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METHODS FOR TREATING BALLAST WATER

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Abstract

A vessel sailing with ballast, or partially loaded, must use its ballast tanks, water currently being the most commonly used medium. An estimate of over 10,000 million tonnes of ballast water is transferred in the entire world each year, transporting 4,000 species of aquatic organisms a day. The most immediate way to confront this problem consists in taking measures on board the vessel through the appropriate treatment of ballast water. Facing the importance of this problem, the International Maritime Organization (I.M.O.) has developed the International Convention for the Control and Management of Ship's Ballast Water and Sediments (BWM-2004), at the moment pending approval. In summary, the Convention obliges members to the "what" but not to the "how", recommending the exchange of ballast water by a "reballasting" method, technique which is not 100% effective. For this reason, important research efforts are being carried out throughout the world dedicated to finding a system that is 100% effective. The main methods currently being studied are the mechanical, physical and chemical ones.

Keywords: Vessel, Ballast, Waters, Contamination, Bioinvaders.

INTRODUCTION

As we know, vessels are designed and built to travel through water carrying the biggest possible amount of cargo and/or passengers. Hence, if a vessel travels with ballast or partially loaded, it must fully or partially fill its ballast tanks so that it can sail in good conditions of stability and safety.

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Water is the ideal ballast as it is an almost inexhaustible resource, which can be easily and cheaply obtained and, given that it is a liquid, it adapts to the shape of any tank. This turns it today, into the most commonly used medium for ballast.

It is estimated that over 10,000 million tons of ballast water are transferred worldwide per year. Each vessel has the capacity to transport from several hundred litres up to 100,000 tons of ballast water, according to the dimensions and purpose of the ship.

Ballast water is loaded at the source port to be discharged at the destination port, sometimes thousands of miles away, which has given rise to an involuntary introduction of exotic organisms (bioinvaders) in diverse areas of the world. In some places these organisms have managed to establish themselves, many times displacing the native species, with the consequent danger of causing zoological contamination. The invader species are a direct cause of 39% of all known extinctions as well as for the loss of biodiversity.

An estimate of over 4,000 species of aquatic organisms, in all their life cycles, are transported daily by ballast water in the entire world.

The studies fulfilled indicate that, normally, less than 3% of the species transported are able to establish themselves in the new regions. However, even if only one species is successful, it could seriously damage the entire food chain, the local ecosystem and their economies.

The most immediate way to confront this problem consists in taking measures on board the vessel through the appropriate treatment of ballast water.

Facing the importance of this problem, the International Maritime Organization (I.M.O.) has developed the International Convention for the Control and Management of Ships Ballast Water and Sediments (BWM-2004), on 13th February 2004 in London, with the participation of 74 countries.

This Convention will enter into force twelve months following the date in which it has been ratified by at least 30 states whose combined merchant fleets do not represent less than 35% of the world merchant shipping gross tonnage (GT). It will be applied, with a few exceptions, to all "ships" –be they of whichever type– operating in the aquatic medium, including the submersibles. However, said Convention, in summary, obliges members to the "what" but not to the "how" given that it recommends the exchange of ballast water through the "traditional" or "reballasting" method, technique that is not 100% effective, until an alternative is found and developed that is 100% effective.

Significant research efforts are being carried out by several scientific institutions around the world, determined to find the integral solution to the problem.

The main methods currently considered include:

— The mechanical ones (filtration, reballasting, dilution and cyclonic separation).

— The physical ones (ultraviolet, heat, ultrasonic, and copper and silver ion).

— The chemical ones (disinfectants and biocides).

The chemical treatments, oxidizers of the organic matter such as, for example, chlorine, are discarded for their use since the waters thus treated preserve a certain biocide nature that could subsequently affect other species. In addition, these can give rise to organochlorine compounds of a toxic and carcinogenic nature.

These methods are, therefore, excluded from our study.

METHODS

Mechanical treatment

Filtration

Filtration of ballast water while it is being loaded on board would enable the removal of large particles such as algae, yet it would not prevent microscopic organisms from being loaded. Residues would be left in the zone of ballast intake, but the cost necessary for this infrastructure could be very high.

Reballasting

The most natural method to avoid contamination would be to exchange the ballast water in deep waters, with sounds of 2,000 metres or more. This is considered to be the most efficient method to minimize the risk of transferring unwanted species. The deep water zones of the oceans contain few organisms, which furthermore have few possibilities of surviving when transferred to coastal or fresh waters.

In all cases, it is crucial to avoid surface waters, dredging operation zones and the zones known to have outbreaks of diseases or of plankton.

The main problem existing with reballasting, in terms of avoiding foreign species, is the difficulty to treat the sediments at the bottom of the tanks. If, when emptying a tank, we do not ensure that no sediments are left behind, then the operation is only successful in diminishing the number of species contained in the water, but it still holds the possibility of contaminating the water at destination. It is even well-known that some species proliferate when fresh water is loaded, making the problem worse rather than solving it.

Dilution

According to I.M.O. recommendations, the flow-through dilution method will be conducted in open sea by pumping ballast water into the tank and allowing the water to overflow, pumping at least three times the total volume of the tank. Since the water is introduced and discharged from the tank at the same time, this method does not entail significant risks as regards the stability of the ship, as there will always be enough water in the ballast tanks, even though it does entail the risk that the organisms not be entirely expulsed.

Theoretically, it would be ideal for the environment if at least 95% of the water in a tank were exchanged.

Cyclonic separation method

Ballast water enters the chamber with a circular flow, passing through the venturi-type passage found between the interior chamber and the separation chamber, with a centrifugal action. The centrifuge helical action propels the particles towards the wall and moves them towards the sediments chamber, going through the clean water towards the exit tube. The sediments are continuously purged through the sediments return pipe.

Some simple controls regulate the flow balance between the clean water and the sediments, and measure the ship's draft, as well as the pressure system to ensure an adequate discharge of mud into the sea. The descent of the pressure is minimal and only 5% or less of the ballast water flow is discharged with the mud.

Physics

Ultraviolet radiation

The effect varies according to the type of organism as some are very resistant to UV radiation, yet it can be very efficient when combined with filtration. It has no toxic or harmful secondary effects for the tubes, pumps or linings.

Ultraviolet radiation produces alterations to the DNA chains of the cells. Exposure to this radiation interrupts the normal replication of these chains and the organisms die or are left inactive.

A problem with this system involves the sediments in suspension. The clarity of the water, the period of exposure, and the energy of radiation exposed, are three factors that must be taken into account when using an ultraviolet radiation plant. These factors can be modified to treat large volumes of water fast and safely.

The treatment of ballast water with ultraviolet radiation requires the water flow to go through a treatment chamber in order to proceed to the disinfection of microorganisms. The treatment chamber must be placed in the water supply pump, between the first filtration system and the ballast tanks of the ship. An additional space on board is required for the control and power tapping used by this technology.

In order to compensate the turbidity of the water, a self-retracting system is placed to continuously adjust the radiation as a way to keep the system running and predetermine the level of radiation.

Ballast water heating technique

Temperatures higher than 40ºC during 8 minutes are mortal for practically all organisms. The ability to reach this temperature depends on whether sources of heat can be made available on board to treat the ballast water during the journey.

The development of heat treatment technologies has enabled their use in the battle against the *zebra mussel.* Heating the water to temperatures of 36º to 38ºC during 6 hours kills the *zebra mussels* and the *Dreissena polymorpha*, which were developed during the end of the 1908s and, subsequently, contributed the bases for using these technologies in the treatment of ballast water.

The Australian Quarantine and Inspection Service (A.Q.I.S.) studied the efficacy of this technology on dinocysts contained in ballast water, coming to the conclusion that the cost of the energy necessary for its effectiveness would be exorbitant. This study has given rise to some alternatives to the direct use of heat in the treatment of ballast water inside the tanks. One of them is to use the residual heat arising from the main floor of the ship, connecting heat exchangers to the main engine. This yields big advantages regarding cost and energy consumption, but requires the reorganization of the entire internal pipe system of the ballast tanks. The latest studies suggest that placing heat exchangers within the ballast tanks themselves would be the best option.

The main factor to take into account regarding the efficacy of the system over possible bioinvaders is the time of exposure and the water temperature inside the tanks.

Ultrasonic

The ultrasonic treatment for liquids utilizes high frequency energy to cause a vibration in the liquid.

When the liquid becomes exposed to these vibrations, a physical phenomenon known as cavitation is produced consisting of the formation, expansion and implosion of microscopic gas bubbles in the liquid. As the ultrasonic energy enters the liquid, the gas bubbles grow until they reach a critical size and implode.

When such cavitation is sufficiently intense, it tears the cell membranes, liberating particles over the solid surface and destroying the organisms by collisions among the particles.

One of the influential parameters when using this technology regards the pressure in the interior of the tanks, the optimum one being 70 PSI.

Electrolytically generated copper and silver ions

Its efficiency rate is considered to be very high, but some organisms can increase their tolerance to the elevated concentrations of copper and silver making their utilization useless. It is also important to consider the environmental consequences of having concentrations of these elements in the water.

Due to these serious inconveniences this system has been discarded for its application.

COMPARING UV, HEAT AND ULTRASONIC TECHNOLOGIES

Each one of these three technologies is capable of treating the ballast water on board the merchant ships efficiently, with or without prefiltration. The first difference among them is the status of the technology applied and the operating conditions necessary to render the disinfection fully successful. As can be seen, the comparison among these technologies as regards their cost, benefits, advantages and disadvantages is complex.

A table is shown below detailing the factors to be taken into account regarding the efficacy of the three technologies of this study:

Table I.

Factor Being Evaluated	Ultravioleta	Heat	Ultrasonic
BIOLOGICAL EFFECTIVENESS	XXX	XXX	XXX
SPACE	XX	XXX	XX
ENERGY	X	XXX	XX
CHANGES	XX	XXX	XX
MAINTENANCE	XXX	XX	XX
SKILLS AND TRAINING	XXX	XX	XXX
TECHNOLOGY DEVELOPMENT	XXX	XX	X
COSTS	XX	XX	XXXX
SAFETY	X	XX	X
Keys: Low: X Moderate: XX High: XXX Very High: XXXX			

Self-elaborated

CONCLUSIONS

1. No method or system in use today, included those commonly used on board the ships, can entirely prevent the zoological contamination by ballast waters.
2. Most of the techniques currently existing designed specifically for treating ship's ballast water, require a change in the structural design of the ship for their installation on board.
3. The IMO has developed and sent a series of voluntary guides that are currently being used. These guides encourage us to minimize the introduction of unwanted aquatic organisms through maritime transport. At present, the best option for minimizing the introduction of bioinvaders is the reballasting and dilution method, technique recommended by the I.M.O.
4. The systems to treat ballast water on board the ships could provide more flexibility at the time of operating them with respect to those placed on land.

   The experiences derived from the treatment plants of residual waters on land provide the working principle of the plants on board the ships. However, the operational capacity associated to the use of the ships, including the high flow of water and sediments of the ballast pumps, impose additional demands of the systems.

5. The management of ballast waters on a world scale demand, hence, a feasible and economical method that may perhaps be achieved by combining a mechanical treatment with a physical one.

   The most promising technologies to ensure the success of ballast treatment are the physical separation techniques. Filtration could displace all the materials of a given size, at the same time displacing many unwanted organisms from the ballast water. The installation of a pre-filtering system would be of 250 µm. The heat treatment technique is potentially acceptable as an alternative to filtration in the treatment of ballast water.

6. Further research will be necessary to establish, more efficiently, the mortality dose at critical temperatures as well as the time necessary to produce an acceptable mortality in ballast water organisms. An improvement in the equipment design is also essential in order to enhance the implementation of these on board the ships.

7. The ultraviolet radiation and acoustic techniques for treating ballast water have proved to be not entirely effective for treating a wide number of organisms, especially on board the ships.

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MÉTODOS PARA EL TRATAMIENTO DE AGUAS DE LASTRE

Un buque que navega en lastre o parcialmente cargado, debe usar sus tanques de lastre, siendo en la actualidad, el agua el medio más comúnmente utilizado como lastre. Se calcula que en todo el mundo se transfieren más de 10.000 millones de toneladas de agua de lastre cada año transportando 4.000 especies de organismos acuáticos al día. La forma más inmediata de afrontar este problema, consiste en tomar medidas a bordo del buque por medio del apropiado tratamiento del agua de lastre. Ante la importancia de este problema, la Organización Marítima Internacional (OMI) ha desarrollado el Convenio Internacional para el Control y la Gestión del Agua de Lastre y los Sedimentos de los Buques (BWM-2004), estando pendiente de aprobación. Aunque dicho Convenio, en resumen, recomienda el cambio de agua de lastre por el método de "relastrado", técnica que no es efectiva al 100%. Por ello están siendo realizados significativos esfuerzos de investigación, en todo el mundo, para encontrar un sistema efectivo al 100%. Entre los principales métodos considerados actualmente figuran: Los mecánicos (filtrado, relastrado, dilución y separación ciclónica); Los físicos (ultravioleta, calor, ultrasónico, e ión de cobre y plata); Los químicos (desinfectantes y biocidas). Los tratamientos químicos, oxidantes de la materia orgánica, como, por ejemplo, el cloro, están desechados para su uso ya que las aguas así tratadas conservan cierto carácter biocida que podría afectar posteriormente a otras especies. Además de que pueden dar lugar a compuestos organoclorados de carácter tóxico y cancerígeno.

METODOS

Mecánicos

Filtrado, Relastrado, Dilución y Separación Ciclónica

El filtrado del agua de lastre permitiría, a medida que se carga a bordo, eliminar grandes partículas pero no impediría la carga de organismos microscópicos.

El relastrado es el método más natural para evitar la contaminación sería realizar el cambio del agua de lastre en aguas profundas. Este se considera el método más eficaz para minimizar el riesgo de transferir especies no deseadas. El principal problema que tiene el relastrado, en términos de evitar las especies foráneas, es la dificultad de depurar los sedimentos del fondo de los tanques.

Según las recomendaciones de la OMI, el método de dilución por rebose se realizará en alta mar, introduciendo agua con las bombas de lastre y permitiendo que ésta rebose por la cubierta, al menos tres partes del volumen total del tanque. Como el agua es a la vez introducida y sacada del tanque, este método no conlleva riesgos significativos en cuanto a la estabilidad del buque, aunque esto conlleva el riesgo de que los organismos no sean totalmente expulsados.

Con la separación ciclónica el agua de lastre entra en el interior de la cámara con un flujo circular, atravesando con una acción centrífuga el pasaje tipo venturi que se encuentra entre la cámara interior y la cámara de separación. La acción helicoidal centrífuga propulsa a las partículas hacia la pared y las desplaza hacia la cámara de sedimentos, atravesando el agua limpia hasta el tubo de salida. Los sedimentos son continuamente purgados a través de la tubería de retorno de sedimentos.

Físicas

Radiación Ultravioleta, Calor, Ultrasónica e Iones de cobre y plata

Cada una de estas tecnologías es capaz de tratar el agua de lastre a bordo de los buques comerciales con efectividad, con o sin prefiltrado. La primera diferencia entre ellas es el estatus de la tecnología aplicada y las condiciones de operatividad necesarias para tener éxito en la desinfección.

El efecto varía según el tipo de organismo ya que algunos son muy resistentes a la radiación UV, pero puede ser muy eficaz combinado con el filtrado.

La radiación ultravioleta produce alteraciones en las cadenas de ADN de las células. Una exposición a ésta, interrumpe la replicación normal de estas cadenas y los organismos mueren o quedan inactivos. Un problema de este sistema es el de los sedimentos en suspensión. La claridad del agua, el periodo de exposición, y la energía de radiación expuesta, son tres factores a tener en cuenta a la hora de utilizar una planta de radiación ultravioleta.

Las temperaturas superiores a los 40ºC durante 8 minutos son mortales para prácticamente todos los organismos. El poder alcanzar esta temperatura depende de que se pueda disponer de fuentes de calor a bordo para tratar el agua de lastre. El principal factor a tener en cuenta con vista a la efectividad del sistema es el tiempo de exposición y la temperatura de agua dentro de los tanques.

El tratamiento ultrasónico para líquidos utiliza energía a alta frecuencia para causar una vibración en el líquido. Cuando el líquido se ve expuesto a estas vibraciones se produce el fenómeno físico conocido como cavitación. Conforme la energía ultrasónica entra en el líquido, las burbujas de gas crecen hasta llegar a un tamaño crítico implosionando o cuál rompe las membranas celulares destruyendo los organismos.

