ANTIFOULING PAINT SCHEMES TO MINIMIZE THE RISK OF TRANSMIGRATION OF INVASIVE SPECIES

A. Mukherjee[1*], Madhu Joshi[2], S.C. Misra[2] and U.S. Ramesh[2]

[1]Gayatri Vidya Parishad, College of Engineering, Madhurawada, Visakhapatnam - 530048

[2]Indian maritime University (NSDRC) , Visakhapatnam campus, Gandhigram, Visakhapatnam 530005

Biocorrosion or biofouling on ships hull occurs to the attachment of barnacles, mollusks and Other aquatic organisms on the surface of ships which leads to increase in fuel consumption, reduction of the vessels speed, premature failure of the hull, etc. Recent developments in antifouling paints, in general, prevent fouling in about 95% percent of the vessels underwater surface, which ship operators find satisfactory as far as the routine vessel operation is concerned. However, this is not sufficient enough to prevent the transport or invasion of alien species which result in numerous environmental issues that include reduction and extinction of native species and thereby seriously disrupting the natural ecosystems. Virtually all ocean going vessels are coated with antifouling paints, predominant among them are "Self polishing coatings" and "Foul Release Coatings". Both these coatings depend on hull shear forces caused by the motion of the vessel, by different mechanisms, to result in the hull to be essentially foul-free. Currently hulls are coated with a uniform layer of antifouling paints. However, CFD analysis conducted on various types of vessels have shown highly non-uniform wall stress distribution along the vessels hull. This results in premature paint failure for "Self polishing Coatings" and insufficient shear forces for "Foul release coatings" to release the attached fouling organisms. Both these factors contribute significantly to the transmigration of invasive species. Preliminary results of the current work indicate that certain areas of the vessel such as such as bow thrusters, sea chest, stern tube, rudder etc. are the likely areas to be heavily fouled thereby warranting special attention in such areas. Solutions to these issues include alternative paint schemes/formulations in the identified niche areas to account for non-uniform shear and polishing of paints. Such schemes would ultimately reduce the risk of transmigration of invasive species

INTRODUCTION

Prevention of fouling on ships hulls has long been a priority for ship owners and operators because of the negative impact fouling has on the economy and performance of a vessel. Hull fouling reduces vessel speed, increases fuel costs and imposes time and costs for hull maintenance (Townsin, 2003). The use of biocide based antifouling paints are the most economical method to control hull fouling (Hare, 2000). Biocide

* Corresponding author: e-mail: admukh@hotmail.com

based antifouling paints that are continuously designed to leach biocides at the paint/seawater interface are the predominant means of controlling fouling for a vast majority of the vessels. Recent advances in antifouling paint technology have led to the development in highly effective antifouling paints which generally result in foul free hulls for periods ranging from three to five years. However, even the best maintained vessels are fouled to the extent of at least five percent of the total surface area. This fouled

area, although a small fraction of the entire vessel surface and does not effect the general performance of the vessel, is the primary vector for transmigration of invasive species, which is a serious environmental issue and immediate measures to address this issue are imperative in order to prevent major and possibly irreversible damage to the marine ecosystem (Drake and Lodge, 2007).

