IALA GUIDELINE

1023

THE DESIGN OF LEADING LINES

Edition 1.1

December 2005

10, rue des Gaudines - 78100 Saint Germain en Laye, France
Tél. +33 (0)1 34 51 70 01- Fax +33 (0)1 34 51 82 05 - contact@iala-aism.org
www.iala-aism.org

International Association of Marine Aids to Navigation and Lighthouse Authorities
Association Internationale de Signalisation Maritime

DOCUMENT REVISION

Revisions to this IALA Document are to be noted in the table prior to the issue of a revised document.

Date	Page / Section Revised	Requirement for Revision
December 2001	1st issue	
December 2005	Ed1.1. Entire document reformatted	Reformatted to reflect IALA Documentation Hierarchy

CONTENTS

CONTENTS

CONTENTS

CONTENTS

List of Tables

List of Figures

List of Equations

CONTENTS

1 INTRODUCTION

1.1 PURPOSE

The purpose of this publication is to enable a person with little or no knowledge of the fundamentals of leading line design to make use of a computer design program for leading lines. **The computer program is attached to the electronic version of the present Guidelines.**

1.2 FEATURES

The computer program has the following features:

a Runs as a workbook in Microsoft Excel®. This format allows various leading line parameters to be entered and modified in any order.

b The output is immediately displayed a change to any of the design parameters results in an immediate update of the program output.

c Provides recommended intensities in addition to the minimum and maximum intensities, in an effort to provide improved service to the mariner.

d Allows for evaluation of the performance of both existing and proposed optics.

e Lateral Sensitivity is expressed as Cross-Track Factor and lends a more physical feel to the performance of the leading line.

f In addition to evaluating the suitability of proposed night-time leading lights, the program also provides for the evaluation of the performance of daytime leading lights or leading marks. Note, off-axis distances and cross-track factors provided by the program are based on the performance of light signals only. When leading marks are used, these performance values are based on the night-time light signals only. The performance of the design using daytime leading lights, however, is evaluated separately from the performance based on night-time lights. When both light signals and dayboards are to be used, this program presumes the light signals are mounted atop the dayboards. It is possible to consider lower positions of the front signal light relative to the dayboard by taking the additional step of entering the front dayboard as an obstruction to be accounted for in the design of the leading line.

g Configurations & Constraints. Section 5 provides advice on standard configurations and practical constraints on the design of leading lines. Addressing these issues will enable the novice designer to produce leading line designs that perform as expected and can be safely maintained by servicing units. The Leading Line Category Selection Aid, found in section 5.9, may assist in determining how best to mark the leading line.

1.3 PROGRAM BASIS

The equations and evaluation factors used in the design program are taken from the IALA Recommendation E-112 for Leading Lights and are explained in detail in section 6. Further references to this document will be made as 'the IALA Recommendation.'

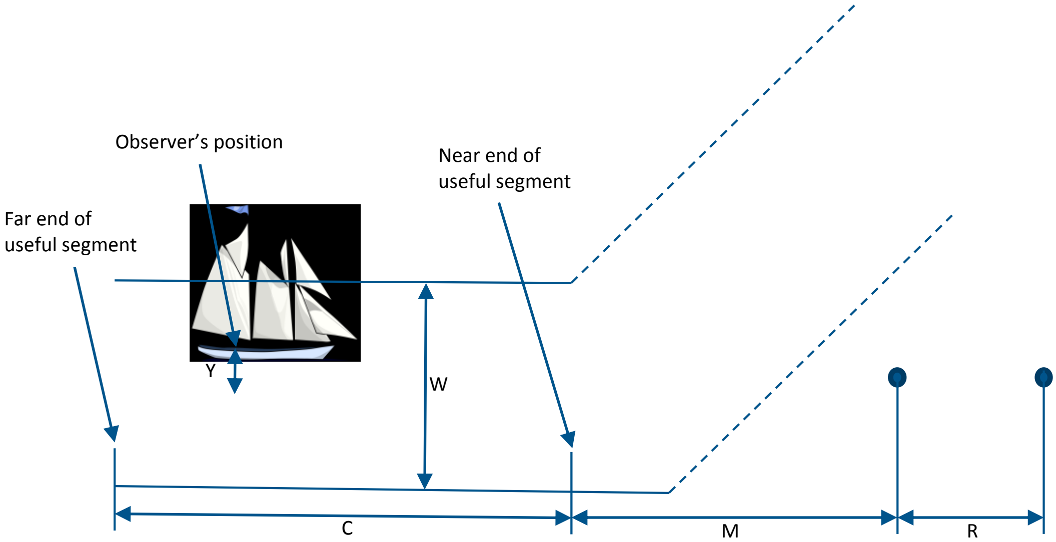
2 BASICS OF LEADING LINE DESIGN

2.1 DEFINITION OF A LEADING LINE

A leading line is defined in the IALA International Dictionary of Aids to Navigation as: 'a straight line used for navigation produced by the alignment of marks (leading marks) or lights (leading lights) or by the use of radio transmitters.' This document is limited to the discussion and design of leading lines based on leading marks (daymarks) and leading lights. Vertical alignment of lights or marks defines the centerline of a channel.

2.2 VIEWS OF A LEADING LINE

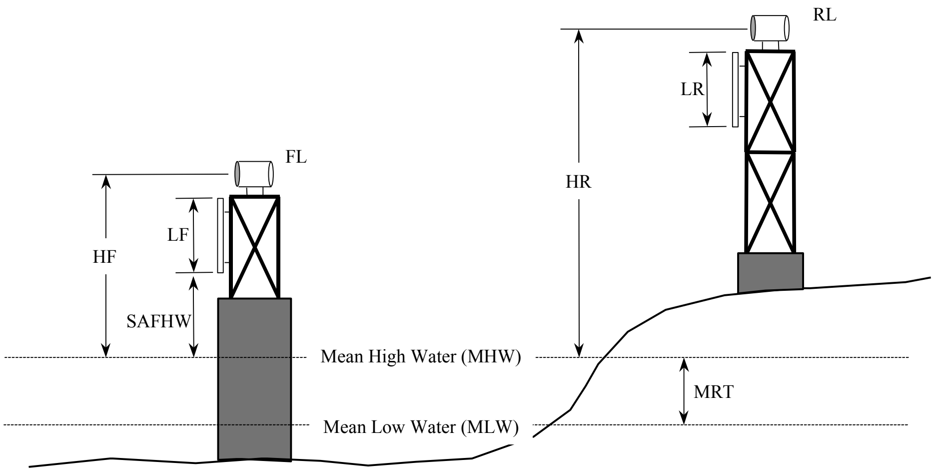
i) Figure 1 shows a plan view of a leading line and defines some variables.



C Length of useful segment (channel length)
W Channel width
M Distance to front structure from near end of useful segment
R Distance between leading line structures
Y Distance of observer from centre line of channel

Figure 1 Plan view of a leading line

ii) Figure 2 is a side view of leading line structures with some additional variables of interest defined. Note, structure (tower) heights are referenced above mean high water (MHW).

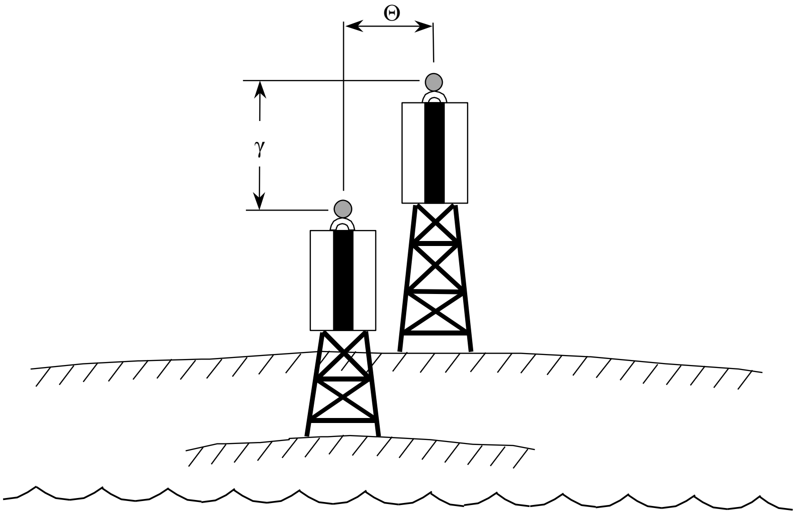


FL = Front Leading Light
LF = Length of Front Leading Mark
HF = Height of Front Tower (above MHW)
SAFHW = Safe Height Above Water

RL = Rear Leading Light
LR = Length of Rear Leading Mark
HR = Height of Rear Tower (above MHW)
MRT = Mean Range of Tide

Figure 2 Side view of leading line structures (towers)

iii) Figure 3 is a front view of the leading line structures as seen from a vessel located to the right of the channel centerline. It also shows the horizontal (Θ) and vertical (γ)angles created by the lights as viewed by the observer.



Θ = Bearing difference between the leading lights
γ = Elevation difference between the leading lights

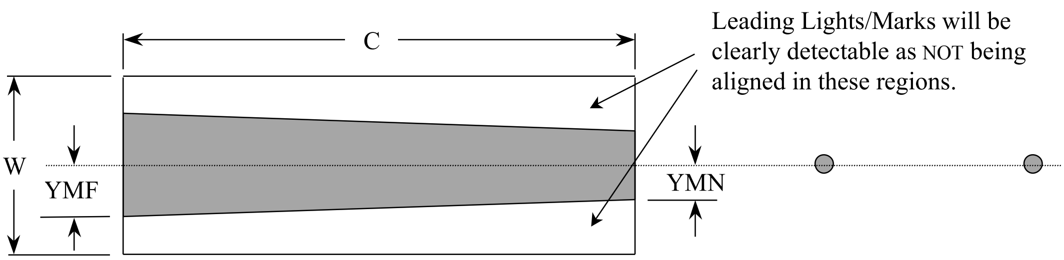
Figure 3 Front view of leading line structures

2.3 CHANNEL LENGTH

The preliminary decision in designing a leading line is to specify the segment of water to be defined by the leading line. Generally, it is costly to build a leading line to serve a long channel, as the rear leading light must be of sufficient height to be clearly visible above the front structure. Leading marks must also be large enough to be visible from the far end of the channel. Both of these conditions result in increases to the required height of the rear structure marking a long channel. The structures must also be sturdy enough to support the leading mark under wind loads. The use of other aids (fixed beacons or buoys) may reduce the overall cost of marking the waterway by reducing that portion of the channel marked by the leading line.

2.4 OFF-AXIS DISTANCE

The off-axis distance is the perpendicular distance from the centerline at which the observer will detect *with certainty* that the leading lights are no longer vertically aligned (Figure 4). The calculated off-axis distance returned by the program, using Equation 15 from IALA Recommendation E-112, is based on the bearing difference calculated by Equation 3 (Θ_D) from IALA Recommendation E-112.



YMN = Off-axis distance at near end of channel.
YMF = Off-axis distance at far end of channel.

Figure 4 Off-axis distance of a leading line

The design of a leading line should provide sufficient room for the various 'nautical margins' needed to navigate the channel with safety, dependent on the types of ships and navigation conditions that will be encountered, between the off-axis distance and the channel edge. This is discussed more thoroughly in Section E, below.

2.5 LATERAL SENSITIVITY—CROSS-TRACK FACTOR

2.5.1 CROSS-TRACK FACTOR

The computer program for leading line design generates a cross-track factor based on the off-axis distance related in the IALA Recommendation for Leading Lights to the bearing difference, Θ_D. The cross-track factor is defined to be a ratio of the lateral distance at which a mariner can detect with certainty that a vessel is not on the channel centerline, divided by half the channel width, and expressed as a percentage. A cross-track factor of 25% indicates that a mariner may be as far as 25% of the way towards the edge of the channel when he can detect, with certainty, that he is off centerline. When using cross-track factor as an expression of lateral sensitivity, a higher cross-track factor implies a lower sensitivity, and vice versa.

