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The Effect of an Advanced Spray Rail System on Resistance and Development of Spray of Semi-Displacement Round Bilge Hulls

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ABSTRACT

Experimental investigations at the Berlin Model Basin on 17 different spray rail configurations demonstrated that well shaped and proper arranged spray rails if combined with a transom wedge are the most effective devices to reduce the hull resistance of given semi-displacement round bilge hulls. An advanced spray rail system (ASRS) developed at VWS incorporating these two external design elements optimally, leads to remarkable power savings which are larger than those obtained by each component solely. Additionally the seakeeping qualities of round bilge hulls are improved by this special spray rail system and the apparent loss of metacentric height of this hull type at high speeds can be reduced considerably.

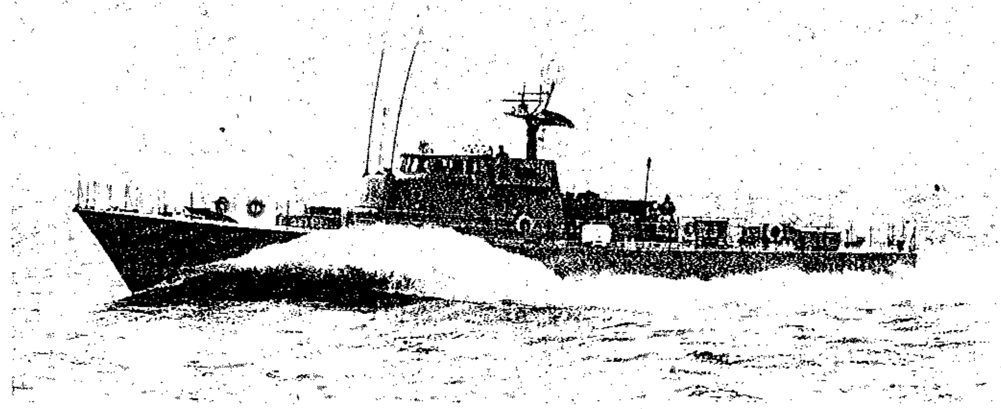

Fig. 1.1 Development of Spray at a Semi-displacement Round Bilge Hull

1. INTRODUCTION

Round bilge hulls are characterized by the development of a large spray formation, which often climbs up to the deck strake (Fig. 1.1). The spray increases the wetted area of the above water hull and causes a wet deck and a reduced visibility from the bridge or the wheelhouse in beamy wind. Since half a century designers are using spray strips to keep fast round bilge motor boats dry and to reduce the spray wetted area with regard to power savings. These strips or rails merely designed on the basis of judgement, experience and aesthetical feeling demonstrated in some cases a power reduction and in other ones a power increase despite having the same configuration. Tests with several fast patrol boat design at VWS showed the same tendency. Until now neither the nature of the spray of round bilge hulls nor the effect of the spray rail configuration on resistance and running trim has been investigated systematically. As reported by many authors [1 - 3] spray rails have not been considered as an effective tool to improve the performance characteristics of round bilge hulls.

At VWS the power of hard chine planing boats could be reduced by nearly 3 - 4 percent due to a set of short spray rails in the spray wetted area. Therefore it was not plausible that similar or larger power savings should not be obtained in the case of round bilge hulls which can have a manifold greater spray wetted area. To bring more insight in the hydrodynamic characteristics of spray rails and to clear up the observed contradictions an extensive and systematic research program has been performed over many years taking into account additionally the results of commercially tested round bilge hull designs with spray rails. On the basis of the test results an optimum spray rail system has been developed.

2. THE PHENOMENON OF SPRAY AT ROUND BILGE HULLS

2.1 General characteristics

As in the case of planing hulls the spray formation at the forebody of round bilge hulls is caused by the stagnation pressure at the hull surface near below the water surface. At $F_n > 0.5$ when the development of spray increases rapidly with speed, the spray climbs up the hull sides and can reach the deck and at speeds above $F_n = 0.8$ the midship body. The height and the longitudinal extension of the spray wetted area increases with the length to beam ratio of the hull and the convexity of its sections. With decreasing length to beam ratios and concave forebody sections the spray is thrown more aside. It is always

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higher outbord than at the hull and gives rise to a wet deck and a reduced visibility from the wheelhouse. At low speeds, $F_n < 0.6$ the coherent spray sheet at the hull is thicker than at high speeds $F_n > 0.6$.

2.2 The spray resistance R_S and its components

The spray resistance R_S is composed of two components

$$R_S = R_{SP} + R_{SF} \qquad \text{kN} \qquad (2.1)$$

having the relation ship

$$R_S = R_{SP}(F_n) + R_{SF}(R_n, W_n) \qquad (2.2)$$

with:

R_{SP} Spray pressure resistance
This component is caused by the generation of spray due to the stagnation pressure at the diverging waterlines. It depends on the Froude Number and cannot be determined neither analytically nor experimentally.

R_{SF} Spray frictional resistance
This component is caused by the friction of the spray at the above water hull and depends on the Reynolds Number R_n. The frictional resistance is to some extend affected by surface tension effects which are characterized by the Weber Number

$$W_n = \frac{V_{SR}^2 \cdot d_{SR} \cdot \rho}{\sigma} \qquad (2.3)$$

with:

V_{SR}	spray velocity	m/s
d_{SR}	spray thickness	m
σ	surface tension	N/m.

A reliable calculation of the frictional spray resistance is not possible, because the spray velocity V_{SR} is unknown. By this a correct specific frictional resistance coefficient is not calculable.

