according to ICAO. So the yield point was sufficiently positioned at a height of 12.5mm from the mounting base. For the device to give away before any other part of the luminaire in case of a collision, a groove of 4.25mm depth was made at the specified height (Figure 24 position C). Reducing the diameter results in lower resistance to bending moment, thereby causing the device to fail before any part of the structure. The calculation to support the theory is given in the next chapter along with the test performed.

To aid mating of the yield device with the mounting base, a hexagonal socket of dimension 65mm across flats, is designed at position F, to be conveniently tightened or removed using an adjustable wrench. In certain cases when a mounting base is acquired from one supplier and the yield device from another, based on the mating position the hexagonal socket becomes inaccessible for use. To avoid such a scenario, the internal section is also given a hexagonal shape of size 27mm across flats, to allow the release of the device using hex key. The light has been designed to degrre of protectin rating IP67 so drain holes were not required as the luminaire is water-sealed. As specified by Federal Aviation Administration FAA 150-5345-47D 'Specification for Runway and Taxiway Light fixtures' par.3.6.1, the water developed internally is capable of draining past the yield point. There is no possibility of water accumulation around the yield point. IP 67 ensures protection against tools and wires over 1mm in diameter and total protection against dust entry (numeral 6). Numeral 7 guarantees protection against the effects of immersion between 15cm and 1m.

Cataphoresis of thickness 10-20 microns, is conducted on the final machined surface to give an excellent base for finish paint and increase the corrosion resistance. Electrostatic painting with polyester based powder paint on the surface protects it from ultraviolet light deterioration. Also the power paint has better finish and increases corrosion resistance. As specified by the governing bodies (ICAO, FAA and STANAG) the paint colour should be semi-gloss yellow RAL 1007.

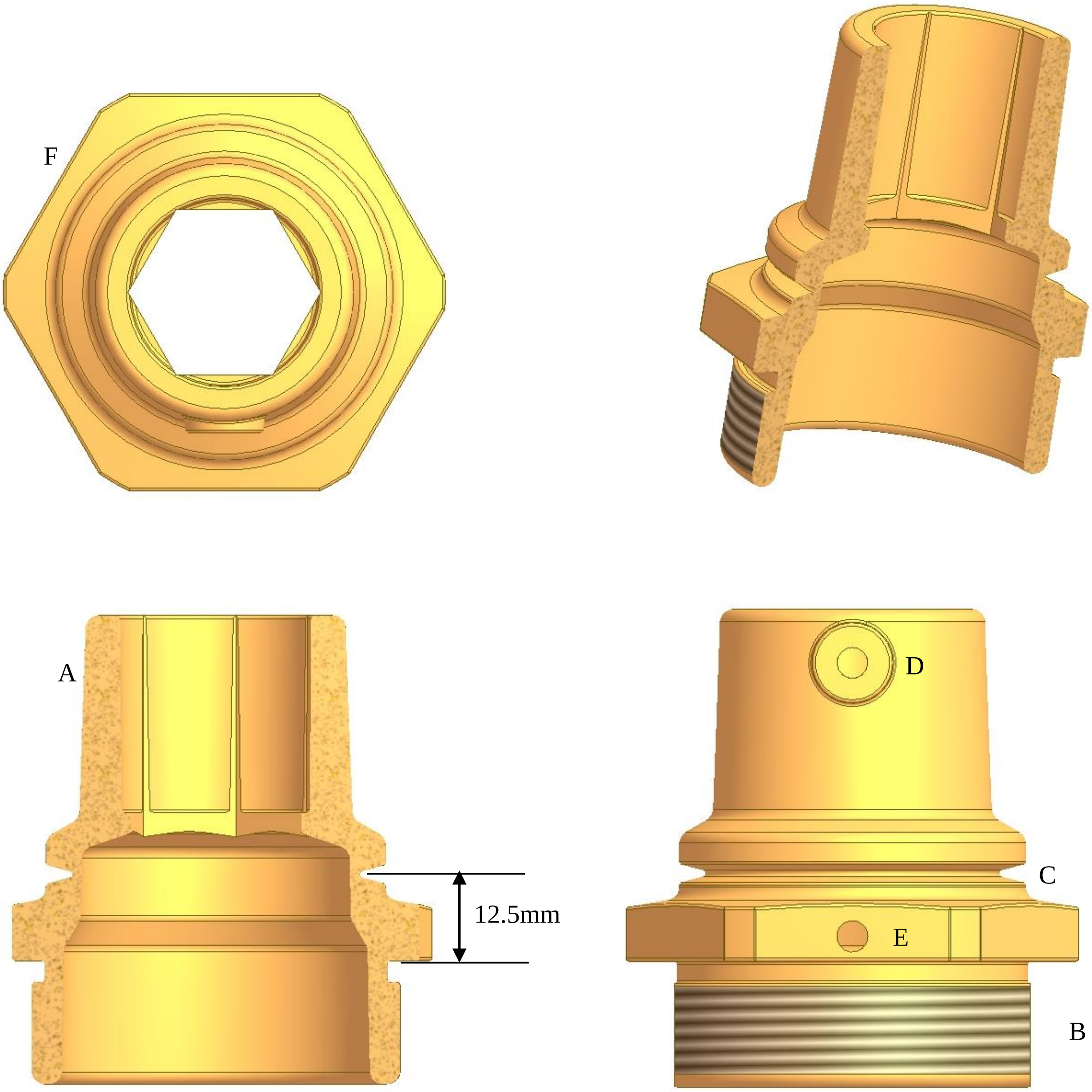



Figure 19 Breakable coupling

#### 4.3.3.5 LED mounting base

Based on the photometry and chromaticity simulations run on TracePRO® software, a near perfect optical performance was achieved by placing 6 LEDS at a relative angle of 120 degrees from each other. The challenge now was to design a mounting base to accommodate six metal core printed circuit board which can also efficiently dissipate heat generated from continuous operation of the lights.

A hexagon, with an inward inclination of 5 degrees from the vertical was designed as per the data procured from photometry simulations. The part is machined from a commercial Aluminium round bar AlSi1MgMn-Anticorodal 100 (EN AW-6082) of diameter 65mm. The aluminium alloy 6082, also known as structural alloy, has excellent corrosion resistance and most commonly used for machining. The presence of 0.4-1% Manganese controls the structure of the grain which results in a strong alloy. The base properties include- tensile strength 340 Mpa, shear strength of 210Mpa and thermal conductivity 180 W/mK.

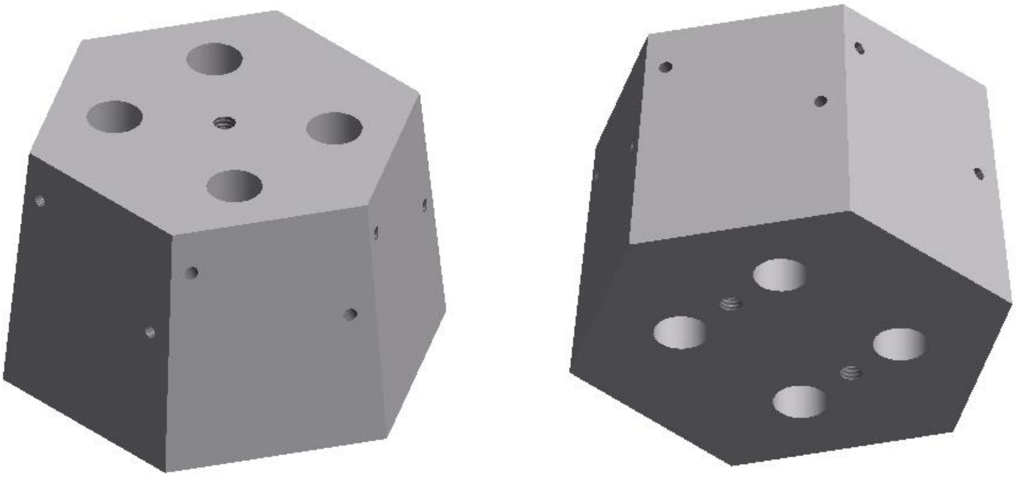


Figure 20 LED mounting base

The side face contains a drilled and tapped hole of M2.5x0.45 to bolt in the LED board through an M2.6 hole provision on the lens. The surface of the board should be in contact with the support walls at all times to ensure dissipation of heat generated by LEDs. Four through holes on the top face are made to increase the surface area for heat conduction. The bottom face contains two additional M4x0.7 holes to join the support with the electronic housing.

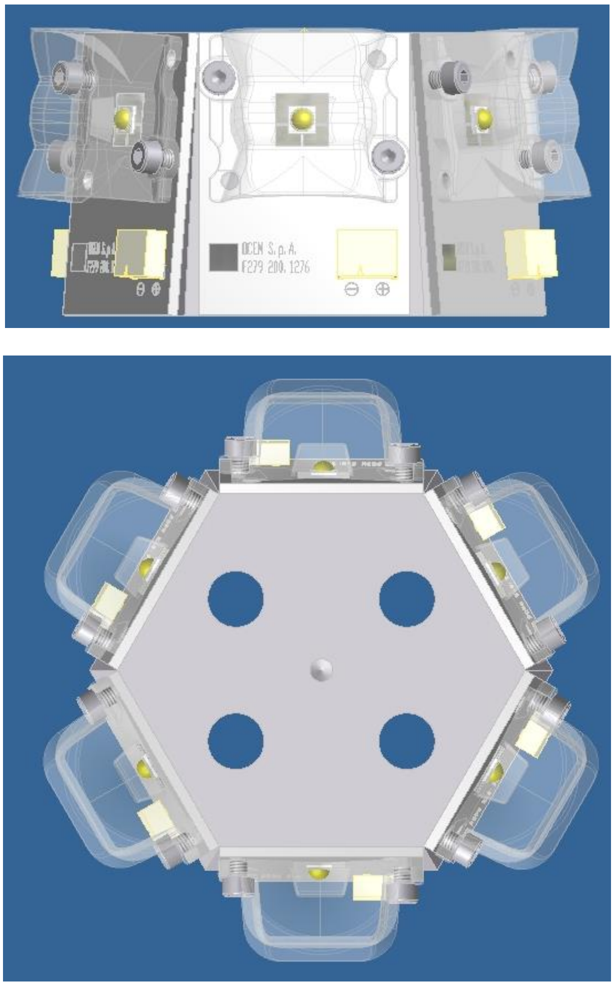



Figure 21 LED and lens assembly on the support

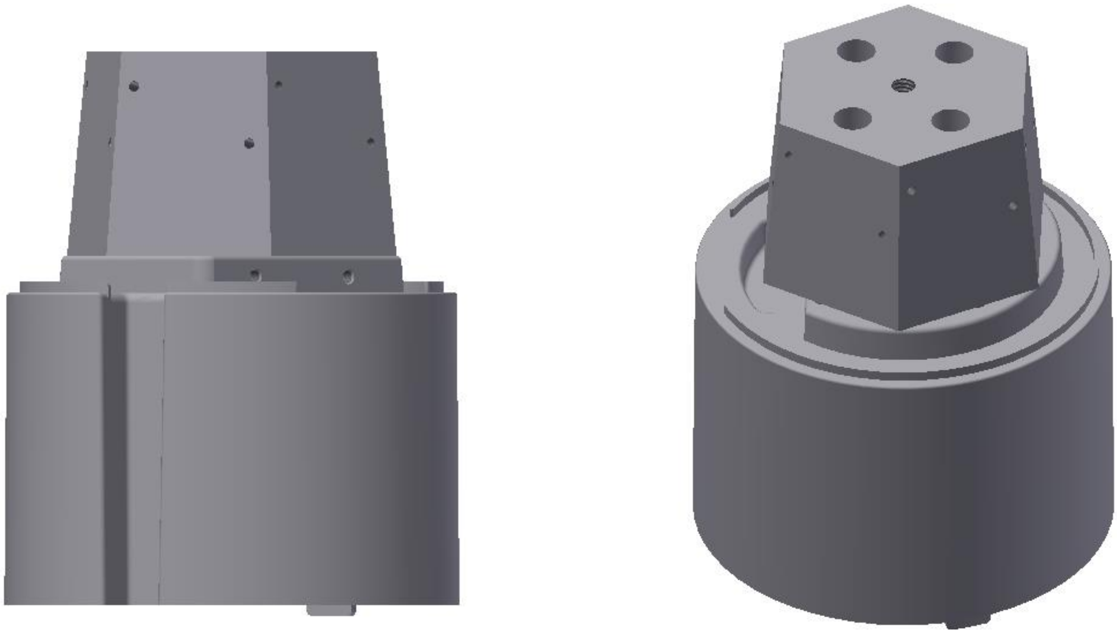


Figure 22 LED Support with electronic housing

To attach the top polycarbonate bowl with the rest of the assembly an M6x1 hole is provided to bolt the cover and support together.