2.5.2 EVALUATION OF ACCEPTABLE CROSS-TRACK FACTORS

0 provides guidelines on the description and acceptability of various cross-track factors.

Instead of setting upper (%) limits on the cross-track factor, the designer should weigh the nautical margins available against the risk that passing vessels will be overly confined (a small (%) cross-track factor may result in increased risk of collision between passing vessels).

- if the cross-track factor at the far end is adequate, chances are good that the cross-track factor at the near end is much smaller;

  If there are marks at the turning point at the near end, they will allow the mariner to judge the edge of the channel, and the small cross-track factor may be of no concern.

- when a small cross track factor is a problem, the range design can be modified to have an identical cross-track factor at the far end, but the cross-track factor at the near end will not be as small.

  Figure 5 illustrates the situation where the cross-track factor at the far end is identical, but the cross-track factor at the near end varies with the two designs. By moving the range structures back from the near end of the channel and increasing M and R, the cross-track factor at the near end is increased while keeping the cross-track factor at the far end the same.

2.5.3 RANGE DESIGN SELECTION

Usually the range shown on the bottom of Figure 5 will give better service because the cross-track factor does not vary as much between the near and far ends, and the illuminance produced by each light on the eye of the user will be more nearly equal along the entire length of the channel. On the other hand, this design might require larger dayboards, taller towers, or lights of increased intensity. It is up to the range designer to select the design that is most appropriate for the given situation.

*Table 1 Cross-Track Factor**

Values of Cross-Track Factor	Description	Interpretation
Over 75%	Not Acceptable	Range must be improved or it will be unworkable.
50% - 75%	Poor	Decrease the cross-track factor if physically possible.
30% - 50%	Fair	Decrease the cross-track factor only if moderate cost involved.
20% - 30%	Good	Decrease the cross-track factor only if little cost involved.
15% - 20%	Very Good	Do not expend more funds to decrease the cross- track factor.
10% - 15%	Excellent	The cross-track factor should not be less than 10% at the far end of the channel.

* Use this table using the cross-track factor ***at the far end*** of the channel.

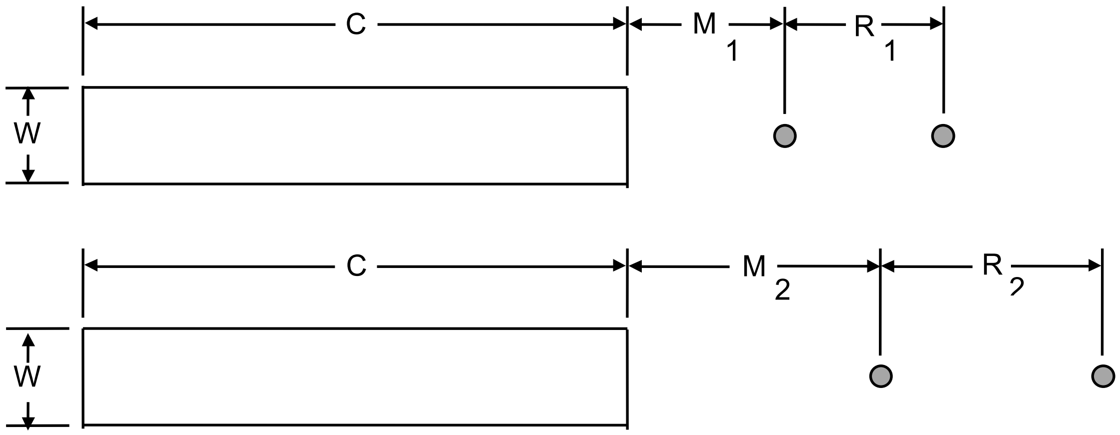


Figure 5 Two range designs having the same cross-track factor at the far end but different cross-track factors at the near end.

2.6 BEAM WIDTH OF LEADING LIGHTS

2.6.1 Spread Lens

There is often confusion regarding the effect of a narrow spread lens on the sensitivity of a leading line. The beam width of the optic has nothing to do with the lateral sensitivity of a leading line. The beam width is of some concern when a narrow spread lens is used, as care must be taken to ensure that the minimum intensities identified as necessary by the program are provided over the full width of the channel. The angle subtended at the far end of the useful segment, ϕ (see Figure 6) is given by:

$$\phi\ (in\ degrees) = (57.3\ degrees/radian)\left(\frac{W}{X}\right)$$

Equation 1 The angle subtended at the far end of the useful segment

Where:

X is the distance from the light to the far end of the channel, in metres

W is the width of the channel, in metres

The need for acquisition of the leading lights prior to turning onto a leading line should also be considered when selecting the beam width of the leading lights. In order to reach the first useful segment of the leading line it will often be necessary to observe at least one of the leading lights in a region to seaward and/or to either side of the channel. This is called the "acquisition region." The selected leading lights should have a beam width (and intensity) sufficient to cover the desired acquisition point.

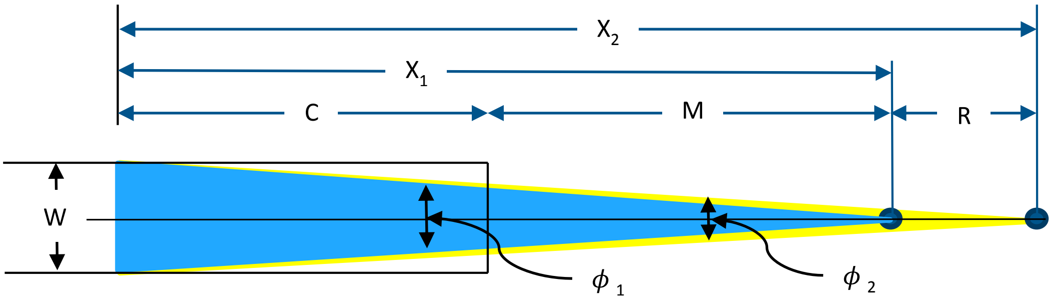


Figure 6 Beam Width of Leading Lights

2.7 DAYMARKS OR DAYTIME LIGHTS

Traditionally leading lights, particularly those powered by batteries, were secured during daylight, with the daytime signal provided by leading marks. Recent efficiency improvements in optics combined with solar power have allowed expanded use of daytime leading lights, even when commercial power is not readily available. The following are some points to consider when deciding on the daytime signal:

- Marks are simple. Having no moving parts, they require little maintenance and so are more reliable than lights. Smaller marks are also easy to maintain, with no special training required for servicing personnel.
- Daytime leading lights provide a superior signal. In marginal conditions they can be seen further than day marks. Furthermore, substituting lights for large marks may result in less costly tower structures and foundations. Daytime lights, however, require more complex lighting and power systems, which will increase hardware costs and the technical demands on the servicing personnel. The higher initial equipment costs will likely be more than offset by reduced structural costs.

2.8 CONSIDERATIONS REGARDING INTENSITIES

1 Night-time lights should be of sufficient intensity to mark the entire channel length for 90% of the nights. The 'Minimum Intensity' values provided by the program will provide adequate signals; however, higher intensities will generally provide better signals. Experience has shown intensity values ten times greater than the minimum values will provide a better signal. Therefore, the program provides a 'Recommended Intensity' that is approximately ten times the Minimum Intensity, with good illuminance balance. It is often easy to provide the Recommended Intensities and provide not just an adequate, but a good signal.

2 Daytime lights should be of sufficient intensity to maximize the percentage of time that the channel is adequately marked. If you can meet the 'Minimum Intensity' you do not need to go beyond that intensity. If you cannot meet the 'Minimum Intensity' put in the brightest light possible. The program uses a value of 1000 microlux (1×10^{-3} lux) as the required illuminance for daytime.

2.9 STANDARD LEADING LINE CHARACTERISTICS

Fixed (F) characteristics should be used sparingly, if at all. Lights displaying a fixed characteristic, especially white light signals, can be difficult to identify against even minimal background lighting. Furthermore, lights displaying a characteristic with a three second flash duration provide approximately 92% of the intensity of a fixed light signal, yield longer lamp service intervals, have lower power consumption, and provide greater conspicuity than the fixed light signal.

2.10 VISIBILITY VALUES

The computer program requires entry of three visibility values; Minimum Visibility, Design Visibility, and Maximum Visibility. All three values are computed in nautical miles (NM) (a nautical mile is 1852 meters).

2.10.1 Minimum Visibility

The minimum visibility is the historic value of meteorological visibility at the site that is met or exceeded 90% of the time. This value is used by the program to establish the minimum luminous intensities required to ensure that the leading lights are usable as leading line signals at least 90% of the time.

2.10.2 Design Visibility

The design visibility was originally conceived as the median value of meteorological visibility for the site; that is, the value met or exceeded 50% of the time. Design visibility is used by the program to establish the recommended ratio of luminous intensity of the leading lights. As a practical consideration, use of a fixed value of 10 NM is recommended.

2.10.3 Maximum Visibility

The maximum visibility value is used by the program to evaluate the potential for glare produced by the leading lights. As a practical consideration, use of a fixed value of 20 NM is recommended.

3 PROGRAM OPERATION

3.1 SYSTEM REQUIREMENTS

The program will run on any computer that has Microsoft Excel® 97 (Windows), Excel® 98 (Mac OS), or later versions.

3.2 DATA INPUT-PRELIMINARY

You can enter and modify any of the leading line parameters in any order, but when first starting out it is recommended that the input data be entered in the order outlined below. The input cells are shaded and outlined with a box. An Initial Channel Layout Worksheet is included in the workbook to recommend a 'very good' leading line design (see Table 1) in the event that the locations of the front and rear structures are not initially known. To use this preliminary design tool, click on the 'Initial Input' worksheet tab and enter the data indicated below. All input cells require data unless otherwise indicated.

3.2.1 Leading Line Name

Enter the name of the leading line. OPTIONAL

3.2.2 Length of Channel (C)

Enter the length of the channel, in meters. REQUIRED

3.2.3 Width of Channel (W)

Enter the width of the channel, in meters. REQUIRED

Recommended **Distance Between Front Light (FL) & Rear Light (RL) Towers (R)**, and recommended **Distance from FL to Near End of the Channel (M)** are computed and displayed on the **Initial Channel Layout**. These values are also shown on the '**Leading Line**' worksheet adjacent to the data entry cells for these values. The user then elects to use these values, or other values as circumstances may require.

3.3 DATA INPUT-LEADING LINE ANALYSIS

Click on worksheet tab 'Leading Line.' It is possible to enter and modify any of the leading line parameters in any order, but when first starting out it is recommended that the input data be entered in the order outlined below. All input cells require data unless otherwise indicated. If required input cells are left empty the Cross-Track Factor, Off-Axis Distance and γ will not be computed correctly. Data is already entered from the previous worksheet for you in the following fields:

- Leading Line Name;
- Length of Channel (C);
- Width of Channel (W);
- Night or Day Lights (N).

3.3.1 MEAN RANGE OF TIDE (MRT)

Enter the mean range of the tide (difference between mean high water and mean low water), in meters. REQUIRED.

3.3.2 BACKGROUND LIGHTING

Enter the amount of background lighting that is present, either 'None,' 'Minor,' or 'Considerable.' Minor background lighting refers to widely spaced lights and/or dim lights such as residential lighting. Considerable background lighting refers to numerous lights and/or very bright lights such as parking lots, highways, factories, and industrial lighting that compete with the intensity of the range lights. **PROGRAM ASSUMES 'CONSIDERABLE' IF CELL IS LEFT BLANK**.

3.3.3 HEIGHT OF EYE (HOE)

Enter the height of eye of one to three observers above the water, in metres. (The program can evaluate how well the leading line design works for up to three different vessel types simultaneously.) The input cells for HoE are located in the centre of the spreadsheet. **AT LEAST ONE ENTRY IS REQUIRED.**

3.3.4 MINIMUM VISIBILITY

Enter the minimum visibility for which the leading line is designed, in NM. Generally, it is the visibility that occurs 90% of the time for the location of the leading line. **REQUIRED**.

