1. INTRODUCTION

Maritime shipping is entirely dependent on oil. The latest price increases have placed tremendous cost pressures on the industry: today, marine fuel costs from US-$500 to US-$1200 or more per ton depending on the grade and quality – a price that seemed inconceivable just a few years ago. And there is no end in sight to this trend: The respected investment bank Goldman Sachs considers an increase in the price of oil to US$ 200 a barrel to be possible in the near future.

Cargo shipping is the most efficient transportation of the world. However cargo shipping is now considered one of the primary causes of climate-damaging emissions and as such contributes significantly to the pollution of our environment.

Maritime shipping, with its output of 813 million tons of CO_2 per year, is responsible for almost 3% of worldwide CO_2 emissions (ca. 30 billion tons in 2005). Meanwhile, other studies consider the figure to be more like up to 5% (The Guardian).

The use of cheap and highly sulphurous fuel oil places cargo shipping among the main global producers of climate-damaging gases. Experts estimate that shipping is responsible for 10 million tons of sulphur dioxide emissions per year, which corresponds to more than 7% of the worldwide emissions. == Lloyd's Register Quality Assurance (London)

Sulphur oxides can exacerbate respiratory disorders and are considered one of the contributing causes of acid rain.

In addition, the burning of heavy fuel produces mostly nitrogen oxides. Nitrogen oxides react with hydrocarbons (HC) in sunlight to form ozone, and can lead to smog. Ozone itself is toxic, causes respiratory problems in humans and damages plant life.

In April 2008 the International Maritime Organization (IMO) - the UN agency responsible for maritime safety and protecting the seas - approved a reduction in sulphur emissions for the shipping industry.

From the year 2020 shipping companies either have to use distillate fuels with a limited sulphur content of 0.5% instead of heavy fuel oil or have to use scrubbing technology to clean their exhaust gases. For shipping companies using distillate fuels means a doubling of fuel costs in the future, since refined products such as MGO and MDO are considerably more expensive than highly sulphurous bunker oil.

In addition to the regulations already passed, the IMO is currently preparing a regulation on the reduction of CO_2 emissions from shipping in the form of a CO_2 indexing scheme. Experts assume that corresponding regulations will be implemented in a timely manner. Thus, shipping companies will also be burdened with emissions-based levies in the future. CO_2 emissions can only be effectively reduced by burning less fuel.

The only way out of this subjection to the oil price is to open up alternative energy sources for ships.

This makes the use of wind power especially attractive.

USING WIND POWER PROFITABLY

Wind is cheaper than oil and is the most economic and environmentally sound source of energy on the high seas. And yet, shipping companies are not taking advantage of this attractive savings potential at present - for a simple reason: So far no sail system has been able to meet the requirements of today's maritime shipping industry.

However SkySails, a company based in Hamburg, is offering a wind propulsion system based on large towing kites, which has the potential to meet all these requirements.

Depending on the prevailing wind conditions, a ship's average annual fuel consumption – and emissions - can be reduced by 10 to 35% by using the SkySails-System. Under optimal wind conditions, fuel consumption has been lowered by as much as 50%.

These figures are based on test results with ocean going vessels and current kite sizes. As the technology advances, relative kite sizes can be increased and fuel savings will grow.

Virtually all existing cargo vessels and new builds can be retro- or outfitted with the auxiliary wind propulsion system. The kite system is used for relief of the main engine, which remains fully available if required. This dual propulsion solution offers the flexibility required to minimise operating costs.

Economical acquisition and operating costs for the SkySails-System lead to short amortization periods of between 3 and 6 years, depending on the routes sailed.

The ship's regular crew is adequate for operating the system and no additional personnel costs should arise.

The business case for an 88m ship burning 5.7 tonnes per day runs as follows:

Fuel costs (210 days) ==	1200 tonnes MGO fuel at €750 per tonne	€900,000
Annual savings on route:	Rotterdam to Reykjavik (est. 29%)	€261,000
Annual saving on route	Rotterdam to Marseille (est. 15%)	€135,000
Acquisition plus installation cost		€465,000
Annual maintenance and servicing		€45,000

2. SKYSAILS TECHNOLOGY SUMMARY

The SkySails-System consists of three simple main components: A towing kite with rope, a launch and recovery system, and a control system for automatic operation.

