The INDOSAIL – Wind Propulsion System

Review regarding the INDOSAIL wind propulsion system aboard Maruta-Jaya, Rainbow-Warrior-II and Syscomp-I/Sedna-IV in preparation of renewed implementations

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This report was prepared with kind support from Mr. Peter Schenzle and Captain Peter Willcox

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1 INTRODUCTION

This report summarizes the concept of and experience gained with the INDOSAIL wind propulsion system implemented onboard different sailing vessels built and sailed in the past 30 years. The aim is to give an overview on technical requirements and design options for a renewed application of this system onboard the "Trial and Training vessel for RMI" as well as the CERULEAN vessel design. The collected experience gained onboard these vessels shall be the basis for further detailed planning and construction drawings to be prepared by a specialized engineering office for wind propulsion systems.

The INDOSAIL System was originally developed in the framework of a joint German – Indonesian research and development project between 1980 and 1995. The aim was to develop a high performance system that is easy to manufacture, cost effective and simple to operate with a small crew, suitable for commercial cargo operation.

Intensive prototyping and testing of the system in the wind tunnel (HSVA) and onboard different sized trial vessels led to a highly effective and robust technology that proved suitable for low cost heavy duty applications onboard small to medium sized commercial cargo vessels. Nevertheless, the prototype cargo vessel MARUTA JAYA showed some shortcomings concerning the durability in sea service of some locally produced rigging components.

Shortly after the implementation onboard MARUTA JAYA 900 the system was installed, in a slightly modified setup as a retrofitting measure onboard RAINBOW WARRIOR II of Greenpeace. Onboard this vessel the system was used very successfully for several years till 1994. The gaffs were removed and the sails replaced by triangular yachting style systems. The vessel continued service for Greenpeace until 2011 but the performance of the early years with the INDOSAIL system was never reached again. It was sold after the new build RAINBOW WARRIOR III was taken into service. The vessel was finally decommissioned in 2018.

In 1992 the INDOSAIL system was retrofitted onboard the vessel SYSCOMP I (ex SAINT KILDA, later SEDNA IV). Onboard this vessel, mechanization of the system was further improved, by using well proven conventional rigging technology. The general layout however was still based on the original INDOSAIL concept.

Different approaches on operational technology, materials for rigging and sailcloth have been followed in the different applications of the system onboard the vessels. Long-term experience aboard those vessels will help in the development of a suitable application for efficient service for new applications on board small to medium sized commercially operated vessels.

This document will start with a description of the functionality of the system, followed by a short presentation of the different implementations of the system onboard different vessels. At the end of the document the findings for improvements are listed in a detailed construction proposal.

The document has been reviewed by Mr. Peter Schenzle who was in charge during the INDOSAIL-PROJECT and also participated in the design of the systems on board RAINBOW-WARRIOR-2 and SYSCOMP-I. Mr. Peter Willcox worked as a captain on board the INDOSAIL vessels RAINBOW-WARRIOR-2 and SYSCOMP-I and also on board other vessels like RW-1 and RW-3 (traditional rigging and yachting technology). His experience with different WP-systems allows for comparison between the technologies on board these vessels. Mr. Willcox comments, concerning experience onboard the different vessels are added to the different chapters and also in the appendix.

2 INDOSAIL - TECHNICAL DESCRIPTION

The following drawings have been prepared by Peter Schenzle who was in charge of the INDOSAIL project and as well of the implementations onboard RAINBOW WARRIOR II and SYSCOMP I.

2.1 GENERAL LAYOUT

The INDOSAIL Utility Sailing Rig, with a total of four sails and three masts was implemented aboard all three vessels. SYSCOMP I /SEDNA IV carried an additional large double-genoa sail for improved performance in light stern-wind conditions.

The INDOSAIL system makes perfect use of all available space between the masts for generating driving power from the wind. This is further emphasized by high very high aerodynamic force coefficients, superior to many other known systems.

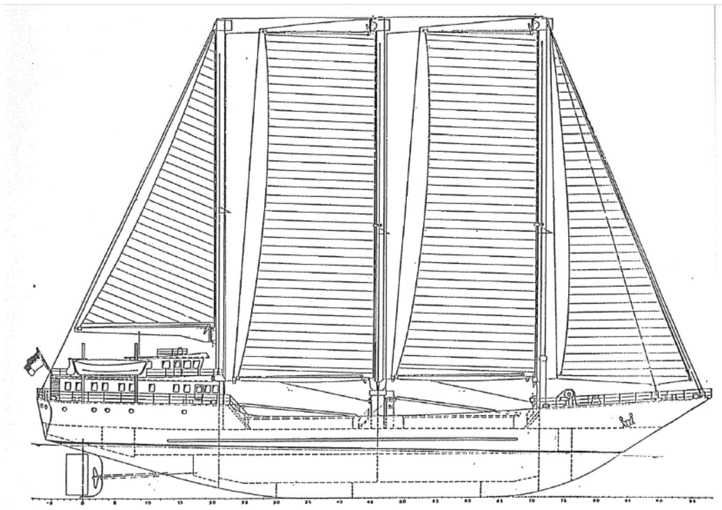


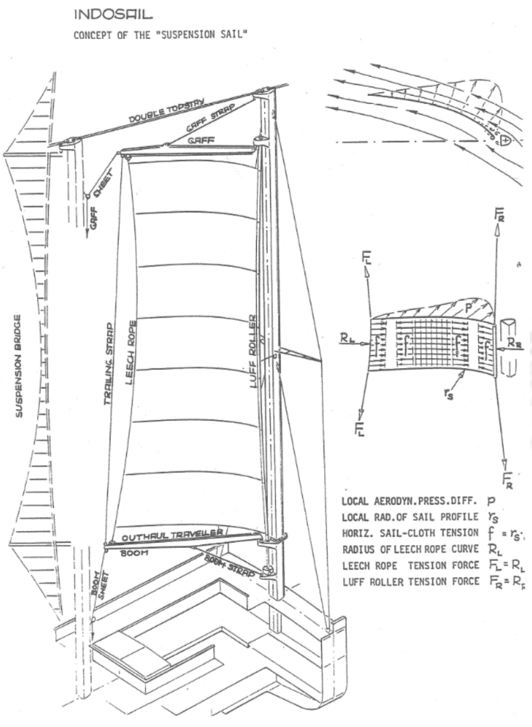
FIG. 5.2 INDOSAIL 50/3 PROTOTYPE RIG (DEZ. 1984)

The large gaff (basically a reversed boom), that is sheeted to the top of the mast behind the sail and connected via a permanent trailing-strap to the boom, allows a highly efficient operation by having full control of the sail in all situations.

The balanced jib-sail concept allows easy and automated foresail operation.

The pre-tensioned frame around the sails ensures easy setting and furling of the sailcloth in all weather conditions almost independently of the course sailed towards the wind. The hollow-cut leech of the sails can be interpreted just like the concept of the suspension bridge.

At high wind load on the sail the leech rope will take-over the tension from the trailing strap, indicating thereby an overload situation, that is clearly visible for the helmsman (slackening of the trailing strap) or can be used for automated reefing systems.