3.3.5 DESIGN VISIBILITY

Enter the design visibility, in NM. A value of 10 NM is recommended. **REQUIRED**.

3.3.6 MAXIMUM VISIBILITY

Enter the maximum visibility for which the leading line is designed, in NM. For practical considerations, a value of 20nm is recommended. **REQUIRED**.

3.3.7 DISTANCE BETWEEN FRONT LIGHT & REAR LIGHT (R)

Enter the distance between the structures, in metres. **REQUIRED**.

3.3.8 DISTANCE FRONT LIGHT TO NEAR END CHANNEL (M)

Enter the distance from the near end of the channel to the front structure, in metres. **REQUIRED**.

3.3.9 SAFE HEIGHT ABOVE WATER (SAFHW)

Enter the required safe height above water, in meters. It is the minimum height required to keep the front light/mark from being damaged by wave action, spring tides, or vandals. **PROGRAM ASSUMES 0.0 METRES IF CELL IS LEFT BLANK**.

3.3.10 DAYMARKS TO BE USED

Enter a 'Y' to use leading marks or an 'N' for no leading marks. **PROGRAM ASSUMES 'NO' IF CELL IS LEFT BLANK**.

3.3.11 DAYTIME LIGHTS TO BE USED

Enter a 'Y' to use daytime lights or an 'N' for no daytime lights. **PROGRAM ASSUMES 'NO' IF CELL IS LEFT BLANK**.

3.3.12 OBSTRUCTIONS

Enter the distance from the near end of the channel to the obstruction(s), in metres, and the height of the obstruction(s), in metres. **OPTIONAL**.

3.3.13 FL SELECTED DAYMARK LENGTH

Enter the length of the front leading mark, in metres. Ignore this block if not using leading marks, or enter 'None'.

3.3.14 RL SELECTED DAYBOARD LENGTH

Enter the length of the rear leading mark, in metres. Ignore this block if not using dayboards or enter 'None'.

3.3.15 FL SELECTED INTENSITY

Enter the intensity of the selected signal for the front leading light. **REQUIRED**.

3.3.16 RL SELECTED INTENSITY

Enter the intensity of the selected signal for the rear leading light. **REQUIRED**.

3.3.17 SELECTED HEIGHT FL

Enter the height of the focal plane of the front optic, in meters, above MHW. Note that this value may be different for daytime and night-time leading lights (see Chapter 5 for more details). **REQUIRED**.

3.3.18 SELECTED HEIGHT RL

Enter the height of the focal plane of the rear optic, in metres, above MHW. Note that this value may be different for daytime and night-time leading lights (see Chapter 5 for more details). **REQUIRED**.

3.4 DATA INPUT - OPTIONAL DAYTIME LEADING LIGHTS

Click on worksheet tab 'Leading Line-Day.' Data is already entered from the previous worksheet for you in the following fields:

- Leading Line Name;
- Night or Day Lights (D);
- Length of Channel (C);
- Width of Channel (W);
- Mean Range of Tide (MRT);
- Background Lighting (None);
- Height of Eye (HoE);
- Minimum Visibility;
- Design Visibility.

3.4.1 Maximum Visibility

- Distance Between FL & RL (R);
- Distance FL to Near End Channel (M);
- Safe Height Above Water (SAFHW);
- Daymarks To Be Used.

3.4.2 Obstructions

- FL Selected Daymark Length;
- RL Selected Dayboard Length;
- Selected Height FL (Night Light Height plus 1 metre);
- Selected Height RL (Night Light Height minus 1 metre);

You can enter and modify either of the daytime intensities in any order, but when first starting out it is recommended that the input data be entered in the order outlined below. Both cells require data. If required input cells are left empty, the Cross-Track Factor, Off-Axis Distance, and γ will not be computed correctly.

3.5 PROGRAM OUTPUT

Samples of the output data are included as section 5.11, section 5.12 and section 5.13. Section 5.11 and section 5.12 show the detailed analyses of the leading line performance for all the entered variables and display problems codes if warranted. Section 5.13 shows a more streamlined summary of the design with generic graphic diagrams. The output data is immediately computed upon entering any variable.

Explanations of the outputs:

3.5.1 Recommended Daymark Length

The recommended length of the daymark, in metres, based on the minimum visibility.

3.5.2 Minimum Intensity

The minimum intensity (in candela) required to ensure the leading light is useable at the far end of the channel for the given minimum visibility. (For daytime leading lights the program only provides values of minimum required intensities.)

3.5.3 Recommended Intensity

The recommended intensity (in candela) to assist the mariner in detecting, recognizing, and using the leading lights. This value is approximately ten times the minimum intensity, taking into consideration the recommended illuminance ratio.

3.5.4 Maximum Intensity

The maximum intensity (in candela) of the leading lights that can be used without causing glare during conditions of maximum visibility.

3.5.5 Recommended IR/IF

The recommended intensity ratio for the rear and front optics where:

$$IR/IF = \frac{Recomended\ Rear\ Light\ Intensity}{Recomended\ Front\ Light\ Intensity}$$

3.5.6 IR/IF for Selected Intensities

The intensity ratio for the selected light signals.

3.5.7 Recommended Min Height

The recommended focal plane height of the optic.

3.5.8 Distance from Near End

The distance of the observer from the near end of the channel at ten evenly spaced intervals along the entire length of the channel.

3.5.9 Cross-Track Factor

The cross-track factor at the indicated distance from the near end of the channel.

3.5.10 Off Axis Distance

The distance perpendicular to the range axis (in metres) needed to indicate to the observer that they are off the leading line axis, at the indicated distance from the near end of the channel.

3.5.11 γ (mrad) (MLW)

The apparent vertical angle subtended by the leading lights (vertical angle separation), in mrad, at the indicated distance from the near end of the channel.

3.5.12 Illuminance Ratios & Values

Provides information on the apparent brightness of the two range optics for the selected design visibility, at the indicated distance from the near end of the channel (values are in microlux).

3.5.13 Problem Codes

Chapter 4 discusses Problem Codes and Daymark Problem Codes which may appear on the output sheet. The sample Night-time/Daymark Design worksheet provided as enclosure (3) shows all the potential problem codes for informational purposes.

3.6 SINGLE-POINT-IN-TIME PERFORMANCE RUN

To see how the leading line will perform on a given day with a given visibility enter the same visibility for Minimum, Design, and Maximum Visibility. The output is a snapshot of how the leading line will perform for that given visibility.

3.7 LEADING LIGHT SELECTION

Use the Leading Line Design Program to determine the recommended intensities for the front and rear leading lights. Select the combinations of lanterns, lenses (colour/spread), lamps, and rhythms which best meet the desired intensities, and which have adequate beam widths to cover the required region (see section 2, Section F). When possible, use of omnidirectional lanterns is highly desirable, as the signal can be acquired even when vessels are well off the channel centerline. The use of omnidirectional lanterns also precludes the requirement for passing lights on towers located in navigable waters.

3.8 SAMPLE LEADING LINE DESIGNS

Four sample printouts are provided in Enclosure (2) through (5). The first is an Initial Channel Layout based on two simple inputs. The second is a leading light design analysis which shows a Night-time Leading Light with Daymarks for daytime signals. The third sample shows the analysis of the same leading line with daytime light signals added. The fourth sample shows a more streamlined summary of the design with generic graphic diagrams.

4 TROUBLE SHOOTING

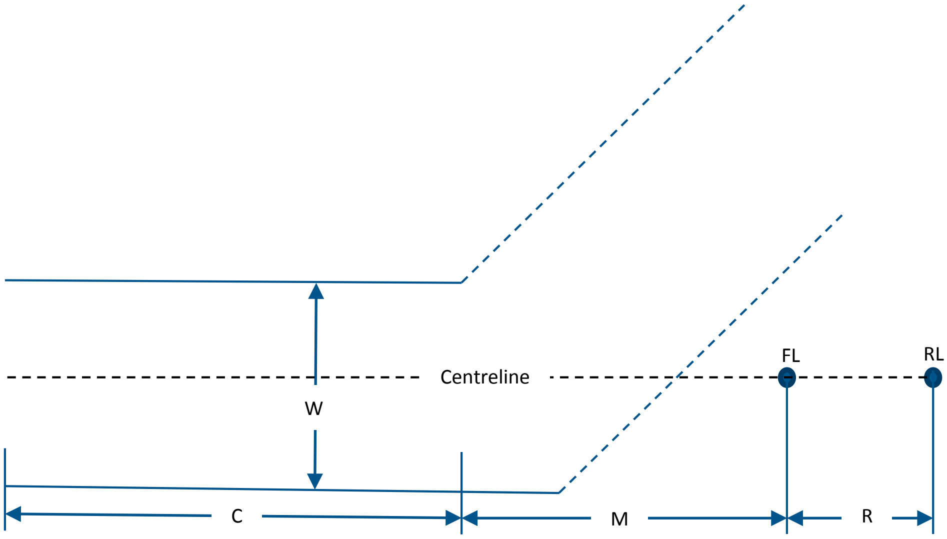


Figure 7 Leading Line Diagram

4.1 PROBLEM CODES

Below is a list of the possible problem codes that may be displayed while running the leading line design program.

1 Lights will blur.

2 Cross-Track Factor too big.

3 FL not bright enough in min visibility.

4 RL not bright enough in min visibility.

5 FL exceeds glare limit in max visibility.

6 RL exceeds glare limit in max visibility.

7 FL Dayboard too small in min visibility.

8 RL Dayboard too small in min visibility.

9 RL appears lower than RFL.

10 FL below Safe Height Above Water.

11 FL below the horizon.

12 Obstruction #1 obstructs FL.

13 Obstruction #1 obstructs RL.

14 Obstruction #2 obstructs FL.

15 Obstruction #2 obstructs RL.

4.2 DAYMARK PROBLEM CODES

Below is a list of the possible daymark problem codes that may be displayed while running the leading line design program.

1 Portion of FL mark below horizon.

2 FL mark below Safe Height Above Water.

3 FL obscures part of RL mark.

4 FL obstructs more than 1/2 RL mark.

5 Obstruction #1 obstructs FL daymark.

6 Obstruction #1 obstructs RL daymark.

7 Obstruction #2 obstructs FL daymark.

8 Obstruction #2 obstructs RL daymark.

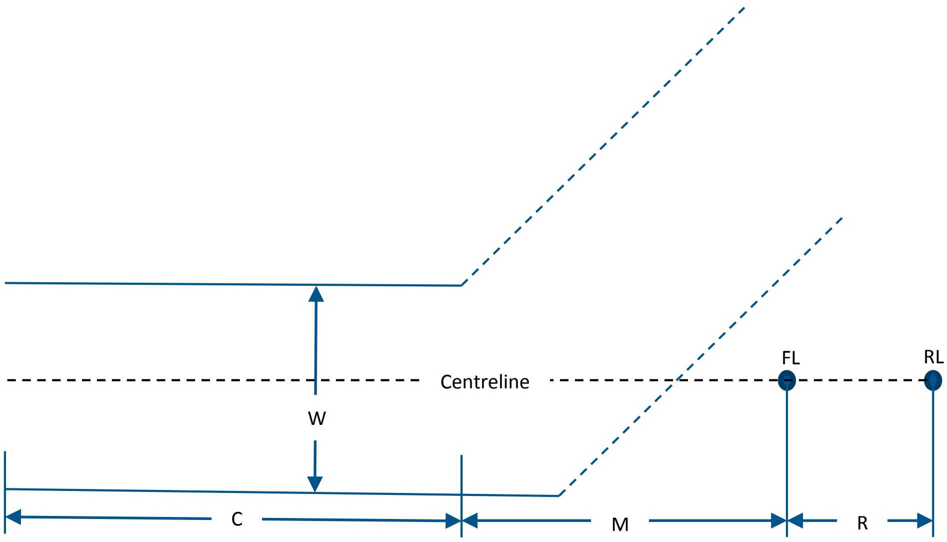


Figure 8 Leading Line Diagram

4.3 PROBLEMS AND FIXES

Below are some suggestions on resolving problems with leading line designs, with possible constraints and costs. Common problem codes are grouped together.