Instead of a traditional sail fitted to a mast, SkySails uses large towing kites for the propulsion of the ship. Their shape is comparable to that of a paraglider.

The towing kite is made of high-strength and weatherproof textiles.

The tethered flying kite can operate at altitudes between 100 and 300 m where stronger and more stable winds prevail.

By means of dynamic flight manoeuvres, e.g. the figure of "8", the kites generate five times more power per square meter sail area than conventional sails.

The traction forces are transmitted to the ship via a highly tear-proof, synthetic cable.

The launch and recovery system manages the deployment and lowering of the towing kite and is installed on the forecastle. During launch a telescopic mast lifts the towing kite, which is reefed like an accordion, from its storage compartment. At sufficient height the towing kite then unfurls to its full size and can be launched. A winch releases the towing rope until operating altitude has been reached. The recovery process is performed in reverse order.

The entire launch and recovery procedure is carried out largely automatically and lasts approx. 10 - 20 minutes in each case.

The ship's crew can operate the system from the bridge. Emergency actions can be initiated at the push of a button. The automatic control system performs the tasks of steering the towing kite and adjusting its flight path. All information on the operation status of the system is displayed in real-time on the monitor of the workstation and thus easily accessible for the crew.

The kite system supplements the existing propulsion of a vessel and is used offshore, outside the 3-mile zone and traffic separation areas.

The system is designed predominantly for operation in prevailing wind forces of 3 to 8 Beaufort at sea. The system can be recovered, but not launched at wind forces below 3 Beaufort.

With regard to classification society regulations, the kite system is categorized and treated as an auxiliary propulsion. The operation of the system is not limited by any regulations at present.

Their double-wall profile gives the towing kites aerodynamic properties similar to the wing of an aircraft. Thus, the system can operate not just downwind, but at courses of up to 50° to the wind as well.

The kite is easy to stow when folded and requires very little space on board ship. A folded 160m² kite for example is only the size of a telephone booth.

In contrast to conventional sail propulsions the kite system requires no superstructures to obstruct loading and unloading at harbours or navigating under bridges, since the towing kite is recovered as soon as the 3-mile zone is reached.

Unlike conventional forms of wind propulsion, the heeling caused by the kite is minimal and virtually negligible in terms of ship safety and operation.

Depending on the operator’s preferences, the main engine can either be throttled back to save fuel, or kept running at constant power and using the kite tow forces to increase the ship's speed.

3. HISTORY & MILESTONES

SkySails started with the development of the world's first practicable towing kite propulsion system for commercial shipping in 2001. Having successfully completed the basic research and engineering in 2005, the system’s towing kite area was scaled up to 160m^2 and thoroughly tested on the 55m-long former buoy tender MV “Beaufort” in the years 2006 and 2007.

Currently the SkySails-System is being pilot tested on board the pilot customer vessels MV “Michael A.” (WESSELS Reederei; first retrofit system) and MV “Beluga SkySails” (Beluga Shipping; first installation on new build) during regular shipping operations. Within the framework of this pilot phase, all system components are being durability tested and the results immediately flow into the process of improving and optimizing the product for series production.

The following pictures document the development process of the SkySails-System:

2001/02: Testing platform I "Da Vinci"

The basic physics underlying the technology were examined with the modified catamaran "Da Vinci" that served as a SkySails testing platform. The catamaran was easy to operate and had the desired hydrodynamic properties. The ship and the towing kite were controlled manually. The series of tests demonstrated that it is physically possible to propel a ship with a towing kite.

2003/04: Testing platform II "Galileo"

As Testing Platform II SkySails used the "Galileo" an 8-meter, 2-ton scale model of an existing container ship from the Hamburg Ship Model Basin (HSVA). The first step was to conduct scientific tests in the towing tank at the Hamburg Ship Model Basin to examine a kite's traction behaviour on conventional cargo ships. Practical tests on the Baltic Sea that used this very same model propelled by a small towing kite proved that the SkySails technology is suitable for cargo shipping. The data collected in the test allowed the first back calculation to be made on the system in original scale. Already at that time the ship and towing kite were remotely controlled.