INVASIVE SPECIES

An alien (also known as exotic, introduced, invasive, non-indigenous, non-native) species is any species intentionally or accidentally transported and released by man into a habitat outside its native geographical range: otherwise it could not be able to overcome environmental barriers (ocean waters, land masses) separating its region of origin from new locale. These human- mediated invasions, often referred as biological pollution, represent a growing problem due to the unexpected and unwanted impacts the nuisance species might cause to the environment, economy and human health (Minchin and Sides, 2003). Effects of alien species on marine environment and native biodiversity are numerous. They include changes in resource competition (food, space, spawning areas); physical changes in habitat (reduced water movement, biogenic erosion of shores, alteration of bottom substrate); limitation of resources (nutrients, light, oxygen); detrimental changes in the tropic web due to introduction of a new functional group; harmful algal blooms; genetic effects on native species (hybridization, change in gene pool, loss of native genotypes); drastic reduction of the population size or even extinction of native species. Environmental changes induced by biological invasions often also cause economic impacts as well,. For instance: invasive alien species can compete with and reduce commercial fish stocks; toxic blooms can affect aquaculture, erosion of shores can harm coastal installations. Invasive species may also directly effect: water abstraction (clogging of water intake pipes); aquatic transport (fouling of boats, buoys etc., including costs of cleaning and antifouling painting, which, in turn, harms the environment); tourism (massive accumulation on shores causing smell, discoloring of water, sharp shells); fisheries (clogging and fouling of fishing gears, damage of catches in nets); aquaculture (fouling of lines, cages, cultured mollusks, fish kills, etc.) as well as human health (newly brought infections, toxins in wild-harvested fish and shellfish, new intermediate hosts for human parasites, etc.). The United Nations Environment Programme (UNEP) and World Conservation Union (IUCN) announced at the World Summit on Sustainable Development (WSSD) in Johannesburg in 2002, that invasive species are the second greatest threat to global bio-diversity after habitat loss. Alien aquatic species are mostly transported intentionally for stocking and aquaculture purposes or unintentionally with interregional and intercontinental shipping. The importance of ship transportation in the spread of invasive species has increased tremendously in recent time primarily due to the fact that there has been a large increase in shipping traffic as well as an average increase in vessel speed, thereby increasing the chances of survivability on the transported organisms (Cohen & Carlton, 1995, Eno *et al*, 1995). Vessels provide habitats for a large variety of organisms, from viruses and microorganisms to various plants and animals, due to their transport of ballast water, sediments in tanks and hull fouling.

ANTIFOULING PAINTS

The control fouling, antifouling coatings are used on the underwater hull area of vessels. A wide variety of these coatings are available quite often to suit the requirement of the vessels speed and activity. An excellent review of commercially available antifouling paints is given by Yebra *et al.*(2004) and the major groups of coatings that are widely used by the commercial shipping industry are listed below

Coating Type	Characteristics
Soluble Matrix	Water soluble
Insoluble Matrix	Water insoluble
Self Polishing	Water Reacting
Foul Release	Low energy Surfaces

These coatings are briefly discussed below

Insoluble Matrix Antifouling Paints These paints are also called diffusion or insoluble matrix coatings, based on insoluble resins such as chlorinated rubber, vinyl, or acrylic groups (Kjaer, 1992). In these types of paints, only the biocides are leached out leaving behind a porous paint film skeleton and as the thickness of the porous layer increases, the leaching rate of the biocide is reduced. The paint skeleton remaining after the leaching process is over is relatively weak, making re-coating with fresh paint difficult. The effective life of these paints is about 12 months. (Anderson, 2000)

Soluble Matrix Antifouling paints In the conventional free association paints, the biocide is physically dispersed and subsequently released from the paint matrix. Sea water penetrates into the paint film and leaches out the biocide. The water-soluble biocides are typically dispersed in a slightly soluble matrix usually made of resin, plasticizers, or synthetic polymers (Callow, 1996). The life span of these paints is usually between 12 and 18 months. In the eroding/ablative or controlled depletion polymer coatings, in addition to the leaching of the biocide, the paint matrix is continually worn of by a dissolution/erosion process which increases the leaching rate of the biocide. The most common biocide used in these paints is copper either as a metal or as a compound. To improve the efficiency, booster biocides are frequently incorporated into the paint matrix. The AF performance of these paints is reported to be approximately 30 months.

Self-polishing copolymer To reduce the leaching rate of the biocide and to increase the efficacy of the paints, self-polishing (SPC) paints were introduced in the mid-1970s. In this class of paints, the biocide is chemically bonded to a copolymer (Anderson, 1993, Hunter and Cain, 1996). The leaching rate of the biocide is very controlled due to the fact that biocide is released when sea water reacts with the surface layer of the paint. The SPC paints allow the application of thicker coatings with the biocide chemically bonded throughout the coating. This results in the slow and uniform release of biocides to the surface. The biocide release for these coatings is only a few nanometres deep and the spent layer is slowly eroded away and a new active layer develops. SPC coatings are the most widely used in the shipping industry. The popularity of these AF coatings was primarily due to a controlled chemical dissolution of the paint film capable of long dry-dock intervals, typically between five to seven years; predictable polishing, enabling tailor-made specifications by vessel/operation; thin leached layers, making it easy to clean and recoat; good weather ability, quick drying, and extremely good value for money.