Table 2 Problem codes

Problem	Possible Fix	Constraint/Cost
1. Lights will blur.	Raise RL. Reduce intensities. Lower FL. Decrease C.	Extra cost; decreased sensitivities Lights harder to acquire & use Closer to water May not meet users requirements.
2. Cross Track Factor too big.	Increase R. Increase FL height or decrease RL height.	May need real estate; extra cost; may need to increase RL height. Lights may blur
3. FL (RL) not bright 4. Enough in min visibility.	Increase intensity.	May cause glare/blur; extra cost
5. FL (RL) exceeds glare 6. Limit in max visibility	Reduce intensity Increase M.	Light harder to acquire & use. May need real estate; extra cost.
7. FL (RL) daymark too 8. Small in min visibility	Increase daymark size. Use daytime lights	Extra cost. Extra initial equipment cost.

Problem	Possible Fix	Constraint/Cost
9. RL appears lower than FL.	Lower FL. Raise RL Decrease R.	Lights/daymark closer to water. Extra cost; decreased sensitivities Decreased sensitivities.

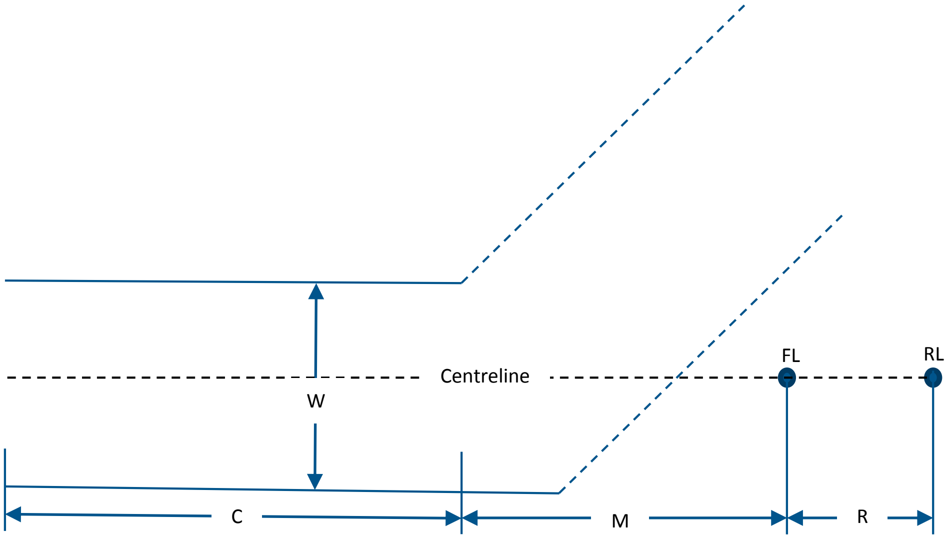


Figure 9 Leading Line Diagram

Table 3 Problem codes (continued)

Problem	Possible Fix	Constraint/Cost
10. FL below Safe Height Above Water.	Raise FL. Use smaller daymark.	May cause blur; raise RL. May not be adequate.
11. FL Below Horizon.	Raise FL. Decrease M.	May cause blur; raise RL May cause glare; harder to balance illumination ratios.
12. Obstruction #1, #2	Raise FL.	May cause blur; need to raise RL
13. Obstructs FL.	Remove obstruction. Decrease M.	May not be legal/possible. May cause glare; harder to balance illumination ratios.
14. Obstruction #1, #2	Raise RL.	Decreased sensitivities; extra cost.
15. Obstructs RL.	Remove obstruction Decrease R.	May not be legal/possible Decreased sensitivities.

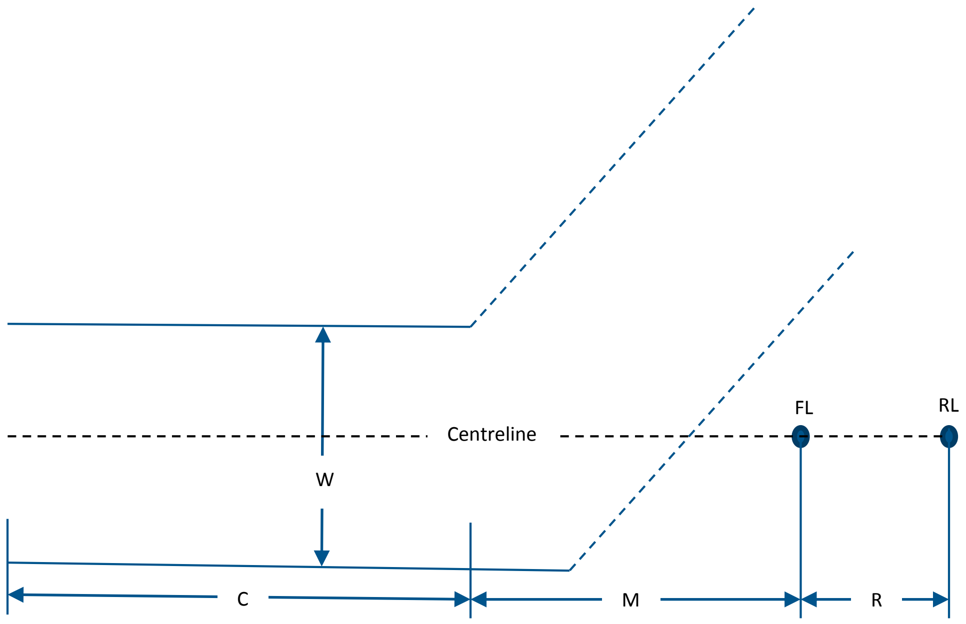


Figure 10 Leading Line Diagram

Table 4 Daymark problem codes

Problem	Possible Fix	Constraint/Cost
1. Portion of FL mark below horizon.	Raise FL daymark. Decrease M. Use daytime lights.	Extra cost due to larger tower; may need to raise rear tower. May cause glare; harder to balance illumination ratios. Extra initial equipment cost.
2. FL mark below Safe Height Above Water.	Raise FL daymark. Use daytime lights.	Extra cost due to larger tower; may need to raise rear tower Extra initial equipment cost.
3. FL obscures part of RL mark.	Lower FL daymark Raise RL daymark. Use daytime lights.	Closer to water, decreased sensitivities. Extra cost, decreased sensitivities. Extra initial equipment cost.
4. FL obstructs more than 1/2 RL mark.	Lower FL daymark. Raise RL dayboard. Use daytime lights.	Closer to water, decreased sensitivities. Extra cost, decreased sensitivities. Extra initial equipment cost.
5, Obstruction #1, #2	Raise FL.	May cause blur; Extra cost; need to raise RL tower.
7. Obstructs FL daymark.	Remove obstruction. Decrease M.	May not be legal/possible. May cause glare; harder to balance illumination ratios.
6, Obstruction #1, #2	Raise RL.	Decreased sensitivities; extra cost due to larger tower.
8. Obstructs RL daymark.	Remove obstruction. Decrease R.	May not be legal/possible. Decreased sensitivities.

4.4 MAXIMUM INTENSITY LESS THAN MINIMUM INTENSITY

This situation arises when one or both leading lights (usually the FL) are too close to the channel, creating a glare problem. The best solution is to move the leading lights back from the near end of the channel, increasing M, until the situation is resolved. If that is not possible, then choose a light signal that provides the Minimum Intensity, to alleviate the glare situation as much as possible. Another way to reduce glare is to set the focal heights of the lights so as to be significantly different from the primary HoE for vessels using the channel. This may result in the user being out of the primary portion of the beam, resulting in a reduction in intensity as the vessel approaches the near end of the channel.

4.5 MAXIMUM INTENSITY LESS THAN RECOMMENDED INTENSITY

This problem is similar to that described above, except that the Minimum Intensity does not result in glare. It is still generally best to move the leading lights back from the near end of the channel, thereby allowing selection of the Recommended Intensity. If that is not possible, then select an intensity between the Minimum and Maximum Intensities for the constrained leading light. The intensity for the remaining light should be selected to try and match the recommended ratio of intensities, so as to provide a good balance of illuminances. Note, in some instances this may result in the selected intensity for the RL being less than the Minimum Intensity. The leading line designer must compromise between the intensity requirements and the recommended ratio of illuminance to optimize marking of the channel.

4.6 COMPROMISES DURING LEADING LINE DESIGN

There is no single correct design for a given leading line. There are multiple successful combinations of optics, lamps, structure locations, optic heights, flash characteristics, colours, etc. With all the different designs possible for a given leading line, there comes a point where the designer must select which design to use. Selecting the design that optimizes the cost/benefit ratio for marking a channel is a trial and error process that requires practice. The selection criteria may include cost of construction, maintenance, cross-track factor, off-axis distance, tower heights, power requirements, HOE of primary user, and user input. This is just a partial list, but indicates that design of a leading line is more of an art than a science.

5 LEADING LINE CONFIGURATIONS & DESIGN CONSTRAINTS

5.1 INTRODUCTION

This section discusses a few of the constraints and recommended configurations when designing a leading line. These items should be considered during the design phase, so that performance of the aid will be as predicted and that personnel can safely service the lights and marks.

5.2 TOWER PLACEMENT

Placement of the leading line structures determines the axis of the leading line. Tower placement along the centerline should be within ±3 metres of the desired position, while the lateral error in placement of the towers to either side of the true centerline should be limited to approximately ±0.3 metres. See Figure 11.

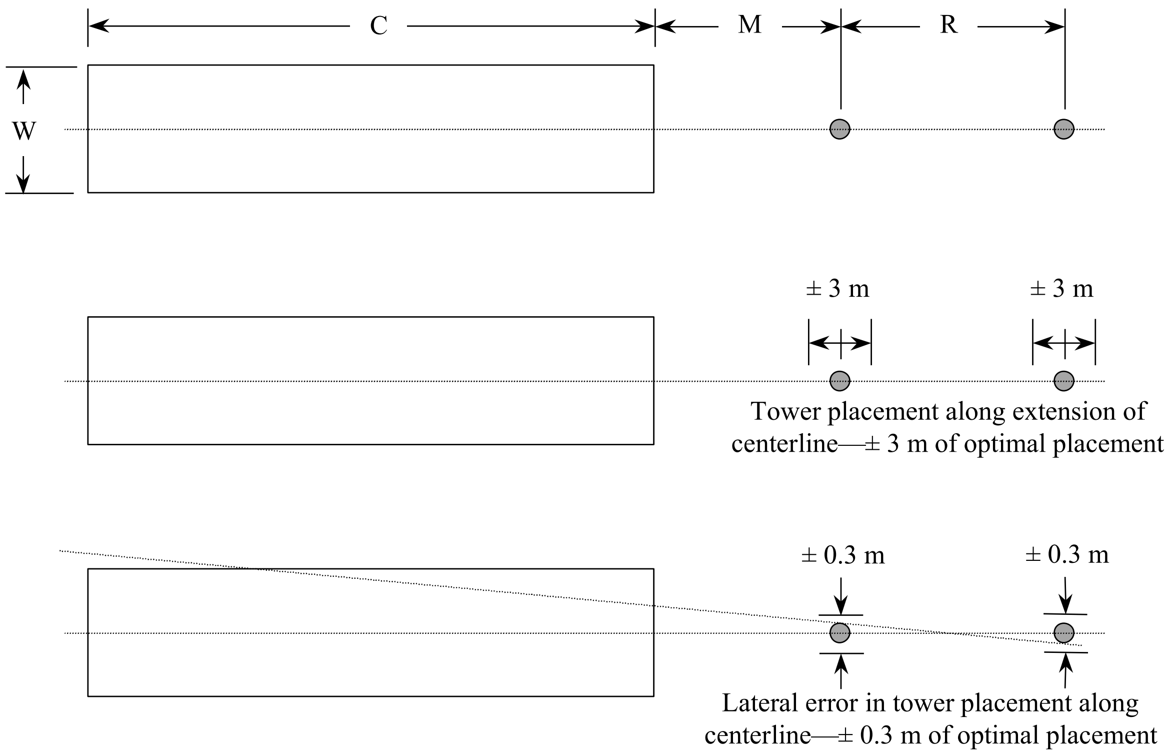


Figure 11 Tower placement

5.3 BEACON PLACEMENT

Proper beacon placement is necessary to ensure that blur will not occur during night-time and that each light or group of lights will be viewed as a single source. The heights listed in the design program are the heights from MHW to the centerline of the optics. When using day & night leading lights, the lower optic on the front tower and the upper optic on the rear tower should be the night-time lights. The only exception is if the front tower uses an omnidirectional night-time light, which should then be mounted above the daytime light(s). Multiple optics for daytime lights should be installed on a horizontal plane, and should typically not exceed three across. Horizontal separation should be kept to a minimum to be sure the lights are viewed as a point source. Figure 5-2 details some common configurations of day/night optics.

