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# CONTENTS


| ARTICLES | PAG. |
|---|---|
| A PRE-OPERATIONAL OCEANOGRAPHIC SYSTEM AS PART OF THE RESPONSE TO THE PRESTIGE OIL SPILL IN CANTABRIA (SPAIN)<br>**S. Castanedo, R. Medina and I. J. Losada** | 5 |
| THE INFLUENCE OF SOME SHIP PARAMETERS ON MANOEUVRABILITY<br>**F. Pérez Arribas and J. A. Clemente Fernandez** | 21 |
| MARINE POLLUTION FROM SHIPS' BALLAST WATER<br>**J. Perera Marrero and E. Melón Rodríguez** | 27 |
| ANALYSIS OF THE MANOEUVRABILITY AND STRUCTURAL STRAIN OF A COORDINATED RUDDER ON AN OPERATIONAL TUG<br>**E. Cueto** | 39 |
| FUEL QUALITY RELATED TO UNSEAWORTHINESS<br>**J. I. Gómez Gómez and F. Arvelo Valencia** | 53 |
| TRANSFER OF NAUTICAL KNOWLEDGE FROM THE U.S.A. TO EUROPE IN THE NINETEENTH-CENTURY:THE CASE OF THE SUMNER LINE OF POSITION AND ITS INTRODUCTION INTO SPAIN<br>**I. Ibáñez Fernández, J. Llombart Palet and M. A. Iglesias Martín** | 63 |

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# A PRE-OPERATIONAL OCEANOGRAPHIC SYSTEM AS PART OF THE RESPONSE TO THE PRESTIGE OIL SPILL IN CANTABRIA (SPAIN)

**S. Castanedo[1], R. Medina[2] and I. J. Losada[3]**

## ABSTRACT

**This paper presents a pre-operational oceanographic system which was developed to provide guidance for the actions taken in response to the Prestige oil spill in Cantabria.**

**The goal of this system was to forecast the wave climate, tidal and wind currents, and oil spill trajectories to provide the decision-makers with technical assistance in the response to the Prestige oil spill. The two main components of the system were data collection and processing, and its incorporation into numerical models in order to provide forecasts. Regarding the data used, the information from overflights received daily became essential in order to determine correctly the initial position of the oil slicks. Meteorological and oceanographic data were also received daily by means of an emergency protocol established between Puertos del Estado (Spain), the Naval Research Laboratory (USA) and the University of Cantabria.**

**These data were used to run the trajectory model, the wave propagation model and the shallow depth-integrated flow model. The information generated by the numerical simulations was presented to the decision makers every day in the form of maps of easy and quick interpretation as a tool to assist in response planning.**

**In addition, in order to develop a defensive or protection strategy for sensitive areas such as estuaries, a hydrodynamic study was carried out by the University of Cantabria in all the estuaries of the region. The results of this study consisted of a boom deployment plan for each of them.**

**Key words: Prestige, oil spill, operational oceanography**

## 1. INTRODUCTION

On November 19, 2002 the single-hulled oil tanker *Prestige* broke in two about 130 nautical miles off the Spanish coast, west south-west of Cape Finisterre (42º15'N, 12º08'W). The stern of the Prestige sank into 3500 meters of water at 12:00 h and the bow followed at about 16:00 h. The tanker carried 77.000 tonnes of heavy fuel (fuel oil #6) and the initial amount of oil released was estimated at 30.000 tonnes. The oil spill reached Cantabria, which is located about 450 nautical miles east of the sinking point, 17 days later, on December 5, 2002 .

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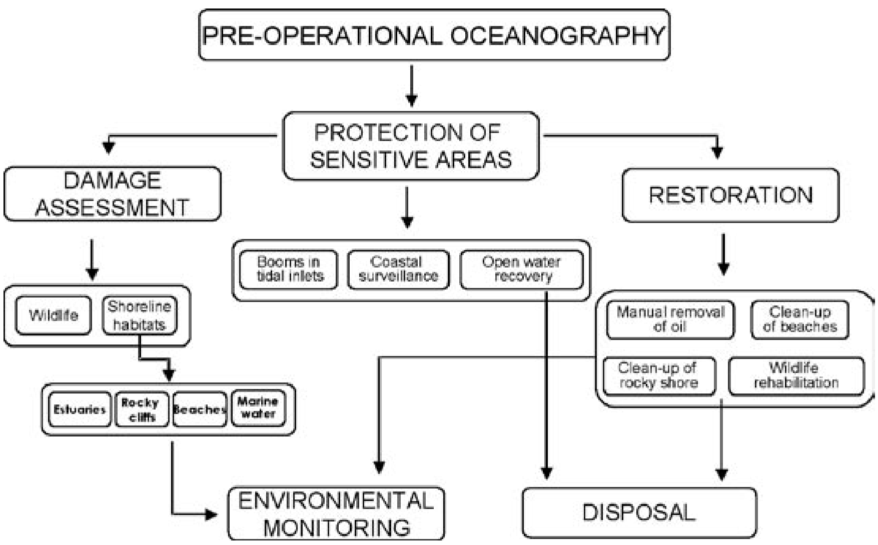
Cantabria is a region located on the Northern coast of Spain. Along more than 200 km of coastline there are a lot of rich marine/estuarine ecosystems, including more than 100 beaches, 14 estuaries and marshes, some of them with shellfish growing areas, European protected areas (Santoña Estuary, Oyambre Natural Park), areas of special protection for birds, etc. Also, economic activities related with the marine environment are very important in the region, such as fishing, commercial harvesting of algae and tourism which is becoming one of the most important factors in the region's development. The area initially affected by the Prestige oil spill covered almost 50 % of the coast, the west coast being the most affected.

In order to protect the Cantabrian coast from the damage induced by the accident of the oil tanker and due to the lack of a regional contingency plan for accidental marine pollution, an emergency spill response system was developed by both the local government of Cantabria and the University of Cantabria with the external collaboration of several national and international agencies and institutions. The organisation of this emergency plan started the day right after the Prestige sank in Finisterre. The main objectives of this plan were:

(1) To establish a pre-operational forecasting system for developing proper response strategies, for making detailed risk assessment and for protecting natural resources.
(2) To perform damage assessment and monitoring of coastal ecosystems
(3) To propose and apply restoration measures in oiled coastal areas

To carry out the aforementioned objectives, the system was organised according to the scheme presented in Fig. 1. Within this plan, developing a pre-operational forecasting system, the technical assessment of the protection of sensitive areas, the damage assessment and monitoring and the analysis of remedial techniques were the tasks that the University of Cantabria was directly involved in.

*Figure 1. Structure of the response plan developed in Cantabria*



Operational Oceanography can be defined as the activity of systematic and long-term routine measurements of the seas and oceans and atmosphere, and their rapid interpretation and dissemination. Important products derived from operational oceanography are: (1) nowcasts providing the most accurate description of the present state of the sea including living resources, (2) forecasts providing continuous forecasts of the future condition of the sea for as far ahead as possible and (3) hindcasts assembling long term data sets which will provide data for description of past states, and time series showing trends and changes (www.eurogoos.org).

There are some examples of Operational Oceanography Systems that are being developed or are already operating in the world: EuroGOOS (Woods et al., 1996), Nittis et al. (2001), Varlamov et al. (2001). However, in Spain, although a forecasting system for wind conditions and wave climate exists (www.puertos.es), at the time of the spill there was no operational response system ready to be used in an oil spill incident.

This paper outlines the work developed by the University of Cantabria regarding the pre-operational oceanographic system. The goal of this system was to forecast the weather conditions, wave climate, tidal and wind currents and oil spill trajectories to provide the decision makers with technical assessment in the response to the Prestige oil spill. The main components of the system were the overflight information, meteorological and oceanographic data collection and numerical models.

In addition, in order to develop a defensive or protection strategy for sensitive areas such as estuaries, a hydrodynamic study was carried out by the University of Cantabria in all 14 estuaries of the region. The results of this study consisted of a boom deployment plan for each area.

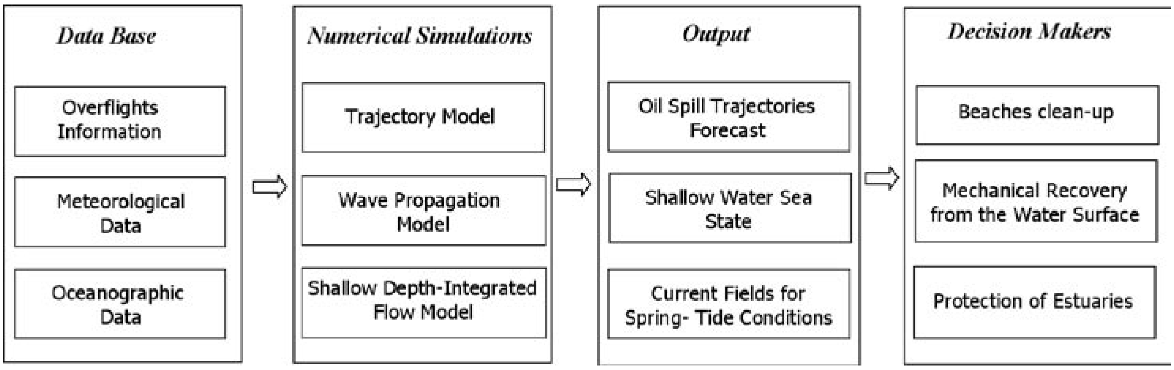
## 2. STRUCTURE OF THE FORECASTING SYSTEM

The pre-operational forecasting system was developed as a part of the emergency *Prestige* oil spill response plan established in Cantabria. Spilled oil moves horizontally in the marine environment under forcing from wind, waves and currents. To implement these effects the system had to include meteorological and oceanographic data along with overflight information from aircrafts. Next, numerical models were implemented in order to obtain a graphical output (see Fig. 2). The main objectives of this pre-operational system were the following:

• To provide in real time the location, size and predicted trajectory of the oil slicks, in order to evaluate the different strategies to minimise the damage induced by the oil spill in the coast.

• To provide in real time reliable information and forecast for weather conditions, wave climate and tidal and wind currents in order to plan cleaning-up of the shoreline, the recovery of oil from the sea and the protection of estuaries by means of booms. The different components of the system are described below.

*Figure 2. Schematic structure of the pre-operational forecasting system*




### 2.1 Description of the data

**Overflight data**

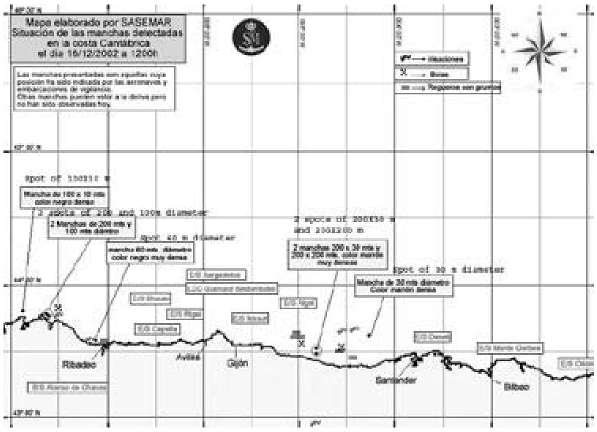
During the initial phases of an oil spill response, information about the release is often incomplete. Although various types of remote sensing techniques are available for detecting and mapping oil distribution, the most reliable technique is visual observations from aircraft (NOAA, 1996). One of the main components of the forecasting system developed by the authors was based on the information from overflights by aircraft belonging to several institutions.

Owing to the great distance that the oil travelled from the accident point to the Cantabria coast, its physical characteristics changed due to various processes usually referred to as *oil weathering*. The heavy crude from the *Prestige* reached Cantabria mainly in the form of water-in-oil emulsion or "mousse" which had approximately 80 percent of water and a brown/orange colouration and a cohesive appearance. This fact multiplied by five the size of the spill and the problems of cleanup and recovery were magnified. Moreover, the oil spill usually arrived in the form of tarballs increasingly fragmented and dispersed. This, combined with the lack of experienced observers, meant that the reports from aircraft were, in general, incomplete.

The overflight data were provided twice a day, at noon and at 17:00 h, by the Spanish Government and by the local government of Cantabria by means of fax and email. Theoretically, the information consisted of overflight hour, oil slick coordinates, coverage area and main characteristics of each oil slick, such as appearance, colour and thickness, but in fact, most of the time there was no information about the size and thickness of the oil slicks. Fig. 3 shows an example of the maps elaborated daily by SASEMAR (the Spanish organisation in charge of sea rescue and pollution control) based on aerial observations for the North of Spain.

All the information gathered from the different sources was processed and reviewed. A worksheet was filled in with these data and other interesting information about each oil slick such as whether there were ships recovering the oil spill at the moment that the overflight was taking place.

*Figure 3. Map of the distribution of the oil slicks observed in the North of Spain on December, 16th, 2002 at 12:00h (SASEMAR)*




**Meteorological and oceanographic data**

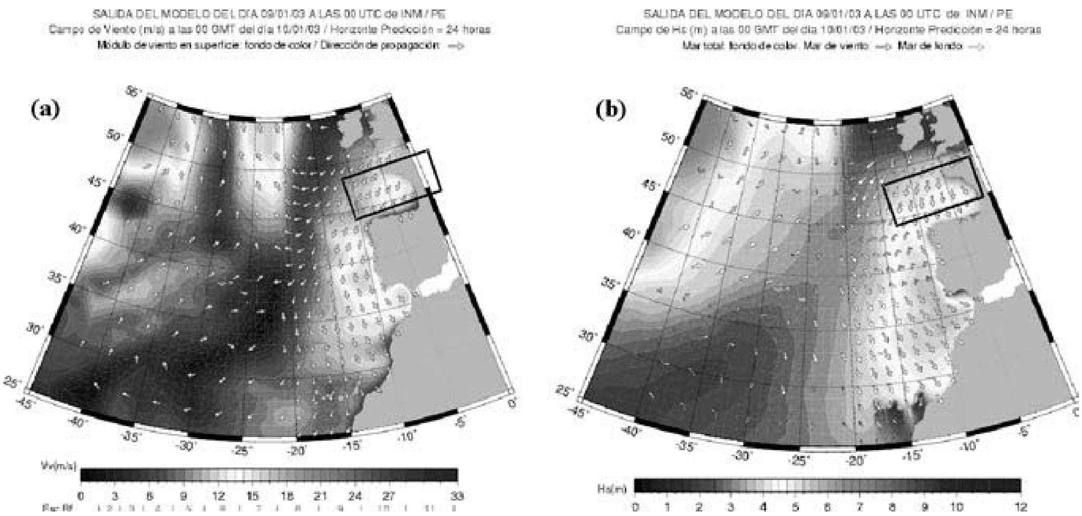
Meteorological and oceanographic conditions are crucial to the evolution of spilled oil in the marine environment. Given that most oils are initially buoyant and float on the sea surface, their transport is dominated by the surface current, winds and wave fields (ASCE, 1996). Although data from coastal stations and meteorological buoy stations would be more precise, direct observations and measurements in the place of incident are very rare. This is because in this work the output of numerical models was used as a source of regular data.

The forecast of wind data was provided by the INM (National Meteorological Institute) based on results from the numerical model HIRLAM (High Resolution Limited Area Modelling), a state-of-the-art analysis and forecast system for numerical weather forecasts (Cats and Wolters, 1996). The forecast model is a hydrostatic grid-point model, the resolution used in this work was 0.5° and the results were the 48 hours forecast of wind velocity and direction with a 6 h time interval.

Sea state conditions data were delivered by Puertos del Estado (State Ports of Spain) as an output from the numerical model WAM, a third generation model which computes spectra of random wind-generated waves (WAMDIG, 1988; Komen et al., 1994). The WAM model solves the energy transfer equation for the wave spectrum. The equation describes the variation of the wave spectrum in space and time due to the advection of energy and local interactions. The grid resolution used in this work was 0.25° and the results were the 48 hours forecast of significant wave height, direction and mean period with a 6 h time interval.

The numerical results of both models were provided by State Ports of Spain (www.puertos.es) daily, at 7:30 h, sending the data to the pre-operational system established at the University of Cantabria. An example of wind conditions and sea state calculated by HIRLAM and WAM respectively is shown in Fig. 4.

*Figure 4. (a) Forecast wind field simulated by HIRLAM for January 10, 2003, 0 h.; (b) Forecast significant wave height calculated by WAM for January, 10$^{th}$ , 2003, 0 h. Source: puertos.es*




Oceanic currents data were the output of a version of the Princeton Ocean Model (POM) (Blumberg and Mellor, 1987), implemented at the Naval Research Laboratory (NRL). This information consisted of 48 hours forecast of velocity and direction of surface currents in a grid of resolution equal to 0.05° and with a 3 h time interval. The data were sent daily at 17:30 h to State Ports of Spain and finally to the University of Cantabria over the Internet.

### 2.2 Oil Spill Model

There are a large number of oil spill models available today (Spaulding, 1988; ASCE, 1996; Reed et al., 1999; NOAA, 2002). The capability of the models depend on their final goals. Some were developed for providing rapid and accurate prediction to minimise environmental damage caused by oil, whereas other models were created to be used in oil spill contingency planning and/or training.

When oil is spilled into the sea it undergoes a number of physical and chemical changes that depend on oil properties, hydrodynamic conditions and environmental conditions. Spill models are usually composed of mathematical formulations to represent oil transport and fate processes (advection due to current and wind, spreading, emulsification, evaporation, dissolution, etc). The most sophisticated models currently available consist of a set of algorithms to simulate the transport and fate of oil in three dimensions: MOHID (Miranda et al., 2000), OILMAP (ASA, 1997), Chao et al. (2003), Tkalich et al., (2003).

However, when rapid response is required, models like GNOME, a widely used oil spill trajectory model that simulates oil movement due to winds, currents and tides (NOAA, 2002), is a good choice. Consequently, in this work, owing to the emergency response required in Cantabria during the *Prestige* incident, a two dimensional (2D) lagrangian model was used.

**Model Description**

The spilled oil at sea is usually transported by the movement of the surface seawater due to wind, wind-generated waves, wind-driven currents and tidal currents, and also it diffuses by turbulence. In order to consider all these factors, a two-dimensional lagrangian model was developed as a part of the pre-operational forecasting system. In this model, the drift process of the spilled oil was described by tracking the numerical particle equivalent to the oil slicks by means of the transport equation for non-weathering hydrocarbons.

Every time step, the new position of the particles is computed by the superposition of the transports induced by the mean flow, tides, wind/waves and turbulent dispersion

$$x_i^{t+1} = x_i^t + u\Delta t + TDT \qquad \textbf{(1)}$$

where $x_i^{t+1}$ and $x_i^t$ are the location of the $i^{th}$ particle at time $t+1$ and $t$ respectively; $\Delta$t is the time step; $u$ is a vector sum: $u = u_c + C_D W + u_w$ ; $u_c$ is the surface current velocity; $C_D$ is the wind drag coefficient which, according to the state-of-the-art, varies from 2.5% to 4.5% (ASCE, 1996); $W$ is the wind velocity and $u_w$ is the wave-induced Stokes drift, calculated as $u_w = (gH/8c)$, where $g$ is the gravitational acceleration; $H$ is the wave height and $c$ is the wave celerity (Dean and Dalrymple, 1991).

In equation (1) TDT stands for the turbulent diffusion transport. This term is calculated by a random walk procedure where diffusion is simulated by a random Brownian motion of the particles (Koutitas, 1988).

**Model calibration**

On December 20$^{th}$, 2002 four Argos drift buoys were deployed by the Marine Research Institute (IIM-CSIC) and the University of Vigo (GOFUVI) on a large oil slick from the tanker *Prestige* in order to follow the oil slick trajectory. In Fig. 5 the paths followed by the buoys are shown. Buoys number 16751 and 16753 arrived at the coast on January 30$^{th}$, 2003 and buoy 16754 grounded on February, 1st 2003. However, buoy 16752 was captured at sea on January, 19$^{th}$, 2003. As can be seen, all three buoys that grounded were found on the Cantabrian coast (black rectangle) which was consistent with the fact that the largest amounts of beached oil were found in this part of the Spanish north coast.

In order to verify the oil spill model performance and to estimate the value of the wind drag and turbulent diffusion coefficients, a comparison between buoy trajectories and numerical predicted paths was performed. In Fig. 6 the comparison between model results and buoy paths on 23-24$^{th}$ of December, 2002 is presented. As can be seen, in this case, for $C_D$=0.02, the predicted trajectories show good agreement with the actual path of the two buoys nearest to the coast; however, the model overpredicted the transport for the other buoys. This kind of analysis was carried out periodically in order to correct the model parameters.

