# DESIGN STUDY:
# AN OPTIMUM FISHING VESSEL
# FOR
# GEORGES BANK GROUNDFISH FISHERY

Working Paper No. 3
May 1969

DIVISION OF ECONOMIC RESEARCH
(U.S. BUREAU OF COMMERCIAL FISHERIES)

WORKING PAPER SERIES

1. An Application of an Investment Model to Channel Catfish Farming by R. Thompson and F. Mange.

2. The Development of Catfish as a Farm Crop and an Estimation of Its Economic Adaptability to Radiation Processing by D. Nash and M. Miller.

3. Design Study: An Optimum Fishing Vessel for Georges Bank Groundfish Fishery by A. Sokoloski (Project Monitor).

4. The Relation between Vessel Subsidy Percentages and the Rate of Return on Investment for Various Technologies and Scale Levels: The Haddock Fishery by D. Nash, A. Sokoloski and F. Bell (Project Monitors).

5. An Economic Justification for Recommended Legislative Changes in the 1964 Fishing Fleet Improvement Act by F. Bell, E. Carlson, D. Nash and A. Sokoloski.

6. The Economic Impact of Current Fisheries Management Policy on the Commercial Fishing Industry of the Upper Great Lakes by D. Cleary.

7. Cost and Earnings in the Boston Large Trawler Fleet by B. Noetzel and V. Norton.

8. Some Elements of An Evaluation of the Effects of Legal Factors on the Utilization of Fishery Resources by A. Sokoloski.

9. A Report on the Economics of Polish Factory Trawlers and Freezer Trawlers, by B. Noetzel.

10. An Inventory of Demand Equations for Fishery Products by D. Nash and F. Bell.

11. Industry Analysis of West Coast Flounder and Sole Products and an Estimation of Its Economic Adaptability to Radiation Processing by D. Nash and M. Miller.

12. Bio-Economic Model of a Fishery (Primarily Demersal) by E. Carlson.

13. The Factors behind the Different Growth Rates of U. S. Fisheries by F. Bell.

(continued on inside back cover)

# DESIGN STUDY:

# AN OPTIMUM FISHING VESSEL

# for
# GEORGES BANK GROUNDFISH FISHERY

Sponsor:

U. S. Department of the Interior
Fish and Wildlife Service
Bureau of Commercial Fisheries

Project Monitor:

Dr. Adam A. Sokoloski
Division of Economic Research
Bureau of Commercial Fisheries

ABSTRACT

A functional model of a fishing system on the Georges Bank was developed. Relationships among the functions were mathematically quantified and programmed for computer usage. Return on investment (ROI) was determined for various operating conditions and techniques. An "optimum vessel" was designed, based on the design characteristics predicted by the computer output for maximum ROI.

ACKNOWLEDGEMENTS

Drs. Virgil Norton and Adam Sokoloski, of the Branch of Economic Research, served as project monitors and provided many helpful suggestions and criticisms. Much valuable data were obtained from the personnel of the U.S. Bureau of Commercial Fisheries, the Fishing Vessel Section of the FAO-UN, and the International Commission for the Northwest Atlantic Fisheries.

In addition, industry people gave freely of their knowledge in informal discussions. The study was carried out under the direction of Mr. Cyrus Hamlin of the Ocean Research Corporation with the assistance of the following staff: Larry Leist, Ilene McAdoo, John R. Ordway, Richard Seymour, and Paul Weene.

## TABLE OF CONTENTS

## FIGURES



## TABLES



## PLATES (at back of volume)

## 1.0 INTRODUCTION

Planning the exploitation of a fishery resource raises many questions. These questions are related to, among other subjects, international law, resource conservation, and economics.

A very important question is how best the resource might be exploited. And a vital link in the chain of exploitation are the fishing vessels which will harvest the resource.

Two major problems face a study of fishing vessels; the great number of variables involved, and the fact that fishing is essentially a hunting operation and is far from being an exact science in its present state. Taking into consideration the biological and environmental aspects of the fish resources and the methods of finding, harvesting and processing the fish, fishing vessel design must be evaluated relative to productivity, and to construction, operation, and maintenance costs.

In the past there has been relatively little effort in the U. S. toward designing fishing vessels as elements of an overall fishing program. This has been the result of several factors, including:

1. A lack of purpose and/or ability within the industry to finance large-scale changes.

2. Restraints placed on the naval architect by the vessel owner such as, "Design her just like Joe's, but two feet longer", or, "design her for a _______engine because I already have it".

3. A lack of industry integration, i.e., absence of a single community of interest covering the progress of the fish from the sea bottom to its end use.

The result has been a reliance on traditional methods and a resulting low average efficiency.

There is a clear need for an approach to fishing vessel design based on logical and rigorous judgements with respect to economic efficiency. Although an eventual vessel owner may incorporate his own subjective prejudices in an actual vessel, the incidence of this should be greatly reduced if a method of making rational decisions is available. Despite the range and number of variables involved, there are precedents for assuming that these variables may be evaluated and manipulated to produce an optimum vessel design for given requirements. For example, the fishing fleet of a Norwegian company was recently redesigned on the basis of a computer

1.0 (Continued)

program (Ref. 86). Also, optimization studies are fairly standard practice prior to the design of cargo vessels. (Ref. 12, 14, 38, 49).

This study was performed to fill the need for a general methodology of vessel design to assure the best possible vessels as the New England fishing fleet is replaced. More specifically, it was performed to design an optimum vessel for the Georges Bank Groundfish fishery, based on a logical and mathematical procedure.

## 1.1.0 Objectives of the Study

The primary objective of the study was to develop a conceptual design of an optimum fishing vessel for the Georges Bank Groundfish fishery. The criterion for "optimization" was economic; that is, the design which would ultimately yield the greatest return to capital expressed as "Return on Investment" (ROI)*. A subsidiary objective was to produce a model capable of evaluating and correlating: the interrelationships among vessel characteristics; the impact of introducing new gear, methods, procedures, etc.; characteristics peculiar to a particular resource; prevailing market conditions; and other important industry parameters. This model was used to derive a set of characteristics defining an optimum Georges Bank fishing vessel.

## 1.2.0 History of Fishing Vessel Optimization

Until recent years fishing vessel optimization was an intuitive process based on trial and error. This evolutionary process has been slow, but the resulting vessels and fishing methods in general kept up with technological advance, which also was slow.

Following World War II, however, there has been a virtual explosion in the improvement of fishing gear and methods. These improvements, in conjunction with similar advances in shipbuilding methods, propulsion systems, hydrodynamics, etc., is forcing upon the fishing industry innovations which are becoming essential to success. Some of these advances and innovations are: stern trawling; high-powered, light-weight diesel engines; shipboard processing equipment such as freezers, filleting machines, fish-meal plants; hydraulic power; irradiation; stabilizing devices; electronics.

The ship owner and the naval architect must make broad decisions affecting major characteristics of a proposed vessel and its gear, with due

* See Appendix 8.1.0 for definitions.

1.2.0 (Continued)

regard for a basic vessel life of 20 to 30 years. The number of variables and possibilities which must now be considered during the decision-making process require a quicker optimizing method, and one capable of handling more factors, than the intuitive method.

Powerful economic forces were operating on the fishing industry at the same time as the technological upheaval. The advanced technologies themselves were tending to increase the cost of each fishing vessel; a single innovation could have an appreciable effect on vessel cost. At the same time, although the ability to predict revenues has been developed to a high degree by the Bureau of Commercial Fisheries, nevertheless revenue does not increase as rapidly as other indicators. Hence the ability of the fisherman to purchase a sophisticated vessel is severely limited.

In response to growing technical and industry interest, the Food and Agriculture Organization of the United Nations set up a Fishing Vessel Section in 1945, the first broad international body to deal with fishing problems. The effect of this section was to bring together all elements of this highly fragmented industry, and begin the synthesis of a technology of fishing through continuing research and development work and by holding international congresses on fishing vessels and fishing gear.

The combined efforts of the FAO-UN and national fisheries agencies have led to formal treatment of the problems of the fishing industry. This treatment has included systematic mathematical analysis of fishing vessel design (Ref. 3-Doust) and systems analysis of various segments of the industry, including vessel design and operation (Ref. 86, extract from the Norwegian paper). In the United States, the U. S. Bureau of Commercial Fisheries has carried out research on virtually all phases of the fishing industry. A systems approach to the New England ground-fishing was recently carried out for the National Council on Marine Resources and Engineering Development (Ref. 100, Litton Study). The present study is a continuation of the Bureau's program, and will supplement Ref. 100, (Litton Study).

## 1.3.0 The Present Georges Bank Fishing Operation

The Boston Fleet competes principally with Canada and Russia for the haddock and other groundfish species of the Georges Bank. Unlike its foreign counterparts, the Boston Fleet is comprised principally of privately owned trawlers competing individually among themselves as well as with foreign fleets. The Boston fishery is not vertically integrated to any extent; each phase in the progress of fish from the vessel to the consumer is a distinct business entity. (By "vertically integrated" is

1.3.0 (Continued)

meant, in this study, that a single corporate entity controls the entire fishing and processing operation at least up to the wholesaling of the product).