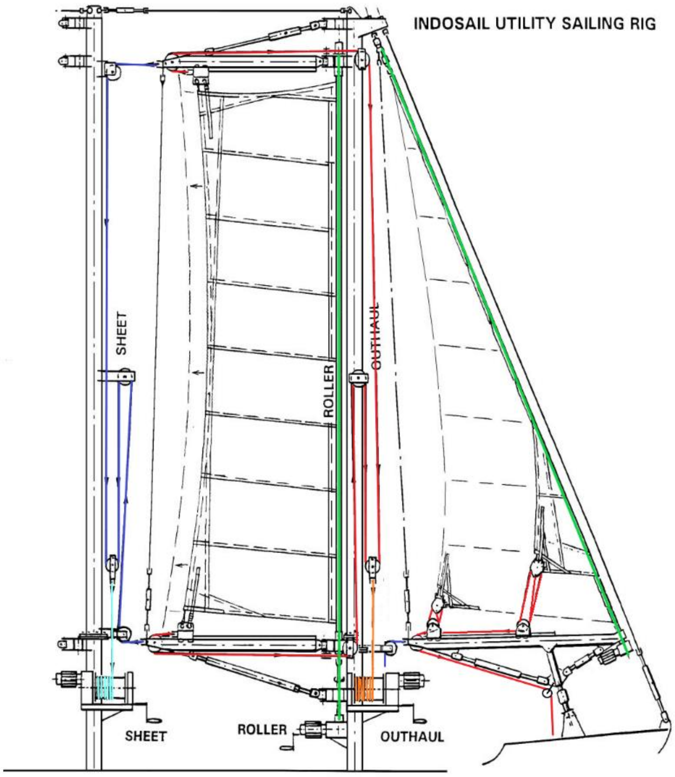
2.2 SCHEMATIC OPERATION OF THE UTILITY SAILING RIG

For each sail there is one furling / roller system (green) in combination with an outhaul system (red/orange) as well as a specialized drum-winch equipped with a clutch/brake system for controlling the sheet (blue).

The outhaul system for the rectangular sail is acting by force distribution, whereby the outhaul sheets from gaff and boom are connected (red lines). The drum winch pulls at both ends simultaneously while the force is equally distributed to the upper and lower clew corner of the sail.

The sheeting of gaff and boom is also acting by force distribution based on the same principle (blue lines).

Jib-sail control and operation is done in a similar manner but the outhaul requires an additional block-and-tackle (see diagram) to allow the clew to move upwards while furling the sail while keeping the pull angle tangential to the leech.



SCHEMATIC OPERATION SYSTEM

The furling systems of all sails reduces the effort for setting and reefing of the sails to a minimum. This reduced effort for setting sails will lead to increased usage times of the wind propulsion system even on short tracks, where labor intensive systems would not be utilized due to the higher workload.

This low-effort approach is also followed by the design of the jib-sail, which can be tacked in the same way like the other sails, without the need to switch from a portside sheet to a starboard side sheet.

If the system is equipped with remote controlled electrical winches and furling systems, the sheeting of all sails can easily be adjusted by the helmsman via a control panel from inside the wheelhouse.

Further automation of opening, reefing and furling is possible if the required systems for monitoring sail positions and angles as well as information on torque or force inside the furling and winch-systems are available as well.

2.3 OPERATION AND REEFING

The furl systems allow very flexible adaptation of the sails to the actual strength of the wind.

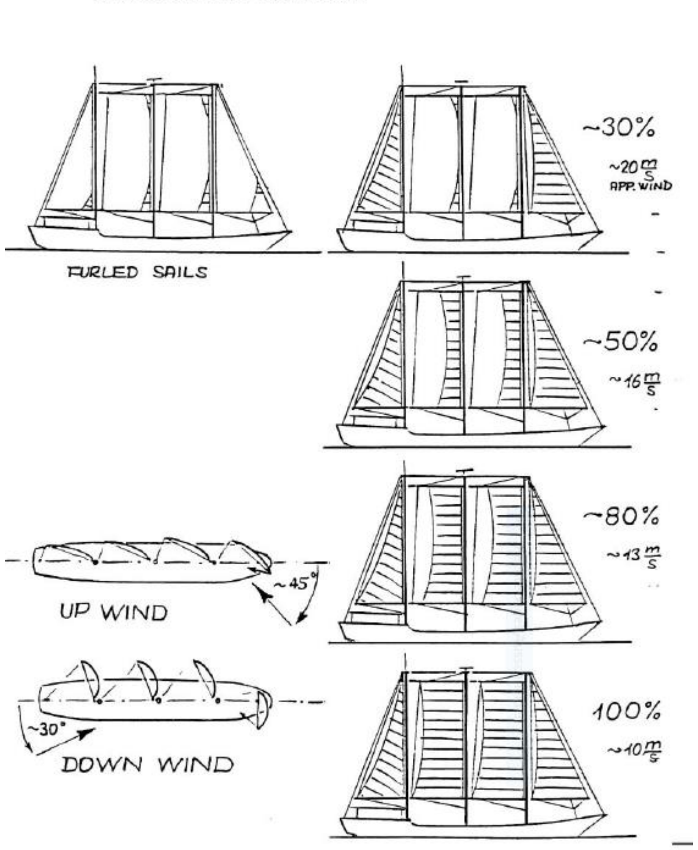
The reefing of the two rectangular main sails, leads to a narrow low aspect ratio sail shape that has proven high efficiency during strong wind conditions.

The triangular jib and mizzen sails can be fabricated using strong sailcloth for use in heavy weather conditions.

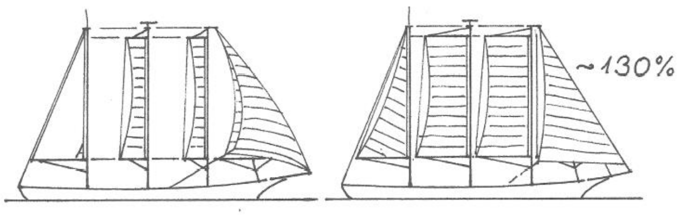
Due to different wind conditions in winter and summer, two sets of sails could be provided. Large light-wind sails for summer season and a heavy sailcloth set, cut to ~80% of boom length, for winter season.

By providing two sets of sails, regular maintenance intervals (change every six month) of the sails will be made easier.

INDOSAIL UTILITY SAILING RIG



A light-wind genoa sail could be installed in addition to the boomed jib sail, increasing performance of the vessel in light airs.



This large extra sail however cannot easily be automated and would therefore need extra crew during operation

2.4 GRADE OF MECHANIZATION

The layout of the Indo-Sail system allows implementing different operational modes and grades of mechanization and automation.

- Manual operation of all systems
- Direct electric/hydraulic operation of all systems by local control for reduced labor effort, increased operational speed and safety
  (manual operation should always be possible as a back-up)
- Remote controlled electric/hydraulic operation via a control panel inside the wheelhouse
  (in addition to local electrical/hydraulic and manual control of the systems).
- Semi-automated operation. The system will sheet all sails to predefined optimum sail positions according to actual apparent wind speed and direction on command of the helmsman. Display of wind conditions and optimum sail angles.
- Automated operation in combination with detailed wind and weather data, information from the electric/hydraulic systems on the actual position of all running rigging (sail sheets, sail-furling system). The system will sheet the sails to the optimum according to actual apparent wind speed and direction. Reefing or easing the sheets according to actual heel angle.
- Use of weather routing programs to find the fastest track towards destination is always possible and recommended, independent of specific layout of the system.

Comments by Capt. Willcox

Manual backups for all the hydraulic or electric winches is a great idea. A manual back up for the furlers is not an easy item. I would certainly support it if it could be worked out.

One thing I noticed on the third R.W. was the consistency of breaking hydraulic hoses and fittings. I would strongly suggest the use of peanut oil, instead of petroleum based hydraulic fluid. Then when something breaks, it is not a panic party to keep the fluid out of the ocean. I do not know all the advantages of hydraulic vs. electric

I would not make it possible to set or reef or furl the sails from the wheelhouse. Make the crew go out to the base of the mast.

I would not use a semi-automated operation. It is the same as letting your GPS talk directly to your auto-pilot. It takes the operator too far out of the program. Make the mates aware of what is going on, and make them adjust the sails.

Nor would I use a fully automated system. What could go wrong? Adjusting sails to the optimum wind angle does not require a computer.

2.5 SYSTEMS NEEDED FOR AUTOMATION

- An ultra sonic (no moving parts) wind sensor two meters above the top of the foremast. It must be tied into the GPS, so a read out of true wind speed and direction is possible.
- Measurement of tension in connecting wire ('trailing strap') for automated reefing in case of overload.
    - pre-tensioned trailing strap will become slack if pressure on sails is too high! Indicating sailcloth overload -> manual or automated reefing
- Use of appropriate measurement systems or other solutions for identification of exact position/length of all controlling lines of the sail system (sheets, reefing ropes (roller) / outhaul ropes)
- All winch and furling systems should measure torque/forces to be used for automation process.
- For commercial operation, combined engine and wind propulsion can be regarded as a common operational mode. Since the propeller will influence hydrodynamic behavior of the vessel, engine settings should be included in the effort of automation of every Sail system as well.