#### 4.3.3.6 Polycarbonate bowl

Previous elevated lights were designed to incorporate a custom made glass cover to encapsulate the LED and lens assembly. In the new design it was decided to use a polycarbonate cover to save weight as well as cost of production.

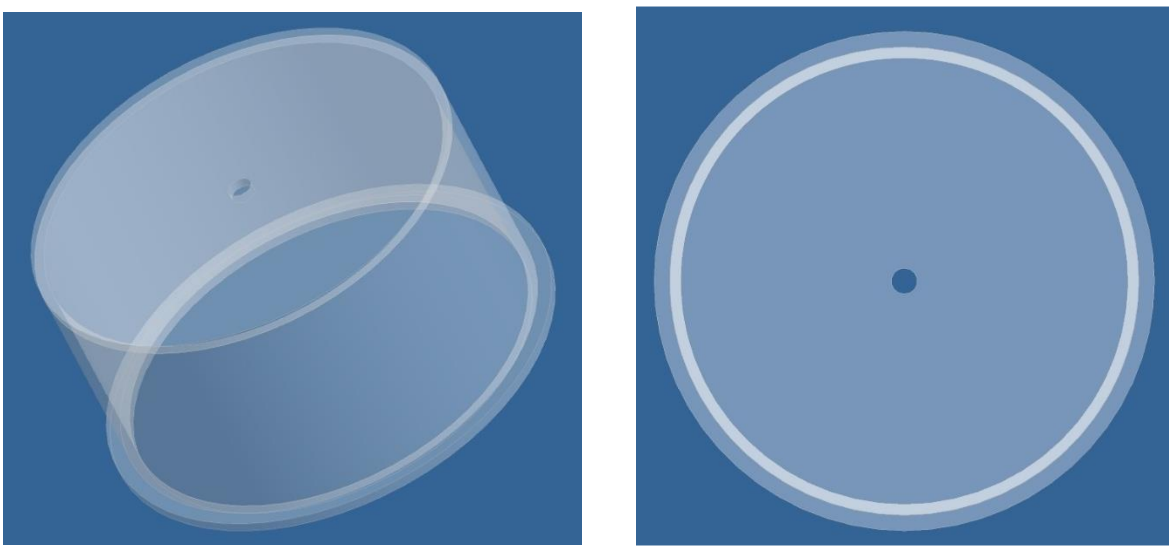


Figure 23 Polycarbonate bowl


Figure 24 Polycarbonate bowl front view

It comprises of a simple three piece design glued together using a cyanoacrylate adhesive. Part A is 90mm diameter piece cut out from a 2mm thick sheet, with a hole on the top face for attachment with the LED support. Part B is a standard 90mm diameter polycarbonate tube with a wall thickness of 2mm and cut to a height of 48mm. Part C is again cut out from 2mm polycarbonate sheet with 99mm external diameter and 90mm internal diameter. The three pieces are adhered together to form a bowl shape top cover.

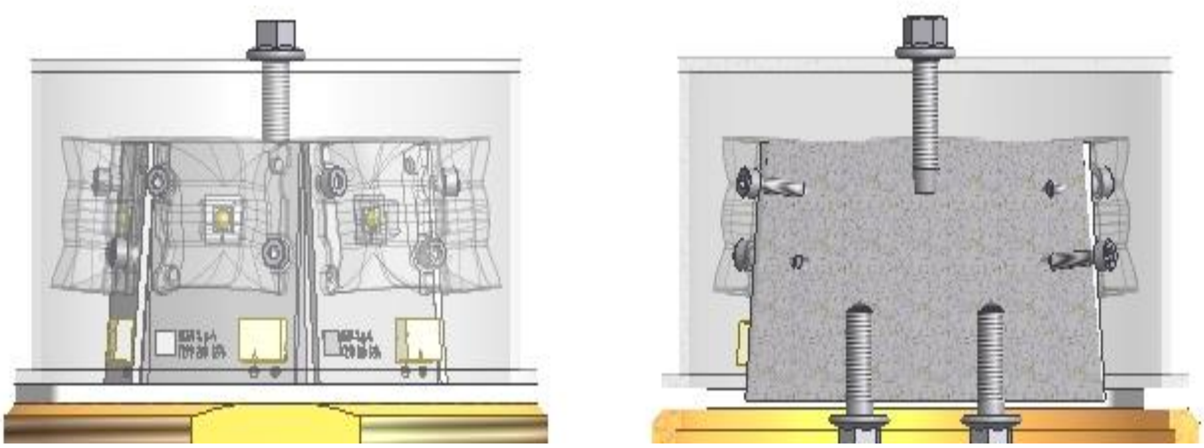


Figure 25 Polycarbonate Bowl Mounted on LED Support

A 3mm compact silicon gasket of hardness shore A 60, is placed between the polycarbonate bowl and main body to create a water tight seal.

### 4.3.4 New design 2

Design 1 was a good approach but lacked the mechanical strength and water tightness needed for IP47 rating. So the few parts used in design 1 were retained in design 2 with a couple of modified and new sub-assemblies. The parts used in design 2 are mentioned as below:

- Breakable coupling
- Mounting pole
- Main outer body
- Electronic housing
- Top cover
- LED mounting base
- Blocking ring to connect the cover with the main body

#### 4.3.4.1 Breakable coupling

The same breakable coupling used in Design 1, was to be used in Design 2 for a mounting height under 250mm. For light structures that required a height of more than 250mm needed a coupling which could provide more stability.

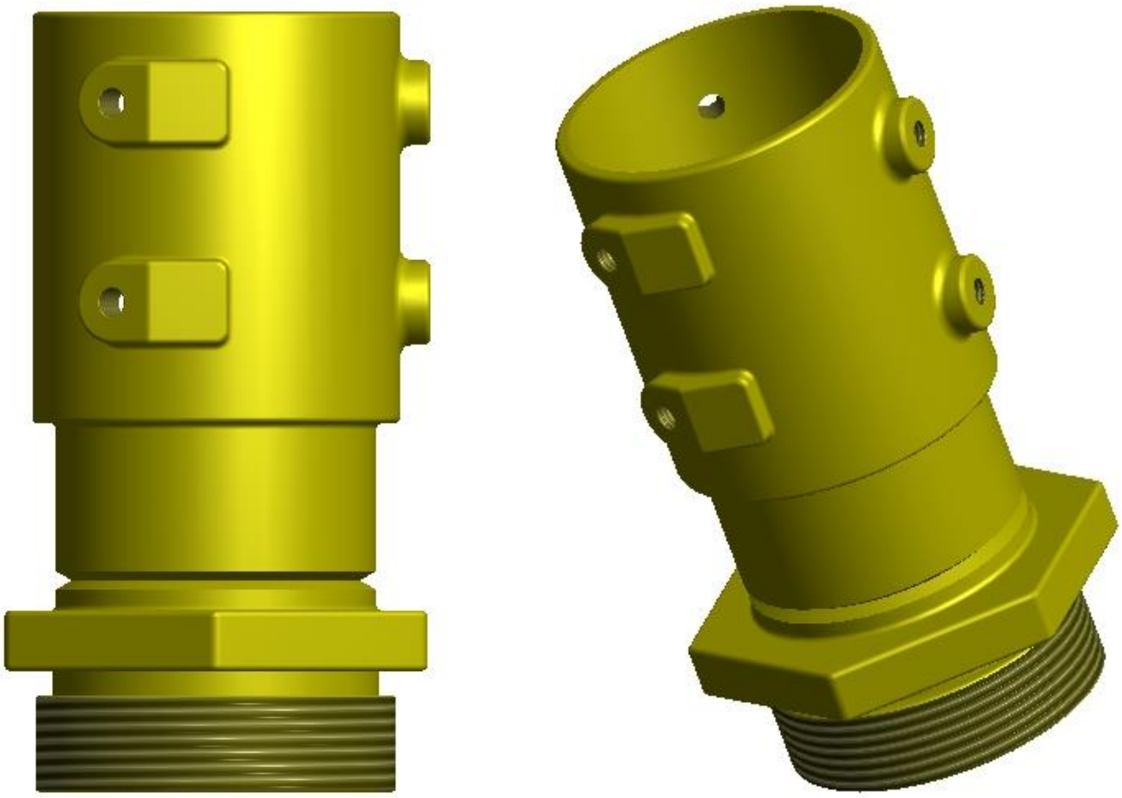


Figure 26 Breakable coupling for high altitude mounting design

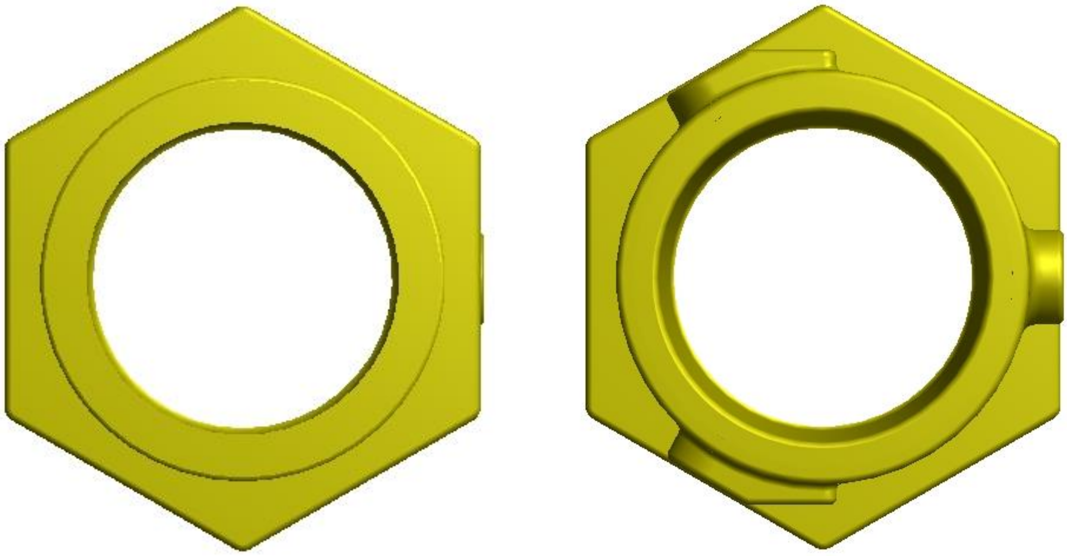


Figure 27 Breakable coupling for high altitude mounting front view

The second version of the breakable coupling or the yield device is 53mm longer than the version 1 to provide lateral wind resistance at high altitude, to mounting pole of maximum 2m of height. The base is kept same as the mounting position does not vary. The top however houses two rows to 3 M6x1 threaded holes at an angle of 120 degrees for tightening the mounting pole with the coupling.

#### 4.3.4.2 Mounting pole

The mounting pole for design 2 uses two different versions based on the required height. The first version is same as design 1 since the yield device or the breakable coupling used at height less than 250mm is same.

When the required mounting height is more than 250mm the mounting pole is a three piece part welded together with one end always left unworked. This is done to facilitate the alteration of pole height on field as per requirement.

The material selected for the part is stainless steel EN 10088-2-X5CrNi18-10+2B (AISI 304). For part (a) electric resistance welded (ERW) tube of diameter 54mm and wall thickness 2mm is used, for part (b) is stainless steel sheet of thickness 2mm and part (c) is stainless steel tube of diameter 30mm and wall thickness 2mm. ERW tubes were preferred over seamless owing to their better surface quality, almost non-existent casting defects and low cost.