*Figure 5. Trajectory of Argos buoys deployed on December, 20$^{th}$, 2002. Source: http://eddy.uvigo.es/Argos/*

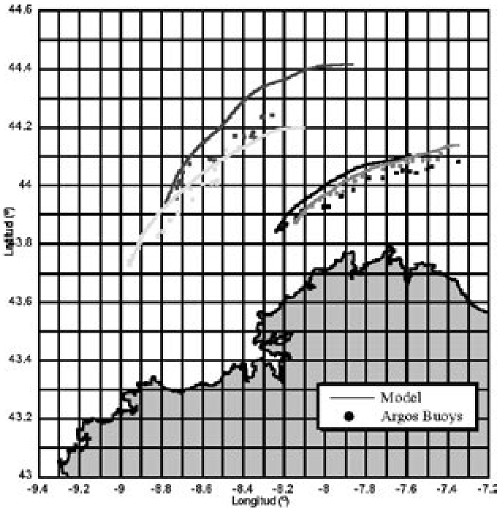
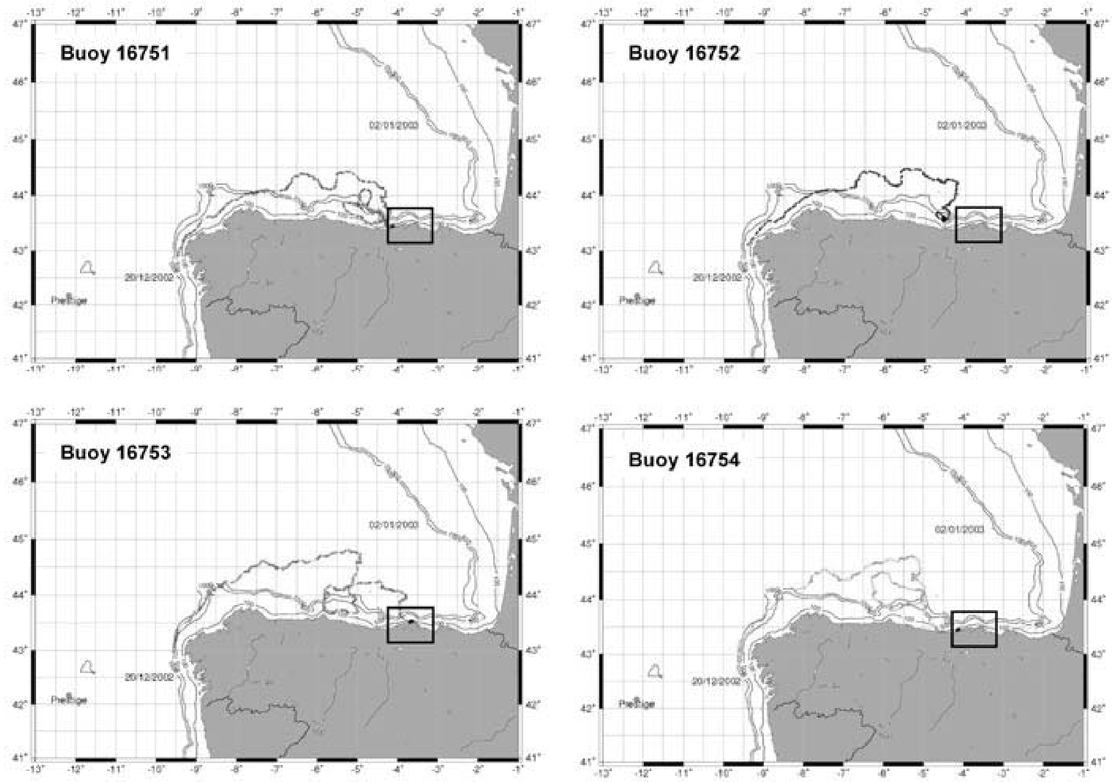


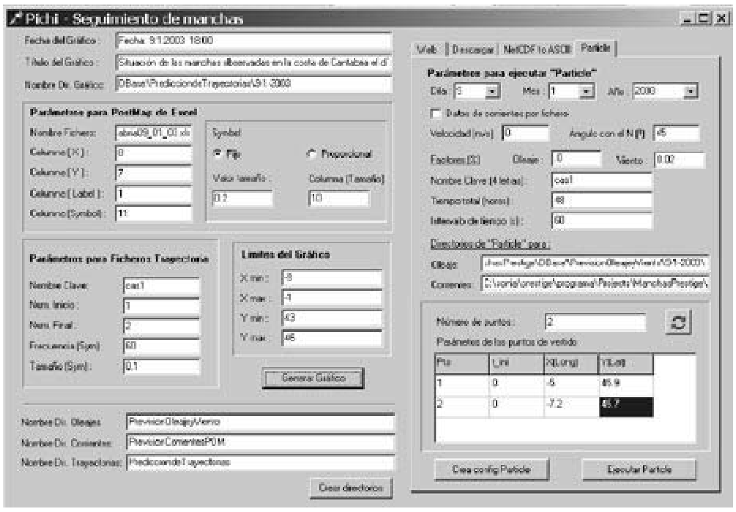

*Figure 6. Simulated trajectories by Oil spill model (solid line) for 23-24 December 2002 compared with actual drift buoys paths (doted line).*




## Simulation results

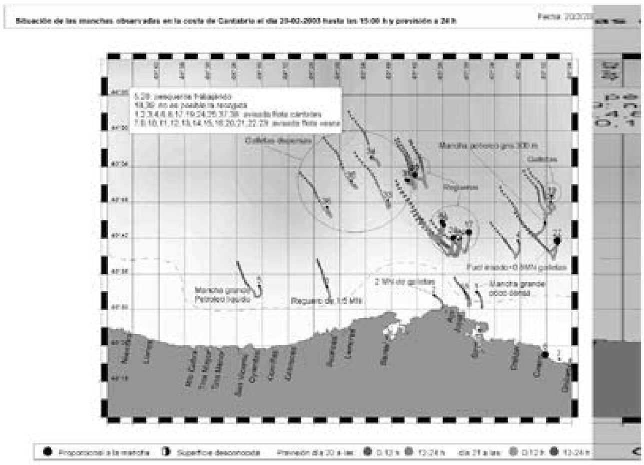
The oil spill model described above was operated with data from aerial observations and the aforementioned meteorological and oceanographic data. In order to make the process user-friendly and operational, the input and output operations were implemented through a graphical user interface (GUI) (see Fig. 7).

*Figure 7. GUI developed to operate the oil spill model and data base.*




The output of the oil spill model consisted of oil spill trajectories forecast for a 12-, 24- and 48-hour horizon period. This result was presented in the form of maps such as that shown in Fig. 8. In this figure the initial location of each oil slick is represented by means of a black circle with a diameter proportional to the size of the oil slick. The path followed by each oil slick is shown by means of coloured dots and each colour stands for a 12-hour forecast period. Moreover, some additional information relevant for each oil slick was usually included in the map.

*Figure 8. Predicted oil spill trajectories for the Cantabrian coast on February, 20$^{th}$, 2003*

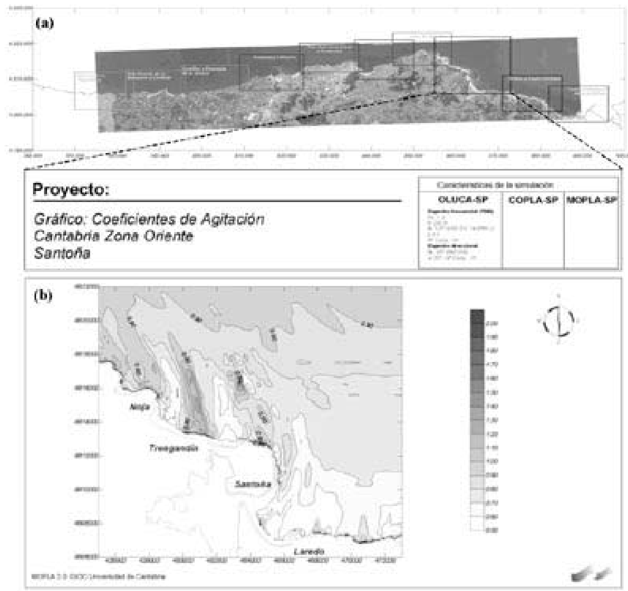


## 2.3 Wave propagation model

The model used to simulate the shallow water sea state was the OLUCA-SP. This wave propagation model, developed by the University of Cantabria, simulates the behaviour of a random sea over irregular bathymetry, incorporating the effects of shoaling, refraction, diffraction and energy dissipation. OLUCA-SP includes most features present in the model REF/DIF developed by Kirby and Dalrymple (1992). The model is constructed in parabolic form and finite difference techniques are used to solve the equations.

In order to apply the wave propagation model, the Cantabrian coast was modelled using several grids to achieve the necessary resolution for wave height and direction (see Fig. 9).

*Figure 9. (a) Numerical grids used in Cantabrian coast; (b) Shallow water propagation coefficients for Santoña coast*




The boundary conditions at the open boundaries were provided by the numerical model WAM described before. The model was run every day to obtain the shallow water wave height and direction forecast for a 48-hour period. These results were sent to the decision- makers in the form of shallow water propagation coefficient maps. Fig. 9 shows one of these maps for the Santoña coast.

### 2.4 Shallow depth-averaged flow model

In order to develop protection strategies for sensitive areas, one of the tasks of the pre-operational system was to carry out a hydrodynamic study of each estuary of Cantabria. The purpose of this work was to provide the decision-makers with technical assessment about boom deployment. In order to do this, a shallow depth-averaged flow model developed by the University of Cantabria was used. This model has been widely applied in previous studies in the Northern estuaries where it was calibrated in order to achieve reliable simulations of the specific circulation in these shallow areas.

The numerical model, H2D, used in this study was based on the solution of the depth-integrated shallow water wave equations. For the numerical solution of these equations an alternating direction implicit (ADI) finite difference scheme was used (Leendertse, 1970). The forcing included in the model are astronomic tide, river discharge, wind and horizontal gradients of density. The results provide by H2D consist of surface elevation, and depth-averaged currents and density for the numerical grid considered. Section 3 of this paper shows the results of this model and its application.

### 2.5 Decision makers

Every day at approximately 18.00 h, the decision-makers received the information, via fax and email, from the pre-operational forecasting system. This information included the graphical output of the numerical models described above: the oil spill trajectories forecast map, the shallow water propagation coefficient maps and the depth-averaged estuarine currents maps, and the weather forecast based on the HIRLAM output.

Based on this information along with the information from other sources such as the 25 surveillants provided by the Environmental Agency of Cantabria covering all the coast and the fishing boats positioned at tidal inlets, the decision-makers had to decide the following day's response strategies for protecting the natural resources. These strategies consisted of deploying booms at tidal inlets, recovering oil spill at sea and cleaning-up the shoreline.

Based on the oil spill forecast map and on the aerial information, the decision makers had to decide how many fishing boats would be operating the next day and which would be the nearest port to optimise operations. Also, the shallow water propagation coefficient maps became a useful tool in order to know the sea state near the coast where the fishermen had to go to recover the oil. Regarding the cleaning-up of the shoreline, based on the information received, the number of persons required and the areas affected had to be determined.

The next section describes how the depth-averaged estuarine current maps were used.

## 3. PROTECTION OF ESTUARIES AND MARSHES

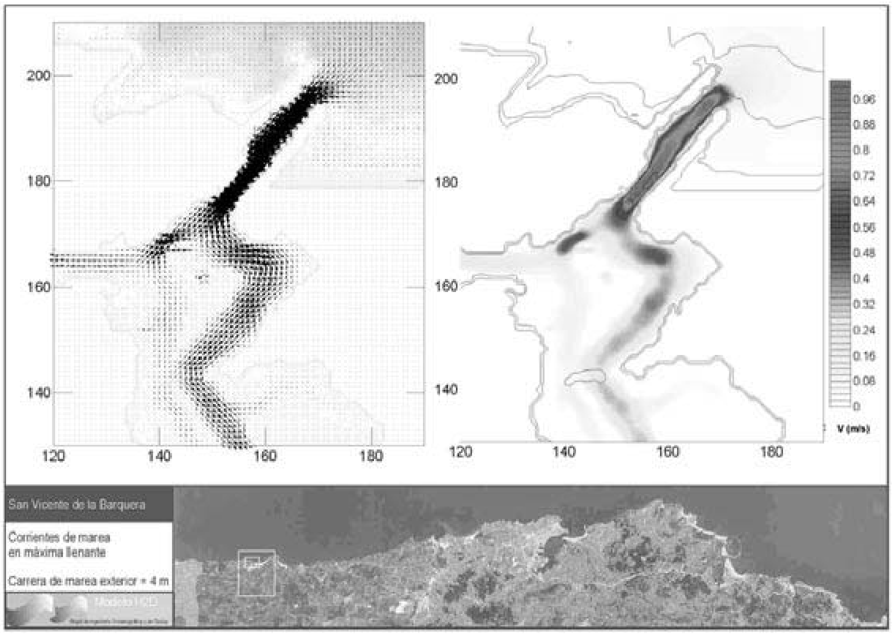
Apart from oil recovery at sea and surveillance of tidal inlets, the primary tools used in Cantabria for protection of sensitive areas were the containment booms. Oil boom types vary considerably in size, shape, design and intended use. There is no single type of boom well suited to meet all on-water conditions including current, tides, winds or deployment area factors. The most ideal situation is where pre-selected booming strategies have been adopted. If, however, a site has not been tested, as was the case for the Cantabrian coast, it will be necessary to check anchor points, shoreline moorings, water depth, currents, tidal effect and whether or not the site is exposed to high energy weather conditions. Therefore, before a booming strategy was implemented, a protection plan was carried out. The plan consisted of the following tasks:

I. Boom location, mooring and anchoring plan.
II. Design of boom anchoring.
III. Boom deployment and maintenance.
IV. Boom monitoring and cleaning.

In this plan, the University of Cantabria was involved in developing the studies needed to carry out Task I. The main objectives of these studies were to obtain the necessary data (wind waves, currents, tide, wind) to adequately set up the containment booms and to analyse the effects that the partial closure of estuaries, bays and marshes would have on the flow and transport of substances.

In order to undertake these studies, the first step was to gather information about boom types, mooring and anchoring systems, aerial photographs and existing bathymetry of the estuaries. The next task was to study the hydrodynamics of all the estuaries of the region. To do this, the aforementioned shallow depth-averaged flow model was applied in all sensitive areas in order to calculate the maximum ebb/flood velocities for spring tide conditions. Depth-averaged estuarine current maps were obtained for each estuary as a result of this study. Fig. 10 shows one of these maps for the San Vicente Estuary.

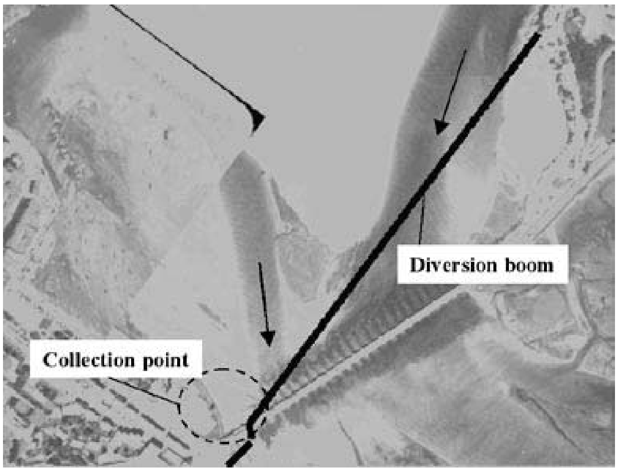
*Figure 10. Current field calculated by H2D for spring tide conditions at San Vicente Estuary (Cantabria)*




After verifying the hydrodynamics of all areas as well as the characteristics of different types of oil booms, the location of the containment systems was decided depending on several criteria such as boom design maximum velocity, maximum angle between boom and currents, shoreline mooring points, port operating and dredged channels.

Owing to the strong currents in most Cantabrian estuaries, in most cases, the boom protection technique consisted of diversion booming, with the boom-to-flood currents angle being less than 45°. This strategy was used primarily to divert oil flow away from a sensitive area or to a collection point. As can be seen in Fig. 11, this was the type of boom installed in the San Vicente Estuary.

*Figure 11. Diversion boom installed in San Vicente Estuary (Cantabria)*




On the other hand, in some estuaries with small tidal prism the protection technique used was a kind of mixed solution between exclusion booming and a rubble dam which closed part of the tidal inlet. Before choosing this technique, the hydrodynamic study described before was used to analyse the effect that this partial closure would have in the estuary.

In those inlets that had to allow the maritime traffic, diversion booms were used attempting to have a free navigation channel at the same time that they guarantied most of the oil would be trapped.

## 4. CONCLUSIONS

In this paper a pre-operational system to respond to the Prestige oil spill crisis has been presented. The pre-operational system, which started from scratch the day right after the Prestige sank in the Galician coast, is based on an innovative way of integrating previous knowledge and numerical tools together with the help of external institutions providing fundamental data. The key-bone of the system is the development of a robust, efficient and reliable protocol, able to satisfy the requirements imposed by the decision- makers who where demanding a quick response.

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## **APENDICE:** SISTEMA DE OCEANOGRAFÍA PRE-OPERACIONAL COMO PARTE DE LA RESPUESTA FRENTE AL VERTIDO DEL PETROLERO PRESTIGE EN LAS COSTAS DE CANTABRIA

### INTRODUCCIÓN

El accidente del petrolero Prestige frente a las costas gallegas en Noviembre de 2003 y la posterior afección del derrame a las costas de Cantabria a partir del 5 de Diciembre del mismo año hicieron necesario la puesta en marcha de un complejo operativo que permitiera: (1) Predecir la llegada de nuevas manchas de fuel y (2) proteger la costa, y fundamentalmente los estuarios, ante dichas manchas.

### METODOLOGÍA

#### Sistema de predicción

Los objetivos del sistema de predicción elaborado eran los siguientes:

1. Proporcionar de forma operacional las posiciones, tamaño y evolución de las manchas de fuel a diferentes escalas espaciales con el fin de poder evaluar en tiempo real las estrategias correctas de actuación para minimizar los efectos sobre el litoral.
2. Proporcionar de forma operacional las condiciones meteorológicas y de clima marítimo necesarias para planificar las actividades de las embarcaciones que operan en mar abierto.
3. Proporcionar de forma operacional las condiciones de oleaje, corrientes y marea y viento en la costa para planificar las actividades de limpieza en playas y acantilados.

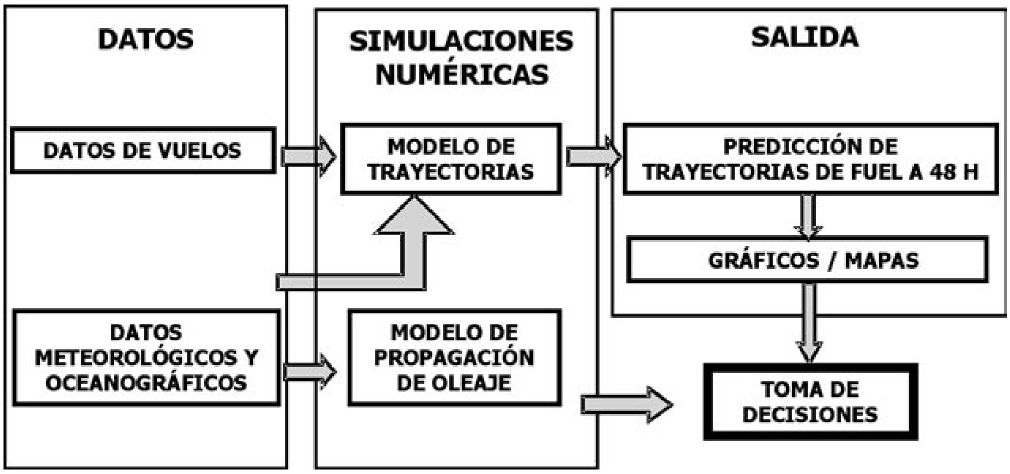
Para ello, y con base en los modelos desarrollados en la Universidad de Cantabria y la información facilitada por otros organismos (Puertos de Estado, INM, NRL, SASEMAR, Delegación de Gobierno de Cantabria, Consejería de Medio Ambiente) en la Universidad se elaboraba todos los días dos predicciones de la previsible evolución de las manchas de hidrocarburos, una de detalle referida al ámbito de la Comunidad Autónoma de Cantabria y otra general de la cornisa Cantábrica.

El protocolo de trabajo era el siguiente (Figura 1):

1. A las 12,00 horas se recibe información relativa a predicción a dos días de oleaje, viento, corrientes en la plataforma Cantábrica. Esta información es facilitada por Puertos del Estado, el INM y el NRL americano.
2. Con base a esta información se ejecutan los modelos de detalle de predicción local (referidos a la comunidad de Cantabria) de la Universidad de Cantabria.
3. A las 15,00 horas se reciben los partes de avistamientos de manchas reportados por las diferentes administraciones y servicios públicos (marina mercante, salvamento, Policía Nacional, Guardia Civil...). Esta información es facilitada por la Delegación de Gobierno.

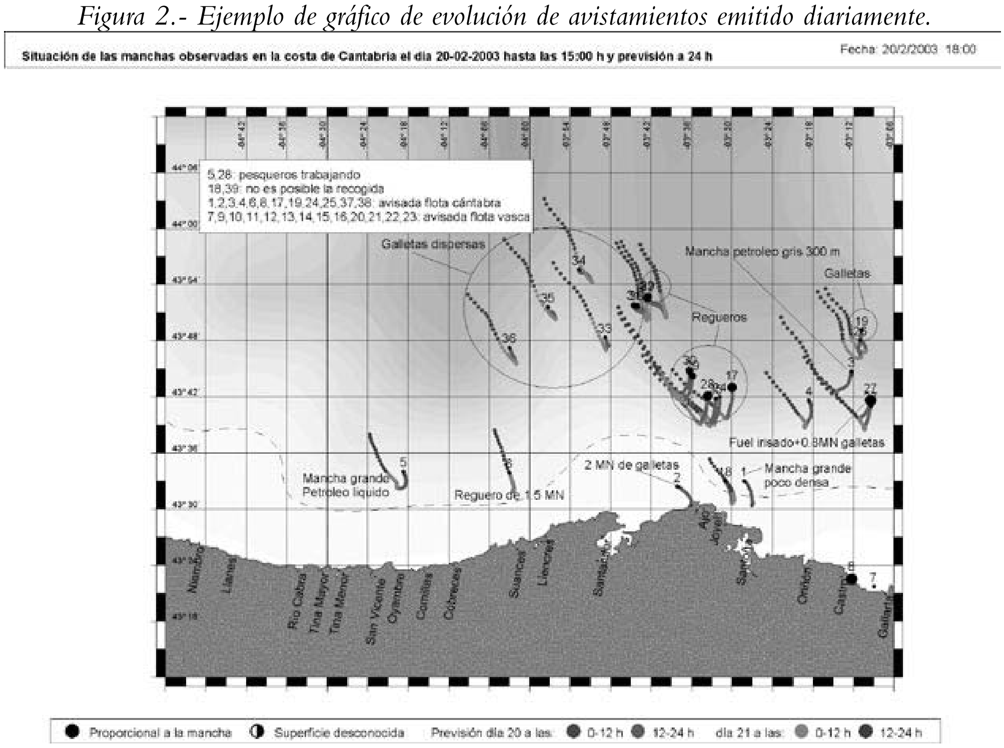
4. A las 17,30, una vez procesada la información oceanográfica y verificadas todas las observaciones, se emite un informe de posición de manchas y evolución a 24 y 48 horas. Este informe es enviado por la Universidad de Cantabria a la Delegación de Gobierno, CECOPI Cantabria, Sasemar y a la Consejería de Medio Ambiente para su posterior distribución a los operativos de limpieza y protección.