5.4 ADDITIONAL LIGHTS

If the design does NOT use omnidirectional optics at night, and the structure is located in navigable waters, it may be necessary to add omnidirectional lights to the structure. These additional lights should be mounted where they will not be blocked by the structure.

1 Additional lights should be mounted at a low enough height to ensure that the lights will be visible to vessels with a low height of eye (HoE). As an example, if a leading line has a front tower height of 8 m and a rear tower height of 25 m, the additional light for the front tower can be mounted directly above the front leading light. The additional light should display the same characteristic as the leading light, and should be synchronized with the leading light.

2 On towers greater than about 12 m, the additional lights may be designated as passing lights and installed at a lower level than the leading light. Installation of a passing light requires two optics, as the structure will partially occlude the output from each lantern. The passing lights should be mounted on opposite corners of the structure, and should be synchronized.

5.5 SERVICING CONSIDERATIONS

Towers should be designed to ensure that they can be serviced safely. Since many optics are serviced from the front, there should be 0.75 m of deck space available all around the optic, to allow for easy and safe access. Additionally, lanterns should be elevated a minimum of 0.5 m off the deck. When lanterns are installed more than approximately 1.25 m above the deck, a work platform should be built into the structure to allow personnel to comfortably access the lantern. Optic support structures should take into consideration any doors or servicing hatches on the installed lanterns. Railings should be installed, where appropriate, with either careful placement to prevent obstruction of the light or removable safety chains in front of optics. Operation and maintenance guides, if prepared, should be passed to the assigned servicing unit.

5.6 CONSTRUCTION DETAILS

Boat landings should be oriented to allow easy boarding under prevailing current and wind conditions. Boarding ladders should have rail extensions to allow easy transition from the deck to the ladder. For towers in excess of 20 m height, the designer should consider installation of a stairway instead of a ladder. All-weather, hand operated winches, with covers, should be installed on the main deck containing power system equipment and on the lantern deck to facilitate easy handling of hardware. Solar panels should be installed so that access to both sides of the array are possible and shall not be shadowed by railings, antennas, towers, shelters, etc., within an arc of ± 90 degrees of panel orientation.

5.7 SAFETY

Installations using large batteries should have safety covers on intercell connectors to protect from accidental shorting. Battery rooms should have servicing equipment (hydrometer, tarp for covering solar panel, etc.) and safety equipment (eye wash station, gloves, goggles, etc.) available to servicing personnel in the event they do not bring the equipment with them.

5.8 DAYMARKS

Daymark mountings on structures should be strong enough to secure the daymark up to the tower’s designed wind load, while allowing servicing personnel easy replacement. Daymark mountings should not exceed the tower strength (daymark mountings should fail before the structure does). Access to the daymark by ladder or platform is necessary to remove/replace fasteners. Use of day/night lights is encouraged on ranges requiring marks in excess of 3 m in length, as these marks are the most hazardous to replace.

5.9 ENCLOSURE 1: LEADING LINE CATEGORY SELECTION AID

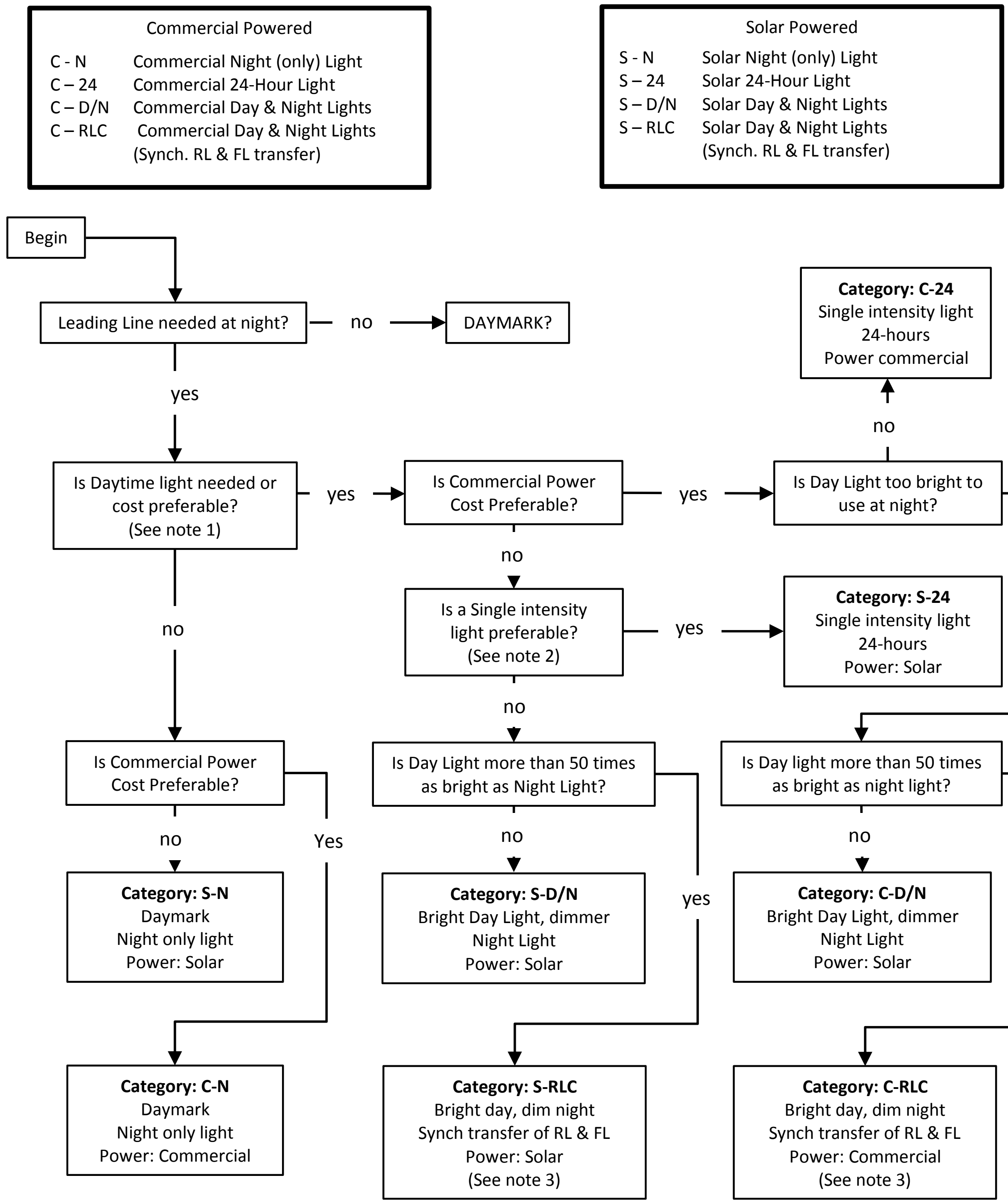


Figure 12 Leading Line Category Selection

5.9.1 LEADING LINE CATEGORY SELECTION NOTES

1 There are several factors to consider when deciding whether or not to use daytime lights. The leading line designer should compare the performance characteristics and associated costs of a design using daymarks and one using daytime lights before making a final judgment.

2 Like most aspects of leading line design, choosing between a single intensity, 24-hour signal or a dual intensity, day/night signal for solar applications involves trade-offs:

a Factors that favour a single-intensity light include:

- Fewer optics (to buy and service);
- No need for day/night control switching;
- Higher intensity night-time light usually provides a superior signal;
- Simpler system.

b Factors that favour a separate optics for daytime and night-time lights

- Allows for brighter daytime light and less intense night-time light;
- Requires fewer solar panels than a single (high intensity) 24-hour light;
- Requires less battery capacity than single (high intensity) 24-hour light;
- Less intense night-time light will tend to lower required height of RL.

3 Use of a device to synchronize switching of the front and rear leading lights is recommended when daytime and night-time light signal intensities differ by a factor of 50 or more. If the leading lights do not switch at the same time, the leading line may not be useable during the period when the front and rear lights are not in the same mode.

5.10 ENCLOSURE 2: INITIAL CHANNEL LAYOUT WORKSHEET

1. Leading Line Name:	**Test Channel Aug 2001**	
2. Channel Length (C):	8 000	(m)
3. Channel Width (W):	175	(m)
Distance Near End/Front Twr (M):	1 600	(m)
Distance between Towers (R):	2 201	(m)

Preliminary Values to Enter into Leading Line Design Program for Analysis

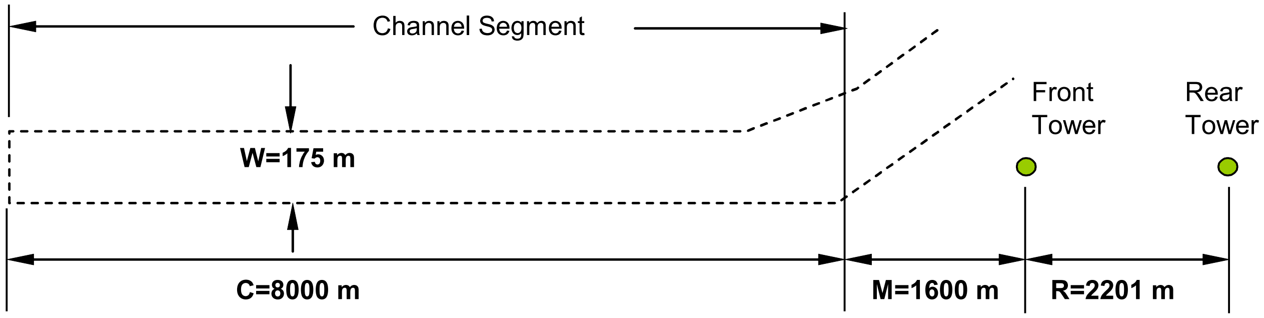


Figure 13 Initial Channel Layout Worksheet

5.11 ENCLOSURE 3: NIGHT TIME LEADING LINE WITH DAYMARK

1. Leading Line Name:		Test Channel Aug 2001	
Night or Day Lights? (N or D)		N	
2. Length of Channel:		8 000	(m)
3. Width of Channel:		175	(m)
4. Mean Range of Tide:		2	(m)
5. Background Lighting:		none	
(none, minor or considerable)			
7. Minimum Visibility:		7	(nm)
8. Design Visibility:		10	(nm)
9. Maximum Visibility:		20	(nm)
10. Distance betwn FL &	2201	2 201	(m)
11. Distance FL to near ε	1600	1 600	(m)
12. Safe Height Above Water:		4	(m)
13. Daymarks to be used? (Y or N)		Y	
14. Daytime Lights to be used? (Y or N)		Y	
15. Obstructions (option	Location*	Height**	
#1	500	4,0	
#2			

*Distance from near end of channel to obstruction (m).
**Height above MHW (m).

