SOME ASPECTS OF SAIL POWER APPLICATION IN THE GERMAN SEA FISHERY

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SUMMARY

Increasing oil prices did start the discussion on sail propulsion for German fishing vessels especially the smaller ones.

Operational data of small German trawlers is presented and discussed with regard to sail application as well as data of long term wind conditions needed for reliable prediction of sail power output.

Sailing and motor sailing tests with a 24 m standard fishing vessel were performed in 1980/82. The results of these investigations demonstrate that a considerable contribution to the propulsion power can be obtained by a sail area of sufficient size.

In favourable conditions of wind force and course angle the design speed of the vessel was gained by sail propulsion only.

1. INTRODUCTION

One of the most important influences on the economic performance of fishing vessels during the last decade was obviously the ever increasing costs of fuel. Fishermen had to face a sevenfold increase in fuel costs between 1972 and 1982. To demonstrate this development the price of diesel oil at the German fishing port of Cuxhaven is plotted in Fig. 1.

For selected vessels of the near water fishing fleet there is statistical data available /1/ (Tab. 1), showing the composition of operating costs since 1967. A considerable
part of the total operating costs is accounted for by fuel, which increased from 9.6 % (1971) to 22.9 % (1982) of the total costs. With regard to additional sail propulsion for these vessels we must keep in mind that, in spite of the increasing fuel costs, the major part of the operating costs is incurred for the crew. From this fact we can conclude that any sail arrangement making an increase of the number of crew necessary will by no means improve the economy of the vessel.

On the other hand the prices for fish and fish products increased at a lower rate than the fuel price. The economic results of the German near water and inshore fishery are listed in Tab. 2/2/. The landings are made up of wet fish for human consumption, industrial fish for fish meal production and shrimps, wet fish being the major part. In these circumstances a reduction of fuel consumption is one of the main problems for owners and skippers of fishing vessels.

On the gear side, different types of low energy fishing gear, e.g. set nets, longlines, danish seines, were improved and widely used by small fishing vessels. On the vessel side, the fuel consumption was decreased by slow steaming and main engines were prepared for the use of low grade oils to reduce the fuel bill. Another possibility for reducing the fuel consumption of fishing vessels would be the use of wind power for propulsion which is the subject matter of this paper. The paper will concentrate on the North sea for two reasons:

1. The North sea is the most important area for the German near water and inshore fishing fleets.

2. Detailed statistical data of wind conditions, operating conditions of fishing vessels, and catches is available for this area.

2. WIND CONDITIONS ON THE FISHING GROUNDS

The estimation of the propulsive power which can be obtained by wind force must be based on long term wind statistics of the area where the vessel will operate. Unfortunately statistical wind data is not always available, especially for those wide sea areas, where no permanent meteorological observations are performed. For German coastal waters of the North Sea there is long term wind data from weather stations on seven light vessels, which can be used for detailed calculations /3/.

To describe the wind conditions of the North Sea the wind data from the light vessel "TW Ems" will be used in this paper. Until 1978, when "TW Ems" was taken out of commission, the vessel was positioned at 54° 10' N, 6° 21' E.
The data relates to a period of 5 years (Dec. 1971 - Dec. 1976). The wind speed was measured continuously by a cup anemometer 18 m above sea surface and which recorded the average value of every 10 minute period. The wind speed at the standard height of 10 m is calculated according to the proposal of the "Informal meteorological Panel for the North Sea and adjoining waters", De Bilt 1977:

\[
U(h_2) = U(h_1) \cdot \left( \frac{h_2}{h_1} \right)^{1/7}
\]  

(1)

The frequency distribution of the 10 min. mean values \( U_{10} \) at \( h = 10 \) m is plotted in Fig. 2.

