RESEARCH/DEVELOPMENT SUGGESTIONS RELATED TOWARDS SUSTAINABLE MERCHANT SHIPPING

R. G. Boothroyd (Retired Chartered Engineer)

ABSTRACT

Maintenance of adequately low costs in merchant shipping is vital to the future world economy. Three areas have been identified as of sufficient importance to merit more detailed attention.

1) The development of marine diesel engines for large vessels which would use CWS (coal-water slurry) fuels instead of conventional heavy fuel oil. It is argued in this paper that we now have sufficient technological experience to be reasonably certain of the commercial success of this enterprise. A new design of cylinder head is outlined which is intended to allow those engine components which are vulnerable to damage by CWS fuels to be replaced while the engine remains operating. An adaptation of the variable geometry SEMT-Pielstick combustion chamber is also considered in order to render increased durability for the piston rings and cylinder liners.

2) The further development of parasail technology for wind-assisted propulsion to suit all vessels up to the largest size. The parasail can also be used very conveniently to generate all the electrical power supplies for the ship. It is suggested that this energy is best stored by slight air pressurisation of the hull.

3) The exploitation of this inexpensive way of pressurising the vessel to enable much lighter construction methods to be used in shipbuilding. This would also contribute very significantly in restraining the increasing costs of shipbuilding which is a major component of marine transport costs.

KEYWORDS: marine diesels, coal water slurry fuel, Skysails, Kitesails, shipbuilding, container ship

1) A NEW FUEL FOR THE MARINE DIESEL

1.1 Introduction and Background

Between 55% and 65% of the present day running costs of many cargo ships can be attributed to the high cost of 'heavy oil' to fuel their slow-speed diesel engines [(1)]. Heavy oil, which might be described as the 'dregs' from the petroleum fuel refining process, is nevertheless still relatively expensive. Inevitably its cost will rise once the current economic recession corrects itself. Future costs, and adequate supplies, of conventional heavy oil are also of much concern because of developing trends in the petroleum industry.
Today's marine diesels dominate the ship propulsion market because of their outstanding

thermodynamic efficiency -often exceeding 50%-; their extreme reliability; fast response and the high power levels needed to keep a ship out of trouble in inclement and variable weather.

Coal is potentially a much cheaper fuel with longer future availability but the cost of its conversion to liquid fuels remains relatively high. Also the coal to liquid fuel conversion processes we have such as Fischer-Tropsch/ Sasol,/ underground gasification have problems including those related to environmental damage. Higher market prices for lighter fraction motor fuels have made Sasol type technology more attractive. In this technology coal is gasified in a very clean way to produce carbon monoxide and hydrogen which is then used to produce lighter fraction liquid fuels using catalysts. However it seems to make no economic sense to try to produce relatively cheap heavy oil in this way. A useful reference concerning these issues and their economics lies in Chandrashekar's paper[(2)] and associated papers at the same conference . Based on 2006 prices of $40/barrel of crude oil, ex refinery fuel cost $41 compared with $55 using Sasol type coal to liquids conversion. The capital investment cost in coal to liquids conversion was 5 times as big as refinery capital costs using petroleum. These monetary figures have changed considerably in recent years but the conclusions remain the same. In many ways-and especially with regard to future fuel costs and availability- the use of coal-water slurry (CWS) fuels seems to be more attractive for big marine diesels.

Since the time of Rudolf Diesel himself the use of coal as a fuel has been a 'holy grail' of diesel technology and many independent researchers (e.g. ref (3)) have considered it before consigning it to the 'too hard basket'. However, more recent and more determined large-scale research [(4-5)] has changed the situation to such an extent that coal slurry diesel engines are now much more easily attainable.

The very encouraging work in ref(4) was directed at developing a CWS diesel running at 1900 rpm which is a much more demanding task than developing a slow speed marine diesel which might not exceed 200 rpm. If CWS diesels are to become commonplace in tomorrow's world, then it is suggested that development must surely stem from marketing the big marine diesel first? This is a new and complex technology and we can only expect attractive marketable developments from extensive operational experience. Present-day big marine diesels are the result of many years of development and the amalgamation of manufacturers into much larger conglomerates.

There is also a hidden agenda to this paper This is anticipation of the use of CWS fuels to drive most of our future agricultural machinery. Reasonably priced fuel for broad-acre agriculture, with its large diesel-powered implements, is even more vital to the world economy than sustainable merchant shipping. Already many farmers worldwide are growing their own biofuel in an attempt to cope with rising fuel costs. However growing your own biofuel may not always be the most efficient way to use good agricultural land which is becoming in ever shorter supply worldwide. Also some useful farmland in the world is ill suited to growing biofuel because of climate or other reasons. It is anticipated that CWS fueled diesels will be adopted in the future agricultural sector. As will be explained below a diesel engine which can use CWS fuel is equally well adapted to using the crude biofuels (called straight vegetable oil (SVO)). SVO is the most convenient and most easily produced form of fuel for the farmer who "grows his own". The alternative of making "home brew" biodiesel, although quite commonplace, is not so easy, requiring more care and regular supplies of methanol.

Thus a significant and very large future market is seen for manufacturing the CWS diesel engine with its natural ability to also use SVO fuel, but it all seems to depend on developing the marine diesel first because this is envisaged to be the easiest way to develop this new technology. We have only to follow the 50 years of history leading to the development of today's personal computer to see how a good marketable product can arise from the most humble beginnings.

1.2 Brief Review of Status of Conclusions arising from Refs(4 &5)

Firstly references (4) and (5) give access to much of the available technical literature in their bibliographies.

In the study in ref(4), one cylinder of an 8 cylinder high speed **direct injection** two-stroke diesel engine was fueled with CWS to provide 85kW which was 80% of the rated power of each of the other 7 cylinders. Combustion of CWS at over 99% efficiency was essentially complete within 1.5 msec. NOx emissions were less than half of those using conventional diesel fuel. This is a natural and very desirable characteristic to be expected with all CWS diesel engines so there is no problem on this score. However unburned hydrocarbon emissions were about twice as high as is found in conventional diesels. Technical improvements can be expected in this area in the future. The solution seems likely to be found in the recipe for the additives in the CWS. Apart from stabilizing the CWS in storage, these additives may be used to vary atomization and also the speed of combustion.

