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MID-WATER TRAWL DESIGN FOR THE SURVEY VESSEL MFV SAGARIKA

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ABSTRACT

In this assignment a four panel prototype mid-water trawl was designed for the Fishery Survey of India, in particular the survey vessel MFV Sagarika for experimental mid-water trawling along the central west coast of India. The aim was to investigate the potential for pelagic fishing in the area and to promote the use of mid-water trawls as a substitute for bottom trawls. The design is based on basic formulas and calculations for the design of fishing gears and specific scientific reports on modelling and full scale tests of mid-water trawls. The design is also based on available knowledge on the behaviour and morphology of the targeted species. The resulting net plan is presented as conventional 2D blueprint and 3D model, visualising three optional hanging ratios (0.5, 0.3 and 0.2) and rigging.

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LIST OF ABBREVIATIONS

2D: Two dimensions
3D: three dimensions
CMFRI: Central Marine Fisheries Research Institute
EEZ: Exclusive Economic Zone
FAO: Food and Agricultural Organisation
Fig.: Figure
FSI: Fishery Survey of India
GPS: Global Positioning System
MFV: Marine Fishing Vessel
Sonar: Sound Navigation and Ranging
VHF: Very High Frequency

LIST OF UNIT ABBREVIATIONS

BHP: brake horsepower
kg: kilogram
kgf: kilogram-force
knot: nautical mile
m: meter
mm: millimetre
m/s: meter per second
ps: Pferde starke

LIST OF FIGURE SYMBOLS

#: number of meshes
Φ: diameter

1 INTRODUCTION

Fishing is an ancient practice in many countries. Fishing has undergone radical changes, from the traditional to the highly mechanised. After the introduction of motors, many European countries made evolutionary changes in vessel size, horse power, net design, etc. The invention of electronics for fish detection and net design was another breakthrough for the fishing industry.

India is one of the largest countries in the world, with a combined coastline of 8041 km in length, and an EEZ of 2.02 million km^2. The Indian fishing industry was traditionally based on indigenous crafts and gears; mechanisation in India started in the middle and late 1950s. Trawling was first introduced in India under an Indo- Norwegian project in the year 1954. The catches during that phase increased drastically. Further, it has been observed that the increase in marine landings over the last half decade is only marginal which, to a certain extent, might be due to intense fishing efforts in a limited narrow coastal area (Vivekanandan *et al.*, 2003). However, the catches from the inshore waters (<50m) reached the catchable potential during 1995-2000 (Vivekanandan *et al.*, 2003). India still has some unused potential to exploit further the offshore fishing resources (>50m), while the majority of trawlers are currently operated in the inshore waters. When we consider the fact that marine organisms such as eels, cat fish, sciaenids, pomfret, Indian mackerel and cephalopods have already been over exploited in coastal waters (Vivekanandan *et al.*, 2003).

Mechanised fishing vessels include stern and out rigger trawlers, gillnetters, purse-seiners, long liners and dol netters (dol nets are set bag nets, held stationary against the current, mainly used for the Bombay duck) (Flewwelling and Hosch 2006). Trawling is one of the most important methods of commercial fishing constituting about 50% of the total marine landings of India (Morgan 2004). The mechanised fishing is almost confined to shrimp trawling along the narrow coastal waters (Vivekanandan *et al.*, 2003).

Maximum Sustainable Yield in the Exclusive Economic Zone of India is estimated as 3.92 million tonnes per year out of which about 16% is in the offshore region. The present exploitation is about 3.02 million tonnes (Anon 2008a). The marine fish resources from the inshore waters have reached the maximum level and the effort now should be towards conservation and management of these resources (Somvanshi 2001). To reduce overexploitation, it has been realised that there should be no increase in effort in the shallow waters. However, diversification of fishing activities and mechanisation of indigenous crafts has been suggested to improve the present yield. The Indian government is emphasising the introduction of resource specific vessels (> 20m) to explore the possibilities of deep sea and oceanic resources (Anon 2008b).

The landing pattern of west coast of India for the years 1970-1998 shows that the average annual landings of pelagic fish contribute 59% to the total landings. The dominant groups (and species) in the pelagic landings are oil sardine (*Sardinella longiceps*), Indian mackerel (*Rastrelliger kanagurta*), Carangids (Caranx spp. and *Decapterus russelli*), whitebaits (Stolephorus spp.) lesser sardines (Sardinella spp.), seerfishes (*Scomberomorus commerson* and *S. Guttatus*), sharks (*Scoliodon laticaudus* and Carcharhinus spp.), barracudas (Sphyraena spp.) and tunas (*Euthynnus affinis* and *Auxis thazard*). The remaining 41% is made up of demersal fishes, shrimp, crustaceans and cephalopods (Vivekanandan *et al.*, 2003). The catch analysis of 2005 indicated that pelagic fish contribution to the total catch was 55% (Anon 2008c). These resources are caught by purse seines, drift gillnets, ring-seines, and hooks and lines mainly but considerable catches have also been reported in the bottom trawl. The survey conducted by M.F.V. Samudrika in the years 1994-96 using bottom trawl reported a considerable quantity of pelagic species in the catches (Srinath *et al.*, 2003)

Bottom trawl fishing has both a direct and indirect impact on the marine ecosystem as well as on biodiversity. As a mobile non selective fishing gear (some extend), the bottom trawl net collects every organism in its path and incidental capture of non-target species by-catch has become a major concern related to bottom trawling (Biju and Deepthi 2006). This method of fishing collects and kills huge amounts of non-targeted species and the young ones of the commercially valuable species. It also mechanically disturbs the sea bottom and injures a wide variety of marine benthic creatures (Knieb 1991). To overcome these problems there is a need to reduce the pressure on demersal resources by diversifying to resource specific trawls i.e. mid-water trawls.

In this project a prototype mid-water trawl was designed according to the specifications of MFV Sagarika for the purpose of carrying out experimental mid-water trawling trials along the central west coast of India. Currently the Fisheries Survey of India is working towards assessment of the fish resources and charting of fishing grounds in the Indian EEZ. Further, the Fishery Survey of India is planning to purchase two mid-water trawlers to carry out the pelagic resources surveys along the Indian coast. This proto-type design is part of developing the required fishing gear to be used in this assignment of assessing fish resources as the Indian waters have both demersal and pelagic marine resources.

For the development of a prototype mid-water trawl design, great concern has to be given to the reduction of by-catch, oil economy and sustainable utilisation of the resources. By-catch studies, conducted by FAO (Alverson and Freeberg 1996), have revealed that as much as 2.23 million tonnes annually of edible marine fish are thrown away in the Indian Ocean (East Indian Ocean and West Indian Ocean). The main component of by-catch is low quality fish and juveniles of commercially valuable fish species. Since the by-catch component carries a major portion of juveniles of valuable fish resources, it is of even greater importance to reduce the by-catch to a minimum level. Profitability of trawling to a great extent depends upon fuel price. For towed gears, oil consumption is directly proportional to the resistance of the fishing gear. It is advisable for the fishing industry to go for low resistance gears. The resistance of the gear is influenced by netting area, towing speed of the vessel, warp and otter board, etc. (Buckingham 1972). Large mesh sizes of net and thin twine diameter reduce the drag of the net with a specific horse power (Prado 1977, Fujishi 1985).

Keeping all these factors in mind, a prototype experimental mid-water trawl net has been designed. It will help to catch the pelagic resources efficiently without damaging demersal biota of the marine ecosystem.

Goal and objectives of the project:

The aim of the project is to develop a suitable mid-water trawl net design for the departmental vessel MFV Sagarika with the following objectives:

i) To study the rigging and operations of pelagic trawls.
ii) To study the acoustic equipment needed for pelagic trawling.
iii) To design a prototype of a pelagic trawl for the survey vessel MFV Sagarika.
iv) To draw the prototype design in 2D and 3D using the Design Cad 3D Max 19 2008 software

2 LITERATURE REVIEW

2.1 Pelagic fishery

The Icelandic fisheries information on the pelagic fishery indicates that pelagic fish stocks in Iceland are highly abundant and move in large shoals. Their migration routes are highly extensive. The catches of oceanic redfish began in Iceland in 1989, blue whiting in 1997 and mackerel in 2006 (Anon 2008d). In the world's total catch of marine species, the top 10 of the fish species caught are pelagic fish and the pelagic fishery itself contributes more than 50% to the total world's marine fish landings (FAO 2006). The world's most abundant pelagic fisheries are herring, pilchard and Peruvian anchovies (FAO 2006). Most of the pelagic fisheries are seasonal and exclusively harvested by vessels operating purse seines, pelagic trawls and driftnets. A large portion of the pelagic species are utilised for fish meal and oil production. However, an increasing share is used for human consumption (Anon 2008d).

The Indian fishery is an open access multi species fishery system. Currently and nationwide the pelagic fishery is able to sustain a significantly increased production (Vivekananda 2002). The status of inshore resources is portrayed as fully exploited, or overexploited, with possible room for expansion offshore (Flewwelling and Hosch 2006). Catch assemblage of 2005 shows that of the total catch, 55% are pelagic species (Figure 1), which are caught mostly by purse seiners. Gill nets and bottom trawls also contribute a significant catch (Anon 2008c).

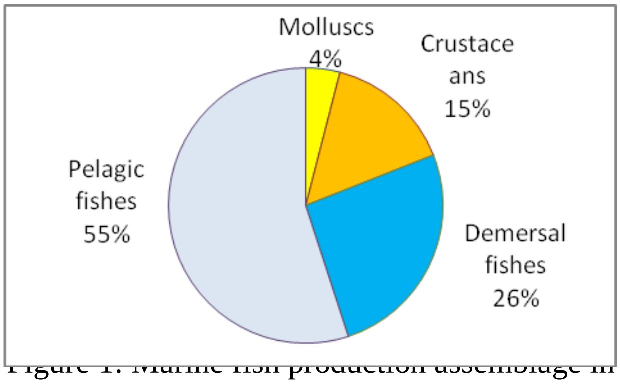


Figure 1: Marine fish production assemblage in India (2005) (Source: Anon 2008c)

The region wide distribution of major pelagic finfish resources in the EEZ of India is shown in the map (Figure 2). It shows that in the north west region of India ribbon fish and bombay duck are the major resources followed by the central west region and south west region the oil sardine and mackerel, south east region lesser sardine and oil sardine and north east region hilsa and bombay duck fishery. Overall, the oil sardine, mackerel, bombay duck and ribbon fish fishery play a major role in the catch statistics of India (Anon 2008e).

In the demersal trawl surveys carried out by MFV Samudrika, sister vessel of MFV Sagarika, in the years 1994-96 nearly 45% of the catches were pelagic, epipelagic and mesopelagic species. Among those, 15.7% were Carangid species (Srinath *et al.*, 2003). Watson *et al.* (2006) observed that catches of pelagic species had increased in bottom trawls.

Figure 2: Major pelagic fish distribution in the Indian EEZ (Source: Anon 2008e)

2.2 Fish behaviour

Mid-water trawling is carried out for specific pelagic resources, e.g. mackerel, sardine etc., and before designing the net, the designer needs to have adequate knowledge of the shape, size and general information of the target fish species. The targeted fish species in this study are pelagic, epipelagic, and mesopelagic in nature. Some of the commercially important mid-water species and their behaviour patterns in the Indian water are as follows.

2.2.1 Mackerel (Rastrelliger kangurta)

Figure 3: Indian mackerel (Rastrelliger kanagurta) (Source: Fishbase 2008)

The mackerel is a pelagic shoaling scombroid fish (Figure 3), widely distributed in the Indo Pacific region. But it is only at the Indian coast, that these species are highly exploited. Distribution in the inshore waters is limited to waters of 25 m depth, but the Fishery Survey of India vessels are catching these species in waters of up to 60 m depth. The mackerel of different size groups move in separate shoals. They move in semicircular or arrow head formations and their speed is about 8-10 miles per hour. They scatter, when pursued by seer fish, but when the shoals are chased by sharks or porpoises, the mackerel submerge with the head downwards into a compact mass. When the mackerel dive, a patch of muddy water is seen at the surface which is due to churning of water by a large mass of fish. The luminescence caused by mackerel shoals passing through a patch of phosphorescent phytoplankton (noctiluca) are noticed in many areas. The fish is a plankton feeder, feeding to a great extent on zooplankton and to a lesser extent on the phytoplankton. The average size in catches observed is 18-24 cm. Mackerel is caught mainly by purse seines, ring seines and gill nets but considerable catches are recorded in trawl according to Anon (2008f).