FL-Recommended daymark length:	10,2	(m)
FL-Recommended daymark width:	6,8	(m)
16. FL-Selected Daymark length:	10,2	(m)
RL-Recommended daymark length:	17,2	(m)
RL-Recommended daymark width:	11,5	(m)
17. RL-Selected Daymark length:	12,2	(m)
Practical limit is 12.2 meters in length		
FL - Minimum Intensity:	848	(cd)
18. FL - Selected Intensity (IF):	12 000	(cd)
FL - Recommended Intensity:	8 477	(cd)
FL - Maximum Intensity:	29 137	(cd)
RL - Minimum Intensity:	2 129	(cd)
19. RL - Selected Intensity (IR):	30 000	(cd)
RL - Recommended Intensity:	23 484	(cd)
RL - Maximum Intensity:	196 474	(cd)
Recommended IR/IF:	2,77	
IR/IF for selected intensities:	2,50	
(FL & RL heights referenced to MHW)		
Recommended Min Height FL:	14,7	(m)
20. Selected Height FL:	15,5	(m)
Recommended Min Height RL:	38,3	(m)
21. Selected Height RL:	39	(m)

Test Channel Apr 2001

6. HEIGHT OF EYE: 8 (m)

Distance from Near End	Off Axis Distance (m)	Cross Track Factor	γ (mrad) (MLW)	PROBLEM CODES:
8 000	19	21%	1,7	8,
7 200	17	19%	1,8	8,
6 400	15	17%	1,9	
5 600	13	15%	2,0	
4 800	11	12%	2,2	
4 000	9	10%	2,4	
3 200	7	8%	2,6	
2 400	6	7%	2,8	
1 600	4	5%	3,0	
800	3	3%	3,1	
0	2	2%	2,6	

6. HEIGHT OF EYE: 15 (m)

Distance from Near End	Off Axis Distance (m)	Cross Track Factor	γ (mrad) (MLW)	PROBLEM CODES:
8 000	20	22%	1,8	8,
7 200	17	20%	1,9	8,
6 400	15	18%	2,1	
5 600	14	15%	2,3	
4 800	12	13%	2,5	
4 000	10	11%	2,7	
3 200	8	9%	3,0	
2 400	7	8%	3,4	
1 600	5	6%	3,9	
800	4	4%	4,5	
0	2	3%	5,1	

6. HEIGHT OF EYE: 23 (m)

Distance from Near End	Off Axis Distance (m)	Cross Track Factor	γ (mrad) (MLW)	PROBLEM CODES:
8 000	21	23%	1,9	8,
7 200	18	21%	2,1	8,
6 400	16	19%	2,3	
5 600	14	17%	2,5	
4 800	13	14%	2,8	
4 000	11	12%	3,1	
3 200	9	11%	3,6	
2 400	8	9%	4,1	
1 600	6	7%	4,9	
800	4	5%	6,1	
0	3	3%	8,0	

Test Channel Apr 2001

ILLUMINANCE RATIOS & VALUES

Distance from Near End	For 10 nm visibility: (E in micro-lux) E+/E-	E (RFL)
8 000	1,2	27
7 200	1,1	37
6 400	1,1	51
5 600	1,0	72
4 800	1,0	103
4 000	1,1	154
3 200	1,2	238
2 400	1,4	391
1 600	1,6	695
800	2,1	1 409
0	3,2	3 611

PROBLEM CODES:
1. Lights will blur.
2. Cross Track Factor too big.
3. FL not bright enough in min visibi
4. RL not bright enough in min visib
5. FL exceeds glare limit in max visi
6. RL exceeds glare limit in max visi
7. FL dayboard too small in min visi
8. RL dayboard too small in min visi
9. RL appears lower than RFL.
10. FL below Safe Height Above Wat
11. FL below the horizon.
12. Obstruction #1 obstructs FL.
13. Obstruction #1 obstructs RL.
14. Obstruction #2 obstructs FL.
15. Obstruction #2 obstructs RL.

DAYMARK PROBLEM CODES:
1. Portion of FL mark below horizon.
2. FL board below Safe Ht Above Wa
3. FL obscures part of RL mark.
4. FL obstructs more than 1/2 RL ma
5. Obstruction #1 obstructs FL dayma
6. Obstruction #1 obstructs RL daym
7. Obstruction #2 obstructs FL dayma
8. Obstruction #2 obstructs RL daym

Figure 14 Night Time Leading Line with Daymarks

5.12 ENCLOSURE 4: DAY TIME LEADING LIGHTS

Leading Line Name:	Test Channel Aug 2001	
Night or Day Lights? (N or D)	D	
Length of Channel:	8 000	(m)
Width of Channel:	175	(m)
Mean Range of Tide:	2	(m)
Background Lighting: (none for daytime)	none	
Minimum Visibility:	7	(nm)
Design Visibility:	10	(nm)
Maximum Visibility:	20	(nm)
Distance between FL & RL:	2 201	(m)
Distance FL to near end channel:	1 600	(m)
Safe Height Above Water:	4	(m)
Daymarks to be used? (Y or N)	Y	

Obstructions (optional):	Location*	Height**
#1	500	4,0
#2	0	0,0

*Distance from near end of channel to obstruction (m).
**Height above MHW (m).

FL-Recommended daymark length:	10,2	(m)
FL-Recommended daymark width:	6,8	(m)
FL-Selected Daymark length:	10,2	(m)
RL-Recommended daymark length:	17,2	(m)
RL-Recommended daymark width:	11,5	(m)
RL-Selected Daymark length:	12,2	(m)

Practical limit is 12.2 meters in length

FL - Minimum Intensity:	847 171	(cd)
18. FL - Selected Intensity (IF):	1 050 000	(cd)
RL - Minimum Intensity:	2 128 886	(cd)
19. RL - Selected Intensity (IR):	2 650 000	(cd)
Recommended IR/IF:	2,77	
IR/IF for selected intensities:	2,52	

(FL & RL heights referenced to MHW)

Recommended Min Height FL:	14,7	(m)
Selected Height FL:	16,5	(m)
Recommended Min Height RL:	37,7	(m)
Selected Height RL:	38	(m)

Test Channel Apr 2001

HEIGHT OF EYE: 8 (m)

Distance from Near End	Off Axis Distance (m)	Cross Track Factor	γ (mrad) (MLW)	PROBLEM CODES:
8 000	18	20%	1,5	8,
7 200	16	18%	1,6	8,
6 400	14	16%	1,7	
5 600	12	13%	1,8	
4 800	10	11%	1,9	
4 000	8	10%	2,1	
3 200	7	8%	2,2	
2 400	5	6%	2,4	
1 600	4	4%	2,5	
800	3	3%	2,4	
0	1	1%	1,7	

HEIGHT OF EYE: 15 (m)

Distance from Near End	Off Axis Distance (m)	Cross Track Factor	γ (mrad) (MLW)	PROBLEM CODES:
8 000	18	21%	1,6	8,
7 200	16	19%	1,7	8,
6 400	14	17%	1,9	
5 600	13	14%	2,0	
4 800	11	12%	2,2	
4 000	9	11%	2,4	
3 200	8	9%	2,7	
2 400	6	7%	3,0	
1 600	5	5%	3,4	
800	3	4%	3,8	
0	2	2%	4,2	

HEIGHT OF EYE: 23 (m)

Distance from Near End	Off Axis Distance (m)	Cross Track Factor	γ (mrad) (MLW)	PROBLEM CODES:
8 000	19	22%	1,8	8,
7 200	17	20%	1,9	8,
6 400	15	18%	2,1	
5 600	14	16%	2,3	
4 800	12	14%	2,5	
4 000	10	12%	2,8	
3 200	9	10%	3,2	
2 400	7	8%	3,7	
1 600	6	6%	4,4	
800	4	5%	5,4	
0	3	3%	7,1	

Test Channel Apr 2001

ILLUMINANCE RATIOS & VALUES

Distance from Near End	For 10 nm visibility: (E in micro-lux) E+/E-	E (RFL)	E (RRL)
8 000	1,2	2 382	2 778
7 200	1,1	3 229	3 643
6 400	1,1	4 452	4 827
5 600	1,0	6 262	6 475
4 800	1,0	9 029	8 813
4 000	1,1	13 436	12 206
3 200	1,2	20 836	17 266
2 400	1,4	34 185	25 075
1 600	1,6	60 856	37 658
800	2,1	123 261	59 122
0	3,2	315 977	98 697

PROBLEM CODES:

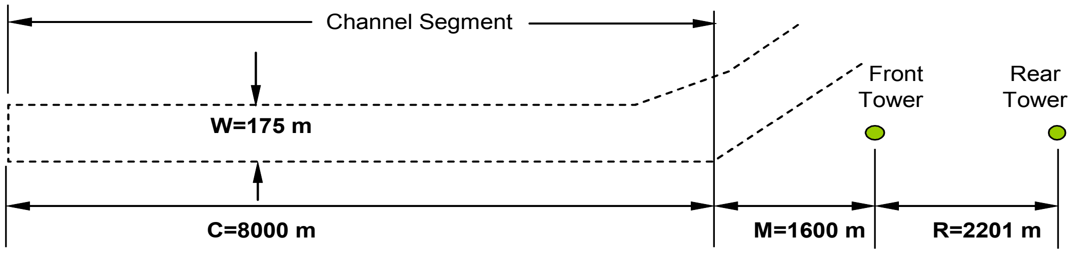
8. RL dayboard too small in min visibilty.

Figure 15 Day Time Leading Lights

5.13 ENCLOSURE 5: FINAL LEADING LINE CONFIGURATION SUMMARY

Leading Line Name: **Test Channel Aug 2001**

Channel Length (C):	8 000	Meters
Channel Width (W):	175	Meters
Distance Near End/Front Twr (M):	1 600	Meters
Distance between Towers (R):	2 201	Meters
Range Front Light Intensity (Day):	1 050 000	Candela
Range Front Light Intensity (Night):	12 000	Candela
Front Dayboard Height:	10,2	Meters
Range Front Light Height (Night):	15,5	Meters
Range Front Light Height (Day):	16,5	Meters
Range Rear Light Intensity (Day):	2 650 000	Candela
Range Rear Light Intensity (Night):	30 000	Candela
Rear Dayboard Height:	12,2	Meters
Range Rear Light Height (Night):	39,0	Meters
Range Rear Light Height (Day):	38	Meters



Final Channel Layout

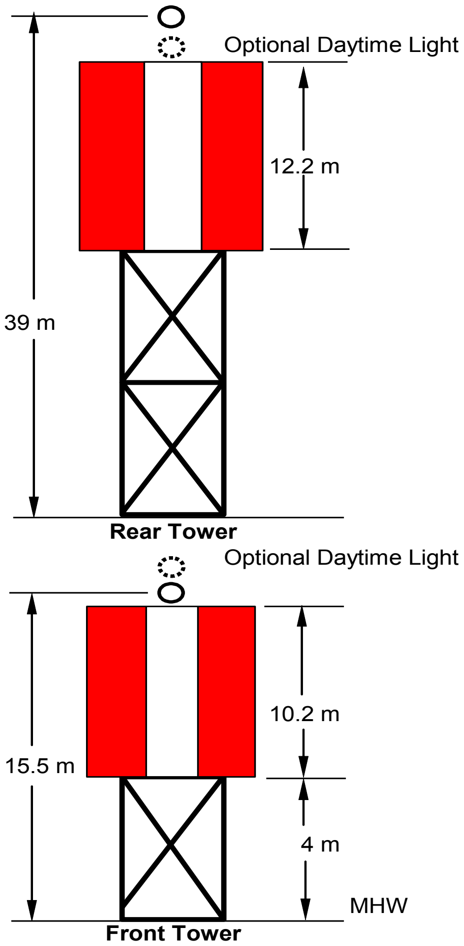


Figure 16 Final Leading Line Configuration Summary

6 ENCLOSURE 6: DESIGN PROGRAM METHODOLOGY

6.1 INTRODUCTION

The IALA Leading Lines Design Program is based on the IALA Recommendation for Leading Lights (E-112), hereafter referred to as the Recommendation. The Recommendation provides specific guidelines for the design of towers and lights. The computer program is in the format of a Microsoft Excel Workbook containing four worksheets. The purpose of this enclosure is to show the linkage between the theory of the Recommendation and the detailed leading line design produced by the spreadsheet program. The locations in the spreadsheets of the described calculations are also provided in order to help users and reviewers to understand in detail the spreadsheet calculation methods (e.g.: see cell B15).