All these achievements make the development of a slow speed marine diesel a very reasonable proposition.

The main weakness in the study in ref (4)) was the injector which was completely inadequate in design for commercial application. The injector used in ref (5) was far superior in design. It used a stainless steel diaphragm to separate the abrasive CWS from the hydraulic fluid used to operate the injector (in this case conventional diesel fuel was used as the actuating hydraulic fluid). The injector used in ref (5) is similar to the concept in ref (3) but it has the advantage of actual extensive operational experience. Nevertheless it seems likely that CWS diesel engine injectors will never have the durability of ordinary diesel fuel injectors. This must be expected to influence significantly the final design of a commercially viable CWS engine.

The coal used in refs (4&5) was pulverized to below 10 microns in size after prior treatment to remove contaminants so that ash content was less than 1%. This can be described as a very clean coal. Water content was about 50% in both studies. Additives are important and are a large research topic in their own right with regard to fuel atomization, fuel droplet dispersal and combustion control. Patented mixtures are of particular interest [(6)].

In view of the fact that future developments are likely to result ultimately in our seeking cheaper and higher ash content CWS fuels, a fairly conservative approach is suggested as desirable in the design concept proposals outlined below.

1.3 Requirements for successful marketing of a CWS Marine Diesel

Although experimental CWS engines have been run for extended periods successfully, hard and comprehensive facts are needed concerning the long-term erosion wear to be experienced with CWS fuels in a commercial application. There are three main areas of concern, the injector nozzle, cylinder walls/piston rings and exhaust valve seatings.

Conventional heavy oil is a dirty fuel, sometimes contaminated with traces of ex-refinery alumina catalyst which is very abrasive [(7)]. The largest conventional marine diesels with cylinder bores of about 100 cm diameter can experience cylinder bore wear of as much as 5mm before they need major overhaul [(8)]. Exhaust valve seatings can be damaged by slag, vanadium and sodium contaminants in heavy fuel oil [(9)].

In order for a CWS diesel to be acceptable, long lasting and reliable, the following criteria are critically important in its design

a) Wear due to ash particles acting on the cylinder wall and piston rings must be constrained within the limits experienced with the use of conventional heavy oil.

b) It is essential that the CWS injectors and the exhaust valves and their seatings can be replaced easily, cheaply and quickly when necessary. Preferably this should be achievable while the engine is in use if this is possible.

The other components in a CWS diesel do not appear to be problematical to any serious extent..

1.4 Suggested Roadmap for the Design of the CWS Marine Diesel for Large Cargo Vessels

References (4 &5) were directed at developing a *direct injection* CWS engine. Nobody can deny that today's turbocharged *direct injection* common rail motors with their computer-managed piezo-electric multiple pulse injectors are a vast improvement on the indirect (pre-chamber) engines of yesterday. Consequently the indirect injection engine has almost disappeared from the marketplace. One of the main influences in bringing about this state of affairs is that public demand from the automobile industry is for a diesel car which performs like a petrol-driven car. Also, although a diesel engine is much more efficient than a petrol engine, largely because, by its very nature, it is a natural stratified charge engine, the fact remains that *indirect injection* always results in a slightly inferior specific fuel consumption.

It seems, however, that a commercially successful CWS diesel can only result from resurrecting old-fashioned indirect injection technology. In fact we have a similar situation with diesels using SVO (straight vegetable oil). Direct injection diesels which use SVO soon fail from gummed up piston rings which then become 'coked', whereas indirect injection engines are found to be far more durable(9).
Fig.(1) shows a plan view of a design recommendation for the cylinder layout of a CWS 4-stroke marine diesel. Fig.(1) is schematic and not to scale and is a plan view from above for each cylinder . It will be seen that the design is unusual in that each cylinder has two prechambers. Only one prechamber is in use at any one time.
There may be a problem with nomenclature here because indirect injection diesels which use a separate chamber to start ignition use the term "prechamber" if there is no significant swirl intended in the design. Where strong swirl is intended in the design it is usually called a "swirl chamber". As the design proposed here is a unique one, yet involving specially designed swirl, it has been called a prechamber nevertheless..

Operation is as follows:-
If the prechamber A1/B1/V1/I1 is in use and its monitored exhaust temperature,for example, indicates impending malfunction of the injector I1 or the valve V1 or its seating, then fuel to this cylinder is cut off. The engine continues to operate on its remaining cylinders at slightly reduced power. Motorised gate valve A1 is slowly closed and valve A2 is opened slowly and simultaneously. It is noted that the cylinder head and wall structure is suitably strengthened to support valves A1 and A2.. The gate valves B1 and B2,(note that these are below A1 and A2 in fig (1)) which are lighter in construction than A1 and A2, are also opened and closed in unison with each other. When A1 and B1 are fully closed and A2 and B2 are fully open, fuel is supplied to prechamber V2/I2. Because this prechamber is in a "cold start" condition the initial fuel supply might be methanol, or some other suitable 'cold start' fuel. When the new prechamber is hot enough, solenoid valves (not shown in fig.(1)) change over to CWS fuel.

When it is unbolted the defective prechamber complete wjth its injector I1 and exhaust valve V1 is removed as a unit and replaced with a factory reconditioned spare. It slides out vertically along the lines Y1/Y1 and X1/X1. Support for removing this prechamber is by a small gantry hoist which is a permanent part of the engine structure. It should be noted that the exhaust valve V is operated hydraulically, not mechanically. Hydraulic operation is normal present-day practice. Fuel and hydraulic actuating fluid to the exhaust valve in the new prechamber unit are bled as per normal practice before the new replacement prechamber is opened up for use. Defective prechambers are sent for factory reconditioning when the ship docks.