2.3 Measures to reduce the spray resistance

The pressure resistance component cannot be reduced without an extensive alteration of the main dimensions and the hull form. However without any hull modifications, the frictional resistance can become smaller. By means of suitable spray rails which peel away the spray sheet from the hull, the spray wetted area can be minimized. The use of spray rails is especially effective for hulls with small length to beam ratios $L_{WL}/B_{WL} < 6.0$ where the spray wetted area can amount up to 50 percent of the wetted area of the hull at rest [4, 5].

3. THE SPRAY RAIL RESISTANCE R_{SR}

To reduce the hull resistance by means of spray rails, their resistance should be as small as possible. The resistance of the spray rails is composed of two components

$$R_{SR} = R_{SRP} + R_{SRF} \quad \text{kN} \tag{3.1}$$

with:

R_{SRP} Spray rail pressure resistance
This component is caused by the generation of hydrodynamic lift due to the deflection of the spray sheet in the longitudinal direction at the bottom of the rail.

R_{SRF} Spray rail frictional resistance
This component is caused by the friction of the spray sheet at the bottom of the rail.

Both components cannot be calculated because the velocity of the spray and its direction at the bottom of the rails are unknown.

4. EXPERIMENTAL INVESTIGATIONS OF SPRAY RAILS AT THE BERLIN MODEL BASIN

The experimental investigations of the hydrodynamic characteristics of spray rails have been performed in 4 steps:

4.1 Determination of the rail design parameters

By means of previously tested round bilge hulls the design parameters of spray rails have been established.

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3. Bottom width b_{SR}
4. Break off angle
5. Mean angle of in
6. Height of spray
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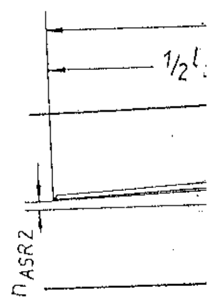
8. Submergence of t
9. Number of rails

In total 46 variati



α_0 : Ra
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4.2 Systematical resistance tests

The effect of 9 design parameters on spray wetted area, resistance, running trim and development of spray has been investigated in a speed range of F_n = 0.3 - 1.0 by means of 91 resistance tests [4 - 6]. Following design parameters have been tested (Figs.4.2.1, 4.2.2) at 7 different models of 3.8 m DWL length.

1. Type of rails, 3 variations,
2. Bottom angle β, 6 variations,
3. Bottom width b_{SR}, 7 ratios b_{SR}/L_{WL},
4. Break off angle γ, 3 variations,
5. Mean angle of incidence α_{om}, 5 variations,
6. Height of spray rails above the waterline h_{SR}, 4 different slopes,
7. Length of spray rails L_{SR}, 5 ratios L_{SR}/L_{WL},
8. Submergence of the aft end of the rails t_{SR}, 8 ratios of t_{SR}/L_{WL}
9. Number of rails n, one and two rails.

In total 46 variations have been tested.

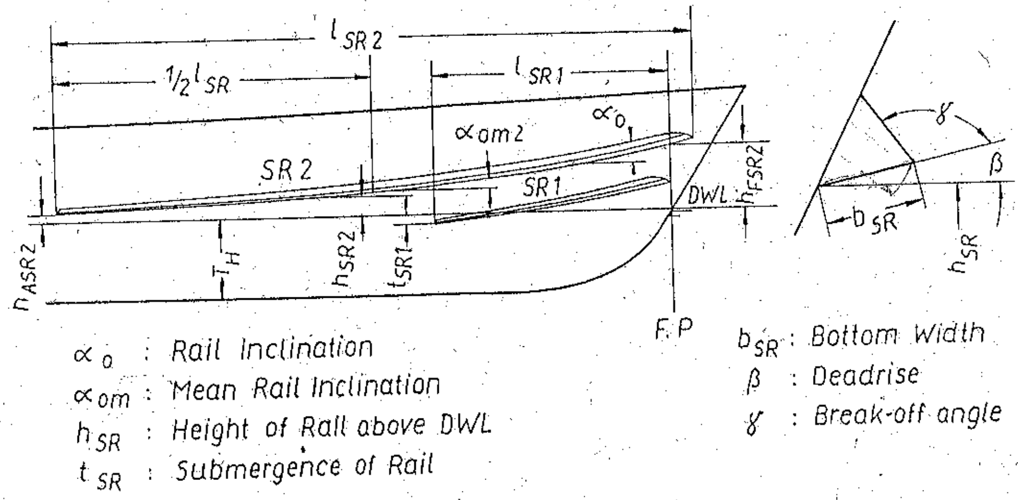

Fig. 4.2.1 Geometry of Spray Rails

4.3 Development of an optimum spray rail system

On the basis of the extensive test results an optimum spray rail system (ASRS) has been developed taking into account the effect on resistance of each design parameter.

4.4 Resistance and seakeeping tests with the optimum spray rail system

The advanced spray rail system has been tested at 3 NPL high speed round bilge hull designs having length to beam ratios of L/B = 4.54; 6.25 and 7.5 in smooth water. Seakeeping tests have been performed with several patrol boat designs equipped with this rail system.

The extensive test data of all spray rail tests are presented in 410 diagrams [4 - 5].