2004/05: Testing platform III MY "Jan Luiken"

The outfitting of systems components for towing kites having a surface area of up to 40 square meters onto the 15-meter, 18-ton "MY Jan Luiken" as Testing Platform III began in November 2004. All key system components, such as the launch and recovery system, were successfully tested in practice first-hand over the course of 2005. The system operated in a semiautomatic mode and the alpha version of the autopilot was already implemented at that time.
The "MY Jan Luiken" still serves the company today as a development platform. New engineering and technology concepts are tested aboard her in small scale before being implemented in full scale on the experimental ship "MS Beaufort." This approach helps reduce development costs. The "MS Jan Luiken" was named after Jan Luiken Oltmann, the founder of the Oltmann Group, the renowned ship financing company based in Leer.

2006/2007: Further development SkySails-System for cargo ships

Work to equip the almost 55-meter and 800-ton former buoy tender "MS Beaufort" (formerly the "MS Buk") began in January 2006. After completion of the installation, test operations with system sizes of 80m2 commenced.

By the end of 2006 the towing kite's area of the SkySails-System on this ship had been scaled all the way up to 160 square meters and thoroughly tested on the North and Baltic Sea in the year 2007. This marked the first time that the SkySails-System aboard the "Beaufort" had reached full-scale size. Small cargo ships, fish trawlers and super yachts can already be equipped with systems of this size.

The SkySails staff reported: *“We used a 160m² kite on the Beaufort for the first time, which was during the last period of tests on this vessel, the kite generated so much thrust at a wind of force 6, (25 knots) that the ship was going faster just with the kite than with its engine (1,260kW). At a speed of 11 knots, compared to the normal 9 knots the captain told us to stop because he got frightened by the power of the kite and the abnormal speed of his ship. This made it clear to us that we had to put this kite on bigger vessels, which we did.*

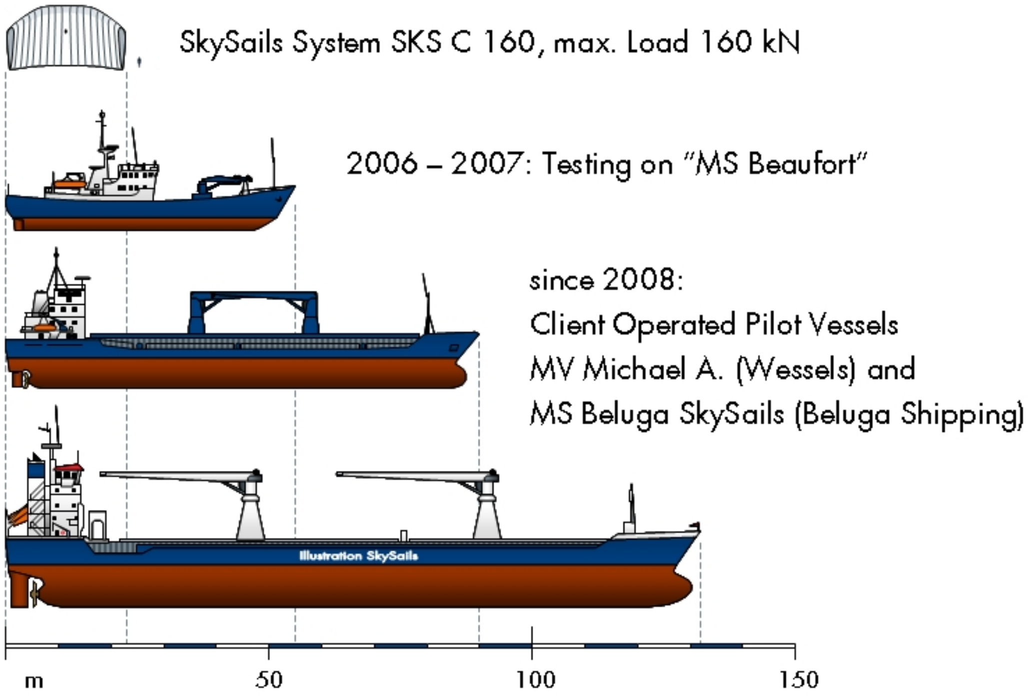
2007/2008: Pilot Series Cargo Ship

Since the end of 2007 / beginning 2008, the SkySails-System is being pilot tested on board the cargo vessels MS “Michael A.” (WESSELS Reederei; retrofit system) and MS “Beluga SkySails” (Beluga Shipping; installation on new build) during regular shipping operations.