International regulation of the fishery is carried out by the International Commission for the Northwest Atlantic Fisheries (ICNAF), made up of 12 signatories, (Canada, Denmark, France, Federal Republic of Germany, Iceland, Norway, Poland, Portugal, Spain, U.S.S.R., U. K. and U. S. A). The ICNAF area, and the subareas, are shown on the map, Figure 1.3.0-I.

1.3.1 The Resource

Georges Bank occupies an area approximately 150 miles by 80 miles, the long axis running northeast and southwest; the Bank is centered at approximately 67 degrees 40 minutes west longitude and 41 degrees 20 minutes north latitude. The boundaries of Georges Bank are fairly well defined by the hundred fathom curve, and depths of less than 20 fathoms are common. The distance from Boston to the center of the Bank is 150 miles.

In addition to Georges Bank, the Boston fishing fleet fishes Brown's Bank, south of Nova Scotia, Bankuereau, southeast of Nova Scotia, Nantucket Shoals, southeast of Cape Cod, and many areas of the Gulf of Maine and the Bay of Fundy.

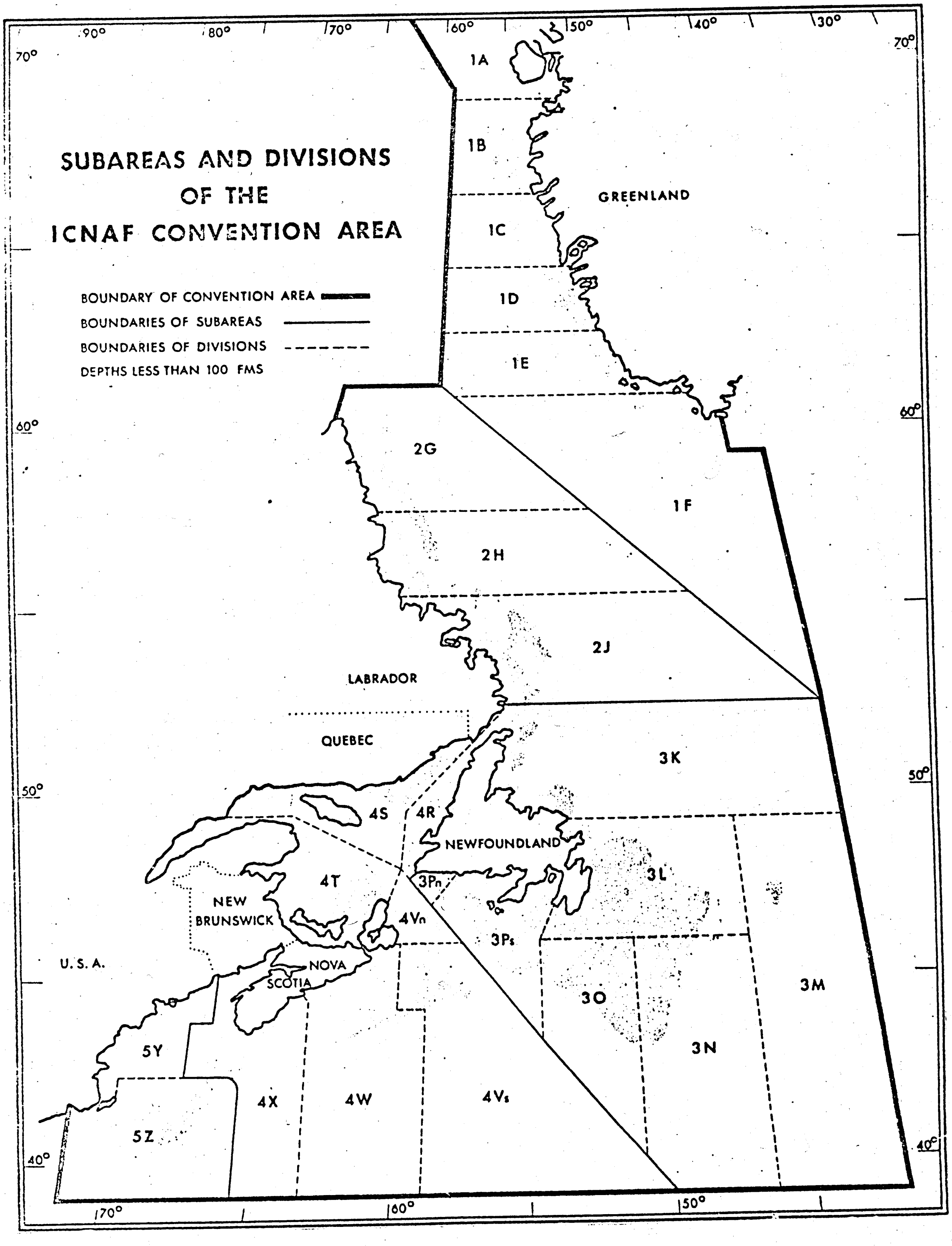
Table 1.3.1-I gives an environmental description of the Georges Bank on a monthly basis.

Georges Bank is contained in ICNAF subarea 5Z, shown on the map, Figure 1.3.0-I. Other subareas fished by the Boston fleet are 4X and 5Y.

Figure 1.3.1-I is a graph of the yearly catches for all countries and for the U. S. over the entire ICNAF area, and for the combined subareas 4X, 5Y, 5Z. Some inferences might be drawn from these data, such as:

1. The maximum yield of the entire area probably very nearly has been reached, as indicated by the flat curve for 1965 - 1966 and in view of the accelerated fishing effort by foreign vessels in the area. If this is so, then total production of the area may be expected to drop in the future, since the maximum yield is always greater than the maximum sustainable yield. (Exploitation of presently untouched species may require adjustment of this prediction).

Figure 1.3.0-I




Source: "List of Fishing Vessels and Summary of Fishing Effort in the ICNAF Convention Area, 1965".

1.3.1 (Continued)

Table 1.3.1-I

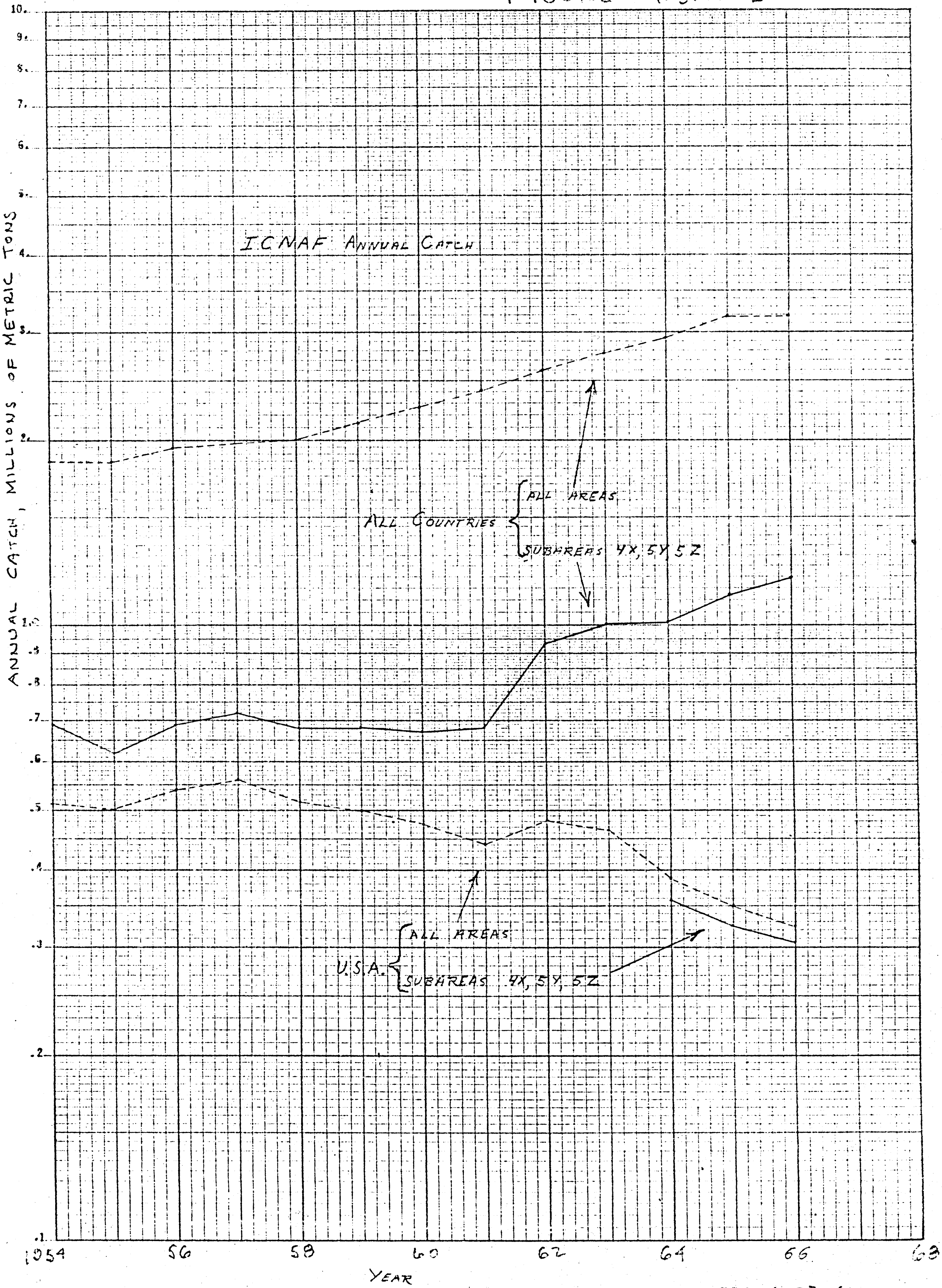
ENVIRONMENTAL DATA
GEORGES BANK

Source: "Climatological and Oceanographic Atlas for Mariners, Volume I - North Atlantic Ocean"