From this observed distribution of the mean wind speed \( U_{10} \), the variance \( V_{U_{10}} \), and the standard deviation \( U_{10} \) are divided:

\[
U_{10} = \sum p(U_{10}) \cdot U_{10}
\]  

(2)

\[
V_{U_{10}} = \sqrt{\sum p(U_{10}) \cdot U_{10}^2} - U_{10}^2
\]  

(3)

\[
\sigma_{U_{10}} = \sqrt{V_{U_{10}}}
\]  

(4)

With the "TW Ems" data from Fig. 2 we get

\[
\bar{U}_{10} = 7.74 \text{ m/s}; \quad V_{U_{10}} = 12.72 \text{ m}^2/\text{s}^2; \quad \sigma_{U_{10}} = 3.57 \text{ m/s}
\]

Wind speed distributions which are based on long term observations are usually approximated by a Weibull distribution \( U_{10}/s \) /5/:

\[
p(U_{10}) = \frac{c}{a} \left( \frac{U_{10}}{a} \right)^{c-1} \exp \left( -\left( \frac{U_{10}}{a} \right)^c \right)
\]  

(5)

Mean value and variance of the Weibull distribution can be expressed in terms of gamma functions:

\[
U_{10} = a \Gamma \left( 1 + \frac{1}{c} \right)
\]  

(6)

\[
V_{U_{10}} = a^2 \Gamma \left( 1 + \frac{2}{c} \right) - \bar{U}_{10}^2
\]  

(7)
With \( \bar{U}_{10} \) and \( V_{10} \), derived from the observed distribution and inserted in equations (6), (7) the Weibull parameters \( c \) and \( a \) can be calculated by means of numerical or graphic methods as described in [4], [5]. With the data from light vessel "TW Ems" we get \( c = 2.4; a = 9.73 \). The corresponding Weibull distribution is plotted in Fig. 2.

\( \bar{U}_{10} \) was calculated for the complete period of observation. When calculating \( \bar{U}_{10} \) for shorter periods of one month, the variations of \( \bar{U}_{10} \) during the year can be found [6], and which show a minimum in summertime (June - August) and a maximum in wintertime (November - December) (Fig. 3). The summer minimum, which makes this time less favourable for sail use, would be no handicap for most of the small German fishing vessels because they usually have their annual lay-up time of 4 - 5 weeks for repair and maintenance during these months.

The distribution of wind direction frequency is plotted in Fig. 4.

Less detailed wind data, based on observations made on commercial vessels is available for other areas of the North sea. The long term mean values \( \bar{U}_{10} \) derived from these observations are plotted in Fig. 5 [5].

When dealing with cargo ships running on more or less determined routes between different ports, the prevailing wind directions are a decisive influence on the long term sailing performance of the vessel [6], [7]. Considering fishing vessels, this problem is of minor importance, due to the way they operate on the fishing grounds. The assumption of equal probability for all course angles (ship's course/true wind direction) should be reasonable as a first approximation in this case.

3. THE COMPOSITION OF THE GERMAN FISHING FLEET

The German sea fishing fleet is organized in three main sections:

1. Distant water trawlers (Große Hochseefischerei)

2. Near water trawlers (Kleine Hochseefischerei)
   Wet fish trawlers operated by skipper owners. Size: up to 175 GRT. Crew: 4 - 5. Area of operation limited
to the Baltic and to the North Sea south of \(63^\circ\text{N}\) and east of \(7^\circ\text{W}\), and \(10^\circ\text{W}\) for the west coast of Ireland and the Channel. Gear: mainly bottom trawl, seasonal use of mid-water trawl, pair trawl and beam trawl.

3. Inshore fishing vessels (Küstenfischerei)

Small fishing vessels operated by skipper owners. Size: 37 GRT max. Crew: 1 - 3. Area of operation limited to the coast of Germany and adjoining countries (German bight and western Baltic) Gear: Bottom trawl, beam trawl (shrimp trawl). Increasing use of low energy fishing gear, mainly gillnets, in recent years. Number of vessels (near water + inshore): 646 (31.12.81)

The modern distant water trawlers powered by diesel engines were developed from steam trawlers which were introduced at the end of the 19th century. There is no tradition or experience of sail propulsion on this type of vessel since the first German steam trawler started to operate on the North Sea fishing grounds in 1885, and there is obviously no realistic chance for sail use on these vessels in the near future. Therefore the problem of sail propulsion for distant water trawlers can be omitted from this paper.

On the other hand the type of fishing vessel of section 2 + 3 was a sailing vessel by origin. There was no mechanical propulsion until 1903 when the first experiments with internal combustion engines were performed by the German Sea Fisheries Society (Deutscher Seefischerei-Ver- ein) /9/, /10/.