2.6 SYSTEM SECURITY

- The use of a wind propulsion system in addition to a conventional drive train will always increase safety of the vessel due to redundancy in vessel propulsion.

- Load limit, by torque and/or current limitation:
  Overload situation in a sudden wind gust can be prevented by limiting the load in the sheeting drum-winch. The brake/clutch of the winch will open automatically if the limit is reached.

- Limitation of traveler trolley position (traveler ropes) through the use of limit switches:
  Limit switches can be used to indicate end positions of the travelers and thus prevent system damage by misuse. The same effect may be achieved by 'soft end stops' to be determined by teach-in based on counting winch drum angle.

- Emergency button:
  A single button in reach of the helmsman, to release all sheeting brake/clutches to instantly open all sails if necessary in any kind of unexpected situation.

- Manual operation of all systems in case of system failure or blackout will ensure continued service (just more labor intensive) and safe return to port if a system repair is not possible onboard the vessel.

3 IMPLEMENTATIONS OF THE INDOSAIL-SYSTEM ABOARD DIFFERENT VESSELS

3.1 THE INDOSAIL-PROJECT AND IMPLEMENTATION ABOARD "MARUTA JAYA 900"

Lessons learned:

Despite of exceeding all expectation regarding sail performance, several aspects of rig and vessel-design proved to be difficult and led to later changes in design and especially in construction of the system.

Findings concerning the functionality and robustness of the system can be grouped in different categories:

Materials:

- Sailcloth: the sun-resistant acrylic sailcloth used for the first set of sails revealed stretch and shape deformations at edges because the cloth was woven of short fibred yarn.
  - ➔ Use of standard sail-cloth will prevent sail deformations.
  - ➔ new endless yarn sun-resistant materials can be tested for increased lifespan and shape stability compared to conventional sailcloth.

- Gaff made of steel proved difficult to control in swells without wind pressure.
  - ➔ lightweight aluminum construction will improve the difficulties with swinging gaff

- Balanced-Jib-boom was not weight balanced and therefore required an additional set of sheets on the forward end to hold the desired sail angle in light winds, thus counteracting the effort of simple and remote sail angle control from within the wheelhouse.
  - ➔ weight balanced jib-sail-boom would help.

Sail control and technology:

- Experience showed that for efficient sheeting of the sails the pull function of the electric drum winches worked very well and forces on the sheet were quite low (as a result from the boom-strap that prevents the need for downward pull of the boom)

- For opening the sail-angle however, the best option is to open the clutch/brake of the drum-winch, preventing the sheet to fall loose if the wind is too weak to push the sail out.
  - ➔ Modern smart drum-winch systems have the option to hold automatically a minimum tension on the sheet (preventing the slack automatically).

- Maruta-Jaya was equipped mostly with locally available technology that was not proven for offshore maritime use. Many technical components had severe damage due to corrosion after only short time in service
  - ➔ Proven maritime technology should be used wherever possible: Especially for the furling systems (roller) and all other winches and mechanical fittings that are used on deck.

Integration of the cargo gear:

- Different approaches have been tried to integrate the cargo-gear in an efficient way into the rigging. Efficient cargo handling is considered as important as efficient propulsion in commercial operations. To use the sail-boom like a cargo boom (to safe costs for additional cargo gear) would require to release all tension from the tensioned frame and would therefore lead to considerable effort in switching from cargo to sailing mode.

- The most promising option would be to have a doubled boom-strap, that allows the use of a trolley underneath the boom. Requirements for this to work out is sufficient height of the boom above the cargo hatches. But this increased height would compromise sail efficiency, prevent deck cargo and was not possible onboard MARUTA JAYA as well.

- In the end, the 'union purchase' cargo gear was installed completely independently from the wind propulsion system in front of the masts, whereby all difficulties in combining the two systems were avoided.

- The design of the INDOSAIL allows to swing out the booms to more than 90° to the water side (forward angled spreaders) and thus the system stays out of reach of most cargo gear operations. Options to fix the boom in this outward position by preventers must be provided also for down-wind sailing.

Performance in combination with hull design and engine drive-train layout

This topic is not specifically connected with the choice of the rigging system but will have an influence on the usability of the rigging as there is always interaction between aerodynamic and hydrodynamic forces when using wind propulsion.

- The large bow-overhang ('integrated bowsprit') of the vessel proved to be very practical in operation, by preventing slamming loads that were feared to have significant influence on the structural dimensioning of the rigging. This large bow-overhang moves the lateral pressure point of the aerodynamic system considerable forward and thus reduces the load on the rudder, due to a more balanced aero- and hydrodynamic layout.

- Ruder layout: For the Maruta-Jaya the rudder effect was reduced when sailing without engine support. The free milling propeller reduced flow velocity around the rudder and thereby reducing required rudder efficiency. The only solution in those situations was to keep the (electric) engine running at low rate for increased rudder efficiency.

- There was no distinctive keel system used on board Maruta Jaya. The hull had a V-shapes mainframe with a small deadrise angle. Furthermore, the vessel was trimmed to the aft for improving yawing momentum stability and to reduce the load on the rudder.

3.2 RETROFIT RAINBOW WARRIOR-II

The rig is based on the principal lay-out of the INDOSAIL system combined with conventional yachting winches and some experimental modifications.

Sail operation is done by manual and electrical winches and electric furl-systems. Sheeting is done locally, while opening, reefing and furling the sails was attempted by central control from the wheel house.

Lessons learned:

- The shorter gaff construction prevented the complete reefing of the mainsails.
  - ➔ Return to original design with a gaff of approximately the same length as the boom.

3.3 RETROFIT: SYSCOMP 1 / SEDNA 4

The rigging of SYCOMP I has been designed and executed according to the operation experience of the INDOSAIL prototype MARUTA JAYA 900 and RAINBOW WARRIOR II.

For easy operation of the system, the focus was consistently on simple electrical operation with largely proven rigging technology.

Unlike the original layout, the ship is equipped with an additional double headsail, which probably improves the performance both beating close upwind and running downwind with open double sail, in light airs.

Lessons learned:

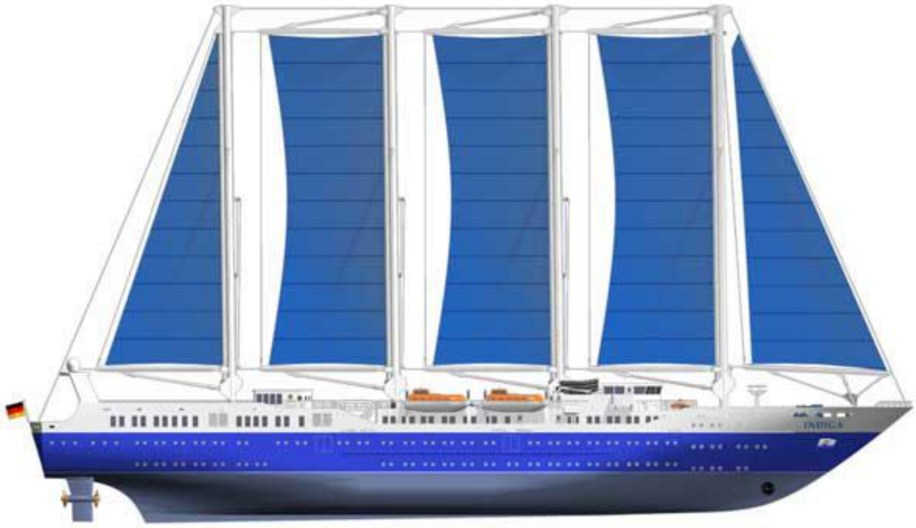
Simple operation leads to higher percentage of usage for the wind propulsion system as compared to the manual handling aboard traditionally rigged vessels and also compared to the partly manually controlled RW-II.

Comment Peter Willcox:

The biggest difference between Syscomp 1 and the second R.W. was the rudder. The R.W. had a rudder that went to 35 degrees. Syscomp 1 had a rudder that went to 70 degrees. It made it a much easier boat to drive. I would strongly recommend this. I would also recommend a bow thruster.