6.2 INITIAL CHANNEL LAYOUT WORKSHEET

The Initial Channel Layout Worksheet (click on worksheet tab 'Initial Input') permits the user to establish a beginning position for the leading line towers when they are not otherwise constrained. For these preliminary calculations it is necessary to assume values for vertical separation of the lights, cross-track sensitivity and a distance from the near end of the channel to the front tower.

6.3 BEARING DIFFERENCE.

Refer to IALA Recommendation E-112 Equation 3b:

$$\theta'_1 = 0.16 \times 10^{-3} + 0.12\gamma \;\; for\; \gamma \le 5\, mrad$$

Equation 2 Bearing sensitivity

for the bearing difference necessary to detect with certainty that the lights are not aligned; on page 1 it is recommended "that if before adopting the final luminous intensities a preliminary investigation of appropriate sites is undertaken, it should be based on a value of $\gamma_m = 1.5 \times 10^{-3}$ radians".

∴ Assuming $\gamma_m = 1.5 \times 10^{-3}$ radians and substituting in Equation 2:

$$\theta'_1 = 0.16 \times 10^{-3} + 0.12(1.5 \times 10^{-3}) \;\; for\; \gamma \le 5\, mrad$$

$$\theta'_1 = 0.34\, mrad$$

$$\therefore \theta_D = 0.34\, mrad$$

6.4 OFF-AXIS DISTANCE

Refer to IALA Recommendation E-112 Equation 16 for the off-axis distance at which a mariner can detect with certainty that a vessel is not on the channel centerline:

$$Y_D \;=\; \theta_D\, x\, (1 + \; x/R)$$

Equation 3 Off-axis distance for detection that a vessel is not on the channel centerline

Where:

R is the Distance between the front and rear lights.

x is the Distance from front light to far end of channel (C+M), where

C is the Channel length

M is the Distance between near end and front light

W is the Channel Width

The distance M is assumed to be 0.2C. This value is based on design experience, but may be deemed too low if background lighting or low visibility requires bright lights, which could cause glare at the near end of the channel.

6.5 SEPARATION OF FRONT AND REAR TOWERS

By substituting known values in Recommendation E-112 Equation 16 and solving for the unknown value R, a relationship to compute the value for R can be arrived at.

By identity, we can divide both sides of the equation by (1/2W):

$$\frac{Y_D}{1/2W} = \left(\frac{[\theta_D\ x\,(1 +\ x/R)]}{1/2W}\right)$$

In this Guideline's terms, $Y_D/(1/2W)$ is defined as the 'cross track factor.' The cross track factor is defined to be the lateral distance at which a mariner can detect with certainty that a vessel is not on the channel centerline, divided by half the channel width. For these preliminary calculations, a cross-track factor of 20% is assumed, inferring a 'very good' leading line (see Table 1).

Assuming $\frac{Y_D}{(1/2W)} = 0.2$ and substituting in above equation:

$$0.20 = \frac{Y_D}{(1/2W)} = \left(\frac{[\theta_D x(1 + x/R)]}{1/2W}\right)$$

$$0.10W = \theta_D\ x\ \left(1 + \frac{x}{R}\right)$$

$$\frac{W}{10\ \theta_D\ x} = 1 + \frac{x}{R}$$

$$\frac{W}{10 \times \theta_D x} - 1 = \frac{x}{R}$$

$$R = \frac{x}{\left[\frac{W}{10 \times \theta_D x}\right] - 1}$$

But $x\ =\ M\ +\ C$; and $\theta_D\ =\ 0.34\ \times\ 10^{-3}$

$\therefore R\ =\ (M\ +\ C)\ /\ [W/\ (10\ (0.34 * \ 10^{-3}\ )(\ M\ +\ C) - 1]$

and R, the Distance between the front and rear lights

$$R\ = \frac{(M\ +\ C)}{\left[\frac{1000W}{(3.4 * \ 10^{-3}\ )(\ M\ +\ C) - 1}\right]}$$

<u>*Equation 4*</u>   <u>*Distance between front and rear lights (1)*</u>

Where:

R is the Distance between the front and rear lights.

x is the Distance from front light to far end of channel (C+M), where

C is the Channel length

M is the Distance between near end and front light

W is the Channel Width

This can also be expressed as:

$$R = \frac{x}{\left(\left(\frac{1000W}{3.4x}\right) - 1\right)} \quad \text{; see cell B15}$$

Equation 5 *Distance between front and rear lights (2)*

This formula will always yield a cross track factor of 20% for γ = 1.5 mrad.

6.6 LEADING LINE DESIGN WORKSHEET

The detailed design for a leading line is accomplished on the Leading Line Design Worksheet (click on worksheet tab 'Leading Line').

6.7 MINIMUM INTENSITY

IALA Recommendation E-112 suggests that the lights shall provide an illuminance at the eye of the navigator at least equal to 1 x 10^{-6} lux, and that the lights shall be sized such that the illuminance be nearly equal as possible while viewing them within the channel segment.

Refer to IALA Recommendation E-112 Equation 5 (Allard's Law):

$$E = I\ d^{-2}(0.05)^{d/V}$$

Equation 6 *The illuminence at the eye of the light (Allard's Law)*

Where:

E is the threshold of illuminance in lux.

I is the intensity in candelas.

d is the distance from the light to the far end of the channel in metres.

V is the visibility in metres.

The minimum night-time intensity can be calculated by solving Equation.16 for Intensity (I):

$$I = \frac{E\ D^{-2}}{(0.05)^{D'/V'}} \qquad \text{see cells D30 and D35}$$

Equation 7 *Minimum night-time intensity (1)*

Where:

I is the intensity in candelas.

E is the threshold of illuminance in lux.

D is the distance from the light to the far end of the channel in metres.

D' is the distance from the light to the far end of the channel in NM.

V' is the Visibility in NM

The threshold of illuminance (E) increases during night-time conditions when background lighting is present. The illuminance is multiplied by factors of 1, 10 and 100 for none, minor and considerable background lighting, respectively. For daytime conditions the threshold of illuminance (E) multiplier is set to 1000. **See cell C68**.

A selected intensity value lower than the suggested minimum intensity will result in printing of only a portion of the leading line evaluation. It is assumed that the lights will not be usable in the unprinted portions.

6.8 MAXIMUM INTENSITY

Maximum intensity is determined by the glare limit (see Prevention of Glare, p. 4 in IALA Recommendation E-112) using the same equation, as above. Glare occurs when the illuminance at the eye of the navigator (E) exceeds 0.01 lux when viewed at night with no background lighting and 0.1 lux with background lighting in maximum visibility. **See cell C69.**

6.9 EQUALITY OF ILLUMINANCES

The illuminances at the eye of the navigator within the useful channel segment provided by the two lights should be as nearly equal as possible. This requires a suggested intensity ratio between the front and rear lights. Allard's law is used to determine the ideal ratio.

Since, from Equation7, $I = \dfrac{E\ D^{-2}}{(0.05)^{D/V}}$

and since transmissivity (T) and visibility are related by the expression $T = 0.05^{-1/V}$, then by substitution intensity can also be expressed as:

$$I = \frac{ED^{-2}}{T^D}$$

Equation 8 *Minimum night-time intensity (2)*

Also, since the illuminances of both the front and rear lights are to be designed to be equal (i.e.: $E_R = E_F = E$), the following equation applies:

$$\frac{I_R}{I_F} = \left((D_{R^2}E/T^{DR})/(D_{F^2}E/T^{DF})\right)$$

$$\frac{I_R}{I_F} = \left((D_{R^2}T^{DF})/(D_{F^2}T^{DR})\right)$$

Equation 9 *Intensity ratio*

Where:

$\frac{I_R}{I_F}$ is the Intensity ratio.

D_R is the distance from the rear light to the halfway point of the channel in NM.

D_F is the distance from the front light to the halfway point of the channel in NM.

T is the transmissivity.

E is the illuminance (factors out).

The equation determines the ideal intensity ratio to achieve equal illuminance at the halfway point in the channel. An additional calculation is performed at the far end to ensure that the ratio does not exceed 2:1. **See cells C88 to C90**.

6.10 SEPARATION OF LIGHTS

The rear tower shall be of sufficient height so that the lights do not blur together. The calculation is performed at both the near and far ends using the calculated luminances at these points. The following equation determines the vertical separation in milliradians required to prevent the lights from blurring together.

Refer to **IALA Recommendation E-112 Equation 11** (master blur equation). **See cells AA7 to AA17, AA23 to AA33 and AA39 to AA49**.

$$\gamma_m = [2.4 - 0.06 * ABS\ Log\ (E_2/E_1) + 0.26 * ABS\ Log(E_2/E_1)^2 + Log\ E^+ * (0.2 - 0.02 * ABS\ Log\ (E2/E1) - 0.02 * ABS\ Log\ (E2/E1)2)] * 10^{-3}$$

Equation 10 Vertical separation in milliradians

Where:

E_2/E_1 is the illuminance ratio.

E^+ *is* the maximum illuminance of either the front or rear lights.

γ_m = vertical separation in milliradians.

Refer to **IALA Recommendation E-112 Equation 13.**

The vertical separation of two lights given the front and rear tower height is expressed as

$$\gamma = \frac{H_2 - b - c}{x + R} - \frac{H_1 - b - c}{x} - 6.75 * 10^{-8} * R$$

Equation 11 Vertical separation of front & rear lights

Where;

H_2 *is the* rear tower height at mean low water (MLW) in metres

H_1 is the front tower height at MLW in metres

b is the height of eye in metres (the program assumes *b* is at MLW)

c is the mean range of tides in metres

x is the distance from front tower to observer in metres

R is the distance between towers in metres

Solving for H2 at mean high water (**cells C108 & C109**):

$$H_2 = (x + R) * [(\gamma + (H_1 - b)/x + (6.75 * 10^{-8} * R)] + b - c$$

This calculation is performed at both the near and far ends of the useful segment.

The front tower and dayboard (if equipped) must be tall enough to be seen at the far end of the channel at the lowest height of eye.

Refer to **IALA Recommendation E-112 Equation 18**, (geographical range).

$$3849 * (\sqrt{(H - c)} + \sqrt{(b)})$$

Equation 12 Geographic range (metres)

Where;

H is the front tower height in metres.

c is the mean range of tides in metres.

b is the height of eye at mean high water in metres.

The program uses the equivalent equation in English units:

$$D = 1.144\sqrt{H}$$

Equation 13   Geographic range (feet & NM))

Where:

D is the distance to the horizon in NM.

H is the height of the tower/observer in feet.

The geographic range is the sum of the distance to the horizon from observer (b) and front tower (H_1). Therefore:

$$x = 1.144\sqrt{b} + 1.144\sqrt{H_1}$$

Equation 14   Distance from front tower to observer in nautical miles

Where:

b is the height of eye in feet.

H_1 is the front tower height at mean high water in feet.

x is the distance from front tower to observer in NM.

Solving for H_1 in metres:

$$H_1 = (x \,/\, 1.144 - \sqrt{b})^2/3.28$$

See cell C98.

Since the bottom of the dayboard must be seen at the geographic range, the front dayboard length (if used) is added to H_1.

The entire rear dayboard (if used) must be visible at the far end of the useful segment and at least one-half of it visible at the near end of the segment.

Refer to **IALA Recommendation E-112 Equation 13** with γ set to zero.

$$\gamma = (H_2 - b - c)/(x + R) - (H_1 - b - c)/x - 6.75 * 10^{-8} * R$$

Where;

H_2 is the rear tower height at MLW in metres.

H_1 is the front tower height at MLW in metres.

b is the height of eye in metres.

c is the mean range of tides in metres.

x is the distance from front tower to observer in metres.