*Figura 1.- Diagrama de flujo del sistema de predicción de evolución de los avistamientos de hidrocarburos.*




Como parte de este informe se enviaba diariamente figuras como la presentada en la figura 2.

*Figura 2.- Ejemplo de gráfico de evolución de avistamientos emitido diariamente.*



## SISTEMA DE PROTECCIÓN

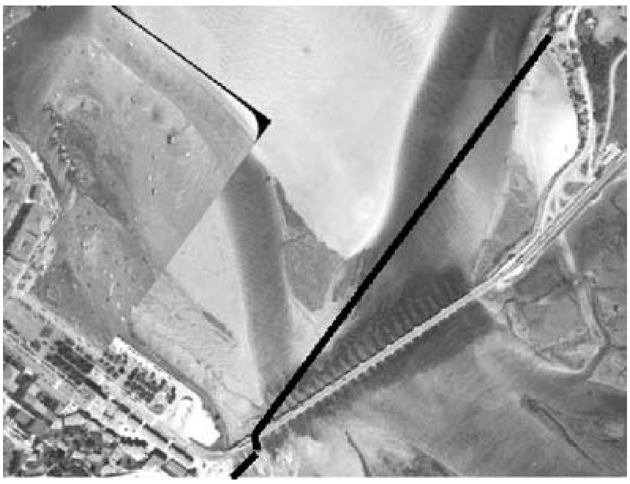
Los objetivos del programa de protección eran los siguientes:

1. Proporcionar la información de oleaje, corrientes, marea y viento necesaria para la correcta ubicación de medidas mecánicas de protección, tales como barreras, especialmente en la entrada de rías, estuarios y marismas en las zonas afectadas.
2. Generar la información hidrodinámica y de transporte de sustancias necesaria para valorar el efecto del cierre parcial de zonas estuarinas y de marisma sobre el ecosistema.

A tal fin se realizaron estudios hidrodinámicos de todos los estuarios de Cantabria. Estos estudios permitieron evaluar el campo de velocidades de máxima llenante en las bocanas y, con esta información, se realizó un análisis de la ubicación, disposición y sistema de protección mas adecuado (barreras flotantes, cierre parcial, cierre total ...) para cada una de las bocanas de los estuarios de Cantabria.

En la mayor parte de los casos, la solución propuesta se materializó en barreras oceánicas dispuestas con un ángulo igual a inferior a 45º con respecto a la dirección de la corriente en máxima llenante, en algún lugar de la desembocadura en la que se dispusiera de una zona de "sacrificio" en tierra donde poder recoger el fuel atrapado por la barrera, véase, por ejemplo la disposición de las barreras en la marisma de San Vicente de la Barquera a la altura del puente de la Maza (Figura 3).

*Figura 3.- Ubicación de la barrera de contención en la marisma de San Vicente.*



En algunas bocanas, como en el caso de la marisma de Joyel, la alternativa de cierre propuesta incluía el cierre físico de parte de la desembocadura por medio de un dique de escollera que permitiera limitar la longitud de la barrera de contención al tiempo que garantizara la correcta renovación de la masa del agua del estuario. A tal efecto se realizaron las correspondientes simulaciones numéricas por medio de un modelo no-lineal de propagación de ondas que resuelve las ecuaciones de Navier-Stokes integradas en vertical.

En aquellas desembocaduras en las que se ubican puertos comerciales o pesqueros (Santander, Santoña) las barreras fueron ubicadas de modo que se respetara un canal mínimo de navegación al tiempo que se garantizara que las líneas de corriente del flujo principal quedaban "atrapadas" por las barreras.

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# THE INFLUENCE OF SOME SHIP PARAMETERS ON MANOEUVRABILITY

**F. Pérez Arribas[1] and J. A. Clemente Fernandez[2]**

## ABSTRACT

**Although there are advances in safety devices for ships every year, the risks of collision or grounding are still significant. Shipping accidents can have numerous negative effects involving not only damage to the cargo or delays due to ship repair but even loss of the ship, which may result in ecological disasters, in the case of oil or chemical tankers, as well as significant risks for both humans and wildlife.**

**Collision and grounding are the most common accidents in ship operation. Some accidents are due to human error, but several research projects have shown that a high percentage of these accidents could have been avoided izf the ship had had better manoeuvrability characteristics.**

**In this paper, numerical methods will be used to study the influence of some ship parameters on the manoeuvrability a model ship. This kind of analysis can help the naval architect to improve the manoeuvrability characteristics during the early stages of ship design.**

**Key words: manoeuvrability, hydrodynamics, numerical models**

## 1. MANOEUVRABILITY EQUATIONS

In this paper, manoeuvrability will be approached as a bidimensional phenomenon. Two reference systems will be used, one of them fixed (X,Y) and the other moving with the ship, with its origin at the centre of gravity of the vessel. Yaw motion is assumed to occur around this point. In the moving reference system, the x axis is positive forward and y is positive starboard. For both systems, moving and fixed, angles are positive in the clockwise sense.

In Fig. 1 U is the ship's velocity, which can be decomposed into an advance velocity u and a transversal velocity v. The ship has also a rotation velocity with respect to the z-axis. This axis is normal to the XY plane and passes through the ship centre of gravity. $\beta$ is the angle between U and the x axis and it is called the *drift angle*. $\psi$ is the ship heading angle and dr is the rudder angle.

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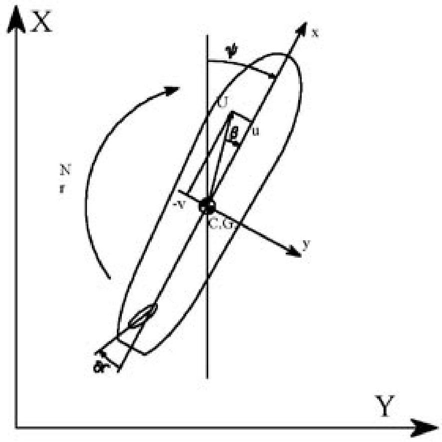
*Figure 1: Reference axis*




Once the reference systems have been defined, the ship is considered as a solid with three degrees of freedom: surge, sway and yaw. Roll, pitch and heave are not considered in this case. Roll begins to be important at high Froude numbers when the roll angle is large and this affects manoeuvrability. This case is not considered in the present paper.

Taking into account these three degrees of freedom, Newton's equation is applied to the moving reference system of Fig. 1 for each motion (1):

$$\begin{aligned} Surge: &\quad m\cdot(\overset{*}{u}-v\cdot r)=X_H+X_P+X_R \\ Sway: &\quad m\cdot(\overset{*}{v}+u\cdot r)=Y_H+Y_P+Y_R \\ Yaw: &\quad I_Z\cdot\overset{*}{r}=N_H+N_P+N_R \end{aligned} \qquad \textbf{(1)}$$

The subindexes H, P and R stand for hull, propeller and rudder. X, Y and N are the forces (X, Y) and moments (N) acting on the ship with respect to the moving reference system *x*, *y*. A short review of the force terms in equation (1) follows:

-$X_H$ is the force acting on the hull in the *x* direction or the advance resistance at speed u.
-$X_P$ is the propeller force in the *x* direction or propeller thrust corrected with speed r, which will affect the flow entering the propeller. This effect will be included in the wake fraction.
-$X_R$ will be the rudder drag, which can be obtained by using the *x* component of the rudder force.
-$Y_H$ will be the *y* component of hull damping.
-$Y_P$ will be the transversal propeller force.
-$Y_R$ will be *y* component of the rudder force.
-$N_H$ is the moment of $Y_H$ with respect to the ship's centre of gravity.
-$N_P$ is the moment of $Y_P$ with respect to the ship's centre of gravity.
-$N_R$ is the moment of $Y_R$ with respect to the ship's centre of gravity.

The effect of waves, sea currents and wind forces are not included in (1). On the left side of (1), v·r and u·r represent the centrifugal component of the acceleration. The coefficient m is ship displacement and $I_z$ is the ship inertia moment with respect to the *z* axis.

## 2. NUMERICAL MODEL USED FOR SHIP MANOEUVRABILITY

A non-linear numerical model that predicts ship manoeuvres from a small set of parameters will be described in this section, Pérez (2000). This method gives the different components of (1)

### 2.1 Surge equation

$$(m + m_x) \cdot \overset{*}{u} - (m + m_{vr}) \cdot vr = X(H) + X(P) + X(R) \qquad \textbf{(2)}$$

-$X(H) = -\frac{1}{2} \cdot \rho \cdot S \cdot C_T \cdot u^2$ (Advance resistance at speed u).
-ρ: density
-S: wetted surface
-$C_T$: total resistance coefficient. This is considered as constant during the manoeuvres. In this paper it is calculated using the Holtrop method.
-$X(P) = (1\text{-}t) \cdot \rho \cdot n^2 \cdot D_p{}^4 \cdot K_T$ (Propeller thrust)
-n: propeller rate
-t: suction coefficient
-$D_p$: propeller diameter
-$K_T$: propeller thrust coefficient, which can be expressed as a function of the propeller advance coefficient ($J = \frac{(1-w_P).u}{n.D_P}$) using a second order polynomial that is calculated using a least squares fitting: $K_T = C_1 + C_2 \cdot J + C_3 \cdot J^2$; $K_T$ is based on Wageningen B systematic series.
-$w_P$ = wake fraction, modified with the turning effects as will be seen later.
-$X(R) = -(1 - t_R) \cdot F_N \cdot \mathrm{Sin}(\delta)$ (Rudder drag)
-$t_R$: rudder drag coefficient. This coefficient is obtained by using the expression of Kijima & Tanaka (1993)
-$F_N$: normal force acting on rudder face
-δ: rudder angle

The coefficients $m_x$ and $m_{vr}$ are called added masses for surge and crossed for sway and yaw respectively. These added masses are calculated using Lewis (1989).

### 2.2 Sway equation

$$(m + m_y) \cdot \overset{*}{u} + (m + m_{ur}) \cdot ur = Y(H) + Y(R) \qquad \textbf{(3)}$$

The coefficient $m_y$ is the sway added mass and is calculated using Ankudinov (1987).

$$-Y(H) = Y_B \cdot \beta + Y_r \cdot r' + Y_{BB} \cdot \beta \cdot |\beta| + Y_{rr} \cdot r' \cdot |r'| + Y_{Brr} \cdot \beta \cdot r' \cdot r' + Y_{BBr} \cdot \beta \cdot \beta \cdot r'$$

represents the hull effects according to Kijima et al. (1990). All the coefficients of the equation are non-dimensioned by $½ \cdot \rho \cdot T \cdot L_{pp} \cdot U^2$. $\beta$ is the drift angle of Fig. 1 and $r' = r \cdot L_{pp} / U$ where U is the ship speed.

$$-Y(R) = -(1+a_h) \cdot F_N \cdot Cos(\delta) \quad \text{(Rudder effects)}$$

In this formula, $F_N$ is the normal force acting on the rudder face and $a_h$ represents the interaction between rudder and hull forces. It is calculated using Kijima & Tanaka (1993).

### 2.3 YAW EQUATION

$$(I_{zz} + i_z) \cdot \overset{*}{r} = N(H) + N(R) \tag{4}$$

$i_z$ is the added inertia moment, Ankudinov (1987).

$$N(H) = N_B \cdot \beta + N_r \cdot r' + N_{BB} \cdot \beta \cdot |\beta| + N_{rr} \cdot r' \cdot |r'| + N_{Brr} \cdot \beta \cdot r' \cdot r' + N_{BBr} \cdot \beta \cdot \beta \cdot r'$$

represents the hull effect on yaw, Kijima et al. (1990). As in the sway equation, all the coefficients are non-dimensioned by $½ \cdot \rho \cdot T \cdot L_{pp}^2 \cdot U^2$.

$$N(R) = -(1+a_h) \cdot X_{rg} \,.\, F_N \cdot Cos(\delta) \quad \textit{(Rudder effects)}$$

$F_N$ is the normal force acting on the rudder face and $X_{rg}$ is the distance between the rudder axis and the ship centre of gravity. So, N(R) is the moment of Y(R) with respect to the ship centre of gravity. The interaction between rudder and hull is supposed to be positioned at the rudder axis in this formula.

### 2.4 NORMAL FORCE ACTING ON RUDDER FACE

The normal force is usually presented as:

$$F_N = ½ \cdot \rho \cdot C_L \cdot A_R \cdot V_R^2 \cdot Sin(\alpha_R) \tag{5}$$

- $C_L$: rudder lift coefficient, which depends on the rudder mean line, generally a NACA profile.
- $A_R$ : effective rudder area.
- $V_R$ : speed at the rudder leading edge. It can be calculated using Kijima et al. (1990) or in towing tank tests. This speed depends on the hull, rudder and propeller interaction and is a function of propeller and rudder characteristics and wake coefficient.

-$\alpha_R$ : effective rudder angle. Due to the variation in the flow entrance angle to the rudder during the manoeuvres, the rudder angle $\delta$ is corrected and transformed into $\alpha_R$, Kijima et al. (1990).

## 3. THE INFLUENCE OF SOME MAIN PARAMETERS OF THE SHIP ON ITS MANOEUVRABILITY

The previously described method is now applied to a Fast Ferry to see how the variation in some of its main parameters affects its manoeuvrability. The ship stations can be seen in Fig. 2 and its main characteristics are:

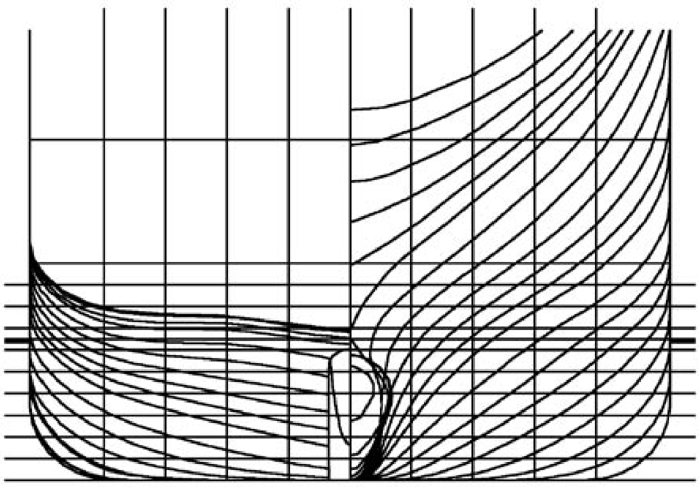
*Table 1: Ship main parameters*

| | | | |
|---|---|---|---|
| Lpp = | 173 m | Speed = | 29 knots |
| Lwl = | 174.8 m | kW = | 4 x 12000 kW |
| B = | 23 m | P.M. = | 4800 Tm |
| T = | 5.5 m | PAX = | 1500 Pax. |
| CB = | 0.53 | CM = | 0.97 |

This ship has two 5 m diameter propellers and two rudders with an area of 18.9 $m^2$ and a height of 5.2 m each.

Displacement and block coefficient are constant for all the calculated variations. Affine transformations have been applied to make these variations and for every one of these, a turning manoeuvre with a rudder angle of 35º and a Zigzag manoeuvre of 20º have been studied. All the transformations are assumed to be without trim. For every variation, propulsion and resistance have to be recalculated and this was carried out using the Holtrop method for the resistance prediction and the Wageningen BB propeller series for the propulsion. Once the new variation is completely defined, manoeuvres can be calculated.

*Figure 2: Stations of the example ship*



The variations subject to analysis have been:

Original ship without changes
– 5% Beam, + 5% Draft
– 5% LCB (Afterward)
– 5% Rudder area
– 5% Lpp, + 5% Beam
– 5% Lpp, + 5% Draft
+ 5% Beam, – 5% Draft
+ 5% LCB (Forward)
+ 5% Rudder area
+ 5% Lpp, – 5% Beam
+ 5% Lpp, – 5% Draft

In the plots of the turning manoeuvres, abscissa and ordinates are adimensionalised with ship length.

*Figure 3: Beam and Draft effects on 35º Turning manoeuvre*

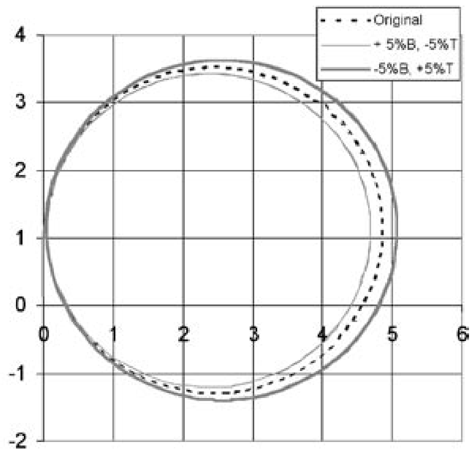



*Figure 4: Beam and Draft effects on 20º Zigzag manoeuvre*

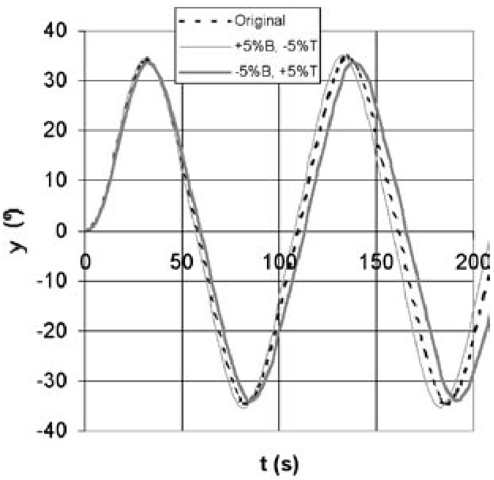



*Figure 5: LCB effects on 35º Turning manoeuvre*

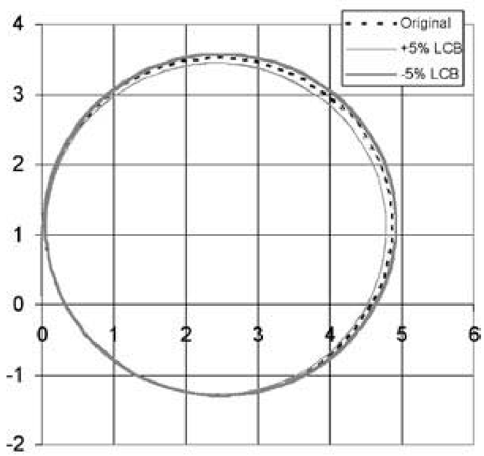
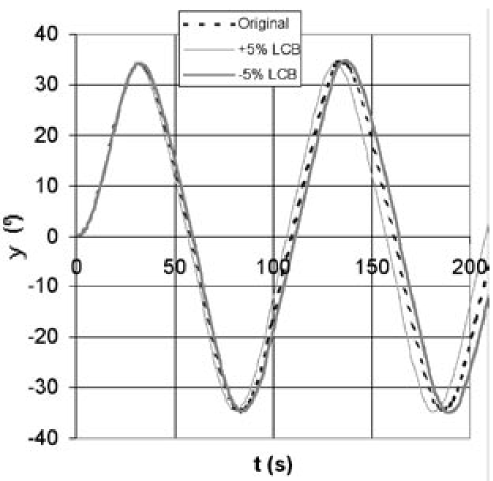



*Figure 6: LCB effects on 20º Zigzag manoeuvre*




## 3.1 Beam and Draft effects

From Fig. 3 and 4, it can be seen that increasing beam and decreasing draft have a positive effect on the turning manoeuvre. Turning diameter and advance diminish as beam increases (Fig. 3). The effects on the Zigzag manoeuvre (Fig. 4) are of minor importance.

### 3.2 LCB position effects

Displacing the position of the LCB forward has a positive effect on the turning manoeuvre as can be seen in Fig. 5. As in 3.3 the effects of this transformation on the Zigzag manoeuvre are of minor importance (Fig. 6).

### 3.3 Rudder area effects

Fig. 7 shows that increasing rudder area results in a clear improvement in the turning manoeuvre. Decreasing this area will have quite a negative effect. As in the previous variations, the effect on the Zigzag manoeuvre is negligible (Fig. 8).