Navy Hydrographic Office

| Month | Percent of Time Wind exceeds 34 knots | Percent of Time Visibility less than 5 naut.miles | Mean Air Temperature, Fahrenheit | Percent of Time Wave Height exceeds 12 feet |
|---|---|---|---|---|
| January | 7% | 18% | 36 deg. | |
| February | 6% | 20% | 34 deg. | Winter - 10% |
| March | 5% | 22% | 39 deg. | |
| April | 5% | 25% | 43 deg. | |
| May | +% | 31% | 51 deg. | Spring - 0% |
| June | +% | 40% | 60 deg. | |
| July | 0% | 32% | 67 deg. | |
| August | +% | 24% | 67 deg. | Summer - 0% |
| September | +% | 18% | 65 deg. | |
| October | 4% | 16% | 57 deg. | |
| November | 5% | 14% | 48 deg. | Fall - 5% |
| December | 7% | 12% | 41 deg. | |

FIGURE 1.3.1 - I


ICNAF Annual Catch
Annual Catch, Millions of Metric Tons
10.
9.
8.
7.
6.
5.
4.
3.
2.
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
All Countries
All Areas
Subareas 4X, 5Y, 5Z
U.S.A.
All Areas
Subareas 4X, 5Y, 5Z
1954
56
58
60
62
64
66
68
Year

1.3.1 The Resource (continued)

2. The total yield for the area (subareas 4X, 5Y, 5Z) fished by the Boston fleet was still increasing, as of 1966. This indicates that the maximum yield had not been attained, although one can only conclude that this will occur in a very short time.

3. The U. S. share of the resource, in percent as well as in weight, is dropping rapidly, although the rate of the drop appears to be decreasing.

4. The difference between the total and U. S. catches is a measure of the resource potentially available to U. S. fishermen. How the U. S. fisherman will increase his share, whether by Federal extension of sovereignity, increased competitive fishing effort, or international agreement, is a matter for further study.

To sum up, in the area fished by the Boston fleet (subareas 4X, 5Y, 5Z) there is a resource capable of producing about 1,000,000 metric tons of fish on a sustained basis. The present U. S. share is about 300,000 metric tons. The balance, 700,000 metric tons, represents room for potential expansion of the New England fishing fleet. Table 1.3.1-II gives a breakdown of the total 1966 Boston landings.

Table 1.3.1-II

1966 Landings - Boston

| | Pounds | % | Dollars | % |
|---|---|---|---|---|
| COD | | | | |
| Large | 6,022,165 | 6.7 | 623,143 | 5.8 |
| Market | 4,536,515 | 5.0 | 531,970 | 4.9 |
| Scrod | 2,117,295 | 2.4 | 227,779 | 2.1 |
| FLOUNDERS | | | | |
| Large | 1,520,086 | 1.7 | 178,381 | 1.7 |
| HADDOCK * | | | | |
| Large | 17,781,840 | 19.8 | 2,758,607 | 25.6 |
| Scrod | 47,569,436 | 53.1 | 5,430,168 | 50.5 |
| Snapper | 103,785 | 0.1 | 12,029 | 0.1 |
| POLLOCK | 3,998,500 | 4.5 | 290,840 | 2.7 |
| OTHER | 6,045,742 | 6.7 | 693,204 | 6.5 |
| | 89,695,364 | 100.0 | 10,746,121 | 100.0 |

* Scrod Haddock - 1½-2½ lb., 15" to 18" long, 2½ to 4 years old.°

Large Haddock - over 2½ lb., up to 30" long and 8-10 years old.°

° Source: "Fishes of the Gulf of Maine", Bigelow and Schroeder, U. S. Fish and Wildlife Service, 1953

1.3.2 The Vessels

In 1964 the Boston fleet was made up of 41 vessels, 7 in the class from 60 tons to 320 tons, 34 in the class up to 60 tons. The average age of a Boston otter trawler was 23.6 years.

At this writing, all vessels of the Boston fleet are side trawlers, and only the largest are built of steel. (a new and modern stern trawler, 131' LOA, is now under construction).

1.3.3 Methods of Handling and Preserving Fish

The entire production of fish intended for human consumption and caught on the Georges Bank is presently handled in the same way, with few innovations incorporated since the introduction of otter trawling.

The fish are dumped from the cod end of the trawl into a penned-off space on the main deck. From this area the fish are sorted out, with undesirable species and other trash being thrown overboard. The larger ground fish are processed on deck by evisceration, etc., as is deemed proper; the smaller fish (flounder, ocean perch) are brought into port whole. After being washed in sea water, the fish are dumped or chuted down into the hold where they are packed in layers of ice, the quantity of which, depending on the seasons, is equal to 50% to 70% of the weight of fish. The hold is divided into sections closed off with removable vertical partitions to prevent movement of the fish with the motion of the ship; in addition, horizontal shelves are provided at intervals to limit the crushing effect of upper layers of fish.

Conventially, the processing is done with few if any devices or furnishings to ease the work and improve efficiency. The "ripper", who sorts the fish and cuts open the belly when required, stands in the pen, stooping over to pick up each fish. He throws the appropriate fish to the "gutters" (two for each ripper) who perch on the "checker" boards, completing the evisceration of the fish. The gutters toss the fish into a washer, from where they are sent down to the "icer(s)" in the hold for stowing.

On arrival in port, shore crews called "lumpers" lift the fish out of the hold in baskets, weigh them, and move them to the processors.

1.3.4 The Market (as seen by the fishing vessel operator)

The value of the fisherman's catch is measured at dockside. The fish are sold at auction while still in the hold, then unloaded to the

1.3.4 (Continued)

buyer's account.

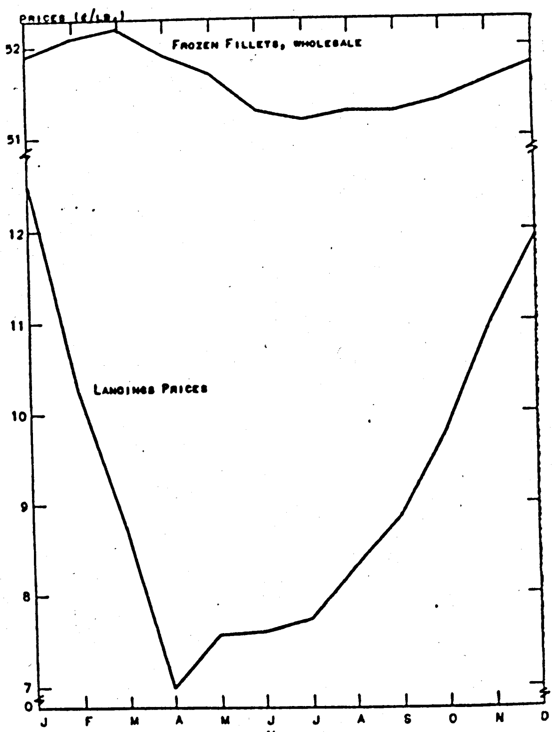
The method of selling the catch differs somewhat from port to port, but falls into one of two main categories. In Boston and New Bedford virtually all fish and scallops are sold at auctions held each morning. At other New England ports, fish are sold by the vessel operators, either directly or through agents.

The price of fish paid to the fishermen fluctuates rather widely in annual as well as short-term cycles. Some of the factors affecting price are as follows:

1. Above-normal landings of fish will result in depressed prices, and below-normal landings will result in elevated prices. (To further add to the confusion, however, some recent data indicate that for some species both price and quantity may decline simultaneously). The relative quantity influences price not because of marketing feedback but because the processors can absorb only so many fish at a given time, and because of a long-term feedback from storage facilities which wish to maintain a certain equilibrium of stocks.

   The result of this inter-play is that the wholesale price to the retailer remains at a fairly constant level, while the price to the fisherman fluctuates over a wide range, (Figure 1.3.4-I.)

FIGURE 1.3.4-I




Source: University of Rhode Island "Maritimes", Autumn, 1964.

