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THE "INDOSAIL" PROJECT

by

P. SCHENZLE
(HAMBURGISCHE SCHIFFBAU-VERSUCHSANSTALT GmbH)

G. WESELMANN
(INGENIEURBÜRO WESELMANN, HAMBURG)

F. WEISS
(FORSCHUNGS- UND ENTWICKLUNGS-GmbH, AHRENSBURG)

ABSTRACT

In the first three phases of the joint Indonesian-German R+D - Project INDOSAIL for the development of cargo sailing vessels for the Indonesian inter-island trade preliminary studies and the design of a prototype vessel have been carried out.

1. An evaluation of the boundary conditions revealed:
   The weather in the Indonesian waters is governed by light but steady monsoon winds.
   The rapidly expanding inter-island transport is a typical coastal trade with short sea turns and a relatively high percentage of port time.

2. The selection of technical alternatives for the rigs of a modular series of 3-, 4- and 5-masted coastal sailers of between 900 and 2000 t DWT led to the concept of a mechanized roller-reefing gaff-rig with integrated loading gear, which was successfully tested on large free-sailing models.

3. A half size Test-rig has been installed on a 20 m vessel and the design of a 50 m, 900 t DWT Prototype-hull has been completed. The design of the 3-masted, 1100 m² Prototype-rig can be finished as soon as the current structural and handling trials with the Test-rig have been completed.

In the forth phase of production the working drawings for the Prototype are being prepared on the shipyard in Surabaya.

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INTRODUCTION

In 1979 the Indonesian Minister for Research and Technology initiated an Indonesian-German co-operation in the development of cargo sailing vessels for the Indonesian inter-island trade. Accordingly the bilateral R+D - Project INDOSAIL was started in 1980 under the joint sponsorship by the Ministeries for Research and Technology of the Republic of Indonesia and the Federal Republic of Germany.

The R+D programme of the project was conceived in five phases:

1. Boundary conditions and project definition
2. Technical alternatives and rig development
3. Design of a Prototype ship
4. Construction of the Prototype by Indonesia
5. Extensive trials and evaluation of the experience.

Together with the Indonesian partner, the Agency for the Assessment and Application of Technology (BPPT) of Jakarta, it was realized during the first and second preliminary phases of project defination and search for an up-to-date technical concept that the new design of a cargo vessel with main propulsion by wind energy could not be based on any recent experience with a comparable development [1].

Only after the decline of commercial sail some 80 or 60 years ago the scientific and technical prerequisites were developed for an efficient and labor-saving utilization of the wind for ship propulsion. Therefore traditional examples as well as modern possibilities and requirements had to be carefully examined to form the basis of a present day concept for the design of a prototype ship and rig which will be yet in many aspects an experimental system for alternative solutions in detail.

BOUNDARY CONDITIONS

The Indonesian archipelago comprises more than 13000 islands about 10% of which are substancially inhabited. Of the total Indonesian population of more than 150 millions, more than 90 millions (or 60%) are living on Java which is only the fifth largest of the islands with an area of 130 000 km^2 (about 7% of the land area). The average population density on the main island is thus three times as high as in central Europe, while the other large islands are in wide ranges almost uninhabited. This may be an indication of the mutual significance of improvements in the distribution of the population, the economic development and the increasing demand for inter-island transportation systems. These systems have to serve a sea area extending about 2700 nm west-east and nearly 1000 nm north-south (Fig. 1), where the western industrialized area around

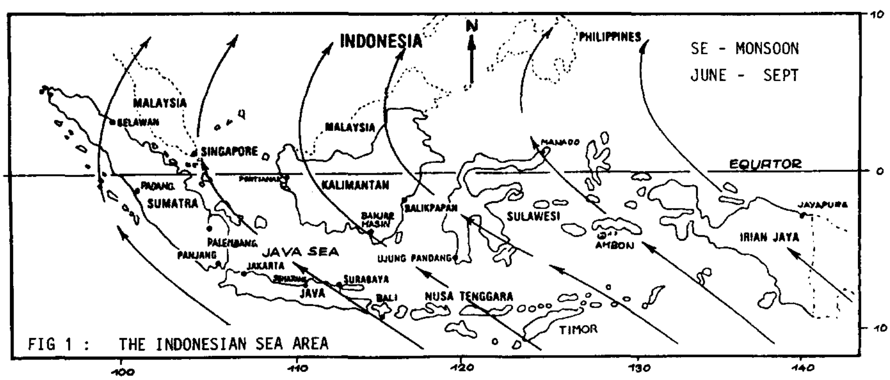

FIG 1 : THE INDONESIAN SEA AREA

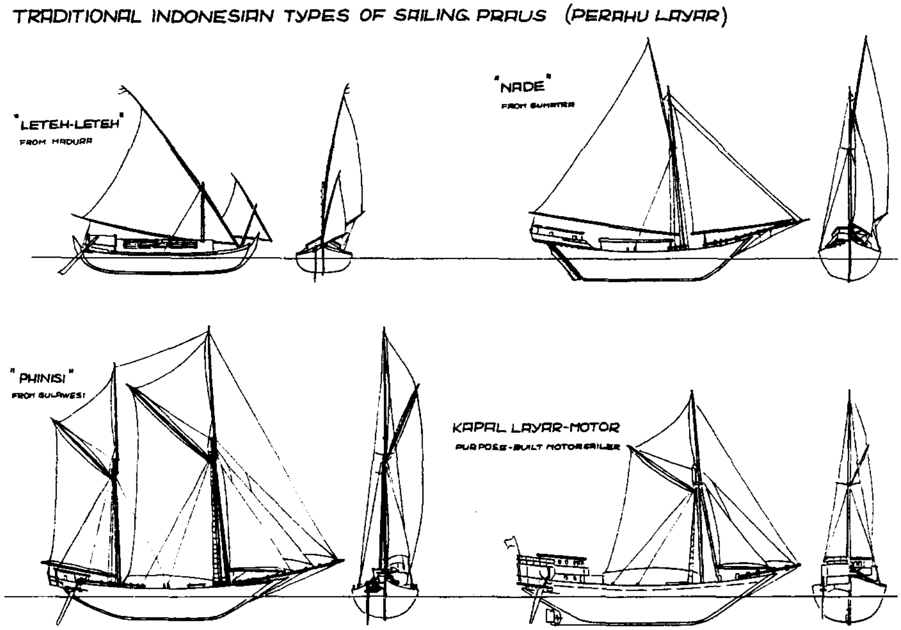

FIG. 2 : TRADITIONAL INDONESIAN PRAUS

the shallow Java Sea with about 90% of the population stands against the even more extended eastern part of the archipelago with very low density of population and economy. Accordingly the future requirement for communications is not only for an increase in capacity of seatransportation, but for the development of a diversified system of various forms of services, types of ships and methods of cargo handling to meet the manifold regional economic situations, social structures and development prospects respectively.

Presently shipping on Indonesian inter-island routes is organized on four different levels:

- The major network of the "Regular Liner Service" (RLS) that interconnects major ports, with motor ships of between 500 t DWT and 2500 t DWT on specially assigned routes.

- "Local" feeder services between secondary ports and connecting these to major ports, with motor ships of between 100 and 650 t DWT.

- Industrial carriers (known as "khusus") operated by industrial firms for their internal transportation needs which comprise special tankers, log carriers, tugs and barges ...

- Peoples Shipping Cooperative ("PELRA") vessels operating out of special local ports in a tramp mode on local and inter-island routes. These privately owned traditional wooden sailing praus ("perahu") of generally between 100 and 200 t DWT are increasingly converted to and operated as motor sailers (Fig. 2).

The routes for typical inter-island round trips may be selected from the "Regular Liner Service" catalogue. Due one to the short sea-turns, especially in the Java Sea, and relatively long port stays, the typical port-to-seatime ratio is about 60-to-40 with single port- or seatimes 2 to 4 days each. This equal significance of port speed and sea speed calls for equally serious considerations of the systems for ship propulsion and cargo handling. This holds especially for most inter-island ports lacking any land-based cargo handling facilities.

The wind conditions in the Java Sea are light and governed by a monsoon system of steady south-easterly winds of force 3 - 4 from May to October, slightly less steady north-westerly winds of similar strength in the rainy season January and February and even lighter variable winds during transition months (Fig.3). Scarce data on the eastern part of the Indonesian sea area (east of Sulawesi or Celebes) indicate generally stronger winds but severe storms are seldom and tropical cyclones or typhoons are practically impossible. The traditional sailors take additional advantage of the dayly pattern of coastal winds developing in the second half of day and night respectively after the heating-up and cooling-down of the coastal landscape.

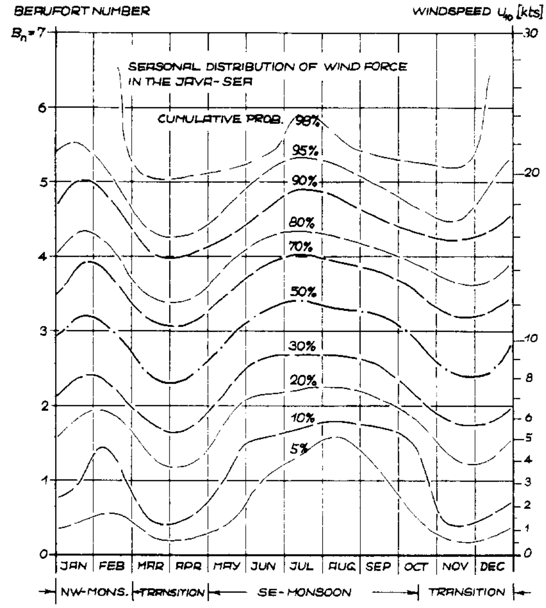

FIG. 3 : SEASONAL WIND CONDITIONS IN THE JAVA SEA

OBJECTIVES OF THE PROJECT

The basic objective of the INDOSAIL project is the development of an efficient and energy-saving coastal and inter-island cargo transportation system, which is not intended as a replacement of the traditional cooperative shipping under sail but as a supplementary element in the "Regular Liner Service" (RLS) of coastal motor ships. Thus short-term operational economics are not considered as the final end of the development effort but only as a means to reach the long-term ends of national economy such as:

- substantial saving of fossile fuel and reduction of environmental pollution,
- maintaining the huge and growing inter-island transportation system in a future of ever increasing oil prices and decreasing oil supplies,
- demonstration of an efficient utilization of steady monsoons or trade winds for coastal and inter-island communications in the tropical zone all around the globe.