By this means, vulnerable components in the CWS engine can be replaced while the engine is operational.

The prechambers themselves have special design features. On the compression stroke, a powerful vortex is induced in the circular prechamber. The injector is placed directly above the exhaust valve. This has a dual purpose. The top of the exhaust valve is a hot spot for that part of the injected fuel which can reach it. Also the fuel itself is a major contributor in cooling the valve.

The exhaust valve V and injector I are offset from the line of symmetry across the cylinder. The induced vortex in the prechamber thus has a very low pitch spiral action. When combustion takes place in the prechamber the coarser (more agglomerated) ash particles are centrifuged by the vortex swirl towards the walls of the prechamber. It is likely also to be beneficial to incorporate a slight circular ridge in the input neck of the prechamber. The purpose of all this is to retain the bulk of ash particulates within the prechamber so that only the finer particulates and combusting gas enter the main cylinder during the expansion stroke. In this way most of the abrasive ash is retained in the prechamber and is exhausted when the valve V opens to vent the spent products of combustion.

1.5 Experimental Equipment and Research Support needed for Development

It is suggested that all the technical developments considered in this paper are of sufficient economic importance to merit international financial support. The reasons are concern over the future availability of heavy oil. It seems to be appropriate that a research contract should be awarded to one or more manufacturers of large marine diesels. It is also possible that some support may be available from non-government sources such as the presently hard pressed coal industry.

The details of such a research/development programme are a matter for the parties concerned. Nevertheless the following points may merit consideration in planning.

The fluid dynamics approach of 'partial modeling' is unlikely to be of any value in designing CWS diesels of different size. There are simply too many relevant variables especially agglomeration characteristics of particulate ash as it is formed in the combustion process [(10)].

An experimental rig would be somewhat similar to that shown in fig (2) in ref (4), except that there would be much more of it. Visual data, such as in (ref (5)), of the combustion process are needed. If the largest CWS diesel to be marketed has a cylinder diameter of 1000mm, then an experimental set-up with a single cylinder size of 400 mm might be sufficient for reliable design extrapolation.

There is a wealth of useful research information concerning the fluid dynamics within conventional IC engines. This information , together with application of small aerosol particle fluid dynamics can be used to detail the optimum design of the cylinder head and the top of the piston. Also details of the research programme which lead to the marketing of 'Aquadiesel' by Shell are likely to be of much interest. One suggestion for the design of the piston head and cylinder head is shown in fig (2). This is an adaptation of the SEMT-Pielstick variable geometry combustion chamber shown on page 74 of ref(7) The intention in the original SEMP-Pielstick design was to produce indirect injection which resembled the direct injection process. This is not the intention in fig (2) where the design is an attempt to minimise the transfer of ash aerosol particles towards the vicinity of the cylinder wall/piston rings. Present day engines have a piston cleaning ring to remove ash deposits but this cleaning ring must not be overloaded.

The development of the design in fig (2) would need consecutive stages of analysis.using computational fluid dynamics followed by actual confimatory physical testing. Any other design would need to be developed in a similar way.

It appears that this CWS technology can be adapted to give a long-stroke, uniflow 2-stroke engine similar to those used in large cargo ships today. Also the technology seems to be suitable for retrofitting existing engines to run on CWS fuel. These single engine and screw prime movers seem to be preferred by today's ship-owners. However there are grounds to suspect that a twin engine/screw configuration may be preferred in future CWS-fueled vessels.

The MARPOL regulations relating to CO2 and SOx emission of CWS diesels have not been considered here. This is for the very good reason that it is reasonable to expect technological developments to be equally applicable to both conventional and CWS diesels.

Impending environmental rules for shipping are the subject of much present controversy [(11)]. Sulphur dioxide emissions by ships are to be reduced drastically whereas CO2 emissions will not. Yet apart from health considerations, sulphur dioxide released from shipping is beneficial and causes significant global cooling estimated at $31mW/m^2$. This pollutant also stimulates cloud formation and rainfall. Also whereas CO2 persists in the atmosphere, SO2 is soon dissipated.

All this suggests that high sulphur/low ash American coal should normally be used for CWS fuel when the ship is well away from land. In this case engine corrosion from burning sulphur is not a problem with a hot engine. When nearing land the low sulphur/high ash Australian coals may produce a more suitable CWS. Bunkering different CWS fuels is feasible but it is yet another complication in this complex technology.

2 ISSUES RELATING TO APPLICATION OF PARASAIL TECHNOLOGY TO LARGE CARGO VESSELS

2.1 Introduction

In recent years rising fuel costs have raised much interest in wind-assisted propulsion of merchant ships. This part of the paper is concerned mainly with raising relevant matters for consideration. The points raised must inevitably be considered as requiring much more detailed examination than can be considered here.

2.2 Commentary on Present Technology and Possible Future Developments

Companies such as Skysails and Kitesails have already made significant advances in developing wind assisted ship propulsion and they are already well into the marketplace with their products. However, we need to ask ourselves the following question. What is the best approach for applying this technology to the largest cargo vessels? Is it better to use a large single bow-mounted parasail, or would it not be better- as seems to be the case- to take advantage of the length of a large vessel and have several smaller kites mounted along each side of the vessel? With regard to this question, it seems that the most troublesome part of parasail technology is recovery of the kite just prior to re-stowing it in its protective container. By the very nature of the air-ram inflated wing of a parasail, it must have many light cables attaching it to its control pod. For this reason, is it easier to cope with smaller kites which have less cables? The present main argument for bow mounting, namely that a ship's superstructure can impede kite deployment and retrieval, seems to be a problem which can be overcome. For example a relatively lightly constructed telescopic mast supported on the side of a vessel by four steel cables can be inclined up to 45 degrees to the vertical to give unimpeded launching and retrieval of the parasail. In this way several kites could be deployed and retrieved in a sequence and the orientation of a ship with regard to wind direction can be altered using its diesel engine to avoid any significant superstructure interference problems.

