THE USE OF LASER TECHNOLOGY IN AIDS TO NAVIGATION SERVICE

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Summary

The objective of this paper is to describe the studies, tests and experiments with laser technology conducted by the Canadian Coast Guard over the past 6 years. This work consisted of the development of laser lights, which could potentially replace conventional range lights and other fixed lights, resulting in increased range light effectiveness and possibly reduced costs.

This paper will:

- Summarize our work on laser technology to date;
- Present the performance and the characteristics of the laser ranges in detail;
- Describe the level of service offered to the users; and
- Present a cost benefit analysis of the laser system.

This paper will help marine organizations save time in trying to implement new technology in aids-to-navigation equipment. There is considerable interest from other IALA Members in our laser research. A paper was presented on the subject at the last conference in 1998, and an article was included in the April 2000 Edition of the IALA Bulletin. Furthermore, the laser light development was discussed at the last IALA LITES Workshop in Germany in May 2001.

Résumé

Le but de la communication est de retracer les études, les tests et les expériences menés par la Garde côtière canadienne au cours des 6 dernières années dans le domaine de la technologie laser. Ce travail a porté sur la mise au point de phares au laser qui sont susceptibles de remplacer les feux d'alignement traditionnels et d'autres phares fixes, ce qui donnera lieu à une réduction des coûts et à une augmentation de l'efficacité des feux d'alignement.

La présentation :

- *résumera les travaux que nous avons effectués jusqu'ici sur la technologie laser;*
- *présentera le rendement et les caractéristiques des feux d'alignement au laser en détail;*
- *décrira le niveau de service offert aux utilisateurs;*
- *présentera une analyse des coûts avantages du système laser.*

La présentation facilitera la tâche des organismes maritimes qui veulent réduire leurs coûts opérationnels, grâce à la mise en œuvre d'une nouvelle technologie en matière d'aides à la navigation. Notre recherche sur l'utilisation de laser suscite beaucoup d'intérêt chez les autres membres de l'AISM. Une communication a été présentée à ce sujet lors de la dernière conférence en 1998 et un article a été publié dans le numéro d'avril 2000 du bulletin de l'AISM. De plus, l'utilisation grandissantedu laser et les innovations afférentes seront un sujet de discussion lors du prochain atelier IALALITES *qui s'est tenu en Allemagne en mai 2001.*

INTRODUCTION:

Canada has a continental coastline approximately 59,000 km long and about 3,000 km of navigable inland routes. The Canadian Coast Guard (CCG) has one of the world's leading aids to navigation systems consisting of about 18,000 aids to navigation, of which 60% are floating aids and 40% are fixed aids. The system is made up of both short-range aids (buoys, beacons and lights) and long-range aids (Loran C and Differential Global Positioning System). It is the CCG's goal to be an international safety leader through the development of partnerships and technologies to maintain the highest standards of marine safety and environmental protection for the benefit of all Canadians.

In 1995, the Canadian Coast Guard (CCG) began a Marine Aids Modernization Project to modernize the Canadian aids to navigation system in order to meet the needs of the modern mariner and its financial challenges by taking advantage of modern technology. The aim was to create a more equitable, safe, cost effective and environmentally friendly aids to navigation system across Canada. To realize these objectives, the CCG began developing and implementing a more effective aids to navigation system, implementing a Differential Global Positioning System (DGPS) service and began to review the requirements for conventional aids. The development of a laser range light project is part of the Marine Aids Modernization Project under the heading of new technology.

BACKGROUND

The laser range light project was initiated as a result of developments in laser technology and the need for the CCG to reduce its operating costs. It was suggested that replacing the two sites required for a conventional light range with a single site could decrease costs. It was proposed to replace the conventional lights with a more powerful and accurate light source capable of providing adequate and fast information to mariners.

A project was therefore set up to develop a light source that would:

1. require one site instead of two;
2. be as visible as a standard range light;
3. be eye-safe; and
4. consume less energy than a standard range light

Initial research indicated that laser technology could provide greater light range effectiveness than conventional lights for less power. The INO (Institut National d'Optique), located in Quebec City, was selected to develop this new type of aid to navigation due to its reputation as a recognized expert in the area of optics and lasers.