Con Iones de cobre y plata generados electrolíticamente se consigue una efectividad muy alta, pero algunos organismos pueden aumentar su tolerancia a las concentraciones elevadas de cobre y plata haciendo inútil su utilización. También hay que valorar las consecuencias ambientales de las concentraciones de estos en el agua.

CONCLUSIONES

Ninguno de los métodos utilizados hoy en día puede prevenir totalmente la contaminación zoológica por las aguas de lastre.

La mayoría de las técnicas diseñadas específicamente para el tratado del agua de lastre en los buques existentes en la actualidad, requieren una modificación del diseño estructural del buque para poder ser instaladas a bordo. Además los sistemas a bordo de los buques para el tratamiento del agua de lastre podrían dar a éstos mayor flexibilidad a la hora de su manejo con respecto a los situados en tierra.

Actualmente, la mejor opción para minimizar esta introducción es el método de relastrado y dilución, que es el recomendado por la IMO.

La gestión de las aguas de lastre requiere, pues, un método factible y económico, que quizá pueda lograrse combinando un tratamiento mecánico con otro físico.

Las tecnologías más prometedoras para el éxito del tratamiento de lastre son las técnicas de separación física. La filtración podría desplazar todos los materiales de un determinado tamaño, a la vez que desplaza muchos organismos indeseables del agua de lastre. La instalación de un sistema de prefiltrado sería de 250 µm. La técnica de tratamiento por calor es potencialmente aceptable como alternativa a la de filtrado en el tratamiento del agua de lastre.

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GLOBAL MARITIME SECURITY: THE ROLE OF SPAIN AS A PORT STATE

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Abstract

Since the year 2001 in the Maritime World, two kinds of concept have emerged out of the common root: safety and security. In this paper we will first analyse the international situation and the preventive agreements reached since 9/11 under the auspices of the International Maritime Organisation (IMO), and then consider the role of a State such as Spain, seeking conclusions that can be generalised to other western countries of the European grouping. Finally, and based on certain experiences in respect of Port State Control, we will discuss the real effectiveness of the measures that appear today to be accepted.

Keywords: Maritime Security, Terrorism, Port State Control, Spain.

INTRODUCTION

A semantic or media question?

In the Spanish language one single word "seguridad" encompasses two English terms that are similar but have different associations: "safety" and "security". In respect of maritime language, people have always spoken of the "safety of life at sea" (as in the SOLAS Convention). "Security" has been a term that has been associated with maritime legislation only since the tragic terrorist attacks of 11 September 2001. In fact it was necessary to assimilate into Spanish a term different from that of

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"seguridad" to convey the semantic content of the word "security": that term was "protección", which was used in the Spanish version of the International Ship and Port Facility Security Code (ISPS). In an editorial piece in a maritime journal, published shortly after the events in New York, it was said: "A reasonable definition of security might be that it is a sub-set of safety, where the perceived risk is seen to arise from person or persons with criminal or malevolent intentions. In maritime transport our experiences of breaches of security have been concerned with mainly domestic issues such as cargo theft, stowaways, piracy etc." In a certain way we can say that, since the year 2001 in the maritime world, two kinds of concept have emerged out of the common root of "seguridad"; these have resulted, in the case of their application to ships, in two codes of management: the already existing International Safety Management Code (ISM) and the new ISPS code, duplicating the tasks in an ISM Officer and an ISPS Officer, although in practice, in most ships, responsibility for both rests with the same figure of the Chief Officer; similarly, for safety and for security, there are two plans, two audits and two records.

As we shall see in this article, after five years, this need for duplication is not so much real as for propaganda purposes, to demonstrate to the public, via the communications media, that actions are being taken to defend us against International Terrorism. But everything that runs counter to these policies is being criminalised, and a type of policy is being defended that effectively expands the predominance of the USA in the world, as has already been argued in previous papers (King, 2005; Stasinopoulos, 2003). This is because the Government of the USA has, to a large extent, unilaterally imposed not only the cost-benefit analysis of this dual attribution of safety and security, but also the analysis of the real likelihood of these risks and the preventive efficacy achievable by implementing these measures (Banomyong, 2005a).

In this paper we will first analyse the international situation and the preventive agreements reached since 9/11 under the auspices of the International Maritime Organisation (IMO), and then consider the role of a State such as Spain, seeking conclusions that can be generalised to other western countries of the European grouping. Finally, and based on certain experiences in respect of Port State Control, we will discuss the real effectiveness of the measures that appear today to be accepted.

Maritime Security before September 2001

Explicit policies in respect of *Maritime Security* are relatively new in the history of international navigation and maritime transport; although in earlier times ships and sailors always went armed and prepared to defend themselves against all types of threat. But, since the middle of the 20th century, a stable level of safety has been assumed in maritime transport, on which the trading relationships of most countries of the world are based. International concern about security has been growing during the last 40 years, despite relatively few serious events occurring. Only piracy and the assaulting of vessels, which seemed to be phenomena reserved to films and literature at the start of the century, have been considered serious threats to which the IMO itself has given relative priority, especially since the United Nations Convention on the Law of the Sea. Today piracy at sea, carried out systematically, has been concentrated more in particular parts of the Third World, especially in countries like Somalia, Indonesia and Malaysia (Ong-Webb, 2006; Yun Yun, 2007; Birnie, 1987). In any case, acts of maritime piracy should not be considered, to our way of thinking, as acts of maritime terrorism, since the motives for piracy are usually economic in origin, in contrast to acts of terrorism, which are usually intended to pressure Governments in respect of their social, economic or religious policies.

The Ship as a weapon of mass destruction (WMD).

To date, suicide boat attack has been Al Qaeda's preferred method of maritime terror attack (Daly, 2003). Thus in the new 21st century, the two events directly attributed to maritime terrorism, in accordance with the principles established previously, had as their targets two vessels, one military and the other civil: the "Cole" and the "Limburg". Evidence has also been found of unspecified actions planned to attack US and British warships as they passed through the Strait of Gibraltar (Nincic, 2005; Gottschalk et al., 2000; Burnett, 2002).

However the fundamental change in the emphasis on maritime security policies really took place, as we all know, by terrorist attacks that had nothing to do with maritime transport: those that took place on the infamous date of 11 September 2001 in the city of New York. These attacks marked a major turning point in the global concern about terrorism, and this was reinforced by the attacks in 2004 in Madrid and 2005 in London.

It has been since 2001 that much greater emphasis has been placed on security in those places where protection may be weakest, that is, in the various points of admission to a country, on land borders and at seaports and airports, together with the stricter control and inspection of persons and merchandise entering a country. As stated by Donna J. Nincic (2005), a merchant ship could be used as a WMD, either as a weapon delivery system (chemical/biological/nuclear weapons could be hidden on a ship, and primed to detonate), or as a delivery system for both fuel and cargo (traditional or dangerous cargo). This is evident, but the doubt remains the same: with imagination, almost anything can be deemed a potential risk. How can we assess the risk from something which experience has taught us is a harmless tool? What sort of neuroses will we develop if we have to fear everything?

The U.S. measures

The international scenario of the year 2001 allowed the USA to use its military power to manage global affairs and trade (King, 2005). Its hegemonic character has permitted the unilateral establishment of a large number of measures aimed at controlling and preventing terrorist attacks; these have enabled the US to exercise greater control of oceans and sea lanes to achieve its strategic objectives. Therefore critical elements of maritime infrastructure, such as ports, waterways and vessels, are of paramount importance (Stasinopoulos, 2003).

From a new organisation of the US government departments involved, and the creation of the new Office of Homeland Security, a new policy has been designed that has gradually been imposed on maritime transport on the world scale, with the objective, in principle, of limiting terrorist activity in that country; this policy is based on three fundamental proposals:

I. The necessary modification of international regulations, with special incidence in the SOLAS'74 Convention, and in the creation a new International Ship and Port Facility Security Code (ISPS), and the implementation in other states of the philosophy of the US Maritime Transportation Security Act of 2001 (US Cong., 2002, 2003).

II. Putting into action a series of programs intended to detect terrorist threats in the cargo of vessels, especially the "Container Security Initiative" (CSI) program (Willis et al., 2004; OECD, 2005; Cook, 2007).

III. The exhaustive control of all the persons who intervene in the transport of merchandise by sea, including the movement of persons within port facilities.

We can summarise the most important initiatives promoted by the Government of the USA (Dalgaard-Nielsen, 2006):

— Container Security Initiative (CSI).
— Megaport.
— 24 hours Rule.
— Customs - Trade partnership against terrorism (C-TPAT).
— The S.O.S. (Sail Only if Scanned) Act

Many other initiatives are being put into effect in respect of the security of logistic chains, and affect all modes of transport; these include the:

— CIP - Carrier Initiative Program; and, at the private level, the
— SCIA - Super Carrier Initiative Agreement;
— ACSI - Americas Counter Smuggling Initiative;
— BASC - Business Alliance for Secure Commerce.

THE RESPONSE OF THE INTERNATIONAL ORGANISATIONS

IMO Maritime Security Policy

Since its Assembly of 1987, the IMO has been expressing its concern over the danger to passengers and crews represented by the increased acts of piracy and other illicit acts. Its Maritime Safety Committee drew up a series of proposals, although the response of countries was very limited. Shortly after, the Convention for the Suppression of Unlawful Acts against the Safety of Maritime Navigation (SUA) was signed in Rome on 10 March 1988 and entered into force on 1 March 1992 (Roach, 2004; Valencia, 2004).

On 5 July 1996 the IMO, through its Maritime Safety Committee, adopted the circular MSC/Circ.754 on passenger ferry security, which made recommendations on security measures for passenger ferries on international voyages shorter than 24 hours, and for ferry ports. And thus we come to the 22nd Assembly of the IMO, on 20 November 2001, when a new Resolution A.924(22) "Review of measures and procedures to prevent acts of terrorism which threaten the security of passengers and crews and the safety of ships" was approved. The resolutions of this Assembly only one month after the assault of 9/11 crystallised a year later (on 13 December 2002) in a Diplomatic Conference on Maritime Security, which put into effect the following new international instruments: the amendments to the SOLAS Chapter V, with the program for the accelerated implementation of the Automatic Identification System (AIS), the new amended SOLAS Chapters XI-1 "Special measures to enhance maritime safety" and SOLAS XI-2 "Special measures to enhance maritime security", together with the new International Ship and Port Facility Security Code (ISPS). Thus the IMO, only one year after the attacks of 9/11, adopted the philosophy of the Government of the USA in respect of most of the measure on maritime security that the US had unilaterally put into operation (Hesse, 2004; IMO, 2003a-d; Jones et al., 2006, IMO-ILO, 2004).

The reform of Port State Control (PSC)

One of the most controversial rules of the new SOLAS Chapter is that referring to the Inspection of Vessels (Rule XI-2/9), which establishes two regimes: the conventional PSC in port, and the control that can be exercised before the vessel enters port (the new "anti terrorist" regime).

— Traditional PSC regime.

This involves verification of the existence of a valid certificate of security on board the vessel. If it does not have a Certificate, or if there are well-founded reasons for suspicion, the following control measures can be applied: delay or detention of the vessel, restriction of its operations, restriction of movement, and expulsion from the port if there is an immediate threat to persons or goods and there is no other reasonable means of eliminating the threat.

— New regime "prior to entry in port".

The following information is required from the vessel: confirmation of the existence of the International Certificate of Security, and the authority that has issued it; confirmation of the level of security at which the vessel operates, and at which it has operated previously; confirmation of special or additional measures previously adopted; and confirmation of compliance with the security procedures. If there are well-founded reasons for suspicion of non-compliance, the Port State will be able to impose measures: it can demand rectification of the non-compliance; it can demand that the vessel must move to a specified place in its territorial or internal waters; it can inspect the vessel; it can deny entry in port if there are well-founded reasons for believing there is an immediate threat to persons and goods, and there are no other means of eliminating the threat; it can oblige the vessel to notify it of the control measures adopted. There is also a procedure for preventing unnecessary delays to the vessel, and the vessel has the right to indemnity in respect of undue delays or detention.

Bearing in mind that Rule XI-2/9 of the new SOLAS, which stipulates the measures for controlling vessels that are already in port, and for controlling the vessels that intend to enter the port of another State, could provoke conflicts of national interests, the MSC proposed a provisional model for implementation, so that it should be consistent, uniform and harmonised. Thus on 21 May 2004, the Maritime Safety Committee issued the circular, MSC.159 (78), titled "Interim guidance on control and compliance measures to enhance maritime security" (Alcázar et al., 2002; Piniella et al., 2005; Sage, 2005).

THE ROLE OF A PORT STATE

The role of the European Union

The European Economic and Social Committee is one of the bodies of the Union that has shown very clearly its apprehensions on the subject of the "Security of Transport" (EESC, 2002). This body reminded the sadly-deceased Transport Commissioner, Loyola de Palacios, that international maritime transport has become more costly due to the additional maritime security measures; these costs include demands for notification, more frequent inspections, and obligations in respect of escorting by tugs; all this has resulted in an increase in costs and in longer waiting times. The Organisation for Economic Cooperation and Development (OECD) established that the cost of the delays, the administrative work, and compliance related to crossing frontiers now represents 13% of the value of the merchandise involved, compared with 5% previously, and that a further 1% to 3% could be added to those costs in respect of security measures (OECD, 2003). This increase is corroborated by the data from UNCTAD, which estimated an average of 488 million euros per annum spent by each port for operating the ISPS Code (UNCTAD, 2004). Added to this figure are the costs of implementing the security system, which range between 827 million and 1,729 million euros. Investment in equipment accounts for 35% of this cost, infrastructures for 26%, personnel for 14%, training for 8%, and processing costs for the rest. These costs are equivalent to increasing the total charge for international maritime transport by about 1% with respect to the initial cost and by 0.5% with respect to the annual cost, the report explains (Alderton, 2002; Boscke et al., 2003; Barnes et al., 2005; X-Li et al., 2003; Banomyong, 2005b; Dulbecco et al., 2003).

Despite European reservations, all the measures required by the USA at the international level were put into operation in Europe by the Directives of Maritime Security; the first of these was Regulation (EC) Nº 725/2004 of the European Parliament and of the Council, of 31 March 2004, on enhancing ship and port facility security, where the application of the IMO regulation was even extended to passenger ships engaged in national traffic, and belonging to class A, and to their owner companies and to the port facilities that serviced them, and the implementation of this Regulation from 1 July 2007 in all the European States. This made it obligatory to apply a series of dispositions included in part B of the ISPS Code, which at first appeared as guides. Later the Commission Regulation (EC) Nº 884/2005 of 10 June 2005 laid down "Procedures for conducting Commission inspections in the field of maritime security". In 2005 the new Directive 2005/65/CE of the European Parliament and Council, of 26 October, continued the work undertaken by the approval of Ruling 725/2004/CE. The Directive creates the Local Security Committee, and puts emphasis on the importance of security in wheeled traffic entering or leaving port facilities; this affects a large number of automobiles and other vehicles loaded with merchandise, and has the object of ensuring the introduction of adequate security measures for these (Bichou, 2004).

Spain in the global scenario

Spain like the USA has been the victim of a large-scale terrorist attack and, in the case of Spain, the perpetrators also utilised a means of transport: the train. A series of 10 explosions took place on the morning of Thursday 11 March 2004, on the Madrid metropolitan railway system; terrorists had planted bombs, disguised as rucksacks, loaded with explosives, on crowded early-morning commuter trains. The result was the deaths of 191 persons and injuries to more than 1,700. The terrorist "commando group" was located some weeks later, in an apartment in the Madrid suburb of Leganés. After police had surrounded the building, the members committed suicide together by blowing up the apartment as the security forces were initiating an assault to capture them. All the members of the Islamist cell who were present, together with an agent of the police group, died in this action.

We can say, therefore, that Spain is a country that has experienced extreme terrorist violence, not only that of Islamist character but also by extremists of the Basque secessionist movement in the North East of Spain, more or less continuously over more than 40 years.