Accordingly the INDOSAIL vessel has to be designed from the bottom up against requirements that must be derived from the objectives of the project by a careful assessment of the present and future operating environments. On this basis the following major design criteria were established:

- In order to become a viable part of Indonesia's future inter-island transportation system, the INDOSAIL coastal sailing ship shall be able to compete in every respect but speed with modern coastal motor ships in the RLS. The range of ship sizes anticipated in rig design shall be between 800 and 2500 t DWT.

- In order to maximize fuel saving and operating efficiency the INDOSAIL vessel shall depend primarily on sail propulsion. It shall be equipped with a small but appropriate auxiliary drive for port entry and exit, for schedule keeping in low winds and for general safety of operation.

- In order to be economically viable in the anticipated operating environment, the added investment costs for the rig shall be minimized as much as possible. For this reason the rig shall be simple, cargo handling shall be accomplished to the maximum extent practical by utilizing sailing rig components, and a light-weight safe rig structure shall be achieved by - simply implemented - limited rig forces.

- The INDOSAIL vessel will be equipped with cargo gear typical of a general cargo carrier and in capability equivalent to that of any equal-size motor ship. For example, the vessel will have hatches and cargo derricks designed to handle (empty) ISO containers (5 t) for their internal redistribution between Indonesian import and export ports and will be able to load/unload lighter pallets or bags by the most efficient method of operating derricks in union purchase.

- For reason of long-range viability the sail handling operations of the INDOSAIL vessel will be mechanized to the extent that the future crew will not be larger than on an equivalent motor ship and will be working in the same comfort and safety as on the latter. For example, all sail control operations will be carried out from the ship's deck, i.e. no sailor will be required to work aloft.

According to these criteria the INDOSAIL vessel shall be, as a modern sailing ship, slower than but otherwise absolutely comparable to motor ships. Thus, it can be employed on a large part of the Indonesian inter-island routes, particularly in view of the fact that the light but steady monsoon winds in Indonesian waters offer relatively predictable wind conditions resulting in the schedule-keeping reliability for the sailing ship that is essential for its employment on RLS routes.

Since similar criteria hold for many areas of comparable economic and meteorological conditions a successful concept could be easily adapted to the vast areas of rather stronger monsoon and trade winds, not only between the pacific archipelagos but also along the coasts of the Indian and South Atlantic Oceans.

A TECHNICAL CONCEPT FOR COASTAL CARGO SAILERS

Even more than in the case of motor driven ships the design of a wind-propelled cargo ship is governed from the early stage by the necessities of restrictions and of combining or integrating several different functions in the same place or even the same element.

A rather serious restriction for a sailing ship is the limitation of the most important dimension of a fluid dynamic lifting system, the span, both in air and in water. The limit of the (water-) draft, in our case to about 5 m, is due to the sandy estuaries where most of the indonesian ports are situated. The air-draft or mast height is limited not only by requirements to pass under certain bridges but also in connection with weight, stability and cost considerations. A further restriction is imposed on the rig and general arrangement by view requirements from the wheel house resulting in upper limit for the position of the wheel house and/or a lower limit for the sail area.

If we accept that a height-limited rig will be a multi-mast rig then we will find in the very first stage of sketching the basic configuration of hull and rig (Fig. 4) that the position and spacing of masts cannot be chosen independently of the subdivision of the hull. The structural advantage of introducing the loads of masts and shrouds directly into the bulkheads is quite obvious but at the same time the spacing of the masts is determining the length of cargo holds and

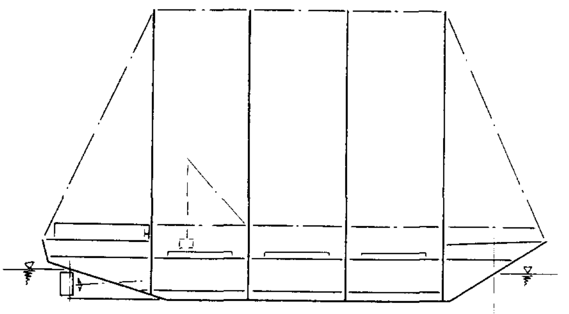

FIG. 4 : PRINCIPAL DESIGN SKETCH

hatches. A simplified shroud system only in the planes of the bulkheads requires a lengthwise system of stays over the mast tops resulting in a trapezoidal rig configuration which is matching well with a hydrodynamicaly favourable trapezoidal hull outline.

If the hull of a multi-mast sailing ship of ordinary commercial-ship type, on even keel, without fin-keels or center-boards is sailing close-hauled at a small drift angle the hydrodynamic side force will develop rather close to the stem, and together with the more evenly distributed aerodynamic side force or the sails a windward yawing moment is resulting which must be balanced by a permanent angle of the rudder to develop a side force in the same order as that on the hull. The windward yawing moment is even more serious in the heeling condition due to an effective camber of the immersed part of the hull. This high permanent loading of the rudder would result in reduced manoeuvrability and increased resistance or require an unusally big rudder. The traditional way to counteract this tendency is to shift the sail-plan forward relative to the hull as on large multi-mast ships with bow-sprit and small-size mizzen sails and/or a rake of keel increasing the draft gradually from stem to stern as on the famous schooners of the last century (Fig. 5).

In an attempt to adapt these features to modern design principles we came down with a trapezoidal hull (Fig. 5). The very raked stem has in its upper part the function of an integrated bowsprit, shifting forward the sail-plan, while its lower part is extremely cut-away to shift the the hydrodynamic sideforce back.

For practical raesons the hull is designed without a rake of keel, with parallel deck and keel and with the bulkheads and masts at right angles to both. The effect of a rake of keel is simulated instead by a full-load design loading-condition with a stern trim of about 2% of the length. To compensate this angle in the accommodation area the decks aft of the cargo space are tilted slightly upwards.

The type of the afterbody is sometimes called a "free flow"- or "buttock flow" stern with the bottom bending gently up into straight buttock lines ending at a wide transom. The advantages are a low resistance, high stability and sufficient space for accommodation aft of the mizzen mast. In the stern-trim condition the flat, narrow skeg has some effect of a fin-keel at a position (well aft) where it is most required. A retractable center board below the skeg, though favourable, was not adopted to avoid complication and damage. The lateral underwater outline of this type of hull, together with its mirror image with respect to the water plane, resambles of a slender delta wing, the lift (sideforce) of which is proportional to the square of the max. span (max. draft).

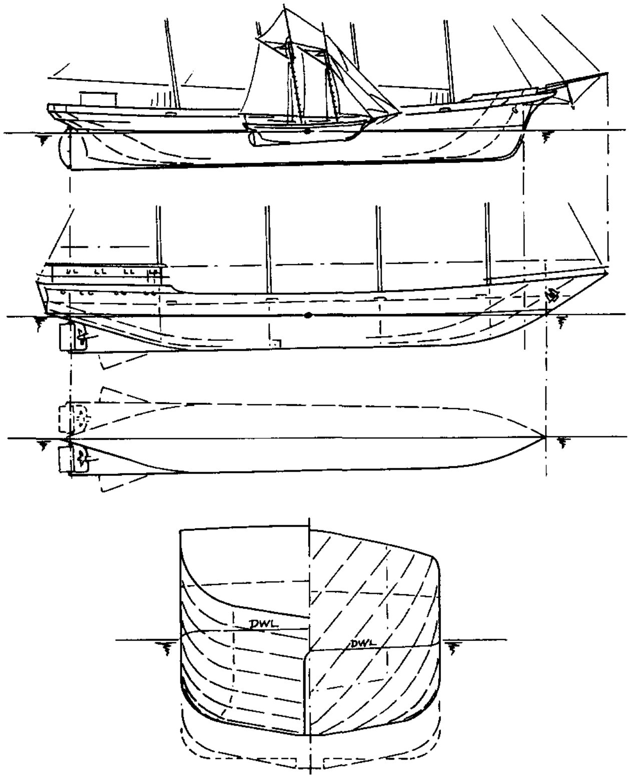

FIG. 5 : CONCEPT OF THE HULL FORM

The midship section is designed with a marked rise of floor and well rounded bilges thus reducing the wetted surface and avoiding increased resistance at significant stern trim. An alternative midship section with same draft and area but with a flat bottom plus rectangular bar-keel showed no increase in side force at small drift angles but a remarkably increased resistance, when tested in the towing tank. It might be concluded that a bar-keel is only worth-while as a retrofit which is increasing the draft. Otherwise a smoothly rising floor of the same total draft would be preferable.

The simple surface of a hull of this type could be more than 90% developable consisting of flat and cylindrical portions without hard chines but with two small double-bent portions at the transition between the midship bilge and the fore and aft shoulders respectively (Fig. 5).

