THIS PAPER NOT TO BE CITED WITHOUT PRIOR REFERENCE TO THE AUTHORS

INTERNATIONAL COUNCIL FOR THE EXPLORATION OF THE SEA

C.M. 1980/B:15
FISH CAPTURE COMMITTEE

FISHING VESSEL SPEED AND FUEL ECONOMY

BY

TORBJØRN DIGERNES & ANDERS ENDAL
INSTITUTE OF FISHERY TECHNOLOGY RESEARCH
HÅKON HÅKONSONS GT. 34
7000 TRONDHEIM NORWAY

1. ABSTRACT

Reducing free running speed of a fishing vessel 10% may reduce free running fuel consumption 30-40%. Depending on type of fishing, a 10% free running speed reduction may reduce the total annual fuel consumption as follows:

Trawling	:	10-12%
Longlining	:	15-20%
Purseseining	:	20-25%

Total fuel saving for the Norwegian fishing fleet by a 10% free running speed reduction, is estimated to 60-80.000 tons of oil.

Speed selection is a matter of balancing fuel cost against time cost.

If speed is reduced too much, the loss of fishing time may more than offset the gains of fuel savings.

Economical speed and economical engine power is a balance between time and fuel consumption. It therefore depends on fuel prices, and the value of time, which in turn depends on fish prices and catch rates.

An example of this effect is that a 100% increase in fuel price, nearly halves economical engine power, while it increases fuel cost for steaming a fixed distance by about 20%.

A continued trend of large relative price increases on fuel, calls for a change in vessel design practices.

1. BACKGROUND

During the last 30 years fishing vessel engine power has increased tremendously. This trend has been encouraged by the availability of fuel of high quality and low prices.

In view of rising fuel prices the Institute of Fishery Technology Research of Norway has investigated the fuel saving potential of speed reduction.

This paper is a summary of the report: "Fart og drivstoffkonomi i fiskeflåten". ("Speed and Fuel Economy in the Fishing Fleet") by the first author of this paper.

2. SPEED AND POWER
(Simplified vessel technology)

The resistance of a vessel is extremely speed dependent.

A typical feature of a vessel resistance curve is moderate increase at low speeds, with increasing steepness in the higher speed regions.

Fig. 1 shows a typical curve for engine horsepower and speed for an 80 ft. vessel.

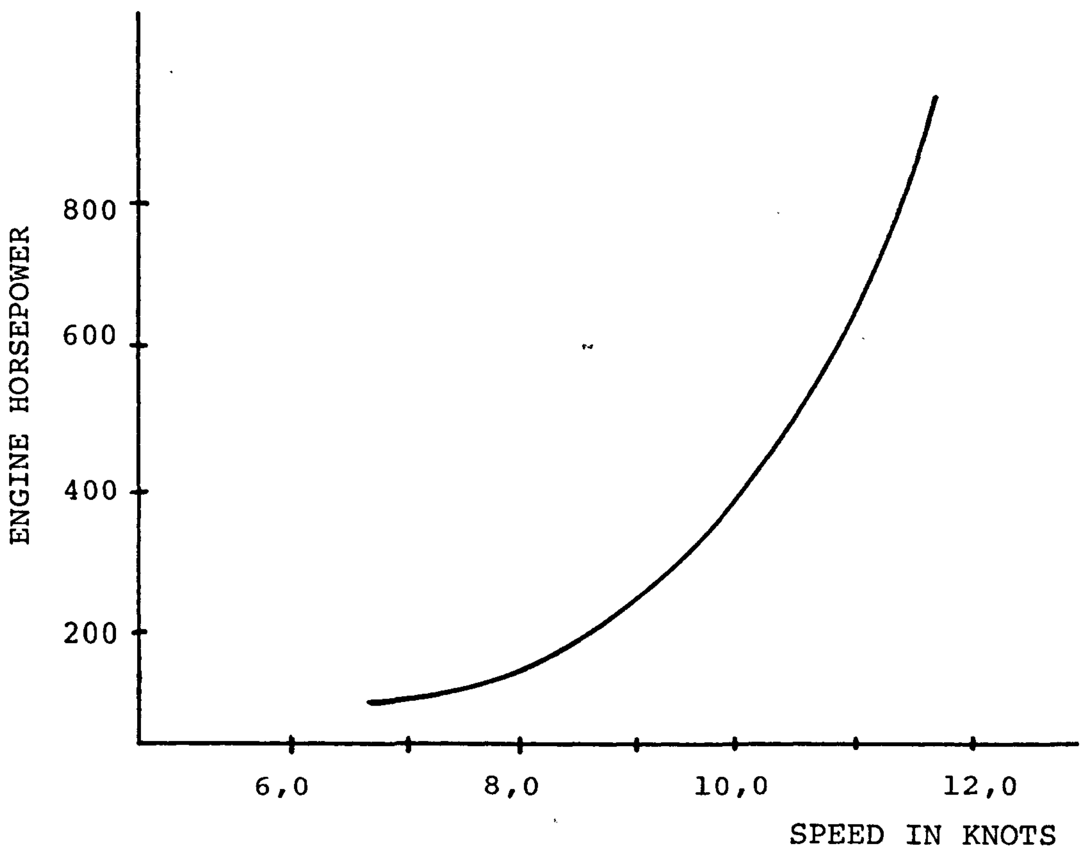


Fig. 1

The first 100 HP will give the vessel a speed of 7,5 knots, the next 200 HP increase the speed 2 knots, to 9,5 knots. Another 200 HP will give slinghtly less than 1 knot increase to about 10,5 knots.

If we increase the power from say 600 to 800 HP, the speed increase is only 0,5 knots.

Two main factors determine the shape of the resustance curve for a vessel:

- Vessel displacement (total weight)
- Vessel length

Resistance is roughly proportional to the displacement, if the displacement of a vessel increase with 50%, the resistance will increase with 35-45%. The displacement determines the "level" of resistance.