The material EN 10088-2-X5CrNi18-10+2B (AISI 304) is an Austenitic stainless steel with high resistance to hot corrosion is up to 850degrees and possesses an ultimate tensile strength ≥520Mpa.

The pieces are welded together using Gas tungsten arc welding. Intermittent fillet weld is done with 1.5mm triangle size and weld length of 10mm at an interval of 5. The bottom contains 1.5mm triangle with 20mm weld length of pitch 5.

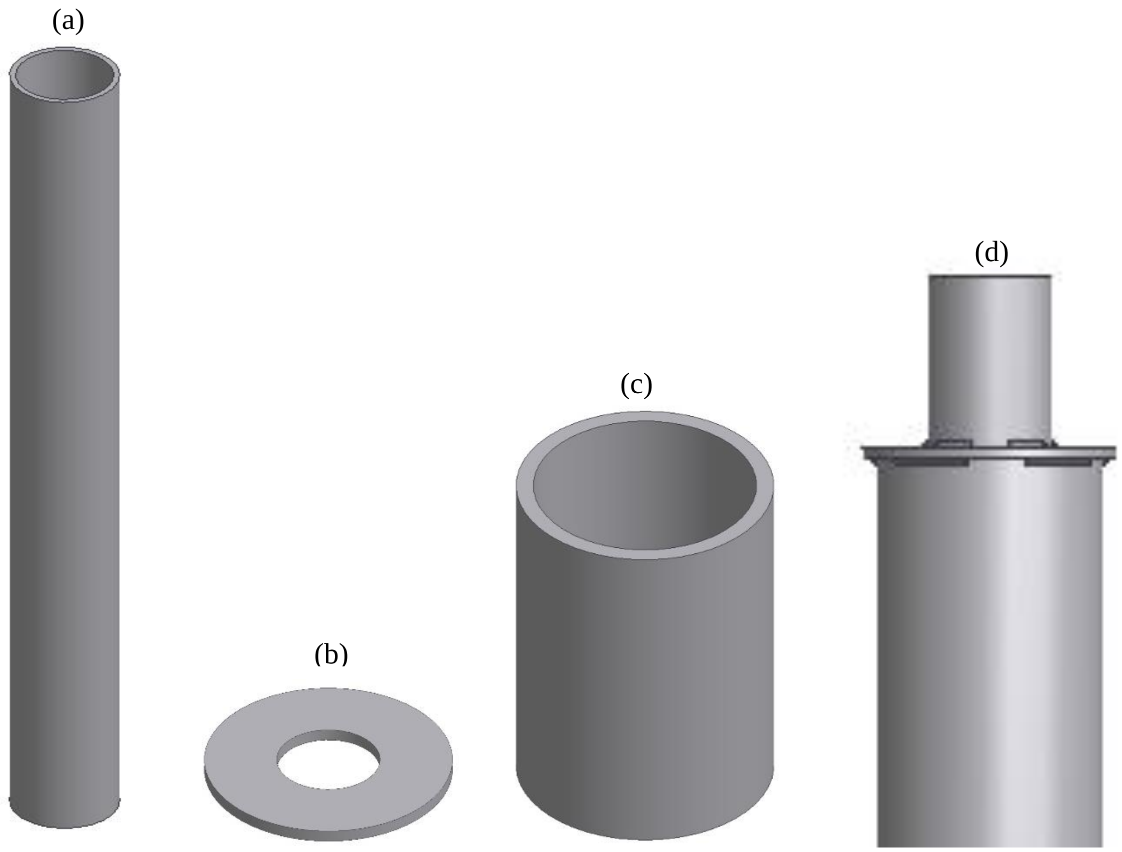



Figure 28mounting pole assembly

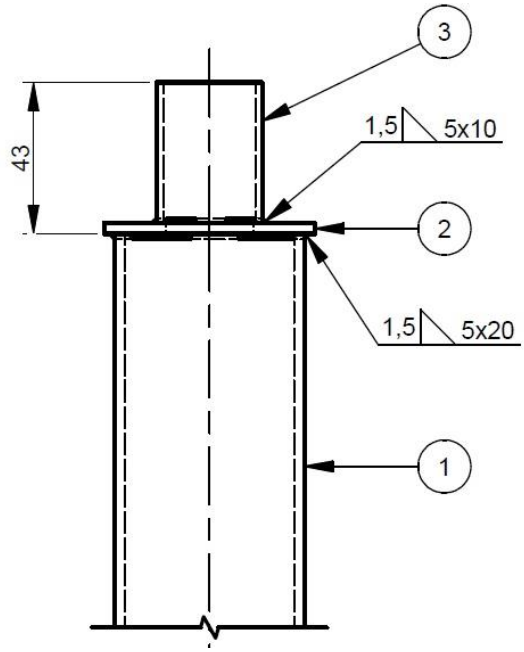



Figure 29 mounting pole welding designation

#### 4.3.4.3 Main outer body

The outer body is kept same with only the groove for the circlip has now been removed. And an additional machining is performed for M100x3 external threads to fasten the blocking rings.

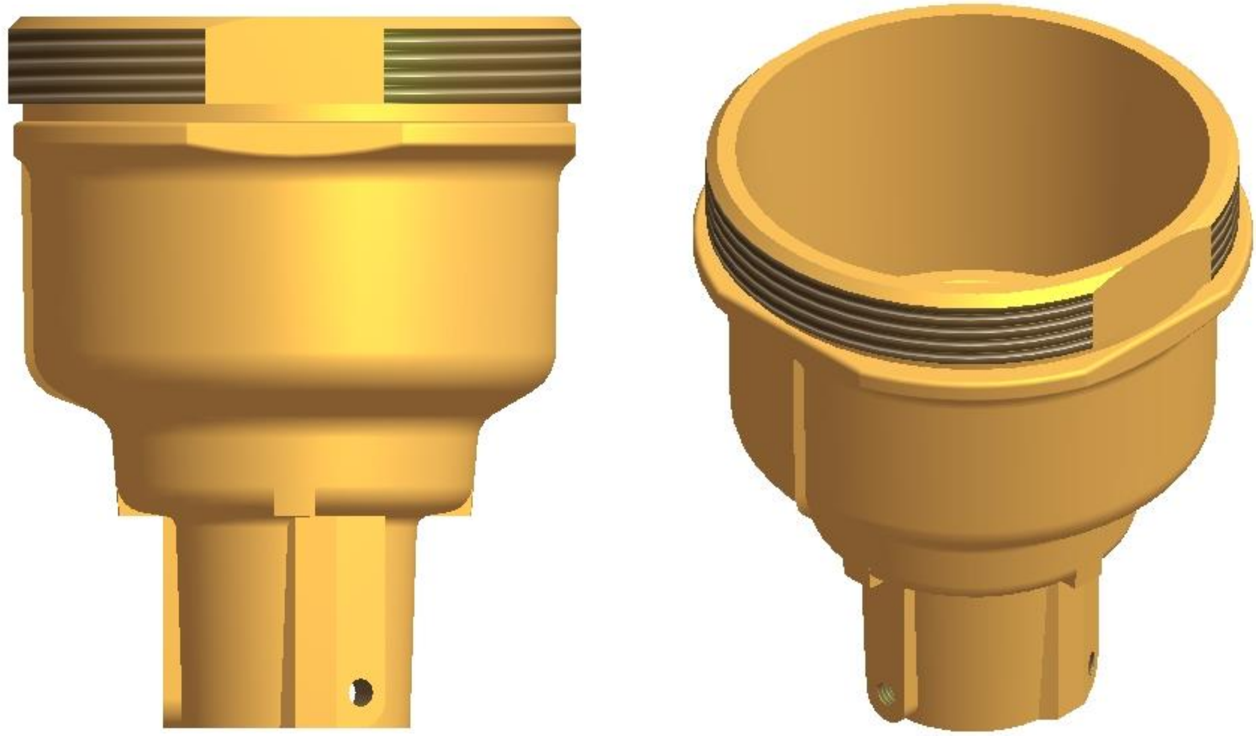


Figure 30 Design 2 main outer body

#### 4.3.4.4 Electronic housing

The housing is kept same as in the previous design, since the internal structure of the main outer body hasn't been changed. Only the height of the housing has been increased to compensate for the circlip spacing. With the new design the top surface of the housing lies in-line with the top of the main body as shown in picture below.

Also the gasket placed on top of the assembly will be more efficient at resisting water entry if the surface was even. To ensure better performance, the gasket was changed from 3mm compact to 10mm expanded silicone. This was done so that when pressure is applied by the blocking ring from the top, then the gasket compresses to fill in the gaps perfectly.

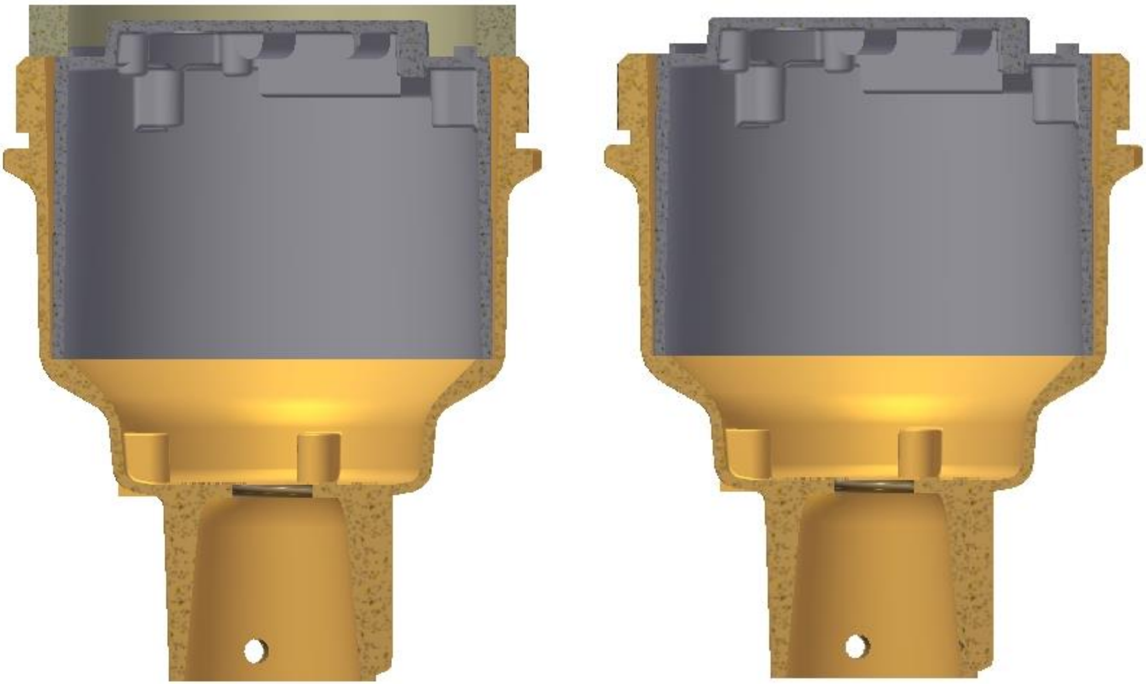


Figure 31 Assembly with and without gasket respectively

#### 4.3.4.5 Top polycarbonate cover

The design of the polycarbonate bowl was reconsidered after running a photometry test on the LED and lens assembly with the bowl. It was found that the areas which were glued together inhibited uniform distribution of light around the vertical axis.

So a new design was resolved which consisted of thermoforming polycarbonate sheets into required bowl shape. The final product would be a single piece item with no surface discontinuities to allow uniform light spread.