2.2.2 Oil sardine (*Sardinella longiceps*, *Valenciennes, 1847*)

Figure 4 : Oil sardine (Sardinella longiceps) (Source: Fishbase 2008)

The oil sardine is a neretic-pelagic clupeoid fish (Figure 4), which occurs on both the west and east coasts of India. It is a shoaling species of the west coast of India particularly. During the July-August period, juveniles appear along the coast and by September-December, they form a large proportion of the catch. The shoals are capable of moving at a speed of 3-5 km/h. The shoals extend from a minimum of 1 m^2 to 500 m^2. The depth of the shoal normally is 0.5-8 m. When the shoal moves flipping, pattering, rippling and leaping actions can be seen. The appearance of most of the shoals is bluish, pinkish and luminescent in shades. The oil sardine is mainly caught by purse seines, shore seines and gillnets. The average size range of the catch is 15-17 cm.

A study of commercial catches since 1925 revealed that there seems to be an inverse relationship of the occurrence of oil sardines to that of mackerels, i.e. in a season when the oil sardine fishery is good, then the mackerel fishery is a failure and vice versa. The reasons for this occurrence are still obscure according to Anon (2008f).

2.2.3 Ribbon fish

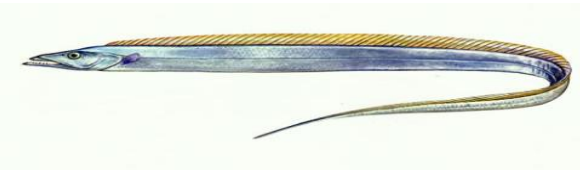


Figure 5: Ribbon fish (Source: Fishbase 2008)

The ribbon fish or hair tails (Figure 5) are of the family Trichiuridae and are represented in the Indian waters by *Trichiurus lepturus* (Linn) *Lepturacanthus savala* (Cuv), *Eupleurogrammus intermedius* (Grey), *E. muticus* (Grey). They have a wide range of distribution throughout the warm seas mostly confined to depths of 100-500 m at the continental shelf margin and at the upper part of the slope (Nakamura and Parin 1993)**.** *Trichiurus lepturus* has been known to be the most common species occurring in the Indian Ocean around the Archipelago and in various parts of the Pacific.

In the Indian waters the species composition in the catch differs from place to place. The commercial catches of these species are usually in the size range of 16-18 cm, but occasionally fish can measure over one metre in length. The different species of ribbon fish inhabit different ecological zones but samples of caught fish usually represent all age groups. The commercial size of *E. intermedius* is from 14-35 cm. and of *L. savala* and *E. muticus* from 25-75 cm. Each shoal consists of one species only. They are caught in various types of fishing gears but chiefly in seines and to some extent in gillnets and trawls and sometimes on longline. In Gujarat and Maharashtra landings are the highest in the fourth quarter (October-December) and lowest in the third [t] quarter (July-September). In Kerala, Tamil Nadu and Andhra, they are highest in third quarter (July-September) and lowest in the first quarter (January-March). The fish is marketed fresh or in cured condition according to Anon (2008f).

2.2.4 Carangid

Figure 6: Indian scad (Decapterus russelli) (Source: Fishbase 2008)

The carangid group is an important resource in the Indian waters, of which more than 50 species are reported (Panikkar 1949). Among these major species are Indian scad (*Decapterus russelli*) (Figure 6), horse mackerel and big eye scad. These resources are pelagic or epipelagic in nature, most of the species form small shoals but Indian scad is reported in big shoals of fish in the size range 16-20 cm in length (Jaiswar *et al.* 2001). Horse mackerel and big eye scad also appear in large schools (Panikkar 1949)

2.2.4.1 Horse mackerel

Figure 7: Horse mackerel (*Megalaspis cordyla*) (Source: Fishbase 2008)

Torpedo scad or horse mackerel (Figure 7) is broadly distributed throughout the western Indian Ocean. Elsewhere it is found in the western Pacific Ocean from Japan to Australia. Pelagic species occur in inshore waters of the continental shelf, form schools and feed mainly on fish. The reported maximum total length is 80 cm; it commonly attains 30 to 40 cm in total length and 3 to 4 kg in weight. The main gears used are hook and lines, beach seines, trawls, purse seines and traps according to Anon (2008g).

2.2.5 Anchovies

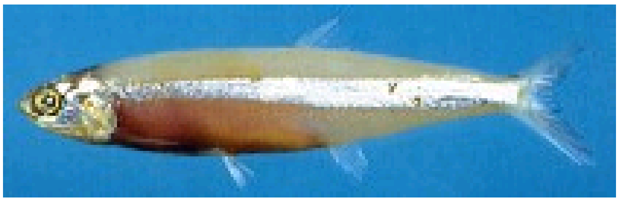


Figure 8: Stolephorus spp. (Source: Fishbase 2008)

Anchovies are found in scattered areas throughout the world's oceans, but are concentrated in temperate waters and are rare or absent in very cold or very warm seas. They can generally accept a wide range of temperatures and salinity. Large schools can be found in shallow, brackish areas with muddy bottoms, as in estuaries and bays (Anon 2009). In the Indian waters there are about 45 species known of which Thyrsa and Stolephorus groups (Figure 8) are the most important. These species are generally dominated in Cape Comorin up to the Gulf of Mannar (Panikkar 1949).

2.3 The mid-water trawl

During the 1960s, pelagic trawling was developed as a capture technique for shoaling species. The trawls which are used to catch these resources are a cone-shaped net which is towed in mid-water. It consists of a cone-shaped body, normally made of four panels, ending in a codend and the net has lateral wings extending forward from the opening. The horizontal opening is maintained by otter boards. Floats and/or sailkites on the headline and weights on the groundline provide for the vertical opening (FAO, Factsheets) (Figure 9). Until autumn 1962, the two panel net type prevailed. This type has been described in detail (von Brandt *et al*. 1960, Scharfe 1960) later it was replaced by the rectangular four panel type (Scharfe 1969).

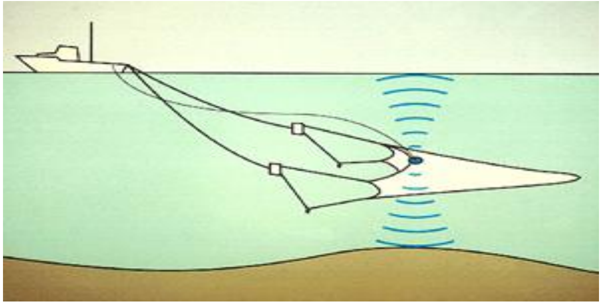


Figure 9: Mid-water trawl (Source: FAO 2008)

The main design requirements for the mid-water trawls are high stability, large mouth opening, low turbulence and low drag (Hameed and Boopendranath 2000). According to a FAO factsheet, large modern mid-water trawls are rigged in such a way that the weights in front and along the groundline provide for the vertical opening of the trawl. The cable transmitting acoustic signal form the net sonde might also provide a lifting force that maximises the vertical trawl opening. Gabriel *et al*. (2005) discussed the use of large mesh sizes in front parts of the trawls and concluded that increasing large meshes has a good guiding effect without losing the effectiveness of the trawl. An increase in the mesh size brings about a decrease in total trawl resistance, a reduction in weight of rigging needed and a possibility to increase trawling speed (Fridman 1969). A FAO, mid-water otter trawl factsheet reported that the use of nearly parallel ropes instead of meshes in the front part is also a common design. The largest mesh size used so far was 128 m on a modern large mid-water trawl, approximately three quarters of the trawl length was made up of meshes above 400 mm stretched mesh size.

2.4 **Otter board**

Mid-water trawling, using a single vessel, makes it necessary to use otter boards for spreading the net horizontally (Gabriel *et al.*, 2005). Hameed and Boopendranath (2000) also reported that otter boards are rigid sheer devices which are used to keep the trawl mouth, bridles and warps horizontally open. Gabriel *et al.*, (2005) reported that in the beginning of mid-water trawling, regular flat and rectangular boards were used but they had a high degree of instability which increased with the length of the lines between the trawls and the boards. Sainsbury (1975) also stated that several designs were available but those commonly utilised were double airfoil “wing” section (cob doors) or single curved surface stiffened with plate (Suberkrub doors) and for these doors the height is greater than its length. Gabriel *et al.*, (2005) reported that the most common boards are Suberkrub otter boards which operate through hydrodynamic principles. These high aspect ratio cambered boards have not only a very good spreading efficiency, but by increasing speed the boards climb immediately.

The rectangular cambered high aspect ratio Suberkrub board has the highest hydrodynamic efficiency with sheer coefficient/drag coefficient ratio higher than 6.0. It is at present the most popular otter board for single boat mid-water trawling (Hameed and Boopendranath 2000). A Suberkrub trawl board is chosen according to a particular net so that it will have a significant effect on the performance of the gear as a whole. Most pelagic-type four-panel nets are designed to have roughly a square mouth, i.e. the head line and footrope are approximately the same length as the sideline. The weight on the footrope and the sweep lines determine the vertical mouth opening while the size of the trawl boards determines the horizontal spread of the net mouth. According to Ferro (1981b), incorrect weights or trawl boards used on a net can prevent the forming of a square opening of the mouth. It is further stated that this might cause distortion of the net itself with an area of slack or strained netting and these features can cause net damage or fish escape.

2.5 The importance of acoustics in mid-water trawling

Pelagic trawling is an aimed fishing technique. The main objective of acoustics in mid-water trawling is to detect the fish shoals, estimate the shoal density, and monitor the gear shape and its position. This is possible with the help of echosounder, sonar, netsonde and various sensors (Figure 10).

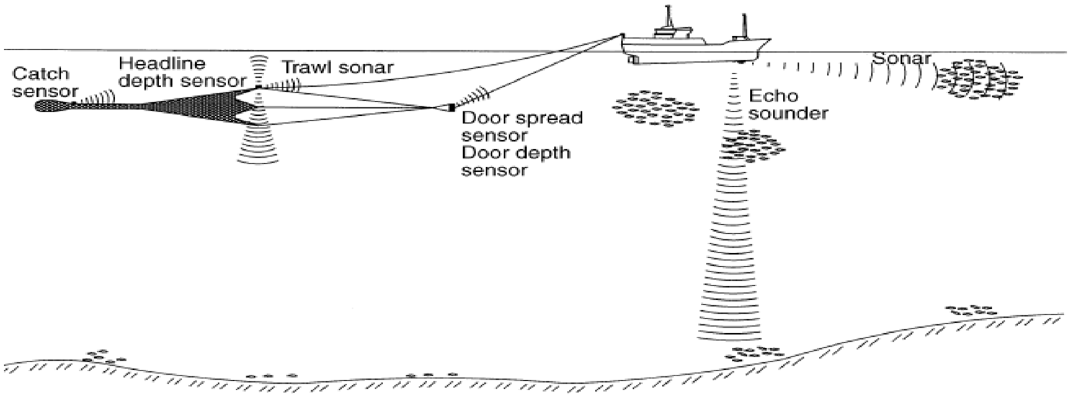


Figure 10: Pelagic trawl equipped with acoustic equipments such as echosounder, sonar, trawl sonar and sensors (Source: Misund 1997).

Misund (1997) reported that the first underwater acoustics trial to detect fish was conducted in the 1930s at the spawning grounds of the Barents Sea cod in Lofoten, northern Norway. All the acoustic devices were formerly based on echo-sounding or echo-ranging techniques in which a pulse of sound energy transmitted through water and received back from the reflected object (Shibata 1971, Hameed and Boopendranath 2000). Acoustic Doppler current profilers have recently been used to estimate the dynamic characteristics and biomass of sound scattering layers or swimming speed of fish schools and also to analyse the spatial distribution of sound scattering layers and various behavioural patterns (Lee *et al.,* 2008). The instruments to locate and follow schools and aggregation of fish and to monitor and control the gear during the fishing operation have improved greatly, in the last few years.