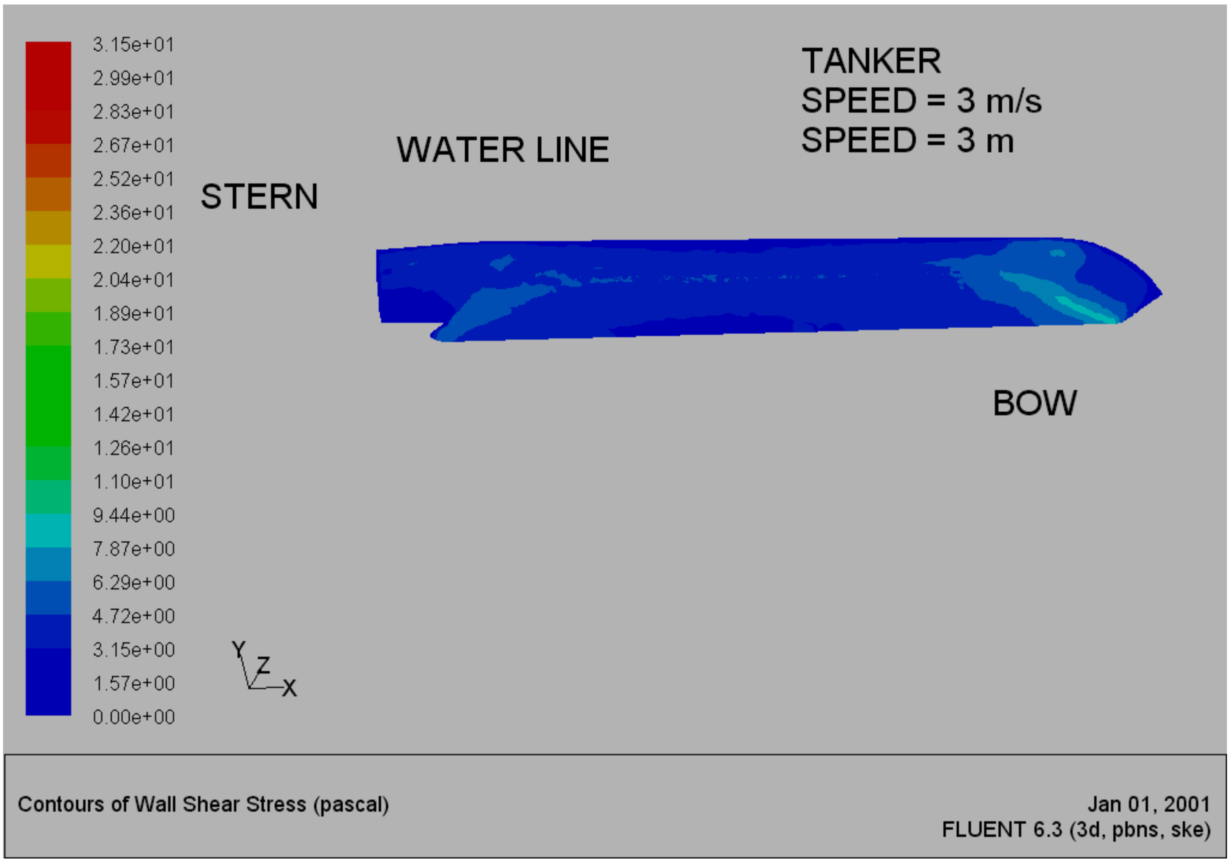
Foul Release Coatings Most non-stick coatings use PDMS (polydimethylsiloxane) as the backbone polymer and are familiarly known as silicone based paints (Baier and Meyer, 1994). The characteristics of these paints are that they possess a very low surface energy for the attachment of marine organisms. In addition, they are hydrophobic, flexible, possess low surface micro roughness, and are biocide free. Marine organisms that do attach on the surfaces coated with these paints are easily removed by low pressure water wash.