In the first half of the pilot phase system robustness and reliability is developed to industry standard. In the second half of the pilot phase system performance will be evaluated extensively and optimized.

The customer vessels remain in regular commercial operation throughout the pilot phase. Initially, three SkySails engineers will be aboard of each ship. All components are being durability tested while the SkySails-Systems are deployed on board. The results immediately flow into the process of improving and optimizing the product.

Once this pilot testing is completed, series production of the SkySails-System for cargo ships will begin in 2009.



Above: Comparison of SkySails kite and vessel sizes

4. CONSULTANTS AND SUPPLIERS

Stefan Müller from Aerolabs AG, Munich, has been responsible for the design of the kites since early times. Development has concentrated on stability, control, and the desire for low control forces to save on energy and to minimize the size of the motors in the gondola.

North Sails New Zealand has been actively involved in kite making for SkySails since the beginning of the development programme and the sailing tests with the Galileo on the Baltic in 2003. The designs have been supplied by Stefan Müller, and SkySails engineers have worked with North Sails staff to improve aspects of construction and material development.

Fortunately for the development programme, sailcloth fabrics as used in racing and cruising spinnakers and gennakers has been excellent adequate for the SkySails kites up to quite large sizes, with appropriate construction techniques.

One feature that will be rewarded as we scale up to larger and larger sizes and loads is to recognise that the main loads run across the kite in a span-wise direction and propagate both span-wise and through the thickness of the section.

Cloth is laid chord-wise for manufacturing ease, and spinnaker fabrics are designed to have the strongest direction along the "warp", which is the chord-wise direction for these kites.

Kite manufacturers will need to work with the fabric manufacturers to develop fabrics which have the main axis of strength in the "weft" or "fill" direction (across the cloth). Fortunately this is not new to cloth manufacturers and there are many existing styles of fabric which are designed this way.

As kites get larger, specialist fibres will increasingly become important, but at present nylon and polyester are perfectly adequate for kite manufacture, further contributing to the economic viability of the system

5. KEY AREAS OF DEVELOPMENT

Autopilot.

Autopilot development is one of the systems unique to the SkySails development programme and has required a large portion of the in-house development attention.

Kite flying is a skill not quickly learned and mistakes would lead to kite crashes and put the system out of action. For these reasons it was recognised from the start that the viability of SkySails depended on developing an automatic kite flying system so that ship crew need not be at all skilled in manoeuvring the kites.

This has progressed enormously over the years. SkySails staff include skilled kite fliers and for a long time the kites were always flown by a SkySails engineer, albeit by remote control and radio signals from the beginning of the programme.

As the autopilot program has developed, not only has the safety improved, but in fact the autopilot software now flies the kite more efficiently than the skilled pilots so that kite performance has increased far behind our earlier standards.

A higher average apparent wind speed at the kite, (from the autopilot skill) and improvements in the kite design have meant that we are achieving line loads well in excess of those forecast and achieved in our early test program

The autopilot resides in the control pod, while overall control of the system is maintained at the bridge station

Routing system & route optimization.

The weather routing system, which SkySails has also developed, provides shipping companies with a means to guide their ships to their destinations on the most cost-effective routes and according to schedule. SkySails meteorologists do the weather routing in four steps:

The first task is to develop the weather forecast. Modern meteorological methods make precise three to five-day weather forecasting possible. Major weather systems and weather trends can be forecast for even longer periods. A decisions model includes requirements of the shipping company. A balance of fuel saving, and the importance of arrival times are important for the decisions on routing and kite deployment.