LASER LIGHT VS ORDINARY LIGHT

- Ordinary light such as that emitted by a light bulb or the sun, is made of light with colours covering a continuous part of the spectrum from UV to infrared. A certain amount of this energy is not useful for vision since the human eye is sensitive to visible light only. Further, these sources emit in all directions without any phase relationship or "coherence of the light". Laser light exhibits two properties that distinguishes it from ordinary light - monochromaticity and coherence.

- Monochromatic light has a single colour and hence a single wavelength, unlike "white" light, which consists of all the colours in the visible spectrum. By choosing a visible laser wavelength all the output energy can be seen by mariners which is not the case for standard lamps. Moreover, monochromatic light can be filtered against the background to increase its visibility.

- Coherence is a property that describes the phase relationship between the various points along a wavefront of light. When light is coherent, there is a phase relationship between the points, which is constant in time. Ordinary light is said to be incoherent because this phase relationship varies in time in a random fashion. When light is coherent, its propagation is determined by the laws of diffraction rather than by the geometric laws governing incoherent light sources. Since the propagation of coherent light is governed by diffraction, it is possible to manipulate the beam shape in an almost arbitrary fashion and then to produce a beam of light having a very small divergence. In other words the laser beam can easily be made directional.

LASER EYE HAZARDS

To limit the power consumption of the system it was decided to explore the possibility of shining the laser directly at the mariners' eyes. It was then necessary to ensure that the laser beam would be safe in the early stages of development. Since lasers are typically very bright, they may represent a danger to the eye. Laser light can be focused to a much smaller spot size on the retina than incoherent white light. This results in a much higher intensity (power per unit area) for the same incident power.

The various factors involved in laser-induced eye damage have been extensively studied, resulting in comprehensive standards for laser safety. The American National Standards Institute (ANSI) standard number ANSI Z136.1-1993, is the standard used here for the Safe Use of Lasers [1]. The important factors in determining safety limits for lasers are laser intensity (power or energy density), length of exposure and laser wavelength, as well as the manner in which the laser beam is viewed (directly, by diffuse or specular reflection, through visual aids, etc.). The key parameter given in the standard is the Maximum Permissible Exposure (MPE), which determines the laser intensity for safe viewing.

A laser can be said to be eyesafe for direct (intrabeam) viewing when its output fluence (energy per unit area) is less than the MPE given in the ANSI standard. The MPE for continuous viewing of a green laser (532 nm) is 1 $\mu W/cm^2$. A laser can be rendered eyesafe by expanding the beam so that its energy or power density is below the MPE. In practice, it may be difficult to expand the beam directly at the laser output to a size necessary for it to be eyesafe. In this case, the beam can be made to diverge so that the laser will become eyesafe at a certain minimum distance called the Nominal Ocular Hazard Distance (NOHD) where the beam area is sufficiently large to reduce the energy density below the MPE value. The lasers developed for this project took these factors (MPE and NOHD) into account.

PREVIOUS WORK IN OTHER ORGANIZATIONS

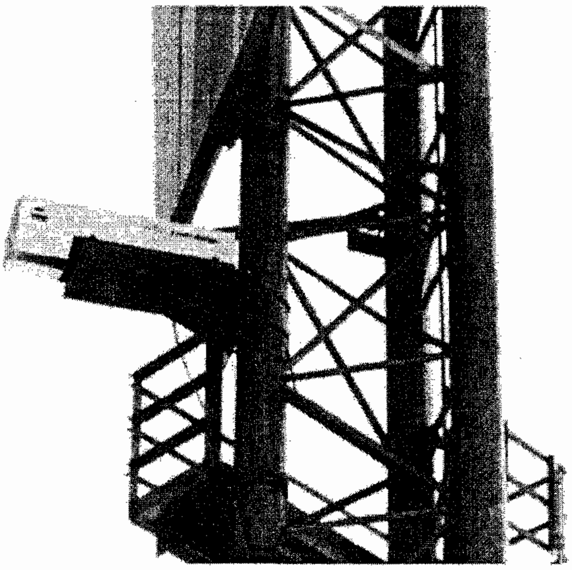
Considerable work on laser aids to navigation has been carried out by the United States Coast Guard (USCG), starting with a field test on the St Mary's River in 1972. In this test, an Argon laser was projected above the channel along the centre of the range, and the scattered light from the beam was viewed overhead. A similar system, known as the single-line laser range, went into operation atop the USCG R&D centre in Groton, CT, on March 1992. The beam from a 1 W Argon ion laser was expanded to a diameter of 10 inches and aimed horizontally over Long Island Sound at a height of 80 feet above sea level. This system also worked by viewing the light scattered from the beam and hence was useful only for night time operation. Both systems are no longer in use but they demonstrated that lasers could be effective aids to navigation.