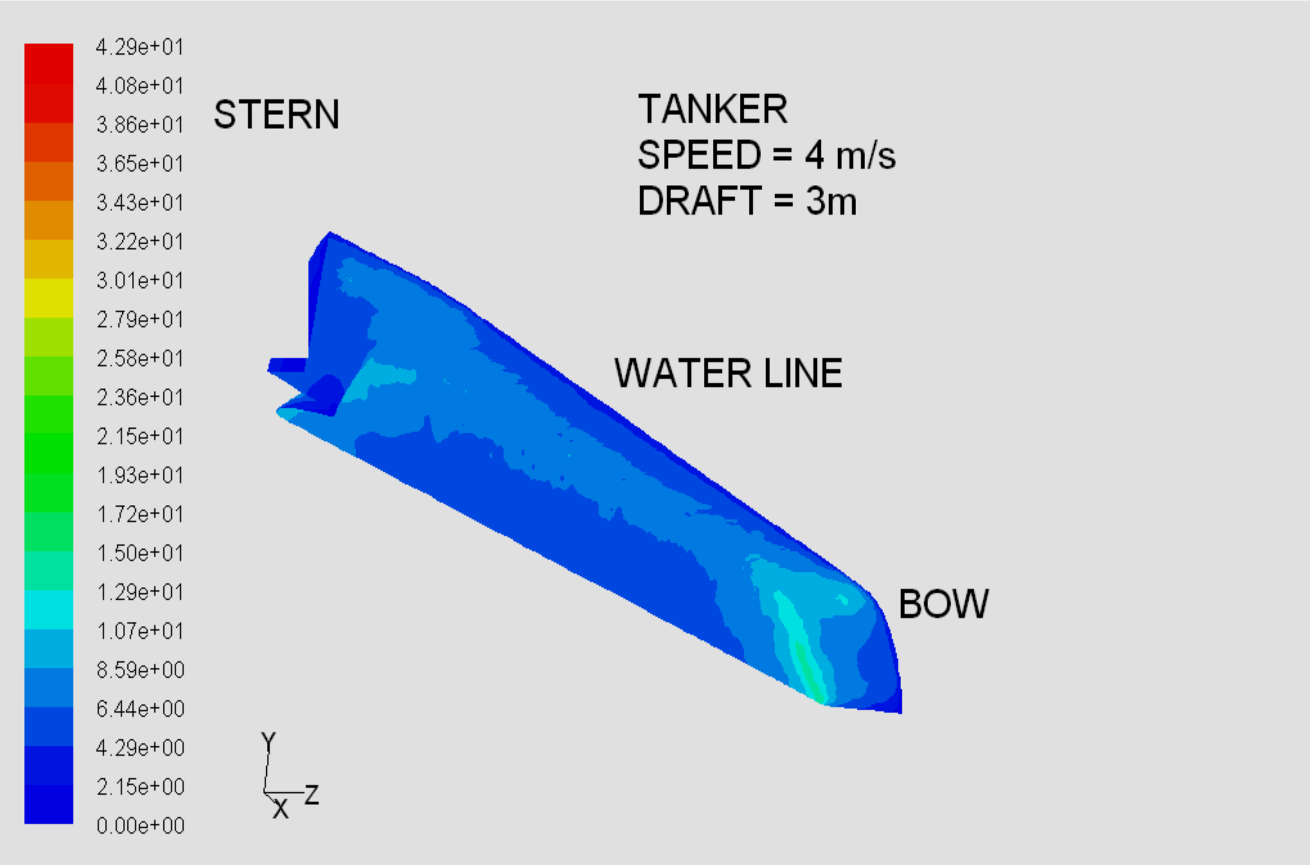
PERFORMANCE OF ANTIFOULING COATINGS

Insoluble matrix and soluble matrix antifouling paints are seldom used in the commercial shipping industry due to short life span and thereby resulting in more frequent dry-dock intervals. However, due to their low cost they are widely used in the boating industry.