Annother field of concurrence of different functions is the rig for sail propulsion and cargo handling, where extra weight and cost should be reduced and interferences must be avoided by double functions of the masts, booms and winches, where it is practicable. The standing rigging should leave the space between the masts as open as possible for loading operations and for deck cargo. The change of rigging from sailing to cargo handling and back should be as easy and as fast as possible.

For handling of light cargo, such as international standard pallets and slings of bags with grain or cement, requiring about 2 t safe working load, a second derrick for each hatch, that must not impair sail handling, can be operated together with the sailing boom in union purchase. The single lifting capacity of the sail boom is 5 t for bundles of pipes or structurals and to take empty 40' containers on deck.

The concept of sail handling is open to any degree of mechanisation, remote control or automation as appropriate to meet present or future requirements.

From the above stated criteria for the auxiliary drive as "motor-assistance" for a real sailing ship, three main operation conditions are resulting:

- a low added resistance from the propeller during pure sail propulsion,
- a relatively low power requirement for a moderate minimum speed in calm weather and during port entry and exit,
- a high thrust requirement to ensure safe manoeuvrability in strong adverse winds and waves in restricted waters.

Since the resulting average and maximum power requirement for propulsion and for board energy supply may well turn out to be in the same order of magnitude respectively, a convincing solution may be a central power plant supplying the required energy for propulsion, light, heating, cargo handling ... under every operation condition - port, cargo handling; sailing, motor-sailing, motoring; calm, fair or bad weather. The precondition for this power-plant solution is a simple and reliable diesel-electric propeller drive, which provides the widest range of propulsion power from motor sailing via calm-weather motor propulsion up to manoeuvring against bad weather. The bad weather condition requires a large diameter low-speed propeller and about double power reserve for high thrust close to the bollard condition. Then the propeller can be fixed-pitch and two-bladed to be locked behind the skeg during pure sailing. Separate prime movers for propulsion and energy supply would require a higher installed power which is run on average at unfavourably low rating and providing less flexibility.

SELECTION OF AN APPROPRIATE RIG TYPE

Since the INDOSAIL-vessel is expected to achieve a major fuel saving percentage it will be a real "windship" with auxiliary propulsion engine. This requires a complete rig as a primary propulsion system with a comparatively large sail area. For the technical system there is a broad variety of historical exemples and modern proposals (Fig. 6). There is the possibility of a modern development on the basis of the traditional rig types of the cargo sailers at the turn of the century. On this line are the proposals of a stepwise mechanisation and aerodynamic streamlining of the square rig, e.g. via the curved yards and the roller-furling of the "Dyna-Ship" to the symmetrically cambered, rigid panels which are used in Japan as wind assistance for motor ships. Similar proposals for the development of the fore-and-aft rig lead via the soft cambered airfoil of the "Princeton Sailwing" eventually to the "Wingsail", a rigid airfoil with trailing edge flaps.

Typical development steps are (Fig. 6):

- Aerodynamic shaping of soft sails and their leading edges,
- mechanized (roller -) reefing and sail handling,
- self-supporting, rotatable masts,
- adoption of rigid airfoil wings (with flaps).

The superiority of the rigid airfoil wingsail over a well-shaped soft sail is restricted to the extremely close-hauled range. Such a rig is especially suitable for light-weight, high speed craft or as wind assistance, when the engine propulsion is providing a relatively high shipspeed with respect to most of the wind conditions. Moreover reefing of large rigid wings is impossible or extremely difficult and the integration of loading gear into such a rig may cause serious problems. Self-supporting masts tend to high structural weight and costs and the manifold subdivision of the sail area of (modern) square rigs seems worth while only in case of very large units.

So-called advanced wind propulsion systems such as Flettner-Rotors, horizontal or vertical-axis wind turbines or kites show some interesting performance characteristics, especially in view of applications to wind-assistance, but a comparative valuation requires further research efforts. After thorough preliminary considerations the further investigations for the selection of suitable rigs for inter-island-cargoships is focused on the comparative valuation of modern multi-masted fore-and-aft (schooner) rigs. While for this rig type some of the components and detail solutions can be adapted from modern sailing yacht technology, there are distinctly different requirements due to the absolute dimensions, the long-term operation under commercial conditions and the additional function of loading and unloading cargo.

In principle, the fore-and-aft sails of a schooner can be fixed as "staysails" on diagonal stays or as "Bermudasails" or "gaffsails" behind the masts (Fig. 9). On a multi-masted cargo ship with the hatches between the masts, the diagonal staysails would impair the cargo handling operations, thus being only suitable as foresails. Triangular Bermudasails utilize only a part of the rectangular space between the masts and therefore need higher masts and longitudinal overlap. Almost rectangular gaffsails have the best fit into the available space and are expected to offer the best relative adjustability for optimum aerodynamic interaction in a multi-mast arrangement.

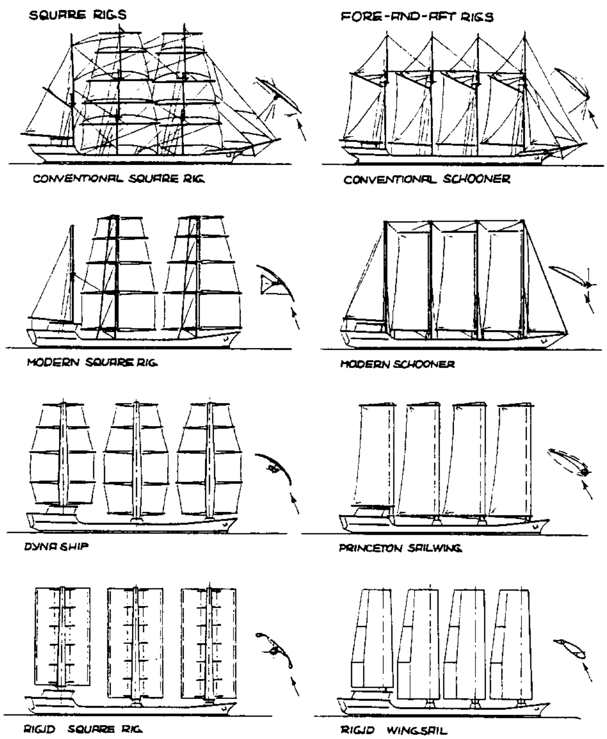

FIG: 6 : POSSIBLE DEVELOPMENT LINES OF TRADITIONAL SAILING RIGS

Alternative configurations of gaffsails differ especially with respect to the gaff and roller-reefing system (Fig. 7). A conventional oblique gaff allows only vertical reefing on a boom-roller, which is incompatible with the function as a loading derrick. Horizontal reefing on a vertical roller behind the mast is possible with a (double) "wishbone"-gaff or with a fixed horizontal gaff.

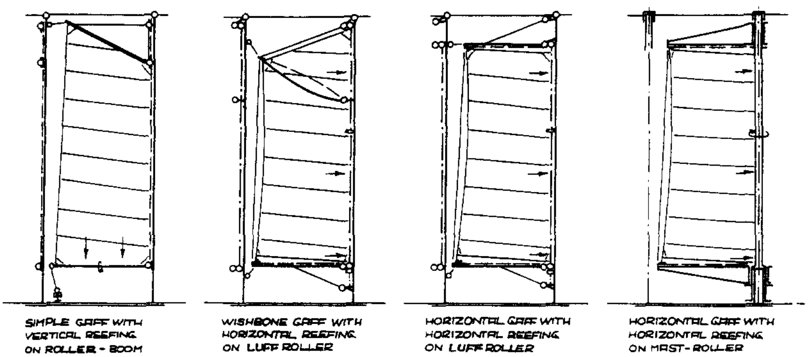

FIG. 7 : DIFFERENT CONFIGURATIONS OF GAFF RIGS WITH ROLLER-REEFING

The INDOSAIL concept for sail shape control is aiming at a simple appropriate technology for long-term commercial use, the requirements of which are differing significantly from those of modern sail racing. Commercial sails should, in our view, be neither dependent on expensive, extra strong and sheer-stiff but short-life material nor on extra skill of the maker and of the handling crew.

Consequently the INDOSAIL concept of a "Suspension Sail" is that of a:

- soft cloth,
- flat-cut sail with
- single horizontal cloth tension and
- suspended by curved leech and luff ropes.

Each horizontal width of cloth may be imagined as hanging independently from the neighbouring cloth beteen the curved leech and luff ropes similar to a vertically standing suspension bridge. Each width of cloth attains its sail profile shape and camber in the equibibrium of:

- aerodynamic pressure difference,
- horizontal cloth camber,
- horizontal cloth tension,
- vertical leech (luff) rope curve,
- vertical leech (luff) rope (roller) tension force (Fig. 8).

A triangular (bermudan) or quadrangular (gaff-, sprit- or square-) Suspension Sail should be with loose foot (and top) and in case of roller-reefing on a luff-roller the leech rope is moving horizontally by traveller(s) on the boom (and gaff). The high vertical control forces are not introduced directly into the sail cloth but into strong leech and luff ropes and transformed by the suspension mechanisme into the much smaller horizontal cloth tension required to maintain the desired camber of the sail profile. Only small local vertical cloth tension is to be expected from secondary effects such as gravity and adjustment of cloth relative to the leech and luff ropes.

No extra sheer- or bias-stiffness of the sail cloth is required for a Suspension Sail due the single axial warp- (or weft-) stress, on contrary a certain sheer stretch is desirable for an easy mutual compensation between the curvatures of the leech- and luff-rope without wrinkles in the sail cloth. This is especially required if only the leech of the sail is hollowcut with a camber in the order of 3 - 5% while the straight-cut luff is fixed to a pre-tensioned roller, the latter sagging significantly only at higher wind loadings.