With relation to the security of its maritime borders, in addition to implementing the previously-described measures as a State belonging a the European Union, Spain has problems of its own, as a result of its geographic location: it forms part of the border of Southern Europe with the Maghreb countries, and offers many possible entry points for illegal immigrants from many countries of Africa and Asia, across the Straits of Gibraltar and from the west coast of Africa to the Canaries. In increasing numbers, Maghrebi and sub-Saharan immigrants are taking advantage of the generally good climate to try and reach the "promised land" of the developed countries of Europe. This represents a considerable security challenge, but is also a human drama of enormous dimensions. Not only are immigrants crossing from the North coast of Morocco to Andalusia in small boats known as "pateras"; there is a substantial traffic from Mauritania, Sahara and Morocco to the Canary Islands, which are part of Spain, by "cayucos", fishing canoes utilised in the small African coastal communities. The number of illegal immigrants has reached figures in excess of one thousand in a single weekend, and in the last full year, 2006, the total number of illegal immigrants reaching Spain by maritime routes has been estimated at 25,000. But even worse are the figures related to the associated losses of human lives at sea, which the Red Cross has estimated at around 2,000 persons each year (Pugh, 2001).

Evidently Spain has opted for two types of measure in recent years in the face of the problems of terrorism and illegal immigration by sea: measures of coercive character and other political measures, which can be summarised in the following terms:

- The administrative unification of the technical means of security between the Ministry of the Interior and the Ministry of Development.
- Implementation of the measures of maritime security approved at the international level by the International Maritime Organisation and adhesion to some of the programs of the USA in the matter of detection in containers, such as the CSI, which have been put into operation first in the port of Algeciras, and later Valencia and Barcelona.
- The establishment of new systems of vigilance.
- Involvement of the authorities of the European Union in the problem of maritime security in the coastal and border areas of the Straits of Gibraltar.
- Political agreements with the governments of Morocco and Mauritania to try and suppress the traffic of illegal immigrants from their coasts.
- Improvement of the humanitarian and health systems for the reception of illegal immigrants apprehended.

As part of this effort, the Government of Spain has put into effect two particular operational schemes termed SIVE, the initials in Spanish of the "Integrated System of Exterior Vigilance". Initially its implementation has been limited to the zones with the highest incidence of illicit traffic: that is, the littoral of Andalusia (from

Ayamonte on the Atlantic, to Cabo de Gata on the Mediterranean coast), the Canary Islands of Fuerteventura and Lanzarote, and the Spanish cities of Ceuta and Melilla on the North African coast. However, the extension of the scheme to the rest of the national territory is not discounted, since as a whole Spain forms part of the southern border of the European Union.

The governmental agreements have reduced drastically the arrival of "pateras" full of undocumented immigrants to the coasts of Andalusia, the majority of them originating from sub-Saharan Africa, although arrivals to the coasts of the Canary Islands have increased.

In Spain, the ports of general interest of the State initially drew up a Security Plan prepared on the basis of the results of a prior "Assessment of the Security of the Port Facility". This assessment identified the risks and threats that could affect the port facilities, and determined their degree of vulnerability to these risks. To this end, the methodology utilised for the assessment of security, and the production of the corresponding security plans for the ports, included the design of a software tool, titled "SECUREPORT", a tool approved by the Ministry of the Interior. Prior to the entry into force of the ISPS Code, the Government of Spain had established some initial measures in respect of maritime security in the ports, although these were not as fundamental or comprehensive as those currently existing.

The Ministry of the Interior is the government department responsible for establishing the levels of security, the minimum contents of the necessary training courses and the contents of the Ship Security Plans, for all vessels. It is also the organ of the State that coordinates the Security Forces of the State in the event of receiving a Security Alert. As regards the detailed application of security measures, the General Directorate of Merchant Shipping (Ministry of Development) is the body charged with reviewing and approving the Security Plans of ships, with verifying on board the implementation of the Security Plans and then issuing the corresponding International Ship Security Certificate, and with authorising Recognised Security Organisations to act in name of the Government. This work is done peripherally in the Maritime Captaincies; thus in Spanish vessels the Flag Inspectors carry out the verification on board of the actual implementation of the Plans, and the production of the Report corresponding to their findings. In foreign vessels, the MoU Inspectors will carry out the same type of inspection, and will report to the Maritime Captain the serious cases of vessels that do not have a Certificate, or if it has expired or is false or raises suspicion of being false, or if it is invalid or not correctly issued or completed. In compliance with the ISPS Code, the peripheral Maritime Administration, through its Inspectors, will undertake the control of access, identification and control of restricted zones, control of the cargo and provisions, control of any unaccompanied luggage, vigilance, communications, training, exercises and practice to make personnel familiar with the Code, as well as the assessment of contingency plans.

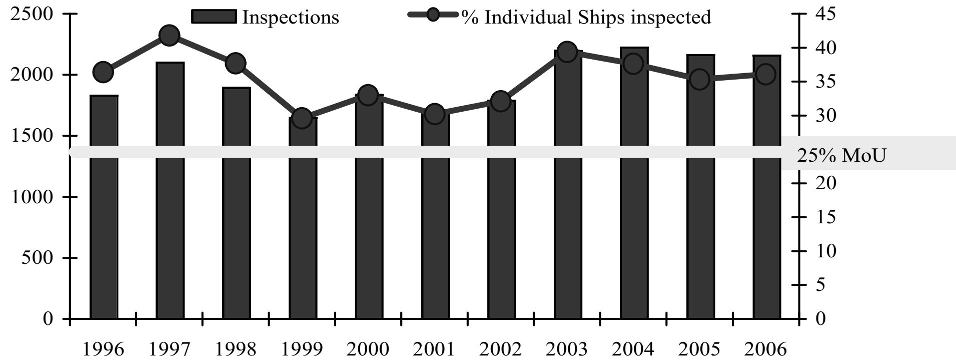
For the communication of any threat, the "Permanent Centre of Information and Coordination" (CEPIC) has been set up in the State Secretariat for Security, through the State Society for Maritime Rescue and Safety (SASEMAR).

The control measures

Spain is a signatory of the Memorandum of Paris (1982), which represents the first regional agreement signed concerning port state control (Piniella et al., 2005). Its level of participation in the agreement is within the limits fixed of 25% of the inspections, and this has even been exceeded by a suitable margin, as can be seen in Figure 1. With the introduction of the International Ship and Port Facility Security Code on 1 July 2004, the Paris MoU mounted a three month programme to verify compliance with new security requirements for ships. Results show that of the 4681 security checks carried out only 72 resulted in the ship's detention on security grounds. The programme, which was held in conjunction with the Tokyo MoU, ran from 1 July to 30 September 2004 and used a uniform questionnaire to test the key elements of the ship's security arrangements. According to the sources of the MoU itself, a total of 4681 security checks were made on 4306 individual ships; a total of 28 inspections resulted in detention solely on security grounds, while another 44 ships were detained on security and other grounds. This represents a rate of 1.5% of inspections resulting in detention for security reasons compared with an overall detention rate for the period of 5.7%. Monthly figures revealed an improving level of compliance as the programme progressed. In July 50 ships were detained compared with 13 in August and 9 in September. The reported cases of non-compliance of the new ISPS Code have not proved to be serious; in fact, most cases of non-compliance were rectified on the spot. The most common non-compliance was a failure to record previous ports of call. As can be appreciated in Table 1-c, the deficiency in compliance with the standards of security that were detected in the Paris MoU Security Campaign is closely related to the rest of the deficiencies by Flags. Of the six flags with more than one detention, five are on the Black List of the MoU for that year.

We can say, therefore that the compliance by the shipping companies was excellent, and in the first year of implementation of the ISPS Code, most ships were becoming adapted to the organisation requirements that were asked of them. If we widen the range of inspections analysed up to the present day, we can see from the data given in Table 2 that the percentage of deficiencies in matters of maritime security (ratio of deficiencies to individual ship x 100) is around 5 to 6% in the two years completed (2005 and 2006). Specifically in the MoU of Paris, some 800 deficiencies are detected annually (817 and 735); this value is very similar to that for non-compliance of other standards of safety or of prevention of contamination (SOLAS, MARPOL, ILO, …). If we look at other PSC Memoranda, the data are similar.

Figure 1. Spanish inspections in Paris MoU.



Source: http://www.parismou.org

Table 1-a. Results of the Paris MoU Security Campaign (2004):
Flags with more than 10 inspections and more than one detention.

Flag State	Inspections	Detentions on Security Grounds	Detention Rate
Georgia	56	5	8.9%
Korea Democratic People's Rep.	22	5	22.7%
Panama	471	10	2.1%
Russian Federation	205	11	5.4%
St Vincent and the Grenadines	186	3	1.6%
Syrian Arab Republic	20	2	10.0%
Grand total for all flags	4681	72	1.5%

Source: http://www.parismou.org
Note: Of those flags with more than 10 inspections and more than one detention, the following six showed rates above average.
Ships registered with these flags accounted for 50% of all detentions on security grounds.

Table 1-b. Results of the Paris MoU Security Campaign (2004):
Non-compliance and detentions.

Most common Non-compliance	No.
Failure to record previous ports of call	349
Access control onto and around the ship	200
Failure to keep records of security drills.	215

Detentions according to the Age	%
15 years or older	90
Less than 15 years	10

Rate of Detained Ship Type	%
Refrigerated Cargo ship	3.6
General Dry Cargo ship	2.6
Roll-on/Roll-off Cargo ship	1.1
Oil Tankers ship	0.6
Bulk Carriers ship	0.5
Container ship	0.2

Source:
http://www.parismou.org

Note of MoU Paris 2004 Report: Much of the certification for ISPS was carried out by Recognised Security Organisations (RSO) on behalf of the ship's flag state. Some of these RSO's are new to the PSC regime and the data in respect of these organisations was not sufficiently complete for analysis. It is also the case that most of the security detentions were due to lack of valid certification, which generally is outside the control of the RSO itself.

Table 1-c. Results of the Paris MoU Security Campaign (2004): Comparison between the Flags with most detentions under the ISPS Code and the general list of vessels detained, by Flag.

Ranking Flag State/Security detentions	Ranking MoU Paris List	Excess Factor
Georgia	**Black list** – Very high risk	4.59
Korea Democratic People's Rep.	**Black list** – Very high risk	9.81
Panama	**Black list** – Medium risk	1.07
Russian Federation	Grey list	0.32
St Vincent and the Grenadines	**Black list** – High risk	3.45
Syrian Arab Republic	**Black list** – Very high risk	4.00

Source: http://www.parismou.org

In the USA, in the past year, only 35 vessels were detained on grounds of maritime security, and of these, 28 were for not controlling the access of persons on board. Of the "black list" of 9 flags in questions of security, 6 were already on the list for questions of safety.

Table 2. Maritime security deficiencias Paris MoU Inspections (2004 – 2006)

			Deficiencies in % of total number	Ratio of deficiencies to indiv. ship x 100
2004(*)	64113	No. Total deficiencies		
	107	Security deficiencies	0.17	0.85
2005	62434	No. Total deficiencies		
	817	Security deficiencies	1.31	6.27
2006	66142	No. Total deficiencies		
	735	Security deficiencies	1.1	5.48

Source: http://www.parismou.org
(*) Security-related data for 2004 given in the table only cover the July - December period.

CONCLUSION

The globalisation of the Planet is the globalisation of trade, transport, and the movement of persons, but it is also the globalisation of risk. It is not ethical to think that globalisation may be rapid in one sense and yet in another that we have to apply all sorts of checks to it, because that way we create an unequal world, which is basically the origin of all these problems. International terrorism is a fact, as is the psychosis produced by horrific attacks of New York, Madrid and London. However, the big problems should be approached with international consensus and not unilaterally. The containers that are shipped to the USA are shipped securely, but who should pay for that security? And what about the containers shipped to other destinations? In maritime transport, the IMO, as a specialist agency of the UN has played an important role in the regulation of safety standards and protection of the natural environment, and can play the same role in respect of maritime security, in conjunction with other international organisations. Following our review of maritime security which has been focused on one state, Spain, in particular, we can state that, in these three years, the western port states have put all the initiatives (ISPS, CSI, …) into operation fairly rigorously. And the control measures reflect that this compliance is at a similar level as compliance with the rest of the standards and agreements that we consider the minimum standard for a vessel to be operated securely. Spain has opted for the investment of public funds in these types of infrastructure, but only a cost-benefit analysis can give a fair evaluation of the investments that we need to make. There can be no doubt that the payment of this cost will have a considerable influence on maritime supply-chain management. But the doubt arises as to whether putting these measure into place in vessels and ports can give us the desired degree of assurance that there can be no re-occurrence of the events that gave rise to the measures.

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LA PROTECCIÓN MARÍTIMA GLOBAL: EL PAPEL DE ESPAÑA COMO ESTADO RECTOR DEL PUERTO.

En la lengua española una sola palabra "Seguridad" engloba dos términos que en inglés tienen acepciones diferentes "Safety" y "Security". En los términos del lenguaje marítimo siempre se había hablado de "Safety of life at sea" (Convenio SOLAS). "Security" ha sido un término que se ha asociado a la legislación marítima sólo a partir de los tristes atentados del 11 de Septiembre de 2001. En este artículo se analiza la situación internacional y los acuerdos preventivos tomados a partir del 11-S en el seno de la Organización Marítima Internacional (IMO) para detenernos posteriormente en el papel de un Estado como España, que puede generalizarse a otros países occidentales del entorno europeo. Finalmente y a partir de ciertas experiencias sobre Control de Estado rector del Puerto discutiremos la eficacia real de las medidas hoy manifiestamente aceptadas.

REVISIÓN Y ANÁLISIS DEL PROBLEMA.

En el artículo se realiza en primer lugar una revisión de las políticas de Protección Marítima anteriores a Septiembre de 2001, posteriormente se analiza lo que hemos denominado "el buque como arma de destrucción masiva", (WMD) tal como ha sido ya establecido en Nincic (2005) a partir de los sucesos trágicos del 9/11. A partir de una nueva organización de los departamentos y la creación del *Office of Homeland Security* se diseño una nueva política en los EE.UU. que poco a poco se va imponiendo a nivel mundial en el transporte marítimo con el objetivo, en principio, de limitar la acción terrorista en el país, en base a tres propuestas fundamentales:

— La necesaria modificación de la normativa internacional, con especial incidencia en el SOLAS y en la creación de un nuevo Código, el ISPS, así como la implantación en otros estados de la filosofía de la Ley norteamericana *"Maritime Transportation Security Act'2001"*.

— La puesta en marcha de una serie de programas que prevengan la detección de amenazas terroristas en la carga de los buques, especialmente el programa *"Container Security Iniciative"* (CSI).

— El control exhaustivo de las personas que intervienen en el transporte de mercancías por vía marítima, incluyendo el movimiento de personas en instalaciones portuarias.

Podemos resumir las iniciativas más importantes promovidas por la Administración de los EE.UU.: Container Security Initiative (CSI); Megaport; Regla de las 24 horas; Acuerdo de Aduanas (C-TPAT); Medidas "S.O.S." *Act. The Sail Only if Scanned.*

En una segunda parte del artículo analizamos la respuesta de las Organizaciones Internacionales, para pasar a analizar el actual doble régimen de los Estados rectores de Puerto (PSC). Y dentro de este papel esta España, contemplada desde un punto de vista de miembro de la Unión Europea. España ha optado por dos tipos de medidas en los últimos años ante los problemas de terrorismo e inmigración ilegal por vía marítima, las de carácter coercitivo y otras de tipo político

CONCLUSIONES

La globalización del Planeta es la globalización del comercio, del transporte, del movimiento de personas, pero es también la globalización de los riesgos. No es ético pensar que la globalización pueda ser rápida en un sentido y en el otro tengamos que poner todo tipo de trabas, porque de esa manera creamos un Mundo desigual, que en definitiva es el origen de todos estos problemas. El Terrorismo Internacional es un hecho, como lo es la psicosis producida por los grandes atentados de Nueva York, Madrid o Londres. Los grandes problemas deben alcanzarse con el consenso internacional y no de forma unilateral. Los contenedores que van a EE.UU. van seguros, pero ¿quién paga esa seguridad? ¿cómo van los contenedores cuando el destino es diferente? En el transporte marítimo, IMO, como agencia especializada de Naciones Unidas ha jugado un papel importante en la regulación de las normas de seguridad y protección del Medio Ambiente, y puede jugar el mismo papel a la hora de la protección marítima, en conjunción con el resto de las organizaciones internacionales. Después de nuestra exposición que hemos particularizado en un Estado concreto, España, podemos apuntar que en estos tres años los países occidentales portuarios han puesto en marcha con cierta rigurosidad todas las iniciativas (ISPS, CSI,…). Y las medidas de control reflejan que ese cumplimiento es al mismo nivel que el del resto de las normas y Convenios que consideramos estándar mínimo para la navegación segura de un buque. España ha optado por la inversión con dinero público de este tipo de infraestructuras, pero solo un análisis de coste-beneficios puede dar la medida justa de las inversiones que debamos tomar. El pago de este coste no cabe duda influye considerablemente en la cadena de gestión logística. Y la duda surge en si con tener en regla estas medidas en buques e instalaciones portuarias podremos tener la certeza de que los hechos que dieron lugar a las mismas no se puedan volver a producir.