The length of a vessel has a different effect. It determines the "steepness" of the resistance curve at different speeds.

In practice the length of the vessel determine the maximum speed a vessel can reach.

The effect of length on resistance can be seen clearly if resistance is shown as horsepower pr. ton of displacement.

This has been done for 6 vessels of different length on fig. 2.

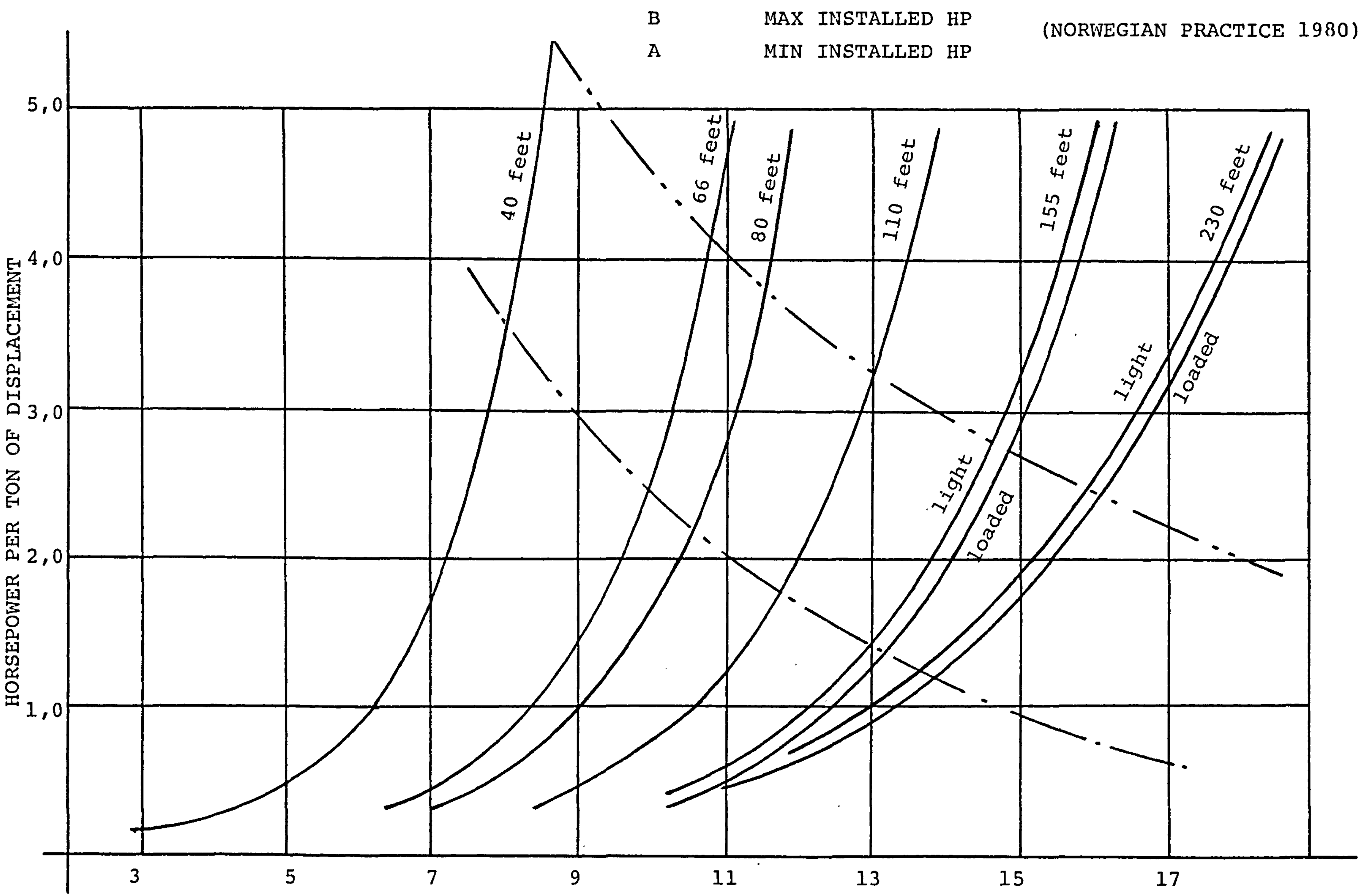

B MAX INSTALLED HP
A MIN INSTALLED HP
(NORWEGIAN PRACTICE 1980)
HORSEPOWER PER TON OF DISPLACEMENT
5,0
4,0
3,0
2,0
1,0
40 feet
66 feet
80 feet
110 feet
155 feet
230 feet
light
loaded
light
loaded
3
5
7
9
11
13
15
17
SPEED IN KNOTS

FIG. 2

We can clearly see that the different vessels have the same horsepower (resistance) pr. ton at different speeds.

The lines A and B are minimum and maximum lines, the area between them representing "normal practice" in the Norwegian fishing fleet today.

The installed horsepower pr. ton is substantially higher for the small vessel compared to the large ones.

The dependency of the resistance curve on vessel length is closely related to the wave-pathern created by the vessel.

The ratio between vessel speed V, and the square root of the length of the waterline is called speed length ratio. $V/\sqrt{L_{wl}}$.

This ratio is closely related to the steepness of the resistance curve.

If speed is expressed in knots and L_{wl} in feet, the steep region of 3-4 HP/ton occurs at $V/\sqrt{L}$ of 1.2-1.4.

In this region the resistance increase with the 6-8th power of the speed.

The maximum practical speed for a displacement vessel may be found by multiplying the square root of the waterline length in feet by 1,2 - 1,4.

3. SPEED REDUCTION AND FUEL SAVING

Fig. 2 shows quite clearly the fuel saving potensial of speed reduction.

Table 1. gives the particulars of the 6 typical vessels includes in fig. 2.