*Figure 7: Rudder area effects on 35º Turning manoeuvre*

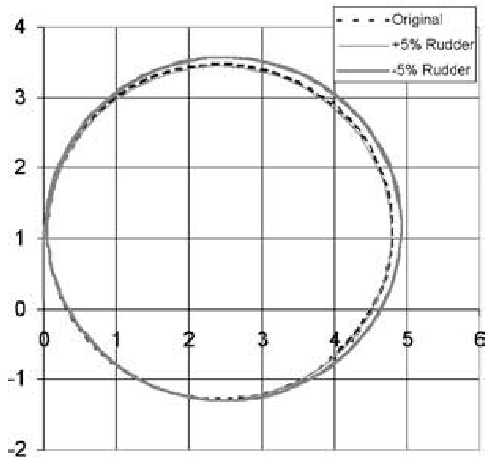



*Figure 8: Rudder area effects on 20º Zigzag manoeuvre*

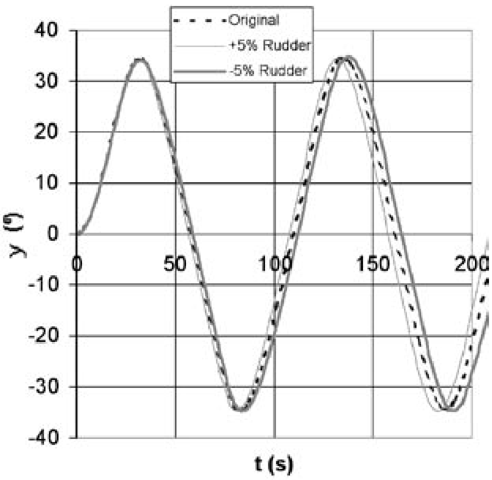



*Figure 9: Ship length and beam effects on 35º Turning manoeuvre*

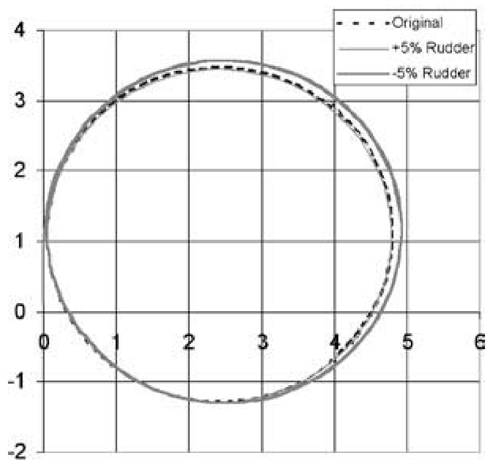
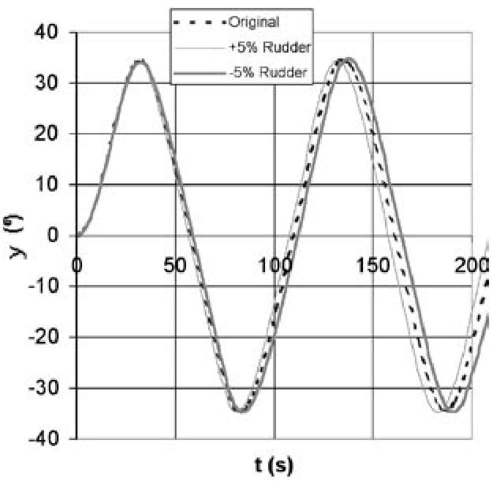



*Figure 10: Ship length and beam effects on 20º Zigzag manoeuvre*



### 3.4 Ship length and Beam effects

As can be seen in Fig. 9, a large effect on the turning manoeuvre is produced by lowering Lpp and increasing beam. Variation in ship length affects the Zigzag manoeuvre more than variations in other parameters. The positive effects on the turning manoeuvre have negative effects on the Zigzag manoeuvre (Fig. 10).

### 3.5 Ship length and draft effects

The positive effect of a smaller Lpp and a greater draft on the turning manoeuvre can be seen in Fig. 11. Ship length and draft affects the Zigzag manoeuvre less than variation in the length and beam. The positive effects on the turning manoeuvre have negative effects on the Zigzag manoeuvre (Fig. 12).

*Figure 11: Ship length and draft effects on 35º turning manoeuvre*

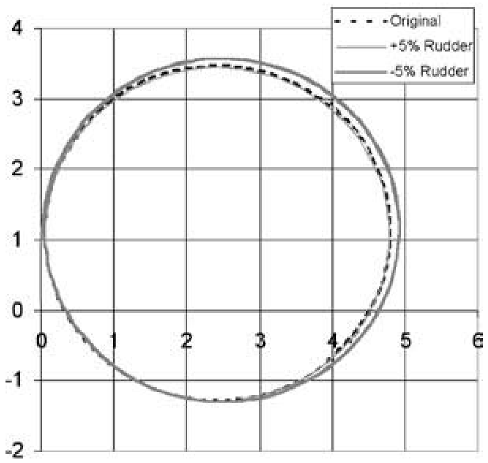
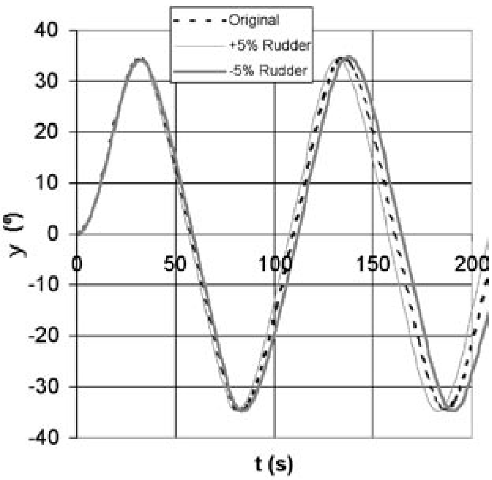



*Figure 12: Ship length and draft effects on 20º Zigzag manoeuvre*




### 3.6 Global effects of the variations

The effect of the variations on some global parameters of the manoeuvres is shown in Table 1. This table presents the advance and tactical diameter of the turning manoeuvre (divided by ship length) and the overshoot angle of the Zigzag manoeuvre.

*Table 1: global parameters of the manoeuvres*

| | Original | +5%B, -5%T | +5%T, -5%B | +5% LCB | -5% LCB | +5% Rudder | -5% Rudder |
|---|---|---|---|---|---|---|---|
| Advance | 3.44 | 3.35 | 3.56 | 3.37 | 3.50 | 3.39 | 3.49 |
| Tactical D. | 4.80 | 4.61 | 5.01 | 4.71 | 4.85 | 4.73 | 4.86 |
| Overshoot | 14.10 | 14.80 | 13.50 | 14.20 | 14.20 | 14.20 | 14.00 |

| | Original | +5% L, -5% B | -5% L, +5% B | +5% L, -5% T | -5% L, +5% T |
|---|---|---|---|---|---|
| Advance | 3.44 | 3.57 | 3.29 | 3.50 | 3.38 |
| Tactical D. | 4.80 | 5.13 | 4.43 | 4.97 | 4.61 |
| Overshoot | 14.10 | 12.56 | 16.12 | 13.17 | 15.16 |

The effects on the Zigzag manoeuvre are small except for variations in ship length. The variations in ship length have the most important effects on the manoeuvres but these effects are negative for the Zigzag manoeuvre. Increasing the beam and decreasing the length reduce the advance and the tactical diameter but increase the overshoot angle. The effect of draft is not clear and depends on the other dimension that is varied. Displacing the LCB position forward is positive for the turning manoeuvre and has little effect on the Zigzag manoeuvre. It is obvious that increasing the rudder area is positive for manoeuvrability, but the negative aspect is the increase in power required to move the rudder. The effect on the Zigzag manoeuvre is small.

### 3.7 Combined variations

Increasing ship length is positive for the turning manoeuvre but negative for the zigzag manoeuvre, so it is better not to modify length if a global optimisation of ship manoeuvrability is desired. The option of choice is: + 5% Beam, – 5% Draft (displacement has to be constant) and +5% LCB. Rudder area and ship length are not varied due to the aforementioned disadvantages. The parameters improved by means of these variations are the Advance (3.29 L, – 4.4%) and the Tactical diameter (4.54 L, – 5.4%).

## 4. CONCLUSIONS

Manoeuvrability is an important issue in ship design due to its influence on ship safety, operability and petrol costs. Manoeuvrability can be studied numerically during the early stages of ship design to ensure that the ship can manoeuvre as required.

The manoeuvres we have studied are a turning manoeuvre with a 35º rudder angle and a Zigzag manoeuvre with a 20º rudder angle. IMO requirements are related to these manoeuvres. Turning manoeuvres are used to check the effectiveness of the rudder in making large heading changes. The Zigzag manoeuvre reflects the inherent effectiveness of the rudder in making changes in heading.

The effects of the parameter variations on the Zigzag manoeuvre are small except for variations in ship length. Diminishing length has a strong positive effect on turning manoeuvres but affects the Zigzag manoeuvre negatively. Ship length is also the most expensive dimension to change.

The increase of beam and the reduction of ship length reduce the advance and the tactical diameter but increase the overshoot angle. The effect of draft on its own is not clear and depends on the variation of other dimensions.

Displacing the LCB position forward is positive for the turning manoeuvre and has little effect on the Zigzag manoeuvre.

It is obvious that increasing the rudder area is positive for the manoeuvrability, but its drawback is the increase in power required for moving the rudder. This variation has little effect on the Zigzag manoeuvre.

Combined variation of several ship parameters can give better results than the individual variation of each parameter.

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## APÉNDICE: INFLUENCIA DE ALGUNOS PARÁMETROS SOBRE LA MANIOBRALIDAD DEL BUQUE

### RESUMEN

A pesar de los cada vez más sofisticados medios de ayuda a la navegación y de detección de otros buques o elementos extraños dentro de su trayectoria, es evidente que los riesgos de colisión o varada no son en absoluto despreciables. Un accidente de cualquier tipo puede redundar no sólo en el daño sufrido por la carga o en el tiempo perdido en reparaciones del buque en dique, sino que puede llevar a la pérdida del mismo y hasta consecuencias más graves, y por desgracia más frecuentes en nuestros días, como es el grave desastre ecológico en la zona en que se produce el accidente, caso del transporte de crudos, derivados del petróleo o productos químicos. En resumen, elevadas cifras monetarias, y riesgo para las vidas humanas.

Entre las causas de accidentes figuran en primer lugar los choques (colisiones, varadas...). Como es lógico, un cierto número de los accidentes son debidos a errores humanos o a causas inevitables, pero según distintos estudios, un alto porcentaje de ellos podrían haberse evitado si el buque hubiera estado dotado de unas mejores cualidades de maniobrabilidad.

### METODOLOGÍA

En este artículo se ha visto como afectan a las cualidades de maniobrabilidad distintos parámetros fundamentales del buque, en este caso aplicado a un Ferry, analizando la maniobrabilidad a partir de métodos numéricos desarrollados en la Escuela Técnica Superior de Ingenieros Navales, y que pueden ayudar al ingeniero naval en las primeras etapas de proyecto en un campo como es el de la maniobrabilidad, poco tratado en las etapas de diseño.

A pesar de los cada vez más sofisticados medios de ayuda a la navegación y de detección de otros buques o elementos extraños dentro de su trayectoria, los riesgos de colisión o varada de los buques aún existen. Un accidente de cualquier tipo puede producir no sólo daño para la carga o tiempo perdido en reparar el buque en dique, sino que puede llevar a la pérdida del mismo y hasta tener consecuencias igual de graves, y por desgracia más frecuentes en nuestros días, como es el desastre ecológico en la zona en que se produce el accidente, como es el caso del transporte de crudos, derivados del petróleo o productos químicos.

Todo esto se traduce en elevadas cifras monetarias a tener en cuenta a la hora de considerar la explotación del buque en un determinado tráfico y la aparición del riesgo para las vidas humanas, tanto la tripulación del propio buque como para personas externas a éste, y el medio marino.

Entre las causas de accidentes figuran en primer lugar los choques (colisiones con otros buques, varadas...) con un 40% del total de buques accidentados. Como es lógico, un cierto número de los accidentes son debidos a errores humanos o a causas inevitables, pero según un estudio realizado por encargo de la U.S. Coast Guard sobre los accidente producidos en la década de los 70, más de 800 casos, alrededor del 35%, podrían haberse evitado si el buque hubiera maniobrado de forma más adecuada a las circunstancias.

Sin llegar a las dramáticas consecuencias antes expresadas, existe otro problema de gran importancia relacionado con la explotación del buque, y en concreto con la rentabilidad del mismo. Generalmente el buque está destinado a moverse la mayor parte de su vida en línea recta, y por eso es lógico elegir las dimensiones principales en el anteproyecto de forma que se optimice la propulsión y a la resistencia al avance.

Ciertos buques poseen una gran tendencia a abandonar la trayectoria rectilínea ante una pequeña perturbación. Se dice que presentan inestabilidad de ruta. Con objeto de que el rumbo sea el deseado, es preciso actuar entonces sobre el timón frecuentemente y con ángulos de timón excesivamente grandes. El buque avanzará entonces con una trayectoria de tipo sinusoidal o zig-zag, más o menos acusada en función de la tendencia que tenga a perder el rumbo.

El tener el timón metido unos grados a una banda causa un aumento de la resistencia al avance del buque y si este realiza guiñadas apreciables, el efecto se hace de mayor importancia. Lógicamente el camino recorrido es más largo debido al abandono de la trayectoria rectilínea.

La consecuencia final es que aparte del excesivo desgaste al que se puede someter al sistema de gobierno con el consiguiente aumento de consumo por parte del mismo, la velocidad media de servicio es menor pudiéndose llegar a contrarrestar las pequeñas mejoras alcanzadas en la velocidad por un estudio cuidadoso del bulbo de proa, una mejora en la estela, o un sofisticado estudio de la hélice. En definitiva, el consumo de combustible aumenta y la rentabilidad disminuye si la maniobrabilidad es mala.

El buque considerado como elemento de transporte de mercancías o pasajeros debe cumplir unos requisitos operacionales, es decir, desarrollar una determinada misión en unas determinadas condiciones ambientales. Si no cumple adecuadamente estos requerimientos se tendrá una baja calidad del buque en cuanto a la misión que tiene que cumplir, y se puede llegar en algunos casos a la incapacidad para realizar dicha misión. Una patrullera por ejemplo debe ser capaz de maniobrar con agilidad a alta velocidad, un pesquero debe ser capaz de faenar en un caladero y un remolcador de desenvolverse con soltura cerca de los buques sobre los que actuará.

Todas las consideraciones anteriores sobre la capacidad para maniobrar de un buque, no son nuevas ni desconocidas. Sin embargo, no suelen ser tomadas en cuenta en la elección de las dimensiones principales que influyen poderosamente en la maniobrabilidad y en la facilidad de gobierno. Ciertos organismos internacionales han puesto requisitos sobre maniobrabilidad para evitar accidentes.

Así por ejemplo la U.S. Coast Guard exige desde los finales de los 70 a los buques que van a atracar en puertos norteamericanos unos gráficos en el puente con las características de maniobrabilidad del mismo. La I.M.O. impone unos límites para ciertos parámetros de las maniobras, como puede ser el avance y el diámetro táctico en la maniobra de giro, o el ángulo de rebasamiento en la maniobra de zig-zag.

## CONCLUSIONES

La maniobrabilidad es un factor a tener en cuenta en la explotación del buque debido a la mejora de la seguridad de operación, operatividad y ahorro de combustible que se consiguen con una adecuada maniobrabilidad.

La maniobrabilidad puede estudiarse en etapas de anteproyecto del buque y ver si el buque cumplirá con los requerimientos de maniobrabilidad impuestos. Esto puede hacerse numéricamente o bien a partir de ensayos.

Pequeñas variaciones de algunos parámetros globales del buque conllevan mejoras en la maniobrabilidad. Así por ejemplo favorece la maniobrabilidad manteniendo el desplazamiento del buque un aumento de la manga, una disminución del calado, desplazar el centro de carena a proa y lógicamente aumentar el área del timón.

Se puede mejorar la maniobrabilidad jugando con múltiples parámetros al mismo tiempo, lográndose un mayor efecto que al variar los parámetros individualmente.

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# MARINE POLLUTION FROM SHIPS' BALLAST WATER

**J. Perera Marrero[1] and E. Melón Rodríguez[2]**

## ABSTRACT

**Today, ballast water is the most common method used in vessels to regulate stability, to increase draught, to improve trim, and hence, to ensure a safe voyage.**

**These waters, which are carried by ships in variable quantities, are loaded at the source port and are discharged sometimes thousands of miles away at the destination port. This entails the introduction of organisms, at different stages of their life cycles, that may cause a zoological pollution which could threaten the survival of the vegetation and animal species of the area where the ballast water is discharged.**

**There is increasing concern about this problem which is severely affecting the marine environment. The International Maritime Organisation is being urged to update and complete its present regulations on this issue.**

**Key words: Pollution, Ballast, Waters.**

## 1. INTRODUCTION

Shipping transports over 90% of the merchandise and basic products around the world and is, thus, an essential element of international trade.

Ballast can be defined as any solid or liquid material that is carried by ships to increase the draught, to modify the trim, to regulate the stability or to maintain the tension loads within acceptable and safe limits.

Therefore, ballast is an essential element in safe navigation both for moving in ballast to the loading port and for completing the displacement of a ship that is only partially loaded. It has been acknowledged that, at present, the only efficient method of impeding the propagation of unwanted organisms is to prevent the discharge of ballast tanks in ports where the waters have a different zoological composition to that of the source port.

Water has been used as ballast since 1880, substituting solid materials, such as sand, stones, bricks and iron pieces, that were commonly used in those days. In general, these solid ballast materials did not pose a zoological threat. (Clarkson, 1999), (Plaza, Perera and Melón, 2003).

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## 2. ZOOLOGICAL IMPACTS

When ships began loading thousands of tonnes of seawater as ballast from remote ports, many local life forms were collected inadvertently and transported to new regions across the oceans. Increasing ship speeds also contributed to the survival of these species during the voyage, helping them to thrive in new seas with no natural predators.

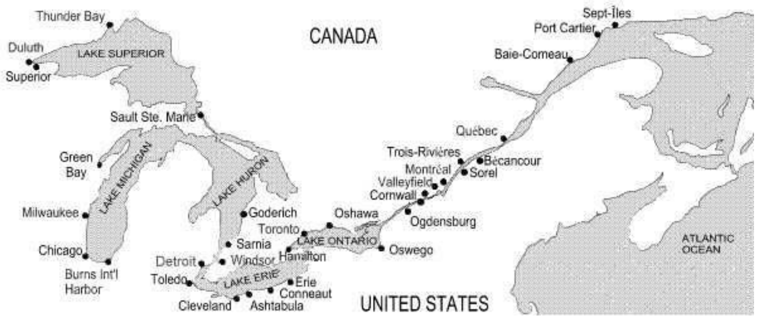
Alien organisms that travel across the oceans in ballast water are having severe effects on the marine environment, maritime facilities and human health.

In comparison to fuel spills and other types of marine pollution caused by shipping, organisms and exotic sea species cannot be purified or absorbed by the oceans. Once they have been introduced, it is almost impossible to eliminate them, whilst they may cause severe damage.

## 3. INVASIVE SPECIES

Specific examples include: the introduction of the European zebra mussel (*Dreissena polymorpha*) in the Great Lakes of North America, resulting in expenses of billions of dollars for pollution control and cleaning underwater structures and water pipes. See figure 1. (http://www.great-lakes.net/envt/flora-fauna/invasive/zebra.html, 1992).

*Figure 1: St. Lawrence Seaway and Great Lakes*




The American comb jellyfish (*Mnemiopsis leiyi*) was introduced in the Black Sea and the Azov Sea (to the north of the former), causing the near extinction of anchovy and sprat fisheries.

The bacillus *Vibrio cholerae* (the causative agent of cholera) was probably transported from Asia to the coastal waters of Latin America via ballast water discharges . The dinoflagellate genera *Gymnodinium* and *Alexandrium*, which poison shellfish, were discharged into Australian waters, causing impacts on the shellfish industry. (Plaza, Perera and Melón, 2003).

The following table shows alien species in Australian waters.

*Table 1: Origin of alien species in Australian waters*

| ALIEN SPECIES IN AUSTRALIAN WATERS | POSSIBLE ORIGINS |
|---|---|
| Yellow fin goby fish | Japan, NE Asia |
| Striped goby fish | Japan, NE Asia |
| Japanese sea bass | Japan, Korea, China, Hong Kong |
| Sobaity seabream | Arab Sea |
| Slater (invertebrate) | New Zealand, Chile |
| Mysid shrimp species | Japan |
| Polychaete worm species | Japan, New Zealand, Pacific Ocean, India |
| Molluscan species | Asian Pacific Coast |
| Sea slug | Japan, New Zealand, South Africa, Mediterranean Sea |

## 4. BALLAST SAFETY

Ships are designed and built to cruise through water carrying a full load of cargo and/or of passengers. Hence, in order to navigate safely, a ship moving in ballast or partially in ballast, must fully load its tanks. This means that the ship will be sufficiently submerged so as to have the propeller and rudder operating efficiently, which will prevent heeling, particularly in bad sea conditions.

Some types of vessels, such as tankers and carriers of dry cargo, mineral and liquid gas, require large volumes of ballast water, especially for long voyages in ballast. Other types need smaller quantities of ballast at almost all times, independently of the load, to control the stability, the trim and the load line. Examples include container ships, ferries, freight vessels, passenger ships, roll-on-roll-off, fishing boats, factory and military ships, etc. (Plaza, Perera and Melón, 2003).

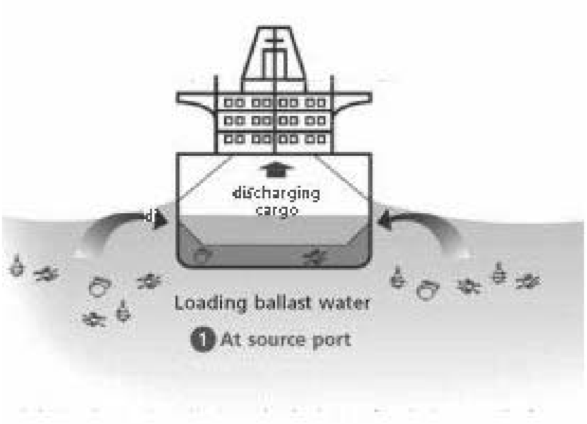
## 5. POLLUTION

It is estimated that each year approximately 12,000 millions of tonnes of ballast water are transferred all around the world. Depending on the size and the purpose, ships may carry volumes ranging from hundreds of litres up to 100,000 tonnes of ballast water. This water, which is probably collected and pumped into the ballast tanks from the port to which the cargo is delivered, or from its surroundings, may contain aquatic organisms in all their life cycle stages.