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ON SCALING LAWS AND MARITIME TRANSPORT

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Abstract

Scaling, as a manifestation of the underlying general dynamics and geometry, is familiar throughout physics. It has helped scientists gain deeper insights into problems ranging across the entire spectrum of science and technology, as scaling laws typically reflect generic features and physical principles that are independent of the detailed dynamics or specific characteristics of particular models. Fluid mechanics and phase transitions are significant examples of physics in which scaling has illuminated important universal principles or structures, and has provided responses to practical problems. Also, complex systems as living organisms obey some scaling relations that capture these systems' essential features, if these do in fact exist. In contrast to the large diversity and complexity of living organisms, one finds the simplicity of the scaling behaviour of biological processes that holds true in a wide range of phenomena and a large range of energy and mass. The constructal theory states that flow systems evolve in time so that they develop the flow architecture that maximizes flow access under the constraints posed to the flow. This "extreme" principle has been quite successful in justifying allometric scaling laws, global circulation and climate characteristics, and even scaling effects in running, swimming and flying. Some of these moving relationships, the scaling between mass and speed, are tested in relation to ships and maritime transport, in which it is possible to find a reasonable continuity with the types of scales seen in living moving organisms, and some preliminary conclusions are drawn, pointing to the convenience but also to the difficulties of using large ships.

Keywords: Scaling laws, Complex systems, Ship speed, Ship size.

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INTRODUCTION

In complex systems, carefully designed decisions and guidelines might produce unexpected results because of particularities, or complex sets of reactions from residents or economic counterparts. Complexity tends to increase with size, such as when, for instance, larger ships or larger buildings are constructed, services tend to concentrate in large agglomerations, and transportation needs take on critical importance. Complex systems such as living organisms are known to follow approximate relationships as scaling laws between the variables that describe them. Some of these kinds of relationships are tested in relation to some questions on maritime transport, especially concerning ship size.

However, detailed physical relationships between the variables that determine these conditions are very complex due to the same complexity of the system and the multiple sets of variables needed to describe it, which are together considered as a physical system. Nevertheless, some ideas and tendencies seem to be shared by many modern ship transport systems: one should optimise such things as energy and time expenses for the transport of goods, and pollution issues. It then seems reasonable to expect some general trends (if not "exact" laws) that modern ships should follow because of these constrains, and it should be acceptable to think about it as complex, physical systems.

Then, we should learn from phenomenological relations in existing complex systems that have evolved over hundreds of millennia. As living organisms represent one of these systems, which have been largely studied, and are indeed a paradigm of complexity, studying general laws or general relationships in biology might give us an insight into our problem. In fact, it seems reasonable to conjecture that the coarse-grained behaviour of living systems might obey quantifiable universal laws that capture the systems' essential features, as (West and Brown, 2004) does.

As pointed out by (West and Brown, 2004), in biology the scaling observed is typically a simple power law: $Y = Y_0 M^b$, where Y is some observable magnitude, Y_0 a constant, and M is the mass of the organism. The exponent b usually approximates a simple fraction. Among the many fundamental variables that obey such scaling laws are metabolic rate, life span, heart rate, lengths of aortas and genomes, tree height, mass of cerebral grey matter, and others.

In fact, the constructal theory states that every flow system evolves in time so that it tends to develop the flow architecture that maximizes flow access under the constraints posed to the flow. It has been quite successful in justifying allometric scaling laws (Bejan, 2000), global circulation and climate characteristics (Reis and. Bejan, 2006), and even scaling effects in running, swimming and flying of animals (Bejan and Marden, 2006). However, as the boundaries and the conditions in complex systems might be not so evident, as (Burd, 2006) points for the case of traffic organisation in ant societies, care should be exercised in interpreting. We keep the main idea that even very complex systems, thus far as living organisms or man-produced systems, should follow some scaling laws if they have common basic principles in their dynamics or working phenomena. In fact, as (Isalgue et al., 2007) points out, transport conditioned complex systems as cities approach reasonably some of the living organisms scaling laws.

In this work, we look for dependency of cruising speed with mass for some home-made transportation devices, ships and planes, and compare them with sustained speeds for living organisms of different masses. We find a reasonable continuity of ships with the behaviour of swimming animals, even though with relatively reduced speeds for ships. This suggests that there is still an ample margin of speed which can be gained by ship transport.

SCALING LAWS IN RUNNING, FLYING, AND MOVING IN WATER

If we take into account that the economy/ecology principles are nearly the same everywhere, we can conjecture that an optimisation of resources in moving would imply a regular distribution of power among the different resistances to the movement (in walking, flying or swimming), for self-propulsating bodies. As many particularities exist in discontinuous jumping or in flying out of the horizontal, only speeds that can be sustained for a considerable time are to be taken into account.

In [(Bejan and Marden, 2006)] it is formulated a simplified model for walking and flying, which first assumes a composite movement of "pulsating" path, in which a muscular produced increase of height of the body centre of mass is followed by a "planning" decrease with air drag as source of resistance to movement. Assuming related movements (in vertical and in horizontal, in the field of gravity), form factors near 1, and drag coefficients also near 1, and equalizing the losses of potential energy and of air drag (in turbulent flow, as the usual case) per unit time, allows to obtain the speed v as function of the mass of the moving body M (both for running on ground or flying), giving the expression and the full line in fig. 1. Also, running on wheels could be considered a smoothing of the previous model, and the points (not designed) representing running cars are not very far (above) the continuous line in fig. 1. Railway transport lies somewhat below the line.

For objects moving in water, two sources of power loss are considered in (Bejan and Marden, 2006): viscous drag with water, and the need to increase the potential energy of the water displaced by the moving object (as nearly incompressible fluid, water has to move upwards to allow the pass of the object, this has been detected even for fish and for submarines). The latter point is equivalent to say "the existence of a wake", even in some cases it might be of very low amplitude and then, difficult to detect. Again, assuming form factors of the order of 1, coefficients of drag also near 1, and equalizing the energy losses per unit time of the two terms allows obtaining the relation of speed v with the mass M of the body moving on water, as the expression and the dotted line in fig. 1.

Data points referring animals in fig. 1 are obtained from (Bejan and Marden, 2006), data for ships refer to the contents of table I, and data for commercial airplanes refer to the contents of table II.

Table I: Data of mass/displacement, cruising speed and power for some ships. The source where only date and page number is indicated refers to the journal (AINE).

Ship	Function	Displacement (metric tonnes)	Speed knots (m/s)	Power (kW)	Source
USS Alabama	Submarine (warship)	18000	25 (12,9)	45000	Wikipedia, 2008
USS A.Lincoln	Aircraft carrier	103000	>30 (15,4)	194000	
A. Bazan class	Frigate (warship)	6250	28 (14,4)	34800	
Marques de Comillas	Container slip	19053	17,7 (9,1)	8580	April 98, p. III ships
Jonas	Fishing	130	10,9 (5,6)	510	March 98, p. II ships
United Nadja	Tanker (chemical)	8197	13,2 (6,79)	2640	January 98, p. I ships
Stolt sea class	Tanker (chemical)	30243	15,2 (7,82)	6500	July 99, p. XV ships
Navion Britania	Tanker (oil)	145910	15 (7,71)	11520	February 99, p. X
Kica	Fishing	358	11 (5,66)	960	June 99, p. XIV
Skane	Ferry	23420	22 (11,32)	7240	December 98, p. IX
Hilder K/ Helgoland	Merchant	9200	15 (7,71)	3520	November 98, p. VIII
Quenn Mary II	Passenger ship	100000	30 (15,4)	117000	Wikipedia, 2008
HMS EnduarancA171	Ice breaker	6000	14 (7,2)	6000	
Isla de Botafoc	Ferry	12000	18 (9,26)	12000	Balearia, 200
Alcantara	Fast ferry	940	38 (19,55)	20400	Acciona, 2008

Table II: Data of mass, cruising speed and power for some commercial airplanes.

Airplane	Mass (kg)	Speed (m/s)	Power (kW)	Source
B-747-B	440000	289	342000	Boeing, 2008
B-737	72100	246	44250	
B-717	51000	225	37080	
A-350-800	245000	289	192470	Airbus, 2008
A-340-600	368000	292	292400	
A-320	73500	242	55580	
Skyhawk	1300	62	110	Cessna, 2008
C-295	22000	133	33000	EADS, 2008

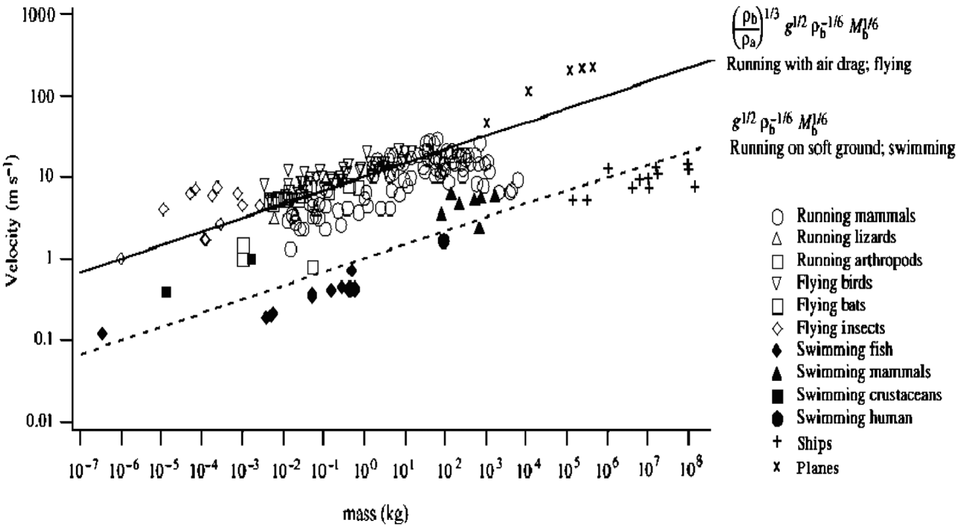

Figure 1. Speed (velocity) versus mass for different moving objects. Values for the straight lines: g, acceleration of gravity (9,8 m/s²); M_b, mass of the moving body; ρ_b, density of the moving body; ρ_a, density of air.

It should be noted that both calculated lines in figure 1 show a power dependence of speed v with mass M, with exponent equal to 1/6. As form factors have been assumed to be 1 or near 1, and density of moving bodies does not vary a lot, mass is approximately proportional to volume and then to representative length to the 3rd power, so speed shows a dependency on representative length to ½, remembering the known law of ships: "critical" speed in knots around square root of the length in feet.

Near 15 orders of magnitude (10^{15}) in mass are covered by data in fig. 1. Speed of moving organisms and moving objects cover only about a factor of 3000, but a clear tendency to follow the lines (continuous for running or flying, dotted for swimming) is observed. The speeds attainable for moving in air or running are higher because of the low density of air, which produces a reduced drag in the usual conditions (in turbulent flow, drag depends on: ρ_{medium} v^2). The detailed conditions of the travel (i.e., running, flying or going on wheels) appear smoothed by the main factors of air drag and pulsating (impact) centre of mass height change, taken as the most important facts in the model.

At low masses of the moving object (insects and crustacean), systematic deviations to higher speeds seem to be present. The reason might be that for small objects, the Reynolds number implied in the movement of the body is relatively low, and then the drag would be lower than assumed. It can be observed that large planes seem to perform very well, but this is an artifact, as the nominal speeds are usually obtained at high altitudes where the density of air is much lower (and then, drag is also much lower) than assumed in the computation of the dotted line in fig. 1.

War ships and fast ferries are the fastest ships. However, even using large amounts of power, they perform just near the dotted line. Also, even nuclear powered submarines do not travel much faster than other ships. The actual belief is that the wake is an important obstacle for increasing ship speed, the existence of a relatively strong wake for ships might seem a justification for relatively low performance of ships compared to some fish. However, the data shows that a nuclear submarine does not perform much better than ships, so it is suggested the real importance of some kind of wake, as the model for swimming assumes, in the form of the need to "expulse" water from the front of the moving object, even if the detection of a wake is more difficult as it becomes larger in extension but of very low amplitude.

Also, it is to be noted that war planes, which have not been represented, can go much faster that the continuous line would suggest, at expenses of very large amounts of power. Rockets are not represented, as they are used mostly for strategic reasons and not for considerable mass transport.

Another question is how do large "hunters", as dolphins or sharks, to perform considerably above the line for swimming in fig. 1. This challenging fact shows that it should be possible to improve ship speeds, maybe with hydrodynamic design, or even with new technologies not yet advised.

A further consideration on power has to be done. From the data in tables I and II, and the data for animals and cities in (Isalgue et al., 2007), we can obtain the figure 2, which shows a gross representation of power as function of mass for the different entities considered. The continuous line follows the observed dependency of metabolic power with mass for the animals, from allometric scaling law (West and Brown, 2004; Isalgue et al., 2007).

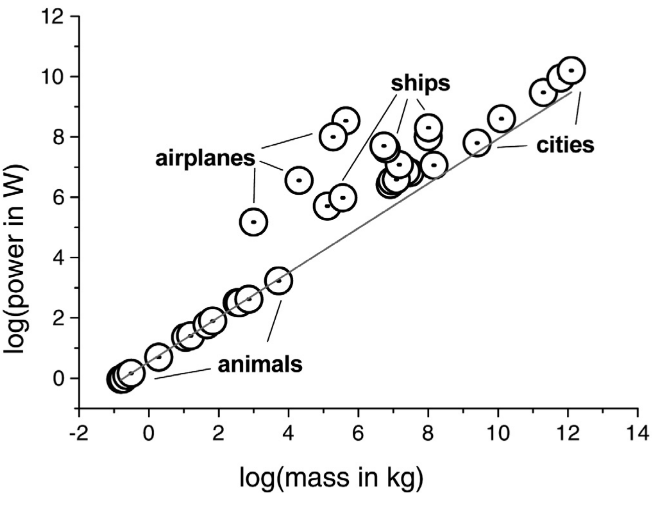

Figure 2. Power as a function of mass. Some animals, airplanes and ships are represented. Data for animals from (West and Brown, 2004), data for cities from (Isalgue et al., 2007) and data for ships and planes from tables I and II.

The different groups appear well separated: animals and cities appear to have approximately the same kind of dependence of power with mass, as (Isalgue et al., 2007) indicates.

Airplanes use lots of power compared to other entities of comparable mass, and the power used by airplanes seems to increase with mass stronger than for animals. The slope in the graph seems to approach 1, in place of the slope very near ¾ for animals [see (West and Brown, 2004; Isalgue et al., 2007) about the slope ¾] . Constructive reasons, and the fact that larger commercial airplanes flight higher than small planes, can be a reason for this.

For ships, large differences in power (a factor of near 100 times) might be encountered for the same mass, because very different ships (different missions) are plotted. Different ships might perform very differently, from a fast warship to a slow tanker. However, it has to be noted that "slow" large ships use comparatively very low amounts of power, near the continuous line, and even warships or fast ferries use much less power than would do an airplane of comparable mass (ships use power less than around 1/100 of equivalently massive airplane). Airplanes are faster, but its speed is only around 50 times higher than that of ships. Then, the result is the known fact that large ships, with large payload compared to its weight, are the best (economic) option for cargo transportation. From the analysis here, larger ships show a decrease in power per unit mass (power increases less than mass) and an increase in speed, so transport with large ships should be preferred. However, large ships ask for large facilities for cargo handling and for maintenance of the ships, and also ask for a large effort in logistics.

CONCLUSIONS

Complex systems as living organisms obey some scaling relations that capture these systems' essential features. The scaling behaviour has been attributed to the basic characteristics of these systems. An "extreme" principle, inscribed in the constructal theory, has been quite successful in justifying allometric scaling laws in living organisms, global circulation and climate characteristics, and even scaling effects in running, swimming and flying of animals. Some of these scaling in movement relationships, the scaling between the mass and cruising speed, has been tested here in relation to ships and maritime transport.