VESSEL	LENGTH (m)	(feet)	TYPICAL DISPLACEMENT (tons)	SPEED/POWER (knots and HP) 1	2	TYPICAL ENGINE POWER (HP)	MAIN ENGINE FUEL CONSUMPTION KG/HP/HOUR
A	12,2	(40)	32	7,5/80	8,5/165	175	0,185
B	20,1	(66)	143	7,0/60	10,0/350	400	0,180
C	24,4	(80)	255	7,5/100	11,0/700	600	0,175
D	33,6	(110)	550	9,5/300	12,0/1050	1100	0,168
E1	47,3	(155)	750 light	11,5/540	14,5/1900	2400	0,160
E2	47,3	(155)	1260 loaded	10,5/490	14,0/2300	2400	0,160
F1	70,0	(230)	1300 light	10,5/520	14,5/2000	3200	0,155
F2	70,0	(230)	2600 loaded	10,5/900	13,5/2700	3200	0,155

Table 1.

Vessel A, B and C are coastal vessels for longlining, gillnetting and inshore purseseining. D is a combination vessel for longline/gillnets/trawl. E and F are combined purseseiners/trawlers.

The data given for each vessel are:

- length
- displacement
- two points on the resistance curve (related speed and engine power)
- typical installed HP for newbuildings of this class
- and fuel consumption pr. horsepower-hour (specific fuel consumption)

The horsepower curves are based on a propeller efficiency of about 0,50 and an addition of 15-20% to still water resistance.

During the following calculations we are only concerned with the fuel used for propelling the vessel through the water. Auxilliary power consumption is not included.

To simplify, we have assumed that consumption pr. horse-pwer-hour is constant regardless of engine loading, which of course is not true. It is, however, of minor importance in this connection.

Based on a fuel price of N.kr pr liter, fuel consumption and sailing time at full speed has been computed for typical sailing distances for each of the six of the above vessels.

Similar calculations have been carried out at a speed reduction of 10-15% for each vessel, and the difference in fuel cost and steaming time has been found.

The results are tabulated in table 2.

Table 2

		Full speed				Reduced speed				Difference in	
Vessel	Distance naut. mil	Speed (knots)	Fuel consumption (litres)	Fuel consumption (kr)	Steaming time (hours)	Speed (knots)	Fuel consumption (litres)	Fuel consumption (kr)	Steaming time (hours)	Fuel cost (kr)	Time (hours)
A (40 ft)	25	8,6	110	116	2,9	7,5	58	60	3,3	55	0,43
B (66 ft)	100	10,2	820	860	9,8	8,5	357	375	11,8	484	1,96
C (80 ft)	100	10,7	2270	2380	18,7	9,5	1315	1380	21,0	1000	2,36
D (110 ft)	500	12,1	8960	9400	41,3	10,5	4680	4920	47,6	4480	6,30
E1(155 ft)	1000	15,1	29840	31330	66,2	13,0	14580	15300	76,9	16030	10,70
E2(155 ft)	1000	14,1	31875	33470	70,9	12,0	14970	15720	83,3	17750	12,40
F1(230 ft)	2000	16,1	71765	75350	124,5	14,0	44530	46760	142,9	28590	18,40
F2(230 ft)	2000	14,0	82230	86340	142,7	12,0	48080	50490	166,7	35850	23,80

Fuel price: N.kr. 1,05/litre

4. FUEL SAVING DIAGRAM

For quick reference a "Fuel saving diagram" has been made, shown on fig. 3.

The diagram is made to show the fuel saving in relation to speed/length ratio ($V/\sqrt{L_{wl}}$ (scale along top edge).

Different speed scales for different vessel lengths are shown below the curves. If a speed scale for different vessel length is required, this may be added. If waterline length is unknown, a relation $L_{wl} = 0{,}93 \cdot L_{oa}$ is reasonable to use.

How to use the diagram

Let us consider a 66 feet vessel. We assume that the free running speed is 10,2 knots. (It is not neccessary to know the horsepower).

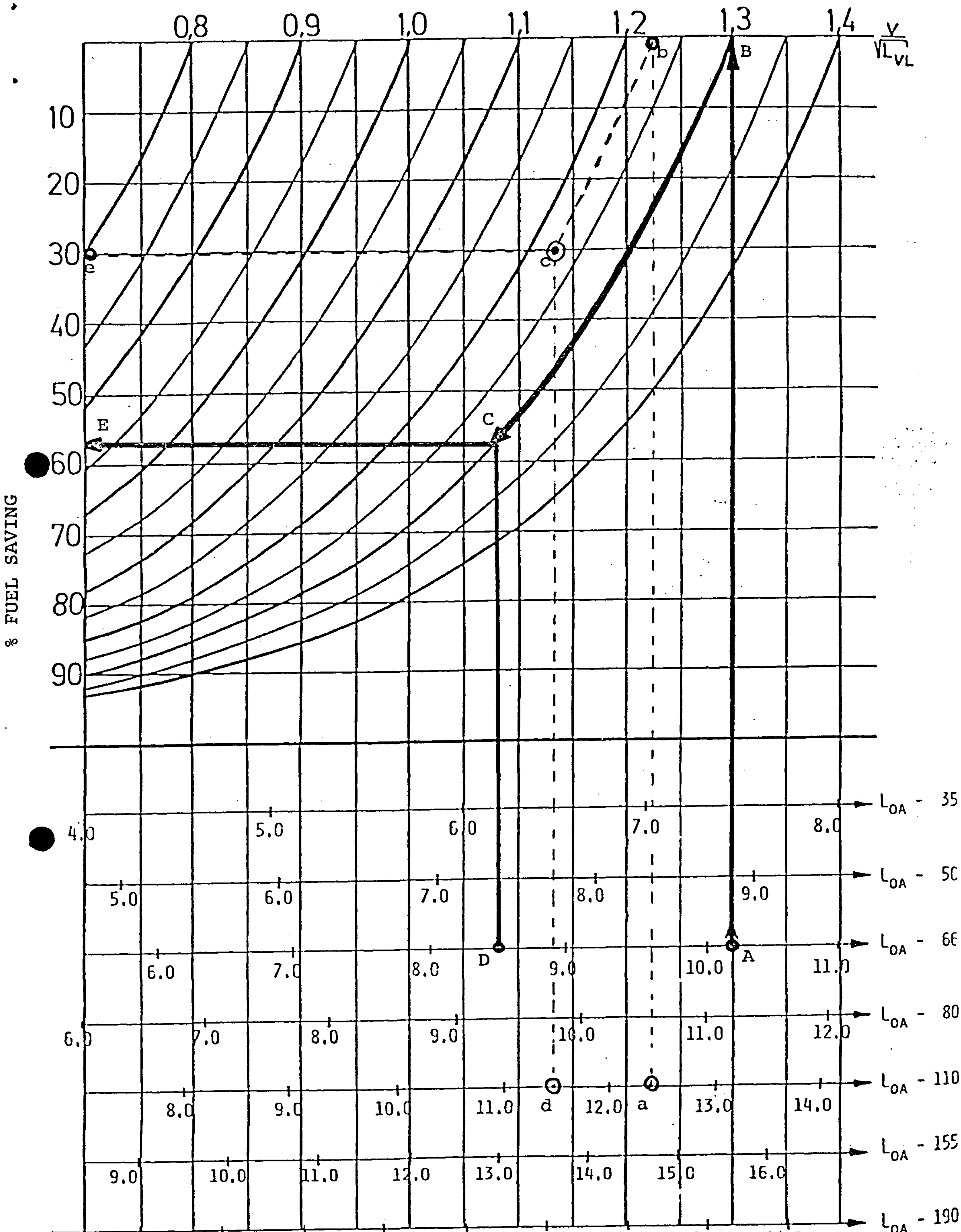
In the speed scale for L_{oa}= 66 feet, we find 10,2 knots at point A. This corresponds to a speed/length ratio of 1,3, found at point B, on the top scale.