The most frequently employed AF paints in the shipping industry are the self polishing paints (SPC). The extent of polishing action in these coatings depends on the hydrodynamic forces at the paint-seawater interface. The higher the hydrodynamic forces, the higher are the polishing rates. Conversely, lower hydrodynamic forces at the paint-seawater interface imply lower polishing rates. Figures 1 and 2 shows the wall shear stresses of a 200 meter long tanker using computational fluid dynamics (CFD) techniques and figures 3 and 4 show the computed stresses of a 100 passenger vessel operated by the Andaman and Nicobar administration. In all the figures shown below there is a variation in the wall shear stresses throughout the hull, which depends on the speed, the draft and the vessel profile. Certain areas of the vessel such experience higher hydrodynamic forces and therefore higher polishing rates thereby resulting in premature fouling. Conversely, areas where the forces are considerably smaller, would experience lesser polishing rates which would result in insufficient amount of biocides being delivered which would again result in premature fouling.

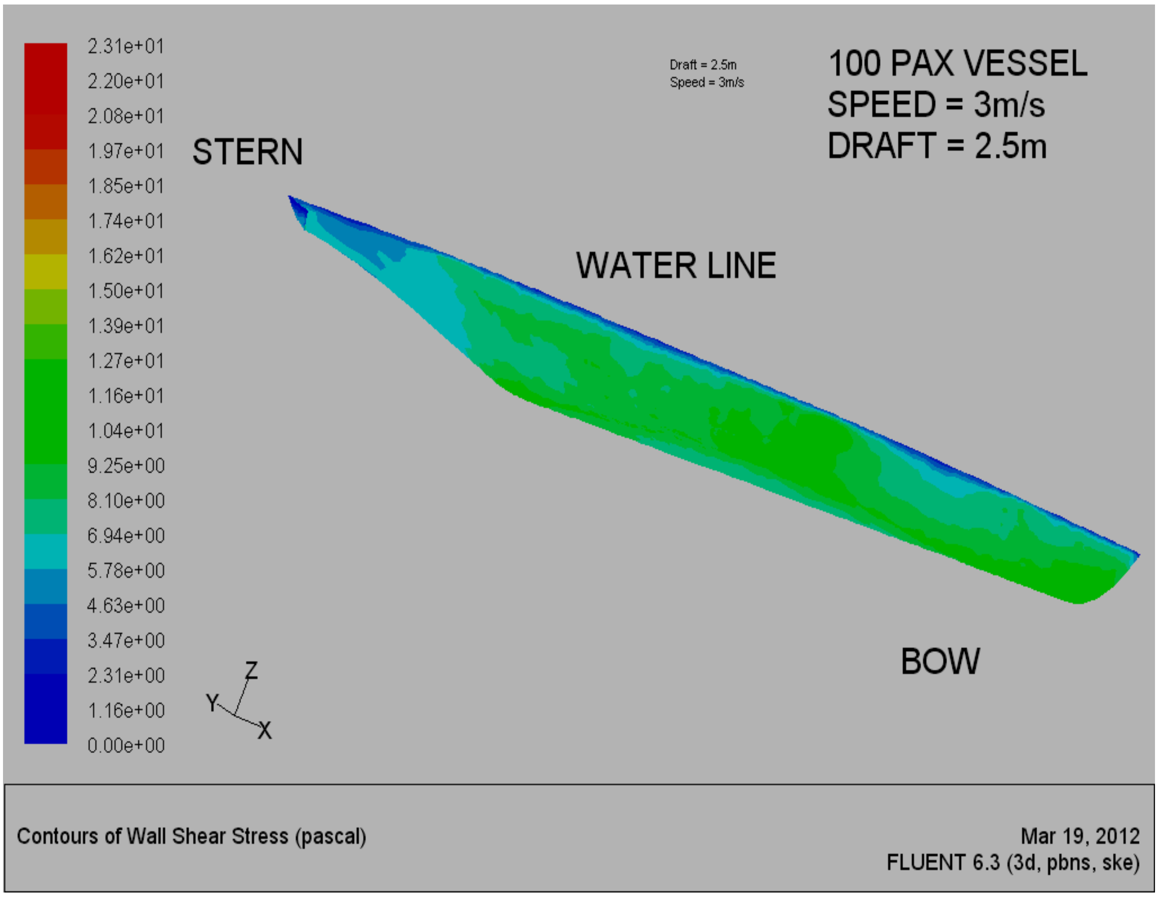
The current painting practice is that an antifouling coating of uniform thickness is applied without taking into considerations of the various hydrodynamic forces. For both the tanker and the 100 passenger (PAX) vessel, the computed shear stresses at the waterline and the stern have lower than average hydrodynamic forces which indicates low polishing rates, the extent of which depends on the draft, speed and type of vessel. In these areas insufficient biocide delivery results which is likely to result in premature fouling. On the other hand, for the tanker in particular, the shoulder of the vessel (below the bow) experiences high wall stresses which result in higher polishing rates in comparison to the rest of the vessel. This would lead to the premature depletion of the antifouling paint and would again result in fouling much ahead of the bulk of the surface of the vessel.