Two other prototype systems were contracted to Loral Electro-Optical Systems and tested by the USCG in the early 1980s. One of these systems was a simple rotating beacon using a red He-Ne laser with an output power of 5 mW. The beam was expanded and shaped into a 1X 10 mrad (0.06° x 0.6°) beam which was scanned and flashed through 360° by a rotating two-facet prism. The beacon was found to be as conspicuous as the existing incandescent lantern with its 5 mW of output power.

The other system was a single-station laser range light using two stationary laser beams, from a red He-Ne laser and a blue He-Cd laser, to provide colour coding of the port and starboard sides of the channel. Further, part of the beams was split off and counter-rotated to produce time-coded, dual-colour flashes that indicated the distance to the channel centre. A ship returning to port would keep to the starboard side of the channel and thus within the zone of the stationary red beam. Deviation to port causes the blue stationary beam to become apparent. If the ship is off axis, the time-coded flashes will be observed with an angular deviation of 8°/s between flashes. The order of the flash colours indicates which side of the channel the ship is on (red/blue - port, blue/red - starboard).

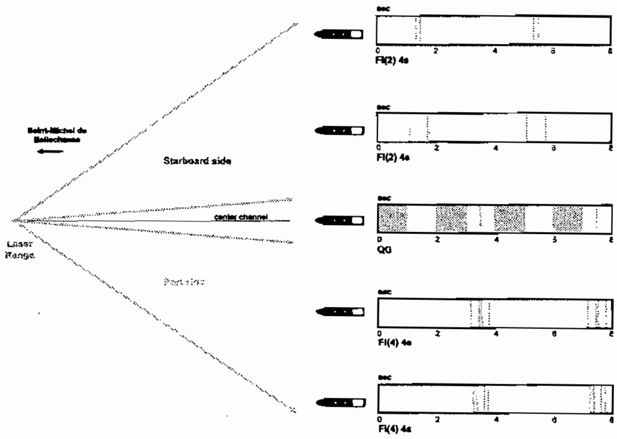
DEVELOPMENT AND TESTING OF A SINGLE COLOUR LASER RANGE - ST-MICHEL DE BELLECHASSE

Building on past work carried out by the United States Coast Guard in the 1970's and 1980's, CCG began its development and evaluation of a green laser light in 1995. It was decided to install the laser on the St-Michel de Bellechasse range tower in the St. Lawrence River near Quebec City. This portion of the St. Lawrence is prone to fog, greatly reducing visibility and effectiveness of conventional range lights. Mariners reported that the laser range light remained the same colour during periods of reduced visibility, which greatly enhanced the mariner's ability to distinguish the range light from other navigational lights and background lighting.



St-Michel de Bellechase Laser Range

The St-Michel de Bellechasse range light characteristic, as displayed on nautical charts, is ISO (2) flashing signal (1 second on, 1 second off). In order for mariners to determine the centre of the channel, where traditional ranges are vertically aligned, the single colour laser displayed a coding scheme, 2 bursts of light were projected on the starboard side of the channel, while four bursts were projected on the port side. The signals were repeated once every 4 seconds. As well, the closer the bursts of light were from one another, the greater the distance from the centre of the channel. As the mariner altered course towards the centre of the channel, the bursts became progressively more separated in time until the point where the ship was aligned in the centre, when only one flashing light was seen.