R is the distance between towers in metres.

For the far end:

$$H_2 = RL + b - c + [(x + R) * (H_1 - b - c) \,/\, x] + [(x + R) * R * 6.75 * 10^{-8}]$$

Equation 15   Height of rear tower from the far end of the useful channel segment

For the near end:

$$H_2 = \left(\frac{RL}{2}\right) + b - c + [(x + R) * (H_1 - b - c) / x] + [(x + R) * R * 6.75 * 10^{-8}]$$

Equation 16   Height of rear tower from the near end of the useful channel segment

Where

RL is the dayboard length in metres.

See cells D110 and D111.

The front tower must be tall enough to be unobstructed by objects placed in front of it. In addition, the rear tower must be tall enough to be unobstructed by objects placed between the towers. Refer to **IALA Recommendation E-112 Equation (14)**:

$$(\frac{H" - b - c}{u + S}) - (\frac{H' - b - c}{u}) - 6.75 * 10^{-8} * S$$

Where

H" is the height of front/rear tower in metres from MHW.

H' is the height of obstruction in metres from MHW.

b is the height of eye in metres.

c is the mean range of tides in metres.

u is the distance between observer and obstruction in metres.

S is the distance between tower and obstruction in metres.

Solving for *H"*

$$H" = b - c + [(u + S) * (H' - b - c) / u] + [(u + S) * S * 6.75 * 10^{-8}]$$

See cells C99 to C102 and C112 to C115.

This calculation is performed at both the near and far ends of the useful segment. Since the entire front dayboard (if used) must be visible at either end of the segment, the dayboard length is added to H' (**See cells D99 to D102**). Likewise, the entire rear dayboard (if used) must be visible when viewed at the far end of the segment and only one-half of it when viewed at the near end (**See cells C112 to C115 and D112 to D115**).

The program evaluates the tower heights calculated by the safe height above water, necessity to avoid obstructions, ability to see the dayboards, geographic range, and separation of lights (blur) for selected intensities, at either high or low tide (whichever is appropriate), and recommends a front and rear tower height. If the selected tower height values are lower than the recommendations, an error message is posted.

6.11 SENSITIVITY (CROSS TRACK FACTOR)

Refer to **IALA Recommendation E-112 Equation 16**:

$$Y_D = \theta_D\, x\, (1 + x/R)$$

Equation 17   Off-axis distance

Recalling that Y_D , the Off-axis Distance, is defined as the lateral distance at which a navigator can detect with certainty that a vessel is not on the channel centerline. The Cross Track Factor (CTF) is defined as the ratio of the lateral distance at which a navigator can detect with certainty that a vessel is not on the channel centerline, divided by the half-width of the channel, expressed as a percentage. The Cross Track Factor (CTF) provides an intuitive method to relate the sensitivity performance of the leading line signals to the specific channel in which is being used. The following calculation applies:

$$CTF = Y_D / (W / 2) * 100$$

Equation 18 *Percentage Cross Track Factor*

See cells AE7 to AE17, AE23 to AE33 and AE39 to AE49.

Where:

CTF is the cross track factor in percent.

Y_D is the Off axis distance in metres.

W is the Channel width in metres.

The off axis distance, Y_D can also be expressed as:

$$Y_D = \theta_D (C_D + M)(C_D + M + R) / 1000R$$

Equation 19 *Off-axis distance (2)*

See cells AD7 to AD17, AD23 to AD33 and AD39 to AD49

Where;

C_D is the Position in channel segment being evaluated in metres.

R is the Distance between lights in meters.

M is the Distance between useful segment and front tower in metres.

θ_D is the Horizontal separation of the lights in radians.

6.12 DAYBOARDS

'The study of visibility by day has not in general been the subject of so much attention. Daymarks are often not so important a necessity to the seaman as are lighthouses, in view of natural landmarks which are available to him. Moreover, it must be admitted that the problem of the visibility of daymarks is vastly more complicated than that of lights by night and this has had its effect in discouraging investigators.'[1]

Early range design calculations were done manually and multiple tables were available to assist the designer in dayboard sizing. Those early tables, derived from work by Dr H. R Blackwell and S. Q. Duntley, provided a method of determining the range of specific dayboard sizes and films against various backgrounds. They were later further simplified to provide the range for a given size, regardless of film type and background. These simpler tables formed the basis of international practice for many years.

The tables used in this leading lines program are derived from the simplified table[2] used by the U.S. Coast Guard from the early 1980's to the present, and which has provided many years of successful dayboard performance in keeping with design expectations. The following table lists the rated visual range in kilometres of selected dayboard lengths in meters. The shaded portion represents the portion of the table that was extrapolated using the appropriate fill command in Microsoft Excel.

1 M. Blaise, IALA Bulletin No. 47 (April, 1971) article Titled 'Daymarks as Aids to Navigation.'

2 USCG, Instruction M16500.4, Range Design (1980), p. E2-2

Table 5 Operational Range in km for Specific Dayboard Lengths

Visibility NM	Dayboard Length						
	1.6m	*2.1m*	*3.1m*	*4.2m*	*6.3m*	*8.6m*	*12.2m*
1	0.9	1.3	1.7	1.9	2.0	2.4	2.7
2	1.1	1.7	2.2	2.6	2.8	3.4	3.8
3	1.1	2.0	2.8	3.5	3.9	4.8	5.5
4	1.3	2.4	3.3	4.3	5.0	6.0	7.0
5	1.5	2.8	3.9	5.0	6.1	7.3	8.5
6	1.5	3.0	4.3	5.4	6.7	8.0	9.3
7	1.7	3.2	4.4	6.1	7.4	8.9	10.3
8	1.7	3.2	4.8	6.5	7.8	9.5	11.0
9	1.7	3.5	5.3	7.0	8.3	10.2	11.9
10	1.9	3.7	5.6	7.4	9.3	11.1	13.0

This table expresses dayboard size in terms of height in meters and range in kilometres based on the presumption that the dayboard height will be 1.5 times the width, a common international practice. For reviewers seeking to reconcile the above dimensions with current U.S. dayboard tables, note that the conversion was based on equivalent areas. U.S. dayboards are constructed with a 2:1 ratio of height to width (largely due to the North American standard plywood size of 4 feet by 8 feet), with height expressed in feet and range in miles.

For example, a U.S. dayboard 24 feet in length and 12 feet in width has a total area of 288 square feet, or 26.8 square meters. The length of an equivalent dayboard using the international ratio is:

Dayboard Length (m) $= \sqrt{1.5 * \ Dayboard\ Area\ (m^2))}$

$$= \sqrt{1.5 * \ 26.8\, m^2}$$

$$= 6.3\ m$$

The contents of 0 are plotted to show the pattern of dayboard lengths for specific visibilities. The best curve fit was chosen and appropriate equation displayed to calculate the dayboard length in a given visibility at a specific range. In this case, the natural logarithmic function was chosen. It is noted that due to the slope of the curves, calculated values outside the limits of dayboard length reveal unsatisfactory results. Therefore, error messages were placed in the program warning the user to select values within the limits.

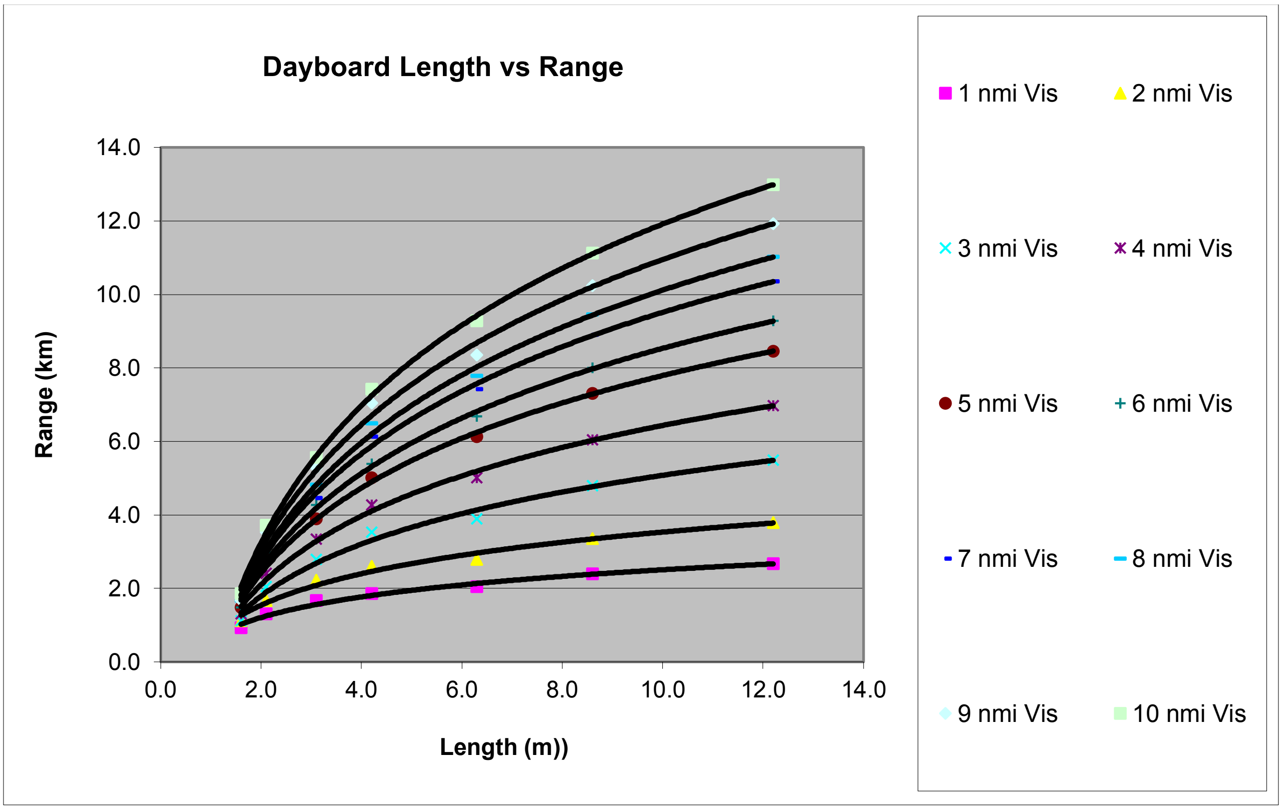


Figure 17 Pattern of dayboard lengths for specific visibilities

The following equations were generated by Microsoft Excel to approximate the curves for the 10 visibilities:

$y = 0.8064Ln(x) + 0.6518$

$y = 1.2356Ln(x) + 0.6893$

$y = 2.0415Ln(x) + 0.3778$

$y = 2.6895Ln(x) + 0.2425$

$y = 3.3375Ln(x) + 0.1072$

$y = 3.7147Ln(x) - 0.0199$

$y = 4.199Ln(x) - 0.156$

$y = 4.5228Ln(x) - 0.2975$

$y = 4.8962Ln(x) - 0.3264$

$y = 5.3861Ln(x) - 0.4892$

These equations are used in the leading lines program to provide a suggested dayboard size for a specific level of minimum visibility (**See cells N92 to R115**). The range of the selected dayboard size is then calculated and compared to the suggested size, and if smaller, displays an error code at points in the channel beyond which the dayboard may not be visible at the minimum visibility (**See cells N75 to R76**).

6.13 DAYTIME LEADING LINE DESIGN WORKSHEET

The detailed design for a leading line is accomplished on the Daytime Leading Line Design Worksheet (click on worksheet tab 'Leading Line-Day'). All computations are the same as described on the night-time leading line worksheet, with the threshold of illuminance (E) set to1000. **See cell C68**.

6.14 FINAL LEADING LINE CONFIGURATION DESIGN WORKSHEET

No additional calculations are made on this final spreadsheet (click on worksheet tab 'Final Design Layout'). This sheet provides a conveniently summarized presentation of all the leading line's prominent configuration and design attributes on a single worksheet suitable for printing and filing in project records.