Now if we wish to find the possible fuel saving, we will follow the "FUEL SAVING LINE" along say to point B, which corresponds to a vessel speed of 8,5 knots (point D) The possible fuel saving potential is found at point E, approximately 56%.

A similar exercise may be carried out for a 110 footer, with a full speed of 12,2 knots (point a, b, c, d and e).

In this case the vessels top speed does not coinside with a curve, but additional curves may be drawn.

FIG. 3 FUEL SAVING DIAGRAM



FISKERITEKNOLOGISK FORSKNINGSINSTITUTT

LIMITATIONS:

- This diagram is correct for vessels 70-100 feet. Smaller vessels may save slightly less (a factor 0,93-0,97), larger vessels somewhat more (a factor 1,02-1,06).

- The resistance is based on the shape of the curve in still water, but for moderate weather the diagram is reasonably accurate for reductions from the speeds attained under such conditions.

- For moderate to heavy water, the percentages given in the diagram are too optimistic.

- Savings greater than 50-60% can normally only be partially realized. In this area decreased propulsive efficiency (especially with variable pitch propellers) and higher specific fuel consumption in the engine will reduce the potential saving read from the resistance curve. If care is not taken, the effect of decreasing propulsive efficiency with variable pitch propellers can affect the saving also at higher power levels. A rule of thumb to keep up propulsive efficiency is to keep full pitch and reduce the rpm of the propeller. Fig. 4 shows the effect of the two alternative ways of reducing the power.