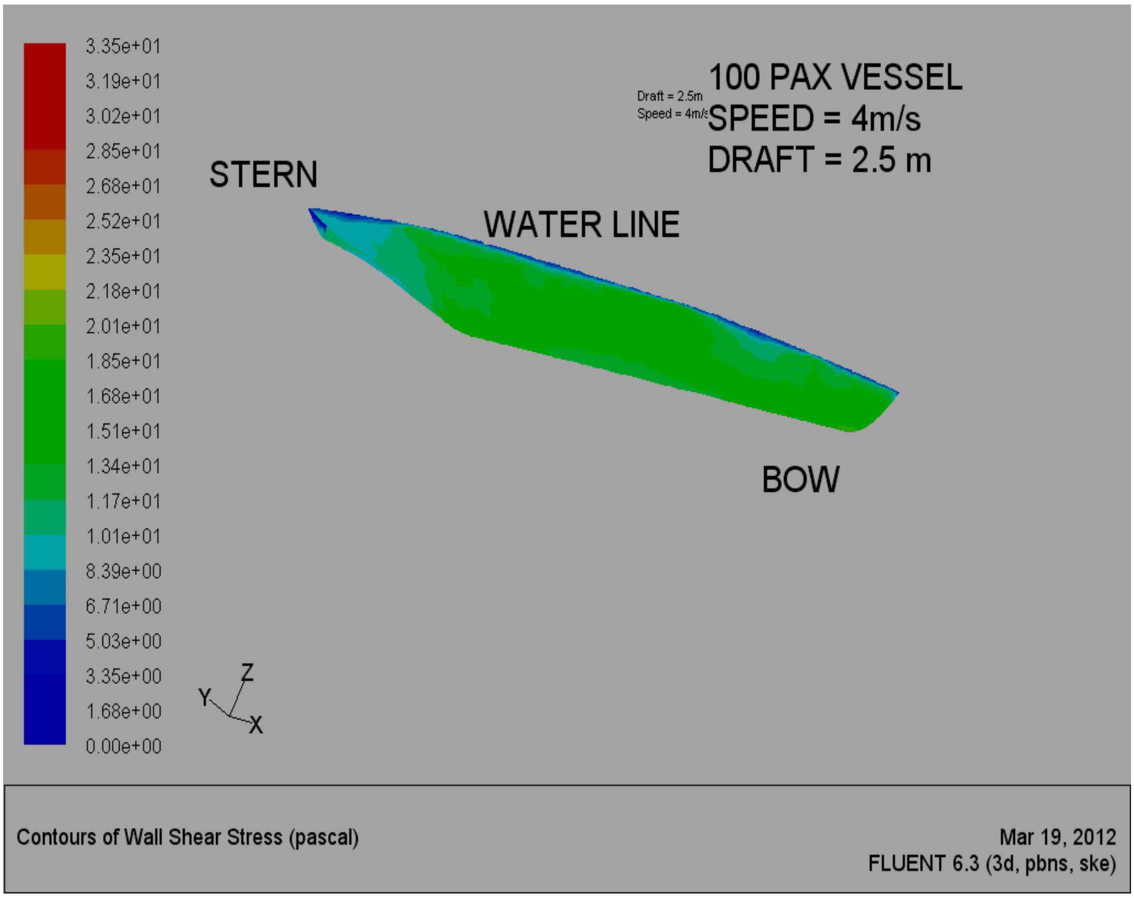




Contours of Wall Shear Stress (pascal)