**New England: Average monthly haddock landings and wholesale prices 1952-62. (Landings prices are arithmetic averages of weighted average prices at the seven major ports; wholesale prices are F.O.B. Boston-Gloucester-New Bedford.)**

**From U. S. Bureau of Commercial Fisheries.**

1.3.4 (Continued)

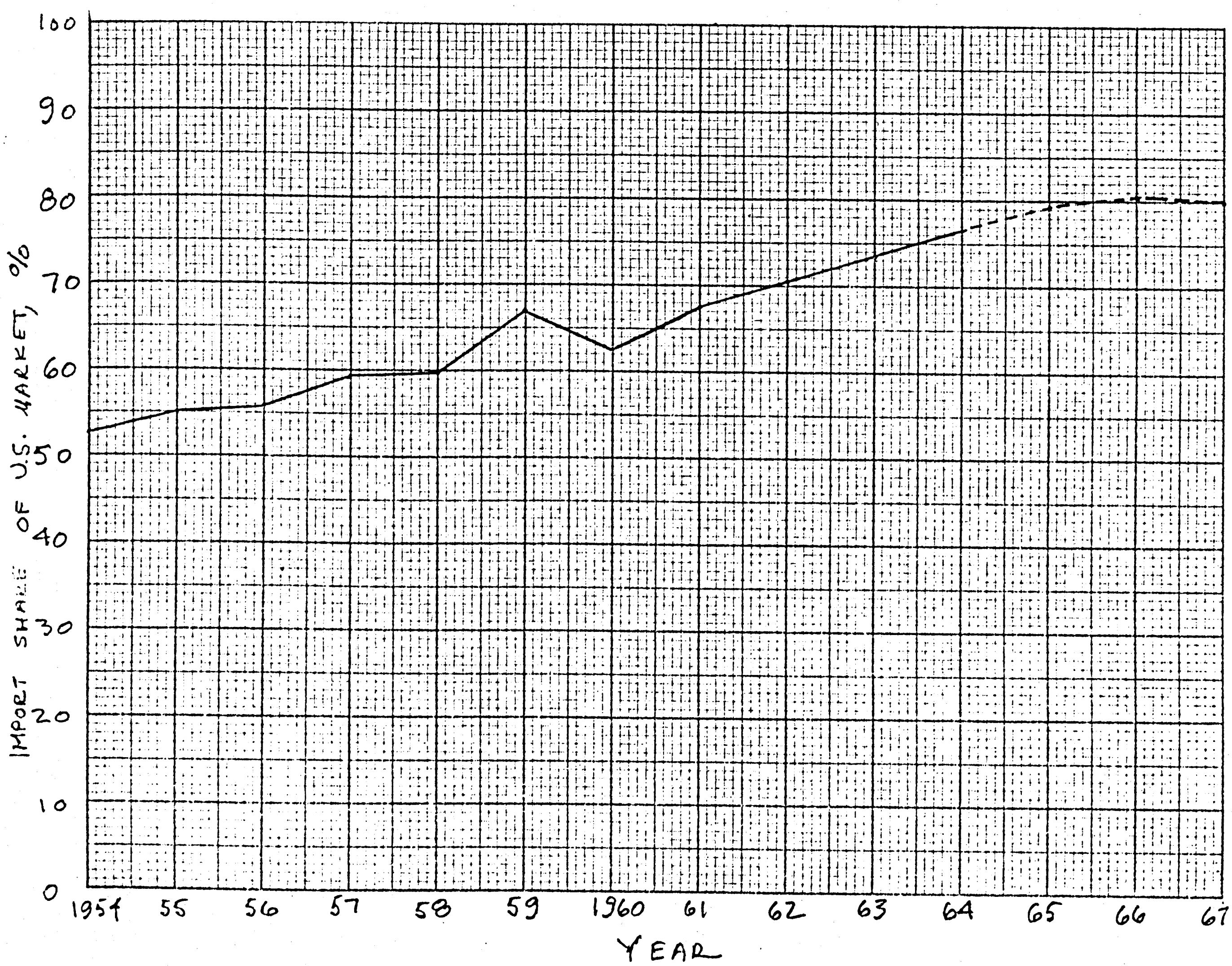
2. The quality of the fish. The quality of fish flesh is sensitive to age, handling, storage methods, etc.; yet there is only a gross type of price feedback on the basis of quality. In Boston, the base port for this study, fish are unloaded from a vessel in accordance with the terms of the auction sale until the purchaser determines that a quantum drop in quality has been reached; at this point he is free to reject further receipts at the original price and the remaining fish are resold.

3. The long-term consumer demand for fish. Since 1946 the average per capita consumption of food fish in in the U. S. has held steady between 10.2 lb. and 11.8 lb. per year (Ref. 58). Natural population increase should, therefore, result in an increase in fish sales by the fleet of a few percent per year. This potential increase is more than wiped out, however, by a steady increase in imports. The graph, Figure 1.3.4-II, gives the trend in imported vs. domestic food fish over the last few years. This imported fish, generally in the form of frozen blocks which makes for simplified processing into sticks, portions, etc., is brought in at a lower price than domestic fish. The result has been a general flow away from domestic purchases which tends to weaken the domestic prices. It is felt by some, but not all, distributors that the removal by the Catholic Church of the ban on eating meat on Friday has adversely affected the market for fish, (Ref.35).

Despite the picture of a rather uncertain situation represented above, there are causes for optimism with respect to improving the market for domestic fish. The per capita consumption is potentially subject to an increase as a result of adequate quality control and imaginative advertising. Table 1.3.4-I lists the per capita consumption of fish in various highly developed western countries, affording some measure of what might be striven for. Emphasis on the highly desirable fresh fish, coupled with improved quality control, offers hope for enlarging the market for domestic New England caught fish. The large mass of imported fish is a threat, but it also gives a measure of the market which can be broken into.

Figure 1.3.4-II

Foreign Import Share of the U.S. Domestic
Market for Groundfish (Percent of Market).




Source: "The Economics of the New England Fishing Industry: The Role of Technological Change and Government Aid"; Bell, Federal Reserve Bank of Boston, 1966.

1.3.4 (Continued)

Table 1.3.4-I

Annual Per Capita Consumption of Food Fish

Selected Countries, 1966

| | |
|---|---|
| U. S. A. | 10.6 lb. |
| Denmark | 37.3 " |
| Norway | 44.5 " |
| Sweden | 47.0 " |
| U. K. | 22.5 " |
| Canada | 15.0 " |
| Japan | 54.7 " |
| New Zealand | 14.6 " |

## 1.3.5 Labor

The numbers of men available for fishing out of Boston has been decreasing over the past few years and the average age has been increasing. Bell reports (Ref. 15) that 62% of the 1964 Boston offshore fishermen were 55 years of age or over. The work is hard and dangerous, and the hours considerably longer than for most industrial occupations, since when fishing it is "watch on, watch off". Although the income aboard the best vessels is good on an annual basis, (in 1964 the average annual income for deckhands working 271 days or more was $7,261, with a few earning over $10,000), hourly earnings are not impressive, as Table 1.3.5-I (Ref. 15) indicates. In addition, with vessels spending up to 300 days per year at sea, there is little incentive for the ordinary urban or suburban family man to join the fishing fleet.

Efforts to recruit younger personnel into the New England fishing fleet are meeting with only indifferent success. Training programs under the Manpower Development Act were instituted in Gloucester, Boston, and New Bedford and have resulted in 50± entering the fishing fleet out of a total initial enrollment of 290. There is hope that the newly formed College of Fisheries at the University of Rhode Island, and the well-established Marine Technology course at Southern Maine Vocational-Technical Institute, in conjunction with the improved vessels being built under the subsidy program, will result in an increased flow of young, trained, people to the fisheries.

A feature of most fishing operations, unique in industry as a whole, is the so-called "lay" system of paying labor. Defined in detail later in this report, this is essentially a division of the percentage of the gross income of each trip among the crew members. In recent years a guaranteed minimum income per day has been instituted. A trip in which each crew share does not equal this minimum rate is known as a "broker", and the difference must be made up by the vessel owner. The differences of annual income among full-time fishermen mirror the productivity of the vessels and are, in general, due to the fact that older vessels, with inefficient and out-of-date equipment, are less effective harvesters and are more apt to break down. In addition, the hunting and harvesting ability of the skipper is of central importance in the success of a fishing vessel; the "best skipper" is able to demand the "best" vessel, and in turn the "best" crew members gravitate to this more profitable combination.

## 1.4.0 Constraints for this Study

The Georges Bank fishery is extremely complex. Variables are many and each covers a statistically broad range. Every facet of the industry, such as vessels, productivity, resource, labor, economics, is fraught with pitfalls for a research project. This study is based solely on the Boston Fishing Fleet of medium and large trawlers; the following constraints are to be understood in the context of the Boston fleet.

## Table 1.3.5-I

Average hourly earnings in Boston offshore fleet and other selected industries and occupations

| Industry or occupation | Average hourly earnings |
|---|---|
| Boston offshore fishermen[1] | Dollars |
| 17-man vessels: | |
| Deckhand | 1.98 |
| Cook | 2.09 |
| Mate | 2.13 |
| Engineer | 2.13 |
| Captain | 5.09 |
| 13 and 15 man vessels: | |
| Deckhand | 1.71 |
| Cook | 1.82 |
| Mate | 1.86 |
| Engineer | 1.86 |
| Captain | 3.76 |
| Major U.S. industry groups: | |
| Mining | 2.83 |
| Manufacturing | 2.53 |
| Contract construction | 3.55 |
| Selected industries, Boston, Massachusetts, Area:[2] | |
| Durable goods manufacturing | 2.68 |
| Primary metal industries | 2.64 |
| Textile mill products | 2.05 |
| Food and kindred products | 2.40 |
| Carpenters, maintenance | 3.13 |
| Electricians, maintenance | 3.24 |
| Engineers, stationary | 3.06 |
| Firemen, stationary or boiler | 2.66 |
| Helpers, maintenance trades | 2.62 |
| Mechanics, maintenance | 2.97 |
| Oilers | 2.48 |
| Painters, maintenance | 2.88 |
| Pipefitter, maintenance | 3.19 |
| Tool and die makers | 3.40 |
| Janitors, porters, and cleaners | 1.86 |
| Laborers, material handling | 2.25 |
| Packers, shipping | 2.32 |
| Shipping and receiving clerks | 2.50 |
| Truckdrivers | 2.91 |
| Elevator operators | 1.55 |
| Guards and watchmen | 1.74 |

[1] Does not include value of meals at sea. This would add approximately 28 cents per hour to the hourly wages of the offshore fishermen.
[2] Non-supervisory or production workers.