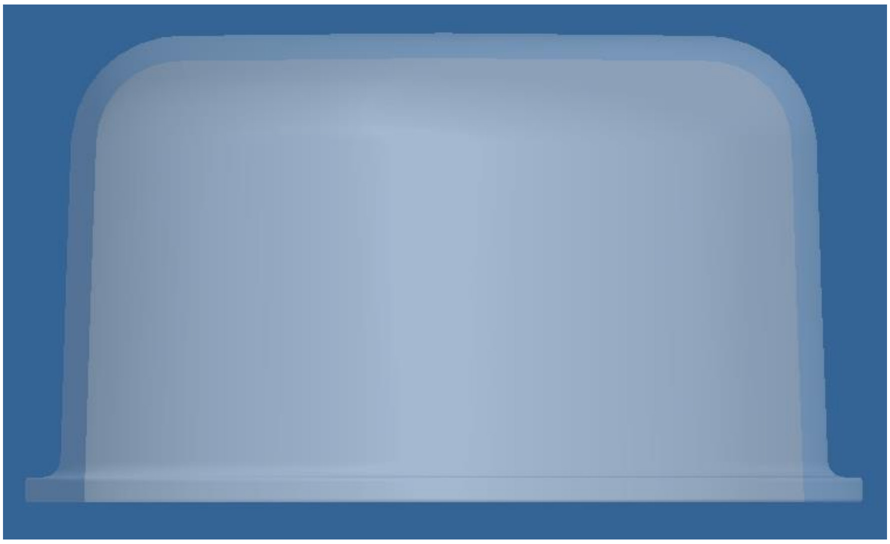


Figure 32 Polycarbonate thermoform bowl front view

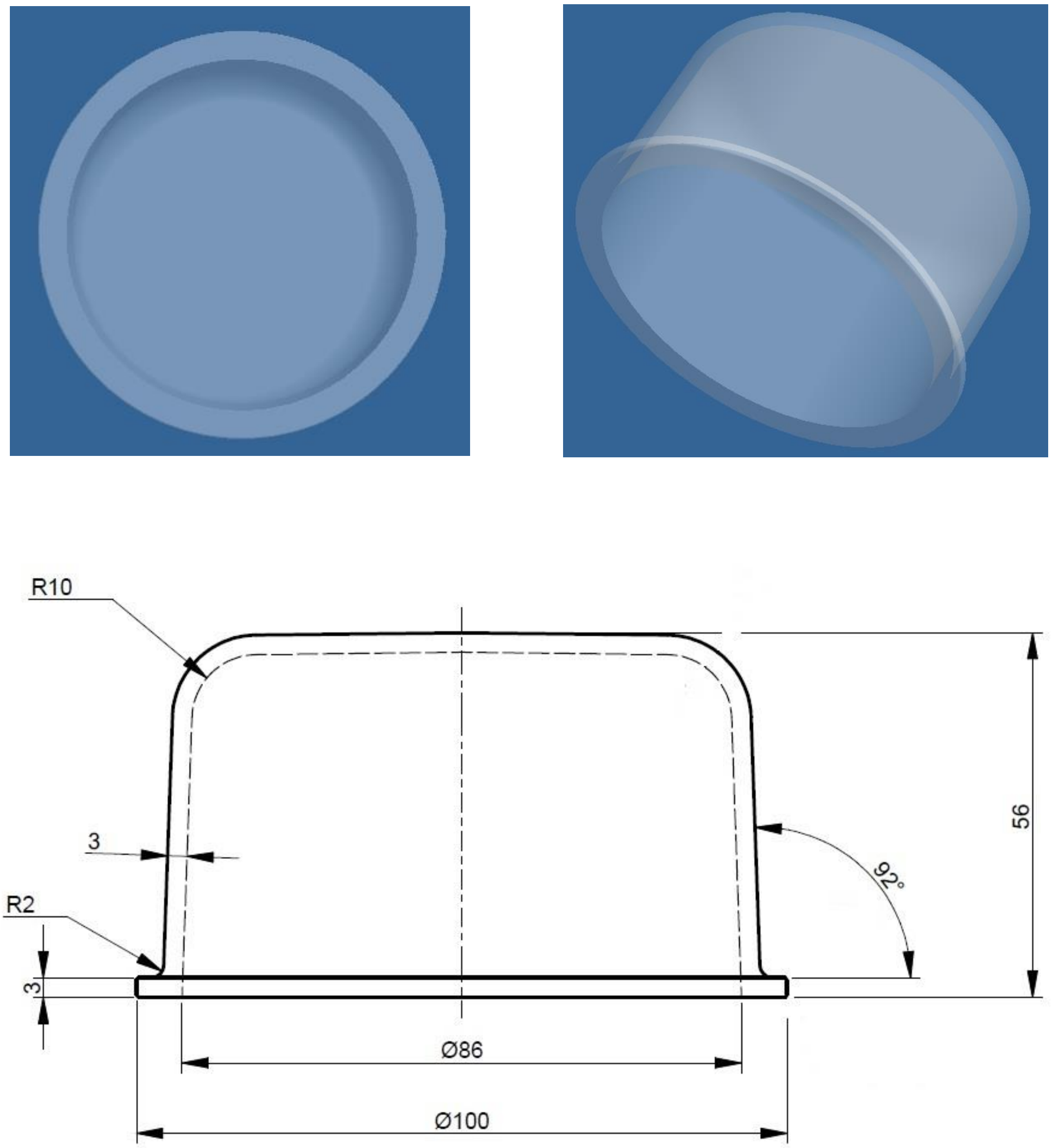



Figure 33 Polycarbonate thermoform bowl design

#### 4.3.4.6 Blocking ring

The concept is easy, to seal the assembly a constraining member needs to be included that can hold the top and bottom structure together. The lower ring is machined from aluminium tube Anticorodal 6060 (EN AW-6060) of external diameter 120mm and 15mm wall thickness.

EN AW-6060, an aluminium alloy of composition AlMgSi0.5, is a widely used extruded pipe. It is preferred when the parts produced need not to have any special strength properties and is quite suitable for coating applications. It also has high corrosion resistance and good machinability.

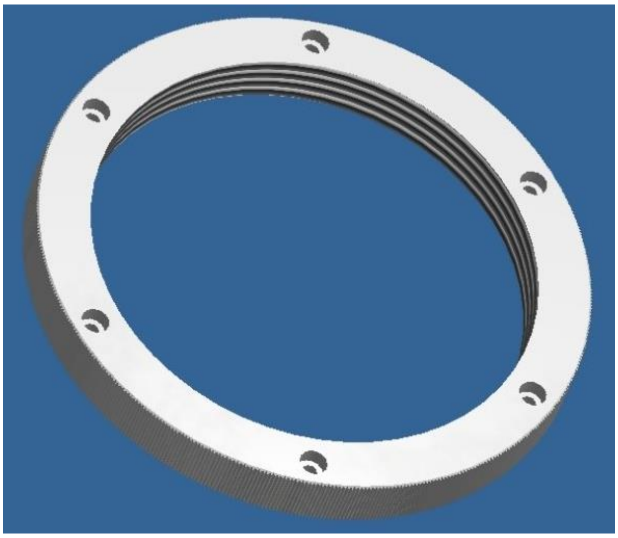
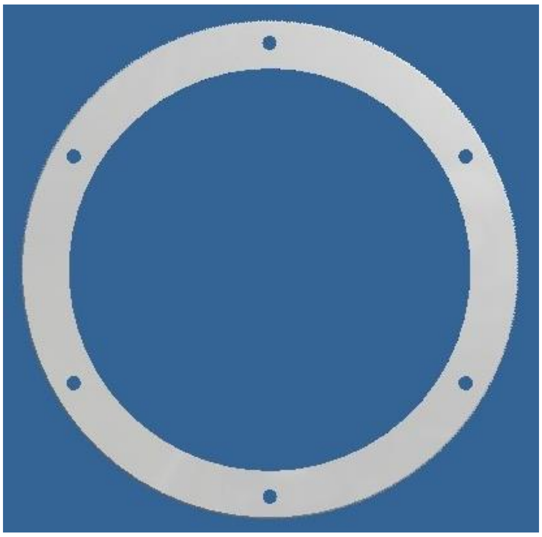
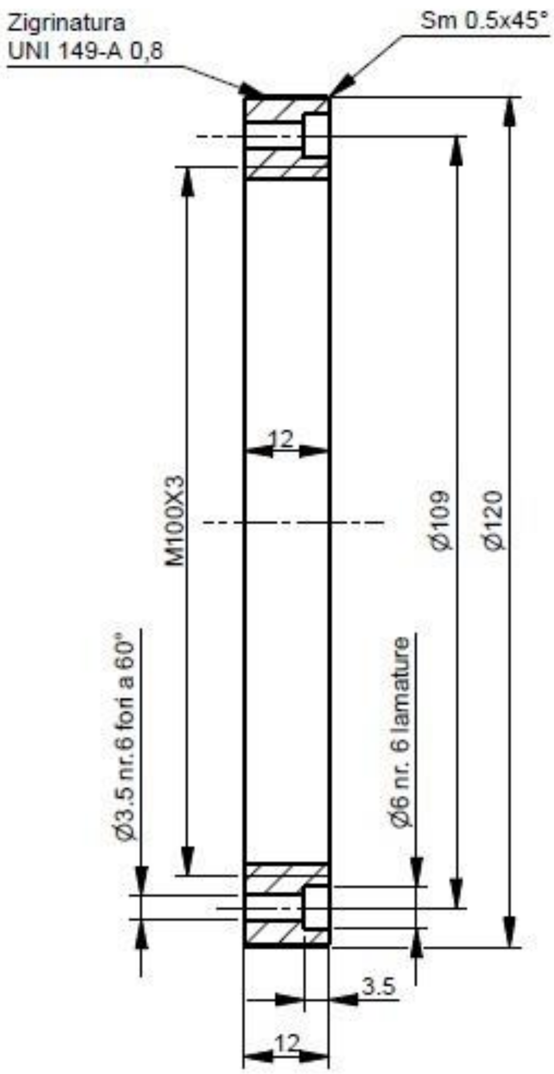





Figure 34 Bottom blocking ring

A facing operation is performed to decrease the height to 12mm. The inner diameter is then machined to have an M100x3 threads which can made with the surface of the main outer body as shown in the figure below.

The outer diameter is worked to contain linear Knurl of specification UNI 149-A0.8, where 0.8 is the knurling pitch. The angle of the profile is 90 degrees. The knurling is done to provide grip while tightening or loosening of the ring over the main body surface.

Six counter bore holes are provided at an angle of 60 degrees to join the lower ring with the top ring using M3x0.5 bolts.