2.5.1 Echosounder

The echosounder helps to record the echoes of different depth zones. It comprises four main units; 1) the transmitter, 2) the transducer, 3) the receiver/amplifier and 4) the recording and display unit (Hameed and Boopendranath 2000). The sound beams are transmitted vertically downwards, and the operating frequency may differ from 12 - 420 kHz. Echoes are displayed based on the backscattering strength (Misund 1997). Simmonds 2005 and Maclennan (2005) stated that the frequencies used for fisheries applications were 38 kHz, 120 kHz, 200 kHz and 420 kHz. Stronger echoes are usually indicated by red or brown colours and weaker echoes are indicated by blue or green colours but these colours are optional and the user can choose between several colour combinations. There are a number of echosounders that are available on the market and these include split-beam echosounders and dual beam echo-sounders.

2.5.2 Sonar

The sonar scans the sea horizontally but it works on the same principle as the echosounder. Hameed and Boopendranath (2000) stated that there were two types of sonars utilised in the fishery sector, i.e. sector scanning or search light sonar and omnisonar. Further, Misund (1997) reported that the search light sonar was a single beam, in which a single beam was trained in sequential sectors with one or more transmissions in each sector. The multibeam or omnidirectional sonar uses several beams, which are trained on a large sector or the whole circle in each transmission. Some sonars may also be operated with an additional vertical beam fan which enables the vertical extent of fish shoals to be projected as well. Nowadays several sonar products and types of data calibration software are available on the market that give detailed information on fish schools, distance from vessel, depth range and speed etc.

2.5.3 The trawl sonde and gear sensors

The trawl sonde was invented to monitor the vertical opening of the trawl and the vertical position of the trawl in relation to fish concentrations and the bottom (Misund 1997). The net recorder operates through a cable to the ship or wireless. The wireless type relies on a transmitter/receiver, transducer, mounted on the trawl headline, sending information through ultrasonic sound beam, to the receiver mounted on the hull of the vessel (Hameed and Boopendranath 2000, Sainsbury 1975). Gabriel *et al.* (2005) stated that any disarrangement of the net could be detected immediately. Some of the net sondes provide total views of the net and there are some combination equipments which provide temperature at the depth of the mid-water trawl. Simmonds 2005 and Maclennan (2005) reported that some net sondes had two transducers with one beam directed downwards and the other beam directed upwards while the combined echogram was displayed in colour on the screen.

To be able to follow how the gear is functioning during fishing, acoustic gear performance sensors have been introduced during the last two decades. On the most modern trawls there are now cableless acoustic sensors to measure trawl depth, door spread, headline height, sea temperature, speed through the water and relative amount of catch in the bag (Figure 10).

2.6 The importance of trawl design

A trawl net design is a scientific field which involves several basic calculations, formulas, tests and knowledge on the size and shape of the targeted species. It is a process of preparing technical specifications and drawings for a fishing net, which has to satisfy the gear handling, technical, operational, economic and social requirements. In the olden days the net design was directly utilised for net construction without knowing much about its geometry in the water. Later the flume tanks were introduced to judge the working shape and position on a model of each gear, the speed, magnitude and direction of forces. Today other methods also exist such as underwater cameras to monitor the real shape of the net in situ and computer software for visualising the shape of the net at different hanging ratios. Each design has its own specifications and there are certain rules to draw the net plans in accordance with international standards.

Net designing has undergone changes in the past decades with modernisation of fishing techniques, methodology and invention of different software. Still the basic principles of designing are the same with a few additional techniques. There are several literature available on net design such as how to make and set nets by Garner (1974), Modern Fishing Gear of the world Volume 1-3 (FAO), Calculations for fishing gear designs by Fridman (1986), Fishermans workbooks (FAO 1977) and several reports and documents presented by FAO and other organisations in the world. It is a continuous process of development in the line of fishing gear design.

3 MATERIAL AND METHODS

The method applied in this study is as described by Fridman in his book “Calculations for fishing gear design” with a combination of Prado “Fisherman’s workbook” and various other books and reports. A prototype mid-water trawl design was prepared according to the specification of MFV Sagarika (Departmental vessel of the Fishery Survey of India).

3.1 The vessel: MFV Sagarika

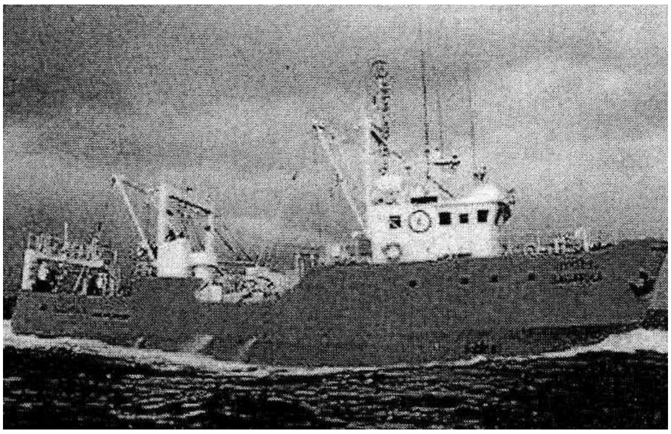


Figure 11: The vessel MFV Sagarika (Source: FSI)

MFV Sagarika is a stern trawler belonging to the Fishery Survey of India (Figure 11). It is operated along the central west coast of India and carries out bottom trawling using a 27 m fish trawl and a 30 m shrimp trawl. In the present study the specifications of this vessel were used while designing the prototype mid-water trawl. The specifications are given below:

Specification:
General information

➢ Year built	:	1993
➢ Builder	:	Nigata Engineering Co. Ltd., Japan
➢ Type of vessel	:	Fishing vessel – Combination trawler
1. Dimensions		
➢ Length overall	:	28.80 m
➢ Length between perpendiculars	:	24.80 m
➢ Breadth	:	7.30 m
➢ Depth	:	3.25 m
➢ Designed load draft	:	2.75 m
➢ Gross tonnage	:	189 tonnes
2. Engine		
➢ Main engine	:	650 ps (BHP = 1.01387 * Ps) X 1450

		rpm; Nigata, Japan
➢ Service speed	:	9.0 knots
➢ Endurance	:	6333 miles, 15 days
3. Compliment		
➢ Officers	:	6
➢ Crew	:	10
➢ Total	:	16 persons (15+1 Scientist)
4. Capacities		
➢ Fuel oil tank	:	67.27 m^3
➢ Fresh water tank	:	41.51 m^3
➢ Fish hold	:	94.17 m^3
5. Navigation equipments	:	Auto pilot, radar, GPS Automatic direction finder, gyro compass,
6. Communication equipments	:	Radiotelephone, VHF (2)
7. Fish finding equipments	:	Echosounder, sonar, net sonde
8. Gear hauling equipments		
➢ Split winch	:	Length : 0.51 m Wire diameter : 18 mm Warp storage capacity: 1000 m
➢ Net drum	:	Length : 1.3 m Diameter : 2.1 m

3.2 Towing speed

The cruising speed of the vessel MFV Sagarika is 9 knots but the trawling speed depends on the net drag. When capturing a fish school the towing speed should be proportional to the swimming speed of the fish. Lower towing speeds being used to catch slow swimming fish and higher speeds for fast swimming fish. Practical observations and special experiments have shown that there is an optimal trawling speed for each species of fish and trawl design which provides the maximum catch (Fridman 1986).

3.3 Prototype design

While documenting the required characteristics of the prototype of a mid-water trawl and its accessories, one must consider the shape and size of the fish, technical characteristics of the fishing vessel from which the gear is going to be operated, such as size of the vessel, engine horse power, towing pull of the vessel, size of the net drum, capacity of the trawl winch and other gear handling devices. After getting all this information we will be able to estimate the towing pull of the vessel and have a rough idea on the size of the net. A draft is made; its towing resistance is calculated and matched to the available towing power and speed requirements.

After designing the prototype the net was drawn in accordance with international guidelines (FAO 1972, Strange 1978) using computer software. In this project the net diagram is drawn in Design CAD MAX 19 software and presented both in 2D and 3D. The net design was drawn in 3D with different hanging ratios to evaluate the most realistic ratio and to select the appropriate bridle lengths and rigging details.

3.4 Calculations

The only knowledge that many good fishermen have is their experience and what they have learned from their fathers. They often distrust the results of theoretical investigations, particularly because they do not know how to take advantage of them. However, with the dynamic changes which have occurred in recent years in the world fisheries, improving the selection of fishing ground, gear and methods, and involving sophisticated equipments such as monitoring instruments, large and powerful fishing gear and automatic machines, fishermen of a new type are needed who are able to blend practical experience with theoretical knowledge (Fridman 1986).

Here the calculations followed for the designing of a prototype mid-water trawl are given bellow. All the calculations were done manually.

3.4.1 The towing force of a trawler

The towing force of the vessel depends upon the engine brake horsepower (BHP) and the towing speed. Fridman (1986) prescribed the following formula for calculating the available towing force.

$$F_t \approx P * (K_F - 0.7 * V) \qquad (3.1)$$

Where,
F_t: towing pull, kgf
P: engine brake horsepower (BHP = 1.01387 * Ps)
V: towing speed in Knots
K_F: empirical towing force coefficient, this coefficient ranges from 10 to 20 depending upon the type of propeller and the presence of propeller nozzle.

3.4.2 Mesh size selectivity and its calculations

In the present study the mesh size selectivity of the mid-water trawl is important. In the wing section of the net it was decided to use large meshes in order to reduce drag, while still providing herding effect on the particular species. Then it goes to descending order in mesh size and twine diameter along the belly towards the codend.

3.4.2.1 Mesh size for codend

The formula prescribed by Fridman (1986) is based on the gillnet mesh size selectivity and calculates the effective mesh size for trawl net as follows:

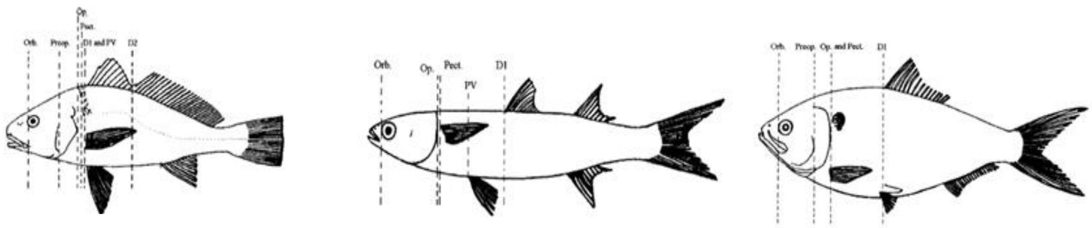
$$M_{OC} \approx \left[\frac{2}{3}\right] * M_{OG} \qquad (3.2)$$

Where,
M_{oc}: mesh opening in the codend
M_{OG}: mesh opening in gillnets

Whereas the mesh opening in gillnets can be calculated with the help of the following formula:

$$M_{OG} = \left[\frac{L}{Km} \right] \tag{3.3}$$

L: is the length of the fish body from the tip of the snout to the base of the caudal fin
Km: is an empirical coefficient depending on the morphology of the fish (value of coefficient *Km* = 5 for a narrow fish, *Km* = 3.5 for medium girth fish and *Km* = 2.5 for thick or deep bodied fish).

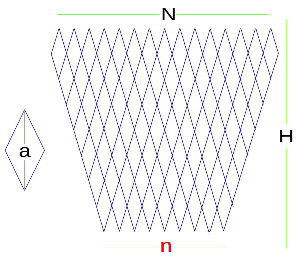


Medium girth fish Narrow fish Deep body fish

3.4.3 Calculation of twine surface area

The projected area in square meters of the twine in rectangular, rhomboidal, trapezoidal, or triangular netting panels, whose size is designated by number of meshes, may be estimated by two different formulas:

Fridman (1986)



$$A = \left[\frac{N+n}{2} \right] * H * 2(a * \phi) * 10^{-6} \tag{3.4}$$

Ferro (1981)

$$A = L * D * (N + n) * 10^{-3} \tag{3.5}$$

Where,
A: twine area (m^2)
N: number of meshes across the top of panel
n: number of meshes across the foot/ bottom of panel
H: number of meshes across the depth or height of the panel
a: stretched mesh size (mm)
Φ: diameter of twine
L: stretched length of the panel (m) i.e. Stretched height of the panel in meters.
D: diameter of the twine

In the above methods, the area of the individual trapezium shaped net pieces are calculated and then summed up to get total net area of the trawl. It is presumed that the drag of the gear is mainly a function of its twine area.