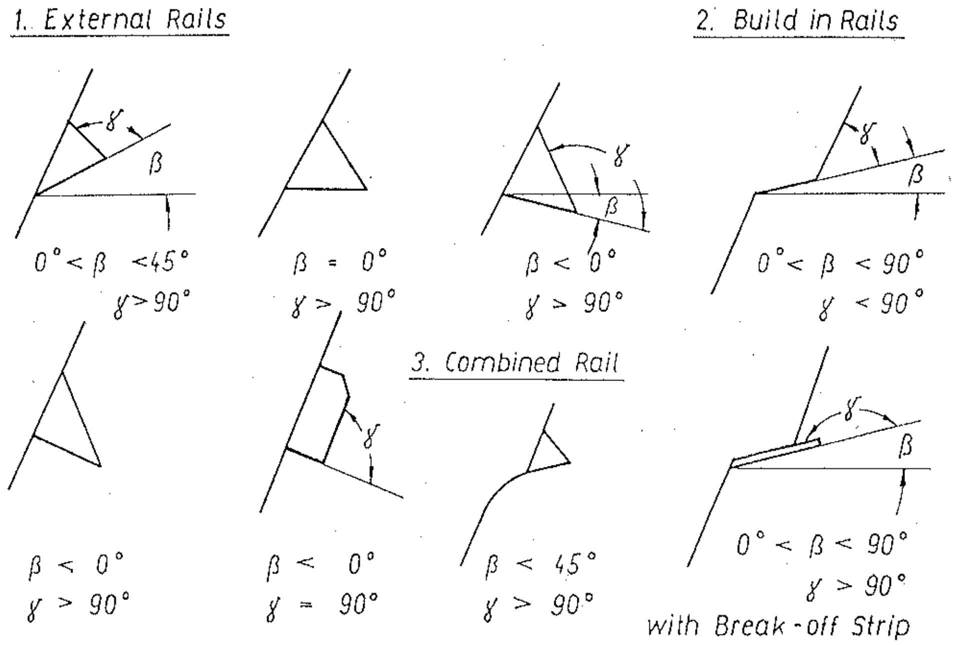

Fig. 4.2.2 Types and Sectional Shapes of tested Spray Rails

5. GENERAL REQUIREMENTS FOR AN OPTIMUM SPRAY RAIL SYSTEM

To reduce not only the frictional spray resistance but also the total hull resistance, spray rails must fulfil the following requirements:

1. The configuration of the spray rails should guarantee at all running trim conditions a minimum of spray wetted area.

2. The spray rail resistance should be as small as possible. It must be substantially smaller than the reduction of frictional spray resistance.

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6. THE ADVANCE

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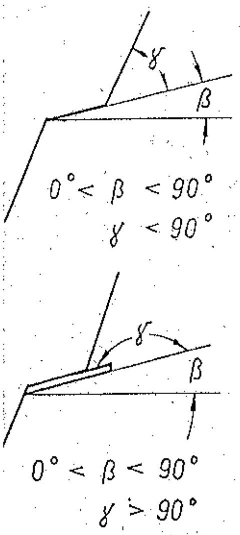

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3. The lift of the rails should raise the hull, by this decreasing the immersed volume and the induced resistance.

4. The spray should be thrown clearly away from the hull. A reattachment of the spray further aft at the hullsides must be prevented.

5. The spray height abreast the hull must be as small as possible. A reflection of the spray at the watersurface should not occur.

6. The spray rails should not increase the vertical bow accelerations while the boat is running in waves.

7. The spray rails should not increase the tendency of trimming down the bow in following seas.

6. THE ADVANCED SPRAY RAIL SYSTEM (ASRS)

6.1 Spray rail configuration

The test results revealed that an optimum spray rail system could be developed by synthesizing the resistance reducing characteristics of each design parameter. Such a controlled combination of design parameters results in an advanced spray rail system having the following configuration:

The rail system consists of two staggered spray rails, a short one designated as SR1 near the stem below the long one, designated as SR2. By means of SR1 the wetted area behind the stem becomes minimal. In addition and this is the main advantage of SR1 the rail SR2 is unloaded, because the front part of the spray which rises abaft the stem is thrown away before reaching SR2. Therefore the risk of overflowing this rail is minimized.

The spray rails have a triangular cross section to facilitate the separation of the spray by means of a large break-off angle $\gamma > 90°$ (Fig. 4.2.2). Shockfree entrance and by this a reduction of the pressure resistance is achieved by providing a variable bottom angle in the longitudinal direction. The bottom angle β which is the angle between the bottom of the rail and the horizontal line, decreases from approximately 30° at the bow to less than 8° at the end of the rails. A constant bottom width b_{SR} = 0,0055 L_{WL}, which is optimal for speeds F_n = 0.6 - 1.0 has been chosen. As spray rails are planing surfaces with an extremely small aspect ratio the longitudinal inclination of the rail governs lift and pressure resistance. The angle at half length of the rails α_{om}, which is used to characterize the rail inclination, has been chosen to α_{om}

= 2.0°. This value was found to be optimal at speeds F_n = 0.6 - 1.0. The angle of incidence decreases from 6° at the bow to 1° at the midship section.

Due to the decreasing angles of incidence the height of the rails above the waterline h_{SR} declines for SR2 from h_{SR2} = 0,025 L_{WL} at FP to h_{SR2} = 0,005 L_{WL} at the midship section. SR1 starts at FP with a height of h_{SR1} = 0.015 L_{WL} and terminates at Sec. No. 16.5 with a valued h_{SR1} = -0,005 L_{WL} (Fig. 6.1.1).

The spray rail SR1 reaches from the stem to Sec. No. 16.5. The length of spray rail SR2 depends on speed and running trim. It extends for F_n > 0.8 from the stem or the FP to Sec. No. 8 at the hull with 20 design sections (Fig. 6.1.1).