The cruising speed of commercial planes is somewhat higher than expected in comparison with the speed to mass relation for flying animals because the reduced density of air at high altitudes (and then, reduced drag). It has been found a reasonable continuity of the relation between speed and mass of ships with the types of scales seen in living moving organisms. The classical dependence of speed with size of a ship (i.e., $v \propto (\text{Length})^{1/2}$) might be recovered from some basic assumptions. Some preliminary conclusions might be drawn, suggesting some improvements in the technology might be able to obtain higher speeds for ships.

The challenging fact that large swimming "hunters", as dolphins or sharks, perform in speed clearly above a line (in fig. 1) designed with a model from (Bejan and Marden, 2006) for swimming, while ships perform generally below, shows that it should be possible to improve ship speeds, maybe with new hydrodynamic design, or even with new technologies not yet advised.

Some considerations on power have been also done, comparing animals, cities, ships and planes. The obtained graph (fig. 2) shows the strong convenience of large or very large ships, as power increases clearly slower than mass, and speed tends to increase with mass (thus reducing time of transport, and then, a diminishing of energy spent in transport is clear for large ships). This shows the convenience of large ships for economy cargo transport. The analysis of energy spent in transport is clearly favourable to the use of large ships. However, large ships produce the need of large facilities and terrestrial transports support to load and unload the ships (as well as of large facilities for maintenance of the ships), and this becomes usually a bottleneck in transport.

A further point to be considered, not done here, is the probability of occurrence and results of an accident, concerning very large loads and human and environmental impact of a loss if using very large ships. This might limit effectively the size of ships recommendable because of economic reasons in case of accident or loss.

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SELECTION OF SHORT SEA SHIPPING TRANSPORT CHAINS IN WESTERN EUROPE, BASED ON EXTERNAL COSTS

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Abstract

According to the mid term review of the EU White Paper on Transport, Short Sea Shipping is expected to grow at a rate of 59% in metric tonnes, from 2000 to 2020. If we consider that the overall expected growth in freight exchanges is of 50% (also in volume), sea transport is one of the most feasible way to reduce traffic congestion on European roads. Marine transport is a possible way to compete with road transport in certain traffics, mainly when assuming external costs. This paper is going to analyse five multimodal routes, considering three different levels of powered ships, which one is going to be the most efficient in terms of external costs.

Keywords: Short sea shipping, western Europe, external costs.

INTRODUCTION

The European transport policy looks to be a sustainable activity that will boost the economic activities in the whole Union. The pollutant emissions reduction and a best equilibrium among different transport modes, releasing the roads from traffic congestion are the basic pillars of the mentioned policy. These factors are encouraging the public and private stakeholders to use in a more extensive way the freight rail mode and of course the maritime alternative, in a constant find for the best solution.

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Most of the developed countries use a national net of roads to move freight, despite it being the most expensive, pollutant transport mode, maintaining the highest rate of fuel consumption per cargo unit (REALISE, 2009).

The maritime sector is one of the less pollutant ways in addition to the additional capacity to contribute to reduce the road congestion in Europe. Particularly the short sea shipping is thought to be the quickest way to reach the sustainability goal. But this opportunity could pose some other inconvenient such as a superior traffic growth and a subsequent increase of the pollutant emissions in the port areas.

On the other hand, the massive use of every day fastest ships affording a competence in time to the truck, could remove the ecological ticket from the marine sector to other means, due to the superior needs in terms of power and then consumption (and emissions). This last question is going to be further analysed.

This paper has been divided in four sections. Firstly, some previous research in this field of our research group is described. Secondly, the definition of the environment regulations applied to transport policies and the different external impacts. Thirdly, the quantification and valuation of external costs on previous selected short sea shipping routes in SW Europe and finally, the conclusions and further research of this study.

PREVIOUS RESEARCH

The previous research carried out by the TRANSMAR research group integrated in the Technical University of Catalonia was the INECEU project, proposing after an exhaustive study some alternative multimodal lines against road transport in SW Europe. Keeping in mind the figures of road traffic passing the Pyrenean borders, the group analysed most of the volumes moved between Spain and France. Among all the Spanish regions we should note the activity of Catalonia, the Basque country, Valencian and Andalusia. The French counterpart is contested by the Pyrenean regions of Aquitaine, Languedoc-Roussillon and Midy-Pyrenees together with Ile-de-France, Rhône-Alps and Provence-Alps-Côte d'Azur.

The French territory is also crossed by important traffic fluxes southbound coming from Westafalia, Baden-Würtemberg and Bayern in Germany and the northern part of Italy. From Spain it is possible to identify the main traffic towards Westfalia and Baden-Würtemberg in Germany, Lombardia in Italy and destinations more spread out up in Great Britain, Holland and Belgium. Regarding the nature of the cargo, we should note that the South and South-East part of the Iberian Peninsula, together with the Valencia coast, are big producers of fruits and vegetables, with the group of manufactured or canned food and alcoholic drinks. This is one of the larger cargo groups that is exported from Spain. There is important traffic involving solid bulk such as building materials or scrap iron, together with oil and chemical products from ports with refineries nearby that are firmly committed to removing trucks carrying dangerous or toxic substances from the road to ships that have specifically designed containers, or Ro/Ros, that will benefit society as a whole.

The study concluded that:

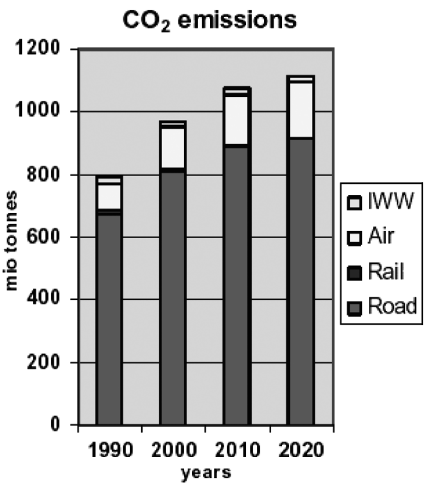
1. The industry in the Mediterranean basin accepts the concept of Short Sea Shipping due to the superior road distance to between Spain and Italy compared to sea link;
2. The Atlantic bulk traffics should take advantage of the SSS funding and official policies using multi purpose ships accepting different kinds of traffic;
3. Fast ships could be justified when serving trips less than 12 hours away and when cost is not so important provided a minor time of delivery can be guaranteed;
4. The conditions shown in the first phases of the study can be submitted to change, always benefiting the ship position when considering factors such as road congestion, accidentability, noise or pollutant emissions.

ENVIRONMENTAL BALANCE OF TRANSPORT ACTIVITIES

The European Union through its sustainable development strategy and the White Paper on transport, has repeatedly manifested its interested to reduce the transport generated impacts. In this sense, there exists a common application of measures to solve the environmental threats in the transport sector.

Regarding road transport, the European Parliament has adopted the Euro V and VI regulations, being progressively stricter regulation on vehicle pollutant emissions, specially referred to particles emission and nitrogen oxides (NO_x) limits. The Euro V will be applied from the 1st September of 2009 and establishes a decrease of 80% in the particles emission limits, what means the future fitting of particles filters on board vehicles. The Euro VI regulation, will enter in force in 2014 and will pose stricter limits, with the aim to reduce the nitrogen oxides up to a 68% from the nowadays levels.

Figure 1. CO_2 emissions segregated by transport mode in millions of tonnes.



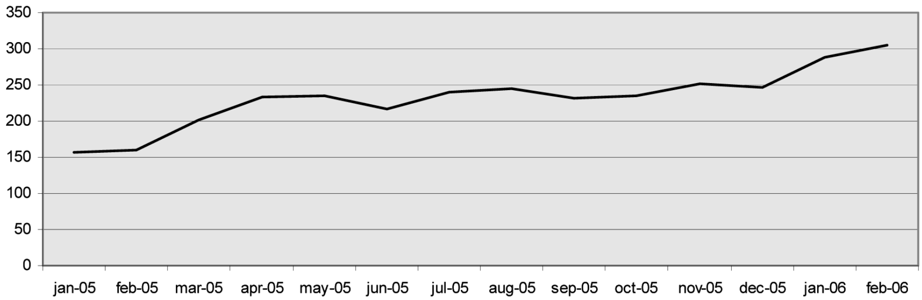
Source: Keep Europe moving. Midterm review of transport white paper. DGTREN, European Commission

The maritime transport emissions are regulated mainly by the MARPOL Convention and some specific European regulations. The new regulations regarding the SO_2 and NO_x maximum emission levels will reduce this kind of pollutant components, the maritime transport weakest point, in the future. Maritime transport is the responsible of the biggest volume of SO_2 into the atmosphere, only to be compensated by means of reduced sulphur content fuels or cleaning exhaust gases systems. Despite of this scenario, in respect to the CO_2 emissions, road transport is responsible for the 80% of the whole, and this justifies the interest for reducing the share of road transport. Additionally the NO_x emissions split in the European Union, points up to a 51% from road vehicles and a 12% from the other transport modes.

As a whole, the balance of emissions to atmosphere is positive to maritime transport and not at all for the road one. This last justifies supporting actions to multimodal chains with marine sections based on short sea shipping links, as a way to reach a more sustainable mobility within Europe.

However the progressive entrance of High Speed Crafts in the market in the short sea shipping traffics as a way to compete with road speeds means also a superior consumption rate because of the fitted high output engines and the derived emissions. Also the high oil price poses the operating companies in an economic threat.

Figure 2. Bunker prices during the period 03/01/06-14/02/06



Source: Grimaldi Group Napoli.

We must mention other factors affecting the rate of short sea shipping pollutant emissions as the fleet age and the highest number of trips done.

METHODOLOGY OF STUDY

In this part we are going to compare the environmental impact and the external costs in five multimodal routes considered more efficient than the same link served by a unimodal chain but keeping in mind up to three different speed ships with (conventional, fast conventional and high speed), using the thematic network REALISE (REALISE, 2009) medium costs.

Following will be detailed the considered previous factors to carry out the study.

a) The cost categories are divided in two:
   1. Environmental external costs: local air pollution, global warming and acoustic pollution.
   2. Non environmental costs: accidents and road congestion.

b) In order to estimate the impact of emissions evolution from different transport modes, there will be considered two scenarios:
   1. Actual condition: from the regulations in force, that is Euro III standards for road transport and no specific limitation for marine transport.
   2. Improved condition: applying future stricter regulations, like in the road sector the Euro IV standard (in force for new trucks from 2006) and for maritime transport considering a decrease of 10% for all the emissions except for S, SO_2 and NO_x.
c) The target routes, are the most efficient ones coming from INECEU project (TRANSMAR, 2005).

Table 1: Routes obtained from the INECEU project.

Route	Origin	Loading port	Discharging port	Destination
Route 1	ZAL Azuq. de Henares	Valencia	Naples	Naples
Route 2	ZAL Barcelona	Barcelona	Civitavecchia	Rome
Route 3	Zal Alicante	Alicante	Genoa	Milan
Route 4	CETABSA Burgos	Tarragona	Genoa	Milan
Route 5	CTB Benavente	Gijón	Hamburg	Berlin

d) In each route will be analysed the multimodal and unimodal possibilities, distinguishing in the marine section, between the conventional, fast conventional and high speed ships, and the road legs will cover from origin to loading port and from discharging port to destination.
   The different ships cargo capacities will be also considered, keeping in mind that they are real ships serving short sea shipping traffics:

Table 2: Cargo capacity depending on each type of ship.

Types of ship	Cargo capacity in (FEU)
Conventional ship	103
Fast conventional ship	94
High speed craft	50

   The cargo unit is estimated in TEU (or FEU as very close to a trailer longitude) as it is the common unit of freight in sea and road legs, considering the container filled up to a 60% (EIG, 2002).
e) The time used for boarding the cargo from one transport mode to another is split in the following concepts, in 2 hours for port manoeuvring when talking about conventional and fast conventional ships (one hour per move) but only one hour for high speed crafts (half an hour per move). The time spent at port has been obtained for each ship's speed in every different route, then having kept in mind the route distance, speed and a week with only 6 working days, carried out in previous studies (Martínez, 2008).

Table 2: Port times depending the route and ship speed.

Route	Type of Ship	Time at port
Route 1	Conventional ship	8 hours
	Fast conventional ship	4 hours
	High speed craft	6 hours
Route 2	Conventional ship	5 hours
	Fast conventional ship	7 hours
	High speed craft	6 hours
Route 3	Conventional ship	4 hours
	Fast conventional ship	3 hours
	High speed craft	10 hours
Route 4	Conventional ship	8,5 hours
	Fast conventional ship	9 hours
	High speed craft	9 hours
Route 5	Conventional ship	4 hours
	Fast conventional ship	11 hours
	High speed craft	11 hours

Source:Martínez de Osés & Castells. http//:tethys.org, January 2007 and *Heavy weather in European Short Sea Shipping: Its influence on selected routes*. Martínez de Osés & Castells. The Journal of Navigation, Vol. 61. January 2008.

It has been kept in mind the hurly consumption on the base of 200 g/kW x hour, depending on the main engine load. We are going to apply the 80% of engine load when sailing, 40% manoeuvring and 20% for time spent at ports due to operations.

Table 4: Hourly consumption depending on the engine load and power.

Type of ship	Speed	Tm/Hour (80%)	Tm/Hour (40%)	Tm/Hour (20%)
Conventional ship	20	4,1472	2,0736	1,0368
Fast conventional ship	27	5,0688	2,5344	1,2672
High speed craft	40	10,88	5,44	2,72

CONCLUSIONS AND FURTHER RESEARCH.

In this last part, we have showed the final results in terms of external costs saving, between a unimodal and a multimodal chain of the 5 different routes, depending on the ship's type and the two mentioned consumption conditions:

Table 3: Multimodal transport savings (in €) per trip in route 1, depending on the ship's type.

Type of ship	Actual condition savings	Improved condition savings
Conventional	130.951,20	76.419,09
Fast conventional	119.528,20	69.761,03
High speed	63.681,50	37.209,71

Table 4: Multimodal transport savings (in €) per trip in route 2, depending on the ship's type.

Type of ship	Actual condition savings	Improved condition savings
Conventional	97.270,11	56.764,04
Fast conventional	88.785,13	51.818,43
High speed	47.302,65	27.639,55

Table 5: Multimodal transport savings (in €) per trip in route 3, depending on the ship's type.

Type of ship	Actual condition savings	Improved condition savings
Conventional	102.210,25	59.646,91
Fast conventional	93.294,35	54.450,13
High speed	49.705,00	29.043,23

Table 6: Multimodal transport savings (in €) per trip in route 4, depending on the ship's type.

Type of ship	Actual condition savings	Improved condition savings
Conventional	58.656,19	34.230,33
Fast conventional	53.539,56	31.247,99
High speed	28.524,55	16.667,37

Table 7: Multimodal transport savings (in €) per trip in route 5, depending on the ship's type.

Type of ship	Actual condition savings	Improved condition savings
Conventional	139.560,46	81.443,11
Fast conventional	127.386,48	74.347,33
High speed	67.868,36	39.656,14

From a general point of view, it is observed that the freight transport represents, in all cases and in both conditions, at least one advantage in respect of external costs compared with unimodal one, however when considering stricter regulations (Euro IV) the savings decrease is important, because of the lower limits posed for road emissions. Also the conventional ships are the most environmental friendly ones, being the difference between the fast conventional and high speed crafts bigger than from conventional to fast conventional ships.

In the analysis we have also obtained the saving per trip per year, and by truck/trip in each route.

Table 8: Yearly (50 weeks) and truck/trip savings for route 1.

Condition	Yearly conventional ship savings	Truck/trip conventional ship savings	Yearly fast conventional ship savings	Truck/trip fast conv. savings	Yearly high speed craft savings	Truck/trip high speed savings
Actual	24.861.866,21	1.271,58	20.428.386,85	1.271,37	9.934.314,04	1.273,63
Improved	14.510.293,59	742,14	11.921.377,98	741,93	5.804.715,14	744,19

Table 9: Yearly (50 weeks) and truck/trip savings for route 2.

Condition	Yearly conventional ship savings	Truck/trip conventional ship savings	Yearly fast conventional ship savings	Truck/trip fast conv. savings	Yearly high speed craft savings	Truck/trip high speed savings
Actual	25.290.227,62	944,37	27.700.961,95	944,52	22.137.639,41	946,05
Improved	14.758.650,39	551,11	16.167.349,44	551,26	12.935.308,08	552,79

Table 10: Yearly (50 weeks) and truck/trip savings for route 3.