3.4.4 Estimation of netting weight

This information is required for ordering netting material for the construction of fishing gear and determining the forces of gravity acting on the gear under operational conditions. It is necessary first to have complete drawings of the proposed net, including netting dimensions and detailed material specifications (Fridman 1986). The weight calculation formula given by Prado (1990) is as follows

For Knotted netting:

$$W = H * L * \left[\frac{Rtex}{1000}\right] * K \tag{3.6}$$

Where,
W: weight of the netting (gm)
H: number of rows of knots in the height of netting
L: stretched length of netting (m)
Rtex: the size of twine in the netting
K: knot correction factor (table published by Prado 1990)

3.4.5 Calculation of the opening of the net:

It is important to estimate or predict the opening of the net for the mid-water trawl to get an idea of trawl shape and performance. Two formulas were used to predict the mouth opening.

The vertical opening of the gear by using Koyama *et al.* (1981) formula:

$$H = 0.16 * a * V^{-0.87} \tag{3.7}$$

Where,
H: vertical opening of mouth (m)
a: maximum circumference of the widest part of the belly(m)
V: towing velocity (m/sec)

Formulas given by Prado (1990) for the calculation of vertical and horizontal mouth opening of the net are as follows:

Vertical mouth opening:

$$VO \approx n * a * 0.25(to)0.30 \tag{3.8}$$

Where,
VO: approximate vertical opening of net mouth (m)

n: width in number of meshes of front edge of belly
a: mesh size (m)

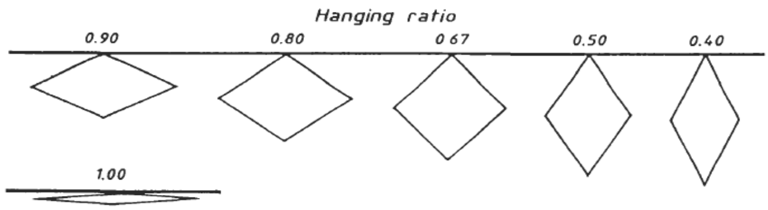
The other formula calculates the horizontal mouth opening of the net:

$$S \approx HR * 0.50(to)0.60 \tag{3.9}$$

Where,

S: approximate horizontal spread between ends of wings (m)

HR: length of head rope (m)



3.4.6 Hanging ratio

The actual shape of mesh is determined by the process of hanging it onto the rope frame. The different shapes of the netting panel are achieved by varying the primary hanging ratio E_1 and the secondary hanging ratio E_2. Here three different hanging ratios were used: E_1= 0.2, 0.3, and 0.5, for the calculation of secondary hanging ratio. The circumference opening of the trawl will depend on the hanging ratio used. The following formula given by Fridman (1986) calculates the secondary hanging ratio.

$$E_2 = \sqrt{1 - E_1^2} \tag{4.0}$$

Where,
E_2: vertical hanging ratio
E_1: horizontal hanging ratio

The actual height of a mounted (rigged or hung) net depends on the stretched height and the hanging ratio. The general formula given by Fridman (1986) in all cases is:

$$M = N * E_2 \tag{4.1}$$

Where,
M = mounted height (m)
N = stretched height (m)
E_2 = vertical hanging ratio

3.4.7 Calculation of netting drag

It is assumed that the drag of the gear is mainly a function of their twine area. Different fishing nets often have shapes which are more complex than a plane netting panel and the hydrodynamic characteristics of their component netting sections may not all be the same. An approximate determination of the hydrodynamic resistance of fishing nets may be carried out on the assumption that the resistance of a combined net of an arbitrary shape is equal to the sum of the drags of its netting components of simpler shape, whatever their size or form may be.

There are a number of formulas available to calculate the net drag in different ways some of the formulas which have been used are as follows:

Formula prescribed by Fridman for the calculation of hydrodynamic resistance of trawl is as follows

$$R = C_x * q * A \tag{4.2}$$

Where,
R: hydrodynamic resistance in kgf
C_x: hydrodynamic resistance coefficient derived from the angle of incidence
q: hydrodynamic stagnation pressure, calculated as follows:

$$q = p * \frac{V^2}{2} \tag{4.3}$$

p: mass density of sea water in kgf.s^2.m^{-4} (105 kgf.s^2.m^{-4} for sea water)
V: velocity of tow (m.s^{-1})
A: total twine area of the panel

Hydrodynamic coefficient C_x:

This non-dimensional coefficient supplies the necessary quantitative information on the influence of the physical properties (twine size, mesh size, material, hanging ratio, etc) of the netting tested on the magnitude of the hydrodynamic forces acting on the netting. It gives this information in the very compact form of a single numerical value which may be used to calculate the response of different shapes and sizes of netting components to different external conditions.

To calculate - C_x we need the angle of incidence (α)
Based on the belly circumference the angle of incidence is calculated using the following formula:

$$\tan\alpha = \frac{a}{b}$$

$$\alpha = \tan^{-1}\frac{a}{b} \tag{4.4}$$

Where,
$\tan\alpha$: angle between the netting and flow direction.

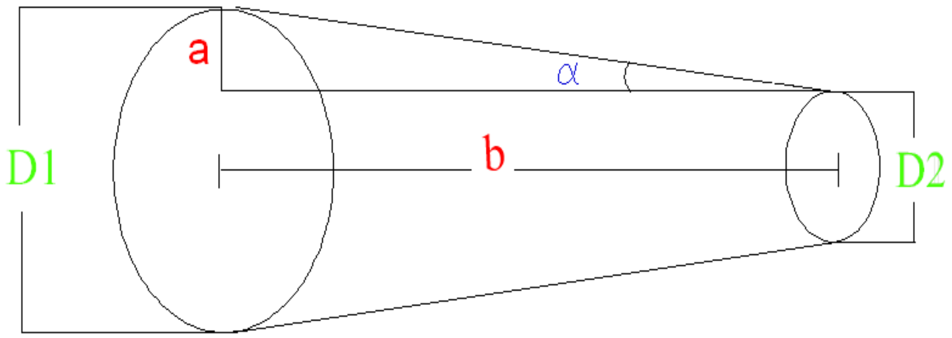


Figure 12 : Angle of incidence of a cone shape body

Where,

$$a = \frac{D_1 - D_2}{2} \tag{4.5}$$

D_1: diameter of the large circle i.e. the front end of the cone shaped belly
D_2: diameter of the small circle i.e. the aft end of the cone shaped belly
b: length of the cylinder
α: angle of incidence

After getting the angle of incidence it can be correlated with table given in Fridman (1986). This value is the C_x value which is used for the calculation of net drag.

Reid (1977) defines a relationship between net drag, net speed and net twine area which is independent of parameters derived from the net geometry using the following equation:

$$D = \frac{V^2 * R}{(54.72 * V + 115.2)} \tag{4.6}$$

Where,
D: drag in tonnes
R: total twine area (m^2)
V: speed in knots

The MacLennan (1981) formula for calculation of net drag is:

$$Rp = \frac{Ta\left\{\dfrac{61.2 + 46.6 * V^2}{1 + 0.0641 * V}\right\}}{9807} \tag{4.7}$$

Where,
Rp: net drag
V: trawling speed (knots)
Ta: twine area for the complete trawl (m^2)

All three formulas were applied to see the variations in the calculated netting drag. Fridman (1986) showed the generalised relationship between the drag of a panel of netting and its angle of incidence to the flow. Whereas the MacLennan (1981) formula is based on engineering trials and the Reid (1977) formula expresses the relationship between net drag, net speed and net twine area.

3.4.8 Drag and weight of otter boards

Each net will require a different size and weight of trawl board in accordance with netting area to achieve the correct spreading of the net (Ferro 1981). The area of the otter board for the prototype mid-water trawl was calculated based on the formula prescribed in the Fisherman's workbook.

$$Sp = (0.0152 * S_f) + 1.23 \tag{4.8}$$

Where,
Sp: surface area of a Suberkrub otter board in m^2
S_f: twine surface area of pelagic/mid-water trawl

In this specific case S_f = 117.2432 m^2 so that a fitting size of otter boards would be: 3.01 m^2

The actual weight of the trawl door required in accordance with surface area of otter board is given by Ferro (1981):

$$W = 75 * B^{\frac{3}{2}} \quad (4.9)$$

Where,
W: weight of the otter board
B: area of the otter board (m^2)

The drag of the otter board is calculated by the Fridman (1986) formula:

$$Ro = Cx * q * A$$

Ro: otter board drag
C_x: angle of attack assumed to be 15^0 the C_x value taken from the Fridman table page no. 68
A: area of the otter board
q: hydrodynamic stagnation pressure which is calculated by formula 4.3

3.4.9 Calculation of total trawl resistance

The drag of the trawl gear is the power required to overcome the hydrodynamic resistance of the gear towed at a particular speed. The total drag of the trawl system should match the available towing force of the vessel (Hameed and Boopendranath 2000).

The total trawl gear resistance is computed by determining the resistance of the various gear components such as netting panels, lines and ropes, floats, sinkers, otter-boards and warps.

Total drag of the gear:

$$Rt = Rn + Rx + Ro + Rf \quad (5.0)$$

Where,
Rt: total gear resistance
Rn: resistance offered by netting panel
Rx: resistance offered by line and ropes i.e. Head rope, foot rope, warp, sweep line and bridal
Ro: resistance offered by otter boards

3.4.9.1 Calculation of net drag (Rn)

Formula 4.6 (Reid 1977) was used to calculate the net drag.

3.4.9.2 Calculation of drag due to floats and sinkers

The basic hydrodynamic formula was used for estimating the drag due to floats or sinkers (Fridman 1986).

$$Rf = N * C_X * q * A \quad (5.1)$$

Where,
Rf: resistance due to floats and sinkers (kgf)

N: number of floats (and sinkers)
q: hydrodynamic stagnation pressure (kgf/m^2) =pV^2/2
A: area of the sphere (m^2)
C_x: drag coefficient (0.5 for all spheres Fridman, 1986 page no.66)

3.4.9.3 Drag induced by lines and ropes (Rx)

Calculation of the drag of ropes and lines i.e. warp, head line, foot rope, sweep line and bridals according to the formula given by Fridman (1981), the *Cx* value and length and diameter will change according to the lines and ropes and their angles.

$$Rs = C_X * L * D * q \tag{5.2}$$

Where,
L: length of rope (m)
D: diameter of rope (m)
C_x: drag coefficient (obtained from Fridman 1986 page no. 64 and 65)
q: hydrodynamic stagnation pressure (kgf/m^2) = pV^2/2

4 RESULTS

4.1 Towing pull

The towing pull of the vessel MFV Sagarika is calculated using Fridman (1986) formula (3.1). Generally the towing force coefficient ranges from 10 for trawlers with conventional pitch propellers to 15 for trawlers equipped with controllable pitch propeller. A value derived at using the equation (3.1) shows that at a slow speed a vessel can tow more weight, but as the speed increases the available towing pull of the vessel decreases. The calculated towing pull of the vessel MFV Sagarika at different towing speeds is given in Table 1

Table 1: Calculated towing pull of the vessel (formula 3.1)

Towing speed (in knot)	Towing pull (in tons) hp = 650 (Empirical coefficients K_f=15)
1.0	9.29
1.5	9.07
2.0	8.84
2.5	8.61
3.0	8.38
3.5	8.16
4.0	7.93
4.5	7.70
5.0	7.47

4.2 Estimation of net drag coefficient (C_x)

All the calculations in this project are based on the prototype mid-water trawl design Figure 16, Tables 8 and 9.

Angle of incidence and drag coefficient values were calculated for the prototype net using different hanging ratio (using lower section net circumference and top section net circumference, as the belly section portion has been taken for the calculation of net drag coefficient). The E_1 and E_2 were derived using the formula (4.0) and the angle of incidence using equations (4.4 and 4.5). When the hanging ratio starts decreasing the opening of the net starts reducing and they are thus proportional to each other. Based on the angle of incidence the C_x value is obtained from the data published in the FAO fishing manual (Fridman 1986) page no.55. The results are shown in Table 2.

Table 2: Cx value at different hanging ratios (formula 4.4 for angle of incidence = α)

Hanging ratio		α	C_x
E_1	E_2		
0.5	0.86	12	0.50
0.3	0.95	7.5	0.47
0.2	0.98	4.5	0.43

4.3 Twine surface area

The twine surface area is calculated using Prado (1990) (formula 3.4) and Ferro (1981) (formula 3.5) for each section of the net and then summed up. The results obtained by using both formulas are the same. The netting area of the trawl is given in Table 3.