Critical to these decisions are the performance calculations. The weather forecast data and the decision model flow into the performance calculation which can then calculate optimal routes based on the projected performance

This route is converted into a series of waypoints, and these, along with the supporting data, are sent to the shipmaster. The solution can of course be re-visited during the actual voyage.

Launch and recovery system

Anyone who has watched kite-surfers operating on a beach can appreciate how much can go wrong during the launch and landing of kites!

The key advantage of kites – the enormous power they can develop for a given kite area due largely to the freedom to fly over a wide surface unlimited by masts and rigging, can become a serious liability in this phase of the operation.

The development of a reliable and simple launch and recovery system lies at the heart of the viability of the SkySails system and, along with the autopilot, has taken much of the development time to date.

As well as demanding system reliability, the company has been at pains to minimize the “intrusion” that any part of the SkySails system makes on the layout of a vessel.

This has resulted in a single integrated unit which can handle all the physical operations of the kite system in one compact location.

The launch and recovery system manages the deployment and lowering of the towing kite. It is installed on the forecastle and consists of a telescopic mast with reefing system which unfurls and reefs the kite respectively during the launch and recovery process.

A coupling mechanism connects the towing kite with the mast adapter attached to the launch and recovery mast. The towing kite is stored in the kite storage on the forecastle.

During the launch, the telescopic mast raises the towing kite - which arrives folded like an accordion - from the kite storage. Subsequently, the telescopic mast extends to its maximum height. The towing kite then unfolds to its full size under natural air flow from the apparent wind, and once it has achieved a flying shape, it can be launched and set flying.

The winch releases the towing rope slowly, and the kite is flown by the autopilot at the “zenith” of its scope, until operating altitude has been reached.

The recovery process is performed in the reverse order of the launch. The winch retracts the towing rope and when fully retracted, the nose of the towing kite is captured at the top of the mast. The towing kite is then reefed. The telescopic mast retracts and the towing kite is stowed in the kite storage unit along with the control pod.

Each of these procedures (launch procedure and recovery procedure) is carried out largely automatically and each requires approximately 10-20 minutes

6. PERFORMANCE

The technical possibilities resulting from the spatial separation of the ship and the “sail” or towing kite give SkySails an entirely new performance spectrum.

The towing kite of the SkySails propulsion can be navigated “dynamically”. This means that the autopilot can perform flight manoeuvres with the towing kite such as the figure of eight in front of the ship.

The high airspeed of the towing kite is particularly relevant since the airflow velocity at the kite’s aerodynamic profile is the key to performance. For the calculation of the traction force of towing kites the airflow velocity is squared:

$F_{line} = V_{Kite}^2 * Rho/2 * A * C_R$

where

$V_{Kite} = a * (V_{AWS} * \cos(theta) * \cos(zeta))^{b}$

F_{line}:= line force

V_{Kite}:= air flow velocity seen by the kite

Rho:= air density

A =: kite area

C_R:= aerodynamic reaction coefficient a,b: coefficients for kite characteristics (depending on profile and trim)

V_{AWS}: apparent wind speed as seen by the ship at kite flight level

theta and zeta are the azimuth and elevation angle of kite line to the apparent wind vector

The kite speed in the air can be many times the apparent wind speed as seen by a static kite. The limit is defined by the overall L/D ratio which defines the "slipperiness" of the kite as flown dynamically

The average sustained force of the kite is proportional to the root-mean square of V_{Kite} and to calculate this exactly requires an integral over the range of theta and zeta prevailing in each situation.

The equation above is semi empirical, and was adapted to suit the theory (in which the velocity would depend on the L/D only), and the flying data which includes the reality of manoeuvring throughout the range of angles. This is what leads to the power term in "b"

If b = 1, then "a" is equivalent to the L/D-ratio.

If the airflow velocity is doubled, the traction force of the kite quadruples. In practice, the towing kite easily reaches speeds three times that of the true wind and often more.

It is for this reason that you will see kite-surfers planing back and forth while the windsurfers are sitting on the beach, and its for this reason that SkySails has observed a factor of more then 5 in the increase of the wind loading (force / sq m) developed by kites as opposed to conventional sails

This efficiency also leads to increased safety as the kite can develop a much larger range of forces for a given sailing situation than conventional sails.