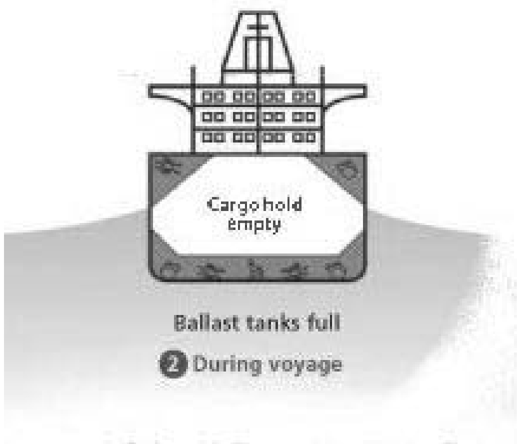
It is believed that, at present, ballast water may be carrying over 5,000 animal and plant species per day all around world. (Zhou, 2002).

The survival rate after discharge depends on the conditions of the receptor area: species coming from zones with similar conditions - particularly as regards salinity and temperature - have a higher probability of survival. Research studies indicate that, generally, less than 3% of the transported species establish themselves in the new regions but provided that one predator fish species is successful, the damage to the local ecosystem could be very severe. (imo.org).

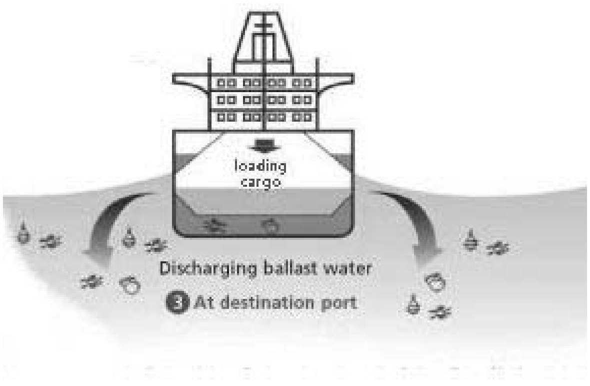
*Figure 2. Transfer of micro-organisms in ballast water*



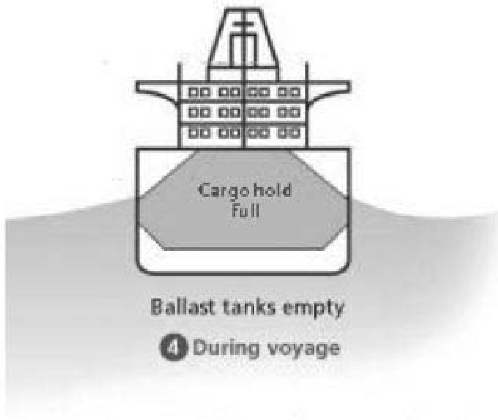

*Loading ballast water with micro-organisms*




*Ballast tanks full during voyage*




*Discharging ballast water*




*Ballast tanks empty*

## 6. IMO RECOMMENDATIONS

Over the last decade the International Maritime Organization (IMO) has worked in conjunction with its Member States to confront the problem. The *Guidelines for preventing the introduction of unwanted organisms and pathogens from ships' ballast water and sediment discharges* were first adopted in 1991.

Later, in 1997, the IMO proposed resolution A.868 *Guidelines for the control and management of ships' ballast water to minimize the transfer of harmful aquatic organisms and pathogens*, which was definitively adopted in January 2001. (A.868, 1995).

In the meantime, the United Nations Organization, during the Conference on Environment and Development (UNCED) held in 1992, had asked the IMO to adopt adequate regulations on ballast water discharges to prevent the propagation of non-indigenous species. Furthermore, in its Declaration on Environment and Development, it proclaimed that the precautionary approach should be widely applied by States according to their capabilities. (IMO/FAO/UNESCO, 1992).

Most recently, the IMO convened an International Conference to be held in February 2004, aiming to adopt a new "International Convention for the control and management of ballast water and discharge sediments".

However, many IMO delegates consider that it is too early to hold this Conference as there are important aspects of the draft that have not been agreed upon by the majority of the delegations. Another reason is that, with the present technology, it is not possible to apply the techniques to eliminate the invasive species in ballast water specified in the draft. In addition, many of the State representatives are people who do not belong to the maritime sector.

Finally, it should be mentioned here that the most important issues on the draft are, first, that the ballast water exchange must be at least 200 nautical miles from the nearest land and in water at least 200m in depth and, secondly, that all ships under the Convention are required to have on board and implement a Ballast Water Management Plan, specific to each ship and approved by the Administration. (OMI, 2004), (Anave, 2003).

Fortunately, it seems that concern over this issue is increasing and there is a growing recognition that we must find solutions to this present-day problem which is already having severe economic and environmental impacts.

## 7. CONCLUSIONS

1. - There is no current method or technology that can completely prevent the introduction of alien species into port and river waters.
2. - The majority of the existent technologies of ballast water treatment cannot be installed on board without modifying the ship's structural design.
3. - The IMO developed and sent a series of Codes of practice guides and recommendations for minimising the introduction of unwanted aquatic organisms by shipping, that are being used at present. At the moment, the best available option to prevent this is by returning and diluting the ballast water.
4. - A plan of ballast operations, together with the ship load plan, could provide more flexibility when managing ballast water. This would result in an increased control of the situation and the weather as a means to reduce the transfer of unwanted species in ballast water.
5. - The IMO Member States are continuously considering the possibility of an amendment to MARPOL 73/78 by including a new annex. In essence, this annex would make the use of the existent Codes and guides compulsory.
6. - The problem of non-indigenous species' transfer does not only affect the maritime industry but also has implications for society in general.

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## APENDICE: CONTAMINACIÓN MARINA POR AGUAS DE LASTRE DE LOS BUQUES

### INTRODUCCIÓN

En la actualidad, el transporte marítimo transporta más del 90% de las mercancías y productos a través de las aguas de todo el mundo, lo que le convierte es un elemento indispensable en el comercio internacional.

El lastre se puede definir como todo sólido o líquido colocado en un buque para aumentar su calado, modificar el asiento, regular la estabilidad o mantener las cargas de tensión dentro de unos límites aceptables y de seguridad.

El agua se empezó a utilizar como lastre a partir de 1880, sustituyendo a los materiales sólidos como arena, piedras, ladrillos y piezas de hierro, que era lo que habitualmente se utilizaba hasta entonces. Dicho lastre sólido, en general, no ofrecía peligros zoológicos. Actualmente, el agua, es el elemento más comúnmente utilizado como lastre.

Estas aguas, que los buques transportan en cantidades variables, se cargan en el puerto de partida para ser descargados en el de llegada, a veces a miles de millas de distancia, provocando con ello la introducción de formas de vida, en diferentes fases, que pueden ocasionar una contaminación zoológica, y que supone un grave riesgo para la subsistencia de las especies vegetales y animales de la zona donde se descargue el agua de lastre.

Cuando los buques empezaron a cargar como lastre miles de toneladas de agua del mar en puertos distanes, empezaron a recogerse inadvertidamente formas de vida locales que luego serían transportadas a nuevas regiones a través de los océanos.

La mayor velocidad y autonomía de los buques contribuyó a que las especies invasoras sobrevivieran más fácilmente a las travesías y llegaran a lugares más remotos, para instalarse en mares que carecen de depredadores naturales.

Los organismos foráneos que se desplazan a través de los océanos aprovechando el agua de lastre de los buques han venido creando importantes problemas para el medio ambiente marino, las instalaciones marítimas y la salud humana.

Entre varios ejemplos cabe citar los siguientes: la introducción del mejillón cebra europeo (*Dreissena polymorpha)* en los Grandes Lagos de Norteamérica, la medusa americana (*Mnemiopsis leidyi*) introducida en el Mar Negro y en el Mar de Azov, o el bacilo *Vibrio cholerae* (agente causal del cólera), que fue transportado desde Asia a las aguas costeras de América Latina.

Expresando el problema en cifras, se calcula que en todo el mundo se transfieren unos 12.000 millones de toneladas de agua de lastre cada año. Cada buque puede transportar desde varios centenares de litros hasta 100.000 toneladas de agua de lastre, según las dimensiones y finalidades del buque. Se estima que, actualmente, el agua de lastre puede transportar más de 5.000 especies de animales y plantas al día, en todo el mundo.

Una de las grandes problemáticas que presenta este tipo de contaminación es que, a diferencia de contaminaciones marinas causadas por el tráfico marítimo, los organismos y las especies marinas exóticas no pueden ser depuradas ni absorbidas por los océanos. Una vez introducidas son casi imposibles de eliminar.

La mejor forma de impedir la propagación de organismos no deseados, es prevenir que se descarguen los tanques de lastre en puertos con aguas zoológicamente diferentes a las del puerto de salida.

La preocupación por este problema es creciente y se insta a la Organización Marítima Internacional (O.M.I.) a que consiga consensuar con las delegaciones una actualización de la normativa existente y completar los vacíos existentes sobre este problema, que afecta gravemente al medio ambiente marino.

## METODOLOGÍA

La metodología utilizada en el presenta artículo ha consistido en la consulta de diversa bibliografía, para poder entender correctamente la evolución y estado actual del tema tratado.

Se ha utilizado, además de la bibliografía ordinaria la información disponible en la red, en portales de organismos internacionales solventes. La bibliografía ha sido tanto nacional como internacional.

Finalmente complementamos el artículo con la información más reciente en cuanto a la legislación correspondiente a dicho tema por parte del organismo correspondiente, la OMI.

Después de esta elección metodológica, se efectuó la revisión de los textos, figuras y tabla. Para esta tarea, utilizamos como herramienta fundamental los textos ya seleccionados y a nuestra disposición. Estos nos servirán para dar el alcance verdadero en ambas vertientes, una en aclarar el problema y otra en constatar nuestros puntos de vista y conclusiones. Estas serían, en suma, las características esenciales de esta investigación para que el panorama quede todo lo definido que es posible y dotado de medios técnicos e informativos como instrumentos de primer orden para la creación del presente artículo.

Posteriormente, el análisis del material recopilado, el examen y compresión de los contenidos tanto en el tiempo como en el espacio, configurarían el estudio del contexto. Como en toda revisión, la documentación consultada es el sostén de nuestras opiniones sobre el tema propuesto, llegando finalmente a las conclusiones que culminan este trabajo.

## CONCLUSIONES

1. Ningún sistema o práctica utilizada en la actualidad puede evitar totalmente la introducción de especies foráneas en las aguas de puertos y ríos.
2. La mayor parte de las técnicas diseñadas específicamente para el tratado del agua de lastre existentes en la actualidad, requieren una modificación del diseño estructural del buque para poder ser instaladas a bordo.
3. La OMI ha desarrollado y enviado una serie de guías voluntarias que se utilizan en la actualidad. Estas guías nos animan a minimizar la introducción de organismos acuáticos indeseados a través del transporte marítimo. Actualmente, la mejor opción para minimizar esta introducción es el método de relastrado y dilución.
4. El plan de operaciones de lastre de un buque, realizado conjuntamente con el plan de carga del viaje, podría dar mayor flexibilidad a la hora del manejo del agua de lastre. De esta forma, se podría controlar la situación y la hora para minimizar el transporte de especies no deseadas en el agua de lastre.
5. Los estados miembros de la OMI están continuamente sondeando la posibilidad de añadir un anexo al MARPOL 73/78. Esencialmente, este anexo implicaría la obligación de uso de las guías voluntarias existentes.
6. El problema de la transferencia de especies no indígenas tiene implicaciones para toda la sociedad y no afecta solamente a la industria marítima.

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# ANALYSIS OF THE MANOEUVRABILITY AND STRUCTURAL STRAIN OF A COORDINATED RUDDER ON AN OPERATIONAL TUG

**E. Cueto**[1]

## ABSTRACT

**We have tested and compared the manoeuvrability of an operational tugboat with two different configurations of the steering system: the first one had a steering nozzle with a conventional fixed rudder blade; and the second had the same steering nozzle with a coordinated rudder, consisting of a pivoting flap fitted on the after part of the nozzle blade. It was found that the configuration using a coordinated rudder provided a considerable improvement in the low-speed manoeuvrability of the tug. We also developed equations for this coordinated rudder configuration which allow us to calculate the final turning diameter, the torque on the stock and the shear forces on the steering system of the tugboat as a function of the propeller shaft speed.**

**Key words: operational tug, steering system, coordinated rudder.**

## 1. INTRODUCTION

The Kort nozzle was discovered in 1933 but its use for the propulsion of tugs, where traction is the main task, was not consolidated until the 1970s, after tests showed an increase in the bollard pull of 20% to 35%, depending on the design. Such a significant increase led to the gradual but widespread installation of fixed nozzles. There were two practical results: the pull was increased, which was advantageous; but manoeuvring capacity was limited, which was clearly negative. The limitation of the manoeuvring capacity produced by this system, together with the scarce effects of a conventional rudder with a fixed nozzle, led to the development of different systems seeking to improve the manoeuvrability.

A number of solutions have been tried to gain manoeuvring power. One of them was to install a transverse thruster at the bow. Various solutions have been fitted at the stern, such as active rudders, flap rudders, rotary cylinders, nozzle rudders, Shilling rudders, Tow Master, Becker and Rudder Coordinators. The most common way of solving the manoeuvrability problems encountered with a fixed nozzle on tugs was to replace it with a steering nozzle.

In recent years the manoeuvring problem has become even worse due to the reduced space left by crowded docks. In Spain, several harbour tugs have been fitted with either fixed or steering nozzles together with coordinated rudders. This solution provides greatly increased manoeuvring power at a low cost.

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This paper presents a short report of the manoeuvrability tests carried out with a real tugboat, 24 meters in length and with a power of 2050 bhp. The tests have been carried out with two types of steering arrangements: one had a steering nozzle with a conventional fixed rudder blade; the other had the same steering nozzle with a coordinated rudder. During the trials, turning circles were measured with a Global Positioning System (GPS) and the strains on the rudder and flap stock were determined by means of strain gauges.

## 2. EXPERIMENTAL METHODOLOGY

Within this conceptual framework we investigated two different types of parameters:
a) Those related to the shape and size of the turning circle.
b) The strain deformations on the rudder stock.

The results obtained have been arranged according to the two types of steering devices described above:

1. Steering nozzle with a fixed rudder blade.
2. Steering nozzle with a coordinated rudder.

The tugboat's manoeuvring capacity was tested by executing several series of six turning circles at sea. The first series of tests was carried out in Pasajes and the second in Santander. Both of these ports are located on the northern coast of Spain.

Each series of tests was performed in the order specified below:

1.- Engine speed 360 rpm, rudder hard-a-port.
2.- Engine speed 360 rpm, rudder hard-a-starboard.
3.- Engine speed 600 rpm, rudder hard-a-starboard.
4.- Engine speed 600 rpm, rudder hard-a-port.
5.- Engine speed 760 rpm, rudder hard-a-starboard.
6.- Engine speed 760 rpm, rudder hard-a-port.

## 3 EQUIPMENT

The equipment used in the trials was as follows:

- A real 24m tugboat.
- A steering system with rotating nozzle and fixed rudder.
- A steering system with rotating nozzle and a coordinated rudder.
- A topographic station.
- Experimental strain analysis gauges.

**Main particulars of the tugboat**
Length over al ........................................ 26,80 m.
Length between perpendiculars ........................................ 24,00 m.
Beam at design waterline ........................................ 7,90 m.
Maximum draught ........................................ 4,30 m.
Normal service draught ........................................ 4,00 m.
Displacement at normal service draught ........................................ 305 Tm.
Bollard poll ........................................ 32,00 Tm.
Main engine ........................................ 2050 bhp.
Speed ........................................ 13,00 kt.

**Steering system**
Rudder torque ........................................ 9000 m-Kg
Time for the rudder to go from one side to the other ........................................ 12 s
Nozzle diameter ........................................ 2136 $mm^2$
Area of the blade fixed to the nozzle ........................................ 0,93 $m^2$
Attack angle of the turning nozzle ........................................ 35

**Coordinated rudder system (CT)**
Area of the rudder blade ........................................ 0,42 $m^2$
**Area of the rudder flap** ........................................ 0,92 $m^2$
Attack angle of the nozzle and rudder blade ........................................ 35°
Attack angle of the second rudder flap (with respect to rudder blade) ............. 35°

With this steering system, when the nozzle rotates 35°, the flap rotates the same angle, actuated and synchronised by the rudder coordinator (CT), as shown in Figure 1.

**Topographic equipment**
Compact Station Geometer system ........................................ Model 400
Global Positioning System ........................................ GPS
Time between measurement ........................................ 0.4 s
Maximum length ........................................ 3100 m
Standard recording book
RS - 232C communication with a compatible PC

**Strain measurement instrumentation**
Technical data of extensometric bands:
Type ........................................ FLA-6-11
Nominal resistance ........................................ 120 Ohms
Gauge length ........................................ 6 mm
Gauge thickness ........................................ 0,0125 mm
Gauge factor ........................................ 2,132

## TRIAL RESULTS

The two tables below show the results of the trials. Table 1 refers to the conventional system of a steering nozzle with a fixed rudder blade. These trials were carried out in the approaches to Pasajes with a calm sea and no wind.

We show the average values of the turning circle diameter, together with the engine speed.

Table 2 shows the results of the second series of trials, after fitting a coordinated rudder, as shown in Figure 1. These trials were performed off Santander on 23 November 1992.

*Table 1. Average diameters with steering nozzle and fixed blade*

| Engine speed | Side | Mean diameter |
|---|---|---|
| Slow ahead | Starboard-port | 50 metres |
| Half ahead | Starboard-port | 65 metres |
| Full ahead | Starboard-port | 80 metres |

The coordinated rudder consists of a rudder blade and a pivoting flap. The blade is fixed to the steering nozzle, and the flap is joined to the blade by means of a hinge. The main parts of the system are illustrated in Figures 1 and 2:

*Figure 1: Schematic drawing of coordinated rudder*

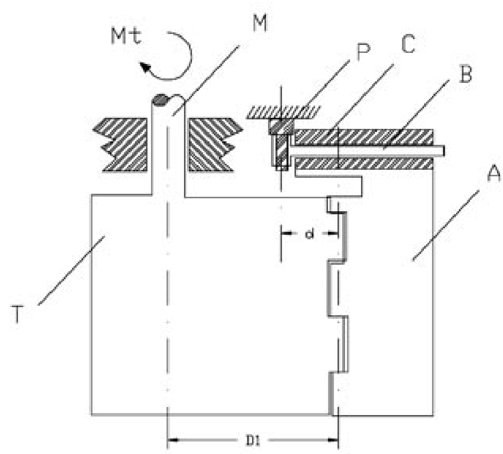
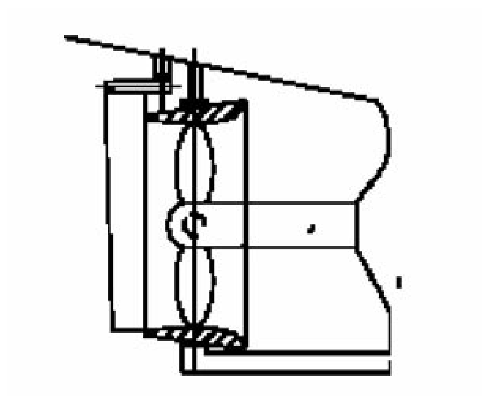



*Figure 2: Detail of coordinated rudder*



T = Nozzle    A = Flap
M = Stock    Dl = Distance between stock and flap axis
P = Pintle    d = Distance regulating flap turning angle
C = Liner    $M_t$ = Rotating torque
B = Arm

During the second set of trials, meteorological conditions were excellent, as was the case during the first one in Pasajes. Therefore, we can assume that weather had no influence on the results.

*Table 2. Average diameters with steering nozzle and CT rudder*

| Engine speed | Side | Mean diameter |
|---|---|---|
| Slow ahead | Starboard-port | 20 metres |
| Half ahead | Starboard-port | 25 metres |
| Full ahead | Starboard-port | 35 metres |

Figure 3 shows the shape and dimensions of the turning circle. Additional details about the manoeuvring data and conditions during the trials are presented in Table 3.

*Figure 3: Turning circle with coordinated rudder*

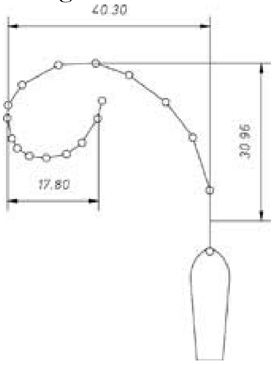



*Table 3: Miscellaneous data on the turning manoeuvre*

| | |
|---|---|
| Engine RPM | 360 |
| Steering side | Port |
| Attack angle of the nozzle | 35º |
| Attack angle of the flap | 35º |
| Propeller RPM | 120 |
| Tug speed | 2,28 kt |
| Length | 24,00 m |
| Time to change heading 90º | 18,10s |
| Time to change heading 180º | 39,26s |
| Tug speed during steady turn | 0,89 kt |
| Speed loss | 70,13% |
| Advance | 30,96 m |
| Tactical diameter $D_t$ | 40,30 m |
| Non-dimensional tactical diameter $D_t$ /L | 1,67 |
| Steady turning diameter $D_g$ | 17,80 m |
| Non-dimensional steady turning diameter $D_g$/L | 0,74 |

*Table 4. Strain deformations on the coordinated rudder*

| Time in seconds | Torque on rudder stock m·Kg. | Torque on hydraulic system m·Kg. | Force on rudder flap m·Kg. |
|---|---|---|---|
| 0 | 251 | 555 | 20 |
| 10 | 256 | 553 | 27 |
| 20 | 258 | 550 | 26 |
| 30 | 1858 | 1350 | 168 |
| 40 | 1249 | 1330 | 154 |
| 50 | 1688 | 1313 | 153 |
| 60 | 1418 | 1310 | 150 |
| 70 | 1519 | 1300 | 150 |
| 80 | 1554 | 1280 | 152 |
| 90 | 1553 | 1250 | 147 |

*Table 5. Results of the trials*

| Time in seconds | Torque on rudder stock m·Kg. | Force on rudder flap m·Kg. |
|---|---|---|
| 0 | 246 | 19 |
| 10 | 202 | 20 |
| 20 | 253 | 19 |
| 30 | 3637 | 329 |
| 40 | 2894 | 295 |
| 50 | 3343 | 300 |
| 60 | 3039 | 299 |
| 70 | 3107 | 298 |
| 80 | 3086 | 298 |

## 4. RESULTS

It can be seen that the manoeuvring capacity of the tug is about two and a half times better with the coordinated rudder system. We should point out that the relationship length / final diameter is less than one (when originally it was about 2). This means that the ship practically turns on the spot.