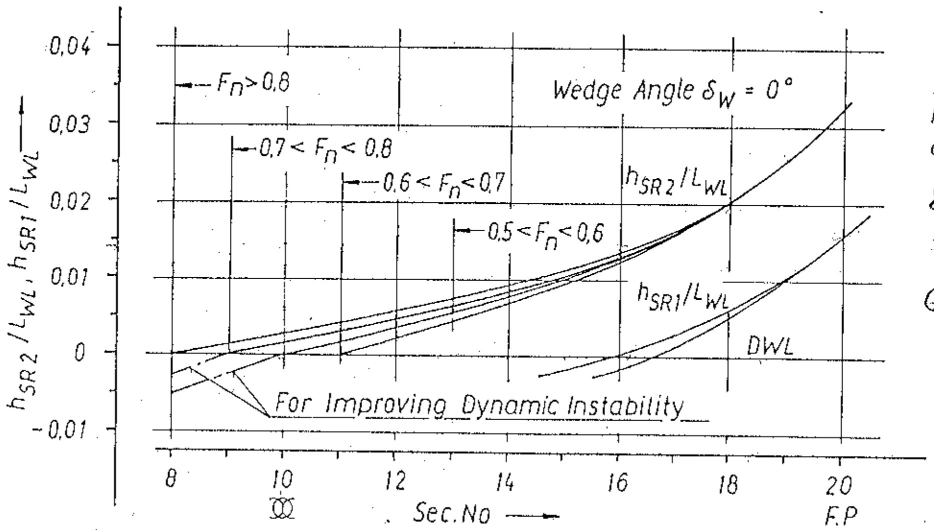

Fig. 6.1.1 Relative Heights of Advanced Spray Rails above DWL

If the design indicates a loss of transversal stability underway, the rear end of SR2 should be terminated at the waterline or maximal 0.5 percent of L_{WL} below (Fig. 6.1.1).

The effectiveness of the chosen spray rail configuration becomes optimal by an interaction with the lift of a transom wedge. In this case the hull can be hoisted like a hydrofoil craft by the lift of the rails and by that of the transom wedge (Fig. 6.1.2). A large rail lift, causing a large induced resistance of the hull, can be balanced by a similar amount of lift of the transom wedge. By this measure the hull resistance decreases twice:

1. The induced hull resistance becomes smaller due to the reduced running trim and immersed volume.

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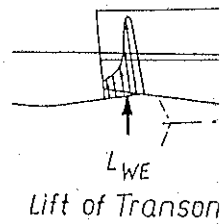

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2. The frictional hull resistance is diminished due to the smaller immersed volume.

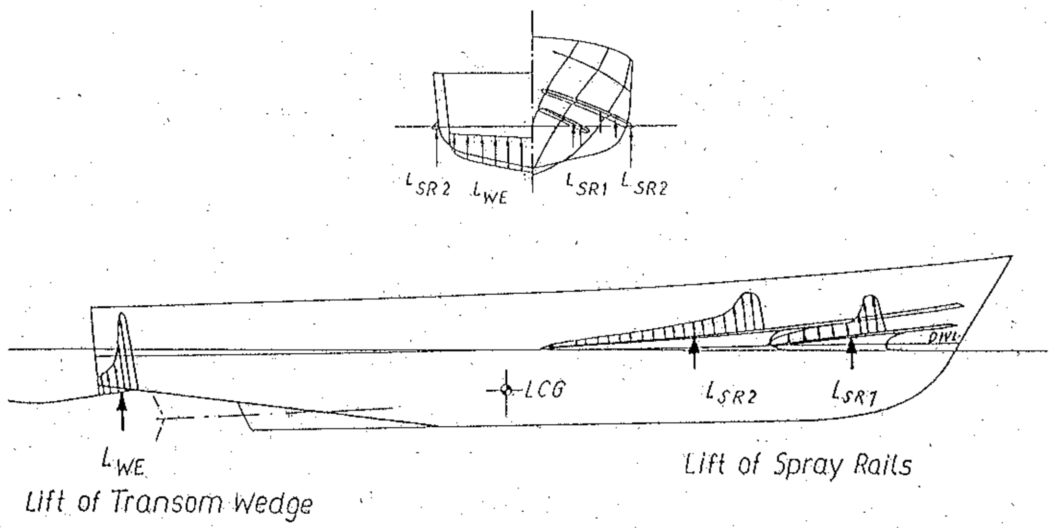

Fig. 6.1.2 Additional Lift Forces of the ASRS

6.2 Reduction of spray wetted area

The spray wetted area of round bilge hulls without spray rails increases with speed, with decreasing length to beam ratios and with decreasing running trim. At a speed of F_n = 1,0 the spray wetted area reaches a mean value of 14 to 30 percent of the wetted hull area. The reduction of the wetted area by means of the advanced spray rail system is remarkably and with both rails larger than with one single rail. With decreasing running trim, due to the action of a transom wedge, the total wetted area becomes smaller. At F_n = 1,0 the remaining spray wetted area, i. e. the area between the waterline and the break off edge of the rails amounts as an average for SR2 solely to 8 percent (Fig. 6.2.1) and for SR1 and SR2 to 3 percent of the wetted area of the hull at rest (Fig. 6.2.2). In these Figures the wetted area factor FWS is given which is the ratio of the effective wetted area underway and the wetted area of the hull at rest without the immersed transom area. By means of the advanced spray rail system a reduction of the spray wetted area up to 80 percent can be achieved (Fig. 6.2.2).