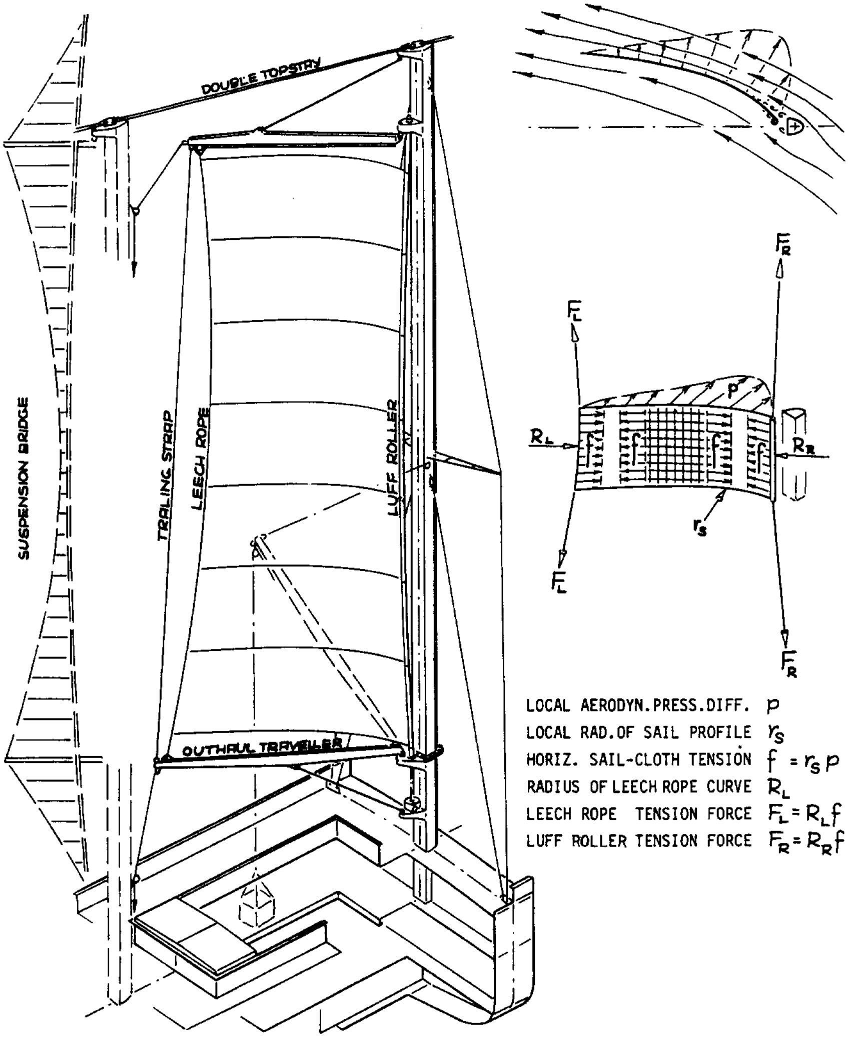

FIG. 8 : CONCEPT OF THE "SUSPENSION SAIL"

AERODYNAMIC EVALUATION OF ALTERNATIVE RIGS

The selection of an appropriate rig type for the INDOSAIL vessel was supported by an extensive test programme in the wind tunnel. In order to investigate in the first place the aerodynamic characteristics of different sail- and mast configurations, about 70 test series were carried out in the wind tunnel of Institut für Schiffbau (IfS) of Hamburg University. A first selection of results is published in[2]. The sail models with about 15 cm chord length were made of sheet metal with a given profile shape of about 10% camber. Rigid models were chosen in order to achieve a Reynolds number of $4 \cdot 10^5$ at a flow velocity of 40 m/s. Soft sail models of so small dimensions would have been difficult to manufacture with the required accuracy and realistic and reproducible trimming would have been pratically impossible under the high wind pressure of 1000 N/m².

The investigated sail types were almost rectangular gaffsails and triangular Bermudan- and staysails in different variants and adjustments. The main variation was the shaping of the leading edge at the mast from the ideal form of the rotatable mast as integrated reefing roller ("Mast-roller") via the structurally simpler reefing roller behind the mast ("Roller-sail") to the freely tensioned roller between the legs of an "A-frame" mast. For comparison special devices were also investigated as e.g. different rigid symmetrical airfoil wings and a "Princeton Sailwing".

Complete rig models were tested in about 80 test series at a Reynolds number of $3 \cdot 10$[illegible] in order to investigate the interference effect on multi-masted schooner rigs (Fig. 9). In a first test series with 1- to 4-masted models with idealized "Mast-roller"-(gaff-) sails the effect of the number of masts was studied. The influence of the details of sail- and mast-type was investigated in a second series of 3-masted models with "Roller-sail" rigs as Bermuda- and staysail-schooner and as gaffsail-schooner with middle- and A-frame masts. Fig. 10 shows as an important part of the results the coefficient of the maximum achievable driving force component depending on the angle of inflow of the apparent wind relative to the ship's head.

By increasing the number of masts from two to four the best close-hauled angle of apparent inflow is increasing by not more than two degrees per additional mast due to the decreasing effective aspect ratio of the total rig. At the maximum achievable driving force between 70 and 90° inflow the tendency is even reversed, that means that the maximum driving force is increasing

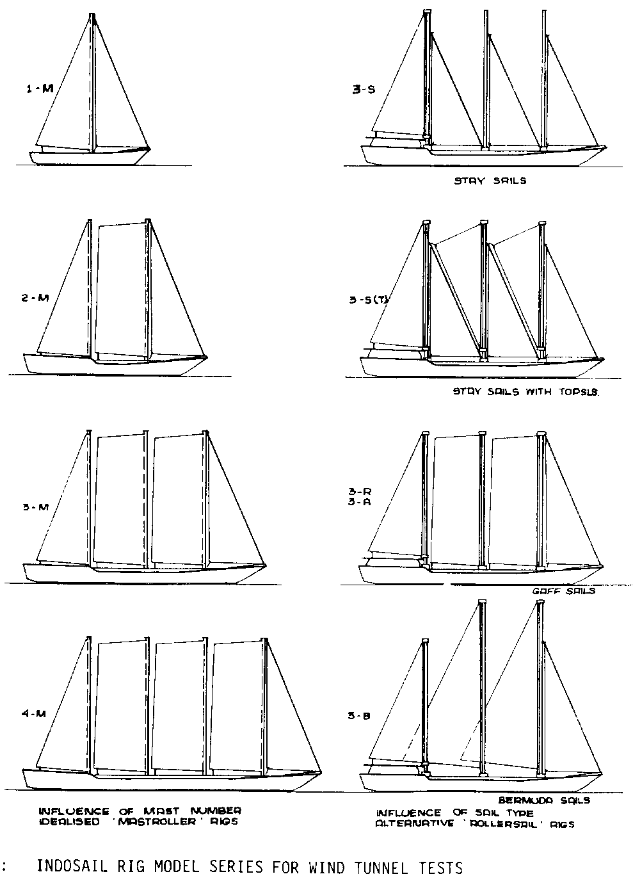

FIG. 9 : INDOSAIL RIG MODEL SERIES FOR WIND TUNNEL TESTS

stronger than the sail area with increasing number of masts. In the reaching condition the driving force coefficients are practically independent of the mast number. The greater mutual sheltering effect with higher mast numbers when running downwind is hardly important in practice since in this range tacking to leeward is anyway the better strategy.

These surprisingly favourable performance properties of multi-masted rigs are due to the total sail area being subdivided into a system of leading edge "slats" (foresails or jibs) main wing (main sail) and one or more slotted trailing edge flaps (following sails) in much the same way as a modern aircraft wing during approach to landing. Here also the angles of the single wing- or rig elements are carefully adjusted according to the local flow conditions in order to shift the flow separation in the whole system into the range of high lift coefficients. The single-masted Bermuda sloop is not directly comparable to the gaff-rigs.