Source: U.S. Department of Labor, Bureau of Labor Statistics. Area wage survey, Boston, Massachusetts, metropolitan area. Washington, D.C., Oct. 1965, Bull. 1465-12: 13-16.
U.S. Department of Labor. Manpower Report of the President. Washington, D.C., Mar. 1965, p. 236-237.
U.S. Department of Labor, Bureau of Labor Statistics. Employment and earnings for states and areas, 1939-1964. Washington, D.C., 1965, Bull. 1370-2: 275-276.

Source: "An Economic Study of the Boston Large-Trawler Labor Force", BCF Circular 248, Norton and Miller, 1966.

1.4.0 (Continued)

To limit the confusion and thus increase the rigorousness of the study, a set of constraints was initially adopted. These constraints were carefully selected to improve the reader's understanding of the problems and their solution without over-simplification.

It should be noted that these constraints are not permanently fixed into the mathematical model or the computer program. Anyone using the program may, with relative ease, vary or remove the constraints, or incorporate his own particular set of constraints.

1.4.1 The Resource Constraints

a. The vessels will fish the areas presently exploited.

b. Species distribution will be the same as present.

1.4.2 The Vessel Constraints

a. The gear will be that commonly in use.

b. The present best catching rate will be used as (1) a rough and ready measure of the resource potential, and (2) a measure of catching efficiency.

c. Vessels will be considered as separate entities, even though they may be elements of a fleet owned by a single company.

d. Consideration will be limited to side and stern trawlers, built of steel.

1.4.3 The Handling and Preserving Constraints

a. The handling and processing conditions will be those presently pertaining to the Boston fleet.

1.4.4 The Market Constraints

There will be no limit on the market demand for the varieties presently caught and prepared by the present processing methods. This is based on (1) the vast quantities of imported fish which represent a potential expansion market for U.S.-caught fish, (2) the increasing demand for fresh fish on both a per capita

1.4.4 (Continued)

and a population increase basis. The assumption here is that if high quality fresh fish is available, it will supersede imported frozen fish wherever the two compete.

### 1.4.5 Labor Constraints

a. The present system of selecting and remunerating crews used in Boston will continue. This system, with the cooperation of the unions, and based on the lay system has the ability to adjust to changing conditions. Although, as discussed in Section 3.1.1, the lay system may not be the ideal method of dividing the revenues, there is no firm basis for predicting what other form a future replacement system may take. As far as manning is concerned, possibilities exist of improving the attractiveness for prospective fishermen by having rotating crews. Nevertheless, from the vessel owners point of view, it is unlikely that changes in division of revenue and manning will materially affect his percentage of the gross income.

b. Increased skills required by technologically advanced vessels will be attracted by better pay (greater catching ability and smaller crews) and better working and living conditions.

### 1.4.6 The Economic Constraints

a. The sole criterion of fishing success, i.e. optimality will be the Return on Investment (ROI).

## 2.0.0 Methodology

The basic approach to the delineation of an optimum fishing vessel for the Georges Bank fishery involved the following steps:

1. Selection of relationships important to fishing vessel design from factors of environment, biology, hydrodynamics, human engineering, etc.

2. Construction of a functional model expressing graphically the relationships so found.

3. Quantifying the relationships on the basis of the best available data regarding the specific fishery, vessel design, gear and methods, economics, etc.

4. Computation of the vessel, gear, and strategy, combination which produces the highest return on the investment, and design of a vessel to suit these characteristics.

Throughout the program, our previous work was constantly checked to verify the relationships derived, and to justify the values used.

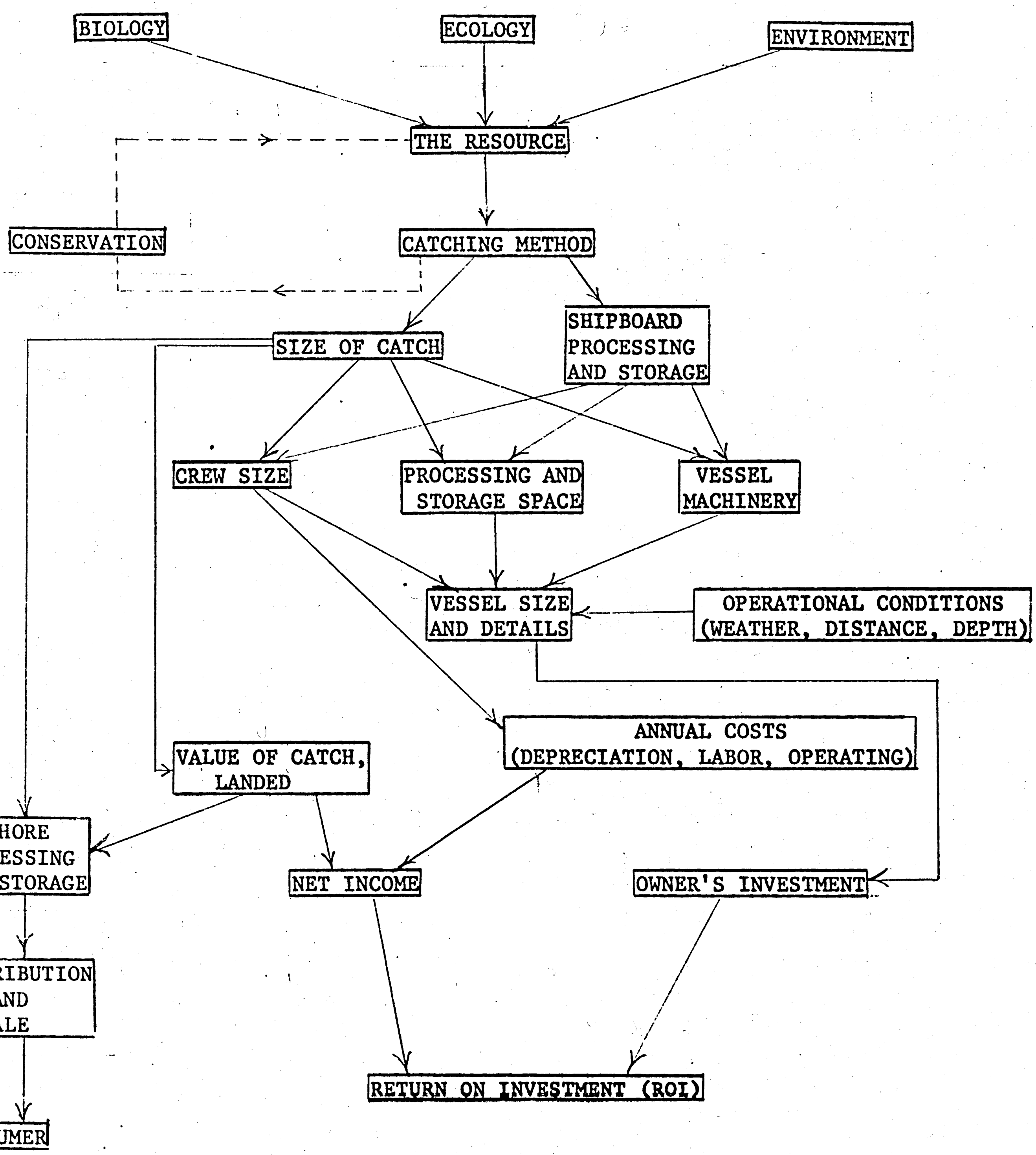
Figure 2.0.0-I is a simplified and generalized flow chart which may be taken to describe any fishery from the standpoint of economics.

The model for the Georges Bank fishery, used in this study, was developed in accordance with this flow chart and the constraints as noted in Section 1.4.0.

Figure 2.0.0-I

FLOW CHART

Generalized Fishery Resource Development Model



## 2.1.0 Data Sources

Section 7.0.0 is a bibliography listing all the data sources referred to in the course of preparing the study. Where possible, specific references are noted throughout the text.

Basically the data may be divided into two groups: Data of an essentially statistical nature, describing the resources of the Georges Bank, meteorologic information, existing vessel characteristics and performance, crew sizes, economic structures, etc.; technical data referring to gear performance, vessel design, hydrodynamics, fishing methods, etc.

The statistical data describing the Georges Bank fishery were obtained from the Bureau of Commercial Fisheries files in Gloucester and Woods Hole, Massachusetts, and College Park, Maryland; of particular value were the data and assistance provided by Mr. Bruno Noetzel of the latter laboratory. Additional sources were Canadian publications, largely the work of Mr. John Proskie, and the publications of the International Commission for the Northwest Atlantic Fisheries (ICNAF). Information was also obtained from individual fishing vessel owners, fishermen, and others associated with the industry.