When underpowered, heading downwind, the autopilot can generate an effective force coefficient of 5 through dynamic flying, yet the same kite can be flown at the zenith and de-powered so that its force coefficient is only 0.5 and that force directed essentially vertically.

A further significant technological advantage of the SkySails propulsion is that the towing kites can operate at altitudes between 100 and 300 m where stronger and more stable winds prevail.

At an altitude of 150m the average wind speed can be 25% higher than at a height of 10m.

For all of these reasons, it is possible to gain significant tow force and fuel savings by using surprisingly small kite areas.

For comparison: The 109m long four-mast barque "Sea Cloud" has a sail area of 3,000m² in total. A cargo ship of the same length would be fitted optimally with a towing kite of about 300m² in size.

During the enduring pilot phase the calculated performance of the SkySails-System has been proven true:

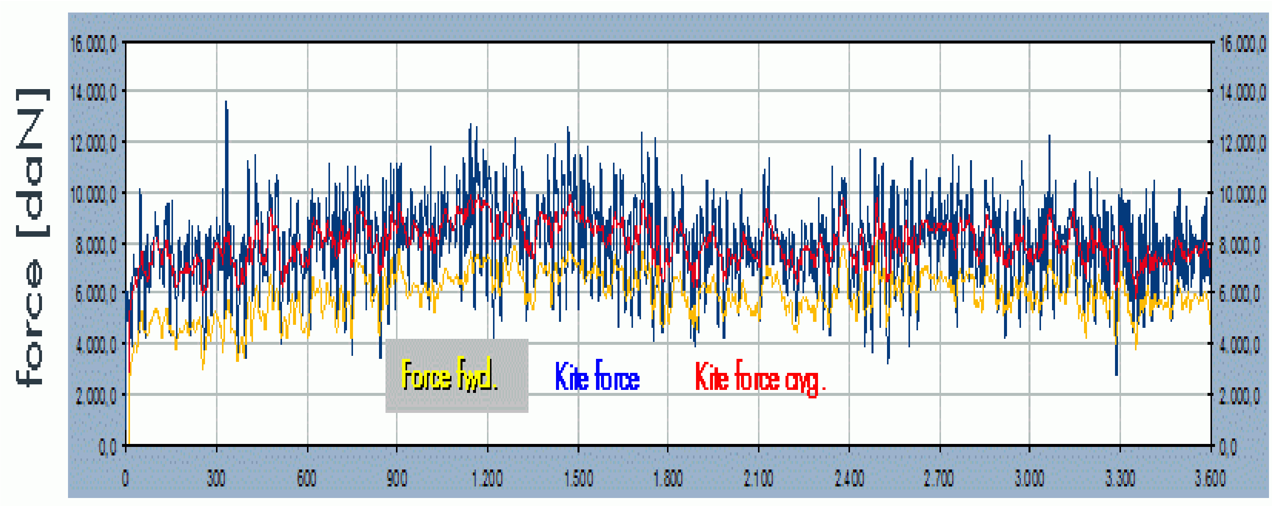
MS "Beluga SkySails":

Savings of 20% at low wind speeds (160m² Kite)
Savings of up to 40% possible (with 320m² Kite)

MS "Michael A.":