Table 3: Twine surface area of the prototype design (formulas 3.4 and 3.5)

Netting panels	N	n	H	a	Φ/D	$L=H*a$	**Prado 1990**	**Ferro 1981**	Panel	Total netting area(m^2)
Wing	25	12.5	25	400	4	10	1.50	1.50	8	12.00
Belly 1	155	125	30	200	3	6	5.04	5.04	4	20.16
Belly 2	250	120	130	100	2.5	13	12.02	12.02	4	48.10
Belly 3	240	90	150	50	1.8	7.5	4.45	4.45	4	17.82
Cod end	150	150	250	30	1.8	7.5	4.05	4.05	4	16.20
Corner piece	4	2	2	400	4	0.8	0.02	0.02	8	0.15
Extra panel	2	2	23	400	4	9.2	0.15	0.15	8	1.18
Wedges	14.5	2.5	6	400	5	2.4	0.20	0.20	8	1.63
Total area										117.24

N : upper section meshes ; n : Lower section meshes ; H : Meshes in depth ; a: Mesh size ; Φ/D : Twine diameter ; L : stretched length of the panel(m)

4.4 Netting drag

To a net designer, attempting to design a net to suite a specific power of vessel, the ability to predict the hydrodynamic drag of the net is essential (Reid 1977). The netting drag of the net is calculated based on the three different formulas given (4.2, 4.6, and 4.7) and using three different hanging ratios (Formula 4.2). Values are given in Table 4**.**

The netting resistance was calculated by using three different hanging ratios, i.e. 0.5, 0.3 and 0.2. The results show that as the hanging ratio increases, the netting drag increases and vice versa. Put another way the net opening depends upon the hanging ratio. Fridman shows the generalised relationship between the drag of a panel of netting and its angle of incidence to the flow on the one hand, and between the total net drag and the mean angle of incidence of the netting (Formula 4.2), on the other.

The simple formula given by Reid (1977) is based on the engineering performance of the pelagic trawl (four panels), assuming that a constant relationship between the net drag coefficient and net towing speed would exist for a set of nylon pelagic nets of similar designs (Formula 4.6).

The MacLennan (1981) formula (4.7) is based on the engineering trial of the bottom trawl net.

The net drag is calculated by using different formulas plotted against the trawling speed as shown in Figure 13.

Table 4: Calculation of netting drag/resistance using three different formulas

Trawling speed (knot)	**Fridman (1986) (** Formula 4.2**)**			**Reid (1977)** (Formula 4.6)	**MacLennan (1981)** (Formula 4.7**)**
	Resistance at different hanging ratio (Resistance in tons)			Drag in tons	Drag in tons
	E_1=0.5	**E_2=0.3**	**E_3=0.2**		
1.0	0.81	0.76	0.70	0.69	1.21
1.5	1.83	1.72	1.57	1.33	1.81
2.0	3.26	3.06	2.80	2.08	2.62
2.5	5.09	4.78	4.37	2.90	3.63
3.0	7.33	6.89	6.30	3.77	4.89
3.5	9.97	9.37	8.58	4.68	6.17
4.0	13.03	12.25	11.20	5.61	7.67
4.5	16.49	15.50	14.18	6.56	9.32
5.0	20.36	19.14	17.51	7.53	11.10

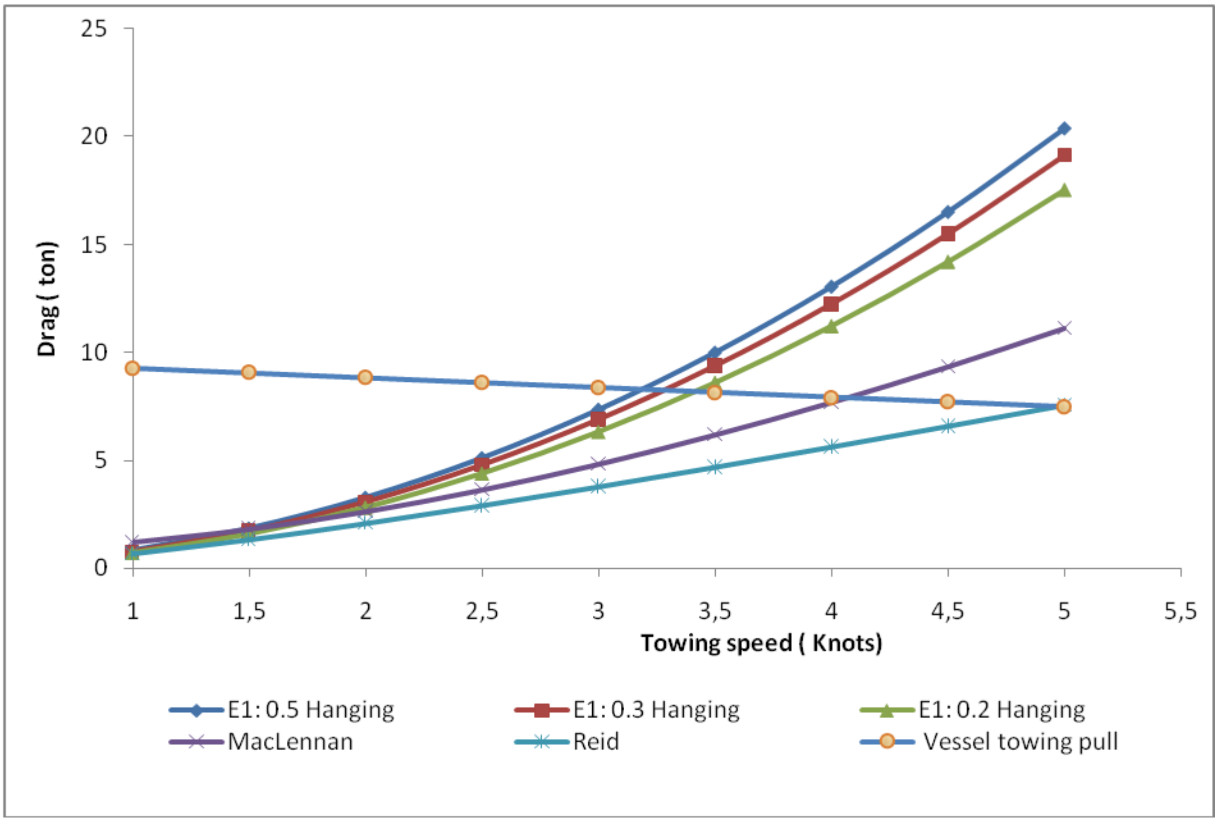


Figure 13: Comparison of netting drag against vessel pull with three formulas. Fridman (1986) (E1: 0.5, E1: 0.3 and E1:0.2 hanging ratio), Reid (1977) and MacLennan (1981)

4.5 Trawl mouth opening

There are two formulas available for the trawl mouth opening, one given by Koyama *et al.*, (1981) (3.7) predicting the vertical height of the trawl gear at different trawling speeds. As the trawling speed increases the vertical net opening of the net reduces. The results are shown in Table 5 and Figure 14.

The other formula (3.8) given by Prado (1990) for vertical trawl mouth opening and horizontal opening (3.9). The vertical mouth opening is based on the number of meshes in the top belly cross section and horizontal opening based on the head rope length of the mid-water trawl. The value calculated for vertical mouth opening is 7.75 m and 14.61 m for horizontal opening.

Table 5: Calculation of vertical mouth opening (Koyama *et al.*, 1981) based on the belly circumference at different hanging ratios and towing speeds (formula 3.7).

Trawling speed	**Mouth opening (m) at E_1= 0.5 hanging ratio**	**Mouth opening (m) at E_1=0.3 hanging ratio**	**Mouth opening (m) at E_1= 0.2 hanging ratio**
1.0	17.67	10.60	7.07
1.5	12.42	7.45	4.97
2.0	9.66	5.80	3.87
2.5	7.96	4.78	3.18
3.0	6.79	4.08	2.72
3.5	5.94	3.56	2.37
4.0	5.29	3.17	2.12
4.5	4.78	2.87	1.91

Note: This vertical opening of the net is based on the empirical formula. It may vary with depth of operation and weight of the foot rope and sweep line etc.

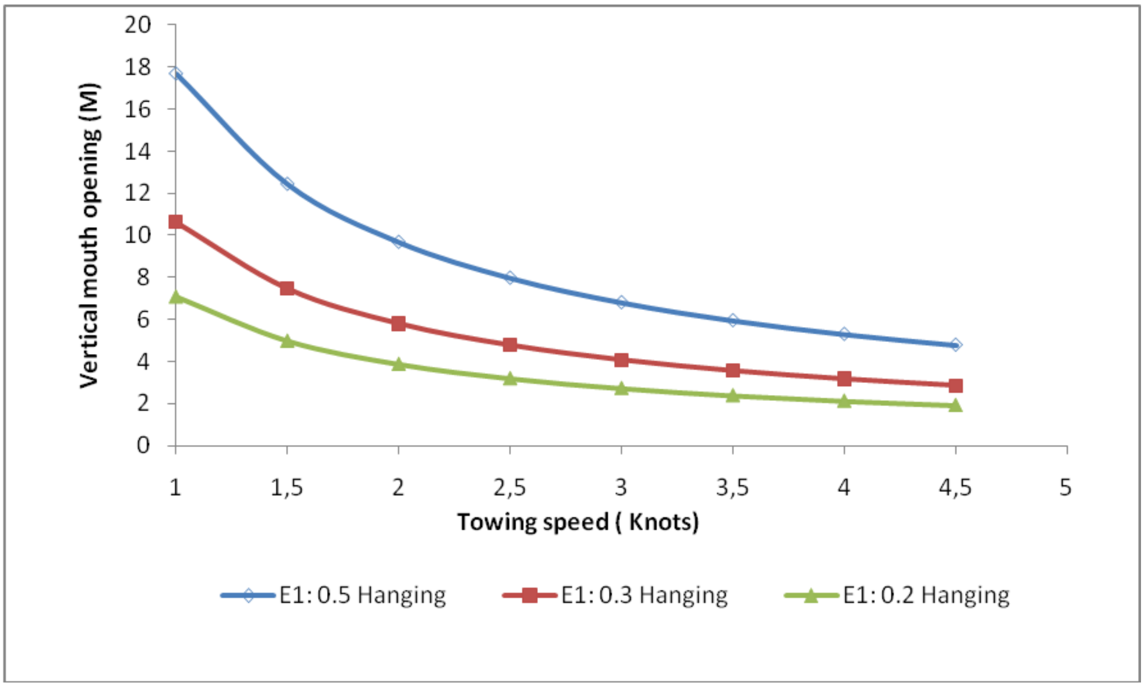


Figure 14: Vertical trawl mouth opening at different hanging ratios as a function of speed

4.6 Netting weight

The netting weight of the prototype net is calculated using Prado (1990) formula (3.6). The calculated weight of the netting materials differs between companies however. Total weight of the mid-water net is shown in Table 6.

Table 6: Calculation of netting weight (K = knot correction factor page no. 35 and Rtex value = page no.14 of Fisherman's workbook) (formula 3.6)

Netting panels	H	H *2	(mesh size) a	*Φ/D*	Stretched length in (m) L=H*a	K	Rtex	Panel	Total netting weight (kg)
Wing	25	50	400	4	10	1.16	10100	8	47
Belly 1	30	60	200	3	6	1.24	4440	4	8
Belly 2	130	260	100	2.5	13	1.40	3400	4	64
Belly 3	150	300	50	1.8	7.5	1.64	1760	4	26
Cod end	250	500	30	1.8	7.5	2.00	1760	4	52
Corner piece	2	4	400	4	0.8	1.16	10100	8	0.3
Extra panel	23	46	400	4	9.2	1.18	10100	8	40
Wedges	6	12	400	5	2.4	1.0	12000	8	2.8
Total weight in kg.									240

H : Meshes in depth ; *a*: Mesh size ; *Φ/D* : Twine diameter ; *L* : stretched length of the panel(m) (Note: The calculated weight of the netting differ with manufactures)

4.7 Resistance of the gear

The mid-water trawl gear resistance is computed by determining the resistance offered by various gear components (Formula 5.0) such as netting panels, lines and ropes (i.e. warp, sweep lines, head rope, footrope and side ropes), floats, sinkers and otter boards. Their values are shown in Table 7 and Figure 15.