One thing seems fundamental and certain in this area of technology. Cargo ships will always depend on big diesel engines for safety reasons. We never want to return to the dangerous times of relying on sail power alone. This being the case, we can always use diesel power to 'tack' a ship so that it can deploy kite sails to use wind power. The ability to position the ship with regard to wind direction is valuable to avoid complications such as eddies from the superstructure which might well complicate deploying or retrieving the parasail. Once a kite is at its operational height it seems unlikely to impede the launching or retrieval of another kite which is attached to the ship, say, 50 metres away. Adjustment of an adjacent kite to its 'zenith' position seems likely to be a suitable method of avoiding adjacent kites from interfering with each other while the kite-sails are being launched.. With regard to the business of 'tacking' the Author is informed by historians that the old 'clipper' ships only tacked infrequently. Perhaps the same situation would apply in the future on long voyages using parasails.

We also need to consider the possibility of using several small kites deployed on a sliding rail system round the periphery of the ship but this design concept does not seem to be encouraging. This system would allow plenty of space for launching and recovery but there are many other problems to be encountered. For example there is the need for electrical connections for the kite control pod . The emergent technology of inductive power transfer [(12)] may be of interest but it is complicated and expensive at the present time. Although this technology is under development mainly for hostile environments [(12)], a marine environment at sea may well be far too hostile for its application. It is of interest that some of the companies quoted in ref (13) intend to use radio control of the pod. This would also provide complications with regard to pod power availability. Bearing in mind the suggestions regarding the tow rope in section (2.5) the pod control system used by Skysails still seems to be the best method available.

Because of the inevitable economic incentive for achieving higher speeds of merchant vessels, we can expect a future demand to increase the contribution from sail power. It seems possible that the present bow-mounted telescopic mast method of parasail deployment may ultimately give way to a system where the line of action of the towing rope is lowered to become closer to the centre of buoyancy of the vessel. Apart from the need to make sail retrieval simple and reliable, this system would need a more positive method of sail launching. In this respect, the upper leading edge of the parasail could incorporate a closed pocket at its upper surface which could be inflated with electrolytically generated hydrogen (see section (2.3)). A wide-bore hose supplying the hydrogen would detach itself automatically when the parasail was sufficiently high. This hose would be fitted with two back-to-back non-return valves at the point of detachment. The hydrogen would soon diffuse away through the material of the 'theoretically-impermeable' pocket on the sail but not before it had used its bouyancy to launch the sail. Any possible hydrogen ignition problem with electrostatic charge should be solvable using wire connections in the towing cable. A system using a tow rope passing through the hull close to the ship's water line would require use of a bilge pump operating at all times. If future towing ropes are of the "tape type" (see section (2.5) then an 'in-use replaceable' seal in the ship's hull for the towing tape is relatively easy to design and service.

2.3 Using a Parasail to generate all the electrical power required in a cargo vessel.

This is an important and very useful facility which could be incorporated very easily and quickly into present-day technology. Although this technology is being developed for land-based power generation, it is even more suitable for use on a ship.

A ship's towing parasail can be used not only for ship propulsion but also to generate electricity in sufficient quantities for the entire ship. The principle is very simple. The tow rope is released in 'high lift' configuration of the parasail and in doing so it drives a generator on the ship. The control pod then reconfigures the parasail for minimum lift conditions allowing a motor on the ship to retract the cable. The cycle is then repeated. About 12% of the electricity generated is used to retract the cable. The remaining 88% is available for use. Very recently this research was reviewed [(13)] giving the names and organizations involved with this technology. The schemes proposed in this article [(13)] are intended for land-based electricity generation using several generators to ensure continuity of supply. However this would not be necessary on a ship. A single parasail would suffice. It is suggested that the parasail towing unit/generator would use a high volume low pressure blower instead of an electrical generator. This would be used to slightly pressurise the entire interior of the ship. Electricity could then be generated by using an air engine exhausting to atmosphere to drive the generator according to the power requirements of the ship. Di Pietro air engines will work with air at only 7kPa pressure differential and this makes them eminently suitable in this application. A much larger model of the Di Pietro motor would be more attractive than those currently available but upsizing the basic Di Pietro design seems to present no problem. In any case several smaller independent electrical generators deployed throughout the ship offer distinct advantages.

Energy storage by compressed air has been shown to be inefficient compared with battery storage of energy (14) but this is almost a trivial consideration in the parasail technology proposed. The energy from the wind costs nothing. The cost comes from the equipment to harvest it. Bossel's paper (14) demonstrated that only about 50% of compressed air energy was available for driving a compressed air-driven car. The problem of inefficiency arises because air compression and expansion is closer to the adiabatic reality instead of the isothermal ideal. This factor is unimportant in the present application. A ship's hull is also an ideal and very adequate storage vessel for using energy from low pressure compressed air. However, crew would need sliding door airlocks to access the outside of the vessel.

It is appropriate to point out that numerous patents have been taken out in this general area (15) of kite power generation but it is questionable if they can withstand legal challenge. Kite flying is a very old technology as affirmed in ref (13).

2.4 Other possible applications of parasail technology

Small naval patrol boats need to travel fast on occasion. Nevertheless a parasail might be a useful supplementary form of propulsion to increase the patrol range of these small vessels. In particular a parasail might be particularly useful when carrying a radar transmitter/receiver in its control pod. At a typical working height of 300m this would give good 'over the horizon radar' without sea clutter. A pod-mounted video camera might also be worth consideration.

Many years ago there was much interest in developing submarine cargo vessels. As is shown in fig (7.4) in ref (16), a submarine moving at a depth of about 2.5 times its maximum diameter will experience much reduced drag because wave resistance is minimized. It is remotely possible that today's increasing fuel costs may renew interest in submarine cargo vessels despite their obvious disadvantages such as poor cargo access and complications concerning harbour facilities. This topic is raised for consideration mainly because hull pressurization can be achieved cheaply with a parasail and submarines can avoid bad weather conditions experienced at sea level.