## 5. MATHEMATICAL EXPRESSIONS DERIVED FROM THE TEST DATA

**Final turning diameter**

The following expression is obtained

D = final diameter

P = Number of revolutions of the propeller shaft

$$D = 2.88 + 0.048 \cdot P \quad \textbf{(1)}$$

The equation above gives acceptable results for propeller speeds from 100 to 300 rpm.

**Relationship between propeller r.p.m. and torque on the stock**

Many equations have been used to calculate the forces on the rudder stock, but for the configuration tested we propose the following:

M = Torque on the stock
P = Shaft revolutions

$$M(m \cdot KN) = -1037.9 + 20.5 \cdot P \qquad \textbf{(2)}$$

**Relationship between propeller r.p.m. and shearing forces on the CT rudder**

Using the same parameters, the resulting formula is:

F = Shear force on the stock

$$F = -37.5 + 1.6 \cdot P \qquad \textbf{(3)}$$

The above expressions are only valid for similar vessels with a CT system, in fine weather, with appropriate draught and a clean hull.

## 6. CONCLUSIONS

Tests performed on an operational 24m. tugboat showed that fitting a coordinated rudder on the steering nozzle provided a great improvement in low-speed manoeuvrability as compared to a steering nozzle with a conventional rudder. We also developed equations for this coordinated rudder configuration which allow us to calculate the final turning diameter, the torque on the stock and the shear forces on the steering system of the tugboat as a function of the propeller speed. As might be expected, we observed a moderate increase in the final diameter with an increase in the shaft speed. The torque and shear forces also increase with the speed of the propeller shaft.

## ACKNOWLEDGEMENTS

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## **APÉNDICE:** ANÁLISIS ESTRUCTURAL DE LA COORDINACIÓN DE TIMONES EN LOS REMOLCADORES

Nosotros hemos hecho una investigación en un remolcador que instaló un sistema "Coordinador de Timones" para accionar el Timón Articulado, de acuerdo con los siguiente proceso:

a) Las gráficas de las trayectorias descritas bajo las especificaciones de las maniobras evolutivas con el sistema de gobierno compuesto por: tobera móvil y timón, y las trayectorias descritas por el mismo remolcador durante una maniobra similar a la anterior con un sistema de gobierno compuesto por: tobera móvil, timón y alerón accionado por una coordinación de timones.

b) Las medidas estáticas/dinámicas evolucionando en el tiempo para obtener el par torsor que se produce en la mecha de la tobera móvil, durante las maniobras con la instalación de tobera móvil, timón y alerón accionado por un coordinador de timones

## SISTEMA DE COORDINACION DE TIMONES PARA NAVES NAUTICAS

Según la figura 1, está compuesto por dos palas de timón situadas en línea, unidas por una articulación vertical, denominados respectivamente timón y alerón, el timón está accionado por la mecha, que le llega el accionamiento del servo y el alerón es movido por medio de un sistema mecánico por los ejes, los cuales forman un subsistema de accionamiento compuesto por un pistón deslizante, en una camisa, este pistón pivota en un pinzote fijo.

El coordinador de timones funciona según la figura, cuando se mete timón a cualquier banda. En la situación de navegar con el timón a la vía no produce efecto. Vamos a estudiar el caso de poner el mando o rueda de cabillas para situar todo el timón a la banda, produciendo un giro en el timón de á 35 º y en el alerón â 70º.

Estos dos timones calados con los ángulos gobernados automáticamente por el sistema de ejes, produce un avance de grados en el giro del alerón superior al del timón, según podemos apreciar en las figuras.

## METODOLOGIA EXPERIMENTAL

En los ensayos se han obtenido dos tipos diferentes de datos, que están diferenciados claramente:

1.- Los referentes a las maniobras
2.- Los que reflejan las deformaciones.

## METODOLOGIA DE: FUERZAS Y PAR TORSOR

Se utilizo para la obtención de las fuerzas y pares torsores la extensometria.
**LA EXTENSOMETRIA:** es el método que tiene por objeto la medida de las deformaciones superficiales de los cuerpos.
Las medidas se realizaron estáticas/dinámicas, tomando la evolución de los esfuerzos en el tiempo.
Se calcularon los esfuerzos a partir de las medidas extensometricas
El extensómetro eléctrico de resistencia es un hilo conductor de pequeño diámetro que al deformarse modifica su resistencia. En consecuencia, transforma una deformación en algo medible eléctricamente.
Expresando la variación de resistencias debida a la deformación, con signo indicativo que es negativa para la banda de estribor por trabajar a compresión y positiva para la banda babor por trabajar a tracción; el segundo sumando de expresa la variación de resistencia con la temperatura.

## TRANSDUCTORES DE PRESION CON GALGAS EXTENSOMETRICAS

Estos transductores utilizan como sensores primarios o elementos elásticos los diafragmas Se pegan a ellos cuatro bandas extensométricas.

## RECOGIDA DE DATOS EXTENSOMETRICOS

Las mediciones extensométricas fueron recogidas cada diez segundos en la base de datos del ordenador durante la realización de las maniobras descritas en el apartado A del presente capítulo.

**MATERIALES**
Los materiales empleados en este trabajo son los siguientes:

- Un remolcador escala 1:1, buque real.
- Un sistema de coordinación de timones instalado.
- Un equipo de topografía.
- Un equipo de instrumentación de extensometría.

## CONCLUSIONES

La investigación se refiere a ensayos en un buque a escala 1:1.

1.-Se aprecia como un aumento en el numero de revoluciones de la hélice origina unos esfuerzos mayores (en este caso mayor momento torsor en la mecha y momento flector en el brazo) en los elementos del sistema de gobierno con la coordinación de timones.

2.- Tras analizar los resultados obtenidos en las diferentes maniobras para el momento torsor en la mecha, hemos llegado a la conclusión de que dichos puntos podrían ajustarse a una senoide amortiguada.

3.- El índice indicativo de el diámetro de giro final entre la eslora para el caso de media máquina se aproxima a 3, mientras que con coordinación de timones es prácticamente la unidad.

4.- El incremento en el número de revoluciones de la hélice supone un aumento del diámetro de giro final. No obstante el índice de el diámetro por la eslora rebasa ligeramente el valor de 1,5 siendo 3,3 en origen., la capacidad de maniobra del buque sea mayor a pocas revoluciones de la hélice.

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# FUEL QUALITY RELATED TO UNSEAWORTHINESS

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## ABSTRACT

**The article examines various aspects of fuel quality based on the parameters given in international marine fuel standards. We consider the effects on engine performance of deviations from these standards, which under certain conditions can affect the seaworthiness of the vessel.**

**Key words: fuel quality, specification, onboard treatment**

## 1. INTRODUCTION

The concept of seaworthiness originated from man's instinct for self-preservation when he made his first primitive log canoes. If the vessel worked satisfactorily, i.e. if it did not sink, then it could be considered seaworthy. In this instance seaworthiness referred to stability.

Today the objective of providing a seaworthy vessel is a complex undertaking which involves the hull and machinery, equipment, stores and crew. Whilst within the confines of charter parties, seaworthiness relates to protection of cargo; to the world at large, seaworthiness conveys the concept of suitability, and safety. Conversely, an unseaworthy vessel is considered as a potential disaster, which may result in loss of life and cause long-term environmental damage. Incidents such as the Amoco Cadiz (1978) and Exxon Valdez (1989) resulted in enormous environmental damage. The Braer incident in 1993 initially looked as if it could lead to a major ecological disaster not only for the UK but also for the Norwegian coastline, but fortunately this did not occur.

It should be noted that the burden of proving unseaworthiness rests on those who make the allegation. Technically, various aspects of fuel quality could, under certain circumstances, lead to such a condition.

## 2. FUEL SPECIFICATION

In considering various aspects of fuel quality, reference needs to be made to a specification. ISO 8217:1996 (Petroleum products - Fuels (Class F) - Specifications of marine fuels) relates to the fuel at the time and place of custody transfer (namely the ship's rail).

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The standard makes no reference to the fuel requiring some onboard treatment before it is actually burnt and the extent of such treatment depends upon the grade. Grades such as DMX, DMA and DMB only require filtration, whilst DMC and the residual grades require further treatment for use in internal combustion engines. It should be noted that whilst various components of the fuel system, including filtration, are subject to periodic survey for classification purposes, there are no classification survey requirements for the fuel treatment system. By custom and practice, treatment of residual fuels almost always involves separation by both gravitation and the use of a centrifugal separator.

## 3. DENSITY

During the development of the specification, 991 kg/ m$^3$ at 15°C was adopted as the density limit at which water could be removed by a centrifuge operating with a water seal. Various papers have been published on water removal and the density limit, and inclusion of the parameter in the specification for the reasons given implies that centrifugal treatment is required. If the vessel is fitted with centrifuges with a water seal and the density is greater than 991 kg/ m$^3$ at 15°C, difficulties will be experienced in maintaining the water seal, and ineffective purification will result. In extreme cases, changing the separator from a purifier to a clarifier could avoid problems on a temporary basis, provided that there is only negligible water in the fuel.

## 4. VISCOSITY

The size of the centrifuge required is a function of the fuel flow and the viscosity of the fuel to be treated. Some older vessels were designed for only IFI80 with a non-pressurised system. Whilst the sizing of the centrifuges is satisfactory for this viscosity, attempts to treat a higher viscosity fuel and maintain the throughput will lead to a tendency for the centrifuge to act as nothing more than a pump due to the limited capacity of the machine. The design viscosity also determines the size of the fuel oil heater. Hence, the correct viscosity is one of the aspects of fuel quality that must be considered when assessing the efficiency of the fuel treatment plant. If the viscosity of the fuel supplied is greater than that for which the fuel system was designed, there is a possibility that the machinery burning the fuel will not operate under design conditions. Incorrect atomisation due to insufficient preheating can lead to increased peak pressure and rapid damage to the ring/ liner interface. In the case of the prime mover, this could lead to engine failure and loss of propulsion or, in auxiliary systems, to a power blackout.

## 5. FLASH POINT

On rare occasions it may be found that a vessel has a fuel oil with a flash point below 60°C. Such a fuel is unsuitable for use within the machinery space of ships classed for unrestricted service, as laid down by international legislation. However, due to operational requirements this fuel may have to be burnt in order to reach port, provided that the vessel's underwriters have agreed. The fuel supplier should be put on notice and the vessel's classification society should be advised of the condition of the fuel. The crew should be advised that hot-working metallic parts, smoking or using any other heat source should be avoided in the vicinity of the fuel storage tanks and vents. The purpose of defining a minimum flash point is to minimise fire risk during normal storage and handling. However, the flash point is not a reliable indicator of the flammability conditions that can exist in headspaces of tanks containing fuel oil. In practical terms this means that a residual fuel can have the potential to produce a flammable atmosphere in the tank headspace, even when stored at a temperature below the measured flash point.

It should be noted that, in some countries, gas oil and diesel fuel is produced for the local land-based market to a national specification. Included in such a specification is usually a minimum flash point and this value may be below that required by international legislation for normal marine use.

## 6. POUR POINT

Historically, there have been occasions when a vessel's fuel system has malfunctioned because of high pour point fuel. This usually applies to vessels with no fuel tank heating arrangements, which trade internationally. For this reason the following note was included in the specification: "Purchasers should ensure that this pour point is suitable for equipment onboard, especially if the vessel is operating in both hemispheres, the North and South." For residual fuels, some areas of the world will supply high pour-point fuels, which sometimes exceed the specification limit of 30°C. If a fuel in storage falls to a temperature below the pour point, wax will precipitate out of solution and settle on the inside of the tank and on the heating coils. When heating is reapplied, the heating effect can be limited by the thermal insulating nature of the wax. In extreme circumstances, the fuel will solidify and it can only be removed from the tank manually. Loss of pump suction will eventually result in the inability to meet engine consumption requirements.

## 7. CARBON RESIDUE

The carbon residue of a fuel is the tendency to form carbon deposits under high temperature conditions in the absence of air, and is now usually expressed as Micro Carbon Residue (MCR). This property is generally considered to give an approximate indication of the carbonaceous deposit forming tendencies of the fuel. The values resulting from secondary conversion processes such as visbreaking are higher than those from other refining processes. Some older engines may experience difficulty when burning fuels with an MCR greater than 12% wt, especially at low load conditions. Where such engines are used for power generation purposes, the possibility of electrical power failure increases, due to increased carbonaceous deposits. Operational experience has shown that the present generation of marine engines designed for burning residual fuel can tolerate a wide range of MCR values with no adverse effect.

## 8. ASH

The ash level is related to the inorganic material in the fuel oil. The actual value depends upon three factors: firstly, the ash present in the crude oil; secondly, the refinery processes employed; and, thirdly, possible subsequent contamination due to sand, dirt, and rust scale. Excessive ash levels are invariably caused by the inclusion of some waste material in the fuel, which will increase the tendency for engine fouling. Increased levels of ash in fuels that have been through an onboard treatment plant will result in poor performance. In extreme cases, choking of the engine can occur, with subsequent loss of power and engine failure.

## 9. WATER

Free water, which may be fresh, brackish, or saline, can normally be removed satisfactorily by the centrifuge, unless tightly emulsified. Excessive uncontrolled water retained in the fuel after treatment, for whatever reason, can lead to total engine failure. Whilst it is likely that emulsified water, even saline, will not result in immediate failure, it is almost certain that, at some unpredictable point, failure of fuel pumps and injectors will occur.

## 10. SULPHUR

Sulphur is the principal non hydrocarbon in all marine fuels. It is a naturally occurring element in crude oil which is concentrated in the residual component; hence the amount of sulphur depends mainly on the source of the crude oil and, to a lesser extent, upon the refining process. The level of sulphur has a marginal effect on the specific energy of the fuel. For example, a 4% wt sulphur fuel compared to a 1%, wt sulphur fuel will cause a reduction of about 0.75 MJ/kg, or some 2%. In general, the corrosive wear, resulting from the burning of the sulphur in the fuel, can be controlled by an alkaline lubricant and suitable lubrication. If low sulphur fuel is burnt continuously, there may be some economic advantage in using a less alkaline lubricant. In the medium-term, maintenance costs may increase if the lubricant/lubrication is not matched to the sulphur content.

## 11. VANADIUM

Vanadium is a metal contaminant that is present in all crude oils in oil-soluble form, and the levels found in residual fuels depend mainly on the crude oil source, with those from Venezuela and Mexico having the highest levels. The actual level is also related to the concentrating effect of the refinery processes used in the production of residual fuel. On combustion of the fuel, the most corrosive ashes are vanadium pentoxide and sodium sulphate, and the temperature at which these ashes form a deposit depends on the vanadium/sodium ratio of the fuel. Some engine manufacturers, besides specifying levels of vanadium and sodium, also give a limiting ratio. High temperature corrosion and fouling are phenomena that can mainly be attributed to the vanadium and sodium in the fuel, as well as to the ash deposits which adhere to exhaust valves and turbochargers.

As a result, the efficiency of these units is reduced and severe corrosion can take place. The extent of hot corrosion and fouling is generally contained at an acceptable level by adequate design and operation of the engine. Control of temperature is the principal means by which corrosion is minimised and in modern designs this is limited to 450°C. Some engine builders use nimonic steels in valve manufacture, whilst others use stellite facing. In each case the objective is to increase the resistance to the effect of ash compounds. In some engines, however, the use of high vanadium fuels and those with a critical vanadium/sodium ratio can result in significant corrosion and fouling. If the engine is used in a system for power generation, this will increase the possibility of electrical power failure.

## 12. CATALYTIC FINES

Whilst there may be very small quantities of silicon, in the form of sand, and aluminium in crude oil, it is generally accepted that if silicon and aluminium are found in fuel oil, this probably indicates the presence of catalytic fines. These fines are particles arising from the catalytic cracking process in the refinery and are in the form of complex aluminium-silicates. Depending on which catalyst is used, this particulate matter varies both in size and hardness. During the 1980s, the generally accepted parameter for limiting the amount of catalytic fines in the fuel was by specifying a limit for aluminium, which was 30 mg/kg. As has already been mentioned, the composition of the catalyst is variable, and now the amount of catalyst present is controlled by limiting the combination of aluminium and silicon to a maximum of 80 mg/kg. Operational experience has shown that excessive catalytic fines can lead to high ring/ linear wear and degradation of the fuel pumps. In extreme cases, where the catalytic fines are at levels greater than the onboard treatment plant can adequately reduce, the wear can be so great that the engine fails to function.

## 13. SEDIMENT STABILITY AND COMPATIBILITY

In the process of blending a particular grade of fuel, the properties of the blend are determined by the proportion and source of each of the components used in the blend, particularly with reference to stability and sediment.

Stability of residual fuel may be defined as the ability of a fuel to remain in an unchanged condition despite circumstances which may tend to cause changes: or more simply, as the resistance of oil to breakdown. Conversely, instability would be the tendency of a residual fuel to produce a deposit of asphaltenic matter as a function of time and/or temperature.

Sediment by extraction is a measure of the content of what are mostly organic materials in the fuel and, as such, is of limited relevance. These materials are insoluble contaminants such as sand, dirt and rust scale, and are not derived from the fuel. What is of greater importance is the total sediment content of the fuel, which can include hydrocarbon material related to stability.

There are various filtration test methods for determining sediment levels under defined conditions. These are the existent, accelerated and potential tests. On a routine basis, FOBAS conducts the sediment accelerated test. The advantage of this test is that it is shorter in duration when compared to the potential test that requires 24 h preparation time. During a FOBAS analysis, if a high value is determined, additional sediment tests are carried out to assess the quality of the fuel as delivered.

Whilst every fuel is manufactured to be stable in itself, in that it does not have a tendency to produce asphaltenic sludge, it does not necessarily follow that two stable fuels are compatible when blended or mixed together. Incompatibility is the tendency of a residual fuel to produce a deposit on dilution, or on blending with other fuel oils. A blend is regarded as stable if it is homogeneous immediately after preparation, remains so in storage and at no time produces or tends to produce sludge to a significant degree. Under these circumstances the fuels forming the blend can be considered as compatible with each other.

In the event of lack of stability or the incompatibility of two fuels, it is likely that filter and centrifuge blockage will be experienced. Such blockages may restrict the flow of fuel to the engine, resulting in limited power output. Also, such fuel is chemically altered, such that its combustion characteristic is different. This gives prolonged burning, resulting in total damage to cylinder components. Should there be a difficulty in identifying the nature of this material, a small portion should be placed in an open container and allowed to float in a vessel containing water at a temperature of 60-70°C. A waxy material will melt but an asphaltenic sludge will not.

## 14. IGNITION QUALITY

The empirical parameters related to ignition quality of CCAI and CII developed in the 1980s both provide an empirical method for ranking residual fuels, but these methods only indicate one part of the multistage process of burn ability. On a worldwide basis there are some residual fuels which have unusual burning characteristics, thus imposing an additional load on the ring/liner interface. If this is not controlled, there is a danger that excessive maintenance will be incurred and, in extreme cases, there is danger of engine failure. In marine diesel engines, ignition performance requirements of residual fuels are primarily determined by engine type and, more significantly, by engine operating conditions. Fuel factors influence ignition characteristics to a much lesser extent. It is for this reason that no general limit for ignition quality can be applied, since a value which may be problematic for one engine under adverse conditions may perform quite satisfactorily in many other circumstances.

## 15. OTHER FUEL PROPERTIES

It is anticipated that other aspects will be included in the fuel specification as this continues to evolve. In the process of this evolution, it should always be born in mind that the inclusion of additional parameters must be reasonable, useful and economical.

## 16. CONCLUSIONS

The quality of fuel as it is delivered to the vessel can affect seaworthiness, as can the subsequent onboard treatment of the fuel. In a world where fuel quality is variable, there is a need for more adequate measures to govern the effectiveness of onboard fuel treatment. The evolutionary process of developing such measures is likely to be preceded by guidance notes.

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## APENDICE: RELACIÓN ENTRE CALIDAD DEL COMBUSTIBLE Y NAVEGABILIDAD

El artículo examina diversos aspectos de la calidad del combustible, en base a los parámetros establecidos en los Estándar o Normas Internacionales sobre Combustible Marinos. Los efectos de la desviación de estos estándares o normas, hay que tenerlos en cuenta en el rendimiento de las máquinas, que bajo ciertas condiciones puede afectar a la navegabilidad de la embarcación.

### Introducción

Hoy la empresa de proporcionar una nave en condiciones de navegar es complicada, al estar compuesta por el casco y la maquinaria, equipos, bodegas y tripulación. Una embarcación incapaz de navegar es considerada como un desastre potencial, que causa un daño medioambiental a largo plazo, además de la pérdida de vidas humanas.

### Norma Del Combustible

La norma ISO 8217:1996 (Productos del Petróleo - Combustibles (Clase F) - Normas de Combustibles Marinos) relaciona el combustible con el momento y el lugar para su traslado. Los estándares no hacen ninguna referencia al combustible que requiere de un tratamiento a bordo antes de que sea realmente quemado y la magnitud de tal tratamiento depende de su calidad.