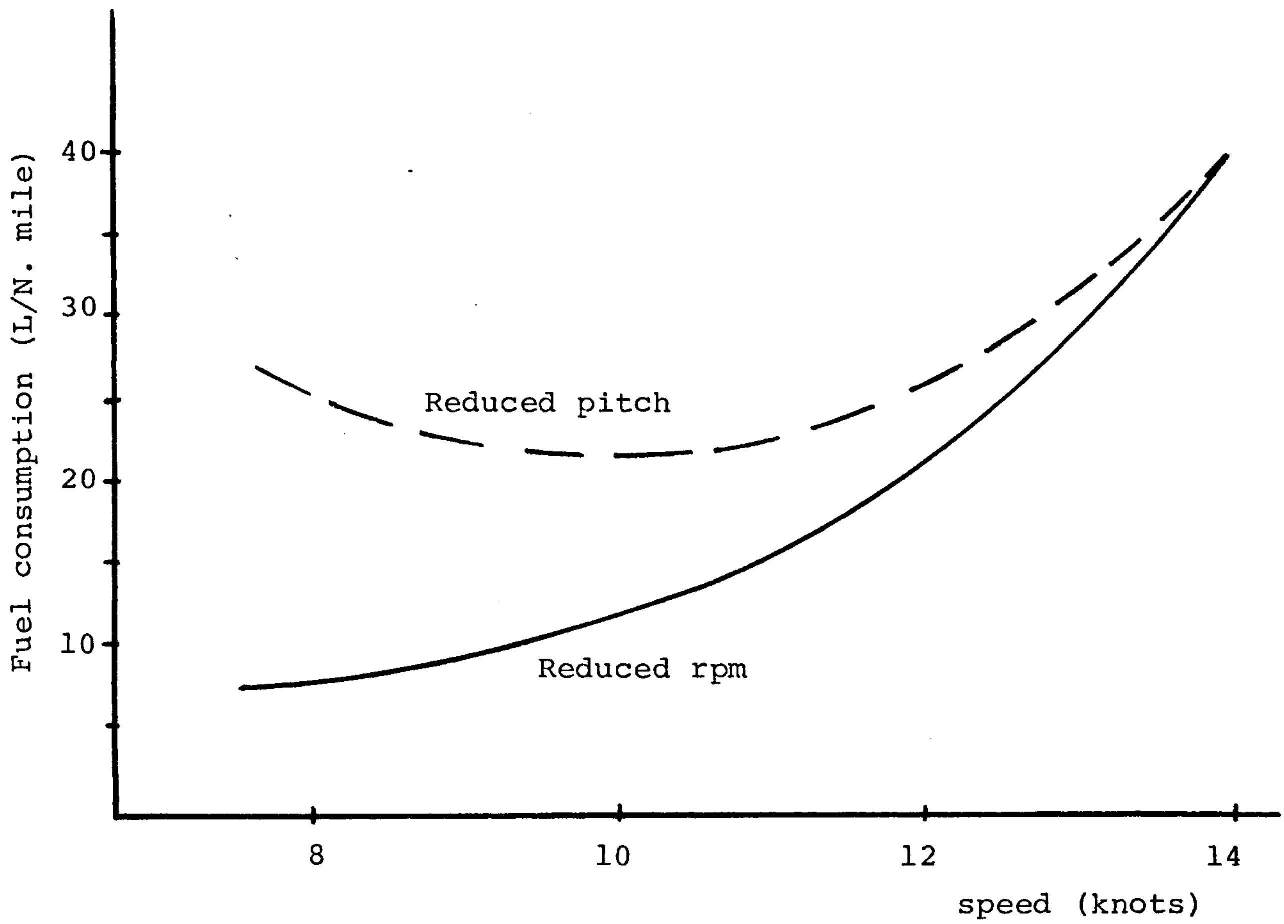


Fig. 4 Effect of power reduction (155 feet vessel)

5. ECONOMICAL SPEED

To select the proper speed for a given situation, the use of time must be balanced against the use of fuel.

A reduction of speed increases steaming time.

If one considers increasing speed, the questions to ask are:

- What is the alternative use of the steaming time saved
- Is the value of the time saved equal to or higher than the extra fuel cost.

Let us continue along this line of thinking and look at the cost of steaming one nautical mile.

With a given vessel, the only costs influenced by a change of speed are:

a: time cost (from a value allotted to time)

b: fuel cost.

Fig. 5 shows a diagram dealing with this.

The figures are related to the 66 footer mentioned earlier. The time value is arbitrarily set to N. kr 100,- pr hour. The time cost is reduced by increased speed, while the fuel cost pr mile increaces.

Adding the two cost curves, produces a total cost curve, the distance cost, which has a minimum. The point at which minimum cost occur may be called "ECONOMICAL SPEED".

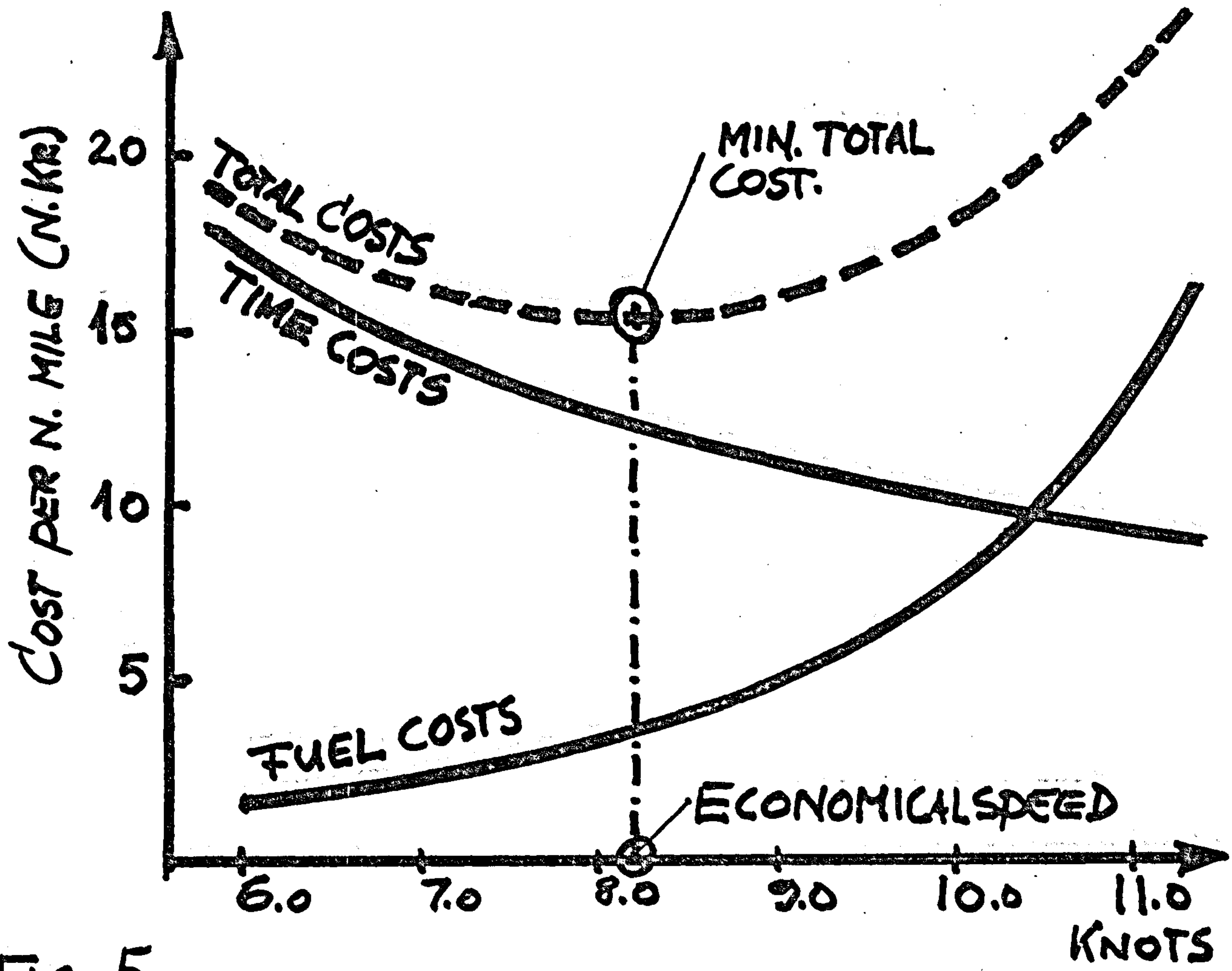


FIG 5

Factors determining economical speed for a vessel are:

- The vessel's resistance-curve
- Engine fuel consumption
- Fuel price
- Time value

For our 66 footer above, with a fuel consumption of 0,180 kg per horsepowerhour, a fuel price of N. kr 1,05 pr litre and a time value of N. kr 100,- pr hour, the economical speed is 8,2 knots.