Condition	Yearly conventional ship savings	Truck/trip conventional ship savings	Yearly fast conventional ship savings	Truck/trip fast conv. savings	Yearly high speed craft savings	Truck/trip high speed savings
Actual	21.259.731,10	992,33	29.107.837,26	992,49	15.507.958,91	994,10
Improved	12.406.557,38	579,10	16.988.441,83	579,26	9.061.488,32	580,86

Table 11: Yearly (50 weeks) and truck/trip savings for route 4.

Condition	Yearly conventional ship savings	Truck/trip conventional ship savings	Yearly fast conventional ship savings	Truck/trip fast conv. savings	Yearly high speed craft savings	Truck/trip high speed savings
Actual	1.349.092,36	569,48	16.704.342,54	569,57	13.349.491,47	570,49
Improved	787.297,53	332,33	9.749.373,06	332,43	7.800.331,12	333,35

Table 12: Yearly (50 weeks) and truck/trip savings for route 5.

Condition	Yearly conventional ship savings	Truck/trip conventional ship savings	Yearly fast conventional ship savings	Truck/trip fast conv. savings	Yearly high speed craft savings	Truck/trip high speed savings
Actual	14.514.287,95	1.354,96	19.872.291,53	1.355,18	14.116.619,35	1.357,37
Improved	8.470.082,93	790,71	11.598.183,69	790,93	8.248.476,67	793,12

From the previous tables data, it is possible to see that apart from the traffic congestion, accidentability and noise generation, the road transport poses higher external costs than the maritime transport to society, being these costs the positive contribution of sea transport. These environmental benefits could justify some public grants at least in a previous step as an economic incentive to convince the user to utilise the maritime transport. One possible application is the ecological bonus offered by the Italian government in several routes to endorse the trailers and trucks on board a ship instead of doing the route in an only road mode. This measure would withdraw a large number of trucks from Italian, French and Spanish coastal roads, removing pollutant emissions from the air and also retiring trucks from touristical and high populated areas.

The results derived from this paper, could justify an ecological grant should be applied in the analysed routes by the Spanish central government, to national carriers.

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SELECCIÓN DE LAS CADENAS DE TRANSPORTE DEL SSS EN EL OESTE EUROPEO BASADO EN COSTES EXTERNOS

Este artículo presenta una comparativa entre los costes externos generados por los buques de transbordo rodado, frente al transporte en camión. Partiendo del hecho que el transporte marítimo consume menos energía por distancia y unidad transportada, se simulan los consumos de tres tipos de buques en función de su velocidad y su capacidad de carga; y se realiza una comparación de los costes externos generados por cada buque y unidad de carga que puede transportar.

Además se han evaluado las siguientes categorías de costes:

— Costes externos medioambientales: contaminación al aire local, calentamiento global y contaminación acústica.

— Costes externos no medioambientales: accidentes y congestión

Para poder prever la evolución del impacto de las emisiones de los diferentes modos de transporte se han tenido en cuenta dos condiciones:

— Condición actual: a partir de los estándares y normativa que se aplica en la actualidad. En el caso del transporte terrestre se ha aplicado el estándar Euro III.

— Condición mejorada: aplicando una normativa futura que se prevé mucho más restrictiva. En el caso del transporte terrestre se ha aplicado el estándar Euro IV y en el caso del marítimo se ha considerado un 10 por 100 menos de emisiones en todos los agentes excepto para el S, el SO_2 y el NO_x.

En general, se observa que el transporte de mercancías multimodal representa, en todos los casos y en ambas condiciones, una ventaja respecto al unimodal con relación a los costes externos, aunque cuando se aplican las normativas más estrictas se aprecia una disminución acuciante del ahorro en costes externos, ya que la normativa aplicada al transporte terrestre es mucho más severa que la aplicada al transporte marítimo.

A partir de las tablas presentadas en el artículo, se puede observar que aparte del problema de congestión del tráfico que representa el transporte terrestre, el modo marítimo también tiene un beneficio económico asociado al menor impacto medioambiental que se puede traducir en ahorros externos.

Estos beneficios medioambientales podrían justificar unas subvenciones gubernamentales, al menos inicialmente, como una iniciativa de política pública para que los usuarios del transporte unimodal obtuvieran un incentivo económico para utilizar el transporte marítimo de corta distancia. Un ejemplo de este tipo de tasa medioambiental es el denominado *ecobono italiano*, que establece incentivos económicos para los transportistas que embarquen sus camiones o semirremolques en barcos que cubran trayectos alternativos a la carretera.

El principal objetivo es el desarrollo de cadenas logísticas, la potenciación de la intermodalidad, el desarrollo del cabotaje marítimo, la reestructuración del sector de transporte por carretera, la innovación tecnológica y la mejora del medio ambiente. Los resultados del presente proyecto permiten sentar las bases para calcular una tasa medioambiental que podría ser aplicada en las rutas estudiadas como ecobono español.

Asímismo también se aprecia que el transporte marítimo convencional es el que representa un mayor ahorro de los tres modos de transporte marítimo por viaje. Aunque existe diferencia entre el buque convencional y el convencional rápido, se nota una diferencia más relevante entre el convencional rápido y el de alta velocidad.

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PORTS AS SUSTAINABLE COMPLEX SYSTEMS

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Abstract

Ports and harbours are very large infrastructure projects which have great impact on the community, environment and the economy of a country. Ports are not only a vital lifeline link between water-side and land-side traffic, but are also sources of national wealth, pride and concern. Stakeholders now want requirements to be described in a creative, rigorous, and policy-relevant manner and for critical issues such as sustainable development to be incorporated into developments. This paper looks at the issue of sustainable development for ports and harbours as being one of managing complexity and considers how wider requirements may be accommodated.

Most of the problems related to sustainability and sustainable development are typically complex and inter-related. It has been shown that the more complex a system the harder it is to manage, but by having insights into the causes of complexity in systems enables decisions to be made actions to be taken where otherwise there may be lost opportunities and ultimately reduced profits. Ports have to achieve a harmonious balance between the local community, the environment and economic issues. By applying systems engineering techniques and ideas surrounding complexity management this paper looks at the designing and subsequent management of ports & harbours and in so doing to develop clearer strategies. Research work into airport processes is used to gain insights into potential approaches for the management of ports and harbours.

Keywords: Systems, sustainable development, ports and harbours, complexity.

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INTRODUCTION

Ports operate within an environment that is driven by natural processes such as tides, currents, and climate, as well as marine biology, society and man-made processes. Within the last six years the literature shows that there has been a rising interest in environmental issues relating to ports and harbours. Port activity is coming under scrutiny, both in terms of capital projects and ongoing operations. For example, the European Commission's transport policies are now expressed largely in terms of their potential impact on the environment and expected levels of pollution. In 2002 David Jamieson, the UK minister of shipping, stated that modern ports must be '*successful, sustainable and safe*', (DTLR, 2002). There are also a number of European research institutes and international organisations that are promoting the sustainable development of ports such as "Ecoports", "Espo", "New! Delta" and "UNEP – regional seas programme".

Ports are traditionally designed and built based on the specified maritime and channel design, quay design, the expected port operations and cargo handling, the terminal layout, and also to the expected marine traffic and type of cargo. Simulation models are used extensively for the analysis and planning of ports, and there are a wide range of published research reports. Existing literature includes simulation models of full container terminals (Nam et al., 2002; Agerschou, 2004), container movements to and from trucks (Sgouridis et al., 2003) and to and from vessels (Sgouridis et al., 2003), vessel traffic (Pachakis and Kiremidjian, 2003; Asperen et al., 2003), and ship handling at the port (Bruzzone et al., 1998). Arena software (Kelton et al., 2004) is a well known simulation package, and is used extensively in commercial operations, including port planning and analysis, (Sharpe et al., 2005; Goldsman et al., 2002).

We are however witnessing an inexorable increase in complexity in all spheres of social life and problems relating to sustainable development are typically complex, interconnected and 'messy'. 'Messy' problems are challenging traditional approaches to problem solving, such as reductionist approaches. Ports, and the problems they seek to solve, are becoming more complex. It is not possible to design part of the port system in isolation without considering the problem and solution as a whole. Simulation models can accommodate the dynamic or transient effects seen in port and shipping operations in unexpected situations, such as adverse weather conditions or equipment breakdown, however they are limited to relatively straightforward problems and cannot cope with complex, inter-related factors such as, for example, the degradation of the local environment through dredging, loss of support from the local community, the effect of more extreme and unpredictable seasonal variations, and the potential effects of a new development on the physical and biological marine environment. Many of the emergent behaviours from these complex relationships are unknown, such as not being able to guarantee cargo handling efficiency, i.e. demurrage payments, which is a characteristic of a complex system. Simulation models and other predictive methods are based on data where 'outliers', i.e. unusual operations are removed from the data sets due to the possibility of creating misleading results, (Khatitashvili et al., 2006). These models fail to provide insight into the complexity of current port systems, of the potentially complex and hidden linkages established between system inputs and system elements.

Complexity is probably the most significant characteristic of all aspects of our lives and of our global society. But even though the rapid increase of complexity is a recognised problem, complexity isn't being used in decision-making and management. Sustainable development is probably not impossible without due consideration to the phenomenon of complexity. Indeed it is common sense to assume that there are limits as to how much complexity a given system may be capable of before becoming unstable and potentially fragile.

Understanding and defining the problem correctly is crucial when defining a realistic representation of a system. It's also clear that new outcomes will not result unless new procedures are employed. We must then look to improving the way we look at problems and the processes by which things are made, (Godfrey, 2006). One approach is to adopt a holistic perspective and to adopt a methodology that enables the system to be driven from the requirements of the key stakeholders. Systems thinking provides such a framework for problem solving. Recent research has shown that a systems approach can define a wider problem boundary than those limits traditionally adopted by engineers, (Fenner et al., 2006). Systems thinking requires whole-life thinking, i.e. consideration of the implications of every decision, and recognition that what happens in one part of a system affects every other part. Thus this can then lead to the creation of a wider design space in which more holistically conceived solutions can be formulated to any given problem, (Fenner et al., 2005).

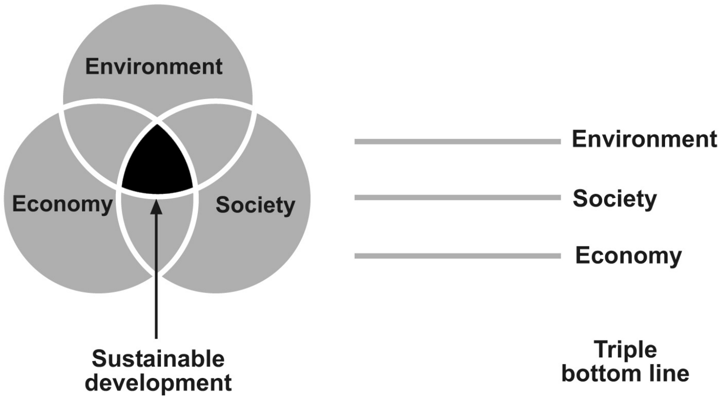
Systems thinking also has the potential to capture complexity. The aim of this paper is to investigate the use of systems engineering techniques and new ideas surrounding complexity management for the designing/managing of sustainable infrastructure systems, within the context of ports and harbours. A key idea being brought to the research study will be to investigate whether comparisons can be drawn between airports and ports and the potential use of distributed data resources/assets can be used for active and sustainable management of systems.

SETTING THE SCENE

Sustainable Development

There has been an enormous amount of work on issues relating to sustainability since the rise of environmental consciousness in the 1970s (Mazmanian and Kraft, 2002), and by far the most common usage of the word "sustainable" is in combination with the word "development", (Mazmanian and Kraft, 2002). According to Parkin et al., (2003) there are over 200 definitions of "sustainable development", and the term has now penetrated planning and various other academic disciplines, and has become one of the pervasive icons of modern times, (Jabareen, 2004). Some researchers see sustainable development as an emerging meta-discipline that is beginning to define a whole new subject area, (Mihelcic et al., 2003).

Fig. 1. Sustainable development: Venn diagram & triple bottom line.



As already indicated definitions of sustainable development vary widely (Jabareen, 2004; Robinson, 2002), however most call attention to the need to maintain resilience in environmental and social systems by meeting a complex array of interacting, environmental, social and economic conditions, (Swart et al., 2004). These dimensions have complex inter-linkages and are often conceptualised as overlapping circles in a Venn diagram, see Fig. 1, and have also been characterised as the Triple P concept: Planet, Profit and People (Serageldin et al., 1994), which emerged out of the Brundtland report on sustainable development (Brundtland, 1987), and is characterised by industry in particular as 'triple bottom line' accounting.

Complexity

Complexity science is a subject that is relatively new and still is compared to more established sciences such as physics, biology and chemistry. With the establishment of the Santa Fé institute in New Mexico in the US in the early 1980s a new research movement emerged which laid the basis for complex systems theory (Holland, 1995; Kauffman, 1995), and this new research is currently attracting a great deal of attention, (Rotmans, 2005). The range of potential research problems and their very diversity can lead to confusion. From one end of the problem domain we might be considering a large software system such as an air traffic control environment, or on the other how Darwinian natural selection accounts for intricate structures such as an eye or kidney, and why rural families in Bangladesh still produce an average of seven children, (Waldrop, 1992).

Most of the systems related to sustainability and sustainable development are typically complex and inter-related, (Brown-Santirso and Peet, 2005; Holmberg and Karlsson, 1992; Giallopin, 2003; Cabezas et al., 2005). These include ecosystems, economies, social systems, and industrial and production systems, (Cabezas et al., 2005). It has been shown that the more complex a system the harder it is to manage. Ports have to achieve a harmonic, complex balance between the local community, the environmental integrity of their processes, and progress economically. One key set of ideas that might be of relevance to all complex systems which various researchers have shown, is that when system's complexity reaches critical levels, which happens over time, systems can become fragile, and therefore vulnerable when exposed to changing and uncertain environments. Conversely the more complex a system the more functional potential that a system posses. In these terms then there are perhaps conscious trade-offs to be achieved in man-made systems, and in particular there may be ways of managing sustainability as a function of complexity. When sustainability and sustainable infrastructures is viewed from the perspective of complexity there may be novel approaches that can be applied to practical systems.

Systems Thinking

Within the last five years there has been a drive by the UK government, the Institution of Civil Engineers (ICE) and the Royal Academy of Engineering to increase the awareness of systems approaches within the Civil Engineering sector, (The House of Commons, 2004; RAE, 2007; Bourgine and Johnson, 2006). There are several examples of its potential benefits in highly published infrastructure projects, and a small group of researchers who are also advocating its use, (P Jowitt from the Scottish Institute of Sustainable Technology; Karl-Henrik Robert from the Natural Step; K Marmen from the Oakland Institute; The Sustainability Institute in Hartland, U.S.; The Polyurethane Industry). In various literature resources, systems and their complexity are now viewed as an essential 21st century science (Living Roadmap for Complex Systems Science), and are predicted to be at the heart of the future Worldwide Knowledge Society. There is also now a "living roadmap" for systems in order to help consultants implement what are considered "big ideas" into European projects, (Living Roadmap for Complex Systems Science). Additionally, since the first major attempt to teach systems was in 1950 at MIT by Gilman, there are now numerous systems engineering centres throughout the world and new systems courses.

The core of systems thinking requires whole-life thinking, i.e. consideration of the implications of every decision, and recognition that what happens in one part of a system affects every other part. Within a sustainable development context this primarily means understanding that the three elements comprising sustainable development are all inter-related and cannot be considered in isolation, e.g. an alternative electricity source such as wind energy installed in a plant must not negatively impact the bottom line, and a new port development cannot be built in an area where air quality and noise emissions negatively impact a local community. Systems approaches begin by understanding the broader system within which problems occur and the principles governing success within that system. This upstream approach means problems are addressed at the source and are turned into opportunities for innovation and business success.

LESSONS FOR PORT PROCESSES FROM AIRPORT MANAGEMENT

The principle operations of a marine port and an airport are fundamentally similar. Both need to dock vessels, offload and load cargo, and are dependant on weather and other indirect social and environmental influences. Perhaps the key difference is the involvement of people, the need for safety, and the shorter times of the key processes. Despite these differences there are perhaps lessons to be learned. A recent study into stress levels of aircraft traffic controllers approached the problem from a holistic systems perspective. The safety of air traffic systems is directly related to the workload and the availability of resources necessary to manage the traffic. For example, a given number of air traffic controllers can efficiently and safely manage only a certain maximum amount of traffic. The goals of the study and ensuing analysis were to identify non-intuitive but distinct patterns of behaviour which governed the overall airport-system processes, and to examine external influences on the airport system from a holistic systems and complexity perspective, and to potentially, in the long-term, outline design and management improvements for the sustainability of airport infrastructure. Insights were gained into airport processes and knowledge models were built from process data. A complex systems analyser (CSA) was used for building the knowledge models from the data and for analysis purposes. The details of this analysis will be discussed in further detail below.