### Densidad

Durante el desarrollo de la norma, 991 $kg/m^3$ a 15° C se adoptó como el límite de densidad a que podría eliminarse el agua de una centrifugadora que opera con un precinto de agua.

### Viscosidad

El tamaño de la centrifugadora requerida es función de la circulación de combustible y de la viscosidad del combustible a ser tratado.

Por lo tanto, la viscosidad exacta es una de los aspectos de la calidad del combustible que deben ser considerados cuándo se fija la tasa de eficiencia de la planta de tratamiento de combustible.

### Flash Point

En el caso infrecuente de que una embarcación tenga un combustible con un Flash Point inferior a 60º C, es inadecuado para el uso dentro del espacio de la maquinaria, como se enmarca bajo la legislación internacional. Cualquier origen de calor debe ser evitado en las inmediaciones de los tanques de almacenamiento de combustible. El propósito de definir un flash point mínimo, es reducir al máximo el riesgo de incendio, durante los procesos de estiba y la maniobra.

### Punto de Vertido

Históricamente, ha habido ocasiones en las cuales, un sistema de combustible de una nave se ha estropeado debido a combustible con un punto de vertido alto. Esto generalmente es aplicable a naves con tanques de combustible  sin una normativa en los calentadores que operan internacionalmente. Para combustibles residuales, algunas áreas del mundo son propensas al suministro de combustibles con punto de vertido altos, que exceden el límite de la norma de 30º C.

### Residuo De Carbono

El residuo de carbono de un combustible es la tendencia a formar depósitos de carbono, bajo condiciones altas de temperatura, en ausencia de aire y se define en general como Residuo Micro Carbónico (MCR).

Experiencia operacionales han demostrado que la actual generación de maquinas marinas, pueden tolerar un amplio rango de valores MCR sin efectos adversos.

### Ceniza

El nivel de ceniza está relacionado con la materia orgánica presente en el combustible. Los valores actuales dependen primeramente, de la ceniza presente en el petróleo crudo, en segundo lugar, de los procesos de refinería empleados y en tercer lugar, de la posible contaminación debido a arena, tierra y óxidos.

Niveles excesivos de ceniza son siempre causados por la inclusión de desperdicios de materiales en el combustible, que incrementan la tendencia de fallos en la maquinaria.

### Agua

Soltar agua fresca, salobre o salina es normal y satisfactoriamente evacuada por la centrifugadora, a menos que esté fuertemente emulsionada. El agua excesiva e incontrolada, contenida en el combustible después del tratamiento, puede provocar un fallo total de la maquinaria.

### Azufre

El azufre es el no-hidrocarburo principal en todos combustibles marinos. Es normal encontrar este elemento en el petróleo crudo. El nivel de azufre tiene un ligero efecto sobre la energía específica del combustible. En general, el desgaste por corrosión, resultante de la combustión del azufre en el combustible.

### Vanadio

El Vanadio es un metal contaminante, que está presente en todos los petróleos en crudo, en forma de solución oleosa, y los niveles encontrados en combustibles residuales dependen principalmente del origen del petróleo crudo. El nivel actual está relacionado por tanto con el efecto de concentración de los procesos de refinamiento utilizados en la producción del combustible residual. La corrosión a altas temperaturas y fallos son fenómenos que pueden ser atribuidos al vanadio y al sodio presente en el combustible.

### Minúsculas Partículas Catalíticas

Estas partículas se generan a partir de procesos de ruptura catalítica en la refinería y se encuentran en forma de silicatos alumínicos complejos, dependiendo del catalizador usado; esta partícula varía tanto en su tamaño como en su dureza. En la actualidad se limita la cantidad presente a una combinación de aluminio y silicio no superior a 80 mg/kg.

### Estabilidad De Sedimento Y Compatibilidad

En el proceso de mezclado de un tipo particular de combustible, las propiedades de la mezcla están determinadas por la proporción y por el origen de los componentes usados; particularmente en lo referente a la estabilidad y a la sedimentación. La estabilidad de un combustible residual se puede definir como la resistencia del fuel a deteriorarse.

### Calidad De Encendido

Los parámetros experimentales relacionados con la calidad de encendido de CCAI de y CII desarrollados en la década de los 80, proporcionan un método experimental para la clasificación de combustibles residuales.

## CONCLUSIONES

La calidad del combustible suministrado a la embarcación puede afectar a la navegabilidad, así como el subsiguiente tratamiento del combustible a bordo. En un mundo dónde es común la inconstante calidad del combustible, hay una necesidad por establecer medidas más adecuadas que regulen la efectividad del tratamiento del combustible a bordo.

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# TRANSFER OF NAUTICAL KNOWLEDGE FROM THE U.S.A. TO EUROPE IN THE NINETEENTH-CENTURY: THE CASE OF THE SUMNER LINE OF POSITION AND ITS INTRODUCTION INTO SPAIN

**I. Ibáñez Fernández[1], J. Llombart Palet[2] and M. A. Iglesias Martín[3]**

## ABSTRACT

**Modern celestial navigation has its foundations on the graphic method for fixing the ship's position, discovered in 1837 by the Captain of the U.S. Merchant Marine, Thomas H. Sumner. After being published, in 1843, this method was quickly adopted by U. S. navigators, thanks to Matthew F. Maury, at the time in charge of the Hydrographic Service in Washington. In Europe, on the contrary, the spread of Sumner's method was uneven. In order to analyse its introduction in Spain, an examination of Spanish specialised journals and texts, published during the nineteenth century, has been carried out. The results, shown in this work in chronological order, have been interpreted in the light of the complex political situation which shaped the progress of science and technology in the nineteenth-century Spain.**

**Key words: Maritime History, Nautical Astronomy, Sumner Line of Position.**

## 1. INTRODUCTION

For many centuries navigation was conditioned by the difficulty of obtaining the geographical coordinates (i.e., latitude and longitude) which define a ship's position at sea. Long ago it was discovered how to determine the latitude, with sufficient precision, by observing stars close to the pole or the Sun at noon. However, reckoning the longitude at sea was considered to be "the limit God had set on human intelligence" (Martínez Hidalgo, 1946, p.75), and this problem did not have a practical solution until the final decades of the eighteenth-century. The method of lunar distances and the chronometer, which eventually allowed navigators to determine this precious coordinate, had been proposed some centuries before. However, for this method to be practicable further progress would have to be made in astronomy, mathematics and precision instrument making.

This quest for a method of reckoning the longitude, together with the age of the great discoveries, has been the dominant interest of maritime historiography of this period. However, other significant events, which were no less important for the progress of navigation, took place during the nineteenth-century. Certainly, the most important technical innovation was the advent of steam powered vessels, which achieved an extraordinary expansion during this century. The success of the new propulsion system brought about the transformation of the whole shipping industry, including position finding: with faster ships it was necessary to determine their position more often.

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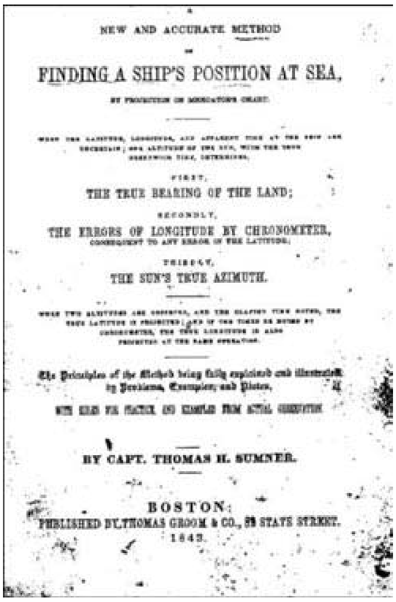
Once the longitude problem was solved, astronomical observations were made specifically for finding latitude (meridian passage) or longitude (prime vertical passage or lunar distances). Although theoretically possible, it was not common practice among navigators to determine both geographical coordinates simultaneously, mainly because of the complex and laborious calculations required. Undoubtedly, the most significant advance in this field during the nineteenth-century was the so-called "new astronomical navigation". The beginning of this is marked by the line of position discovered in 1837, and published in Boston in 1843, by the Captain of the U.S. Merchant Marine, Thomas H. Sumner (1807-1876). For the first time, a simple method for fixing the ship's position was made available to navigators, allowing the nineteenth-century to be considered (see Figure 1) "a golden era of astronomical navigation" (Cotter, 1968, p. 165).

*Figure 1. Title page of Sumner's book.*


NEW AND ACCURATE METHOD

FINDING A SHIP'S POSITION AT SEA,

FIRST,

THE TRUE BEARING OF THE LAND;

SECONDLY,

THE ERRORS OF LONGITUDE BY CHRONOMETER,

THIRDLY,

THE SUN'S TRUE AZIMUTH.

BY CAPT. THOMAS H. SUMNER.

BOSTON:

PUBLISHED BY THOMAS GROOM & CO., 82 STATE STREET.

1843.

## 2. BIOGRAPHICAL SKETCH

Born in Boston on 20th March 1807, in the bosom of a well-off family, Thomas Hubbard Sumner1 entered Harvard at the age of fifteen. There, he studied mathematics and astronomy with Professor John Farrar, and graduated in 1826. Shortly afterwards, when he was nineteen years old, he got married but that marriage lasted only three years. In 1829, after the divorce, he enlisted as a common sailor on a ship engaged in the China trade. After eight years, Sumner had risen to the rank of Captain and become Master of his own vessel. In 1834, he had married Selina Malcom, and they had six children between 1835 and 1848.

With the publication of his work, in 1843, Sumner's career reached its climax, declining soon afterwards as a consequence of an early mental illness. He died on 9th March 1876, after being confined to an asylum for the last 26 years of his life.

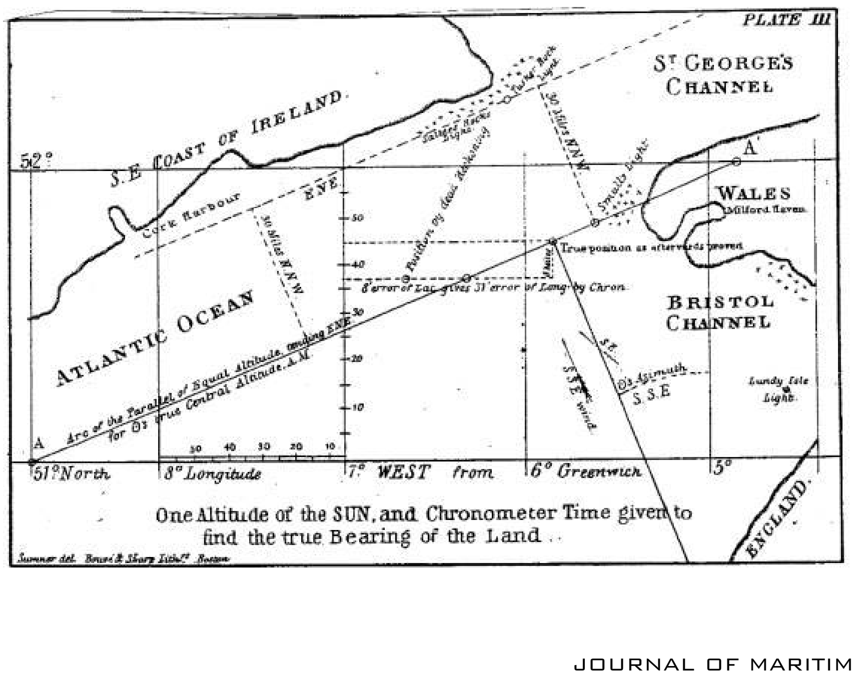
## 3. THE DISCOVERY OF THE LINE OF POSITION BY THOMAS H. SUMNER

Sumner describes in his book the dramatic conditions in which the discovery took place on 17th December 1837, when he was on board his vessel the *Cabot*2, sailing from Charleston (South Carolina) bound for Greenock (Scotland). After passing the Azores, the wind prevailed from the Southward; no observation was made, after passing longitude 21° W, until near land, on 17th December, within 40 miles, by dead reckoning, of Tusker light; at about 10 a. m. an altitude of the sun was observed, and the chronometer time noted. But, having run so far without any observation, it was plain that the latitude by dead reckoning was liable to error, and could not be entirely relied on.

Using, however, this Latitude, in finding the Longitude by Chronometer, it was found to put the ship 15' of Longitude, E. from her position by dead reckoning; which in Latitude 52° N. is 9 nautical miles; this seemed to agree tolerably well with the dead reckoning; but feeling doubtful of the Latitude, the observation was tried 10' further N, finding this place the ship E. N. E. 27 *nautical* miles, of the former position, it was tried again with a Latitude 20' N. of the dead reckoning; this also placed the ship still further E. N. E., and still 27 *nautical miles* further; these three positions were then seen to lie in the direction of *Small's light*. It then once appeared, that the observed altitude must have happened at *all the three* points, and at *Small's light*, and at the ship, at the *same instant of time*; and it followed, that Small's light must bear E. N. E., if the Chronometer was right. Having been convinced of this truth, the ship was kept on her course, E. N. E., the wind being still S. E., and in less than one hour, Small's light was made bearing E. N. E. ½ E., and close aboard. (Sumner, 1843, pp. 37-38)

Sumner had deduced that with a single altitude of a celestial body it was possible to obtain the line of position of the observer, represented by a straight line on the Mercator's chart. (Fig.2).

*Figure 2. Chartwork for the discovery of the Sumner line of position. Source: Sumner, 1843, Plate III.*



At that time, it was known that the places on the Earth's surface from which the same celestial body is observed with the same altitude, at the same instant, are all situated on a circumference whose centre is the terrestrial projection of the body and its spherical radius is equal to the zenith distance-- the complement of the altitude of the observed body. Sumner (1843, pp. 10-11) designated these circumferences "parallels of equal altitude", and showed that, in practice, a small portion of them can be represented by a straight line on the chart.

The usefulness of a single observation was most probably the main advantage of the method which also allowed, for the first time, a practical and simultaneous determination of latitude and longitude. With two altitudes and the indication of the chronometer of the instant the observations were made, the ship's position was fixed by means of the analytical calculation of four longitudes -to the reach of all navigators at the time- and a simple graphic design on the chart.

## 4. ACCEPTANCE, PROPAGATION AND IMPROVEMENT OF SUMNER'S METHOD

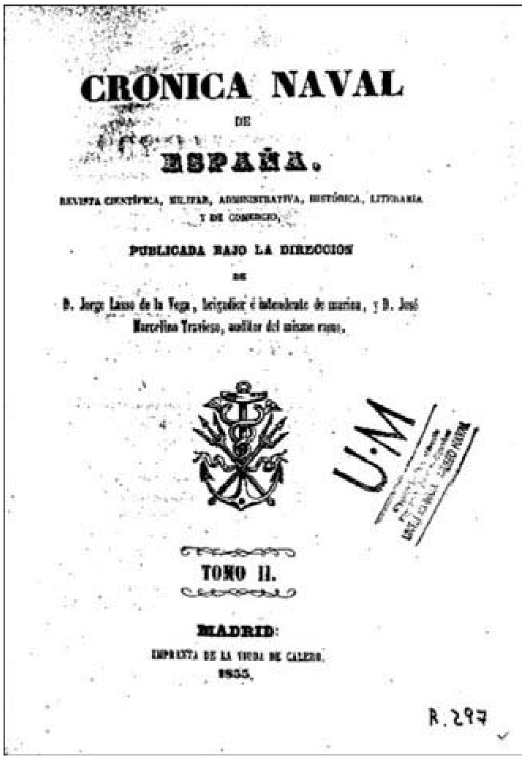
Before publishing his work, Sumner submitted the manuscript for approval to Benjamin O. Pierce, Professor of mathematics at Harvard, and also to the Bostonian *Naval Library and Institute* and to J. Surgis, Captain of the U. S. Revenue Cutter *Hamilton*. The three resulting reports precede the text of the first edition of Sumners' book, under the title "Recommendations". With such guarantees the method was quickly adopted by U. S. navigators. Its use became generalised thanks to Matthew F. Maury (1806-1873), at the time in charge of the Hydrographic Service in Washington, who, in October 1843, wrote to Sumner: "Your method can be considered as the beginning of a new age for the practice of navigation. Orders have been given so that all of our ships be provided with your book"3.

In Europe, however, the spread of Sumner's method was uneven. García Franco (1947, II, pp. 135-136) reports how the new method reached Britain through the *Nautical Magazine* in 1844. It arrived in France in 1847 by means of an article published by the sailor Barther [sic] in *Annales Maritimes*; and in Germany thanks to Henry A. Tobiesen, who in 1855 translated Sumner's work into German. In Spain, according to García Franco, it was 'diffused' in 1865 [sic] by lieutenant Montojo, although Quijano had already used the procedure and referred to it in 1857. Arroyo (1989, pp. 143-145) presents the introduction of the Sumner line into Spain in the very same way as García Franco.

When trying to check on this chronology, it was found that Williams (1994, pp. 113-114) confirms the fact that in 1844 the well-known essayist H. Raper reviewed Sumner's book in the *Nautical Magazine*. Likewise, in the French case, Duval (1955, p. 396) confirms that M. Barthet, a resident of the U.S.A., sent an article explaining the new method to be inserted in the *Annales Maritimes et Coloniales*4. As far as Germany is concerned, Gelcich (1893, p. 40) mentions that the third edition of Sumner's book was translated by Henry A. Tobiesen and published in Hamburg in 1855.

As for the Spanish case, however, a review of specialised journals of the period has shown not only that the learned paper on the Sumner line written by Montojo was published in 1864, but also that almost one decade earlier, in 1855, J. J. Navarro had published translated extracts from the first edition of Sumner's book in the second volume of the magazine *Crónica Naval de España*.(See Figure 3).

*Figure 3. Cover of the second volume of the Crónica naval de España (1855), in which the article on the Sumner line by J. J. Navarro was published.*


CRÓNICA NAVAL
DE
ESPAÑA.
REVISTA CIENTÍFICA, MILITAR, ADMINISTRATIVA, HISTÓRICA, LITERARIA Y DE COMERCIO,
PUBLICADA BAJO LA DIRECCION
DE
D. Jorge Lasso de la Vega, brigadier é intendente de marina, y D. José Marcelino Travieso, auditor del mismo ramo.
TOMO II.
MADRID:
IMPRENTA DE LA VIUDA DE CALERO.
1855.



In order to know the actual way in which the "new astronomical navigation" was introduced into Spain, a methodical and meticulous examination of Spanish specialised journals5 and texts6, published later than 1843, has been carried out. The results are shown later on, as the possibilities of interpretation increase when they are looked at in the light of the political situation which shaped the progress of science and technology in the nineteenth-century Spain.

Sumner's method proved useful and efficient at sea. Its importance for navigation fostered its rapid propagation, attracting the attention of sailors and scientists. A short time later, the initial method was improved and the general theory of celestial position lines was developed. In this process, the contribution of the French Navy officer A. L. A. Marcq Saint-Hilaire (1832-1889) stands out. In 1875, Marcq presented the line of position which bears his name through an article published in the *Revue Maritime et Coloniale*. Known as the "altitude difference" or "intercept method", St. Hilaire's line of position has become the basis of present-day celestial navigation.

## 5. CULTURAL IDIOSYNCRASY IN NINETEENTH CENTURY SPAIN, WITH A PARTICULAR REFERENCE TO NAVIGATION

As López Piñero (1992, p. 13) and Sánchez Ron (1999, p. 36), *inter alia*, claim, the modernisation of scientific and technical activity began in Spain with the *novator* movement of the last third of the seventeenth century. During the eighteenth century, it was promoted by the illustrated governments of the new Bourbon dynasty, reaching its highest point during the reign of Carlos III (1759-1788). So, at the beginning of the nineteenth century, the position of Spain in this respect was excellent, but science soon ceased to occupy a prominent place, mainly due to the internal political situation.

According to Vernet (1975, p. 231), the Peninsular War (1808-1814) meant the collapse of the feverish development of science. According to López Piñero (1992, p. 14) extended up to 1833; indeed, he qualifies the interval between 1808 and 1833 as a "period of catastrophe". In spite of the liberal interruption (1820-1823), absolutism presided the reign of Fernando VII (1814-1820 and 1823-1833) and caused the extinction or lethargy of nearly all scientific institutions. With the main scientists having been persecuted or exiled, the Inquisition was re-established and freedom of the press was suppressed. López Piñero (1992, p. 15) claims that the only Spanish scientific contributions were due to some exiles who were able to work in contact with the new European tendencies.

However, the fact that in Spain, during the first third of the nineteenth century, there was not an active, organised, scientific community, does not imply that there were no isolated researchers within the different scientific branches. With regard to navigation, for instance, as Peset *et al.* (1978, pp. 39-40) assert, there were some Spanish naval officers working individually under the protection of the Navy, who enjoyed worldwide recognition as scientists. However, their contribution to the progress of mathematics or physics was limited as they were obliged to devote all their efforts to pedagogic and technical matters. In addition to the cases of J. Mendoza y Ríos (1763-1816) and G. Ciscar (1760-1829), mentioned by Peset *et al.*, the one of J. Sánchez Cerquero (1784-1850) can be included. Director of the San Fernando Observatory from 1825, Cerquero made important contributions to the fields of mathematics, astronomy and navigation (Ibáñez, 2001).

In spite of the above exceptions, it can be said, as Menéndez y Pelayo (1888, p. 130) claimed, that for Spanish literature and science, the 19th century did not actually start until 1834. As a matter of fact, the cultural scene improved in Isabelline Spain (1833-1868) as a consequence of the end of absolutism. Although this period did not lack political swings, and consequently discontinuity in scientific policy, recovery was possible to a great extent as a result of the lesser control of the edition and circulation of scientific publications, including specialised journals. It should also be mentioned that during this period important educational reforms were undertaken and some scientific institutions established, factors that undoubtedly helped to smooth the way.