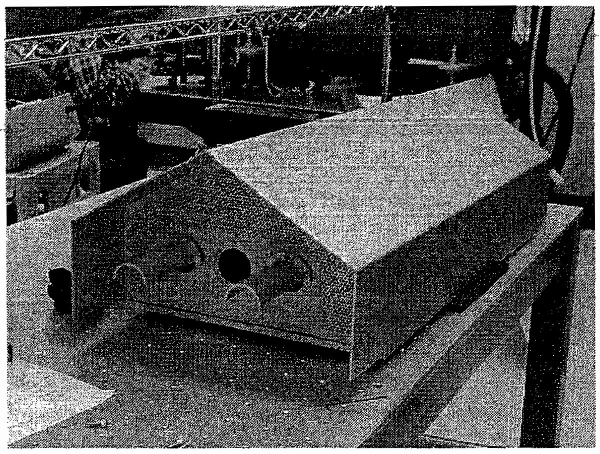
Guiding Code Description

During the evaluation phase of the St-Michel de Bellechasse laser range light, mariners reported favourably on the light strength and high visibility in fog and precipitation. However, they reported that it was sometimes difficult to accurately distinguish between the light coding used for the centre of the channel and the port or starboard coding. Mariners indicated that the starboard coding was easier to interpret than the port coding, which was due to the longer pulse length for the starboard coding. Often, it was reported that under certain angular positions, the port coding did not clearly show 4 pulses, but only 2 or 3.

As a result of the mariner's evaluation of the St-Michel Bellechasse laser trial, it was agreed that in order to provide a more effective and reliable laser range, the position coding shortcomings would have to be addressed. Specifically, the effectiveness of the off-centre code would need to be improved by increasing the duty cycle of the port and starboard angle codes. However, the off-centre-coding problem experienced in the single light laser could be addressed by developing a two-colour laser range.

DEVELOPMENT OF A TWO-COLOUR LASER RANGE LIGHT – HAY RIVER

CCG's initial work on the development of a two-colour laser range light began in 1998. The research and development phase eventually resulted in the installation of a two colour range at Hay River. Hay River is one of the major ports on the Mackenzie-Athabaska Waterway, in Canada's North West Territories, just below the Arctic Circle. The Mackenzie-Athabaska Waterway stretches 2,216 kilometres from Lake Athabaska to the Arctic Ocean. The principle means of moving cargo along the Waterway is by tugs pushing long arrays of barges. The Hay River Range Light marks the entrance to the port of Hay River.



Hay River Laser in Lab

Laser Range Light at Hay River

As with the single colour range light system for St-Michel de Bellechasse, the two-colour laser range was developed for CCG by the National Optics Institute of Quebec. The Hay River system used 20 mW red and green lasers. It was powered by solar equipment and was installed with a gun sight for easy alignment. It was designed for a range of 3 kilometres and a channel width of 115 meters with a planned service life of 10,000 hours.

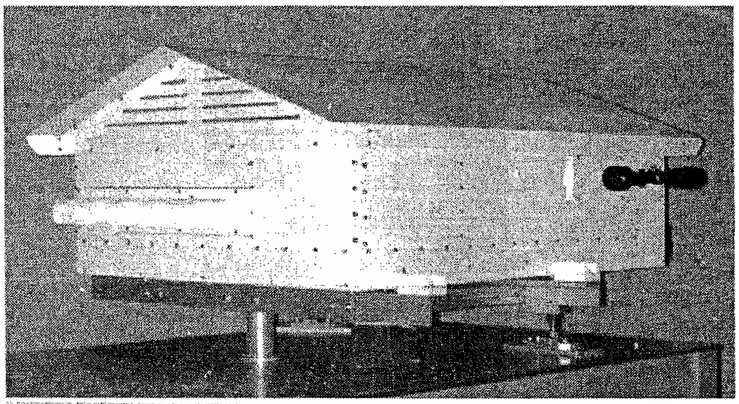
The use of the two colours, red and green, addressed the shortcomings of the single colour system, which was dependent on light coding to indicate channel alignment. In the two-colour system, the red and green automatically showed the port and starboard deviation from the centre channel. For example, on the starboard side, the mariner would see light characteristic red flash of 0.5 second every 2 seconds. In the centre of the channel, the mariner would see an alternating red and green flashing light of 0.5 seconds every 2 seconds. On the port side, the mariner would see the light characteristic green flash of 0.5 seconds every 2 seconds.