I liked the mast baskets and ladder on Syscomp 1. The permanent wires that ran up each side of the ladder for use with self-arresting gear were an excellent safety feature.

3.4 DESIGN-STUDY INDIGA



Lessons learned:

The concept of the INDOSAIL system is scalable, due to the optional high grade of mechanization.

3.5 RECOMMENDATION FOR NEW INDOSAIL SYSTEM DESIGN

- Use of electric (or hydraulic) winch systems. Brake/clutch release options must be integrated. Monitoring of Torque and revolutions should be possible for remote control and automation options.

- pull sheets with electric/hydraulic winch, release sheets by opening the brake/slip clutch, to avoid loose rope in the sheet.

- Use standardized roller-reefing system (yachting technology) for all sails. Either manual system that is operated with a separate drum winch or electric/hydraulic furl-system (super-yachting)

- All sail system control winches and furl-systems preferably have the function for effective manual operation (in case of electric failure). If not other means for manual operation should additionally be implemented to the system to ensure safety in case of electric/hydraulic failure

- Sail angle control (adapt sheeting) from the bridge must be possible

- emergency release button at bridge (opens the brake for all sails at the same time)

- Setting and recovering the sails from the mast position under the sail for better visual control (simple technology).

- For automated reefing and helmsman control of sail size, the winch and furling systems must include torque and revolution data to be displayed for the helmsman.

- Use aluminum for gaff and boom construction for reduced maintenance effort. If possible, use of standardized and proven yachting materials.

- Provide efficient maintenance concepts. Especially for the gaff, as the gaff has proven to be a weak member of the system due to remote position and maintenance difficulties.

- Use Dyneema or comparable low stretch ropes for all running rigging?

4 DESIGN AND CONSTRUCTION DETAILS

In this chapter the construction of the system shall be described as detailed as possible in order to not dismiss any important aspects based on the experience with previously build vessels.

4.1 MAST

Masts can be constructed in steel or from aluminum. Depending on available budget and dimensioning of the rigging. Optimum profile for the masts would be an ellipsoid nose with a flat endplate (Delta section profile) to minimize air flow resistance and sail interference of the rigging (original design). Nevertheless, a simple circular mast will serve the system well enough, by simplifying construction due to the use of standard profiles.

Spreaders and upper shrouds are angled slightly forward to counteract the high bending moment of the pre-tensioned frame and the wind-loaded sail behind the masts. Loads from the sails are transferred solely at the positions of boom and gaff. The governing load for construction strength is therefore buckling stress from the pre-tensioned standing and sail-frame rigging as well as accelerations in waves and the heeling moment.

All running rigging should be mounted externally of the masts to minimize errors caused by undetected damage and simplify maintenance and visual control.

For maintenance purposes, a mast-basket at the height of the gaff should be considered with access to all critical parts of the rigging, especially both ends of the gaff.

The mast basket can be made accessible by a cased-in ladder in front of the masts (see Syscomp-I /Sedna-IV)

4.2 MAINSAIL

The idea behind the mainsail is to simplify setting and reefing of the sail and to simplify sail-cut and profile-trim due to the rectangular shape and the suspension bridge effect of the hollow-cut leech seam, inside a pre-tensioned frame. The frame, setup by mast, boom, gaff and the trailing-strap, is tensioned by the boom and gaff-strap according to the load limits of the sail. Overload of the sail will be indicated by a slack trailing-strap.

4.2.1 Sail

The upper and lower edge and the internal seams of the sail are tilted in a small angle to allow the seams and the reinforced edges of the sail to roll up nicely (seams side by side) when furling around the luff-roller.

The leech seam (tailing edge) is cut concave by ~3% in order to control the horizontal sail cloth tension and to prevent flattering of the trailing edge. A strong, low-stretch leech rope should carry the sail tension by the suspension bridge effect.

4.2.2 Boom

The boom is to be constructed in aluminum. Preferable standard yachting technology should come to application.

The goose neck bearing of the sail boom needs a distance from the mast to leave enough space for the luff roller.

This offset will also provide a good sail shape by slackening the tension of the sail for increasing boom- and sail angles.

The boom-strap is an elongated rigging screw with the option to adjust its length according to the required tension of the frame.

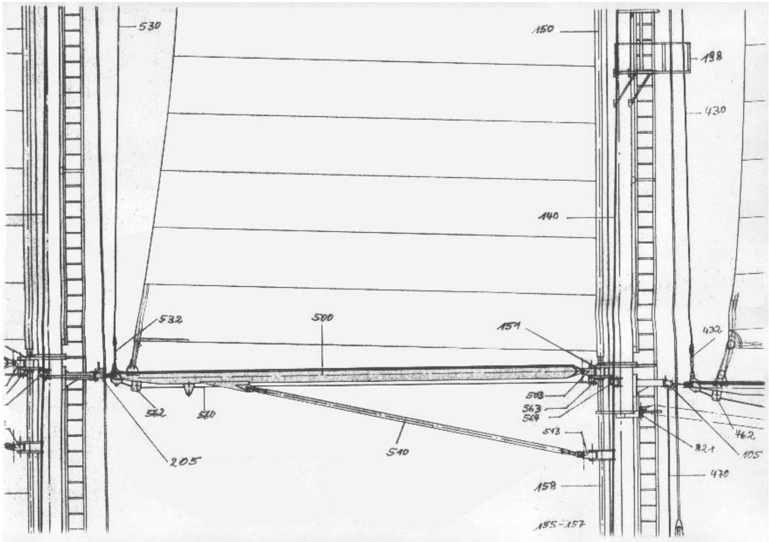


Figure 1: boom design from SYSCOMP-I

4.2.3 Gaff

The gaff can be the exact same construction as the boom (same mechanical function and input of forces, but upside down).

Lightweight aluminum construction is of high importance to better control the swinging of the gaff in a seaway.

The length of the gaff should also be the same as the boom to have a symmetrical sail-cut and smooth furling behavior while reefing.

The gaff-strap can be made from stainless steel rod.

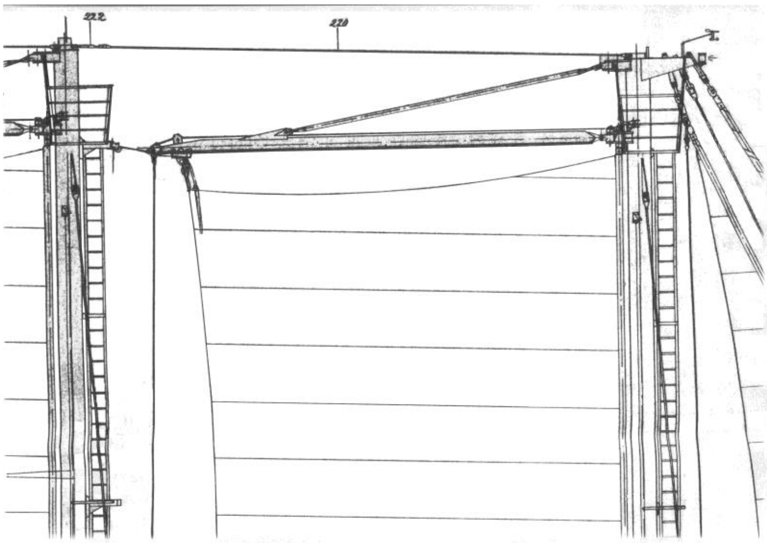


Figure 2: Gaff design for SYSCOMP-I

A good gaff maintenance concept is required to allow for regular inspection and overhaul. On all previously built vessels maintenance of the gaff was a critical issue.

4.2.4 Technical equipment and further components of the system

Furl-system (luff-roller)	Electric/hydraulic controlled yachting system of high quality construction, alternative a manual furling system could be used in combination with drum winch operation thus manual operation of the system will always be possible as well.
Drum-winch (sheeting and outhauling)	Electric/hydraulic drum-winch, with clutch/brake system and monitoring of revolutions and torque
Traveller rails and trolleys on boom and gaff	Rails and trolleys to be selected from standard yachting equipment.
Trailing-strap	connecting gaff and boom needs to be constructed as low-stretch as possible, to prevent shape deformation of the sail in different load conditions.