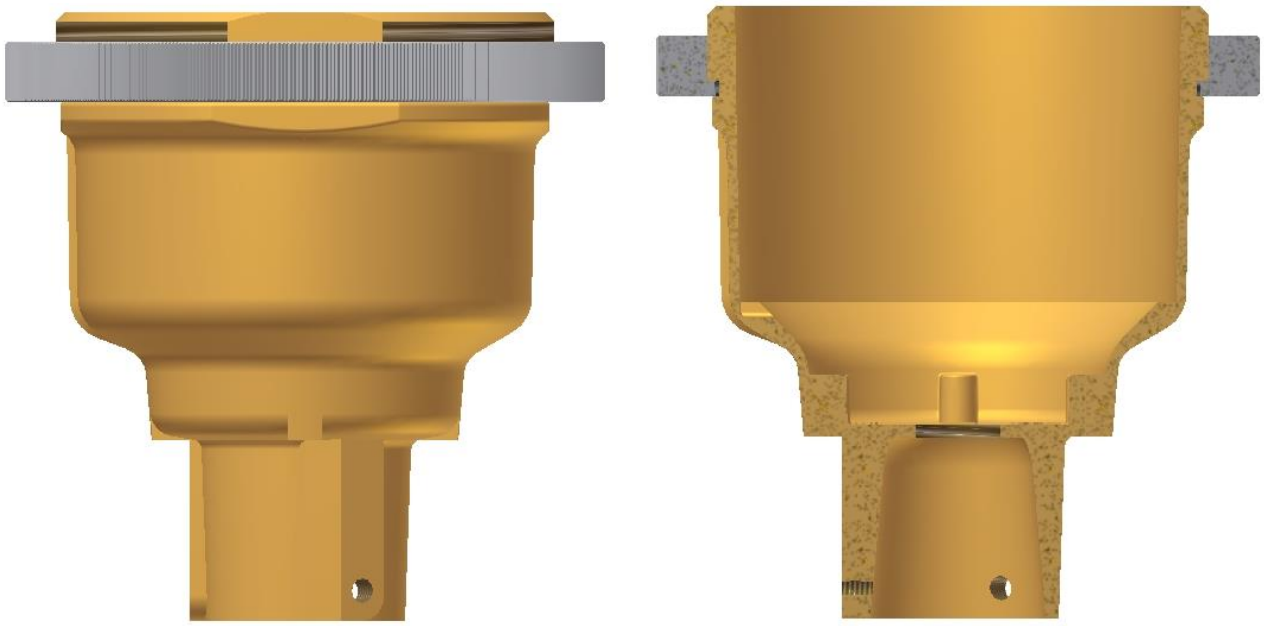
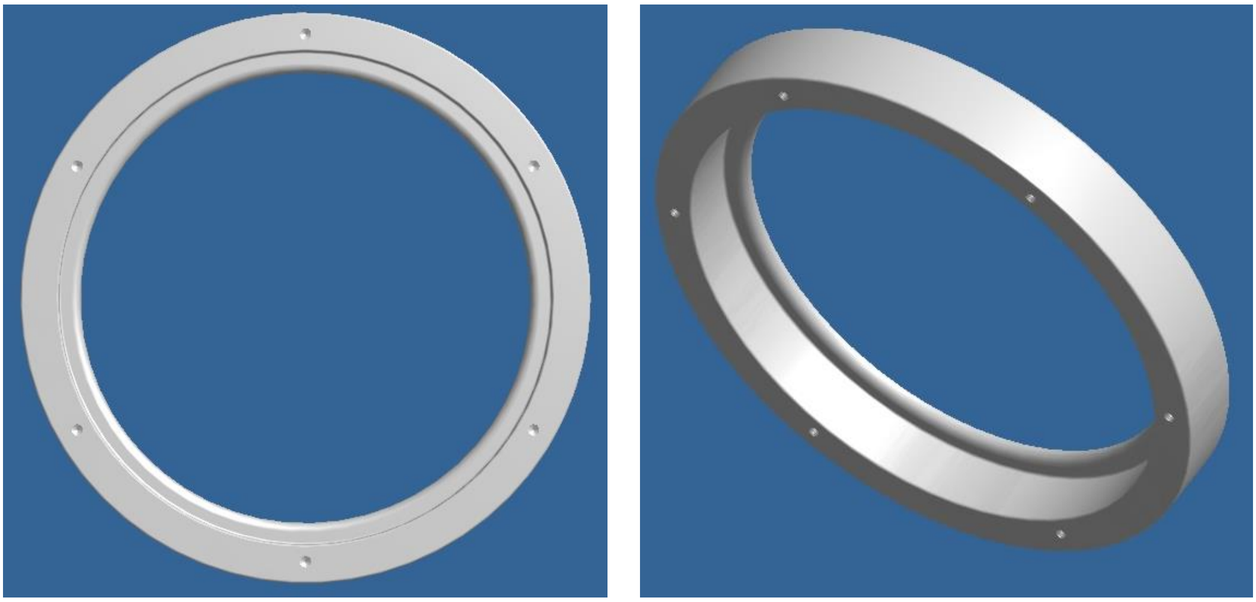


Figure 35 Bottom blocking ring with the main body

The top ring is machined from same raw material as the bottom ring. The total height of the part is 15mm, however turning is performed on the inner diameter to increase the dimension to 102mm up to the height of 12mm. The remaining 3 mm is turned with the final diameter of 93mm. this is done to cap the polycarbonate bowl from the top and restrict its motion in vertical direction. The outer diameter is also reduced to 118mm to cut down the weight.

Six M3x0.5 hole are drilled and tapped at an angle of 60 degrees on the bottom face for mating with the lower blocking ring.

Both the top and bottom ring undergo degreasing after machining, using solvents to devoid the surface off machining fluids. This is done to prepare the surface for phosphor chromatising to increase corrosion resistance and electrostatic painting with polyester based powder paint, semi-gloss white RAL9010. It is then cured at 180deg for 20min to allow the paint to flow and smoothen on the surface.



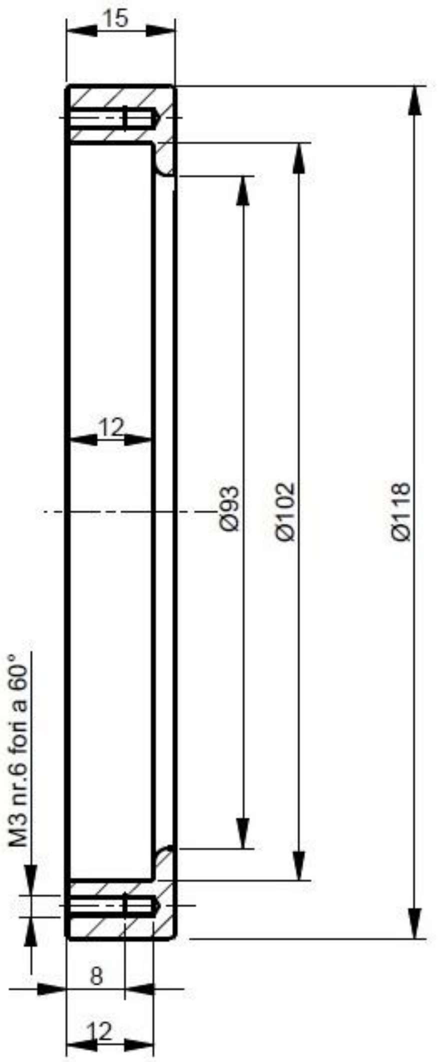



Figure 36 Top blocking ring

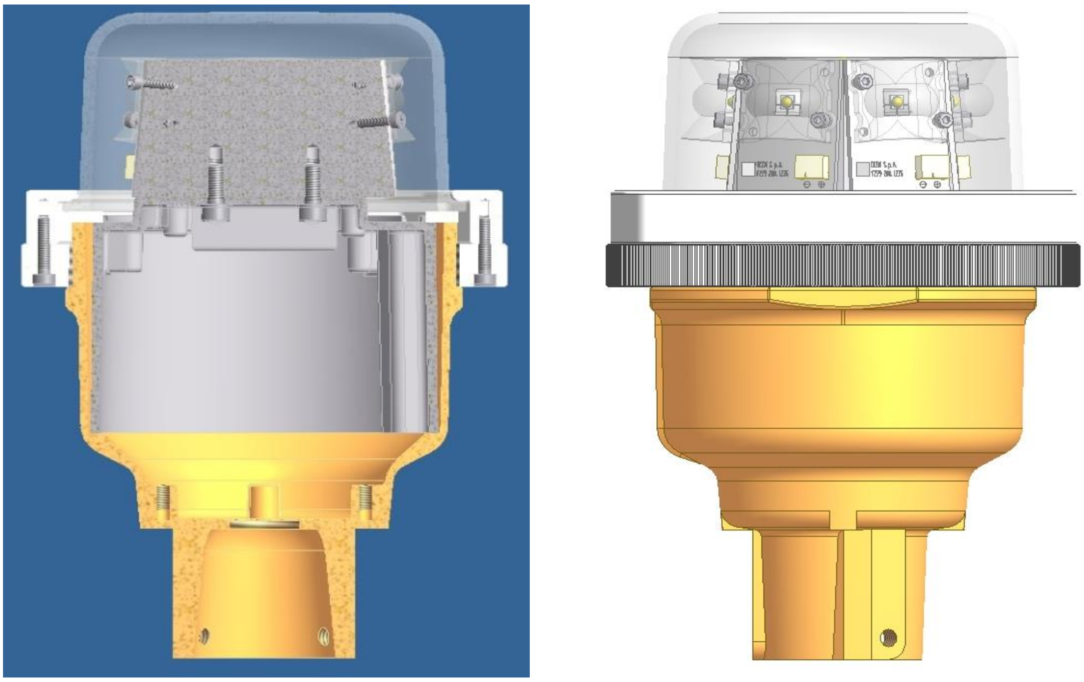


Figure 37 Top blocking ring assembled

#### 4.3.4.7 LED mounting base

The mounting base is kept same as before, only the central hole of M6x1 is removed as it is no longer required.

## 4.4 Final Design

After careful consideration, design 2 was selected on the account of its superior ability to resist water entry and less compliance. It would also provide more stability at greater height in case of lateral wind loading or jet blast.

Finally other accessories such as ground cable and plug for power supply, electronic power unit, and Cable gland with gasket to avoid water entry from below, are added to complete the luminaire structure.

The drawings for the final design are given below for reference.