On the face of it, it may appear to be absurd to suggest that submarine vessels could use parasails. This may not necessarily be true. If the technology for parasail deployment and retrieval can be automated to function reliably without human intervention then it could be used on a submarine. This may not be a practical proposition because parasail retrieval seems to be a difficult area of engineering design. However, if these problems can be overcome, such a system could use tethered pods containing the parasails. These pods would be released to float to the surface. If 'tape-shaped' tow ropes (see section (2.5)) become the norm in the future then these would be preferable in this application to the circular tow lines used at present. Even if it proves to be impossible to automate parasail retrieval, which is quite likely, a wind-inflated and driven submarine freighter could still be developed. Such a vessel could use one or more fins protruding to the surface. In this way parasails could be operated from the top of the fins at sea level.

2.5 The Tow Rope.

"Skysails" use a circular tow rope of special design containing a centrally placed electrical cable used to control the pod. In ref (17) the present Author had to consider the best design of a tow-rope working under about 100 tonnes (1000kN) tension. This would be comparable in strength to the type SKS 1280 tow rope envisaged for the largest Skysail.. It seems that a towing "tape" (with cross section 30cm x 0.5cm) is better than an equivalent rope of circular cross section. This towing tape design could use fine, cold drawn steel wires (AISI 1060/0.6% carbon with some adjacent glass fibre) encapsulated in UV resistant polymer. Less importance need be attached to electrical signals in this other application[17] as compared with Skysails needs but the numerous steel wires offer sufficient redundancy to make electrical connections reliable for a parasail. This towing tape concept seemed to have the following superior features compared with a circular rope:-

a) Because the tape is only 5mm thick it would allow easier spooling on a smaller drum and gives less damaging bending strain on the materials in the tape.
b) The tape would allow easier routine automatic scanning for integrity when it is being used.
c) Most important of all, this design of towing rope is likely to be suitable for factory refurbishing and examination for integrity. It would be more than just a recyclable item. It would be reusable, thus helping to keep costs down

3 IMPLICATIONS OF SECTION (2.3) REGARDING SHIP CONSTRUCTION AND DESIGN

In section (2.3) it was shown that keeping the air pressure in the hull slightly above atmospheric pressure was an attractive proposition. In this way the hull of the ship becomes a large energy storage battery for free wind energy derived from simply programming the parasail pod to operate its parasail through a 'nodding' routine automatically.

When we consider the structural implications for the ship we find that hull pressurisation would enable the ship to become stronger and much more able to accommodate the buffeting from heavy seas. The vessel would acquire the sturdy strength of an inflatable boat, such as a rubber dinghy. The structural implications are that stiffening-members in the hull such as bulkheads now move through a cycle which is more towards tension and less towards compression forces. This enables significantly lighter steel sections to be used in its design. Fundamentally there is no difference in applying this technology to that which is already used in the pressurisation of airliners. Typically an airliner is pressurised to be not more than about 60 kPa above ambient pressure and this figure is not allowed to fall below about 1000 Pa. Different values would be used for a ship. Shipbuilding design [1] is a complex subject and there can be complicating factors. For example, a heavily laden ore carrier moving through heavy swelling seas can experience large bending moment and shear forces along its length. It is in this area of merchant shipping that the submarine cargo ship concept may become an even more attractive proposition. Smaller hatches for loading and unloading are less of a problem here. Also the hull pressurisation could be increased easily and this is useful. This would also allow lighter construction methods to be considered in this type of vessel.

Because cargoes can vary so much it is hard to generalise. Ships are specialised according to their function. It seems that the ability to strengthen a vessel by air inflation with this inexpensive procedure described in section (2.3) may well have a significant impact on future ship design.

It seems to be appropriate to take the container ship as an illustrative example because 90% of non-bulk freight is now transported in containers. Fig (3) shows the sectional view of such a ship design. The suggested concept design bears a resemblance to the ordinary sailing catamaran/multihull vessel and would have similar exceptional stability. Stability and loading problems are a matter of much concern with conventional monohull container ships. One container ship has even capsized in harbour.

Fig.(3) shows three wind-inflated circular steel pontoons joined by 'trampolines' made of heavy interconnected steel chain links to support the lowest layer of containers. During loading it is necessary to tether the outer pontoons to the wharf and to two off-shore mooring buoys. Eventually when the vessel is fully loaded the structure becomes stable. Structurally, the system bears a slight resemblance to the assembled 'suitcase scooter' described elsewhere at this conference [18]. The containers would enjoy much better protection than exists on today's monohull designs and we might reasonably expect a numerical reduction in the 10,000 containers which are swept overboard annually. These lost containers often become a barely-visible floating hazard to other ships especially motor cruisers and ocean-going yachts. With regard to fig (3) there are design issues which need further detailed investigation such as the accommodation of movement between adjacent containers in heavy seas. Inflated air bags between containers may be the best design approach.

There are many other attractive variations on the theme shown in fig. (3). It seems reasonable to suggest and outline here some desirable future objectives in the design of the catamaran style of container ship illustrated in fig (3).

Firstly there is the possibility of 'putting together' a container ship of the desired size by using standardised components. This is a very different concept in shipping, namely to adjust the size of the vessel itself to suit the amount of cargo to be carried and to be able to change the ship size inexpensively for each journey planned, More than two pontoons can be coupled together and the width of the chain trampoline can be varied to give the desired size of ship. This is illustrated in fig (3). The unloaded pontoons, by themselves would be stable hydrostatically. This is because the weight of the engines would place the centre of gravity below the centre of buoyancy. When not assembled into a catamaran,or other multihull vessel, the pontoons would be moored together side by side.