The extreme liberalism which characterised the revolutionary period (1868-1874), extended also to the academic world, and it definitely had an influence on the recovery that scientific activity experienced during the Restoration (1874-1902). Although its level undoubtedly increased during this period, this does not mean that science was promoted by the official political and cultural ideology; rather, it was just consented (Tuñón de Lara, 1982, II, pp. 32-33).

The difficult circumstances that Spanish science suffered during the nineteenth century have been summarised by R. Taton (1995, p. 628): "In the Iberian Peninsula, badly damaged by the Napoleonic wars, in spite of some attempts of liberal reformation, the political situation remained unfavourable for the free progress of science".

From 1833, the different scientific and technical disciplines started to develop again but, according to Vernet (1975, p. 213), at an unequal rate, so that all of them reached maturity during the second half of the century. This proved true as far as navigation is concerned. In the first place, from 1833 the production of nautical works showed a quantitative increase, as well as a growth in the number of translations, signs of a new, more permissive, order. In spite of certain fluctuations, this tendency was consolidated during the second half of the century (Ibáñez, 2002, pp. 290-298). As for nautical journalism, it too was promoted, starting from the reign of Isabel II. *España Marítima*, published between 1839 and 1840, is credited with being the first Spanish marine journal. Its short life was a common characteristic shared by most publications that followed, chiefly due to the lack of subscriptions (Ibáñez, *et al.*, 2003, pp. 506-507). In the educational field, the reorganisation of civil nautical studies did not take place until 1850, and the syllabus implemented then remained in force until the second decade of the twentieth century (Arroyo, 1989, pp. 128-131).

## 6. THE INTRODUCTION IN SPAIN OF THE SUMNER LINE: A CHRONOLOGY7

1855: As mentioned above, José J. Navarro published a translation consisting of extracts from the first edition of Sumner's work in the journal *Crónica Naval de España*. However, it does not appear that this article served to disseminate the new navigation widely in Spain. In Pujazón's words, "the diffuseness and lack of method with which it was written caused it to be little read by our seamen" (Pujazón, 1865, p. 73), but it was more probably a consequence of the limited circulation of this publication (Ibáñez, *et al.*, 2003, p. 508 ).

Even though it may be written without a didactic approach, this 71-page translation is clearly organized in four sections. The first is devoted to the practice of the method which is structured in the classic problem style. The second refers to the advantages of the method. Its fundamentals are explained in the third part, and finally, in the fourth section, the extension of the method to the observation of celestial bodies other than the Sun is shown.

1857: In his work *El compañero del Almanaque Náutico*, Anselmo T. Quijano included ten appendixes, among which, the eighth stands out with the title: *Método de proyección para determinar la situación del buque en la mar* (Quijano, 1857, pp. 36-37).

According to Lasso de la Vega (1857, p. 552), it is "an abstract of the third edition of the American work by Captain Thomas Sumner". It is a meritorious work as, in only two pages, Quijano offers the essence of the usefulness of the method, not only for position finding–by means of two observations, simultaneous or not– but also for determining the compass error or for using the line of position obtained in coastal navigation –when there is only one observation available. He does not solve any examples since what he considers an "advantageous method" requires "a calculation so simple that no navigator ignores its resolution" (Quijano, 1857, p. 37). Finally, he praises and recommends the method, emphasising that "thanks to this clever, though as yet slightly used method, I have safely navigated twice through what is perhaps most reef-sown sea on the globe, the China Sea" (Quijano, 1857, p. 37).

1864: As mentioned earlier, José Saturnino Montojo inserted the same article on Sumner's work in two journals, namely: *El Departamento* and *Anuario de la Dirección de Hidrografía* (see Figure 4), each of which had an off-print (Llabrés Bernal, 1959, p. 50). His intention seems to have been to popularise among Spanish navigators the use of a method that, in his opinion, made it possible "to determine a good fix with two isolated altitudes and little numeric labour", and whose accuracy had already been confirmed by "the practice of many of our naval officers as well as merchant marine captains who have used it and use it daily" (Montojo, 1864, p. 30). In less than thirty pages, Montojo offers in a clear and simple way the essence of Sumner's method, explaining first the principles on which it is based, and then practical instructions to obtain the fix, including just one example as he considers the process "so simple and short in its calculations, which are frequently used by anyone who navigates" (Montojo, 1864, p. 61).

*Figure 4. First page of the article by Montojo inserted in El departamento in 1864.*

Núm. 2. Lunes 29 de Febrero de 1864. Año I.

EL DEPARTAMENTO.

REVISTA CIENTÍFICA DE MARINA.

**Nuevo método de situarse en la mar, del capitan de la marina mercante de los Estados-Unidos Thomas H. Sumner. Escrito con arreglo á los conocimientos generales de nuestra marina militar y mercante por el teniente de navío de la Armada, D. José Saturnino Montojo.**

*Introduccion.*

Durante muchos años ha ocupado á los náuticos con preferencia á cualquier otro, el problema de determinar la longitud en la mar como el de más dificultad é importancia; hoy la perfeccion de los relojes que salen de las acreditadas fábricas de Losada, Johannsen y otros artistas no ménos hábiles, permite obtener con toda seguridad esta coordenada siempre que se conozca igualmente la hora á bordo.

La determinacion de esta hora exige el cálculo de un horario de un astro cualquiera por medio de su declinacion y altura, y la latitud del observador.

El primero de estos elementos se obtiene con gran exactitud en el almanaque náutico que se publica en el Observatorio de Marina de San Fernando cualquiera que sea el astro; no así su altura ni la latitud del observador que están siempre sujetas á errores más ó ménos considerables y que en la mayor parte de las circunstancias influyen considerablemente en la determinacion de la hora á bordo.

Sabido es de todo el que navega que, para que estos errores sean los menores posibles, hay que observar al astro en el momento en que corta al vertical primario, circunstancia que no siempre puede llenarse.

Resulta, pues, que para obtener un buen punto en la mar con los métodos que hasta hoy se conocen, es ne-

1864: Francisco Fernández Fontecha (1835-1886) published his addition to the *Tratado de Pilotage* by Gabriel Ciscar. In this case, what stands out is the absence of any reference to Sumner's line.

This fact is specially relevant as this work was formally declared a textbook for Spanish Nautical Schools[8]. It is very significant that 21 years after the publication of Sumner's book, Spanish seamen still did not have any knowledge of such a useful method when they finished their formal school training.

1865: Cecilio Pujazón (1833-1891) published in *El Departamento*, some reflections on Montojo's paper with the aim of correcting some conceptual errors he had detected and which, at the same time, he removed from Sumner's invention.

1873: Antonio Terry (1838-1900) published his *Manual del navegante* (Fig.5), a work dedicated to professionals, that was also used as a textbook in some Spanish Nautical Schools (Ricart, 1877, p. 228). In a small volume, the author compiled the most necessary elements to obtain the position at sea. This was the first book that included the Sumner line of position to which Terry devoted seven pages (Terry, 1873, pp. 177-183). He gave practical rules for obtaining the fix illustrated with an example, and concluded by reporting other utilities of the method. There were further reprints of this work (1875, 1897 and 1900), which in 1875 was recommended by the Ministry of the Marine to the officers of both navies (military and merchant)[9].

*Figure 5. Title page of the Manual del navegante (1873) by Antonio Terry*


MANUAL

DEL NAVEGANTE

D. ANTONIO TERRY Y RIVAS,

BARCELONA.

1873.

1875: The two volumes of the *Curso de astronomía náutica y navegación* by Francisco Fernández Fontecha, were published. Just like the previous work by the same author, this one has the added value of having been used as an official textbook (Ibáñez, 1997). A 9-page chapter is devoted to Sumner's method (Fernández Fontecha, 1875, II, pp. 304-313), following the same structure (explanation, practical rules, example …) as Terry's *Manual*, on which Fontecha most probably was based.

1877: The method developed by the French navy officer Marcq Saint-Hilare was introduced in Spain through the magazine *Anuario de la Dirección de Hidrografía*.

1879: During the years that J. Ricart supported the *Revista Marítima*, he inserted several articles in it. In the one titled: "Método de Sumner. Determinación numérica del punto de intersección de los paralelos de alturas iguales", he discussed a method due to J. Galí for obtaining analytically the intersection point of the Sumner lines, although Ricart advocated the use of the graphic procedure. The main interest of this work lies in the fact that it proves that the "new navigation" had taken root: there were not only numerous scientists but also modest sailors who, even with a limited mathematical knowledge, undertook the study of the new methods, trying to improve the accuracy of the results obtained.

1880: The second edition of the *Curso de astronomía náutica y navegación* by Fernández Fontecha was published. This 1880 edition (there were further editions of this work in 1891, 1897, 1904 and 1906), which was the last one published in the author's lifetime, was structured in three volumes but no other significant change was made.

1883: Ramón Estrada (1852-1927) published a thorough study of St. Hilaire's method in the *Revista General de Marina*.

1883: Miguel González Aveño (1848-) in his *Compendio de navegación astronómica* devoted the 6th chapter to the simultaneous finding of the ship's position by the observation of two celestial bodies' altitudes (González Aveño, 1883, pp. 163-193). This chapter was divided into two articles: the first one on the graphic methods which provide an approximate solution; and the second one on the accurate solution by means of mathematical calculations. The Sumner line is dealt with in the first article in a four-page section describing the method in a general way. Aveño concluded that the procedure is simply a conditional method which, as it offers no absolute guarantee of safety, cannot be accepted with confidence in complicated situations.

In 1876, González Aveño had been appointed as a teacher of "Cosmography, Piloting and Manoeuvring" at the Nautical School of Valencia (AGMEC). His work is, among those considered, the first one published after the intercept method of St. Hilaire became known in Spain. González mentioned it in a foot note, and these few lines are enough to realise not only that he did not quite understand it, but also his disdain towards a method he considered to be only an approximate solution.

1885: Ramón Estrada published his *Lecciones de Navegación* which was meant to be, according to its title page, a textbook at the Floating Naval School. Estrada's work stands out as the first of the essays analyzed that does not deal with the Sumner line in an isolated way. He included it within the general theory of the new navigation methods (Estrada, 1885, pp. 661-711), in which he paid major attention to St. Hilaire's line of position.

1888: Antonio Perea, in his generic *Guía práctica del oficial de marina* devotes only 16 pages to "Astronomy and Navigation" (Perea, 1888, pp. 354-369), setting forth in the last 4 pages the way of fixing the ship's position by Sumner's method.

1895: The last decade of the nineteenth century was characterised by the publication of several articles and monographs10 about the new navigation. Among them, special mention should be made of the *Nueva navegación astronómica en los buques rápidos* by José Ricart. He established the principles on which the new methods started by Sumner are based, pointing out that Sumner's "lucky inspiration" caused "a true revolution in the methods for finding the geographical position of the ship at sea" (Ricart, 1895, p. 19). Nevertheless, Ricart treated the Sumner line from a historical perspective and even used the concept of St. Hilaire's method in explaining Sumner's, in order to facilitate its comprehension.

## 7. CONCLUSION

The Sumner line of position is credited with being the major achievement that took place during the nineteenth century in the field of astronomical navigation. Once its usefulness at sea had been demonstrated, the method was improved and the general theory of celestial position lines was developed, so Sumner's discovery became a landmark in the progress of this field.

First adopted by the U.S. fleet, the method spread–although at different rates–among the sailors of all nations, because of its interest for the practice of navigation, and fostered by the international character of the profession.

In Spain, during the nineteenth century, the development of navigation –like that of the rest of the scientific and technical disciplines– was, to a great extent, the reflection of the political instability which characterised the period. As a consequence, the diffusion of the methods of the new navigation was delayed.

Indeed, although news of Sumner's method was first given by Navarro in the review *Crónica Naval de España* in 1855, the new navigation method was not set forth until 1864, when Montojo published his work on this subject in two journals (*El Departamento* and *Anuario de la Dirección de Hidrografía*), both with off-prints, in which the author admitted that the procedure was already commonly used by many Spanish navigators. The first book that deals with the Sumner line was the *Manual del navegante* by Terry, published in 1873. In 1877, St. Hilaire's intercept method was made known in Spain thanks to an article inserted in the journal *Anuario de la Dirección de Hidrografía*; and, in 1885, Estrada was the first author to include it in a textbook.

Thus, it can be concluded that, after its utilisation at sea, the Sumner line (1843) made known in Spain through nautical journals (1855/1864), to be finally included, with a marked delay, in handbooks and treatises on navigation (1873/1875).

On the other hand, the late introduction of the Sumner line contrasts with the early diffusion of St. Hilaire's method (1877), and this fact shortened in Spain the useful lifetime of Sumner's method.

As for the way in which the Sumner line is explained, it can be observed how, in the lapse of 40 years, it is first considered in an isolated manner, then it becomes assimilated within the general theory of celestial lines of position, to finally become history.

Likewise, it is worth noting that in the sphere of training, the new generations of merchant marine officers were deprived of the benefits of celestial lines of position because there was no reference to them in the textbooks used in the Spanish Nautical Schools, until the publication of the works of Terry (1873) and Fontecha (1875).

It must be underlined that the originality of Sumner's method was questioned in Spain. Indeed, the only merit conceded to it by some authors11 was that it required shorter and simpler calculations than methods presented previously. And some other authors, such as Miguel González Aveño12, as late as 40 years after the publication of Sumner's discovery, even considered it to be a conditional method on which navigators could not rely. Antonio Terry13 saw certain analogies between the Sumner line and an original method explained in 1803 by the Spaniard Gabriel Ciscar (1760-1829)14. Terry's comment was soon distorted in a highly chauvinistic style: "Permit us to claim for Spain the honour and the glory of having introduced the use of graphic methods, since commandant Terry says [...] it was Gabriel Ciscar who, many years earlier and in his *Arte de Pilotaje*, invented the method which would later be known as Sumner's" (Anonymous, 1895, p. 386).

At present, however, the importance of Sumner's discovery is widely recognised. It is worth mentioning the homage paid to Sumner by the Spanish essayist Luis de Ribera (1867-1936) who pointed out: "Illustrious scientists later developed Sumner's coarse discovery; but that does not lessen his glory which at one time would have been sufficient to write his name with golden letters on Small's Light" (Ribera, 1935, p. 549).

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## NOTES

1 Biographical sketch taken from Richardson, 1946.

2 A small sailing ship of scarce 400 tonnes and 35 m. in length, built in Duxbury (Massachusetts) in 1832. See, e.g.: Duval, 1961, or Smiley, 1961.

3 As quoted in Gelcich, 1889, p. 217.

4 Nevertheless, Brandenburg and Hugon (1965, p. 460) assert that A. Fasci claimed to have been the first one talking in France about the lines of position of the new astronomical navigation.

5 The reviews: * *Anuario de la Dirección de Hidrografía* (Madrid), reviewed from 1863 to 1880; * *Crónica Naval de España* (Madrid), reviewed from 1855 to 1860; * *El Departamento* (San Fernando), reviewed from 1864 to 1865; * *Revista General de Marina* (Madrid), reviewed from 1877 to 1900; * *Revista Marítima* (Barcelona), reviewed from 1877 to 1881.

6 The reviewed books have been selected from the catalogue by Llabrés Bernal (1959).

7 The technical aspects of Sumner's method are not the main concern of this article. Therefore, it has been deliberately avoided to provide, when not necessary, a thorough description of the contents of the works listed below.
8 By Real Orden of 5th november 1864.
9 By Real Orden of 20th march 1875.
10 Apart from the one quoted here, some others can be mentioned, e.g.: Gelcich (1893) or Barreda (1897).
11 See, e.g.: Pujazón (1865, p. 74) or Terry (1873, p. 178).
12 See González Aveño (1883, p. 169). The author's position in this matter did not change eventually as he showed in: González Aveño, 1904, p. IV.
13 This author manifested it several times. See, e.g.: Terry, 1894, p. 1.
14 Ciscar (1803, vol. 4, pp. 144-145) explained how to determine the longitude at the time of obtaining the latitude by the so-called "problem of Douwes". Using two altitudes of a celestial body, fixing the point required the use of four supposed latitudes and the calculation of four hour angles (two for each observation). The analogies between Ciscar's method and that of Sumner lies in the fact that both allowed the simultaneous obtention of the two geographical coordinates and the analogy of the elements to be analitically calculated.

## **APPENDICE:** TRANSFERENCIA DE CONOCIMIENTOS NÁUTICOS DE LOS EEUU A EUROPA EN EL SIGLO DIECIMUEVE. EL CASO DE LA RECTA DE ALTURA SUMNERY SU INTRODUCCIÓN EN ESPAÑA.

Al estudiar el progreso de la náutica en el siglo XIX, se encuentra un descubrimiento trascendental que marca el inicio de lo que la mayoría de autores coinciden en denominar "nueva navegación astronómica". El Capitán de la Marina Mercante de los Estados Unidos, Thomas H. Sumner (1807-1876), descubrió casualmente, en 1837, un procedimiento con el que, por primera vez, podían obtenerse simultáneamente las dos coordenadas geográficas (latitud y longitud) de la situación del buque, de forma sencilla y breve. Sumner dió a conocer su método en Boston, en 1843, con la publicación del folleto titulado *A new and accurate method of finding a ship's position at sea, by projection on Mercator's chart.*

El método de Sumner se propagó de forma desigual. Su uso se generalizó inmediatamente entre los marinos norteamericanos, gracias a Matthew F. Maury (1806-1873), por entonces director del Servicio Hidrográfico de Washington, quien, en octubre de 1843, escribió a Sumner: "Vuestro método puede considerarse como el principio de una nueva era en la navegación práctica. Se han dado órdenes para que todo buque de la marina se provea de vuestro folleto".

Según reseña García Franco, el nuevo método fue conocido en Europa por medio del *Nautical Magazine*, en 1844; por un artículo que en 1847 publicó en Francia el marino Barther, en *Annales Maritimes*, y por el alemán Henry A. Tobiesen, que lo tradujo a este idioma en 1855. En España, continúa García Franco, fue difundido, en 1865, por el entonces teniente de navío Montojo, aunque Quijano lo había ya utilizado, y dado noticias sobre el mismo en 1857. En línea con este autor, Arroyo presenta de forma idéntica la introducción en España del método de Sumner.

Sin embargo, examinando revistas de la época, encontramos que el trabajo de J. S. Montojo, había sido insertado en *El Departamento* y en el *Anuario de la Dirección de Hidrografía*, en el año 1864, así como que casi una década antes, en 1855, *Crónica Naval de España* había publicado la traducción que hizo J. J. Navarro de la primera edición de la obra de Sumner.

Esto despertó nuestro interés por conocer la forma en que el comienzo de la nueva navegación astronómica se extendió en España. Con este fin, se han examinado, en orden cronológico, los artículos publicados en: *Anuario de la Dirección de Hidrografía*, *Crónica Naval de España*, *El Departamento*, *Revista General de Marina*, y *Revista Marítima*; así como las obras de autores españoles, representativas de la segunda mitad del siglo XIX, seleccionadas a partir del catálogo de Llabrés Bernal (1959).

El descubrimiento de Sumner supuso el inicio de los modernos métodos geométrico-analíticos para el cálculo de la situación del buque, por medio de los cuales, con la ayuda de un cronómetro de confianza y la altura de un astro, tomada en cualquier instante, se obtiene una línea de posición que se traza como una recta en la carta mercatoriana. Con dos alturas, se obtienen dos rectas cuya intersección determina el punto donde se encuentra el buque. Esto satisfizo los deseos de los marinos, necesitados de una solución sencilla y breve para la determinación simultánea de la latitud y la longitud, sin tener que observar en momentos determinados.

Aunque inicialmente la originalidad del método de Sumner fue muy discutida, la importancia del mismo propició su rápida propagación, despertando el interés de marinos e investigadores. En corto espacio de tiempo, el procedimiento inicial fue perfeccionado, desarrollándose la teoría general de las líneas de posición de altura. En este proceso, destaca la intervención de Marcq Saint-Hilaire, quien en 1875 dio a conocer la recta de altura que lleva su nombre, habiendo llegado su método hasta nuestros días como el más indicado.

En el caso de nuestro país, la tardía introducción del trabajo de Sumner (1855), contrasta con la rápida difusión de la tangente Marcq (1877), lo que hizo que la vigencia de la secante Sumner fuera especialmente breve.

Asimismo, es particularmente curioso que en 1864, asumido como el año de la difusión general del procedimiento de Sumner en España, llevada a cabo por J.S. Montojo, fuera ya de uso común entre muchos de nuestros marinos, como el propio autor reconoce.

También destaca el hecho de que en el ámbito docente las nuevas generaciones de marinos mercantes fueran privadas de los beneficios del método por no hablar de él los textos utilizados en las Escuelas de Náutica, hasta la publicación de los trabajos de Terry (1873) y Fernández Fontecha (1875). En este sentido, sorprende que, tan tardíamente como 1883, un profesor de pilotaje, como lo era González Aveño, se mostrara poco partidario de los nuevos métodos, por considerarlos poco fiables.

Como resumen final del análisis cronológico efectuado, constatamos que, tras ser utilizada en la mar, la recta de altura de Sumner fue difundida a través de revistas marítimas, para, finalmente, ser incluida en manuales y tratados con notable retraso. En cuanto a la forma en que el procedimiento es expuesto, se observa cómo, en el transcurso de cuarenta años, pasa de ser contemplado de forma aislada, a ser difuminado en la teoría general de las rectas de altura, para, por último, convertirse en historia.

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Kroneberg, A. (1999) Preparing for the future by the use of scenarios: innovation shortsea shipping, Proceedings of the 1st International Congress on Maritime Technological Innovations and Research, 21-23 April, Barcelona, Spain, pp. 745-754.

<u>Technical Reports</u>
American Trucking Association (2000) Motor Carrier Annual Report. Alexandria, VA.

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Aguter, A. (1995) The linguistic significance of current British slang. Thesis (PhD).Edinburgh University.
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