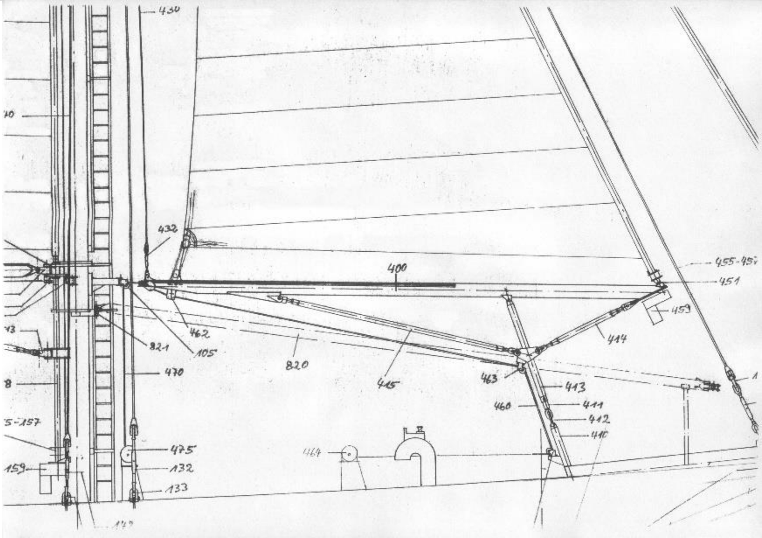
4.3 JIB

The basic principle of the jib sail is the same as for the mainsail. The sail is positioned inside a (triangular) frame in order to easily control sail trim and area, independent of the actual sail angle. The sail can be furled and set inside this frame regardless of the actual boom angle.

4.3.1 Sail

- Conventional flat cross-cut sail with concave leech optimized for use on a furl-system.
- The jib-sail should be made of heavy cloth to be used together with the mizzen in heavy weather situations.
- The leech seam (trailing edge) is cut concave by ~3% in order to control the horizontal sail cloth tension and to prevent flattering of the trailing edge.

4.3.2 Balanced-Jib-Boom

The boom is positioned to have its pivoting point shortly forward of the aerodynamic pressure point of the sail. This will minimize required force to control the sail The boom should be constructed of aluminum and must be weight balanced in order to allow the sail to open even in light wind conditions. The furl-system (luff-roller) is positioned at the front end of the boom	 *Figure 3: Balanced-Jib-Boom design for SYSCOMP-I*
The traveler trolley is equipped with an additional block-and-tackle to allow the clew of the sail to move upward when reefing.	

4.3.3 Technical equipment and further components of the system

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Traveller rails and trolleys on boom and gaff	Rails and trolleys to be selected from standard yachting equipment.
Trailing-strap	The trailing-strap, connecting gaff and boom needs to be constructed as reckless as possible, to prevent shape deformation of the sail in different load conditions.
Swivel at head of the tension frame	The swivel at the head of the frame must allow easy turning of the frame without causing twist in the sail.

4.4 MIZZEN

The basic principle of the mizzen sail is the same as for the mainsail. The sail is positioned inside a (triangular) frame in order to easily control sail trim and area, independent of the actual sail angle. The sail can be furled and set inside this frame regardless of the actual boom angle.

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- Conventional flat cross-cut sail with concave leech optimized for use on a furl-system.
- The mizzen-sail should be made of heavy cloth to be used together with the jib in heavy weather situations.
- The leech seam (trailing edge) is cut concave by ~3% in order to control the horizontal sail cloth tension and to prevent flattering of the trailing edge.

4.4.2 Boom

Use the same design as for the mainsails. For leech (trailing edge) tension control, the trolley needs an additional block-and tackle to maintain tension and angle when reefing (standard yacht-system).

4.4.3 Technical equipment and further components of the system

Furl-system (luff-roller)	Electric/hydraulic controlled yachting system of high quality construction, alternative a manual furling system could be used in combination with drum winch operation thus manual operation of the system will always be possible as well.
Drum-winch (sheeting and outhauling)	Electric/hydraulic drum-winch, with clutch/brake system and monitoring of revolutions
Traveller rails and trolleys on boom and gaff	Rails and trolleys to be selected from standard yachting equipment.
Trailing-strap	The trailing-strap, carrying the boom needs to be as low stretch as possible, to prevent shape deformation of the sail in different load conditions.
Swivel at head of the tension frame	The swivel at the head of the frame must allow easy turning of the frame without causing twist in the sail.

4.5 STANDING AND RUNNING RIGGING

- All standing rigging should be made of stainless steel rope (1*19, 1*37) and doubled for increased security and simplified maintenance. Tensioning of all wires should be simple enough for regular and routine control by the crew of the vessel.
  (Checking tension by natural oscillation frequency according to pre-calculated values).

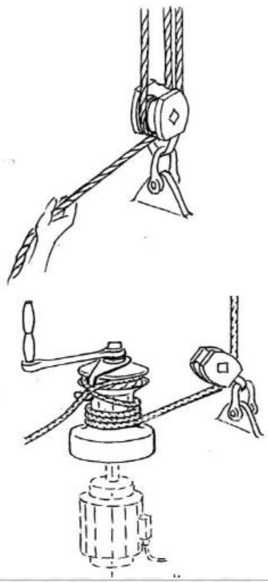
- For all running rigging, dyneema could be an interesting option that should be discussed in more detail.

4.6 SYSTEM OPERATION TECHNOLOGY

There are different options for sail system control technology. Manual operation for low budget applications as well as different grades for remote or automated operation by the use of electric/hydraulic winch and furling equipment.

4.6.1 Manual operation of all systems

If for any reason electric/hydraulic operation of the system is not anticipated, all functions of the system can be set up for manual operation referring to standard yachting technology.

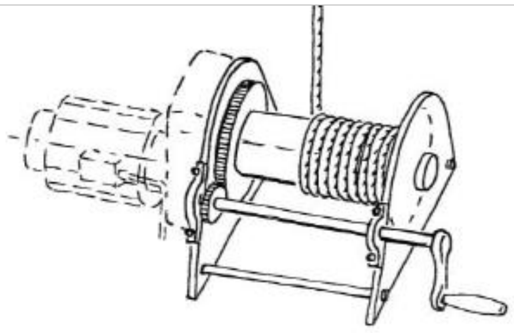
• Manual furling systems (pullout line for furling/reefing function) • Standard or self-tailing sheet-winch for sail setting function as well as for operation of the manual furling system and the sheeting of the sails. • Manual control technology will require crewing of all sails for all sail handling necessities (setting sails, sheeting, reefing). • These small yacht-style winches can also be equipped with electric power to reduce physical effort, but nevertheless will require personnel for all intended operations.	

4.6.2 Remote control sail sheeting

4.6.2.1 Specialized drum-winch system

- 1 - 2t maximum load is enough power for sheeting the sails, since no downward forces are needed. Calculations for maximum load requirements based on final design.

- Electrical system is easier to control / hydraulic system might be more robust



- Pull sheet function by rolling up the sheet on the drum
- Release sheet by opening the brake/slip-clutch. This ensures that there is always tension on the sheet, whereby loose rope on the drum is avoided.
- Ideally the drum-winch is configured in a way that a defined minimum load is required on the sheets. If tension is below this minimum load, then the drum-winch should automatically pull in the loose sheet.
- Options for torque/current measuring and counting the revolutions of the drum will provide all necessary data for setting up a well-functioning system that is capable for further automation.
- Drum-winches with this functionality must probably be developed by a specialized company, as this is a very different usage to normal requirements for weight-lifting drum-winch systems (cargo gear).

Comment by Capt. Willcox

> *The sheeting winches on Syscomp 1 worked beautifully. I would be cautious in making them more complicated.*

4.6.2.2 Yachting captive-reel-winch for sheeting the sails

Different suppliers exist that have developed automated sheeting winches for use in the yachting and super-yachting scene: Lewmar, Harken, etc.