Jan 01, 2001
FLUENT 6.3 (3d, pbns, ske)


2.31e+01
2.20e+01
2.08e+01
1.97e+01
1.85e+01
1.74e+01
1.62e+01
1.50e+01
1.39e+01
1.27e+01
1.16e+01
1.04e+01
9.25e+00
8.10e+00
6.94e+00
5.78e+00
4.63e+00
3.47e+00
2.31e+00
1.16e+00
0.00e+00
STERN
Draft = 2.5m
Speed = 3m/s
100 PAX VESSEL
SPEED = 3m/s
DRAFT = 2.5m
WATER LINE
BOW
Z
Y
X
Contours of Wall Shear Stress (pascal)
Mar 19, 2012
FLUENT 6.3 (3d, pbns, ske)



CONCLUSIONS

CFD analysis of hydrodynamic forces around the vessel's hull shows that there are non-uniform wall shear stresses around the hull of vessels. The current practice of painting is that a coat of uniform thickness is applied over the entire hull and as self-polishing antifouling paints depend on these hydrodynamic forces for the delivery of biocides to inhibit fouling, non-uniform biocide delivery is likely to result in premature fouling in certain niche areas of the vessel. Field data indicates that although premature fouling takes place in less than five percent of the vessels surface area, this is more than sufficient to result in an exponential increase in transmigration f invasive species. In order to alleviate this problem, special paint schemes are required in these niche areas and CFD analysis of the hydrodynamic forces around the vessels hull is a useful tool to identify such areas.

REFERENCES

Anderson, C.D. 1993. Self-polishing antifoulings: A scientific perspective. In, Proceedings, Ship Repair & Conversion 93, London, November 1993.. 1-17.

Anderson C. 2000. Coatings, antifoulings. Kirtk-Othmer Encyclopedia of Chemical Technology. Vol 7. p150-167.

Baier, R.E. and Meyer, A.E. 1994. Surface analysis of fouling-resistant marine coatings.

In, Thompson, M.-F., Nagabhushanam, R., Sarojini, R. and Fingerman, M. (eds.), Recent
Developments in Biofouling Control. A.A. Balkema, Rotterdam. 285-304.

Callow, M.E. 1996. Ship-fouling: The problem and methods of control. Biodeterioration Abstracts 10, 411-421.

Cohen, A.N and J.T Carlton. 1995. Nonidigenous aquatic species in a United States estuary, A case study of biological invasions of the San Fransisco bay and Delta, A report for the United States fish and wild life service and the national sea grant program [NTIS PB96-166525]

Drake J M and D M Lodge, 2007. Hull fouling is a risk factor for intercontinental species exchange in aquatic ecosystems, Aquatic Invasions, 2, 2, p 121-131

Eno, N.C., R.A Clarke and W.G. Sanderson, 1997. Marine species in British waters: A review and directory. Joint nature conservation committee, Peterborough, UK.

Hare, C.H. 2000. Marine fouling and coatings for its control. J. Prot. Coating. Lining. 17 6, 47-48.

Hunter, J.E. and Cain, P. 1996 Antifouling coatings in the 1990s - environmental, economic and legislative aspects. In, IMAS 96: Shipping and the Environment- Is Compromise Inevitable. Proc. IMarE Conf., Part 1. The Institute of Marine Engineers, London UK. 61-78.

Kjaer, E.B. 1992. Bioactive materials for antifouling coatings. Prog. Org. Coating. 20, 339-352.

Minchin D. and E. Sides 2006. Appearance of a cryptogenic tunicate, a *Didemnum* sp. fouling marina pontoons and leisure craft in Ireland, Aquatic Invasions, 1,3, p 143-147

Townsin R L. 2003: The ship hull fouling penalty, Biofouling, 19, p 9-5

Yebra D M, Kiil S, Dam-Johansen K. 2004. Review: Antifouling technology- Past, present and future steps towards efficient and environmentally friendly antifouling coatings. Progress in organic coatings 50. p 75-104.