When the resistance curve of the vessel is expressed mathematically, we can derive economical speed and horsepower as a function of time value and fuel price. This has in the report been computed for the six vessels mentioned before. Only the diagram for the 66 footer is shown here (fig. 6). Four levels of fuel price and a wide range of time values are shown.

How do we determine the value of time?

The issue in the speed decision situation is:

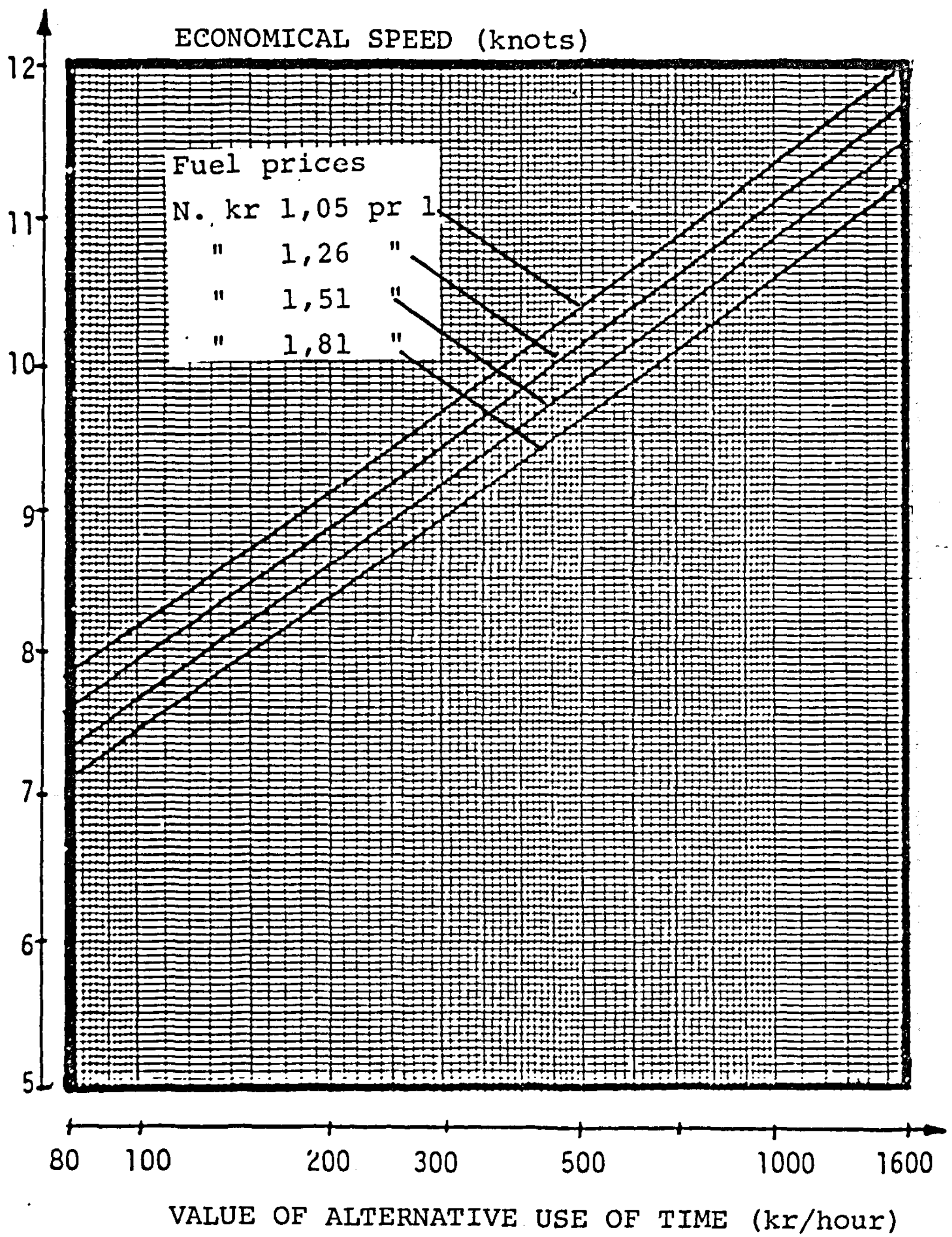
What is the alternative use of the time that I may choose to use steaming the distance in question at a lower speed? And then, how much is this use of time worth to me?