Figure 4: Harken, 1.5t captive reel winch

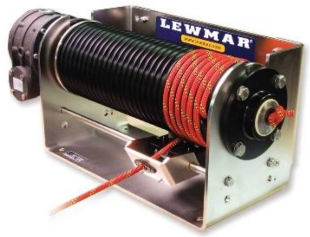


Figure 5: Lewmar, CW-800

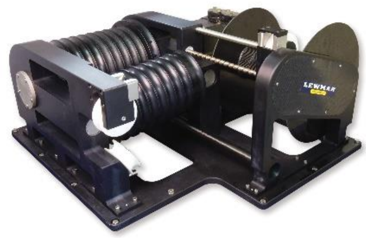


Figure 6: Lewmar, CP 2500

Comment by Capt. Willcox:

We used these captive Lewmar winches on the third Rainbow Warrior.

The winches use "pre-feeders". These were soft silicone wheels. If the compression was too high, it would chafe the line quickly. If the compression was too soft, the wheels would spin and wear out themselves and the line quickly.

We had continual problems with the feeders. Those were the pressure wheels that kept tension on the line as the line went onto the drum. In general, I found these winches to be problematic, and not as reliable as the simpler winches we had on Syscomp-I!. I saw no big advantages with Lewmar winches.

If the feeders were not set to the correct tension, either the line would slip through and chafe, or the wheels would wear out quickly. They were a pretty constant problem.

I would stick with simpler winches.

4.6.3 Remote control luff-roller systems (furling gear)

- Use of standardized equipment for jib- or genoa-sail furling on sailing yachts.
- Manual emergency operation must be possible in case of electric/hydraulic failure
- High quality equipment should be used to ensure durability in Marshallese conditions

Comment by Capt. Willcox:

Also the furlers were very different. The aluminum furlers on both the second R.W. and Syscomp 1 were trouble free. The Rondal furlers on the third R.W. had a lot of troubles. The would not set a reefed sail. They were not strong enough. This was a real sore point in the operation of the vessel. One of the joys of the Indo-Sail rig was that the same mechanism for setting and furling the sails were the same used for reefing. These systems were always used and understood by the crew. It was the most simple matter to reef a sail by any percentage you wanted. We once flew across the Gulf of Lyons in 60 knot winds with 30% of the jib, 10%

of the main and fore and 20% of the mizzen. This was a reliable and seaman like rig. I will add the improvements from the second R.W. to Syscomp 1 were considerable.

4.6.4 Remote control pull-out winch system

- Use of standardized drum-winch system
- For remote operation from the wheelhouse the system must be aligned in its function with the Luff-roller system (one button for setting sails, one for reefing) to control both systems in parallel
- Leek-tension information would be helpful to implement remote operation and avoid misuse or system failure (furl-system and pull-out system working against each other -> ripping the sail apart).

Comment by Capt. Willcox

The setting / furling winches we used on the second Rainbow Warrior also experienced a lot of problems. These were improved on for the Syscomp 1, and provided trouble free operation for many years

4.7 NAVIGATION-LIGHTS AND ADDITIONAL EQUIPMENT

- Navigation lights should be arranged according to best practice on large sailing yachts or traditional sailing vessels.
- Wind measuring system positioned on forward mast
- Further navigational equipment (antennas, etc.) should be positioned on the aft mast to minimize aerodynamic interference with the sails

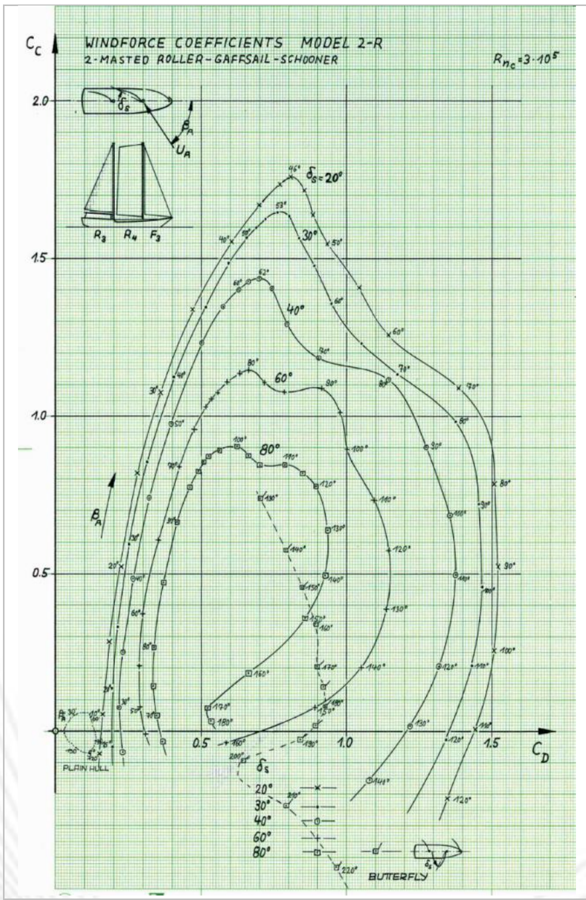
5 APPENDIX

5.1 INDOSAIL-System: wind-channel test series

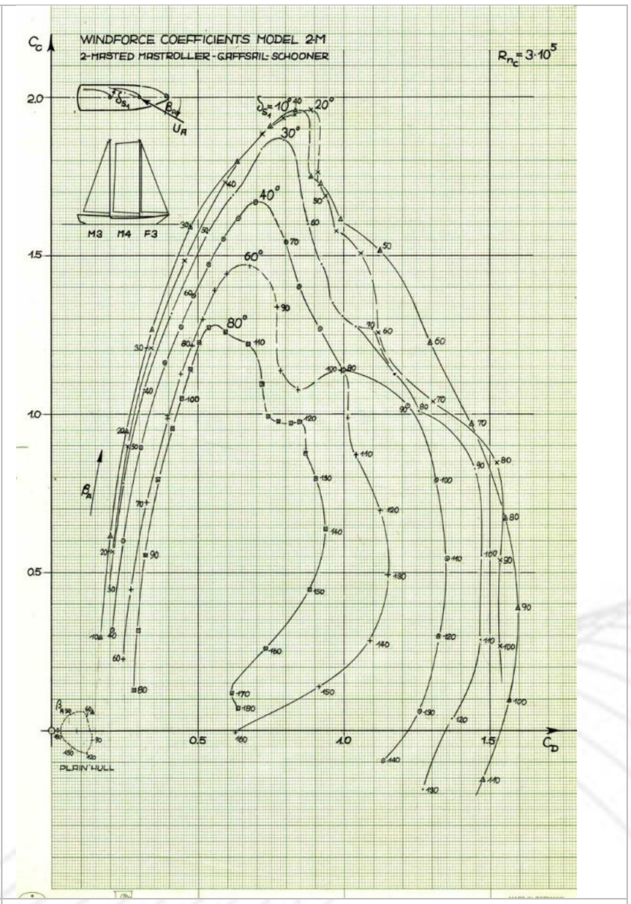
During the INDOSAIL-Project intensive wind-channel experiments were performed to evaluate different rigging concepts in the development process of the INDOSAIL system. An excerpt from these testing series, evaluating as well other types of rigging concepts, is displayed below for the two and three-mast layout of the INDOSAIL concept, as anticipated for the two vessels. The performance measurements were done in the wind-channel at HSVA in Hamburg.