Generally in mid-water trawls, it is not advisable to attach floats to the head rope but this totally depends upon the skipper of the vessel. Instead of sinkers a tickler chain is attached to the foot rope, but there is no exact formula for the mid-water trawl with respect to weight attachments. The otter board size is calculated using formula 4.8, weight (Formula 4.9) and drag by (Formula 4.2).

Table 7: Drag offered by different gear components at different speeds

Speed in knot	**Speed in m/sec**	**q = $pv^2/2$**	**Rn(ton)** (Formula 4.6)	**Rx(ton)** (Formula 4.2)	**Ro(ton)** (Formula 4.2)	**Total drag (ton)**
1.0	0.51	13.65	0.68	0.04	0.04	0.77
1.5	0.77	30.72	1.33	0.09	0.09	1.52
2.0	1.02	54.62	2.08	0.17	0.16	2.42
2.5	1.28	85.34	2.90	0.26	0.26	3.43
3.0	1.53	122.90	3.77	0.38	0.37	4.53
3.5	1.78	170.10	4.68	0.52	0.51	5.71
4.0	2.05	218.48	5.61	0.68	0.66	6.96
4.5	2.29	276.51	6.56	0.86	0.84	8.28
5.0	2.55	341.25	7.53	1.07	1.04	9.65

Note: Rn: Net drag ; Rx: Rope and wires drag ; Ro: otter board drag.

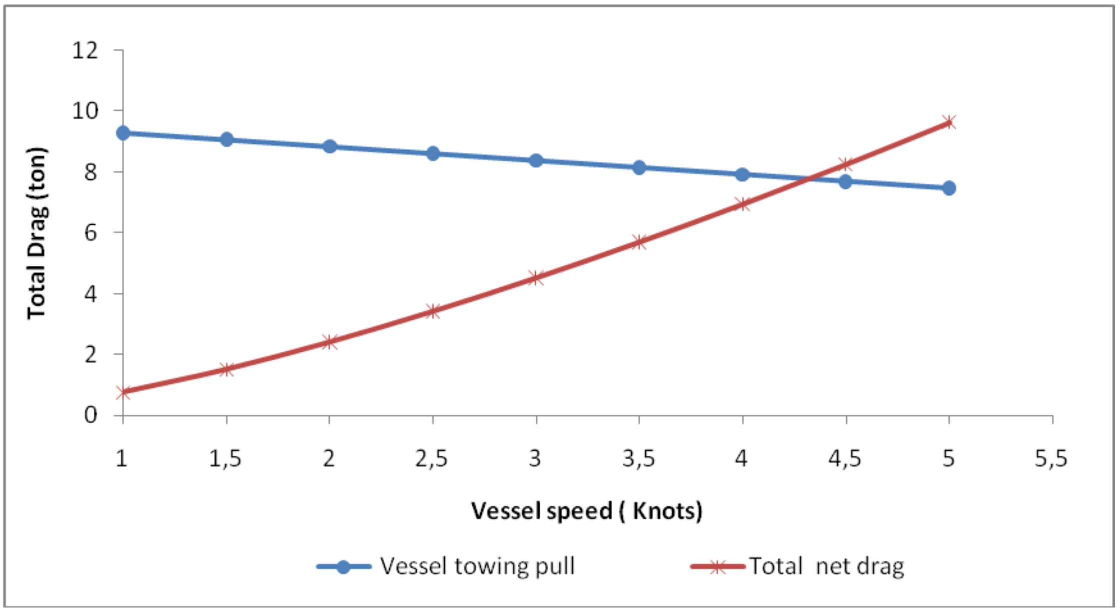


Figure 15: Total netting drag compared to vessel pull at different towing speeds

4.8 Prototype design

4.8.1 General specifications

The prototype is a four panel mid-water trawl, with all the panels of equal size. The front part of the belly is 155 meshes with a mesh size of 200 mm. The mesh size in the wings is 400 mm; the belly is comprised of three different mesh sizes, i.e. 200 mm, 100 mm and 50 mm and terminating into the codend of 30 mm mesh size. Since it is a four panel mid-water trawl the head rope, foot rope and side ropes are kept the same length, i.e. 29.22 m. The detailed specifications of the gear are given in data sheet Table 8 and in Figure 16.

4.8.2 Advantages of the prototype design

The mid-water trawl prototype is of a simple design, it is thus easy to fabricate. The efficiency of the net can be observed in 3D computer generated images. The design calculations are in accordance with the MFV Sagarika specifications. The trawl can be operated at 50-500 m depth and is especially designed for slow, medium swimming pelagic and mid-column fish species i.e. carangids, barracudas, oil sardine etc.

Table 8: Data sheet: prototype mid-water trawl

<table>
<tr><th>Different parts of net</th><th colspan="6">Specification</th></tr>
<tr><th>Webbing</th><th colspan="2">Mesh size</th><th colspan="2">Twine diameter</th><th colspan="2">Material</th></tr>
<tr><td>Cod end</td><td colspan="2">30 mm</td><td colspan="2">1.8 mm</td><td colspan="2">Polyethylene (PE)</td></tr>
<tr><td rowspan="3">Belly</td><td colspan="2">50 mm</td><td colspan="2">1.8 mm</td><td colspan="2">Polyethylene (PE)</td></tr>
<tr><td colspan="2">100 mm</td><td colspan="2">2.5 mm</td><td colspan="2">Polyethylene (PE)</td></tr>
<tr><td colspan="2">200 mm</td><td colspan="2">3 mm</td><td colspan="2">Polyethylene(PE)</td></tr>
<tr><td>Wing, Side piece, Corner piece</td><td colspan="2">400 mm</td><td colspan="2">4 mm</td><td colspan="2">Polyethylene (PE)</td></tr>
<tr><td>Top Wedges</td><td colspan="2">400 mm</td><td colspan="2">5 mm</td><td colspan="2">Polyethylene (PE)</td></tr>
<tr><td colspan="7"></td></tr>
<tr><th>Ropes & lines</th><th colspan="2">Length</th><th colspan="2">Diameter</th><th colspan="2">Material</th></tr>
<tr><td>Head rope & foot rope</td><td colspan="2">29.22 m</td><td colspan="2">12 mm</td><td colspan="2">Wire rope</td></tr>
<tr><td>side panel rope</td><td colspan="2">29.22 m</td><td colspan="2">12 mm</td><td colspan="2">Polypropylene</td></tr>
<tr><td>Side rope (stretched length)</td><td colspan="2">46.4 m</td><td colspan="2">12 mm</td><td colspan="2">Polypropylene</td></tr>
<tr><td colspan="7"></td></tr>
<tr><th>Floats & sinkers</th><th>Numbers</th><th>Size</th><th>Shape</th><th>Material</th><th>Weight in air</th><th>Other properties</th></tr>
<tr><td>Floats</td><td colspan="6">Generally floats are not used on mid-water trawls (but it depends upon the skipper)</td></tr>
<tr><td>Sinkers</td><td colspan="6">Depending upon the depth of operation the weight differs</td></tr>
<tr><td colspan="7"></td></tr>
<tr><th>Otter board</th><th>Numbers</th><th>Size</th><th>Shape</th><th>Material</th><th colspan="2">Weight in air</th></tr>
<tr><td>Suberkrub</td><td>1 pair</td><td>3 m^2</td><td>Rectangle chambered</td><td>Iron</td><td colspan="2">390 kg each</td></tr>
</table>

Note: The material used for the fabrication varies i.e. nylon, PA, dynema, PP and PE

4.8.3 Drawing

The prototype net drawing specifications are given in Table 9. The prototype design is drawn in 3D using Design Cad 3D MAX 19 (2008) software to be able to view the net from different angles and to see if the net design made is functioning properly. In the present study the net is drawn with three different hanging ratios i.e. 0.5, 0.3 and 0.2 to select the right hanging ratio for the net. The colours in the figures represent the mesh size of each section i.e. light green 400 mm for wing, red 200 mm for belly 1, yellow 100 mm for belly 2, green 50 mm for belly 3 and red colour, the codend of 30 mm. Six different views can be observed i.e. top, side, front, isometric, perspective and parallel views. But in the present report three views of the prototype mid-water trawl net and four views of the net with complete rigging are given in Figures 17, 18, 19, 20, 21, 22 and 23.

Table 9: Prototype net drawing specification

Section	**Mesh Size (mm)**	**Meshes in cross section**		**Meshes in depth**	**Cutting Rate**	**Twine Φ(mm)**	**No. of panels**
		Upper	**Lower**				
Wing	400	12.5	25	25	1P2B	4	8
Belly 1	200	155	125	30	1P2B	3	4
Belly 2	100	250	120	130	1P2B	2.5	4
Belly 3	50	240	90	150	1P2B	1.8	4
Codend	30	150	150	250	AP	1.8	4
Corner piece	400	2	4	2	1T2B	4	8
Extra panel	400	2	2	23	AB	4	8
Wedges	400	2.5	14.5	6	AB	5	8

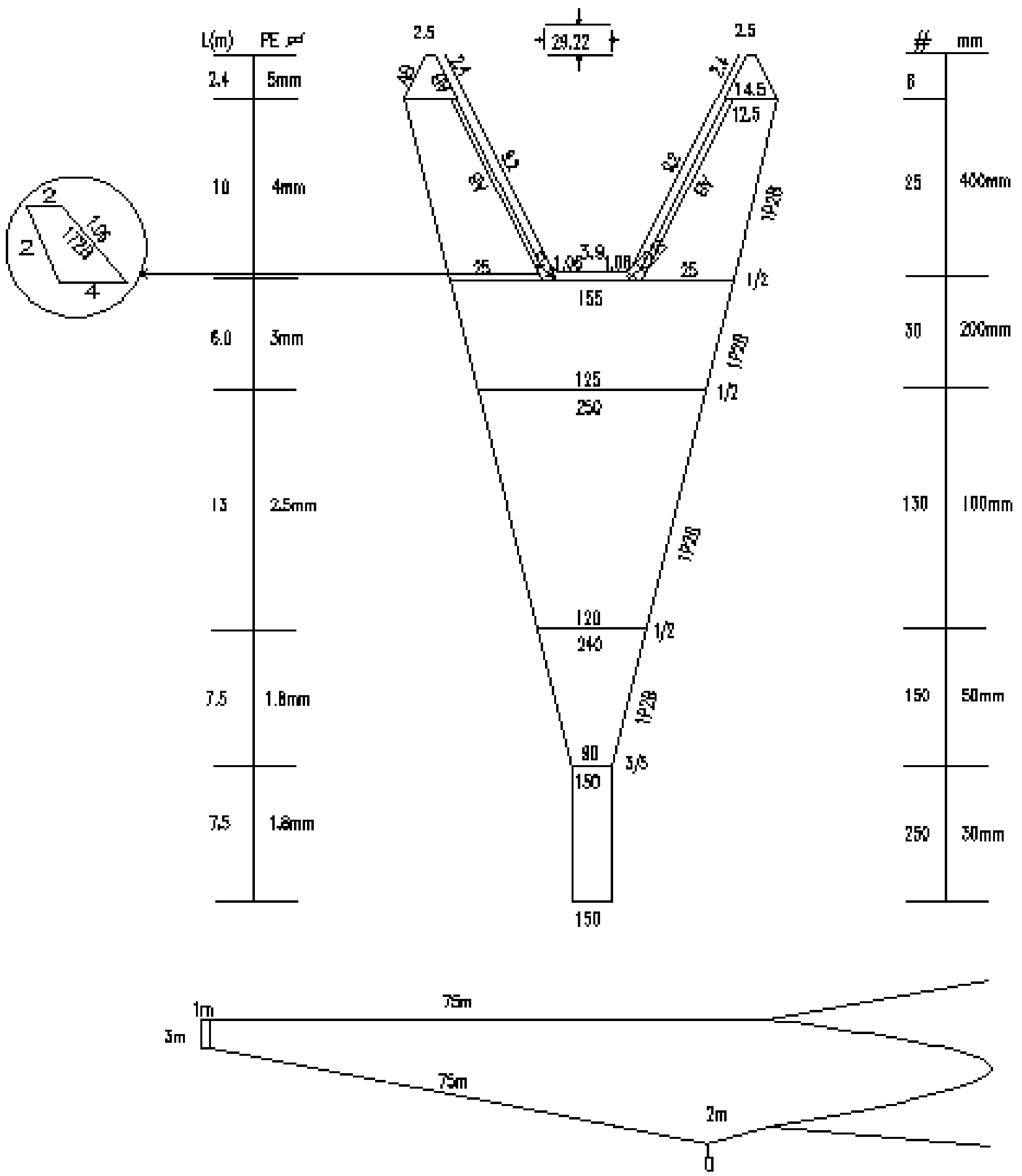
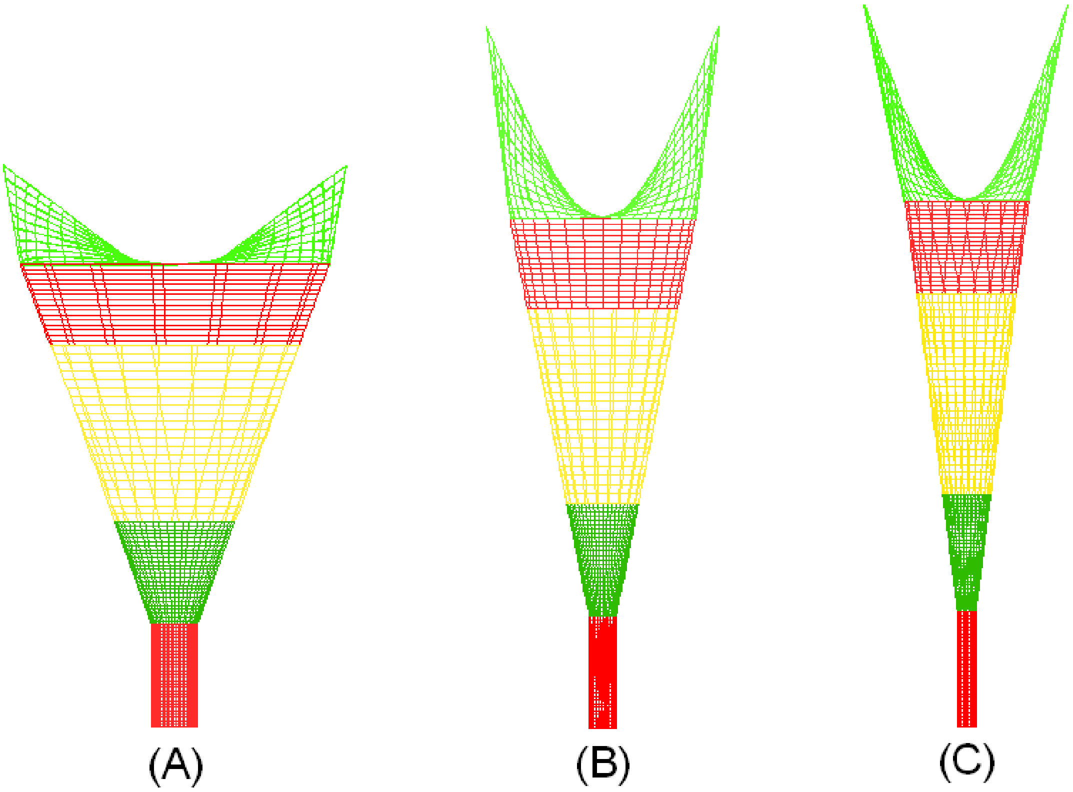