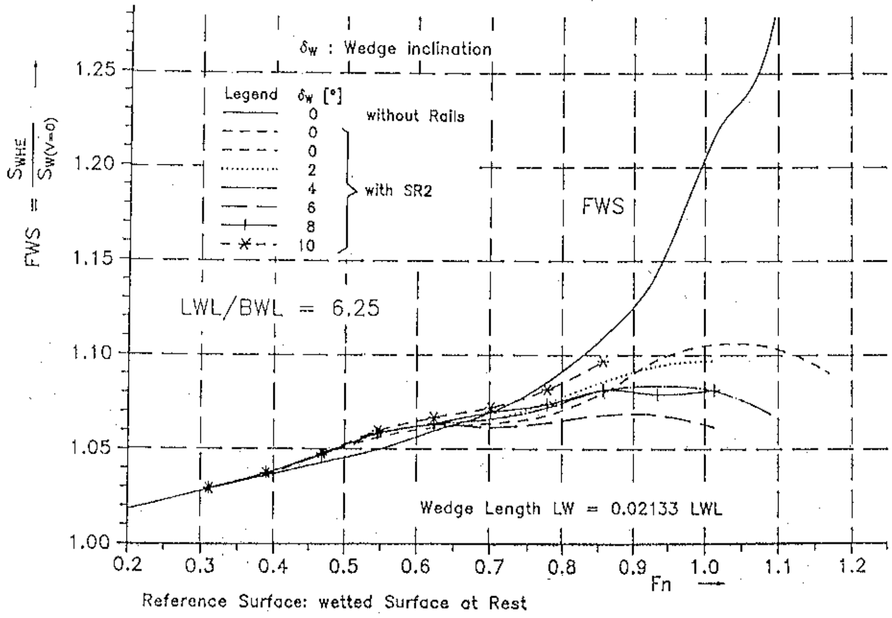

Fig. 6.2.1 Wetted Area Factor for one Spray Rail (SR2)

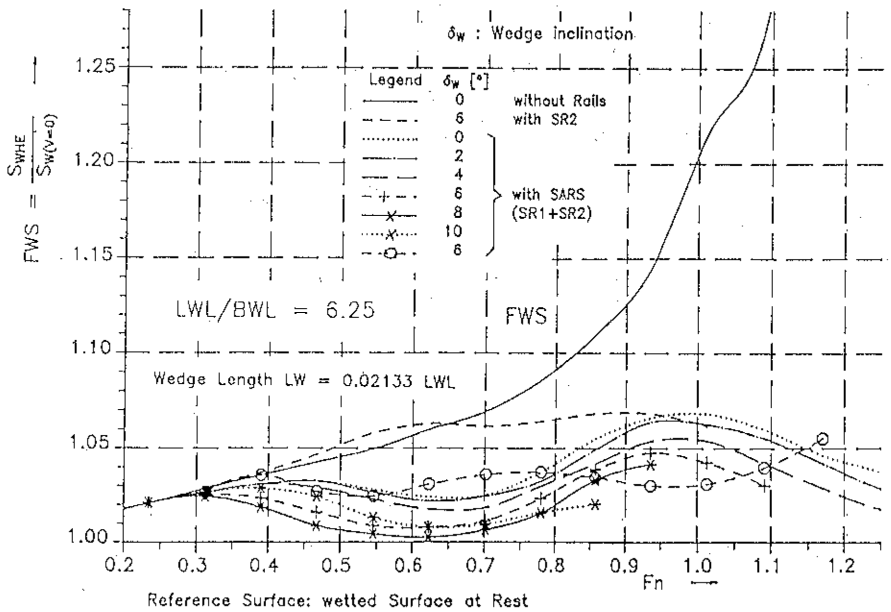

Fig. 6.2.2 Wetted Area Factor for ASRS

6.3 Reduction of the total hull resistance

For a better identification of the power saving effects of the rail system, the drag to weight ratio

$$\varepsilon_S = \frac{R_H}{\rho \cdot g}$$

with:

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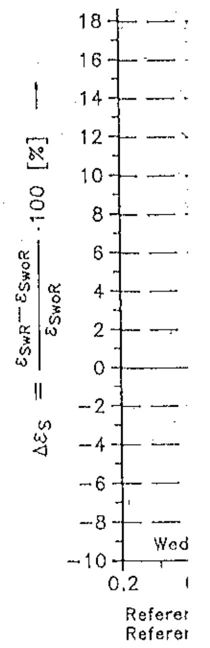

Fig. 6.3.1 Change
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$$\varepsilon_S = \frac{R_H}{\rho \cdot g \cdot \nabla} \tag{6.1}$$

with:

R_H	Total resistance of the hull without appendages	kN

of a full scale patrol boat of 38.0 m waterline length has been used.

The hull with rails shows due to the pressure resistance of the rails at F_n = 0,3 an up to 20 percent larger resistance than the hull without rails. Above F_n = 0.4 the rails are reducing the hull resistance increasingly with speed and transom wedge inclination. For the rail SR2 solely an average gain in resistance or in effective power of 4.0 - 6.0 percent (Fig. 6.3.1) and for both rails SR1 + SR2 of 6.0 - 10.0 percent is achievable (Fig. 6.3.2).