Methodology

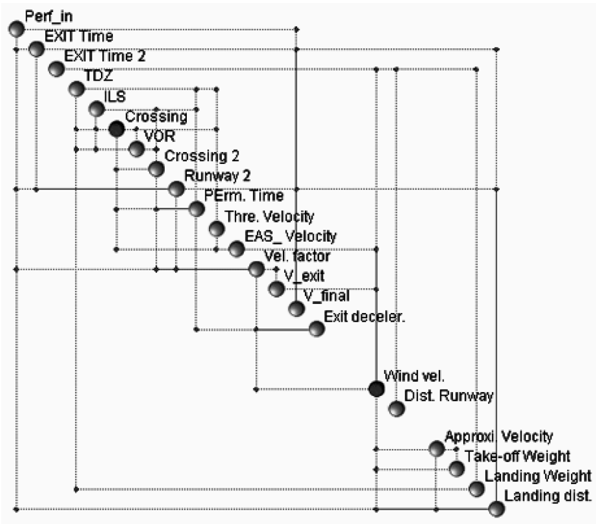
The CSA offers an alternative approach to data analysis, and an entirely novel one, this is to build fuzzy cognitive maps (FCMs) from measured process data characterising the system domain. This novel approach means deriving FCM models and node relationships purely from process data. Fuzzy cognitive mapping is used as a tool for handling imprecise, or ill defined "fuzzy" problems.

The CSA establishes an absolute measure of complexity and this provides a sufficiently robust methodology to allow comparison of similar systems. The software extracts the modes which represent the possible patterns of behaviour of a given system and represents each as a fuzzy cognitive map. System variables are displayed along a diagonal while significant relationships between the variables are represented by 'connectors' located off the diagonal. Hubs, which are inputs with a large amount of connected variables, are indicated in red (an input) and blue (an output). Each relationship establishes, *de facto,* a rule of the type 'if A then B'. The rules being fuzzy. Therefore, a mode in practice corresponds to a set of interrelated fuzzy rules in which certain variables may affect one or more variables at the same time.

Results

Fig. 2 below shows a fuzzy cognitive map from time-series data for the relative movements within the airport and their potential modes of behaviour respectively. Analysed variables are arranged along the diagonal of the map, and 'connectors' off the diagonal show the significant relationships between the variables.

Fig 2. FCM for air traffic management.



As the complexity of a system increases, the number of connectors between the nodes, i.e. the inter-relationships between the variables, increases rapidly. The large red hubs indicate where the system is most vulnerable, and difficult to manage. Analysis reveals that wind velocity appears as an influencing factor of significance within the system, i.e. as the wind increases the workload on the air traffic controllers increases. This data analysis was confirmed by interviews with operators and supported common knowledge and intuition, but which had previously not been formally recognized as a key process variable.

In addition, based on real-time traffic data, complexity may be measured and used to establish and monitor critical traffic density against an agreed baseline. This information is seen to help set workload and also to identify critical periods at different airports in a given traffic sector. Critical complexity of air traffic becomes measurable and therefore manageability and overall operational safety is increased. Knowing "a priori" of critical system complexity, and its causes, provides operators with a powerful new tool for robust operational performance.

Discussion

In the airport example, the primarily concern is the methodology of analysis and the opportunities presented by the novelty of this approach. By taking a wider systems view, say than those immediately obvious measurements such as aeroplane exit time and entry time, landing distribution and runway number, revealed critical system elements previously not focused upon, and most importantly identified critical points and hubs within the process. It was also possible to see how complex the processes are within the airport system and identify the limits of sustainability within that system.

In the case of ports and harbours, we want to look at all the processes within a port system and to find the data that is either available or can be measured to characterise those processes, and then to look at the links and relationships of significance. A range of measures could be analyzed say from dredging metrics to ship movements, cargo handling rates, pilot hours, container movements, no of staff, no of maintenance interventions, rail exports, road movements, exports, and anything else that can be measured and which stakeholders would feel relevant to port operations and that would characterize their processes.

The systems side of the analysis means drawing the system boundaries as widely or narrowly as needed to define the problem, and looking at, and learning from the encapsulated real world events, such as the rise in sea water levels, the loss of marine habitats, and freak weather patterns. The idea is not to look at only one focused part of the system, say the harbour silting model, but to try and look at the system as a whole, and all the interconnecting elements in order to try to discover emergent properties and also the variables that might influence the behaviour in ways not fully apparent at the present. Traditionally this type of analysis is not pursued because there aren't the tools available for this kind of work and it's also very hard to start adding "soft"/"fuzzy" variables into hard models.

In summary, the opportunity here is to use data metrics to characterise a system and use the knowledge model to gain system insights. In this approach the complexity of a process can be captured, and insights can be derived from models. This process does not try to build theoretical models, but rather establish working practice from experience and in a way that enables insight, learning and future planning.

CONCLUSIONS

The scale of the new global challenges demand an alternative approach to engineering problem solving. Systems engineering is a process of continuous learning about the systems in question and their interactions with the dynamic environments with which they are connected. Port authorities are necessarily engaged in a complex global role within business, environment and people. Engineering for sustainable development requires whole-life thinking and consideration of all the implications of every decision.

Systems thinking has much to contribute to improvement in sustainability by helping to create a line of sight from individual activity to emergent properties. A holistic systems approach is a potential way of incorporating real world events into port processes and thus of managing sustainable development. In this context sustainability is seen as directly related to critical system complexity, i.e. a system reaching unmanaged critical complexity will by definition be unsustainable.

Sustainable development presents new problems for port authorities while at the same time presenting opportunities. Solutions offer massive commercial and social gains. The key idea in this paper is to treat sustainability as a branch of complexity science and to bring tools and technologies already available from other fields and to use them as an adjunct to systems thinking.

FURTHER WORK

The next step will be to use port instead of airport data. The challenge will be to convince the various short- and long-term stakeholders that will own various processes and data sets to be willing to contribute to a total system view that will ultimately benefit all parties.

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NUMERICAL STUDY OF THE FLOW FIELD AROUND A SHIP HULL INCLUDING PROPELLER EFFECTS

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Abstract

Although extensive research concerning the flow around ship hull has been carried out in the past decades it is still difficult to calculate the flow around the hull including the propeller. It is well known that the flow behind the ship is affected by the propeller, and the hydrodynamic performances of the propeller are dependent on the incoming flow velocity. In the present paper the viscous flow around an existing vessel is computed including the propeller action. This analysis combines the numerical investigation of flow around the ship with propeller theory to simulate the hull-propeller interaction. The computations are performed using Shipflow code and in-house codes for propeller design. The designed propeller geometry is specified in the flow module in order to obtain the thrust and torque coefficients. The minimum iteration number and grid density are carefully chosen to reduce the computational effort required. The velocity field behind the ship is recalculated into an effective wake and given to the propeller code that calculates the propeller load. Once the load is known it is transferred to the RANS solver to simulate the propeller action. Knowledge on the propeller behavior and the impact of improvements in hull and propeller geometries introduce valuable new perspectives for hull design.

Key words: Potential flow, viscous flow, RANSE, $k-\omega$ SST turbulence model, propeller, wake.

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INTRODUCTION

In recent years, due to the increased computers capacity as well as to the reduced time spent on running the practical calculation of the flow around a ship, the interaction between the ship hull and its propeller seems to be a very interesting topic. Previously studies have focused upon reducing hull resistance while neglecting the effects of the propeller and the interaction between the ship hull and the propeller. Nowadays, the interaction between the propulsor and ship stern flow became the subject of many investigations. Some previous studies focused on observing the propeller action under fully wetted condition, in order to compare the pressures on the hull with and without propeller effects, but this is mainly limited by the high demand of accuracy in the CFD codes and by the large computational effort. It is very important to know how to investigate, locate and even eliminate the influence of the possible errors, such as turbulence modeling errors, integral and interpolation errors, flow limiter errors, grid and geometry errors, iterative errors and other errors yet unnoticed. Therefore, a careful analysis and validation is required.

As a first step, some calculations using the coupled potential flow-boundary layer method have been carried out. Then, various viscous flow simulations based on Reynolds-Averaged-Navier-Stokes (RANS) approach have been performed with and without propeller effects. The RANS computations include the propeller action by applying the body force method. The method considers the thrust and the torque of propeller as a field of forces which can be added to the body force terms in the RANS equations. The propeller forces are calculated using a simple force actuator disk or a lifting line method with specified effective inflow.

MATHEMATICAL MODEL

An alternative approach to the experimental measurements is to use CFD to predict the fluid velocity distribution by solving the fundamental equations of motion using numerical methods. The fundamental equations for fluid flow, which describe the conservation of fluid mass and momentum, are the equation of continuity and the Navier-Stokes equations. In practice, it is impossible to solve these equations directly since the fastest supercomputers with largest memory available falls short of the required performance by many orders of magnitude. However, if the fundamental equations are averaged over a period of time, the computer requirements for the resolution of the flow features are eased enormously. The time-averaging process introduces new variables into the equations that are known as the Reynolds stresses. To close the set of equations, i.e. to have as many equations as unknowns, turbulence models are introduced to express the Reynolds stresses.

Two-equation turbulence models represent the largest class of turbulence models used in engineering CFD. The models generally consist in a coupled transport equations for the turbulent kinetic energy k and its rate of dissipation. Since the standard $k-\varepsilon$ model often does not produce satisfactory results, some other turbulence models have been developed. One of them is the $k-\omega$ model that in some ways performs better then the $k-\varepsilon$ model. A new shear stress transport $k-\omega$ model, with remarkable advantages when compared with $k-\varepsilon$ and previous $k-\omega$ models, was proposed by Menter. The model is based on the assumption that the principal shear-stress is proportional to the turbulent kinetic energy, which is introduced into the definition of the eddy-viscosity. In the $k-\omega$ SST model the $k-\omega$ model is used near the wall and the $k-\varepsilon$ model, transformed to resemble the $k-\omega$ model, is used outside of this region. The different sets of coefficients and the additional cross-diffusion term from the transformed $k-\varepsilon$ model are combined by blending or switching functions F_i in an intermediate region. With these approaches, it is possible to solve all equations without the use of wall functions, and this is itself a significant improvement.

Governing equations and turbulence modeling

In Cartesian tensor notation form, using the Reynolds decomposition, the unsteady incompressible RANS and continuity equation are written as follows:

$$\frac{\partial u_i}{\partial x_i}=0 \tag{1}$$

$$\frac{\partial u_i}{\partial t}+\frac{\partial\left(u_j u_i+\overline{u_j' u_i'}\right)}{\partial x_j}=\overline{R_i}-\frac{1}{\rho}\frac{\partial p}{\partial x_i}+\frac{\partial}{\partial x_j}\left(\upsilon\left(\frac{\partial u_i}{\partial x_j}+\frac{\partial u_j}{\partial x_i}\right)\right) \tag{2}$$

where x_i represents the Cartesian coordinates, $x_i = (x, y, z)$, u_i are the time averaged velocity components in Cartesian directions, U_i are the velocity components in Cartesian directions, $U_i = u_i + u'_i$, u'_i, are the time fluctuating velocity components in Cartesian directions, R_i is the volume force, P is the instantaneous pressure, $P_i = p + p'$, p is the time average pressure, p' is the fluctuating pressure, ρ is the density, υ is the kinematic viscosity, $\upsilon = \mu/\rho$, and μ is the dynamic viscosity. Using the Boussinesq approximation, the Reynolds stress tensor $\rho\,\overline{u'_i u'_j}$ can be written in the following form:

$$\rho\overline{u_i' u_j'}=-\mu_T\left(\frac{\partial u_i}{\partial x_j}+\frac{\partial u_j}{\partial x_i}\right)+\frac{2}{3}\rho k\delta_{ij} \tag{3}$$

where δ_{ij} is Kronecker delta and is the turbulent kinetic energy. The new Reynolds-averaged equations are written as:

$$\frac{\partial u_i}{\partial t}+\frac{\partial\left(u_j u_i+\overline{u_j' u_i'}\right)}{\partial x_j}=\overline{R_i}-\frac{1}{\rho}\frac{\partial p}{\partial x_i}-\frac{2}{3}\frac{\partial k}{\partial x_i}+\frac{\partial}{\partial x_j}\left(\upsilon_E\left(\frac{\partial u_i}{\partial x_j}+\frac{\partial u_j}{\partial x_i}\right)\right) \tag{4}$$

where υ_E is the effective kinematic viscosity defined as $\upsilon_E = \upsilon + \upsilon_T$. The Reynolds stresses are related to the mean rate of strain through an isotropic eddy viscosity $\upsilon_T = \mu_T/\rho$, which is calculated using Menters combination of $k-\omega$ and $k-\varepsilon$ turbulence models:

$$\frac{\partial k}{\partial t}+\frac{\partial\left(u_j k\right)}{\partial x_j}=-\overline{u_i' u_j'}\frac{\partial u_i}{\partial x_j}-\beta^* k\omega+\frac{\partial}{\partial x_j}\left(\left(\upsilon+\sigma_k\upsilon_T\right)\frac{\partial k}{\partial x_j}\right) \tag{5}$$

$$\frac{\partial \omega}{\partial t}+\frac{\partial\left(u_j \omega\right)}{\partial x_j}=-\frac{\gamma}{\upsilon_T}\overline{u_i' u_j'}\frac{\partial u_i}{\partial x_j}-\beta^*\omega^2+\frac{\partial}{\partial x_j}\left(\left(\upsilon+\sigma_\omega\upsilon_T\right)\frac{\partial \omega}{\partial x_j}\right)+2\sigma_{\omega_2}\frac{1-F_1}{\omega}\frac{\partial k}{\partial x_j}\frac{\partial \omega}{\partial x_j} \tag{6}$$

Here β^*, γ, σ_k, σ_{ω_2} are the modeling coefficients for $k-\omega$ equations and F_1 is the switching function for handling the change between the ω and ε equations.

Boundary conditions

The boundary conditions within the computational domain are requiring the no-slip conditions on the hull surface as follows: zero velocity, a Neumann condition for the pressure, and a Dirichlet conditions for k and ω. In the symmetry plane, zero-gradient Neumann conditions are imposed for all the variables. At the upstream, k, ω and the velocity are supposed to be constant, whereas the pressure is extrapolated with zero-gradient. At the downstream, the velocity, k and ω are extrapolated with zero-gradient, while the dynamic pressure has the zero value.

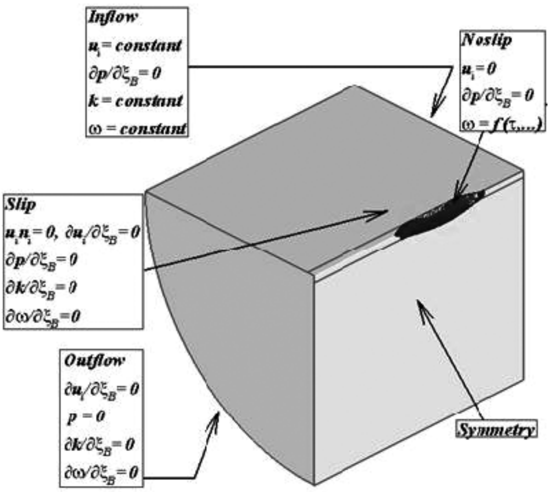


Figure 1. Solution domain

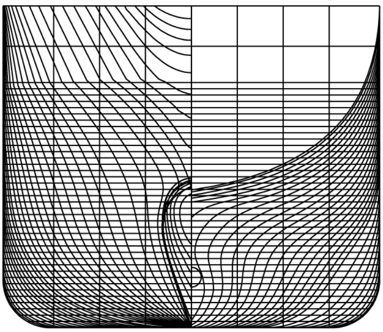
STRATEGY

The geometry of the ship is defined by an offset file based entirely on the lines plan depicted in Figure 2. The offset file has been prepared in order to discretize the hull for the numerical computations. For computing waves, wave resistance, lift and induced resistance, a potential flow method has been used for various Reynolds numbers. This potential solving module provided also the input to a boundary layer method, which predicts transition and boundary layer parameters on the forward half of the ship. For predicting the viscous flow, a RANS code with boundary conditions defined by the potential flow results and the boundary layer parameters was used. The free surface is obtained as potential-flow solution and is kept fixed for the solution of the RANS equations. The viscous computations were performed on a LPG carrier having the main particulars tabulated in Table1, with and without propeller. The propeller model calculates the body-forces based on the effective wake field, which means that the propeller solver, which is implemented in the CFD code, is running interactively with the RANS solver. The viscous module specifies the body forces in the cells of an additional cylindrical grid that covers the location of the propeller. The body forces are distributed between the hub and the maximum propeller diameter and also in the axial direction to avoid abrupt changes and concentration of introduced forces. The propeller can be modeled as an actuator disk with prescribed thrust and torque, or using the lifting line theory. The propeller position, detailed geometry and advance ratio are specified for the lifting line method, while if a force actuator disk model is used, the detailed geometry is not necessary.