Figure 16: Prototype mid-water trawl design for the survey vessel MFV Sagarika



0.5 0.3 0.2

Figure 17: 3D view (top view) of prototype mid-water trawl at different hanging ratios A: 0.5, B: 0.3 and C: 0.2

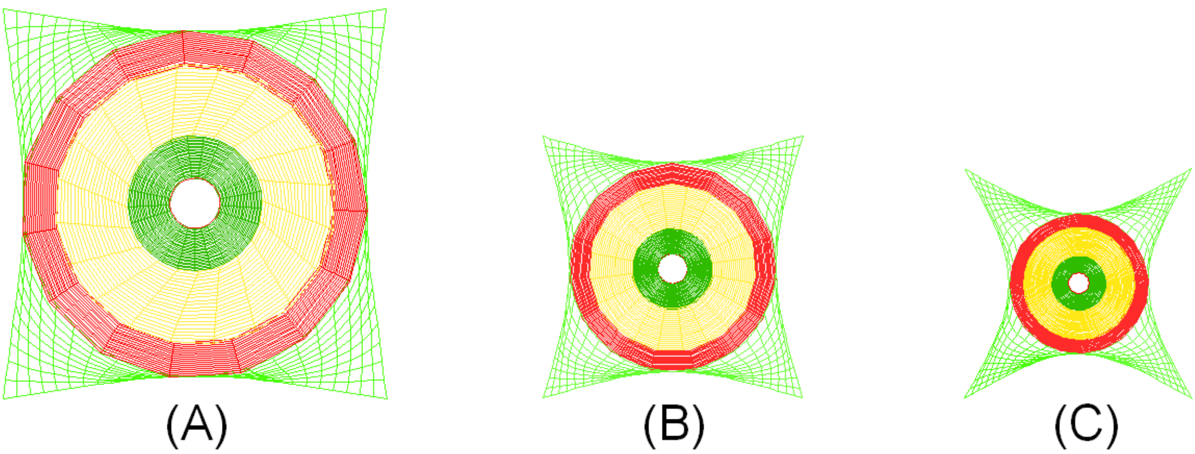


Figure 18: 3D view (front view) of prototype mid-water trawl at different hanging ratio A: 0.5, B: 0.3 and C: 0.2

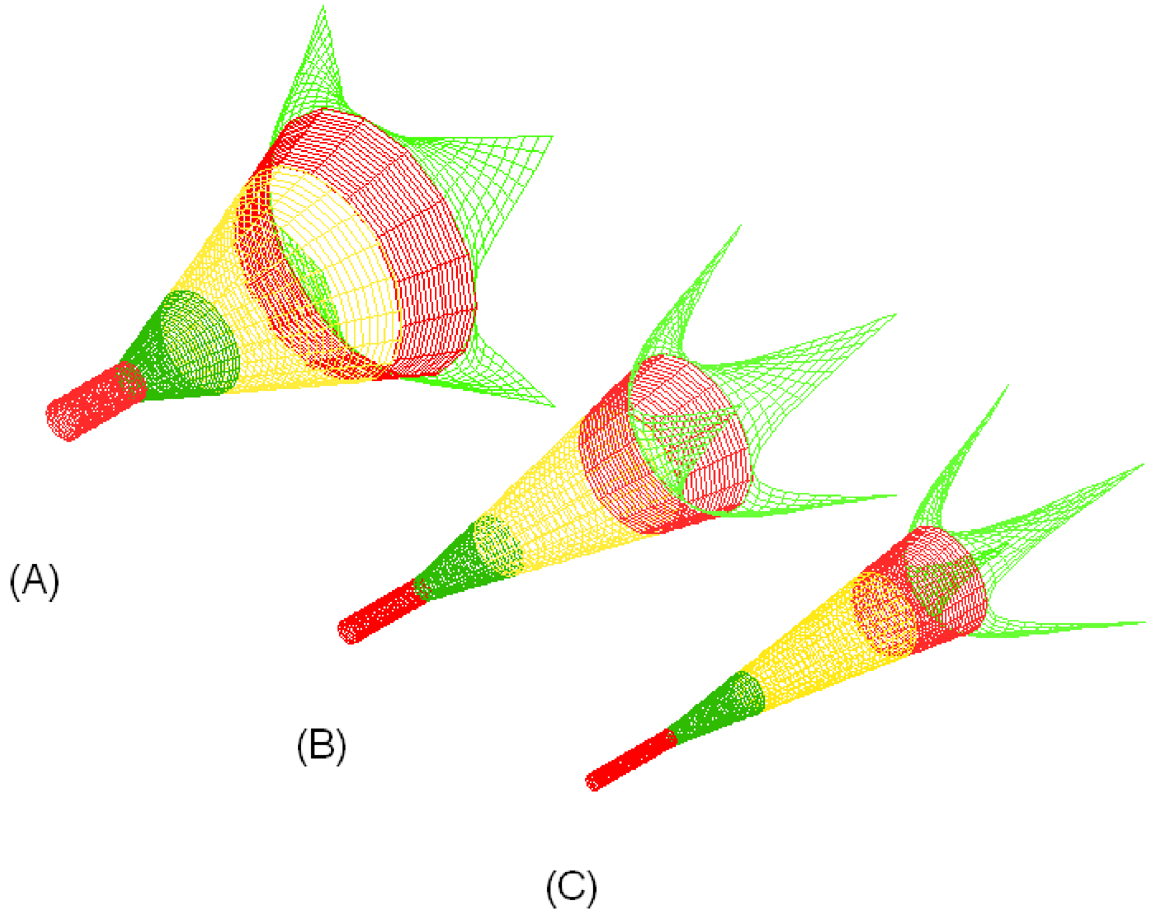


Figure 19: 3D view (isometric view) of prototype mid-water trawl at different hanging ratios A: 0.5, B: 0.3 and C: 0.2

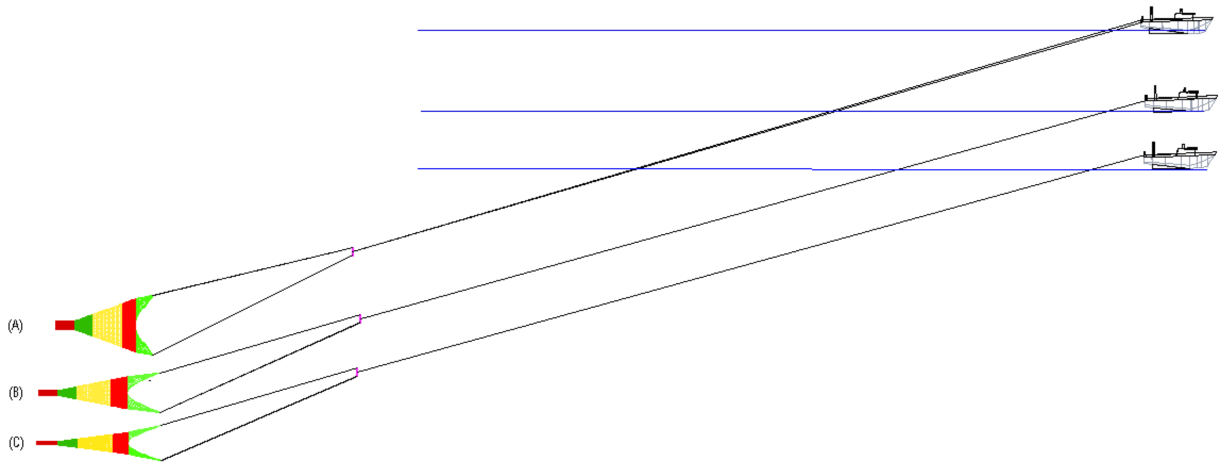


Figure 20: Towing position net view (side view) with combination of otter board (3x1 m), sweep line (75 m) and warp (300 m) at different hanging ratios A: 0.5, B: 0.3 and C: 0.2 at the depth of 100 m