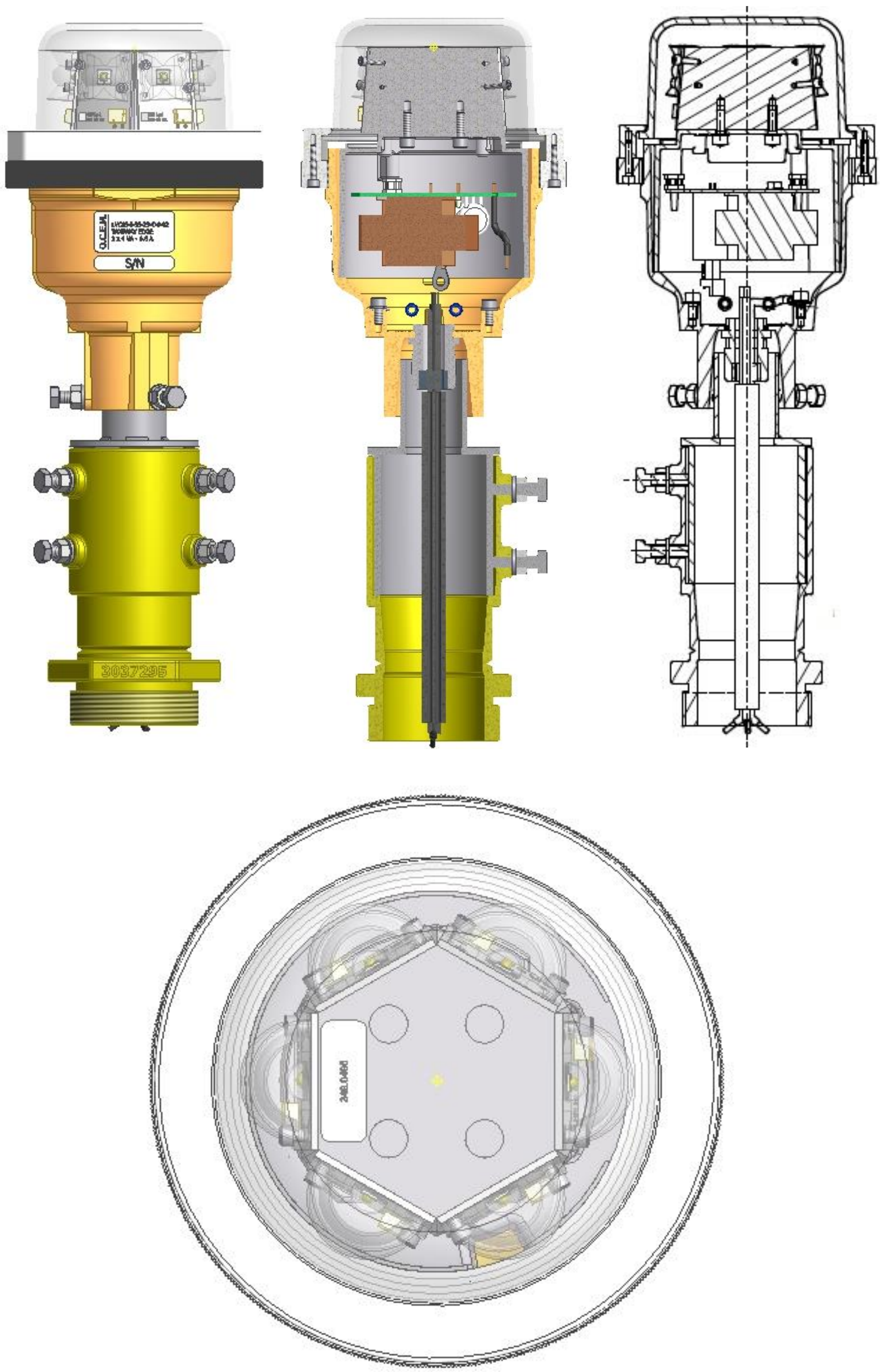



Figure 38 Final assembly for high altitude

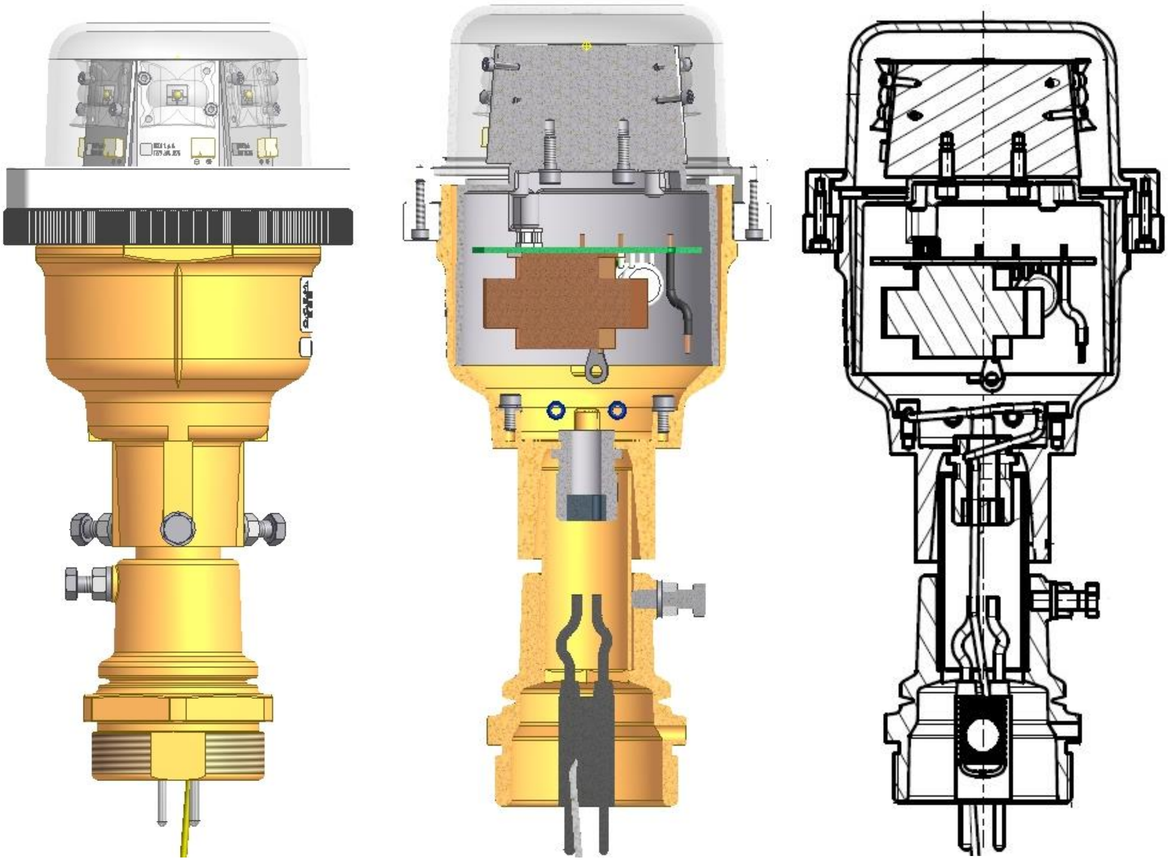


Figure 39 Final assembly less than 250mm height

# 5. DESIGN VALIDATION TESTS

Since the luminaire is still under production, actual tests have not been performed yet. But as part of my internship requirement, I carried out same set of tests on similar elevated lights used on heliports and airports.

Below are mentioned the procedure for the tests to be performed on the Heliport approach light once the luminaire comes back from production.

## 5.1 Corrosion test

All the major components of the luminaire are made of aluminium and then coated with standard paint to protect it from corrosion. Sometimes the parts are not treated adequately before applying paint coats, which can cause speck of dust to enter through a cracked paint edge and lead to scab corrosion or filmform corrosion. So it is necessary to run a corrosion test to confirm the quality of the part as well as the painting process. A well-known fact is that Aluminium resists corrosion due to formation of thin oxide layer on the surface, known as passivation. But passivation can become negligible when in contact with an acidic or alkaline solution to form hydrogen and aluminates respectively.

The conventional salt spray test is basically a comparative study of the quality of different painted products. So the following test was performed to know the difference in the corrosion behaviour between LERE (LED Elevated Runway Edge and Threshold/End Light) and LETE (LED elevated taxiway edge light, similar to LED Heliport Approach Light) in salt spray chamber.

(a) (b)

Figure 40 LERE and (b) LETE test samples

A salt spray chamber provides an environment for accelerated corrosion on the surface of the material to test its suitability for the required application. The test is time dependent, higher the corrosion resistance of a material, longer is the test duration.

The test is conducted in a closed chamber to avoid admission of dust or contamination. An atomizer is used to uniformly spray atomized sodium chloride solution on the test specimen through the nozzle. The specimen is then left exposed to the corrosive saline fog for the stimulated electrochemical reaction to begin. As per the requirement a 5% salt solution is used, known as Neutral salt spray or NSS. The results are mostly represented without the corrosion product and only in terms of testing hours in NSS (example: 96 h in NSS according to ISO 9227).

ASTM B 117 and ISO 9227 are the governing standards for construction of the chamber, test parameters and operations performed. These standards lay out the essential information regarding the test parameters such as chamber temperature, pressure of the atomized salt solution, solution preparation, concentration, pH, etc.

## 5.1.1 Equipment

### 5.1.1.1 Salt spray chamber

- DCTC 1200P Angelantoni CentroSud: It is Dry Corrosion Test Cabinet with a capacity of 1200 litres, capable of performing the conventional salt spray test.
- The chamber is made of single piece fibreglass reinforced plastic and polycarbonate nozzle mounted on hard plastic support for longevity.
- The P model makes use of PLC structure, which allows control of the test parameters like temperature, number of cycles and duration using a touch screen.

### 5.1.1.2 pH meter HD2105.2 DELTA OHM

- It is a portable instrument with an LCD display to measure the pH value of the salt solution
- The pH value is always accompanied with temperature measurement to contain the value within the specified limits.


Figure 41 Temperature-pH meter HD2105.2

### 5.1.2 Test specification and conditions

UNI EN ISO 9227:2012
IEC 6068-2-11

| | |
|---|---|
| Salt solution | 50 ± 5 g/l of NaCl (5%) |
| pH | 6.5-7.2 |
| Temperature | 35 ± 2˚C |
| K pluviometer | 1-2 cc/h |
| Control | 24-48-72-96 h |
| Test End | 96 h |
| Sample positioning | angle between 15-25 degrees vertical |
| Sample preparation | a cross cut preparation was made on the surface according to ASTM D 1654-79; UNI EN ISO 17872:2007. The cut was made to expose the base material to the salt fog |

Figure 42 Cross mark on the surface for test

### 5.1.3 Test results

No change occurred on the surface of the paint or the material exposed under the cross. No signs of corrosion or powdered chemical on the surface was found.

## 5.2 Degree of protection- IP rating

To stipulate the degree of protection necessary for the enclosures of electrical equipment, IEC publication 60529 furnishes a system known as ‘Classification of Degrees of Protection by Enclosures’. The IP rating or Ingress Protection provides information regarding resistance against person or intrusion of objects or entry of water inside the equipment. However, it does not cover the risks under the domain of explosions or conditions such as moisture produced by condensation, corrosive vapours, fungus and vermin.

The table below provides a reference to IEC enclosure classification designations. The table is quite simple to use. First go through the appropriate rating on the vertical axis in the left column to find the first numeral. Then associate it with the second numeral from the right column to specify the rating in terms of IP XX.

The Ingress Protection (IP) for all low voltage enclosures up to 1000 V a.c. and 1500 V d.c. is defined in identical fashion by the standards EN 60529 - IEC 529 it comprises the letters IP followed by two character numerals:

**The first character numeral** indicates the degree of protection provided by the enclosure with respect to persons, also to the equipment inside the enclosure.

**The second character numeral** indicates the degree of protection provided by the enclosure with respect to harmful ingress of water; a third character may be used to indicate mechanical strength. An x signifies that no test has been carried out.

**The first character numeral**
Protection against solid substances.

| IP | Test | Short description | Definition |
|---|---|---|---|
| 0 | | Non-Protected | No special protection. |
| 1 | ø 50 mm | Protected against solid objects greater than 50mm | A large surface of the body, such as a hand (but no protection against deliberate access) solid objects exceeding 50mm in diameter |
| 2 | ø 12.5 mm | Protected against solid objects greater than 12.5mm | Fingers or similar objects not exceeding 80mm in length; solid objects exceeding 12.5 mm in diameter |
| 3 | ø 2,5 mm | Protected against solid objects greater than 2.5mm | Tools, wires, etc...., of diameter or thickness greater than 2.5mm; solid objects exceeding 2.5 mm in diameter |
| 4 | ø 1 mm | Protected against solid objects greater than 1.0mm | Wires or strips of thickness greater than 1.0mm; solid objects exceeding 1.0 mm in diameter |
| 5 | | Dust-protected | Ingress of dust is not totally prevented but dust does not enter in sufficient quantity to interfere with satisfactory operation of the equipment |
| 6 | | Dust-tight | No ingress of dust |

**The second character numeral**
Protection against liquid substances.

| IP | Test | Short description | Definition |
|---|---|---|---|
| 0 | | Non-Protected | No special protection. |
| 1 | | Protected against dripping water | Dripping water (vertically falling drops) shall have no harmful effect |
| 2 | | Protected against dripping water when tilted up to 15° | Vertically dripping water shall have no harmful effect when the enclosure is tilted at any angle up to 15° from its normal position |
| 3 | | Protected against spraying water | Water falling as a spray at an angle up to 60° from the vertical shall have no harmful effect |
| 4 | | Protected against splashing water | Water splashed against the enclosure from any direction shall have no harmful effect |
| 5 | | Protected against water jets | Water projected by a nozzle against the enclosure from any direction shall have no harmful effect |
| 6 | | Protected against heavy seas | Water from heavy seas or water projected in powerful jets shall not enter the enclosure in harmful quantities |
| 7 | 15 cm | Protected against the effect of immersion | Ingress of water in a harmful quantity shall not be possible when the enclosure is immersed in water under defined conditions of pressure and time |
| 8 | m | Protected against submersion | The equipment is suitable for continuous submersion in water under conditions which shall be specified by the manufacturer |

Table 4 IP Rating Chart

Since the product is claimed to be designed to an IP rating (Ingress Protection) 47 so the tests are performed to check for the numeral 4 and 7.

1st Numeral 4- Protected against tools and wires over 1mm diameter; Protected against solid objects over 1mm in diameter

2nd Numeral 7- Protected against the effects of immersion between 15cm and 1mm

IEC 60598-1 ‘General Requirements and Tests’ section 9- Resistance to dust, solid objects and moisture, is the reference document used in order to examine the product. It specifies that the luminaires shall be tested in an ambient temperature between 10℃ and 30℃ and mounted as in normal use. And before the tests for second characteristics numeral, the luminaire complete with lamp shall be switched on and brought to a stable operating temperature at rated voltage.

The detailed test procedure has been described in chapter 2.

### 5.2.1 Test type and material sample

- Verification of degree of protection provided by IP47
- Luminous signal LED model- LETE (LED Elevated Taxiway Edge Light)

Figure 43 LETE sample for the test of degree of protection

### 5.2.2 Technical specification and characteristics

Standards- IEC EN 60598-1
Test duration-20days

Input current 6.6A (mandatory rating as per the airport power regulations)
Total power 1x5VA

Power signal for LED signal
Input 230Vac 50Hz 7A
Output 30Vac RMS max 6-7A

### 5.2.3 Test equipment and conditions

Test wire
6kV Dielectric strength tester
Tub Immersion
Thermohygrometer- Used to measure the content of moisture in the test chamber

Temperature- 23±1℃
Humidity- 48±5 %

### 5.2.4 Test for characteristic numerals

#### 5.2.4.1 First numeral- 4X protection against solid foreign objects

The rigid steel wire with a diameter of $1.0^{+0.05/0.0}$mm and length 100mm is pressed on the openings of the enclosure with the force of 1N±10%

Acceptance criteria:
The access probe shall not penetrate into the lamp

#### 5.2.4.2 Second Numeral- X7 protected against water immersion

Before the start of the test, the luminaire is suspended outside the water tub and it is switched at rated supply voltage until operating temperature is achieved (5h). The water temperature is 18 degrees

The test is made by completely immersing the enclosure in water in its service position as specified by the manufacturer so that the following conditions are satisfied:
Water tight luminaires are switched off and immediately immersed for 30min in water, so that there is at least 150mm of water above the top of the luminaire and the lowest portion is subjected to at least 1m head of water.
Luminaires shall be held in position by their normal fixing means.