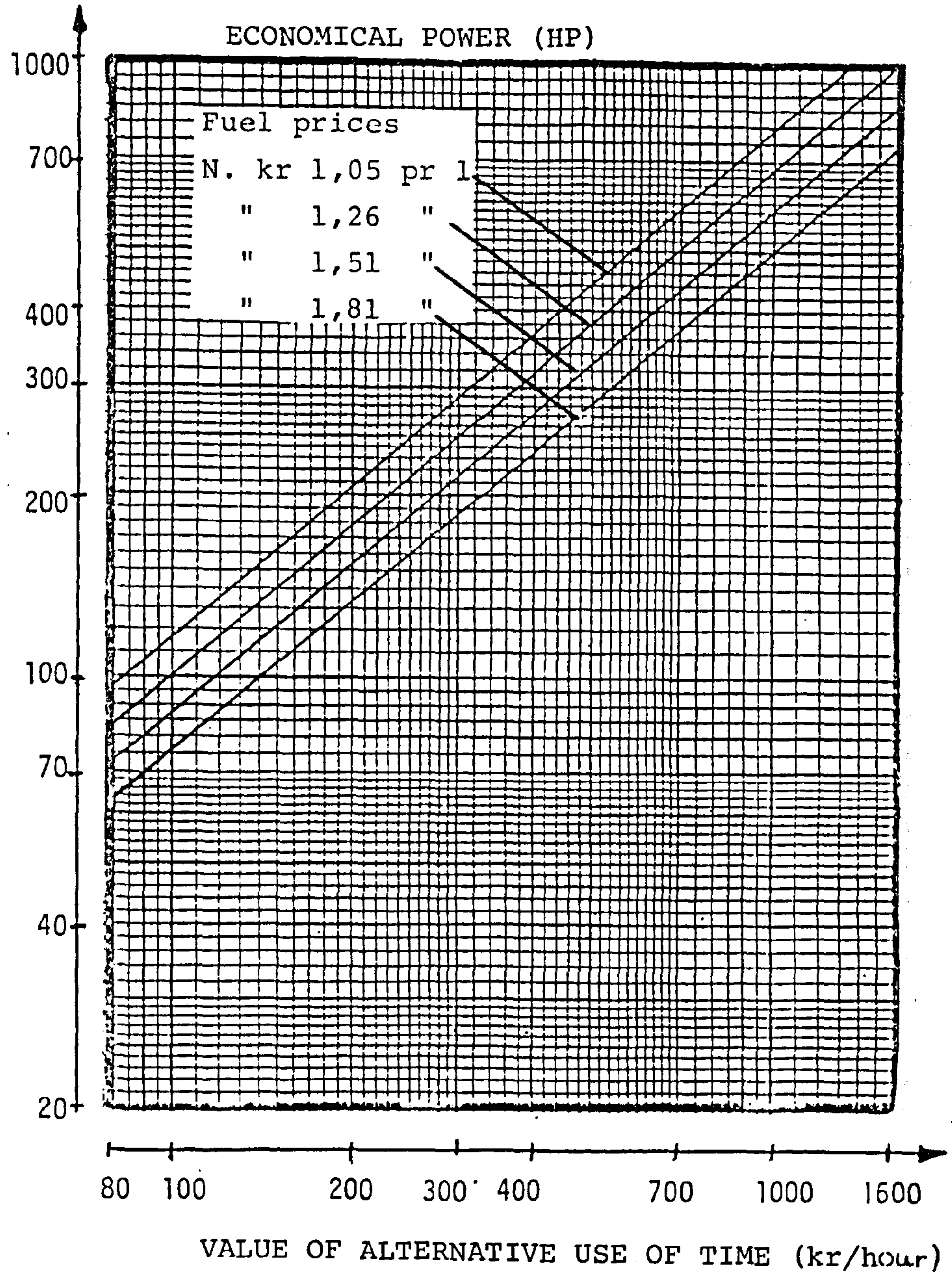
Obviously, the answer to both these questions are very situation dependent. We therefore can conclude that there exist no one economical speed for a given vessel. We can image situations where time value ranges from zero to very large numbers. Conceptually we can look at 3 different situations.

1. Fishing is free, and time is the limiting factor for catch income. Alternative use of time is then increased fishing time. The value of this time is the net income that can be expected from fishing, that is value of catch minus variable costs, plus eventual time proportional costs when steaming (other than fuel costs).

2. The vessel is fishing on a fixed catch quota, such that time is not the limiting factor for catch income. The value of time can then be assessed from the following components:

Fig. 6. ECONOMICAL SPEED DIAGRAM
66 feet vessel - displacement 143 tons





a) Time saved is utilizable time off for the crew, a time which can be allotted a price.

b) The vessel can save timevariable costs by reducing its operational time.

c) The rest of the fishing quota will, if speed is reduced, be fished under other catch rates than present. Value of time now therefore is the difference between net income per hour now and net income at the time when the last of the catch quota is caught.

3. Under both the previous regimes, situations often will arise when time saved will be "dead" time. That is, it will only increase idle time at the point of arrival. One example is steaming to harbour for arrival in the middle of the night, being unable to use the time till morning in any meaningful way.

   In such situations speed should be chosen so as to arrive at the planned time. If the "cost" per hour for arriving later than planned should be less than the time value associated with this speed, the speed should further be reduced to that associated with the cost.

Obviously, assessing the value of time is no clean cut calculation. It will contain both uncertainties and subjective judgement. All the same it is important to introduce this concept, because the heart of the speed choice decision is the balancing between the resources time and fuel. To achieve the right balance in the consumption of these resources they must both be measured in economical terms.

One way to motivate the skipper towards this thinking is reading the economic speed diagram the other way around:

The <u>time value</u> corresponding to a certain speed is <u>equal to the marginal cost of an extra hour using that speed,</u> made payable through the fuel bill.

Form figure 6, we can thus see that at a fuel price of kr 1,26 pr litre, the price we pay for arriving an extra hour earlier using 10 knots is 450 kroner, while the price of an extra hour at the speed of 9 knots only is 220 kroner.

<u>How does fuel price increase affect economical speed and engine power?</u>

Roughly, the results in the report indicate that when the ratio between fuel price and time value increase by a factor f, then the economic power is reduced by a factor $(1 - k \cdot \frac{1}{f})$ where k is between 0,8 and 1. This means, that when the fuel price/time value ratio is doubled, economical power is practically halved.

In fig. 7, the change in the relations between time and fuel costs in a broad speed range is shown for a 230 feet vessel when exposed to a doubled fuel price, maintaining the same time value. Several points are worth noting in this diagram:

a) The 106% increase in fuel price lead to a 22% increase in distance cost.

b) It leads to a 21% increase in fuel cost.

c) The minimum of the distance cost curve is relatively flat. In a power range $\pm$ 15% of the economical power the distance cost lies within 1% of the minimum.