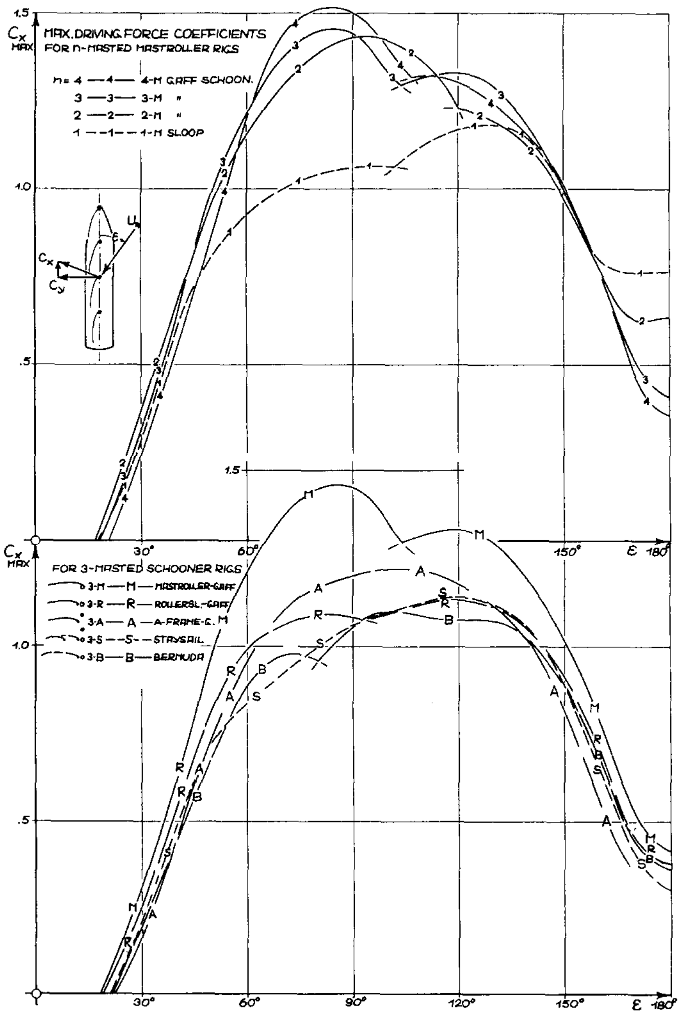

FIG. 10: MAXIMUM DRIVING FORCE COEFFICIENTS OF ALTERNATIVE SCHOONER RIGS

A comparison of the different alternative sail- and mast types in the form of three-masted rigs in the total range of inflow angles indicates a clear superiority of the aerodynamically cleanest "Mast-roller"-gaffrig (M), which may be regarded as an aerodynamic ideal case but structurally complicated and expensive. Next best variants are the "Roller-sail"-gaffrigs with middle masts (R) and with A-frames (A). In the close-hauled condition the middle masts are superior due to their lower drag, while in beam inflow the lower perturbation of the A-frame on the leading edge of the sails yields better results. Presumably both rigs might be improvable by profile masts but a slight superiority of the middle mast on the important close-hauled courses is still to be expected. The Staysail- (S) and Bermudan rigs (B) follow with little distance but both of them are less suitable for a cargo ship due to operational disadvantages.

On the basis of the wind-force coefficients, as determined by the wind tunnel tests and corresponding data for the hull derived from oblique towing tests, the achievable shipspeed under sail is calculated by establishing the equilibrium of forces on the rig and on the hull for a range of windspeeds and all courses relative to the wind.

These speed predictions together with statistical data on the wind conditions in the serviced sea area allow the estimation of possible average (service-) speeds of a sailing ship-design. As an example Fig. 11 shows the expected average speed $\tilde{V}$ of the 1500 t DWT design INDOSAIL 65/4 depending on the average windspeed $\tilde{U}$ of the respective sea area under the assumption that all courses relative to the true wind are equally frequent. Three lines show the the expected average speed under sail on direct courses, the effect of routing deviation, and the effect of an auxiliary drive providing a minimum speed of 4 Kts in 35% of the time. For comparison an equally calculated prediction for the square rigged sail training ship Gorch Fock is also plotted. Although this vessel has at equal displacement a greater shiplength and a larger sail area, the modern design of the INDOSAIL vessel is expected to be nearly 20% faster on average than the conventional squarerigger under equal conditions.

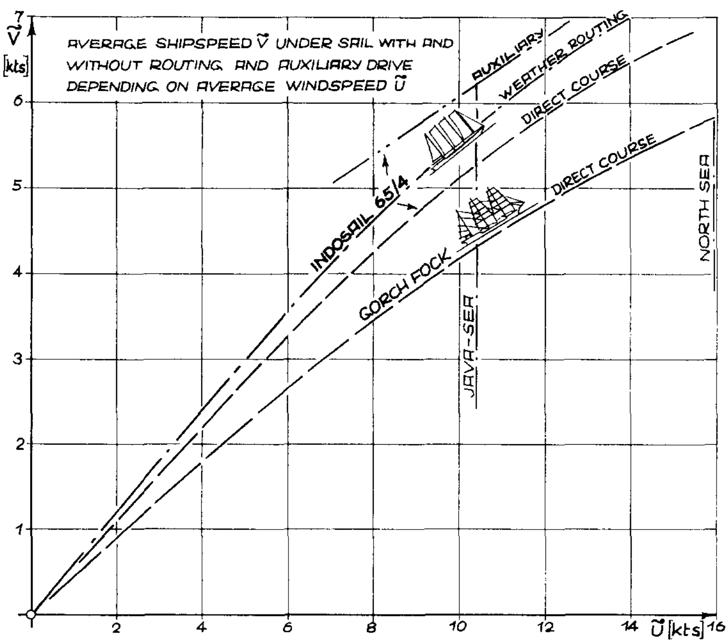

FIG. 11: SPEED PREDICTION FOR STANDARD WIND STATISICS

DESIGN CONCEPT FOR THE PROTOTYPE SHIP

The principal characteristics of the INDOSAIL-Prototype-vessel are given as follows:

- Auxiliary sailing vessel ("motor-assisted windship")
- Three- or more-masted schooner with jib, gaff sails on the forward masts and a bermudan sail on the mizzen mast. (Trapezoidal sail plan.)

As a guideline for component dimensions a basic module was defined consisting of one cargo hold, one hatch, one mast with one gaffsail and loading gear. The key dimension is the mast spacing which is not only determining (via proper proportions) the area of a single sail unit but also the proper beam of the ship, the hold capacity and the hatch size. Going not too far beyond the dimensions of the rigs of already built cargo schooners, the mast spacing S of a novel prototype rig should be not more than about 15 m resulting in a single gaffsail area of about 350 m², which is already beyond the largest commercial sails of the past (about 300 m²).

With an appropriate beam B = 0.8S = 12 m, a draft of T = 0.3S = 4.5 m and a midship section with deadrise and $C_M \sim 0.87$, the displacement of a midship module may be about 725 t at a structural weight of not more than about 150 t. Similar preliminary design estimations for the fore- and afterbody sections yield approximate main dimensions for a modular series of 3-, 4- and 5-masted ships of this modular concept (Table 1, Fig. 12).

With a mast spacing S = 15 m the hatch length is limited to about 10 - 11 m due to the space required for mast, winches, hatch coamings etc. This is sufficient for almost all usual general cargo units except for occasionally occuring empty 40' ISO-containers. But two of them can easily be stored on deck on the sides of each hatch since the shrouds of the masts are only in the transverse plane without any longitudinal spread leaving 15 x 12 m deck- and hatch-area for free and undesturbed access by cargo operation.

A greater mast spacing would result not only in greater rig and sail dimensions but also in a greater beam and draft of the ship, rendering the vessel unsuitable for many shallow ports not only on remote islands. If in a later stage of development a hatch length of 12.5 m will be required for 40' containers then the resulting minimum mast spacing would be 18 m with the consequences of a single sail area of at least 500 m², a beam and draft of 14.5 x 5.5 m and a mini-

	INDOSAIL	50/3	65/4	80/5
Number of masts	n	3	4	5
Length over all	$L_{OA} \approx (1.2+n)S$	63 m	78 m	93 m
Length b. perpend.	$L_{PP} \approx (0.3+n)S$	50 m	65 m	80 m
Beam	$B \approx 0.8S$	12 m	12 m	12 m
Depth	$D \approx$	6.5 m	6.5 m	6.5 m
Draft	$T \approx 0.3S$	4.5 m	4.5 m	4.5 m
Displacement	$\Delta \approx$	1550 t	2300 t	3050 t
Deadweight	DWT ≈	950 t	1550 t	3050 t
Mast height	$h \approx 2.5S$	38 m	38 m	38 m
Sail area	$A \approx$	1050 m²	1400 m²	1750 m²
Engine power	$P \approx$	120 kW	150 kW	180 kW
Hatch size	$l \times b \approx \frac{2}{3}S \times \frac{1}{3}S$	10×5 m	10×5 m	10×5 m
Number of hatches		2	3	4

TABLE 1 : MAIN DIMENSIONS OF MODULAR INDOSAIL SHIP TYPES

mum deadweight of the 3-masted version of 1500 t. Even more problematic than the 20% greater dimensions, the about 70% greater weight of the structural components seems the 40% greater area of the individual sails. The few applications in the past of such large area sails are limited to short time use as light-weather sails on big yachts and no practical experience is available in long term commercial operation on heavy cargo ships in every weather. Thus further investigations are required as to the practical feasibility of extremely large sails, involving rig weight and sail handling to a lesser degree, but primaryly addressing problems of controlling the shape of the sail, strength of the sail fabric, seams and leeches, forces in the rig elements such as masts, spars, straps etc.