Acceptance criterion*:*
At the end of the test, if the water has entered the enclosure, it must not:

- be sufficient to interfere with the correct operation of the equipment or impair safety
- deposit on insulation parts where it could lead to tracking along the creepage distances
- reach live parts or windings not designed to operate when wet
- accumulate near the cable end or enter the cable if any

At the end of the test, must be performed the test voltage between the phases short-circuit and earth to 1500Vac and there must be no destructive charges.

### 5.2.5 Result

Test for 1st Numeral- the probe does not penetrate into the lamp
Test for 2nd Numeral- no water entered the enclosure, the test voltage did not submit destructive charges

## 5.3 Wind load and frangibility

The wind load and frangibility test conducted below was performed on LERA (LED Elevated Runway Approach) Light fixture.


Figure 44 LERA (LED elevated runway approach) light

## 5.3.1 Applicable documents

### 5.3.1.1 ICAO 9157-aerodrome design manual- Part 6- Frangibility

- Wind: Light fixtures may be exposed to extreme wind loads and/or jet blast. Aerodromes should ensure that elevated runway and taxiway lights are capable of withstanding jet blast velocities from aircraft normally expected to operate. These are typically wind velocities of 480 km/h (260 kt) for all high- and medium-intensity lights and 240 km/h (130 kt) for all other elevated fixtures (low-intensity lights).

- Yield Device: The yield point should withstand a bending moment of 204 J without failure but should separate cleanly from the mounting system before the bending moment reaches 678 J. However, certain fixtures may bend instead of separating. In that case, the fixture should not bend more than 25 mm from vertical under the specified wind loading. Non-metallic yield devices should provide the specified performance over the designed temperature range with appropriate grounding capability for the attached fixture

### 5.3.1.2 FAA-150-5345-46D-runway-taxiway light fixture

- Wind loading: The manufacturer must demonstrate (by wind test or static loading) that, when subjected to the wind requirements in paragraph 3.2, no part of the light, mounting system, or yield device is damaged, and the light does not sway more than 1 inch (25.40 mm) with exception of L-804 that must not sway more than 2 inches (50.80 mm).

  Exposure to wind velocities of 300 mph (482 kmph) for all L-804, L-861, and L-862 fixtures, and 150 mph (241 kmph) for all other elevated fixtures.

- Yield device: The yield point must give way before any other part of the fixture is damaged, and must withstand a bending moment of 150 foot-pounds (203 Newton-meters (N-m) without failure. This yield point must also separate cleanly from the mounting system before the bending moment reaches 500 foot-pounds (678 N-m). However, L-860 fixtures may bend instead of separating. The fixture must not sway more than 1 inch from vertical under the specified wind loading.

## 5.3.2 Wind test procedure

To test for the wind resistance of LERA a wind load at the speed of 240 kmph and the point of application of load were calculated.

$$S = S_1 + S_2 = L_1 H_1 + L_2 H_2$$

$$h_G = [S_1 (h_{G1} – h_{YD}) + S_2 (h_{G2} – h_{YD})] / S = [S_1 (0.5 H_1 – h_{YD}) + S_2 (0.5 H_2 + H_1 – h_{YD})] / S$$

$$F_w = ½ ρ Cd S V^2$$

$$M = F_w h_G$$

With:
$F_w$ = Wind force [N]
ρ = Air density @15°C = 1.2 kg/$m^3$
Cd = Drag coefficient. A value of 1.4 is given on a rectangular surface in 90° incidence
S = Surface [$m^2$]
V = Wind velocity = 240 km/h = 67 m/s
M = Moment [Nm]

$h_G$ = Height [m] of the centre of gravity in where the resulting force would be applied from yield device

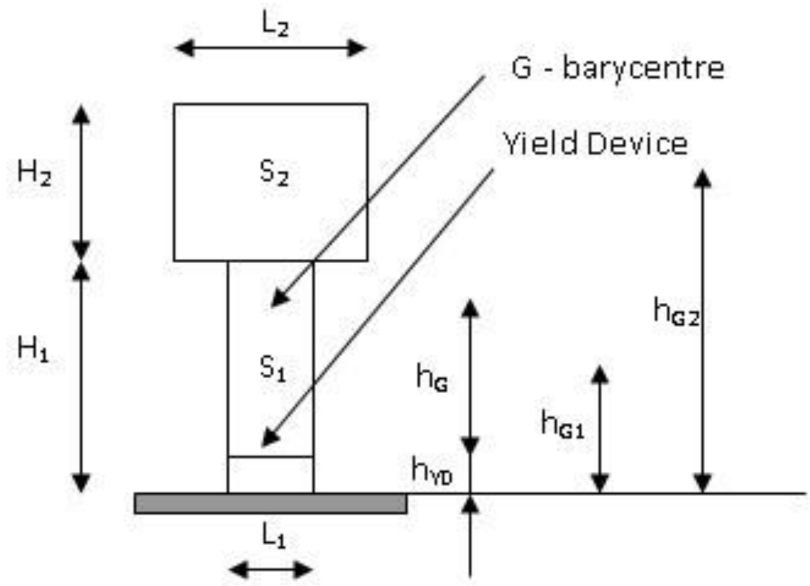



Figure 45 Diagram for wind test calculation

The required test force was calculated as follows
$F_T = M / h_F$

$F_T$ = force applied to the fixture to simulate the moment due to wind on the yield device [N]
$h_F$ = distance between the force and the yield device [m]

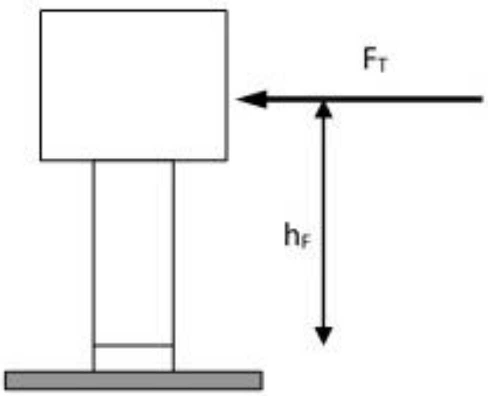



Figure 46 Schematic representation of wind load simulation

#### 5.3.2.1 Test calculation for 2m pipe with 10mm pipe thickness

$S = S_1 + S_2 = L_1 H_1 + L_2 H_2 = 148800 \text{ mm}^2$
$h_{YD} = 30\text{mm}$
$h_{G1} = H_1/2 = 2105/2 = 1052.5 \text{ mm}$
$h_{G2} = H_1 + H_2/2 = 2105 + 150/2 = 2180 \text{ mm}$
$h_G = [S_1 (h_{G1} - h_{YD}) + S_2 (h_{G2} - h_{YD})] / S = 1193 \text{ mm}$

V= 240 kmph

$F_w = ½ ρ Cd S V^2 = 567.1$ N
$M = F_w h_G = 676.5$ Nm

$h_F = 150$ mm
$F_T = M / h_F = 4510.2$ N

The yield device should be able to withstand the calculated test force in order to pass the test. The values for applied load after varying the pipe length and thickness are as below.

| Pipe length (mm) | Diameter (mm) | Wall thickness (mm) | Moment generated by wind (Nm) | Test load (N) |
|---|---|---|---|---|
| 2000 | 60 | 20 | 677 | 4510 |
| 1800 | 60 | 10 | 569 | 3794 |
| 1500 | 60 | 5 | 425 | 2833 |
| 1000 | 60 | 5 | 231 | 1538 |
| 500 | 60 | 4 | 93 | 623 |

Table 5 Applied load for varying pipe diameter

### 5.3.3 Frangibility test procedure

As per ICAO the minimum resistance condition has been stated as 204 Nm whereas IEC requires it to be 408 Nm. Therefore, the higher value was chosen to calculate minimum required force of resistance. The yield device should break below 678 Nm as per IEC, ICAO and FAA.

$M_{min} = 408$ Nm
$M_{max} = 678$ Nm

$F_{T\_min} = M_{min} / h_F$
$F_{T\_max} = M_{max} / h_F$

$F_{T\_min}$ = Minimum applied force the yield device should withstand [N]
$F_{T\_min}$ = Maximum load before which the yield device should break [N]
$h_F$= point of application of load [m]

The results obtained from the test are as below

| Regulation | M [Nm] | $h_F$ [mm] | F [N] | Test Result |
|---|---|---|---|---|
| min ICAO/FAA | 204 | 135 | 1511 | Pass |
| min IEC | 408 | | 3022 | pass |
| max ICAO/FAA/IEC | 678 | | 5022 | Breaking at 3455N-pass |

Table 6 Frangibility test results

### 5.3.4 Test for maximum deflection of light structure

The light structure when subjected to a wind load should have a deflection in a permissible range as required by the document. The calculation was done as follows.

$J = \pi [d^4 - (d-2t)^4]/64$

P= M/ L

$f = \frac{P L^3}{3 E J}$

$\alpha = \frac{P L^2}{2 E J} * \frac{180}{\pi}$

With:

J = Moment of inertia [$mm^4$]
P = applied load [N]
M= moment generated by the wind [Nmm]
L = height of full light structure [mm]
t= pole thickness [mm]
f= deflection [mm]
α = angular deflection [deg]
E= Young's modulus of the material [70000 $N/mm^2$]

Test calculation for 2m pipe with 10mm pipe thickness

J= 510508.8 $mm^4$

P= M/ L = 676.5/2.3 = 300 N

f= 32.1 mm

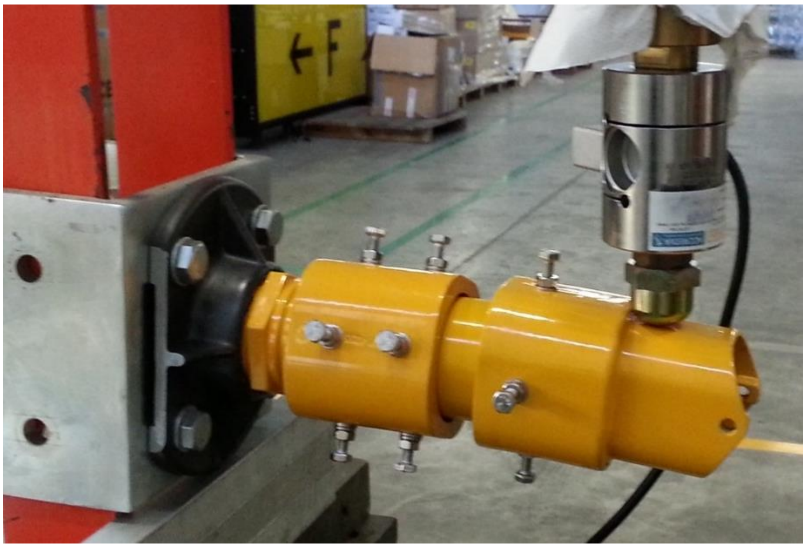
α =1.2 deg

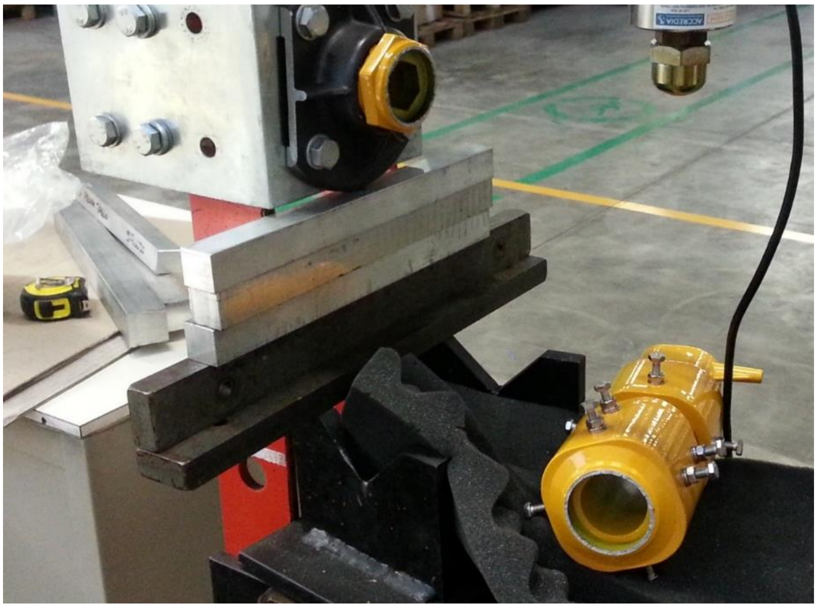
The values for varying deflection after changing the pipe length and thickness are as below

| Pipe length (mm) | Diameter (mm) | Wall thickness (mm) | Deflection, f (mm) | Angular deflection, α (deg) |
|---|---|---|---|---|
| 2000 | 60 | 20 | 26.1 | 1.0 |
| 1800 | 60 | 10 | 22.4 | 0.9 |
| 1500 | 60 | 5 | 18.9 | 0.9 |
| 1000 | 60 | 5 | 5.3 | 0.4 |
| 500 | 60 | 4 | 0.9 | 0.1 |