Meteorological data were obtained from the Environmental Sciences Service Administration (ESSA).

The major sources of technical data were publications of the Fishing Vessel Section of the United Nations (Fishing Gear of the World, I and II, Fishing Vessels of the World 1, 2, and 3). In addition, publications of the U. S. Government, notably the Bureau of Commercial Fisheries were used. Individual sources, some of them noted in the Bibliography, were also used.

## 2.2.0 The Systems Approach

Considerable preliminary thinking with respect to ground fishing regarded as a system, took place before anything was placed on paper. The approach which evolved was based on the assumption that the fundamental factors in a fishing system were the trawl net and the motor force dragging it along the bottom. The number of fish caught is a function, in general terms, of the amount of water passed through the net, and this amount depends upon the mouth area of the net, the towing velocity which in turn is a function of the pulling power of the main engines/propeller system, and the amount of time the net is actually fishing on the bottom.*

The secondary factors are entirely dependent upon the number of fish caught expressed in pounds: (1) The crew must be of sufficient size to handle the nets and process the number of fish caught; (2) the

* See Appendices 8.1.3, 8.1.4, and 8.1.5 for a description and explanation of net geometry, catching rate, net/engine subsystem, and time study of trawling operation.

2.2.0 (Continued)

accommodation space must be sufficient for adequate quarters for the required number of crew; (3) the hold size must be sufficient to accommodate the average catch of fish, with an overage of volume to accommodate the exceptional catches and to provide working room for the crewmen stowing the fish; (4) the engine room must be of a sufficient size to accommodate the main engine and the necessary auxiliaries. These three necessary volumes summed together can be used as a measure of the total cubic number, and displacement, of the vessel.

By varying such factors as length of trip, net size, towing speed and time to recover net, and relating the gross revenue, i.e. the value of the fish caught during the year, to the various expenses, the return on either the total investment or the owner's equity (assuming part of the vessel cost is paid with a subsidy) is easily found. By the use of a computer, variables and other factors and relationships can be altered quite readily to permit investigation of the effects of changes in the vessel and gear, the fishing system, and economics.

By contrast with the present method by which the owner intuitively establishes the primary characteristics of a new vessel, the systems approach seeks to regard the fishing operation as a complex but integrated system which can be designed to produce the highest economic benefits to the owner and his crew.

## 2.3.0 Method of Optimization

Optimizing vessel design for a particular fishery involves the derivation of the vessel with the maximum ROI over the ranges of variables describing that fishery. Variables are changed one value at a time and the fishing system and resulting ROI calculated for each condition. The optimum vessel will be the one which fits that combination of variables producing the maximum ROI.

A study of the Model and Program Description, Appendix 8.1.0, will show how the optimization is structured for one fishery, the Georges Bank ground fishery. Note that the program includes the functional, physical, and economic factors affecting this fishery. Any other fishery may be described in the same format by substituting the particular variables and constants pertaining to it.

## 2.4.0 Fishing Gear

In accordance with the constraints adopted for this study, innovational fishing, handling, and processing, gear was not in general considered. The test for consideration was twofold: 1) Whether the

2.4.0 (Continued)

proposed gear had demonstrated its functional value in commercial use in the Georges Bank (or a similar) fishery; 2) whether the proposed gear would be fairly certain to result in increased return on investment.

Nevertheless, rigorous judgements as to whether or not to consider a particular piece of gear were virtually impossible to make. Some items of equipment, such as the deck fish processing system developed by the BCF Technical Laboratory in Gloucester, and the hydraulic boom, have not, in fact, been proven in commercial use on Georges Bank. Nevertheless, the obviously apparent functional advantages of the former, backed up by experimental evaluation, and the widespread proven use of hydraulic booms in industry and on other types of vessels, led to their inclusion in the final design.

On the other hand, use of other types of gear, such as electrical pulses to immobilize fish immediately ahead of the trawl, have not been tested sufficiently to provide reliable data on either the cost of installation or the increase of revenue resulting from their use. The fact that a particular piece of gear was not included in the final design should by no means be taken to constitute a judgement against such gear. It merely reflects the view that it was not possible to properly evaluate the economic return from such gear.

It should be pointed out that the mathematical program from which the optimum vessel was derived permits virtually endless introduction of new factors and revision or deletion of old. This flexibility encourages accurate system evaluation for new items of gear for which hard data are available, and also permits the investigation of completely new gear on the basis of hypothetical cost and performance characteristics.

## 2.5.0 Derivation of Vessel Characteristics

The first computer outputs of vessel characteristics are the total horsepower and the cubic number. These two values determine the cost of the vessel (see Step No. 45, Appendix 8.1.2). The cost of the vessel is thus independent (from the computer's point of view) of its geometry, and the LWL, Beam and Depth may be selected on considerations other than cost, as long as their product equals the CUBE.

The total outputs of the mathematical vessel program are the following data regarding the vessel itself: Main engine, generator, and winch horsepower, cubic number, displacement, LWL, beam, depth, accommodation requirements, hold size, and cost.

2.5.0 (Continued)

These values are of primary interest with respect to the fishing system. The qualification and quantification of the various relationships, as set forth in the model flow chart, Appendix 8.1.0, were derived from available statistical and theoretical information. The reference notations in the text indicate the major sources of information from which these relationships and values were derived.

What might be termed the secondary vessel characteristics, i.e. those of interest to the naval architect more than to the fisherman, were derived from the information listed above. It is interesting to note that, traditionally, horsepower is one of the last factors of vessel performance to be derived by the naval architect. In this study, however, the horsepower and displacement are the initial inputs in determining the vessel geometry, and it was therefore not easy to find a method for deriving the linear dimensions of the vessel from this input.

It is possible, by the use of a minimum of trial and error and based upon data presented by Geroult (Ref. 3), to allow a fairly prompt convergence on the optimum dimensions, for a given horsepower and displacement, from a hydrodynamic standpoint.

Optimization of a vessel's performance is not, however, a highly critical matter. When all the many complicated relationships are evaluated and integrated, the curves are relatively flat as may be seen by a study of the curves derived by Doust (Ref. 3). It is possible, on the basis of well-established ship designing data, to rather easily approach optimization of any one characteristic; the accumulative effect of this procedure would produce a hull with performance requirements ranging from good to excellent.

The design of an actual vessel should include towing tests in smooth water and in waves. The additional cost of tank testing, including building the model, cost of towing tank time and personnel, and an analysis of the results, will be between $500.00 and $1,000.00.

## 3.0.0 Findings

In this section is presented a detailed description of the specific steps carried out in establishing the characteristics of an optimum fishing vessel for Georges Bank. The simplifying assumptions will be discussed, as well as the steps in the optimization process. Reference to the vessel program, Appendix 8.1.2, will be found helpful.

The design itself will be covered under Section 4.0.0.

### 3.1.0 Simplifying Assumptions

The following assumptions, 3.1.1 to 3.1.6, have been established in conformity with Boston fishing fleet practice and history and in accordance with the constraints noted in Section 1.4.0. The reason for each assumption is stated with it.

#### 3.1.1 Crew

The crew for each vessel is assumed to remain constant in size throughout the year. The Boston lay system and other existing labor regulations and agreements will pertain.

It is possible to argue that a better system of payment and manning could be devised than that now in use at the Boston Fish Pier. However, the lay system is hallowed by a long tradition, and major changes are unlikely to occur in the near future. In any event, the total share of vessel receipts accruing to the crew will probably not change a great deal, even if another payment system replaces the lay.

#### 3.1.2 Gear

In general, the type of gear will be very similar to that presently in use. Exceptions will be, (1) the improved handling, processing, and washing fixtures developed at the Gloucester Technological Laboratory of the Bureau of Commercial Fisheries, and (2) the use of a hydraulic derrick in place of gantries, booms, etc.

In the case of the processing system, a full size setup has been built and perfected on shore, then tried on the research vessel "Delaware" in actual use. Careful measurement of rates of production using this system gave improvements in the processing rate on the order of 30% - 35%.

3.1.2 (Continued)

The hydraulic boom is included because of its well established usefulness in vast numbers of shore-based industries and in some marine applications. The loads to be expected in the cod end rarely exceed five or six thousand pounds, well within the capacity of rather light-weight equipment.

In addition, it is assumed that all vessels have identical electronic position-finding and fish-finding equipment, regardless of size. The assumption is that the process of finding fish is related to the grounds and the resource and not to the size of the vessel.

3.1.3 Vessel

The vessels will be assumed to be built according to first class fishing vessel standards presently in force. Structural innovation such as aluminum deckhouses will not be considered at this time.

As a guide to scantlings, outfit and equipment, the standards of the American Bureau of Shipping✠ A-1 will apply. Where LBP is less than 100', standards will be extrapolated, or equivalent classification rules such as Lloyds will be followed.

3.1.4 Resource

The distribution of the resource will be taken as being constant throughout the year.

To hold the program to a manageable simplicity only the total annual landings are considered, which implies consistent landings throughout the year. Fluctuations which occur can be accommodated by lengthening or shortening the trips. The 30% extra space in the hold for working (Step 27, Appendix 8.1.2) also provides some cushioning effect in the case of large catches. Since the yearly landings used in the derivation and checking of the program reflect seasonal fluctuations, the landings of the Optimum Vessel may be said to reflect them, also.