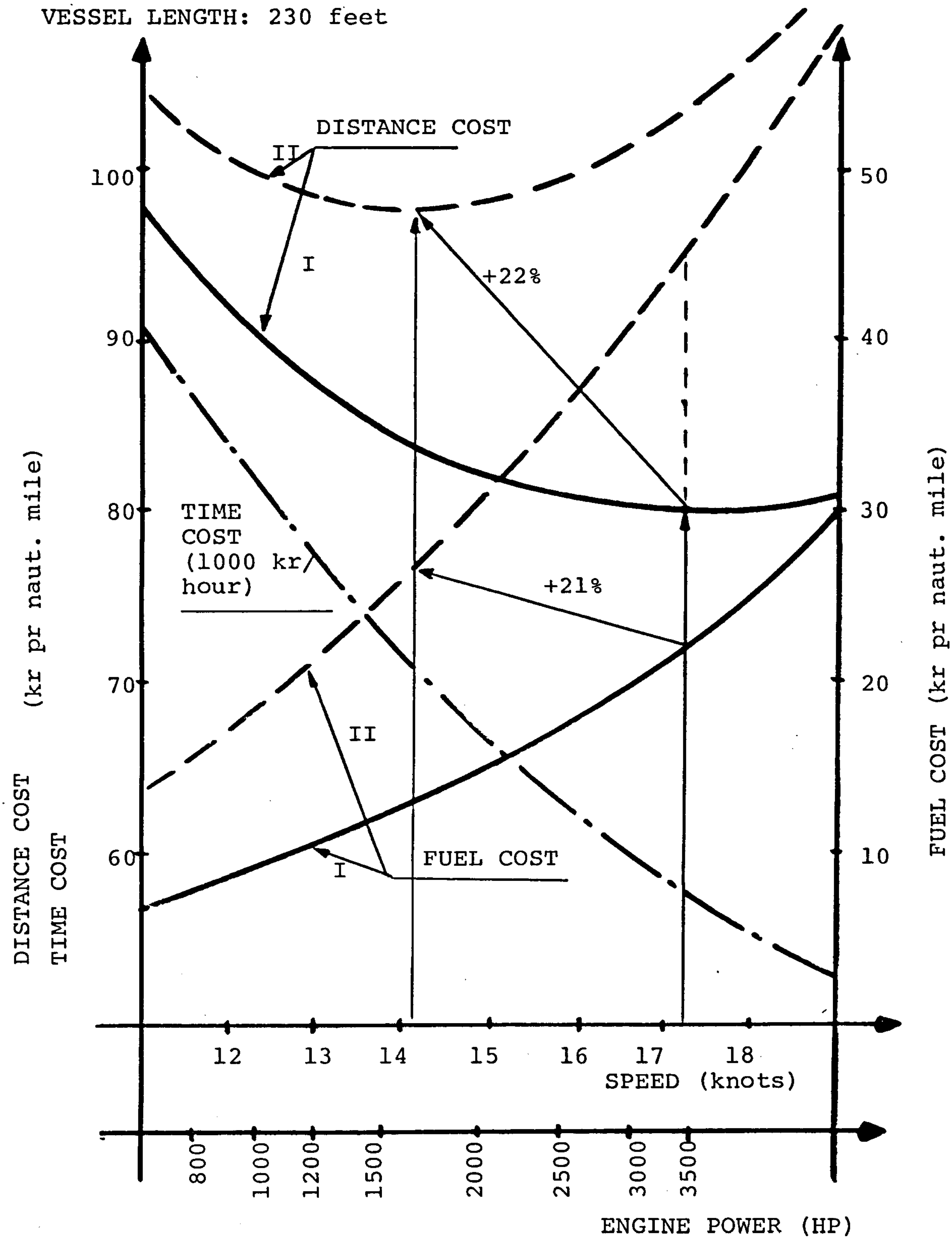
Other results form our work indicate that economical power is not very sensitive to the vessels loading condition. These two facts makes it feasible to think that robust rules of thumb as to what is economical power under various time values may be developed from fairly little information about the vessel resistance. This work continues at our institute.

d) 1000 kr per hour is a moderate time value for a vessel of this size. If this vessel is a purse seiner under a free fishing regime, it may in periods fish under conditions where time is worth 2500-5000 kr/hour. This indicates that even with a considerable additional fuel price increase it will encounter situations where a power of more than 3000 HP is less than economical.
But obviuosly this is not the rule.

The large power reduction called for by large fuel price increases may be hard to achieve efficiently with engine systems of todays vessel. In the design of these, little attention has been paid to producing propulsive power at part loads efficiently.

FIG. 7. EXAMPLE OF CHANGE IN DISTANCE COST WITH FUEL PRICE INCREASE

ALT I : KR 0,64 pr litre fuel } + 106%
ALT II : KR 1,32 pr litre fuel }
VESSEL LENGTH: 230 feet



CONCLUSIONS

The foregoing discussions have dealt with the problem of how to use the engine power installed under various circumstances. We have not discussed the choice of engine size. This is a very complicated question, which we do not intend to go into in full detail here.

A few comments on how a continued trend in price increases on fuel will affect future vessel design is, however, in its place.

Concerning the propulsive system we can say:

- the trend will call for installing smaller engines

- since time value varies widely in the operation of a vessel, the trend will call for systems that can produce propulsive power in a wide range of power levels in an efficient way.

This means

- engines that can be operated continuosly at part loads (preferably as low as 25-30%), maintaining acceptable specific fuel consumption at rpms that do not destroy propeller efficiency

or

- multiple engine systems that allow the individual engine to operate at high load levels at reduced total power levels, possibly combined with two-step reduction gears.

Concerning hull design, the emphasis here will be shifted towards the medium speed range, rather than tuning for the highest possible top speed at high speed/length ratios. The high speed properties will have to be sacrified in compromises where better performance can be achieved in the medium range.