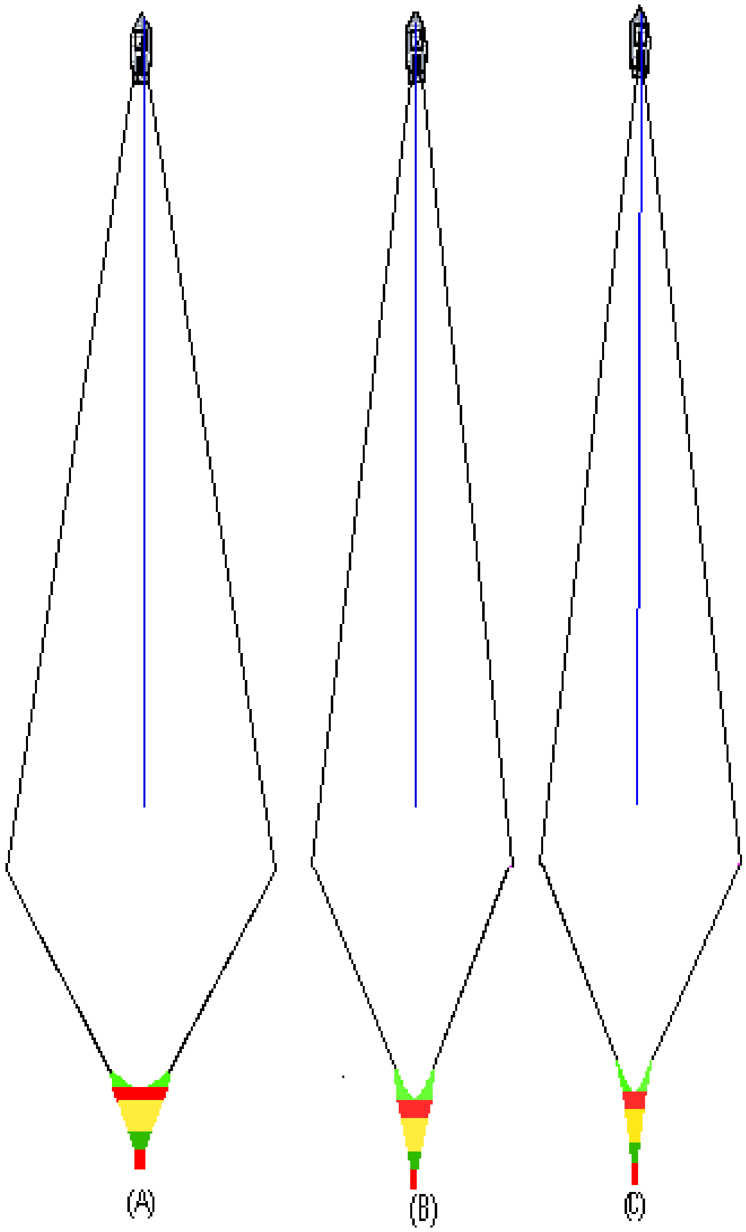


Figure 21: Towing position net view (top view) with combination of otter board (3x1 m), sweep line (75 m) and warp (300 m) at different hanging ratios A: 0.5, B: 0.3 and C: 0.2 at the depth of 100 m

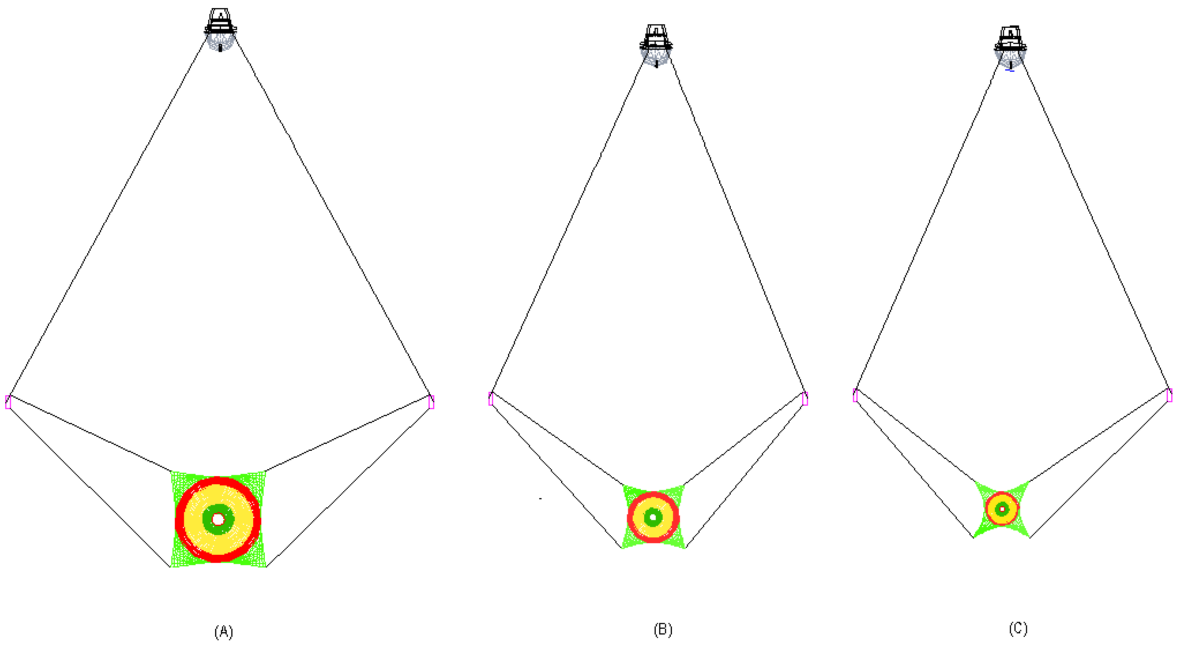


Figure 22: Towing position net view (front view) with combination of otter board (3x1 m), sweep line (75 m) and warp (300 m) at different hanging ratios A: 0.5, B: 0.3 and C: 0.2 at the depth of 100 m

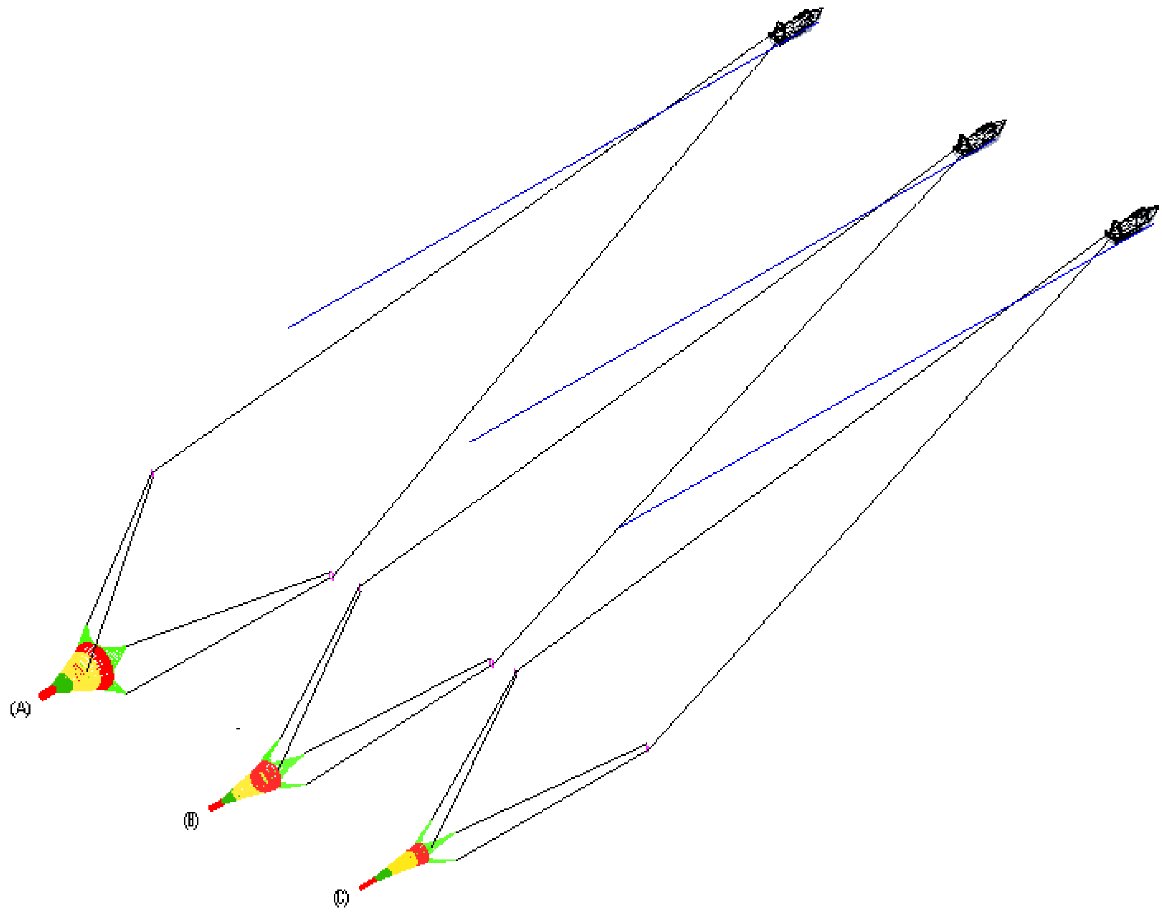


Figure 23: Towing position net view (isometric view) with a combination of otter board (3x1 m), sweep line (75 m) and warp (300 m) at different hanging ratios, depth 100 m

5 DISCUSSION

If we take an overview of Indian fisheries we notice that more than 50 % of the catches reported are pelagic species. These are caught by purse seiners, gillnetters and bottom trawlers but not much attention has been paid so far to developing the mid-water or pelagic trawls. In this project attempts are made to design a suitable experimental mid-water trawl to comply with the available specifications of the departmental vessel MFV Sagarika.

The towing pull of the vessel is factored into the net size of the design. The mesh size of the codend is calculated based on two formulas, i.e. on the basis of gill net selectivity; the result differs with target species. The Indian fishery is a multi-species fishery, but even though it was decided to keep the mesh size constant at 30 mm in the prototype design, it is advisable to select the mesh size of the codend according to the targeted species. The surface twine area was calculated using two different formulas, but they gave identical results. The weight of the prototype design net was calculated at 240 kg approximately, it varies with the netting material. At constant towing speed vertical opening is dependent only on the maximum circumference of the belly section of the net and horizontal opening will be 50% of the head rope length (with rigging), depending on otter board spread. Another important parameter in the net design is the hanging ratio; the net opening depends heavily upon the hanging ratio. In this prototype design three hanging ratios were used i.e. 0.5, 0.3 and 0.2. Based on these ratios vertical net opening and netting drag were calculated. Bethke *et al.* (1999) conducted the comparison study of three pelagic trawls, i.e. Macro, Foto and Krake for herring and sprat survey with three different vertical mouth openings and different sizes of codend meshes, the results showed that the larger the trawl, the larger the proportion of large fish.

The calculated netting drag varies with the three formulas used. For the mid-water trawl Reid (1977) suggested the empirical formula which is based on the engineering trials of four panel pelagic trawls. His formula was utilised in the final drag calculations against the vessel pull. The various other components of the rigged trawl also offer resistance, such as the drag offered by otter boards, line and ropes, which is calculated using Fridman’s formula. The total drag is calculated by adding all drag components, i.e. netting drag; drag offered by lines and ropes, sinkers and floats and otter boards. The total drag of the netting plotted against the vessel pull shows that the vessel can drag the prototype net at the maximum speed of 4.3 knots. Bethke *et al*. (1999) suggested that the pelagic trawl must not be too large in relation to the towing power of the vessel as it must be towed at a minimum speed of 3.5-4 knots.

The otter board suggested is of suberkrub type due to its high power of lifting and horizontal spreading of the net mouth, compared to its size and weight. The spread of the net increases with the towing speed within certain limits and the height of the net mouth tends to reduce in relation to increased towing speed (Park 2007). Lee (1967) suggested that regular bottom trawl boards can be converted to surface trawl boards by attaching hydrofoils to the top edges of the boards. There are many manufactures available which are producing the different types of otter boards, but their specifications are usually not available due to business secrets. The area of the required otter boards for the prototype design is calculated as 3 m^2 and their weight as 390 kg, applying the formula prescribed by Ferro (1981). No formula is available on the weight of the foot rope and sweep lines in mid-water or pelagic trawls; it has to be found out by trial and error.

After designing the prototype trawl, the net was drawn in two dimensions (2D) according to the FAO guidelines. The net plan also has been drawn in three dimensions (3D) using different hanging ratios i.e. 0.5, 0.3 and 0.2 to see how the design functions in the water. The design can be judged using the 3D techniques by visualising the net in different views. After visualising the net behaviour in 3D, it has been decided to select the hanging ratio 0.3 due to its appearance in comparison with 0.5 hanging and 0.2 hanging ratios. The selection of hanging ratio totally depends on the designer's view on the plan. The 3D designing software is the best tool available to judge the net before taking decisions on the actual fabrication of the net; it gives an overall idea on the net geometry when towed in water.

There are different types of mid-water and pelagic trawl designs available in the market but their specifications are not available to refer or to discuses due to their business policy.

6 CONCLUSION

The resultant four panel prototype mid-water trawl net can be towed by the vessel MFV Sagarika at speeds up to 4.3 nm/h. This is sufficient to catch slow and medium swimming pelagic fish and sporadic catches of mackerel, oil sardine, carangids, ribbon fish and barracuda etc. The knowledge acquired and software now available will help to respond to necessary adjustments, which will be revealed in real condition tests in Indian waters. The 3D using Design Cad 3D MAX 19 (2008) software results shows best appearance of the net in 0.3 hanging ratio, but it is a computer generated image. The resultant net plan needs to be tested in real conditions. This study could be helpful to the Fishery Survey of India and to Indian fishers.

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