The stack of loaded containers is shown as 'slightly convex' in fig (3). In this way the steel cables used to hold the composite ship together also secure the cargo, while also restraining the increasing instability of the pontoons as the ship is loaded. When not in use the pontoons would not be pressurised but the parasails F1, F2, Fx ,,,would be deployed to pressurise the pontoons when loading starts. It is envisaged that a harbour mobile crane, operating on the stacked containers on the ship, would load and unload containers directly on to trucks using a ramp from the wharf. This is also illustrated in fig (3). The purpose of this concept is to avoid the need for special loading and unloading facilities so that most small harbours could be used for this style of container ship. It is expected that future increased transport costs will make it particularly advantageous for ships to deliver containers closer to their final destination. In summary the suggested intention in this concept is to develop a 'tramp-steamer' type container ship which can use any harbour with the most basic facilities of a wharf and two offshore mooring buoys.

There are other advantages in this form of ship design. For example, if a pontoon is ruptured due to hitting a reef, it may well be possible to simply expel the sea-water by increasing the inflation pressure within the pontoon. It may even be feasible to effect adequate temporary repairs by unrolling a batten-stiffened mat over the rupture. This sealing mat would be held in place by the increased air pressure in the pontoon. A small crew of 20 persons would probably be sufficient for coping with this form of emergency.

The pontoons shown in fig (3) are shown as single cylinders. This is for the purpose of illustrative clarity. In practice pontoons with better stability would be used by 'welding' together smaller diameter circular cylinders with internal tensioning bulkheads. The principle is similar to the design of the inflatable air-bed used by campers except that each multicylinder pontoon would be a rigid structure.. Again this technology is essentially the same as that now used in the aircraft manufacturing industry such as in the A380 airliner. This design approach would suit easier loading and unloading of the container ship shown in fig. (3). Each of these mulicylinder pontoons would be used with airlocks between the cylinders for crew access. Multicylinder pontoons would also reduce vessel draught, enabling this type of container vessel to go further up navigable rivers. It would also reduce structural weight of the vessel. However some compromise with issues such as increasing hull skin-friction resistance is involved. Such design-detailing and optimisation is well outside the scope of this paper.

Some design issues are common to a wider variety of ship designs. For example, condensation in a ship's hold can be a serious problem [1] and the pressurised vessel lends itself to controlling condensation at minimum cost. Some cargoes such as fruit or inflammable materials may need inert gas instead of pure air This aspect suggests that in some applications suitably scrubbed exhaust from diesel motors might even be worth consideration for some cargoes. CO2 in a ship's hold when docked can be extractable and become a useful chemical, such as for enhanced growing of algae (18).

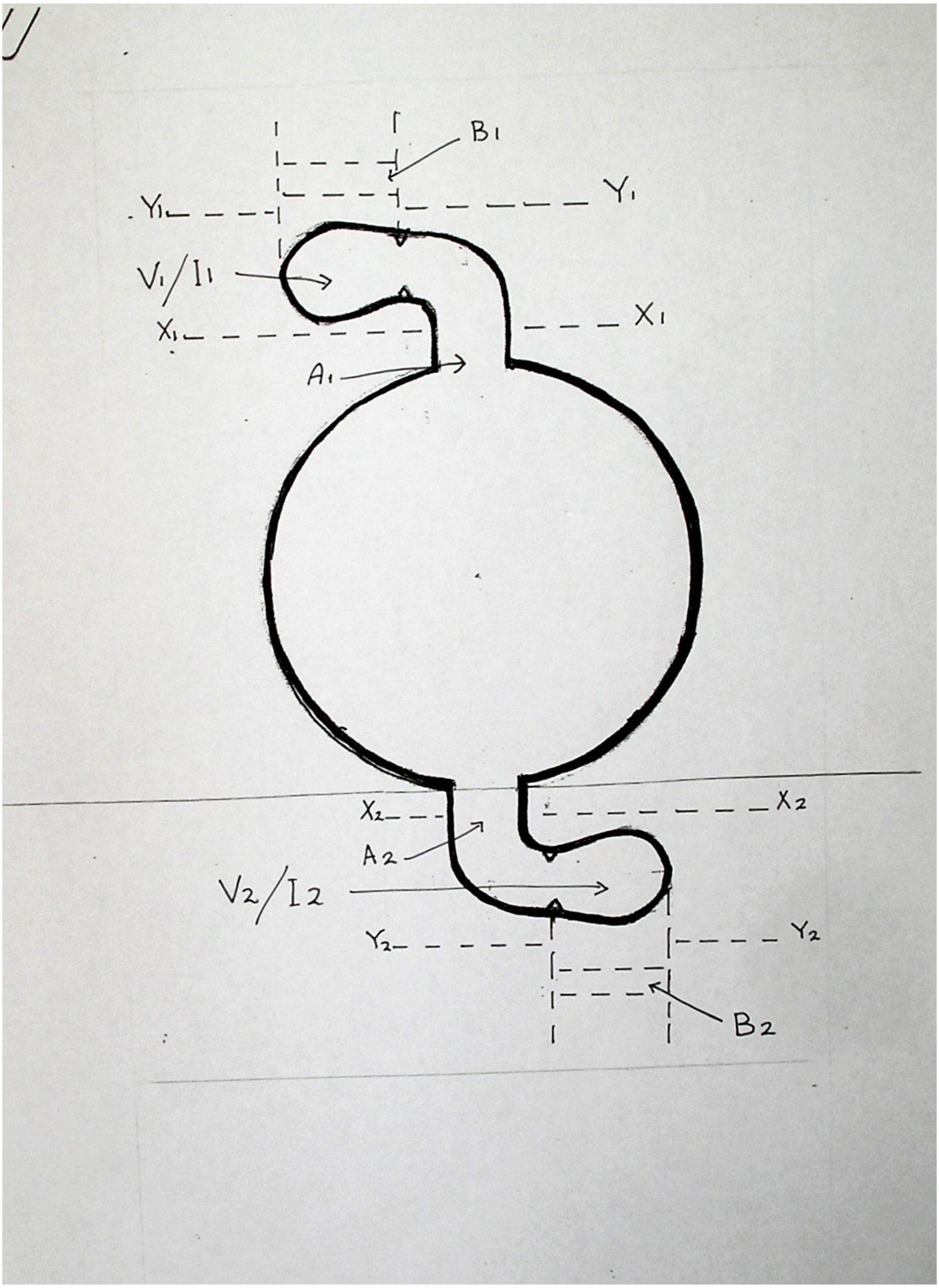

Fig 1 Plan sectional view of cylinder of CWS diesel with replaceable vulnerable components
See text on page 4, section 1.4 for detailed explanation