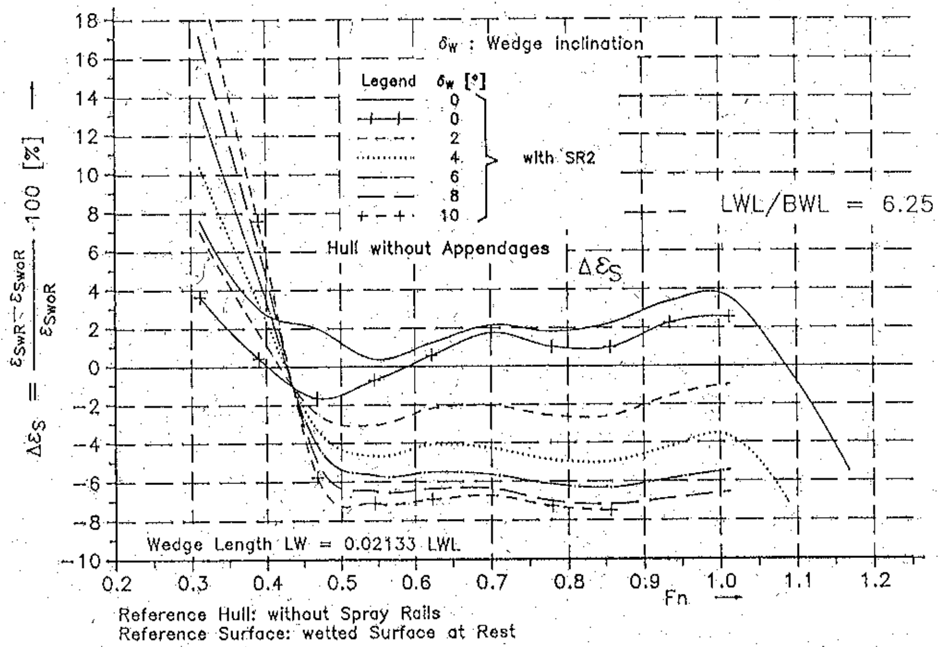
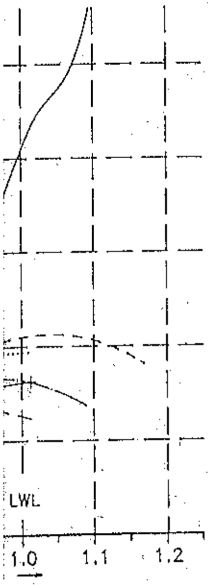


Fig. 6.3.1 Change of the Full Scale Resistance-Weight Ratio of the bare Hull due to one Spray Rail (SR2)



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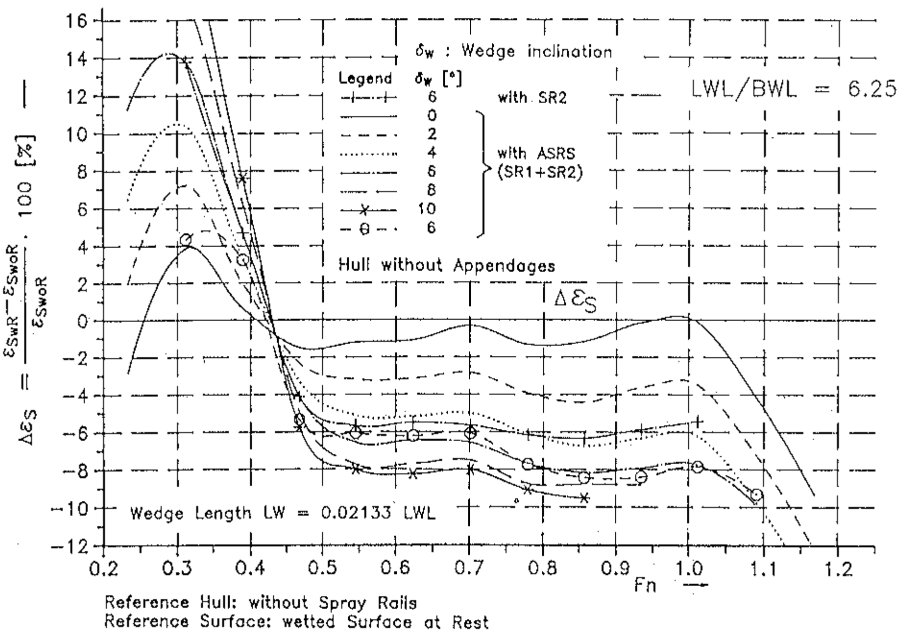


Fig. 6.3.2 Change of the Full Scale Resistance-Weight Ratio of the bare Hull due to the ASRS

6.4 Reduction of the residual resistance

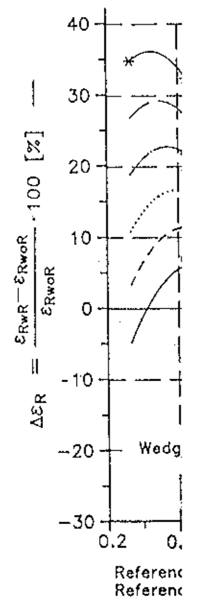
The residual resistance presented by the ratio of the residual resistance to the weight

$$\varepsilon_R = \frac{R_H - R_F}{\rho \cdot g \cdot V} \qquad (6.2)$$

with:

R_F Frictional resistance kN

which is commonly used in calculating the full scale resistance, indicates the same tendencies as the total resistance or ε_S. For the hull with rails the residual resistance increases at F_n = 0.3 rapidly and becomes up to 20 percent larger than in the case of the hull without rails. Above F_n = 0.4 the residual resistance declines with speed and increasing transom wedge angle. In the most important speed range of F_n = 0.6 - 0.9 an average gain in residual resistance of 6 percent for one rail (SR2) and of 10 percent for both rails has been determined for the length to beam ratios 4.54 and 6.25 (Fig. 6.4.1). For the larger ratio L/B = 7.5 the corresponding savings are 8 percent and 12.5 percent.