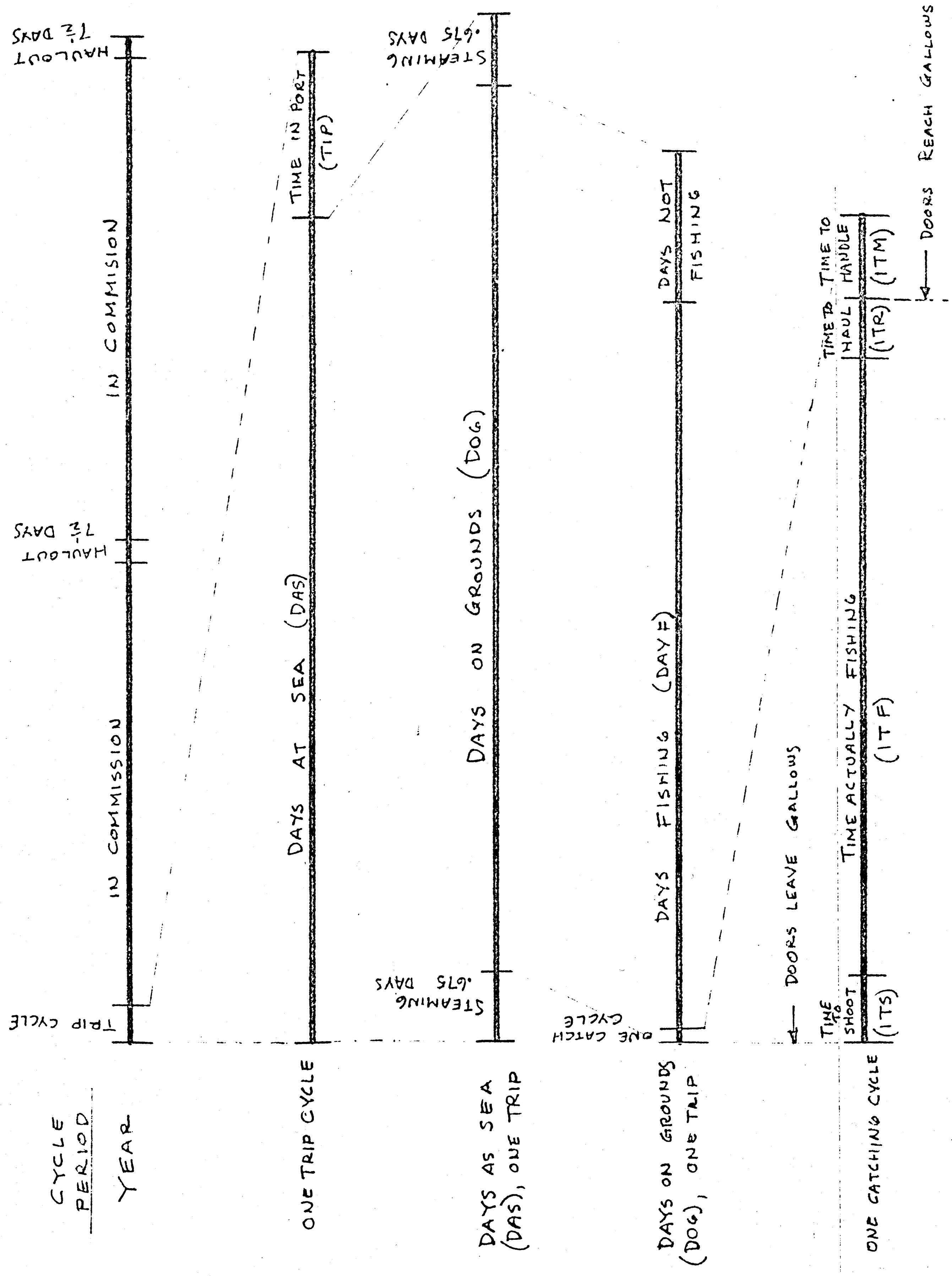
3.1.5 Operation

The assumption made here is that the specific catching rate, i.e. the amount of fish caught per unit volume of water strained through the net, of the optimum vessel will equal that of the present best of fleet.

Figure 3.1.5-I

Time Distribution Pattern for

Georges Bank Ground Fishermen



3.1.5 (Continued)

the best of the present fleet.

The present degree of processing will be maintained. No effort will be made at this time to evaluate the advantages, if any, of full processing at sea including packaging and/or freezing.

Total steaming time per trip is held constant. The smaller vessels, with a slightly lower steaming speed, tend to fish the nearer grounds. For the same speed/length ratio, $\frac{V}{\sqrt{L}}$, the horsepower per ton of displacement will not vary greatly. In other words, given the same horsepower per ton, a 121' vessel may be expected to have a speed $\frac{11}{10}\left(\frac{\sqrt{121}}{\sqrt{100}}\right) = 1.1$ as great as a 100-footer. This difference is mitigated to a large extent by the tendency for smaller vessels to have more horsepower per ton than larger vessels and hence can steam at a higher value of $\frac{V}{\sqrt{L}}$.

Depth of water is held constant at 100 fathoms. Different depths will affect only shooting and recovery (hauling) times.

Time distribution over a year for New England fishing vessels is graphically displayed in Figure 3.1.5-I. Values given on the Figure apply to all vessels. Smaller vessels spend more time in port (TIP) between trips (Step No. 55, Appendix 8.1.2), or to put it another way, less days at sea per year.

3.1.6 Economic

It is assumed that there are no seasonal fluctuations of price for fish. In other words, the price per pound for the fish will be the average for the year.

As shown in Figure 1.3.4-I, prices do fluctuate seasonally, the lowest prices coming in April through July. Vessels which fished only in the good weather, say from March through November, would hence receive a lower average price than vessels fishing year-round. A superficial review of BCF Fishery Products Reports covering a year, however, indicates that some medium trawlers fish all year. For this reason, it is assumed that any optimum vessel will fish all year, of course taking into account that the smaller vessel will spend a greater proportion of its time in port.

In addition, no price premium will be paid for especially fresh fish or fish which have been handled with extra care.

### 3.2.0 The Importance Relationship Table

A first step in constructing a functional model of the Georges Bank Fishery was to tabulate the many relationships involved and if possible assign some order of importance to them. Since it would obviously be impractical to consider every relationship, only those of appreciable importance would be included in the model.

Accordingly, a list was carefully prepared of factors involved in a fishery. These came under the general headings of: Vessel, Machinery, Crew, Instruments, Fishing Gear, Processing Gear, Tactical Properties, Inport and Maintenance Factors, Fishing Grounds, Biology, Economics. A total of 66 separate items were listed, falling within these categories.

Second, a table was made up in which each row and each column was assigned one of these items. The columns were designated inputs, the rows outputs. A sample of the upper-left hand corner of this importance relationship table is shown in Figure 3.2.0-I.

Each intersection was then examined and an importance value assigned to it based on the best judgement of the staff. Scores ranged from 0 to 6, 0 indicating no relationship, 6 indicating a vital relationship.

To score and interpret the importance relationship table, it is read as follows: "The ________(input) bears a ________ (depending on the score) relationship to _______(output)." In other words, one might say "The displacement bears a fairly important relationship to scantlings." or, "The range bears a very slight relationship to the horsepower of the auxiliary machinery".

### 3.3.0 The System Model

The System Model, Figure 2.0.0-I, was derived from the more important relationships (those scoring 4 and over) in the importance relationship table described in Section 3.2.0. This model, graphically portraying the complex relationships in a fishery up to unloading the catch, is sufficiently general in nature to apply to virtually any fishery. Although certain terms may require adjustment in phraseology to fit local or industry custom, the model provides a means of checking relationships and interrelationships within a given fishery.

The complexity of the industry is readily apparent as one studies these relationships. It should be borne in mind that these represent only the more important relationships.