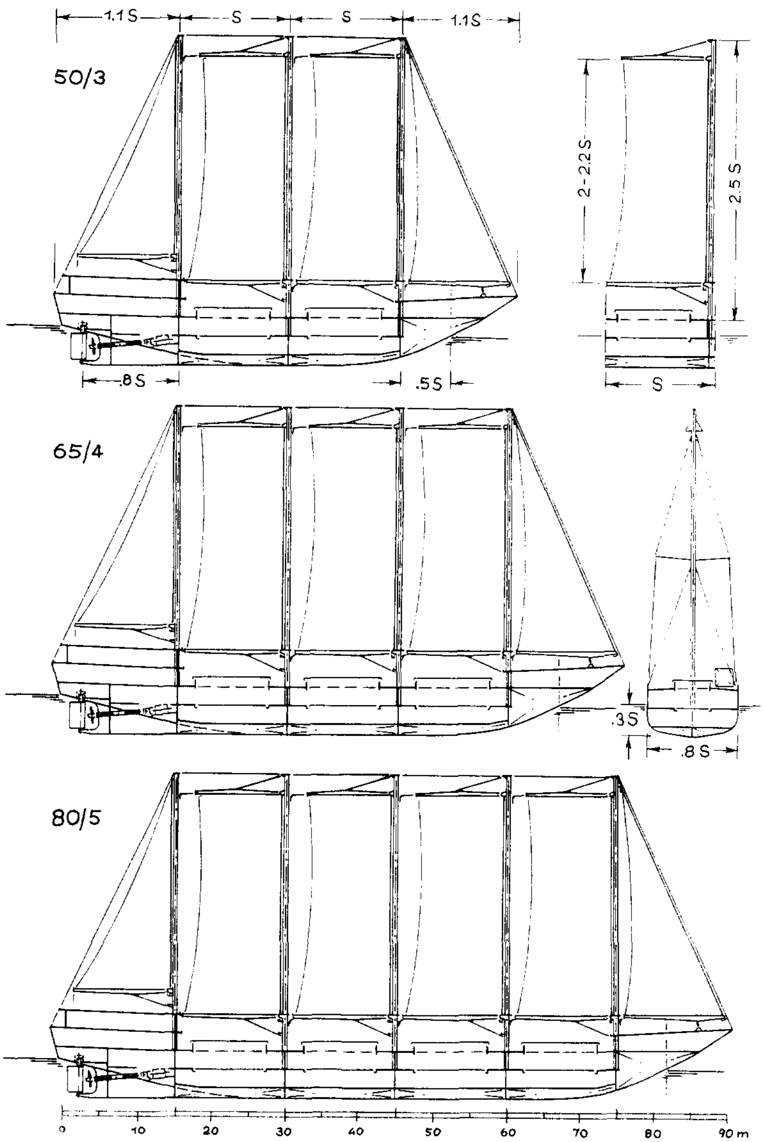

FIG. 12 : MODULAR CONCEPT FOR INDOSAIL COASTAL CARGO SAILERS

From the above reasons it was decided to design and build the prototype ship on the basis of the 15 m modular length and to envisage the later development of an optional parallel (Mark II) series of greater units for the major ports and routes on the basis of practical experience with the Mark I series.

DESIGN OF THE PROTOTYPE HULL

In order to give the possibility of lengthening the modular vessels had to have the same breadth, draught and depth. For determining the optimum main dimensions, especially the necessary breadth, meeting of the stability criteria of the Germanischer Lloyd has been the major design condition. To minimize the investment costs it is necessary that the ship sails under full canvas most of the time. Unreefed sailing must be possible up to a constant wind with a speed of 9 m/s (17.5 knots), which applies to the Java Sea during 90 % of the year. The maximum heeling of the vessel should not exceed 10 degrees.

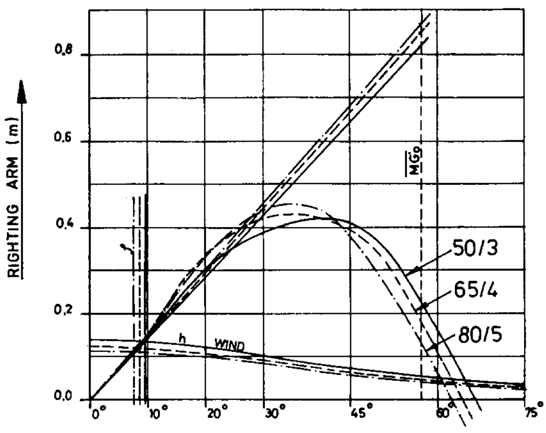

FIG. 13 : COMPARISON OF STABILITY HEELING ANGLE (φ)

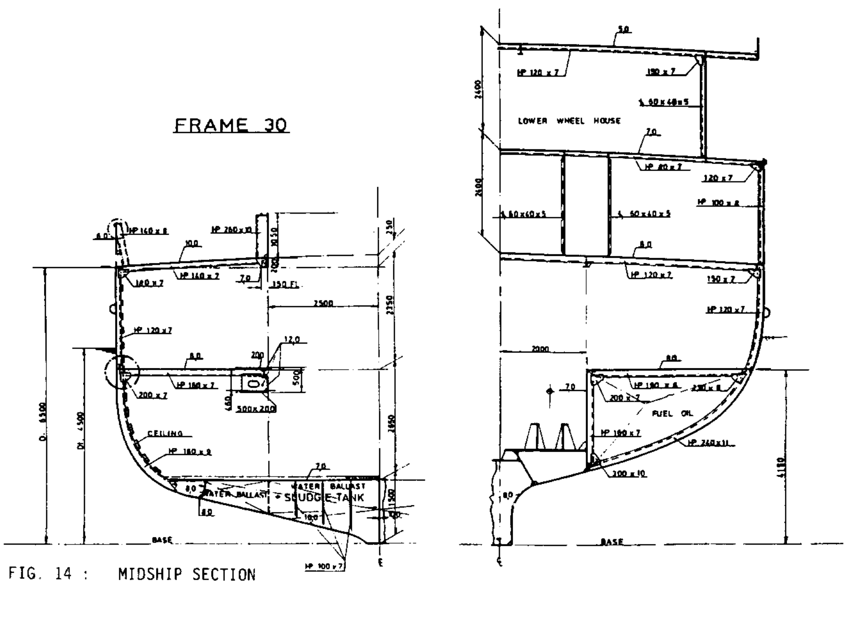

FIG. 14 : MIDSHIP SECTION

Fig. 13 is showing that with a breadth of 12,0 m sufficient stability conditions have been obtained for all three modular vessels. Metacentric height, righting arm, range of stability and heeling angle are not very much differing for all vessels due to an optimum tuning of rig size to displacement and breadth/draught ratio.

The vessels were intended to be built under the parallel class of Germanischer Lloyd and the indonesian classification society BKI + 100 A 4 "Motorsailer" with Freeboard 2,0 m. Furthermore the requirements of SOLAS 1974, MARPOL 1973/ 78 and the national indonesian safety rules should be applied.

To minimize the risque of a new developed vessel the decision has been made to built the 50/3 - type as Prototype vessel.

As a later lengthening to 65 m and 80 m length was intended, investigations have been made into a comparsion of scantlings (Table 2) and the light ship weight for the Prototype vessel for a design length of 50 m and 80 m. Prestrengthening of the short vessel for future lengthening to 80 m requires an additional weight of only 16 t. (Fig. 15)

50/ 3 DESIGN LENGTH	80 m	50 m
flat keel	11.5	10.5
bottom plates	9.5	8.5
bilge strake	7.5	7.5
shell plates	7.5	7.5
sheer strake	9.0	7.5
main deck	9.0	7.5
tween deck	6.5	6.5

TABLE 2 : COMPARISON OF SCANTLINGS (mm)

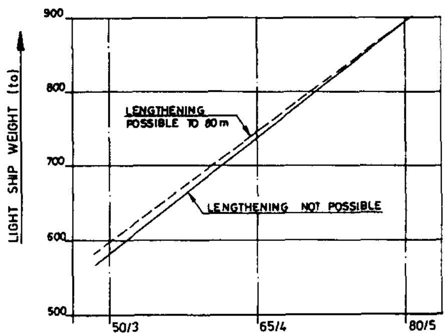

FIG. 15 : LIGHT SHIP WEIGHT

Model tank tests have been made under engine and sailing condition to develope optimum lines of the vessel in the 50/3 and also lengthened version. (Fig. 16)

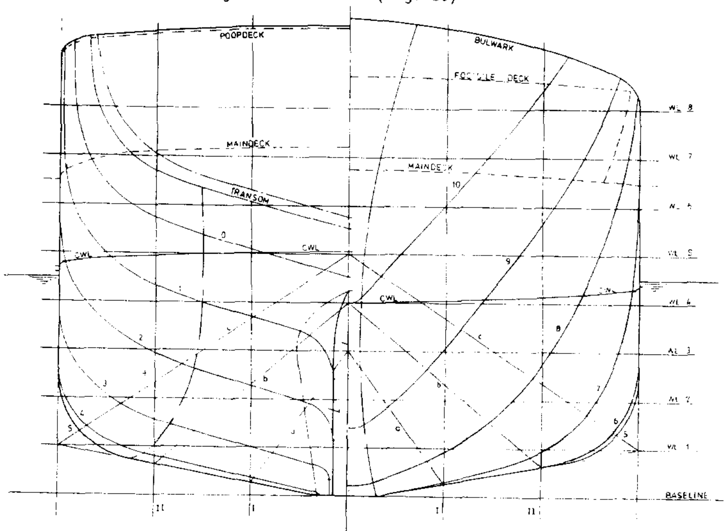

FIG. 16 : LINES PLAN

The General Arrangement (Fig. 17) shows the 2-hatch, 3-mast Prototype 50/3 with raised poopdeck and forecastle, engine and accommodation aft and continuous double bottom. The deck outfit, cargo handling equipment and nautical instruments are designed to the international most modern standard to enable an easy and safe handling of the vessel for the indonesian crew.

For future testing the vessel is equipped with two wheelhouses:
one located on the poopdeck with a wheel stand at each side, to enable good visibility in sailing condition at the lee side of the vessel. The other one is located on the poopdeck to increase the visibility in motoring condition. The accommodations have been designed for a total crew of 30 persons, meeting the special indonesian demand.