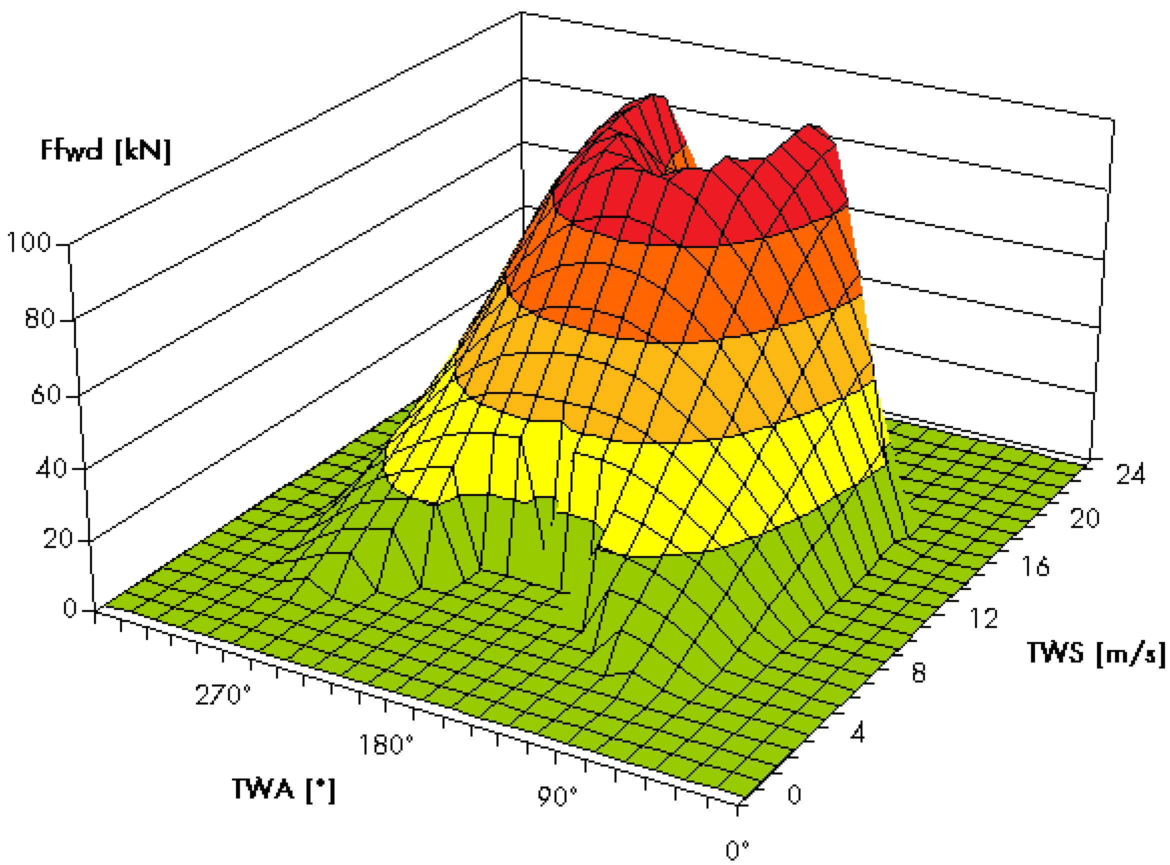
Savings of 70% under optimal conditions (160m² Kite)

Average annual savings of between 10% and 35% (depending on the route) are quite realistic.



Above: Extract from operational results

It can be seen that the forward force (yellow trace) averaged 6000 daN (6 tonnes) in this sample



Above: Force mapping of SkySails propulsion for the SK160 kite system

7. SUCCESSES

The latest measurements made aboard the cargo ship “Michael A.“ of the Wessels Shipping Company demonstrate how the towing kite propulsion system delivers far more than five times the performance per square meter of sail than traditional wind propulsion systems. With the help of the wind, the 160 square meter kite generates up to 8 metric tons of traction force – this approximately corresponds to the thrust of an Airbus A318 turbine engine.

“Our own measurements show that we were able to temporarily save far more than half the fuel by deploying SkySails in favourable wind conditions,” reports Gerd Wessels (37), managing director of the Wessels shipping company based in Haren/Ems, adding that “alternatively we were able to increase the ship’s cruising speed from 10 to 11.6 knots with the help of this towing kite propulsion.”

Each of the shipping company’s next three new 88-meter, multipurpose sister ships with a deadweight capacity of some 3,700 metric tons and nearly 1,500 kW of power will be fitted with a 160 m² kite. With favourable wind conditions, a kite of this size can generate up to 8 tons of traction power. For comparison: in order to reach a cruising speed of 11 knots, these ships require approx. 11 tons of thrust.