Table 1. Main particulars of the ship.

Length overall	125.36	[m]
Length between perpendiculars	117.9	[m]
Breadth moulded	20.5	[m]
Draught	7.64	[m]
Ship speed	16	[knots]

Figure 2. Lines plan.



Along the whole hull a single structured 3D numerical grid was created with clustering of cells in near the bow and stern regions. By using suitable parameters for viscous computations, the 3D overlapping grid generator provided a grid having 283x32x60 grid nodes in the longitudinal, transverse and normal direction, respectively, and the inner surface fitted to the hull (see Figure 3). Taking into account that the solver does not use wall laws, another clustering of cells was needed closest to the hull surface where the height of the cells should be very thin. For generating this single block grid, the program computes the outer boundaries, controlling permanently the orthogonality functions. Interpolation weights are computed and saved for all interpolation points at the edge of each grid. To avoid mismatch, special techniques are used to handle the interpolation between the extremely thin cells close to boundaries where the no-slip condition is to be applied. The detailed grid topology generated around the hull extremities is depicted in Figure3. To make the picture more readable, only some slices in the grid were displayed.

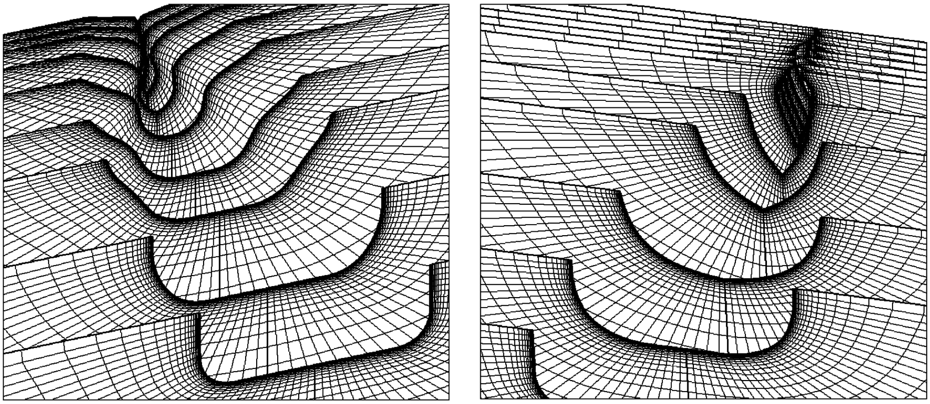


Figure 3. Three dimensional grid generated for the viscous calculations.
The detailed aft (left)and the fore parts of the hull (right).

After the viscous calculations of the flow around the ship without propulsor, an additional cylindrical component grid (having 12x16x16 grid nodes) was added to simulate the operating propeller. Figure 4 shows the circular grid fitted behind the ship to create both symmetric and three dimensional effect of the propeller in order to compute the trust and torque.

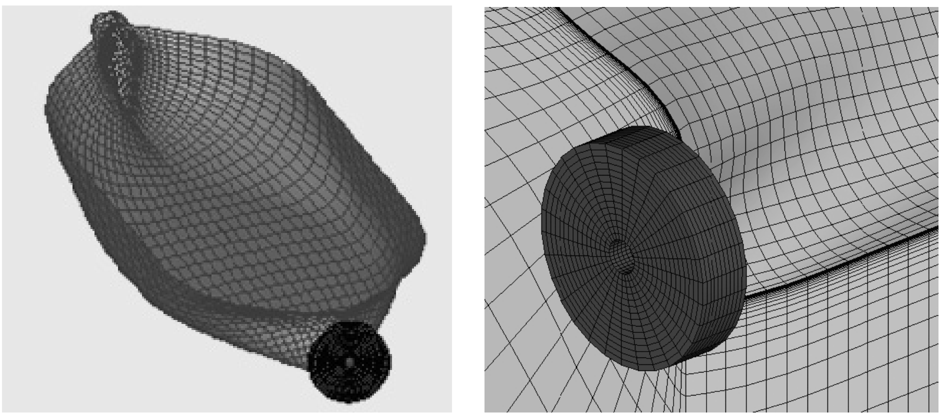


Figure 4. Cylindrical grid for simulating the propeller.

In the code, an actuator disk may be included or the body forces can be computed by a lifting line propeller analysis method that runs interactively with the RANS solver. Using the velocity computed in each numerical cell within the propeller disk, the lifting line program computes the circulation and thereby also the axial and tangential body forces, which are returned to the flow solver in an iterative process. The propeller and hull geometries are represented by no-slip faces resolved directly in the RANS approach and therefore they become parts of the viscous flow solution. The method gives very detailed information about the stern and propeller flows.

RESULTS AND DISCUSSIONS

Useful CFD results are provided by the potential flow method which can be extensively used for the optimization of hull shapes. The optimization is normally based on the predicted waves and hull pressure distribution that is why an analysis of the simulated wave profiles has been performed. The results can be seen in Figure 5, which depicts the wave profile non-linearly computed for the service speed. Another set of simulations was performed for a speed range between 14 and 18 knots for a better understanding on how the velocity affects the wave patterns on the hull. As expected, the more the speed increases, the higher the stern wave crest becomes. For validation purposes, a comparison between the total hull resistance calculated with the Holtrop-Mennen method and the one computed with Shipflow is further brought into focus in Figure 6.

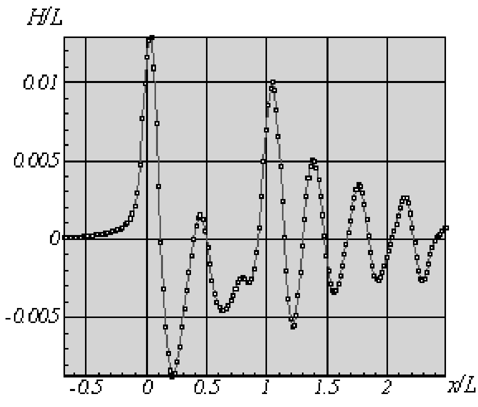


Figure 5. Wave profile non-linearly computed for 16 knots.

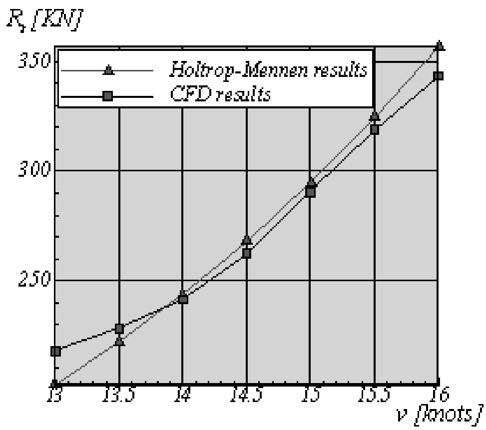


Figure 6. Comparison between the computed resistances.

Having various input data (such as ship resistance and propulsive factors), a set of series propellers have been designed. In the propeller design process, for the estimation of the propulsive performances, it is customary to do first stock propeller simulation. By doing that, one could get a quick idea about the effective wake fraction, thrust and assessment of power before designing the final ship propeller geometry. At this initial stage of the propeller design, series propellers were used (Wageningen B-series propeller) in the numerical and experimental simulations. In the first case, with results from the Holtrop-Mennen method, a B-series propeller was calculated in order to obtain the optimum propeller diameter. Having the main characteristics, some simulations including an actuator disk were performed. The computations provided an effective wake that was used in re-designing the propeller for the next simulation case. Although quite accurate propeller characteristics were obtained, as a last step, a wake-adapted propeller was designed using one of the in-house codes based on the lifting-line theory (case3).

Table 2. Measured and calculated propeller quantities.

Propeller characteristics		Case1	Case2	Case3	Experiment
K_T	thrust coefficient	0.193	0.197	0.226	0.206
K_Q	torque coefficient	0.032	0.033	0.037	0.034
η_0	efficiency	0.637	0.624	0.639	0.623
P/D	pitch ratio	10.007	0.984	0.971	1.05
A_e/K_0	expanded area ratio	0.55	0.55	0.53	0.55
D	propeller diameter	5.4	5.4	5.3	5.4
w	wake	0.268	0.319	0.319	0.290

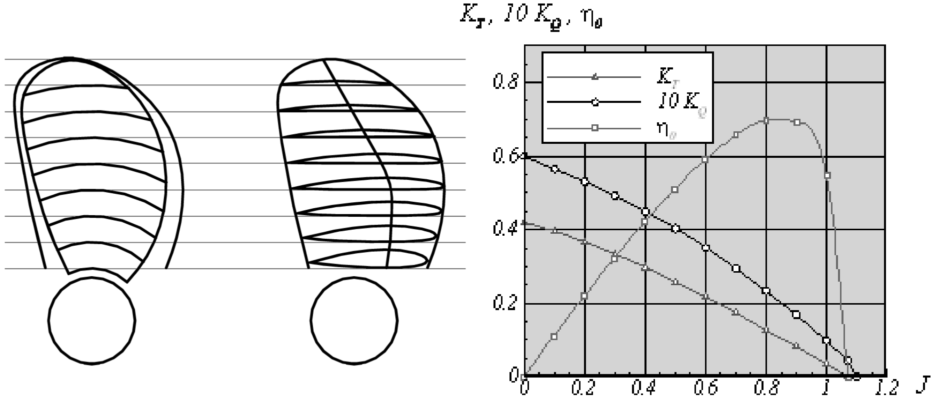


Figure 7. Main characteristics of the B-series propeller used in Case 2. Propeller geometry (left) and open-water characteristics (right).

Simulations based on RANSE approach were carried out to obtain a base reference for comparing the flow around the hull with and without propeller effect. Developing thrust and accelerating the flow in which it works, the propeller leads to different hydrodynamic characteristics in open water and behind the ship. Between nominal and effective wake a serious distinction must be made. The nominal wake is the wake behind the hull without propeller. The wake velocities with the propeller operating behind the ship and developing thrust is called effective wake. As seen in Figure 8, the propeller thrust creates strongly axial flow acceleration behind the propeller comparing with the bare hull conditions.

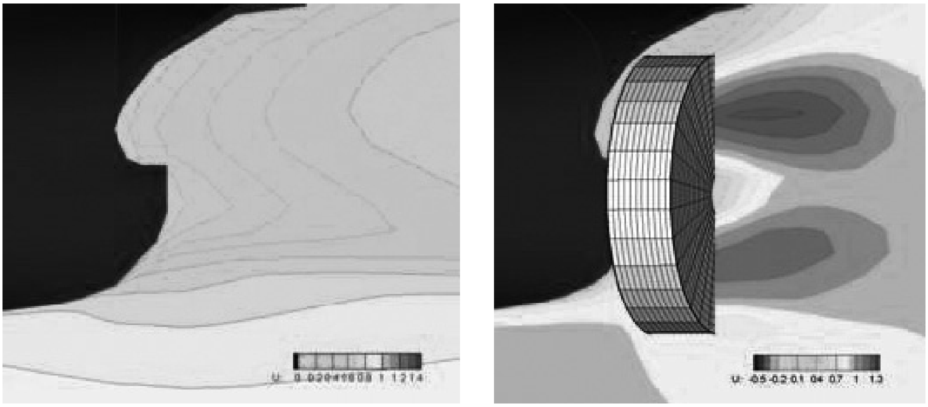


Figure 8. Axial velocity contours for nominal (left) and effective wake (right).

The numerical solution reveals a rather complex flow field in the stern region where the velocity distribution and propeller loading reflects changes in the flow field.

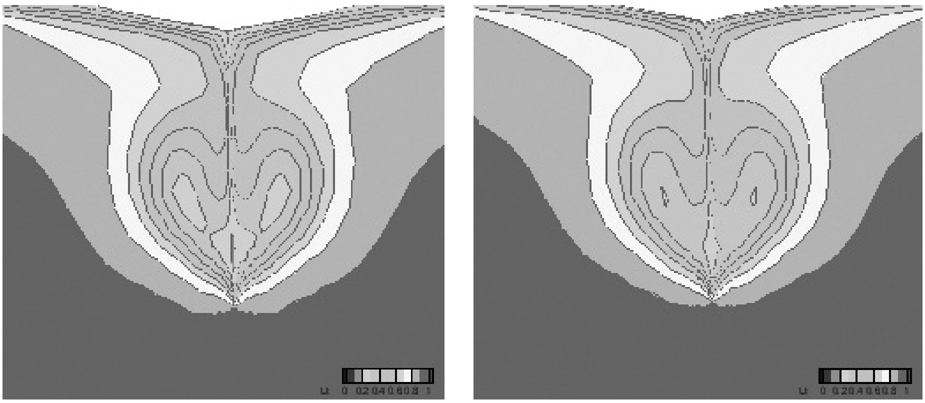


Figure 9. Wake contours behind the ship hull.

The wake contours in the propeller disk are quite well predicted, exhibiting islands of low axial velocity and a fairly pronounced "hook" as proven in Figure 9,. Many researchers in viscous flow CFD directed their jobs towards improving the ability to predict these features. On closer inspection it turns out that the wake hooks, which are present for large classes of ships, are caused by the bilge vortices, generated at the bilge and hitting the propeller plane inside the propeller disk. An accurate calculation of these vortices and then a better prediction of the hooks are determined by the advanced turbulence model. Experience shows that such predictions are mostly sufficiently accurate for design purposes.

CONCLUDING REMARKS

Summarizing the results, non-linear free-surface potential flow around the hull was successfully computed and ship resistance was also determined through the numerical simulations. Based on the RANSE approach various simulations were carried out to compute the flow around the ship hull with and without an operating propeller (applying the body force method). A Wageningen B-Series propeller has been employed to estimate the performances of the given hull. Taking into account the efforts related in modeling the propeller, the method appears to be useful in connection with studies of propeller-hull related flow problems. In general, quite accurate propeller characteristics were obtained. In the prediction of the wake details, turbulence modeling was the key issue. Thanks to the $k-\omega$ SST turbulence model, seems like the RANS method predicted integrated quantities of the wake reasonably well. In the future, another wake validation will be performed by comparing numerical and experimental simulations but using the final optimum propeller.

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The *bibliographic references* are to be arranged in alphabetical order (and chronologically in the case of several works by the same author), as is indicated in the following examples:

Books

Farthing, B. (1987) *International Shipping.* London: Lloyd´s of London Press Ltd.

Chapters of books

Bantz, C.R. (1995): Social dimensions of software development. In: Anderson, J.A. ed. *Annual review of software management and development*. Newbury Park, CA: Sage, 502-510.

Journal articles

Srivastava, S. K. and Ganapathy, C. (1997) Experimental investigations on loop-manoeuvre of underwater towed cable-array system. *Ocean Engineering* 25 (1), 85-102.

Conference papers and communications

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.

Technical Reports

American Trucking Association (2000) *Motor Carrier Annual Report*. Alexandria, VA.

Doctoral theses

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

Patents

Philip Morris Inc., (1981). *Optical perforating apparatus and system*. European patent application 0021165 A1. 1981-01-07.

Web pages and electronic books

Holland, M. (2003). *Guide to citing Internet sources* [online]. Poole,
Bournemouth University. Available from:
http://www.bournemouth.ac.uk/library/using/guide_to_citing_internet_sourc.html
[Accessed 1 November 2003]

Electronic journals

Storchmann, K.H. (2001) The impact of fuel taxes on public transport — an empirical assessment for Germany. *Transport Policy* [online], 8 (1), pp. 19-28 . Available from:
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