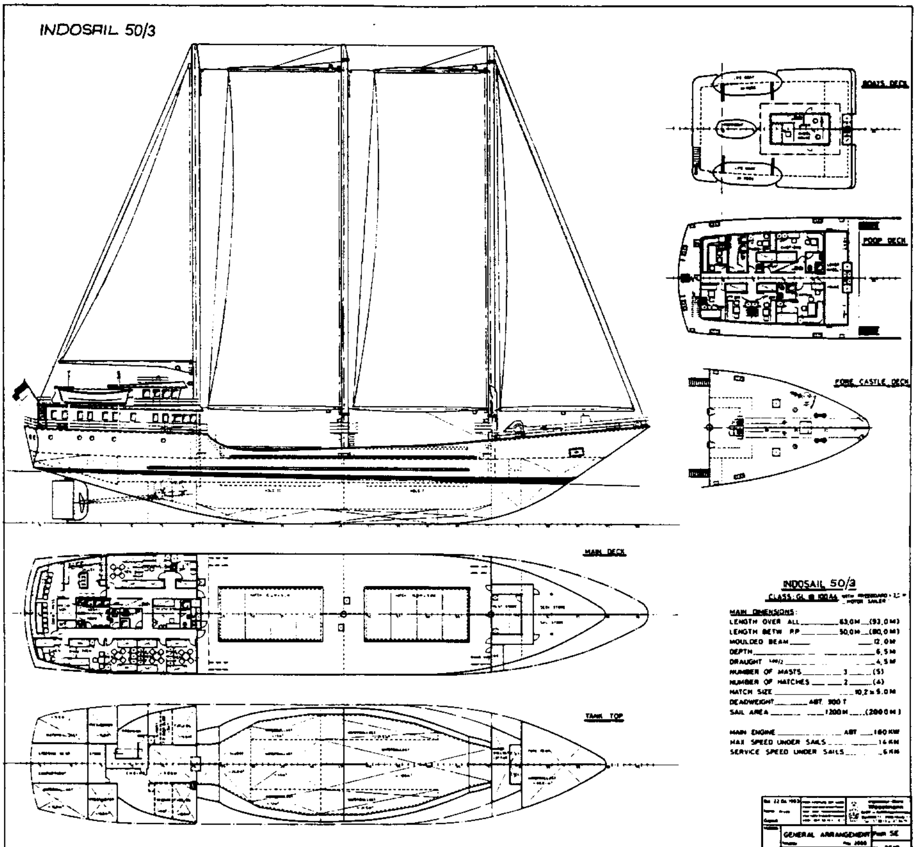

FIG. 17 : GENERAL ARRANGEMENT

Intensive investigations have been done for an optimum layout of the power and propulsion plant. Although the propulsion unit is only an auxiliary drive for this motor-assisted sailing vessel, its output has to be sufficient to ensure safe manoeuvrability in strong adverse winds and waves in restricted waters, for which an output of about 100 KW is necessary. Due to the light winds in the Java Sea the propeller will also be used during most of the time to increase the speed whilst the vessel is sailing. In this condition an output of only 30 - 50 KW is needed. A normal propulsion unit consisting of diesel engine, gear box and propeller was not sufficient for these extreme conditions as the engine would be ruined by an operation over a long period with only little load.

The final decision has been made for a diesel electric combined power and propulsion plant. (Fig. 18)

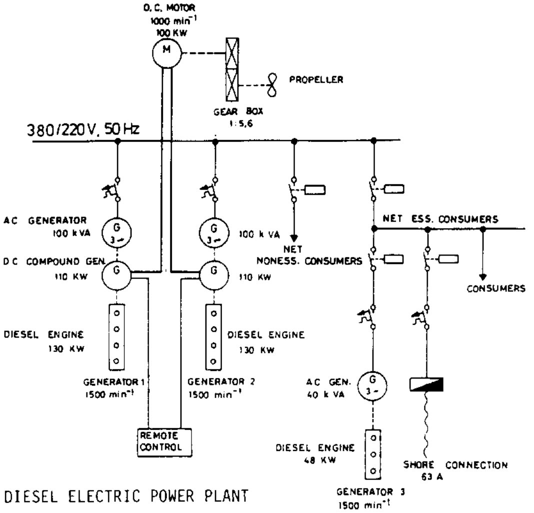

FIG. 18 : DIESEL ELECTRIC POWER PLANT

As, especially for an indonesian crew, the plant should be easy to handle and maintain a "Leonard-System" has been chosen. One DC- motor is supplied by DC- voltage which is continuously controlled by adjusting the exciting of a DC- generator (control generator). The DC- motor has been designed for 70 kW propeller output continuously and for 100 KW output for one hour.

The DC- control- generators are coupled to a threephase-generator and both are driven by a diesel engine of 130 KW. One diesel engine is capable to feed at the same time the power demand of the ship-net and of the propulsion, which will be approximately 40 - 50 % of the maximum load. Automatic consumer circuit breakers are avoiding overloading of the diesel engines. If the power demand of the propeller is exceeding 75 % it will be necessary to operate with separate diesel-generators, one for the ship-net and one for the propulsion. The diesel engines are remote controlled from both wheelhouses.

For harbour condition without cargo operation there is an additional 48 KW diesel generator, which is only feeding the ship net.

The chosen combined diesel electric power and propulsion plant is the most sufficient solution for the wide range of demand for a motor assisted sailing ship.

DESIGN OF THE PROTOTYPE RIG

The rig for the INDOSAIL coastal cargo vessel prototype is being designed according to the following criteria:

- Efficiency as a main propulsion system.
- Economy in construction and service.
- Safety for crew and ship.
- Simplicity in handling and maintenance (foolproofness)
- Simplicity in construction.
- Resistivity against sea water and weather impact.
- Computability based on reasonable load assumptions and theoretical models.

A sailing rig is a propulsion plant with low energy density, especially under light wind conditions. the rig has to pay-back its first and operating costs in competition with the first and operating costs of a motor propulsion plant.

Safety for crew and vessel must be ensured even with untrained sailors. This must be achieved by an uncomplicated rig design, simple to handle and easy to control, if possible with built-in load limitation. Foolproofness requires simple arrangement of winches and control elements.
Simplicity in maintenance is a precondition for lifetime safety and economy. In our case the rig design had to be modified in course of two years' experience to a much more simplified system meeting the lowest material requirement. Long-term reliability is a question of material, design and maintenance. For ship board systems maintenance during service is one of the most critical problems.

Commercial sail cloth has to resist sun radiation for more than 10 000 hours of exposure. Polyester(Dacron-, Terylene-) material as in use for modern sails of yachts and training vessels would have to be 3 to 4 times increased in weight, for this reason, than it would have to be from strength requirements.

Sailing rig design is normally based on experience supported by simple theoretical calculations. The design of a new rig type must be based almost exclusively on theoretical calculations supported, in this case, by the chance of testing the results during the design phase on a 18 m - Test-vessel 18/2 carrying a two-masted 60% full-scale Test-rig.

According to the modular ship design the rig too has been layed-out as a modular system with three types of modules.

The main module consists of mast, gaff, sail boom, derrick, shrouds, double top stays and one quadrangular gaff sail. The gaff is in this case of cantilever type (with integrated topping lift) and the auxiliary derrick, to be used together with the sail boom in union purchase cargo handling, has also the function of a kicking strap for the sail boom during sailing. The quadrangular frame of mast, gaff and boom is closed between the aft tips of boom and gaff by a wire rope which might be called a "trailing strap" or an "aft strap" (Fig. 8, 19).

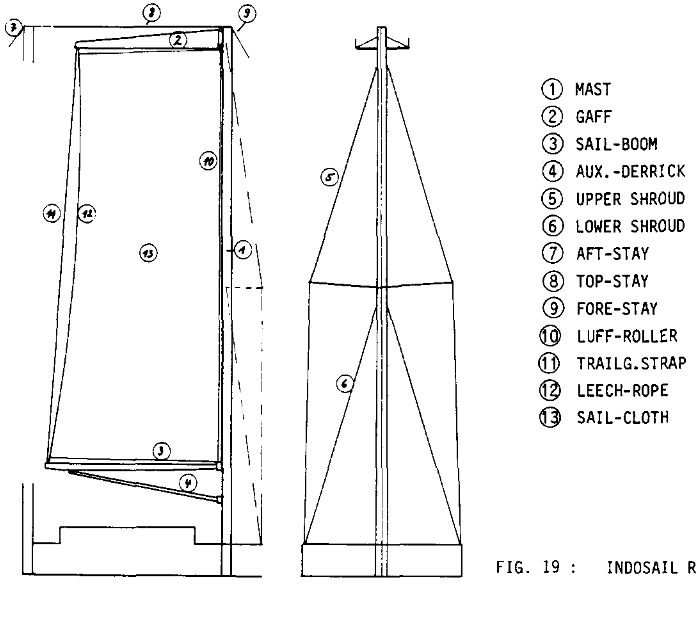

FIG. 19 : INDOSAIL RIG MODULE

The foremast module equals the main module but carries additionally the double fore stay and the jib sail on a luff roller with balanced jib boom and aft strap.

The mizzen module carries on the mizzen mast with shrouds and double aft stay the bermudan mizzen sail and boom with aft strap.

The steel masts are of semi elliptical profile which was found in ..ind tunnel tests to reduce the disturbance of the leading edge flow on the sail. All sails can be reefed and stored on luff rollers behind the masts.
The moveable spars are rectangular box beams, the jib and main booms being steel while the gaffs and mizzen boom are of light alloy. All wire ropes are of galvanized steel except for the stainless steel ropes in the leech seams of the sails.

Gaffs and booms are controlled by sheets and can be fixed with guys if necessary. the jib is set with a balanced boom to maintain a proper sail profile on all courses to the wind.
The flat-cut sails are suspended by luff roller and leech ropes carrying the vertical forces. The sail tension is only horizontal in the direction of the profile which is controlled by the vertical tension in the hollow-cut leech seams. ('Suspension Sail' system.)