8. RETROFITTING, ADAPTING VESSEL DESIGN FOR SKYSAILS

Supply Interfaces

Most of the components are installed on the foredeck on mounts welded to the ship‘s hull. The system requires a connection to the ship‘s electronics and/or hydraulics on the foredeck. The workstation for operating the system is installed on the bridge. In addition to a power supply, an appropriate interface to the ship‘s computer is needed in order to supply the system with the ship‘s data.

Installation & Commissioning

Virtually all existing cargo vessels and new builds can be retro- or outfitted with this auxiliary wind propulsion system. Installation can be made in the shipyard of choice or in any port that has an adequate crane system. The ship can remain in the water during installation.

In line with the installation process, the client first provides the company with all the needed information and records pertaining to the ship onto which the system is to be installed. The company project manager also inspects the ship together with the client to examine the installation options on board.

On the basis of this examination, SkySails provides all background information necessary for the customer to compile and submit the relevant records to the insurance company, the classification society and the installing shipyard. The system is then installed on the vessel at the shipyard designated by the client and under supervision of service staff from the company.

The components are installed in three steps:

1. Preparation of the mounts and foundations for winch and launch system; Cutting of openings for the wiring and hydraulic lines. Reinforcement of the foredeck may be required. Typically, however, the ship‘s structure in this area is designed with adequate strength due to the reinforcement requirements for the anchor windlass.

2. Installation of the components winch and launch system on the foredeck mounts. Installation of the workstation on the bridge.

3. Laying of the electrical and hydraulic lines and connection of the system components. Winding of the towing rope onto the winch. Stowing the towing kite and control pod in the kite storage.

Normally, a total of 3 pairs of consecutive workdays are required for installing the SkySails-System. If necessary, a few more days may be required for work on the electric system, which however can usually be completed while the ship is at sea.

As desired or needed, each of the individual installation steps can be performed independently, at different times and at different locations. This, for example, allows using extended docking times for loading and offloading to install the SkySails-System.

The costs of the installation work are handled directly between the shipyard and the client.

Once the installation is complete, a function check of the components fitted on the ship is conducted in port. The function of the entire system is tested during subsequent sea trials. Following that the seller then provides the buyer with a record of delivery verifying that the system is in proper working order.

Operating conditions

The SkySails-System supplements the existing propulsion of a vessel and is used offshore, outside the 3-mile zone and traffic separation areas. The system is designed for operation in predominantly prevailing wind forces of 3 to 8 Beaufort at sea. The system can be recovered, (but not launched), at wind forces below 3 Beaufort. The kites will provide a net forward force at all angles deeper than 50 degrees to the true wind.

9. FUTURE PLANS

The company is continuing to scale up its towing kite technology. In 2009 towing kites with an effective load of 16 tons will be available, in 2010 32 tons, in 2012 64 tons. The goal is to develop a system able to generate an effective load of 130 tons under standard conditions.

Its universal design opens up an attractive market for the system: Some 60,000 of the worldwide approximately 100,000 ships listed in Lloyd’s Register and about 1,100 of the 1,900 newly built vessels joining the world's merchant fleet each year would be logical ships to be outfitted with kites.

SkySails plans to equip 1,500 cargo ships and fish trawlers, as well as numerous super yachts, with its systems by the year 2015.

Thanks to its broad applicability in the shipping sector, the kite system can make a major contribution to curbing climate change. The systematic and worldwide use of this technology would make it possible to save over 150 million tons of CO_2 a year, an amount equivalent to about 15% of Germany's CO_2 emissions.

10. CONCLUSION

Flying kites to propel ships is a fairly obvious idea in its broad scope, but has many technical issues.

The SkySails concept has explored a novel way in which to propel vessels using kites and by dint of painstaking development over the past 8 years, the company has made progress in solving many of the technical problems. The areas of development that remain are concerned with improving reliability, particularly in the “launch and recover” phases, and scaling the systems to larger and larger sizes.

This will take time and a good deal of hard work remains, but the prognosis is an optimistic one. Since the system was envisaged, oil costs have soared and the potential market for SkySails has grown.

On the supply side, technology advances, both within and outside the company have improved potential performance of the SkySails and the range of application.

The future for this technology looks promising indeed.