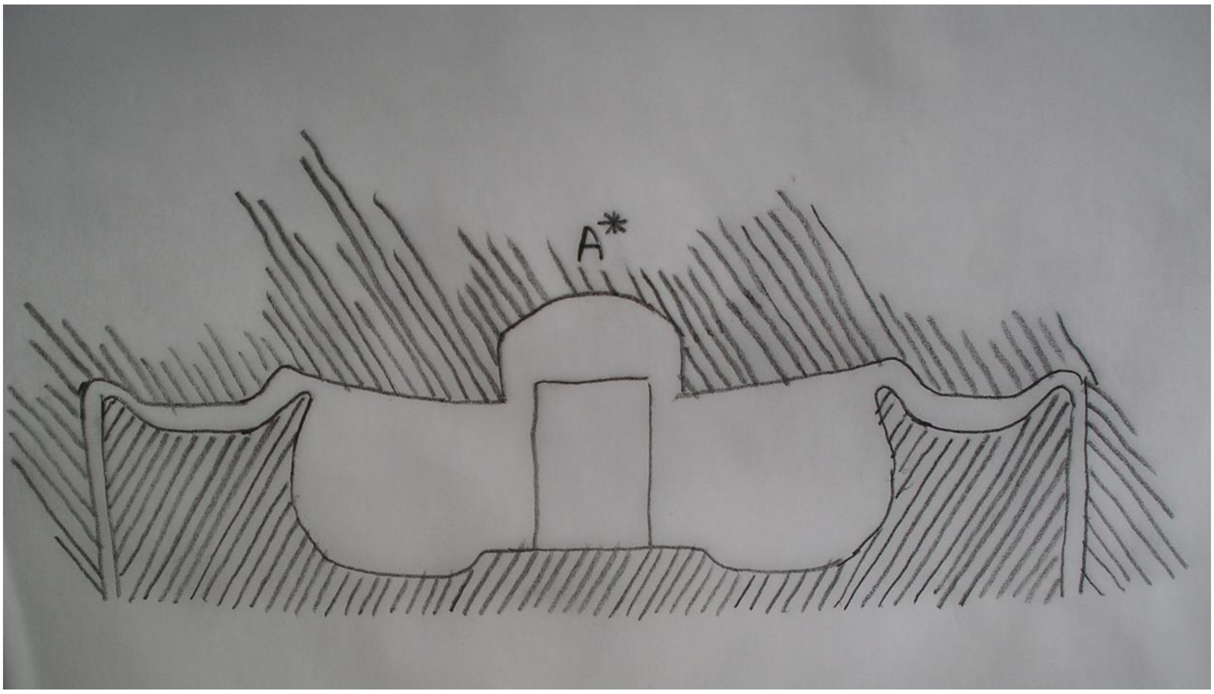

Fig (2) Combustion Chamber Concept to minimise fine ash migration to Cylinder Walls.

There may be grounds for placing the motorised gate valves A_1 and A_2 in fig (1) closer towards the centre of the cylinder head as shown here at A^*

The above suggested configuration is for a long-stroke, uniflow, 2-stroke cycle engine.