The laser was installed on the front tower of the Hay River Range on June 8, 2000. The laser was powered by two 85 watt solar panels and 8 100ah batteries. At the time of installation, the system used 4.32 watts of power, however the laser was designed to use a maximum of 18 watts during cold weather operations when heaters were required for the lens.

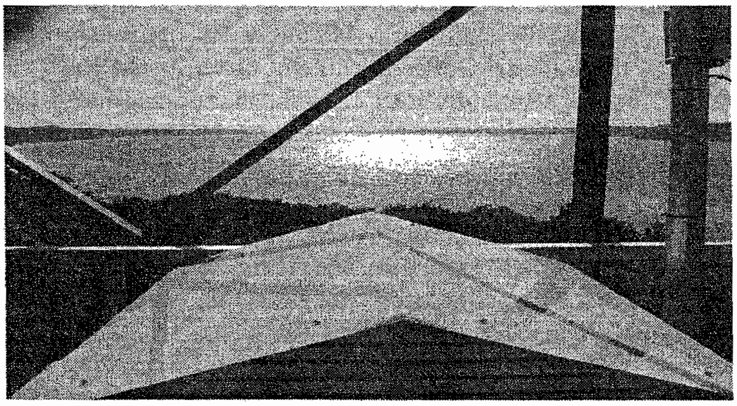
In November 2000, the end of the navigation season, the laser was shut down. The main users of this system were the CCGS Eckaloo and the Northern Transportation Company, which operates a large number of tugs and barges on the Mackenzie River stated that the laser was not bright enough for the arctic navigation season. The mariners also complained that it was very difficult to determine how far they were off the centreline of the channel. However, this prototype indicated that with some modifications, the technology could work and in June 2001, the laser was removed and was shipped to the CCG base in Prescott for storage.

DEVELOPMENT OF A TWO-COLOUR LASER RANGE LIGHT – ST-BASILE

The development of the Hay River system provided the necessary initial groundwork for the development of a more sophisticated two-colour system with greater angular discrimination and greater range. It was proposed to develop and install such a two-colour laser range at the St-Basile range tower in the St. Lawrence River near Quebec City. As with the single colour laser system for St-Michel de Bellechasse and the two-colour laser system for Hay River, the National Optics Institute of Quebec developed the St-Basile laser system for CCG.



St-Basile Laser in Lab

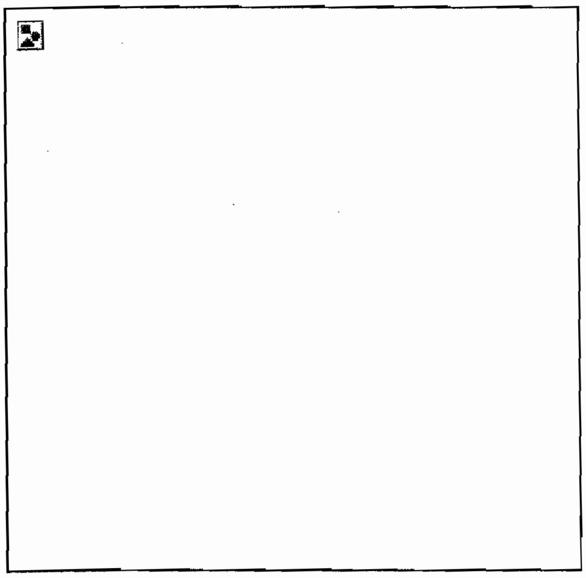


St-Basile Laser on Site

Whereas the Hay River system utilized 3 cones and a range of 3 kilometres, the system for St-Basile was designed with 13 cones and a range of 13 kilometres. From a functional point of view, the laser range coding is designed to indicate to the mariner how far he is off the centre line of the channel. As the mariner moves further off the centre line, the flash frequency increases (see the following table for a description of the codes). The system was installed in July 2001 and preliminary reports from mariners indicate that they find the light too bright. They also find it difficult to determine "exactly" where they are in the channel because they are having difficulties interpreting the code. However, it is hoped that the evaluations by mariners will help CCG measure the effectiveness of the two colour laser and make the final modifications to make this a workable system.