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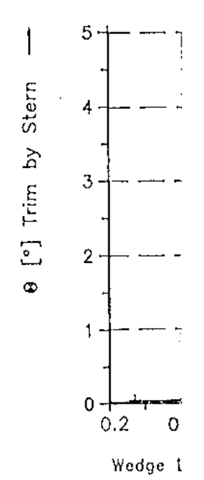

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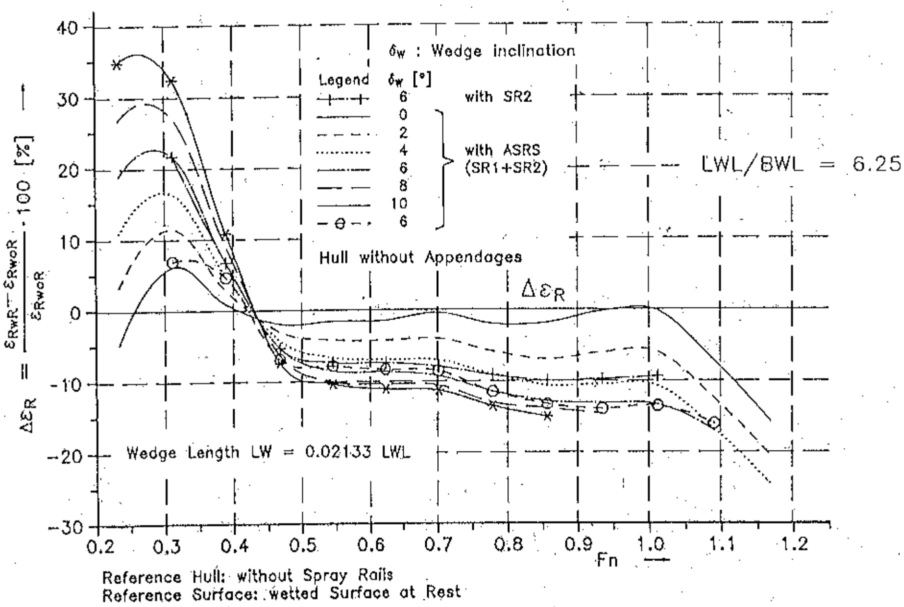

Fig. 6.4.1 Change of Residual Resistance due to the ASRS

6.5 The effect of the advanced spray rail system on running trim

The running trim of a hull without a transom wedge increases above F_n = 0.5 with the number of the rails. In the case of the advanced spray rail system the lift of the transom wedge governs the running trim which becomes substantially smaller with increasing wedge inclination (Fig. 6.5.1).

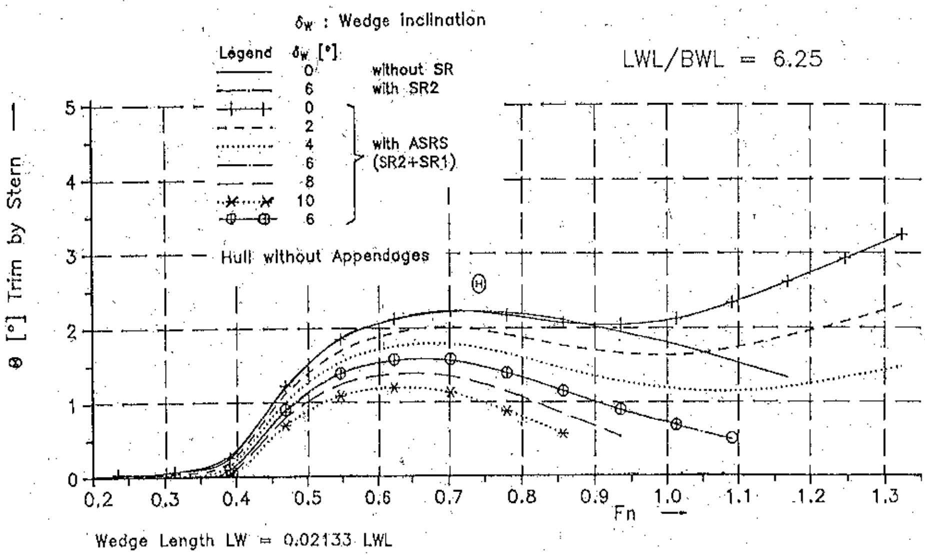

Fig. 6.5.1 Running Trim of the bare Hull with the ASRS

The difference of trim between one or two rails diminishes with the wedge angle. The vertical shift of the centre of gravity LCG is enlarged with an increasing length of the upper spray rail because the centre of pressure moves further aft.

6.6 The effect of the advanced spray rail system on the spray formation

By means of both spray rails the spray is thrown clearly aside. It is not reflected at the watersurface. Compared with the hull without rails the spray height beside the hull is smaller and its maximum is shifted aft. The risk that the spray becomes higher than the deck is delayed to speeds which are in most cases beyond the achievable top speed.

6.7 The interaction between spray rails and transom wedge

The effectiveness of the advanced spray rail system in reducing the resistance is a result of the optimum interaction between the lift of the transom wedge and the lift of the rails. By no other supplementary means an optimum running trim and a minimal wetted surface can be achieved. The gain in power due to the interaction between both devices is considerably larger than that which is caused by spray rails solely or by a trim wedge solely.