In a comparatively short time the sail as the main propulsive device was replaced by diesel engines. In 1925 4 out of a total of 72 near water fishing vessels were still sailing. In 1926 all vessels (68) were powered by motors /11/. Up until the late 50s vessels of this type were designed with auxiliary sails to improve their sea keeping behaviour. For these reasons a discussion of sail use on fishing vessels should concentrate on this type. In 1981, 646 near water and inshore fishing vessels were operating, more than 40 % of a size between 14 m - 18 m length overall (Fig. 6) /2/. Powers range up to 600 HP with the majority below 300 HP (Fig. 7). In this diagram the influence of administrative regulations on the fishing fleet can be recognized.

The number of crew with marine engineering certificate is governed by main engine power as follows:

\[
P < 300 \text{ HP} \quad : \quad 1 \text{ man}
\]

\[
300 \text{ HP} < P < 600 \text{ HP} \quad : \quad 2 \text{ men}
\]

\[
600 \text{ HP} < P \quad : \quad 3 \text{ "}
\]
4. MODE OF OPERATION ON THE NORTH SEA FISHING GROUNDS

The data for this section is based on the statistics of landings at the three main German fishing harbours of Bremerhaven, Cuxhaven and Hamburg. The statistics refer to the North sea fishing grounds (Fig. 8) and vessels > 35 GRT, all trawlers (Fig. 9). Tab. 3 a – e shows the statistical data for the last 3 years (1980 – 1982). The mean duration of trips to the different fishing grounds is plotted in Fig. 10, and vary between 17 days (Shetlands 1980) and 5.5 days (Deutsche Bucht 1982), according to the distance from German ports.

The days spent fishing as percentage of days at sea are plotted in Fig. 11. For all fishing grounds the vessels are fishing about 65 % – 70 % of the time. This value is not very exact because every day the gear is shot, even for a short haul, is recorded as fishing day. A more detailed statistic may indicate 50 % – 60 % fishing time.

With respect to the use of sails we have to consider days running and days fishing separately. Sailing will not always be possible especially when bottom trawling on fishing grounds where fasteners are abundant and a great number of vessels are working simultaneously, or when working with gill nets or longlines.

Trolling seems to be the only method where sails can be used without difficulty. It is more or less equal to the free running condition of a vessel where sailing will always be possible, favourable wind speed and direction assumed. But the application of this fishing technique is limited to certain pelagic species like tuna or salmon which are not available in the areas where German near water and inshore vessels are working.

5. SAILING TRIALS WITH A 30' GERMAN STANDARD TRAWLER

In April 1980 sail propulsion tests with a former German standard trawler were performed by the Federal Research Institution for Fisheries, Institute for Fishing Technology (Bundesforschungsanstalt für Fischerei, Institut für Fangtechnik) in cooperation with the Hamburg Ship Model Basin (Hamburgische Schiffbau-Versuchsanstalt) to obtain full scale test data for the estimation of the sailing performance of small fishing vessels /12/, /13/. These trials were continued in 1982.

5.1. THE STANDARD TRAWLER KFK (KRIEFSFISCHKUTTER)

In the late 30s the German government started a programme to standardize small fishing vessels. This work resulted in a series of 7 vessel types (A – G) at a range of 10 m (A) to 22 m (G) length over all /14/, /15/.
The research and development work was concentrated on the type G (Fig. 12, Fig. 13) including model tests at the Vienna Ship Model Basin /16/. Fig. 14 shows the results of these tests. Starting with the hull form of a successful traditional fishing vessel (Normalform \( L = 22.0 \) m) the lines were improved while keeping the main dimensions and displacement constant. With this hull form (Maierform, \( L = 22.0 \) m) the shaft horse power at \( V_s = 9 \) kts was decreased by 37.9% compared with the original design. In another variation (Maierform, \( L = 27.9 \) m) the length over all was slightly increased at constant displacement, and a total reduction of 43% SHP at 9 kts was measured with this final hull form. The main dimensions of the KFK are:

- Length over all \( L_o,a. = 24.00 \) m
- Length between perpendiculars \( L_{pp} = 20.57 \) m
- Beam moulded \( B = 6.25 \) m
- Depth \( D = 3.00 \) m
- Draft moulded \( T = 2.11 \) m
- Draft max. \( T_{max} = 2.85 \) m
- Displacement \( = 110.00 \) t

Propeller
- Diameter \( D_p = 1220.00 \) mm
- Pitch \( p = 820.00 \) mm
- Disc area ratio \( \frac{D_p^2}{A_o} = 0.47 \)
- Number of blades \( n = 3 \)

Full scale tests with 3 vessels confirmed exactly the model test results /17/, Fig. 15. During World War II 600 KFK were built and used as mine sweepers and patrol boats by the German navy. Most of them were destroyed, the remaining 130 vessels were converted to trawlers in 1945. In 1982 about 20 KFKs were still fishing.

5.2. KFK "FREDDY"

The trials were performed with KFK "Freddy", now owned by the German section of the British Petroleum Company and used as a yacht (Fig. 16).

There is a total sail area of 180 m²:

- main sail: \( 79.5 \) m²
- mizzen jigger: \( 41.0 \) m²
- jib: \( 31.5 \) m²
- outer jib: \( 29.0 \) m²

\[ \text{Total sail area}: 180.0 \text{ m}^2 \]
Displacement: \( t \)

The rig is of traditional design. Sufficient stability is provided by 15 tons of ballast, giving the vessel a positive righting lever up to \( 90^\circ \) angle of heel (Fig. 17).

5.3. TEST RESULTS

5.3.1. SAILING TESTS

The first series of trials were performed in April 1980 in the western Baltic. In April 1982 a second series were performed to complete the test data from 1980. Ship's speed \( (V_s) \), apparent wind speed \( (U_a) \) and direction \( (\xi) \) were measured simultaneously at different apparent course angles by means of an electro-mechanical propeller log and a cup- anemometer mounted on top of the main mast 22 m above sea level.

From this data the true wind speed \( (U) \) and the true course angle \( (\chi) \) were calculated (Fig. 18):

\[
U \sin \chi = U_a \sin \xi \quad (8)
\]

\[
U \cos \chi = U_a \cos \xi - V_s \quad (9)
\]

\[
\tan \chi = \frac{U_a \sin \xi - V_s}{U_a \cos \xi - V_s} \quad (10)
\]

This calculation does not take into account drifting of the vessel. If we do so, the apparent course angle has to be increased by the drifting angle \( \beta \). At high values of \( \chi \) the drifting angle is of minor importance, but at a range of \( \chi < 60^\circ \) the influence of drifting cannot be neglected. For future trials with KPK "Freddy" measurements of \( \beta \) are intended to investigate the drifting performance of the vessel.

For \( 100^\circ \)-ranges of \( \chi (60^\circ < \chi < 160^\circ) \), \( V_s \) against \( U \) is plotted in Fig. 19 a-c. By regression analysis the curves \( V_s = f(U) \) were determined for the 1980-data (solid lines) and the (1980+1982)-data (dotted lines). Some differences in the results were found at \( \chi > 130^\circ \). It may be that the number of measurements in this range was not sufficient to obtain reliable results.

From Fig. 19 a-c ship's speed curves \( V_s = f(\chi) \) can be derived (Fig. 20). Combining these curves with Fig. 15 we find the corresponding power output of the sails (Fig. 21). If we assume, that every course angle \( 0^\circ < \chi < 180^\circ \) will have the same probability the mean value:

\[
N = \frac{1}{180} \int_{0}^{180} N(\chi) \, d\chi \quad (11)
\]

represents the power which can be obtained at different true wind speeds \( U \) (Fig. 22).

\( N \) multiplied with the probability of the wind speed (see section 2) and integrated gives the long term average
power output of the sails which can be expected for the area considered:

$$\dot{N} = \int p(U) \, \bar{N}(U) \, dU$$

(12)

With the test data of KFK "Freddy" and the wind data from light vessel "TV Ems" we get \( \dot{N} = 29.3 \) SHP. If we assume \( \dot{N} \) proportional to the mean wind speed \( \bar{U} \), \( \dot{N} \) can be calculated by means of Fig. 5 for other parts of the North sea.