Table 7 Varying deflection of the pole with different pipe diameters

From the above table it can be seen that while the pipe length is decreasing, we can reduce the wall thickness along with it and keep the deflection below 1in from the vertical.





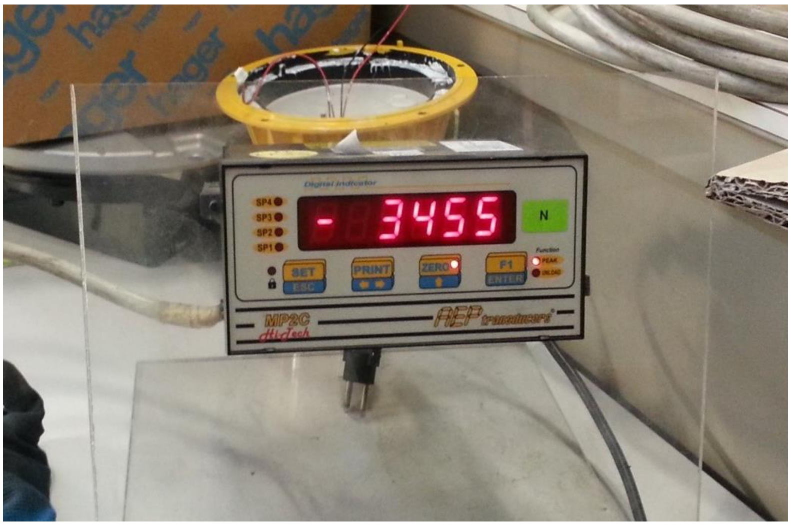



Figure 47 Wind load and frangibility test

## 5.4 Temperature test

### 5.4.1 High temperature test

The temperature test is conducted to check for the defects in the luminaire or behavioural changes associated with high and low temperature in the range of -55℃ to +55℃.

The test is conducted as per the procedure described by IEC 61827, the rules of which has been paraphrased in Chapter 1 above.

The test was conducted on LETE (LED Elevated Taxiway Edge) light structure. At the beginning of the test the room temperature was measured to be 19℃. The rules specify the test to be performed at an ambient temperature of 20℃ ± 5℃.

For the high temperature test, the luminaire was erected in normal operating condition while being powered at the rated current of 6.6A. It was then energized at 55℃ for 24hrs at a stretch.

*Result: No change in the structural performance or luminosity of the light*

### 5.4.2 Low temperature test

The test for low temperature was conducted in the test chamber at the minimum temperature of -55℃ with for 24hours. The light was operated for 5miutes before the initiation of the test and 5minutes after the end.

*Result: No change in the structural performance or luminosity of the light*

### 5.4.3 Test for water tightness of the gasket

Another test was conducted to check the water tightness of the gasket after being subjected to extreme temperature variations. The test was performed on four different samples of gasket in order to select the better product from the available samples for LED Elevated Taxiway Edge Light (LETE).

| **Gasket sample** | **$T_{ambient}$ (℃)** | **$T_{water}$ (℃)** | **$T_{LETE}$ (℃)** | **Comments** |
|---|---|---|---|---|
| Silicone Rosso | 19 | 18 | 46 | No sign of water entry inside the signal assembly. |
| Silicone Bianco<br>Silicone Bianco 8mm | 19<br>19 | 18<br>18 | 42<br>-40<br>46 | • Slight entry of water; visible drops on the gasket<br>• The material retains flexibility at low temperature<br>• No leak |
| EPDM-N12 | 19 | 17 | 41 | Water inside the cylindrical chamber |
| Poron 4701-30 | 20 | 19 | 47<br>-40 | • Considerable amount of water accumulation inside the cylindrical chamber<br>• Occurrence of slight embrittlement at low temperature |

Table 8 Test results for water tightness of the gasket

Each sample, complete with the LETE signal assembly, was kept at a temperature of 55℃ in the test chamber for 2hours. The signal was then immersed in water at room temperature for 5minutes and then was manually checked for any kind of leakage inside the signal assembly.

A second test was performed at low temperature to check for the embrittlement of the gasket material. The sample was placed in the test chamber at -40℃ for 45 minutes and then checked for retention of flexibility.

*Result: Silicone Bianco was selected but it was decided to go for a higher thickness of 10mm to ensure complete water sealing*

# 6. Conclusion

As the current market has shifted the focus to higher efficiency of the light provided by LEDs, switching from incandescent to LED approach light has become a necessity. So the final design of the luminaire was remarkably influenced by the need for a brighter and more uniform light source.

A number of LED brands were tested and simulations were run to obtain the light with high luminosity and uniformity. Also the important factor that contribute towards uniformity is the type of lens that is introduced with LED. If the lens is incapable of furnishing homogeneity of light around the axis then even the best LED will be rendered inefficient. So after a careful consideration, lens with Flare was preferred over the more commonly used Heidi design type. The final selection was Ledil CA10932 Flare-B lens from Philips Lumileds in combination with LED 5000 TX with a luminous flux of 195lm at 500mA. This LED has an efficiency of 93% which guarantees a superior transmissivity and a final flux value of 190lm.

The outer body to encase the electronic assembly was finalised after debating over a dozen designs, out of which only the major two have been discussed here. The underlying factors were weighed before zeroing in on the design- conformity with the standards, raw material procurement, ease of production, time to assemble, total cost and aesthetics.

Design 1 comprised of fewer parts making it a lighter structure out of the two proposed models and also required less time to assemble. But it did not have the ability to avoid water entry as required by the standards. Also special tools would be required to assemble the luminaire because of the unconventional design. So the model was altered to have higher mechanical strength and better ingress protection grade of the surface.

To shave off weight from the structure, all metallic components will be cast or machined from aluminium, with the selected grade depending on the purpose of the part and the availability of the raw material. The top cover for the LED-lens assembly will be shaped by thermoforming polycarbonate sheets instead of the heavier glass bowl used in the older models.

Levelling screws will be used to connect the mounting pole to the yield device at the bottom end and main outer body on the top end of the pole. This is done to save time during assembly and maintenance and provide compliance to the structure so that it can hold up against high speed wind and jet blast from the aircraft. Also it disregards the use of special tools during assembly.

The yield device is threaded into the base with the yield position being cast into the component, thereby saving machining cost and inclusion of additional parts like fuse bolts or gusset plates to provide the necessary frangibility. Different yield device will be used for lights required for low and high altitude. This is done basically to support the different pole length varying between 150mm to 2000mm.

The finalised design will be tested for the ability to withstand wind loading and jet blast, conformity with frangibility criterion, temperature and corrosion tests, in order to demonstrate compliance with civil aviation protocol. Since the luminaire is still in production, all the experiments will be performed at a later stage. However, the calculation for wind load and frangibility has been extemporised and the results corroborate the assumptions.

The procedure for the tests, however, remain same and have been discussed in detail as performed on similar light structures. In case the tests show the design to be in disagreement with the regulations, the design will be reviewed and altered as required. The modified design will repeat the steps from production to testing till all the standards are met.

The design still has a scope of improvement in future depending upon the market trend and technological shift. However, it is safe to say that at the moment this product is most efficient and cost effective in the current market and of superior quality when compared to the products of the competing organisations.

## REFERENCES

[1] International Standards and Recommended Practices "Annex 14 to the Convention on International Civil Aviation-Volume I Aerodrome Design and Operations", ICAO 6th Edition, July 2013

[2] International Standards and Recommended Practices "Annex 14 to the Convention on International Civil Aviation-Volume II Heliports", ICAO 4th Edition, July 2013

[3] ICAO doc 9157 AN/901 "Aerodrome Design Manual - Part 6 Frangibility", 1st Edition, 2006

[4] IEC Technical Specification (TS)- 61827 "Electrical installations for lighting and beaconing of aerodromes- Characteristics of inset and elevated luminaires used on aerodromes and heliports", 1st Edition, 2004-05

[5] IEC 68-2-11 "Basic environmental testing procedures- Part 2 Test Ka- Salt mist", 3rd Edition, 1981

[6] IEC 60598-1 "Luminaires- Part 1 General requirements and tests", 6th Edition, 2003-10

[7] NATO Standardization Agency (NSA) Standardisation Agreement (STANAG)-3619 "Helipad marking and lighting", 4th Edition, November 2007

[8] Federal Aviation Administration (FAA) Advisory Circular (AC) - 150/5345-46D "Specification for runway and taxiway light fixtures", Edition 19th May 2009

[9] Federal Aviation Administration (FAA) Engineering Brief (EB) - 67D "Light sources other than incandescent and xenon for airport and obstruction light fixtures", Edition 6th March 2012

[10] Alex Meyer "Light Measurement Handbook", International Light Inc., Edition 1998

[11] International Commission on Illumination "CIE 1931 XYZ Color Space"

[12] Standards CE and IEC classification, "International standards IP protection classification"

[13] "Optical measurements-Radiometry and Photometry" by Edward F. Zalewski, Hughes Danbury Optical Systems, Danbury, Connecticut

[14] "Progettazione Ottica Roncati"- http://www.progettazioneottica.it/en/design/led-lighting

[15] "Intertek-Valued Quality. Delivered"- http://www.intertek.com/lighting/performance-testing/airport-lighting/

[16] "Devices, measurements, and properties-Vol II", Sponsored by Optical society of America-McGraw-Hill Inc.

[17] http://www.gamma-sci.com/wp-content/uploads/2012/06/Photometry-and-Photometric-Testing-Guide-UDT-Instruments.pdf

[18] "Effects of warm white, cool white and full-spectrum fluorescent lighting on simple cognitive performance, mood and ratings of others", by Paul F. Boray, Robert Gifford and Lorne Rosenblood

[19] "Seesmart LED- How to choose the right LED lighting product color temperature"

[20] "Calculating color temperature and illuminance using the TAOS TCS3414CS Digital color sensor", by Joe Smith, February 27th 2009.

[21] http://www.lumileds.com/products/luxeon-tx

[22] "The CIE Chromaticity diagram", by Denbigh Starkey

[23] http://www.ledil.com/products/?search=true&led=LUXEON+TX

[24] "Philips-Making white light from blue LED"

[25] "Efficient blue light-emitting diodes leading to bright energy-saving white light sources", compiled by the Class for physics of the Royal Swedish Academy of Sciences.

[26] "http://www.elbasrl.com/wp-content/themes/elba/catalogo_elba.pdf"- Material supplier product catalogue

[27] "http://www.commercialefond.it/wp-content/uploads/2014/09/Commerciale_Fond_ALLUMINIO.pdf"- Material catalogue by supplier