Cone	Location	Colour	Length of Cycle (Seconds)	Number of Flashes During Cycle	Duration of Flash (Seconds)
1	Starboard	Green	1.5	3	0.12
2	Starboard	Green	1.5	3	0.12
3	Starboard	Green	1.5	2	0.19
4	Starboard	Green	1.5	1	0.38
5	Starboard	Green	4.5	2	0.63
6	Starboard	Green	4.5	1	1.38
7	Centreline	Green & Red	9.0	2	1.38 Alternating
8	Port	Red	4.5	1	1.38
9	Port	Red	4.5	2	0.63
10	Port	Red	1.5	1	0.38
11	Port	Red	1.5	2	0.19
12	Port	Red	1.5	3	0.12
13	Port	Red	1.5	3	0.12

Laser Coding



POWER REQUIREMENTS AND OUTPUT

Following is a summary of the power requirements and output of the laser ranges:

		St Michele	Hay River		St-Basile	
			Day	Night	Day	Night
Output Power	Green	80mW	1.8mW	1.0mW	100mW	10mW
	Red	Not Applicable	8.3mW	3.9mW	170mW	17mW
Power Requirements		Not Available	18W		300W	

COSTING ANALYSIS

A brief preliminary costing analysis of a conventional range based on the St-Basile Range follows. It is based on a 25-year cycle because it coincides with the estimated life expectancy of a steel tower.

Item	Life Expectancy	Number of Units in Range	Number of Replacements over 25 Years	Unit Cost $000 Cdn	Total Cost over 25 Years $000 Cdn
Property	N/A	2	N/A	30	60
Tower	25 Years	2	1	45	90
Lantern	5	2	5	8	80
Operating Costs	Annual	2	25	1	50
Maintenance Costs	Annual	2	25	2	100
				Total	$380

A similar costing analysis of a laser range located at St-Basile follows:

Item	Life Expectancy	Number of Units in Range	Number of Replacements over 25 Years	Unit Cost $000 Cdn	Total Cost over 25 Years $000 Cdn
Property	N/A	1	N/A	30	30
Tower	25 Years	1	1	45	45
Laser	5	1	5	30	150
Operating Costs	Annual	1	25	1	25
Maintenance Costs	Annual	1	25	10	250
				Total	$500

As can be seen from this analysis, the laser range is not cost effective over a conventional range. Any savings that are realized through lower property and tower costs are quickly lost due to the higher costs for the laser and the maintenance of the laser. It is hoped that this may change in the future if the fabrication costs of the laser can be reduced and the life expectancy can be increased. There is also the possibility that the design can be simplified, therefore eliminating the need professional help in maintaining the equipment

SUMMARY

The preliminary findings in this study have shown that laser light ranges are presently expensive because much site-specific adjustment and configuration is required. It is very difficult to modify a laser light that was designed and built for a specific site to meet the operational needs of another site. The power requirements, the lens and the code must all be specifically designed for each site. Therefore each laser must be designed and manufactured for a specific site and this increases the cost of this system. Other preliminary findings show that lasers are difficult to install, maintain and service. The preliminary findings of this project indicate that presently, laser light ranges are expensive and fragile.

The results of the study are not just negative. On the positive side, it was found that laser lights are visible from very great distances with relatively modest power requirements. It has been suggested that lasers can be used in special applications such as where background lighting interferes with conventional lights.

As reported at the 1998 IALA Conference, CCG is committed to evaluating new technologies in its ongoing work to modernize aids to navigation across Canada. The use of laser technology to replace conventional range light sites will require more work before proving positive, both in terms of potential cost savings to CCG and increased accuracy for mariners. It is possible that costs for laser light ranges may decrease over time or maybe the approach taken to date has been too complex and that it may be necessary to consider a simpler design in order to make significant savings and gain acceptance by the mariner.

CCG will continue to share its results on the use of laser technology for range lights with the greater marine community. Specifically, it will report progress on a regular basis through its representation on the IALA Engineering Committee. CCG welcomes comments from other marine administrations and mariners concerning the use of laser technology in the provision of marine aids to navigation.