5.3.2. MOTOR SAILING TESTS

In order to establish the propulsion performance of the test vessel under engine power, test runs without sails were performed in absolutely calm weather as well as under the wind conditions of the pure sailing and motor sailing (combined propulsion) tests. The engine is a high speed diesel engine

DAIMLER-BENZ TYPE OM 346

with NCR of 150 HP (110 kW) at 1800 rpm driving via reduction gear 1 : 3.5 a three bladed propeller of

- \( D_p = 1.00 \) m
- \( p/D = 0.56 \)
- \( A_p/A_0 = 0.40 \)

For the corresponding Wageningen B-Series propeller the open water characteristics were derived according to /18/, leading to the relationship between advance velocity \( V_A \), number of revolutions \( n_{prop} \) and delivered power \( P_D \) as presented in Fig. 23.

From the trials in calm weather, where not only shipspeed \( V_S \) and revolutions \( n_{MOT} \) were measured, but also the power output was estimated from fuel consumption measurements, the velocity scale between \( V_A \) and \( V_S \) was determined corresponding to a wake fraction \( W \approx 0.24 \)

$$\frac{V_A}{V_S} = 1 - W \approx 0.76$$

(13)

With this velocity scale the measured relationships between shipspeed \( V_S \) and revolutions \( n_{MOT} \) can be plotted into the diagram both for calm weather and for \( U_22 = 20 \) kts corresponding to Beaufort 5. At a shipspeed of 9 kts, e.g., the required power is 25% higher than in calm weather.

Under combined motor and sail propulsion (in the "motorsai-
ling" model 29 measurements of ship speed, wind speed and relative courses were taken at three engine speeds of 1200, 1400 and 1600 rpm with full sails of 180 m² "properly" trimmed on each course respectively.

The average ship speed values for $U_{22} \approx 20$ kts, for four course angles $X = 60°, 90°, 120°$ and $150°$ and for the three engine speeds can be plotted into Fig. 23 in the same way as for pure motor propulsion.

For pure sailing a certain small shaft friction torque on the free milling propeller was assumed and the sailing speeds for the same wind speed and course angles were plotted in the same diagram in the vicinity of the zero torque line $0 = 0$, thus completing the motorsailing lines for the four selected course angles.

The ship speed - power relation can now be read from the diagram Fig. 23 for all three operation modes - "motoring", "motorsailing" and "sailing" and plotted, e.g., as ship speed against power with parameters relative course and revolutions for the selected wind speed $U_{22} \approx 20$ kts (corresponding to Beaufort 5) as in Fig. 24.

If a ship speed of 9 kts, e.g., the power requirement under motor is 100 kW (136 HP) at Beaufort 5 and 80 kW (109 HP) in calm weather. When motorsailing with full sails at Beaufort 5, the required power is 40 kW (54 HP) at 150° course and 2 kW (6 HP) at 90° course relative to the true wind.

If the engine is stopped and the propeller free milling, the sailing speed would be 6.5 kts at 150° and 8.6 kts at 90° course.

If the full engine power of 100 kW (136 HP) would be maintained when setting sails the ship speed would be increased from 9 to 10 kts only at 150° and to 10.8 kts at 90° course.

It is obvious that considerable power reductions are possible when maintaining ship speed in the motorsailing mode but only small speed increase when maintaining full engine power.

If the driving forces generated by a given rig and depending on the apparent wind are known from model tests or from evaluations of full scale measurements, as in the present case, the power savings by wind assistance may be estimated for a given shipspeed at all significant windspeeds and on all relative courses in a similar manner.
as indicated above. Fig. 25 shows, as an example, the required power at a constant ship speed of 0 kts with and without wind assistance for the tested FKF "Freddy" versus course angle relative to the true wind with parameter true windspeed $U_{10}$. For each windspeed $U_{10}$ the average power reduction $\Delta P$ is indicated under the assumption of equal frequency of all relative course angles.

If the probability distribution of windspeeds in the operation area is known, the power reductions $\Delta P$ can be averaged over all windspeeds weighted with the expected frequency $p$ of each windspeed respectively. This has been done in Table 4 for two examples of windspeed distributions with average windspeeds $U_{10}$ of 12 kts (e.g. Caribbean Sea) and of 15 kts (e.g. North Sea) and again for a constant ship speed of 0 kts.