6.8 The effect of the advanced spray rail system on the seakeeping qualities of semidisplacement round bilge hulls

By means of advanced spray rails the seakeeping qualities of semi-displacement round bilge hulls can be improved due to a reduced deck wetness and an increased visibility from the wheelhouse. When pitching in waves, the advanced spray rails can stop the spray from climbing up the hull up to the bulwark where it is blown over deck and bridge. In throwing aside the powerful spray caused by the pitching motions, the external rails are more effective than the incorporated ones. If both rails of the advanced spray rail system extended up to roundness of the stem with the full bottom width the spray in the region directly abaft the stem cannot reach the deck.

As experienced by seakeeping test, the increase of the vertical bow accelerations due to the rails with a bottom width of b_{SR} = 0.0055 L_{WL} is negligible small.

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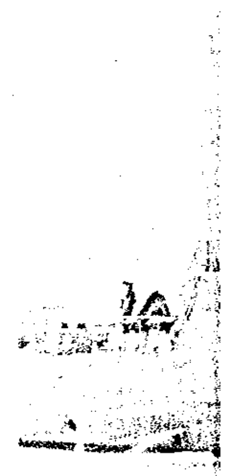

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6.9 The effect of the advanced spray rail system on the transverse stability underway

Due to negative dynamic pressures at the bilge area, semi-displacement round bilge hulls with length to beam ratios L/B > 6.0 are suffering at speeds F_n > 0.8 increasingly on a dynamic instability [7 - 10]. By means of the advanced spray rail system the apparent loss of metacentric height underway can be reduced remarkably. As demonstrated by full scale vessels the presence of the advanced spray rail system increases in general the roll stiffness of round bilge hulls at forward speed. The aft part of the main rail SR2 which terminates in the midship region directly at the watersurface (Fig. 6.9.1) generates hydrodynamic lift already in the upright position of the hull. In the case of heel the immersed rail creates increasingly a restoring moment with list. This moment is comparatively large, because the hydrodynamic lift acts on the largest attainable lever arm which is given by the half beam of the hull.

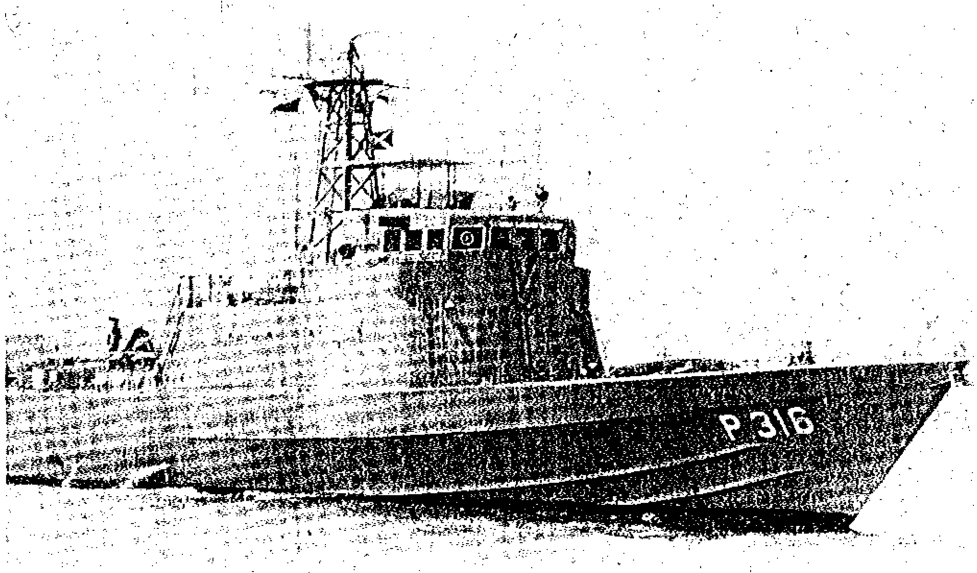

Fig. 6.9.1 Fishery Protection Vessel with the Advanced Spray Rail System

Therefore hulls with advanced spray rails are generally stiffer underway than hulls with an other spray rail arrangement or than hulls with incorporated rails. If a dangerous loss of transverse stability must be expected, the uprighting moment of the main rail SR2 can be increased substantially by

- an extension of the rail up to 0.4 L_{WL} before the transom,
- an augmentation of the rail inclination aft of 0.6 L_{WL} (Fig. 6.1.1),
- an enlarged submergence of the aft end of the rail of maximal one percent of the waterline length,
- a larger bottom width of the aft part of the rail.

Because small trim angles facilitate the occurrence of dynamic instability this risk can be reduced by an increase of running trim due to a larger lift of the rails in the forebody region and by a smaller lift of the transom wedge.

By means of all these measures which cause an additional rail and hull resistance the critical speed for the inception of the instability can be shifted to higher speeds which may be above the speed range of interest.

7. CONCLUSION

On the basis of extensive test results an optimum spray rail system has been developed utilizing the resistance reducing characteristics of each of the nine design parameters. By means of this rail system, which is used in combination with a transom wedge, an average gain in effective power of 5 to 6 percent for one rail (SR2) and of 8 - 10 percent for both rails (SR1 + SR2) could be achieved in a speed range of F_n = 0.5 - 0.9. In addition the rail system improves the seakeeping qualities of semi-displacement round bilge hulls due to a reduced deck wetness and an increased visibility from the bridge. With aid of the advanced spray rails, elongated up to 0.4 - 0.5 L_{WL} and reaching downwards to the watersurface or below, the apparent loss of metacentric height underway can be reduced remarkably. Therefore well shaped and proper arranged spray rails can be considered as the most effective tool in improving the most important characteristics of semi-displacement round bilge hulls without an alteration of the hull lines or the hull dimensions with a minimum of costs and expenditure.

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