Different mast configurations:

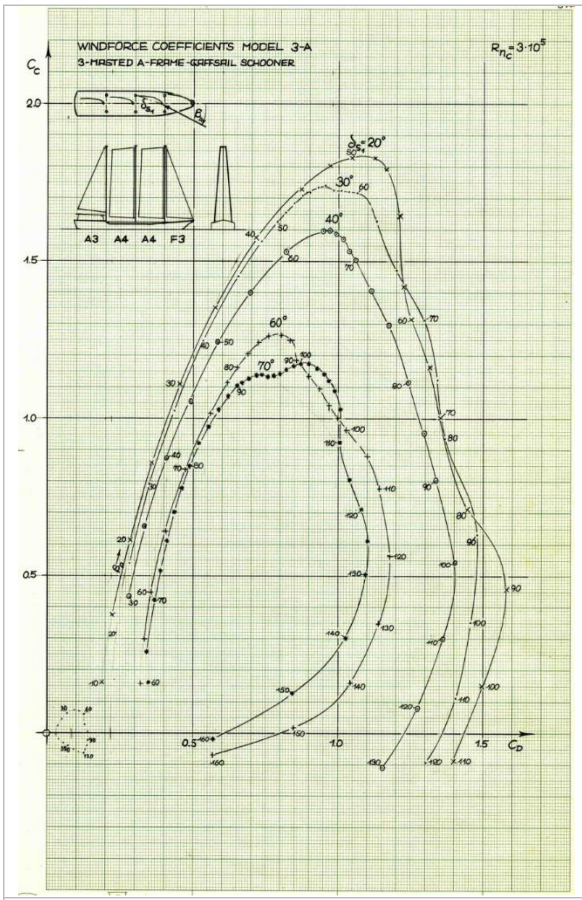
- **Mast-roller (M):** The sail is furled around the mast and thus creates a smooth transition from mast to sailcloth, whereby the mast acts as the leading edge of the profile (mast and sail). Reference area for Coefficients is: sail + mast (sail connected to mast)
- **Rod-Roller (R):** The Sail is furled around a rod that is positioned behind the mast. Reference area for the coefficients is: sail + mast + gap between mast and sail.
- **A-Mast (A):** Sail is furled around a rod that is positioned at centerline between the two parts of the A-Frame mast (free leading edge). Reference area is: sail only



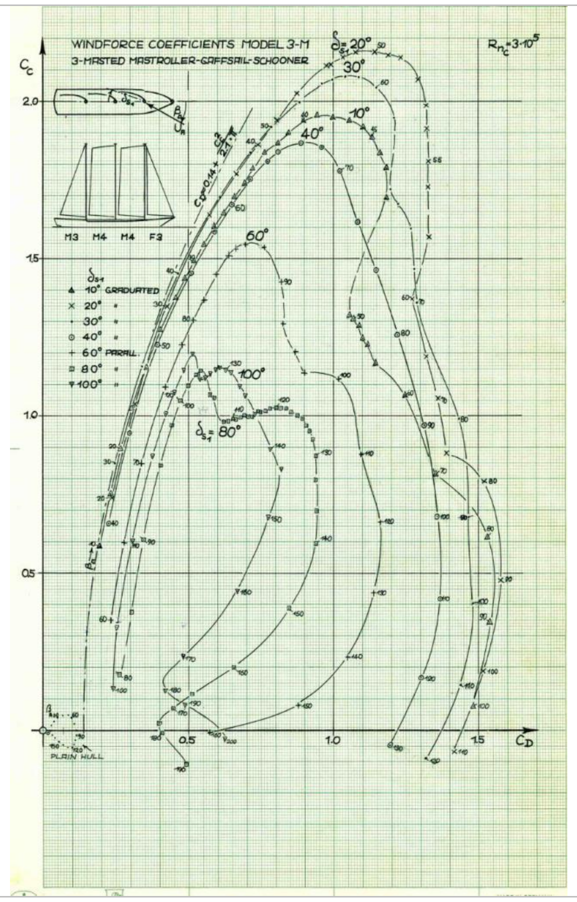
Model 2-R (two mast, rod-roller)



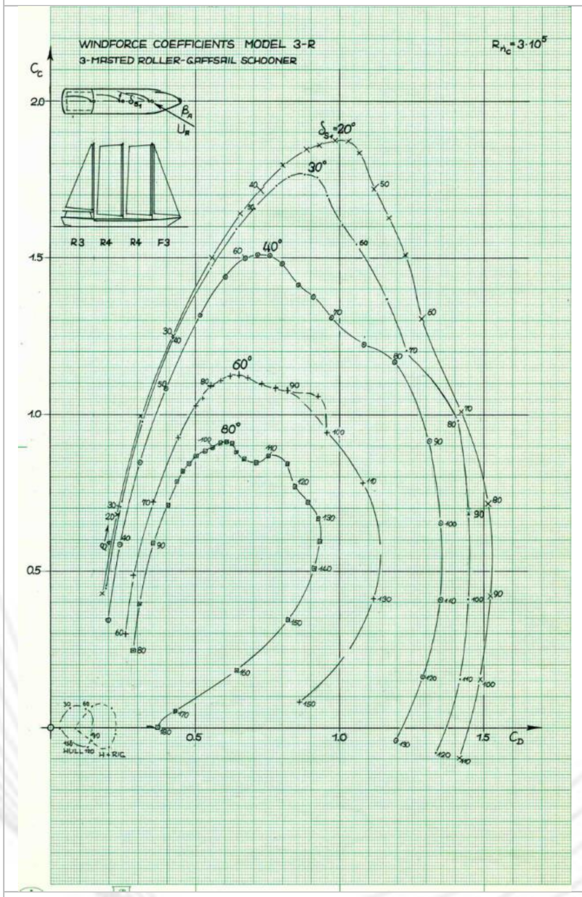
Model 2-M (two mast, mast-roller)



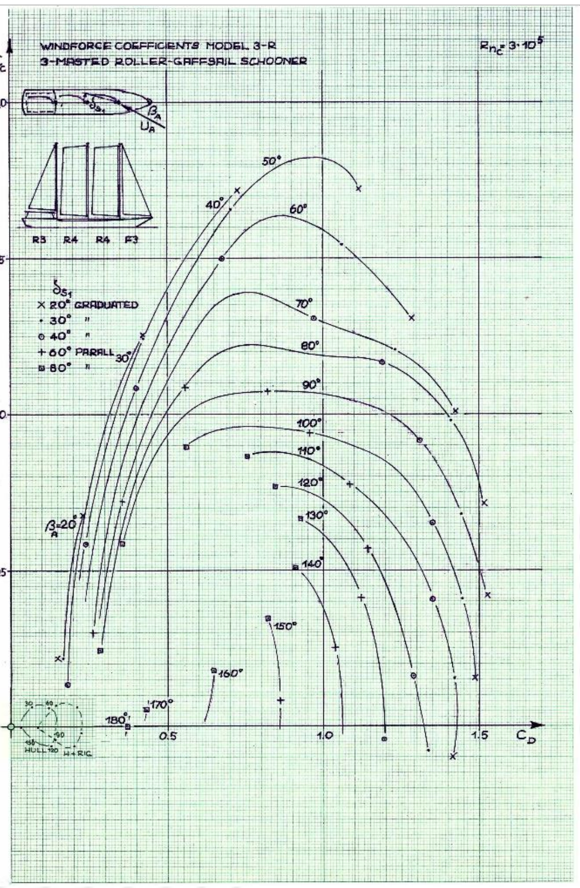
Model 3-A (three mast, A-Frame)



Model 3-M (three mast, mast-roller)



Model 3-R (three mast, rod-roller)



Model 3-R (crosscurves)

5.2 Comments by Captain Peter Willcox

Notes on “Transitioning to Low Carbon Sea Transport – The Indo Sail Rig

By Peter Willcox

General Note

The author’s repeated suggestion to use “yachting technology” causes me some concern. The third Rainbow Warrior used yachting technology. Spars and rigging by Rondal Winches by Lewmar.

The winches use “pre-feeders”. These were soft silicone wheels. If the compression was too high, it would chafe the line quickly. If the compression was too soft, the wheels would spin and wear out themselves and the line quickly.

The setting / furling winches we used on the second Rainbow Warrior also experienced a lot of problems. These were improved on for the Syscomp 1, and provided trouble free operation for many years.

Also the furlers were very different. The aluminum furlers on both the second R.W. and Syscomp 1 were trouble free. The Rondal furlers on the third R.W. had a lot of troubles. The would not set a reefed sail. They were not strong enough. This was a real sore point in the operation of the vessel. One of the joys of the Indo-Sail rig was that the same mechanism for setting and furling the sails were the same used for reefing. These systems were always used and understood by the crew. It was the most simple matter to reef a sail by any percentage you wanted We once flew across the Gulf of Lyons in 60 knot winds with 30% of the jib, 10% of the main and fore and 20% of the mizzen. This was a reliable and seaman like rig. I will add the improvements from the second R.W. to Syscomp 1 were considerable.