The resulting average power reduction at the propeller $\Delta P$ of 90 kW (121 HP) and 90 kW (121 HP) may be regarded as a potential power from the sails, and relating to the sail area of FKF "Freddy", this yields about 0.11 or 0.15 kW per square meter of sail area depending on the windiness of the sea area. The corresponding fuel savings at 9 kts ship speed would be about 103 or 150 kg per day corresponding to about 23% or 34% of the respective fuel consumption without sail assistance.

The potential power from the sails is, of course, not only depending on the wind conditions but also on the ship speed and on the efficiency of the rig. For modern rigger power savings up to 0.25 or 0.30 kW/m² can be expected. At lower ship speeds the absolute power savings are decreasing but the percentage of saving of the full power requirement is increasing until reaching 100% saving at a ship speed low enough that it can be achieved on average by sails alone.

6. CONCLUSIONS

The economy of sail assisted fishing vessels depends on two main factors

1. Wind conditions of the area considered. As a first approximation the wind conditions can be described by the long term mean wind speed $U_{10}$

2. Operating conditions of the fishing vessel considered. The use of additional sails will not always be possible, depending on the fishing technique performed by the vessel
Both factors have to be carefully investigated before dealing with technical problems of a specific rig. To get sufficient propulsion power from the sails the sail area should be as large as possible. With respect to the transverse stability of the vessel there will be an upper limit for the sail area. A certain amount of ballast, which reduces the loading capacity, will be necessary in almost any case.

The influence of sail power on the economy of the vessel has to be considered. When planning additional sails for a fishing vessel the handling of the sails should be possible without additional crew.

PERSONAL BIOGRAPHY

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1938
Born at Küslin (Pommern)

1945 - 50
Primary school at Königsberg, Kaliningrad

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<td>44.0</td>
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<td>15.7</td>
<td>8.8</td>
<td>17.5</td>
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<td>78</td>
<td>43.3</td>
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<td>10.5</td>
<td>8.2</td>
<td>18.5</td>
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<td>1980</td>
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<td>18.1</td>
<td>45</td>
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<td>21.4</td>
<td>15.0</td>
<td>9.5</td>
<td>18.1</td>
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<td>82</td>
<td>39.1</td>
<td>22.9</td>
<td>13.0</td>
<td>9.0</td>
<td>19.5</td>
<td>45 (Jan. - Sept.)</td>
</tr>
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Tab.1 Operating costs of selected vessels of the near water fishers /1/
<table>
<thead>
<tr>
<th>Year</th>
<th>Landings $[10^6 \text{kg}]$</th>
<th>Earnings $[10^6 \text{DM}]$</th>
<th>Kilo-Price $[\text{DM/kg}]$</th>
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<td>0.42</td>
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<tr>
<td>1971</td>
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<td>0.59</td>
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<tr>
<td>1972</td>
<td>130.4</td>
<td>92.3</td>
<td>0.71</td>
</tr>
<tr>
<td>1973</td>
<td>133.1</td>
<td>102.2</td>
<td>0.77</td>
</tr>
<tr>
<td>1974</td>
<td>138.5</td>
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<tr>
<td>1975</td>
<td>116.3</td>
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</tr>
<tr>
<td>1977</td>
<td>110.9</td>
<td>118.0</td>
<td>1.06</td>
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<tr>
<td>1978</td>
<td>105.0</td>
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<td>1.07</td>
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<td>77.6</td>
<td>87.1</td>
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<tr>
<td>1980</td>
<td>91.9</td>
<td>94.5</td>
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</tr>
<tr>
<td>1981</td>
<td>103.4</td>
<td>121.1</td>
<td>1.17</td>
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Tab. 2 Landings and proceeds of the near water and inshore fishery /2/
### Table 3a - c

Near water fishing vessels >35 GRT. Operating data and catches at the North Sea fishing grounds 1980-82