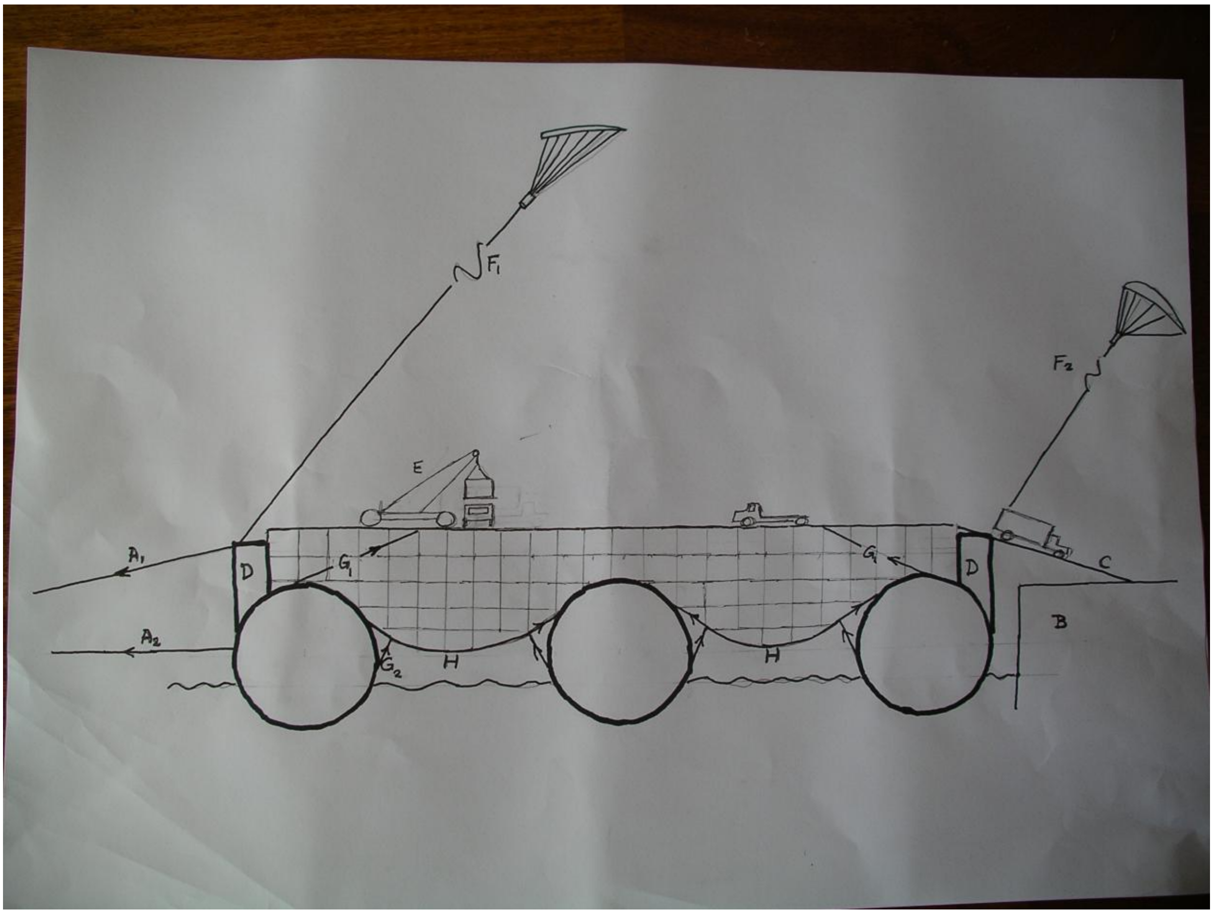

Fig (3) Multihull concept for a container ship (schematic)
Note that the pontoons are shown as single cylinders for illustrative clarity. In reality each of these pontoons would be fabricated from two or more cylinders welded together. The separate cylinders in each composite pontoon would be interconnected with crew-accessible airlocks

A1,A2 Mooring cables to off-shore buoys
B Wharf
C Moveable loading ramp
D Crew quarters or container restraining structure
E Mobile harbour crane loading/unloading containers
F1, F2 Parasail main cables
G1, G2,…Gx Upper tensioning cables attached to container stack and lower tensioning cables attached to pontoons
H Steel chain-link trampoline

References

1) Hughes, C., Ship Perfomance, Technical safety, Environmental and Commercial Aspects, 2nd Edn, 1996, Legal and Business Publishing Division, London
2) Chandrashekar, V.E., "Underground Coal Gasification" Paper (3) in Underground Coal Gasification Workshop, November 12-15, 2006, Kolkata, India. Download from http://fossil.energy.gov/international/International_Partners/November_2006_UCG_Meeting.html Alternatively download directly (and more slowly!) from http://www.fe.doe.gov/international/Publications/ucg_1106_larsen.pdf
3) Boothroyd, R. G. "Diesel Injection of Coal Slurries and Similar Fuels", *Speculations in Science and Technology,**1***, No.(2),123-127,1978
4) Schwab, J.A., Ryan, T.W.,,Kakwani, R.M., and Windsor, R.E., *Coal-Water Slurry Autoignition in a High-Speed Detroit Diesel Engine*, SAE (Society of Automotive Engineers) Paper 941907. Available in "Alternate Fuels: A decade of Promise and Success", R.M. Betz (Ed), pp571-580), 1994 PT-48, SAE, Warrendale, Pa. ISBN 1-56091-593-5
5) Caton, J.A., and Kihm, K.D., *Characteristics of Coal-Water Slurry Fuel Sprays from Diesel Engine Injectors, June 1993. DOE/MC/23174-3490 (DE940000230. Work performed under Contract No: DE-AC21-88MC23174. This document may be downloaded from the Net*
6) Hancock, R.I., & Bognolo, G, (Inventors) *"Combustible Compositions based on coal, oil and water: water stabilized with surfactants and methods for their preparation"* European Patent EPO 107346. See http://www.freepatentsonline.com/EPO0107346. html..
7) Wilbur, C.T., & Wright, D.A., Pounder's Marine Diesel Engines, (6th Edn) 1984, Butterworths, London
8) Knak, C., Diesel Motor Ship's Engines and Machinery, 1990, Marine Management Holdings (for Institution of Marine Engineers) London
9) Deuchar, M., "Operate your Vehicle on Straight Used Vegetable Oil", 4th Edn. Nov.2008, This state of the art text is available for a modest fee by emailing marcus@vegiecars.com
10) Boothroyd, R. G., Flowing Gas-Solids Suspensions, 1971, p103, Chapman and Hall, London
11) Pearce, F., "The Hidden Virtue of Ships Pollution" *New Scientist*, p8-9, 20th March, 2010

12) Jurgen Meins, Gunther Buhler, Robert Czainski & Faisal Turki, "Contactless Inductive Power Supply." Download this and any more recent reports using Google

13) Brooks, M., "High Flyers" New Scientist, No 2656, 12 May, 2008, pp 38-41

14) Bossel, U., "Thermodynamic Analysis of Compressed Air Vehicle Propulsion", Jnl of KONES Internal Combustion Engines,**12**, 3-4, pp 51-62, 2005

15) Olson G, (inventor) *Wind driven apparatus for an aerial wind power generation system (see list of patents claimed)* http://www.google.com/patents?id8d2fAAAABAJ which gives a list of similar devices for which patents are claimed

16) Priebe, P. D. ,"Modern Commercial Sailing Ship Fundamentals" p57, 1986, Cornell Maritime Press, Centreville, Maryland. The original article of this study is Byquist, Tord, "Wave-making Resistance of a Series of Bodies of Revolution", Royal Institute of Technology, Dept of Hydomechanics, !973, Stockholm, Sweden

17) Boothroyd, R. G., "A Proposed Extra International Air transport Corridor along the World's Equatorial Belt" Paper 1069, General Proceedings, 12th WCTR Conference, Lisbon, July 11-15, 2010

18) Boothroyd, R.G. "Replacing the Private Motor Car with a more Attractive Public Transport System" Paper 1061, General Proceedings 12th WCTR Conference, Lisbon, July 11-15, 2010

19) Boothroyd, R. G., Exploiting Algae as a Biofuel Feedstock and for Reduction in CO2 Emissions" Jan 5th 2007. http://www.oilgae.com/ref/sub/sub1.html.