I suggest that yachting winches are not the answer for an Indo-Sail vessel.

1. Introduction.

I would add that the second Rainbow Warrior was very successful until approximately 1994, when Greenpeace, in a move caused from pure ignorance took the gaffs off the boat. I sailed the boat in 1995, and was so disgusted that I never sailed on the boat again.

2.1 General Layout

It is my understanding that the Syscomp 1 never carried a double genoa. It did carry a single genoa, and had long poles to wing out the sail with. There is problem with this. A multi-masted vessel, like the three masted Indo-Sail rigs does not run directly down wind well. When sailing far enough off the wind to carry the genoa to windward, the foresail, and part of the mainsail will be shadowed by the sail aft of it. A faster way to get somewhere is to put the true wind approximately 135 degrees off the bow, in order to keep all the sails pulling. It may require an extra gybe or two, but the net result in my opinion is faster.

There was some improvement to speed when using the genoa in reaching conditions. We very rarely used the sail.

Should more sail area be needed in light airs, I would be tempted to go higher on the masts. The sails can always be reefed a little quicker.

Sailing in the tropics like the Marshallese boats will do, passing showers do bring an increase of wind. In my experience, these showers will increase the wind speed by 50%. If the mate on watch has any concerns, he can easily reef the fore and the main to 50% . I did this often. It is a one person job.

2.2 Schematic Operation of the Utility Sailing Rig

In 1988 we were finalizing the rig for the second R.W. I was 35 years old, and possessed a great deal more energy than I have now. That is why we used hand powered sheet winches. For Syscomp 1, launched in 1992, the rig was finished before I arrived. The Syscomp 1 was a dramatically easier rig to sail.

There was some advantage to be able to slacken the gaff sheets to provide a little twist in the sails. But there was not enough advantage to justify the additional effort.

The difference in required manpower in tacking or gybing the two boats was considerable. On the second R.W. we would need a minimum of six or eight people to tack or gybe. On Syscomp 1, we sailed the boat ten of thousands of miles with one person on deck. A number of times I would get underway from being anchored, and under full sail in less than 15 minutes, with only myself on board.

One the second R.W., I even installed gaff preventers. These turned out to be unnecessary. The boom preventers were necessary, but they did not have to be used all the time. We carried two permanently rigged boom preventers, but often they were stowed under the boom.

The jib did have a traveler for the outhaul. But I saw this as necessary for using the sail in a reefed condition rather than using it to keep the traveler the correct angle to the leech when furling.

I agree that it is important for the helmsman to be able to control the sheets from the helm. I do not believe that the sails should be set or furled from the helm. A big aid in set or furling the sails is your ears. Sail fabric or lines coming under strain can be heard often before it is seen. I would have the furling and setting controls at the base of each mast. For the jib, I would have it in the middle of the foredeck. Having a long wire to the controls will allow the operator to see what is going on from the best angle.

On both boats we carried preventers or backing lines on the jib. These were necessary and did a few different things.

When tacking in light airs or in a seaway, it may be necessary to keep tension on the windward backing line. This will act to hold the sail in its original position, so it can back the head of the vessel around to the new tack.

When running in light winds, the backing line can pull the jib around to a better sheeting angle.

When using the jib in a reefed condition, the back line will be needed, as the sail will not be balanced over the pivot point.

2.3 Operation and Reefing

I am not sure that I agree that two sets of sails are necessary. I would refer this to a sail maker. I would note that it is not an easy job to change any of these sails. Doing it every six months sounds like way too much work.

I would not bother with a genoa.

2.4 Grade of Mechanization

Manual back ups for all the hydraulic or electric winches is a great idea. A manual back up for the furlers is not an easy item. I would certainly support it if it could be worked out.

One thing I noticed on the third R.W. was the consistency of breaking hydraulic hoses and fittings. I would strongly suggest the use of peanut oil, instead of petroleum based hydraulic fluid. Then when something breaks, it is not a panic party to keep the fluid out of the ocean. I do not know all the advantages of hydraulic vs. electric.

I would not make it possible to set or reef or furl the sails from the wheelhouse. Make the crew go out to the base of the mast.

I would not use a semi-automated operation. It is the same as letting your GPS talk directly to your auto-pilot. It takes the operator too far out of the program. Make the mates aware of what is going on, and make them adjust the sails.

Nor would I use a fully automated system. What could go wrong? Adjusting sails to the optimum wind angle does not require a computer.

The use of weather routing systems is necessary.

2.5 Systems need for Automation

An ultra sonic (no moving parts) wind sensor two meters above the top of the foremast is necessary. It must be tied into the GPS, so a read out of true wind speed and direction is possible.

Regarding the measurement of the trailing strap, I do not see a need for a load cell to be incorporated. Peter Schenzle showed me how to measure tension by vibration the wires. We would could a set of ten vibrations. This was critical not only for the trailing straps, but to adjust the tention of the forestay, and jib trailing strap and the backstays. Get the three different materials at the bow, (the head stay, the jib furling tube and the trailing strap) to work with each other was critical. And it is easy to do once you know how. I found this technique difficult to use on the shorter shrouds.

Motor assisted sailing will certainly be used at times. Schenzle's research into the very positive benefits from adding a small amount of horsepower are impressive. But the propeller should be fully feathering. And the boat should be able to make power from letting the propeller free wheel when sailing.

3 Implementaions

This might be the correct place for me to advocate for aluminum masts. Weight aloft is critical to performance.

3.1

Balanced jib boom. I am not sure what is meant by weight balanced. I can not imagine a design that would eliminate the back lines or preventers.

Sail control technology. The sheeting winches on Syscomp 1 worked beautifully. I would be cautious in making them more complicated.

As much as I like the looks of a long sloping bow, I question the efficiency. I think that a plumb bow that is narrow, almost an axe bow would be more sea worthy and efficient. This would increase the water line length and reduce vertical accelerations.

3.3 Syscomp 1

The biggest difference between Syscomp 1 and the second R.W. was the rudder. The R.W. had a rudder that went to 35 degrees. Syscomp 1 had a rudder that went to 70 degrees. It made it a much easier boat to drive. I would strongly recommend this. I would also recommend a bow thruster.

"Simple operation leads to higher percentage of usage for the wind propulsion system as compared to the manual handling aboard traditionally rigged vessels and also compared to the partly manually controlled RW-II."

I agree with statement completely!

You suggested that Dyneema may be used for running rigging. I found the Cup sheet from Gleistein worked very well.

I liked the mast baskets and ladder on Syscomp 1. The permanent wires that ran up each side of the ladder for use with self arresting gear were an excellent safety feature.

4.2.3 Gaff

It was my experience that once the gaff strap is correctly adjusted, it is set for a long time. Being able to adjust it from the mast basket may not be necessary.

4.2.4 Technical

I have never seen a good manual back up for a furling system. But having a battery bank (nicad?) as a back up makes for some redundancy.

The self release mechanism for the sheets are an excellent idea. We did not have this on the third R.W. When the boat would heel past 25 degrees, the generator would cut out. This made it impossible to strike the sails. This is less than optimum.

Traveler rails and trolleys. The cars on Syscomp 1 worked very well. I question the idea of using yacht equipment with its higher maintenance demands.

Additionally

I would add a weather monitoring system, so that automated weather observations can be made and transmitted to authorities.

The vessel should be set up so that a small amount of power can be efficiently connected to the propeller. (Two smaller engines rather than one big one.)

A nicad or similar battery bank, strong enough to strike all the sails and perhaps push the boat a few miles would be highly advisable.

I suggest you consider using PBO (or similar) shrouds. In warm salt water, stainless steel does not last more than seven years. Galvanized does last a year of two longer. When I got off the third R.W. a year and a half ago, we were still using the original PBO standing rigging, after 8 years. I am not sure how long it can go, but I am sure someone knows.