#### a. 1980

<table>
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<tr>
<th></th>
<th>Number of Trips</th>
<th>Days at Sea</th>
<th>Days Fishing</th>
<th>Days/ ds</th>
<th>ds/t</th>
<th>Total Catch</th>
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<td>t</td>
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<td>df</td>
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<td>(ts)</td>
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<tr>
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<td>34</td>
<td>24</td>
<td>0.71</td>
<td>17</td>
<td>76</td>
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<tr>
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<td>423</td>
<td>278</td>
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<td>11.1</td>
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<tr>
<td>Ostkante</td>
<td>47</td>
<td>602</td>
<td>412</td>
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<td>12.8</td>
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<tr>
<td>Gat</td>
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<td>4053</td>
<td>2072</td>
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<td>11</td>
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<td>449</td>
<td>309</td>
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<td>10.2</td>
<td>645</td>
</tr>
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<td>Sudl. Schlickb.</td>
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<td>918</td>
<td>658</td>
<td>0.72</td>
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#### b. 1981

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<th>Days/ ds</th>
<th>ds/t</th>
<th>Total Catch</th>
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<td>1012</td>
<td>608</td>
<td>0.67</td>
<td>9</td>
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<table>
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<th>Days Fishing</th>
<th>Days/ ds</th>
<th>ds/t</th>
<th>Total Catch</th>
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<tr>
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<td>27</td>
<td>0.02</td>
<td>1.34</td>
<td>0.04</td>
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<td>(35)</td>
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<td>0.01</td>
<td>0.03</td>
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<td>0.03</td>
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$\Delta P = 20.02 \text{KW}$ (27.23 HP) \quad \frac{\Delta P}{A_S} = 0.11 \text{ KW/m}^2 (0.15 \text{ HP/m}^2)

$\Delta P = 29.07 \text{ KW}$ (59.54 HP) \quad \frac{\Delta P}{A_S} = 0.46 \text{ KW/m}^2 (0.22 \text{ HP/m}^2)

$A_S = 190 \text{ m}^2$

Table 4: Average power reduction by sail assistance, KFK "Freddy", 190 m$^2$ ketch rig, shipspeed 0 kts
Fig. 1 Diesel oil price at German fishing harbour of Cuxhaven
Fig. 2 Frequency of wind speed $U_{10}$ at light vessel "TW Ems" 1971-76
Fig. 3 Variation of mean wind speed $\bar{U}_{10}$ Jan.-Dec. at "TW Ems"
Fig. 4 Frequency of wind direction at "TW Ems"
Fig. 5 Mean wind speed $\bar{U}_{10}$ for the North sea /8/
Fig. 6  German near water and inshore fishing vessels, length over all

Fig. 7  German near water and inshore fishing vessels, main engine power
Fig. 8 North Sea fishing grounds
Fig. 9 Near water fishing vessels >35 BRT

Fig. 10 Days at sea per trip. North Sea 1980-82
Fig. 11  Days fishing in per cent of days at sea.  
North Sea 1980–82
Fig. 12  Reichsfischkutter Type G (KFK)
General arrangement /15/
Fig. 13 Reichsfischkutter Type G (KFK). Lines /15/

Fig. 14 KFK Results of model tests at the Vienna Ship Model Basin /16/
Fig. 15: KFK Results of full scale trials /17/
Fig. 16  KFK "Freddy". Side view and sail arrangement
Fig. 17 KFK "Freddy", Righting lever and heeling lever of wind pressure

Fig. 18 Speed diagram
Fig. 19a  KFK "Freddy", ship's speed $V_s$ versus true wind speed $V_a$, $\chi = 50^\circ - 80^\circ$
Fig. 19 b  KFK "Freddy", ship's speed $V_s$ versus true wind speed $V_a$, $\chi = 80^\circ - 120^\circ$
Fig. 19c  KFK "Freddy", ship's speed $V_s$ versus true wind speed $V_a$, $\alpha = 120^\circ - 160^\circ$
Fig. 20  KFK "Freddy", ship's speed $V_s$ versus course angle to true wind $\alpha$. 
Fig. 21  KFK "Freddy", wind propulsion power
Fig. 22 KFK "Freddy", long term power output
Fig. 23  Speed-revolutions-power relation of the propeller B 3-40/86 Dp=1.0 m
Fig. 24 Achievable shipspeed depending on delivered power
Fig. 25 KFK "Freddy". Required propulsive power at $V_S = 0$ kts