From today available textile fibre material, polyacryl-nitril (Dralon, Orlon) appears to be of exceptional resistivity to UV-radiation and weather impact. Available cloth, well established for sunshades and awnings, woven of staple-fibre yarn is now tried on the Test-vessel 18/2 and showed satisfying performance under the low cloth loading of the suspension system. However, endless fibre yarn and incresed density of the weave could improve the suitability as a sail cloth and especially reduce long term permanent stretch.

Due to high bending moments, compression forces and the inevitable flexability of the rig, static calculation must account for deformations in all elements of the rig including the sail cloth. the load assumptions are derived from wind pressure, stability criteria and wave-induced motions.
Criteria for the strength of the rig have been set-up as follows :

- The rig has to survive all heeling conditions from 0 to 90 degrees.
- The maximum survival load is based on the maximum sum of the external heeling moment and the gravity load due to heeling
- or on the maximum sum of roll acceleration and the gravity load due to heeling.
- the maximum service load condition is a close-hauled course with 10 degrees heeling angle.
- Rolling and pitching accelerations assumed according to classification rules shall be verified by full scale tests on the Test-vessel 18/2.

The rig with minimum dimensions according to bending and buckling loads is very flexible, especially against forces from the leech rope of the quadrangular sails. Under maximum service load conditions the tips of boom and gaff would move torwards each other by more than one meter, the leech would sag by about 2,5 m and the sail camber would increase from 12 % to more than 30 % of the chord length.

Pre-straining the leech rope would be no solution, but if the aft strap between boom and gaff is pre-strained to the maximum service load of the leech rope, mast and spars are pre-bent and the leech rope takes over the load of the aft strap with increasing wind pressure

The elasticity in the pre-strained frame in which the sail is set is then determined by the elasticity of the aft strap. If the aft strap is stiff, then the rig is virtually stiff in the range below the maximum service load; the camber of the sail profile increases from 12 to 16 % only at maximum service load and is easy to control within a small tolerance.

Above the maximum service load the rig's behaviour is as flexible as without pre-strain. The loading of the rig increases then much slower than the wind pressure. Slag of the aft strap between the tips of boom and gaff is a clear signal for the necessity of reefing. (Fig. 20) The same applies, in principle, to the pre-strained aft strap of the triangular sails between boom tip and mast top.

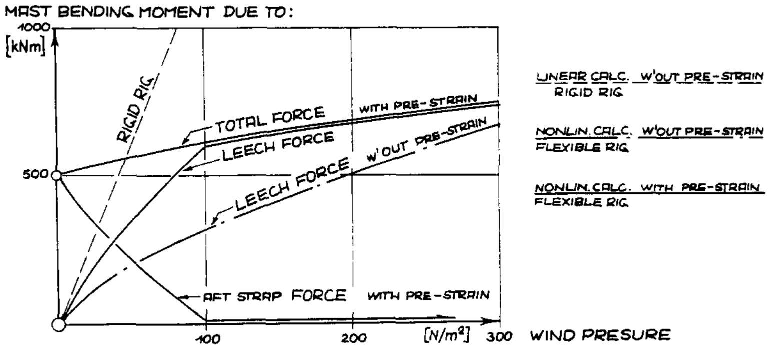

FIG. 20 : EFFECT OF PRE-STRAIN IN THE RIG

STATE OF THE PROJECT AND OUTLOOK

The design of the three-masted Prototype-rig 50/ 3 can be completed and approved by Germanischer Lloyd as soon as the results of the structural and handling trials with the Test-rig 18/2 are available for final dimensioning and detail design.

Before the 60 % full scale Test-rig 18/2 was designed and built in Jakarta, HSVA has designed and built a large-scale functional model in a two-masted version on a 1 : 5 scale model 4/2 of the Test-vessel 18/2 and later in a three-masted version on a 1 : 8.5 scale model of the Prototype ship 50/3.

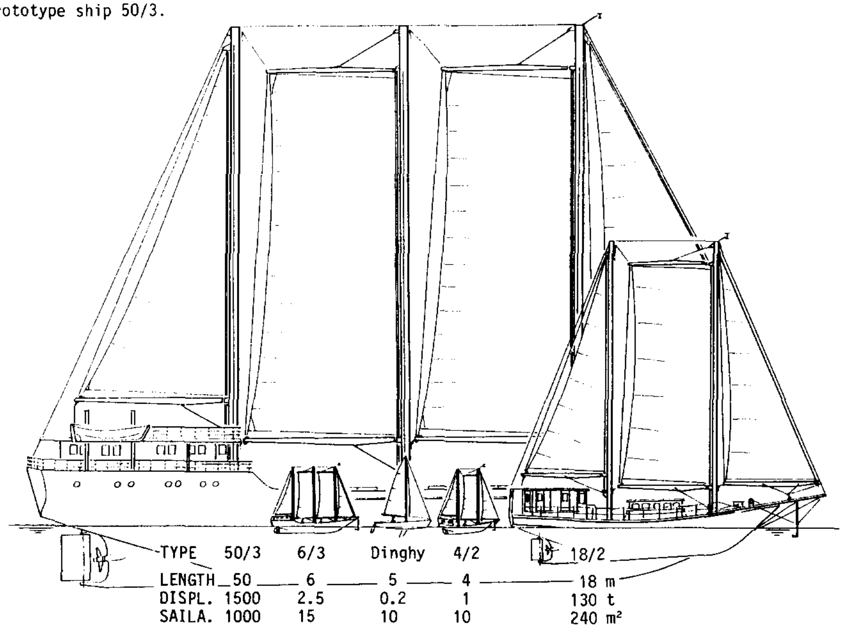

FIG. 21 : MODELS, TEST VESSEL AND PROTOTYPE VESSEL

The models are of 1 and 2.5 t displacement carrying 10 and 15 m^2 of sail and they can be sailed by 1 and 3 persons respectively (Fig. 21). In the sailing tests the excellent handling qualities of the rig and the predicted speed performance could be verified. In addition the chance of the model trials was used to test the measurement system for the Test-vessel 18/2 before the installation in Indonesia.

The two-masted Test-rig 18/2 of 240 m^2 sail area is installed on an experimental 18 m ferro-cement hull of 130 t displacement and fairly traditional prau shape

The measurement system on 18/2 is capable of recording the following dates:

- wind-speed and direction in the top of main mast
- ship-speed
- drift angle
- heeling angle
- ruder angle
- propeller revolutions
- force of the leech rope of main sail
- force of the aft strap of main sail
- force of upper and lower shrouds of the main mast ps. and stb.
- longitudinal acceleration at the mast top.

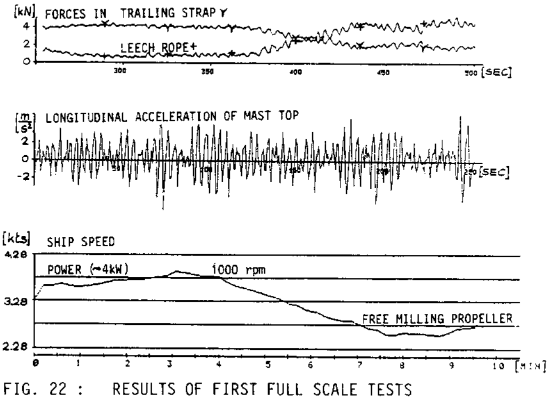

FIG. 22 : RESULTS OF FIRST FULL SCALE TESTS

In spite of the very low wind at the first trials in December 1984 in the Java Sea some important results are worth mentioning : (Fig. 22)

- The tranfer of the load from the aft strap to the leech rope could be verified.

- The longitudinal acceleration reached significant values. At an old swell pitching acceleration reached 1/2 g max

- There was no difference in ship-speed, if the two-bladed propeller was fixed after the skeg or if it was free milling. In case of running the propeller with only small power the speed increased considerably

Comprehensive measurement will follow during this year, the result of the measurement at higher wind speeds being essential for the final Prototype-rig design.

Building of the Prototype-vessel is intended at shipyard PT PAL in Surabaya, Indonesia. After completion of all classification drawings and approval by Germanischer Lloyd for the hull, outfit, machinery and electric by end of 1984 working drawings are under processing at the indonesian yard. Keel laying of the vessel is scheduled for April 1985 and delivery of the ship including the rig is exspected for middle of 1986. There will be further technical assistance to the indonesian yard by the german designing group during the building period for which the necessary agreements will be signed shortly.

An intensive test program for all components of the Prototype-vessel for a period of approximately one year will follow the delivery. Whereafter lengthening of the vessel is intended to the 4- and 5-mast modular version with another intermediate testing phase. Final results for the 80/ 5 - type vessel may be exspected within the next 4 to 5 years.

We are convinced that the Indosail Project will on the one hand prove itself to be a most efficient design for a motor-assisted windship and on the other hand it is an example for a prosperous bilateral cooperation between two countries, Germany and Indonesia, of different technical and cultural background.

ACKNOWLEDGEMENTS

The Authors are indepted to the Indonesian Minister of State for Research and Technology Prof. B. J. Habibie, who has initiated the INDOSAIL Project as a first step towards 'KAPAL SURYA',the Solar Ship, which would be totally independent of fossile fuels. He encouraged the Federal German Ministery for Research and Technology BMFT to share into a joint sponsorship of INDOSAIL as a pilot R&D-project for windship technology, which is gratefully acknowledged.
We are obliged to a great number of collegues and partners for fruitful cooperation and major contributions to the project, in particular to the Indonesian partner BPP-Teknologi of Jakarta, to NAVTEC CONSULT of Emden and to the naval architectural institutes of the Universities of Hannover and Hamburg.

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