Figure 3.2.0-I

Portion of Importance Relationship Table

INPUTS →

OUTPUTS →

| INPUTS | Load Water Line | Beam | Draft amidships | Depth | Displacement | Speed | Range | Prismatic Coefficient | Position of Longitudinal Center of Buoyancy | & angle of entry | Metacentric Height | Hull Form | Construction Material | Scantlings | Hull Finish | Stabilization System | Stern Chute | Horsepower, Main Engine | Horsepower, Auxiliary Engines | Electrical System | Methods of Auxiliary Power Transmission | Propeller |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | . | . | . | . | 4 | . | . | . | . | . | 2 | . | . | / | . | 1 | . | . | . | . | . | . |
| Cost | . | . | . | . | . | 1 | . | . | . | . | . | 2 | / | 6 | 4 | . | . | . | . | . | . | 1 |
| Hull Form | 1 | 3 | 2 | 2 | . | 3 | 2 | 2 | . | 1 | 5 | / | 2 | 2 | . | 3 | . | . | . | . | . | 3 |
| Metacentric Height | . | . | . | . | . | . | . | . | . | . | / | . | . | . | . | 3 | . | . | . | . | . | . |
| Center of Buoyancy & angle of entry | . | . | . | . | . | 2 | 1 | 1 | 1 | / | . | 1 | . | . | . | . | . | . | . | . | . | 1 |
| | . | . | . | . | . | 2 | 1 | . | / | 2 | . | . | . | . | . | . | . | . | . | . | . | 1 |
| Prismatic Coefficient | . | 1 | 1 | 1 | . | 3 | 2 | / | 1 | 2 | 1 | 1 | . | . | . | 1 | . | . | . | . | . | 2 |
| Range | 2 | . | . | . | 2 | 4 | / | 1 | 1 | 1 | . | 1 | . | . | 1 | 1 | . | . | 1 | . | . | 1 |
| Speed | 4 | 2 | 2 | 1 | . | / | 5 | 6 | 3 | 6 | . | 4 | . | . | 1 | . | . | . | . | . | . | 6 |
| Displacement | 6 | 6 | 6 | 4 | / | 6 | 5 | 2 | . | 3 | 1 | 2 | . | 4 | . | 2 | . | . | . | . | . | 5 |
| Depth | 1 | 2 | 2 | / | 1 | 2 | 1 | 2 | . | 1 | 3 | . | . | 2 | . | 2 | . | . | . | . | . | . |
| Draft amidships | 1 | 2 | / | 5 | 1 | 2 | 1 | 2 | . | 1 | 4 | . | . | 2 | . | 3 | . | . | . | . | . | . |
| Beam | 1 | / | 2 | 2 | 1 | 2 | 1 | 2 | . | 2 | 4 | . | . | 2 | . | 2 | . | . | . | . | . | . |
| Load Water Line | / | 1 | 1 | 1 | 1 | 6 | 1 | . | . | . | . | . | 2 | 2 | . | . | . | . | . | . | . | . |

VESSEL (Load Water Line through Stern Chute) · MACHINERY (Horsepower, Main Engine through Propeller)

### 3.4.0 The Vessel Optimizing Program

From the System Model described in paragraph 3.3.0 above, a program was derived for carrying out the optimization of the vessel. This program is not merely a mapping of functional relationships, as in the importance relationship table. Instead it must proceed mathematically toward the desired end, an optimum vessel. However, the functional model was the inspiration for the vessel program and could be used in similar fashion to derive programs for other aspects of the same fishery, or for a variety of aspects of other fisheries.

The Flow Chart of the complete program, together with definitions, values, and equations expressing the relationships, is included as Appendix 8.1.0, and a description of the computer mechanics is given in Appendix 8.2.0.

A starting point was required for the mathematical train which would lead to an optimized vessel. In essence, the fundamental harvesting device consists of a net at the bottom of the sea being towed by a propulsion system at the surface, the two systems being fitted with connecting warps and other necessary gear.

Upon this power/net system depends the number of fish caught per unit time. Upon the number of fish caught per unit time depends, in the final analysis, the number of men the vessel must have as crew, the size of the fish hold, and in conjunction with the machinery space requirements, the size of the vessel itself.

For the naval architectural part of the study, the vessel was initially defined in terms of cubic number, displacement, total horsepower, and crew size. From these, the secondary values of length, beam, depth, prismatic coefficient, speed, and other design considerations were derived.

It should be noted here that the use of cubic number as a primary definition of vessel size permits considerable latitude in establishing the proportions of the vessel, without affecting any other parts of the program to any appreciable degree. In other words, the designer or owner is free to have a vessel which is shallow relative to beam, or a proportionately wider or narrower vessel. Effect on steaming speed of altering these proportions will be slight in the over-all operation of the vessel. As long as the required crew, hold, and machinery requirements are met, the final proportions of the vessel can be adjusted to suit demands of convenience, functional efficiency, safety, comfort, or personal experience. Assuming CUBE and total horsepower are not altered, then changes in the proportions will not affect the economics.

The net and vessel characteristics and performance provide the necessary economic inputs of revenue and costs from which return on investment may be computed.

3.5.0 Major Design Characteristics

Any vessel, of whatever size, is an almost unbelievable collection of things, shapes, proportions, materials, etc. Nevertheless, certain major characteristics define a vessel quite explicitly. Following are general discussions of these characteristics, how they affect the design of a vessel, and how they are treated in this optimization study. The specific optimum vessel and its characteristics are dealt with in Section 4.0.0. Definitions, equations, values, etc., are covered in Appendix 8.1.0.

3.5.1 Shaft Horsepower

The shaft horsepower (SHFHP) required for propulsion of a fishing vessel is primarily a function of the resistance of the net being towed and the towing speed desired. A study of recorded net resistances, towing speeds, and main engine horsepower, has permitted the establishment of a relationship between net resistance horsepower (EFFHP) and installed shaft horsepower (Ref. FAO publications, Ref. 5-10 - Koyama, etc.). The difference between the two is absorbed by the resistance of warps and doors, the resistance of the hull at the towing speed, the propulsive coefficient, and other system losses. The graph, Figure 3.5.1-I, of EFFHP vs. SHFHP shows this relationship, which is also defined mathematically in Appendix 8.1.0.

3.5.2 Displacement

Displacement is perhaps the single most important characteristic of a vessel. Displacement defines the size of the vessel, its cost, and its performance at sea. From our study of available U.S. design data as published in periodicals, etc., the relationship of the necessary functional volumes, i.e., machinery, hold, and accommodation spaces, to the cubic number was established as shown in Figure 3.5.2-I. To permit translating CUBE to displacement, a relationship between cubic number and displacement was established as shown in Figure 3.5.2-II, also on the basis of available data on existing vessels.

3.5.3 Vessel Geometry

Given the displacement and shaft horsepower, it is possible by a relatively simple trial and error method to establish the optimum proportions for this combination. These proportions may be selected to give the maximum efficient steaming speed, although it should be noted that minor improvements available by this optimization are not of great importance where the grounds are relatively close to the home port.

Figure 3.5.1-I

Resistance of Net Only, EFFHP

vs.

Shaft Horsepower Being Used, SHFHP

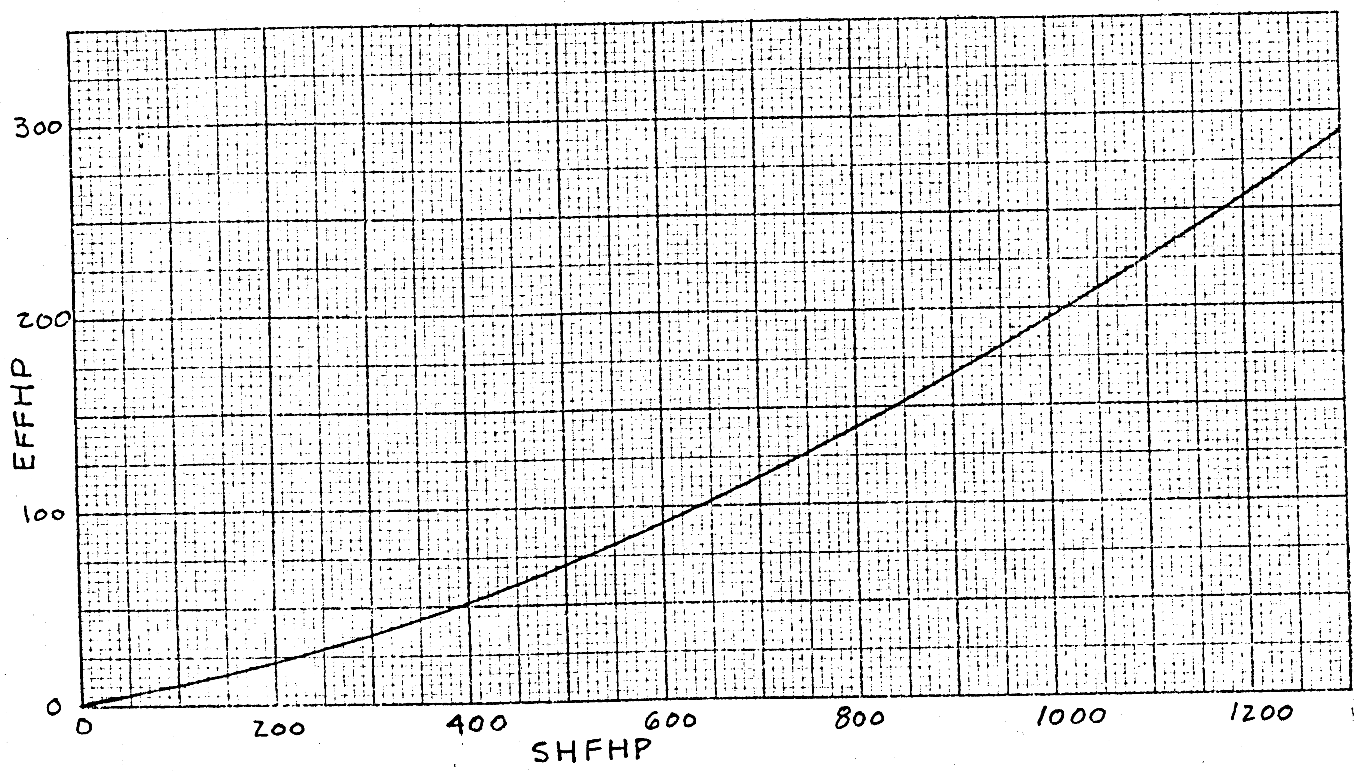
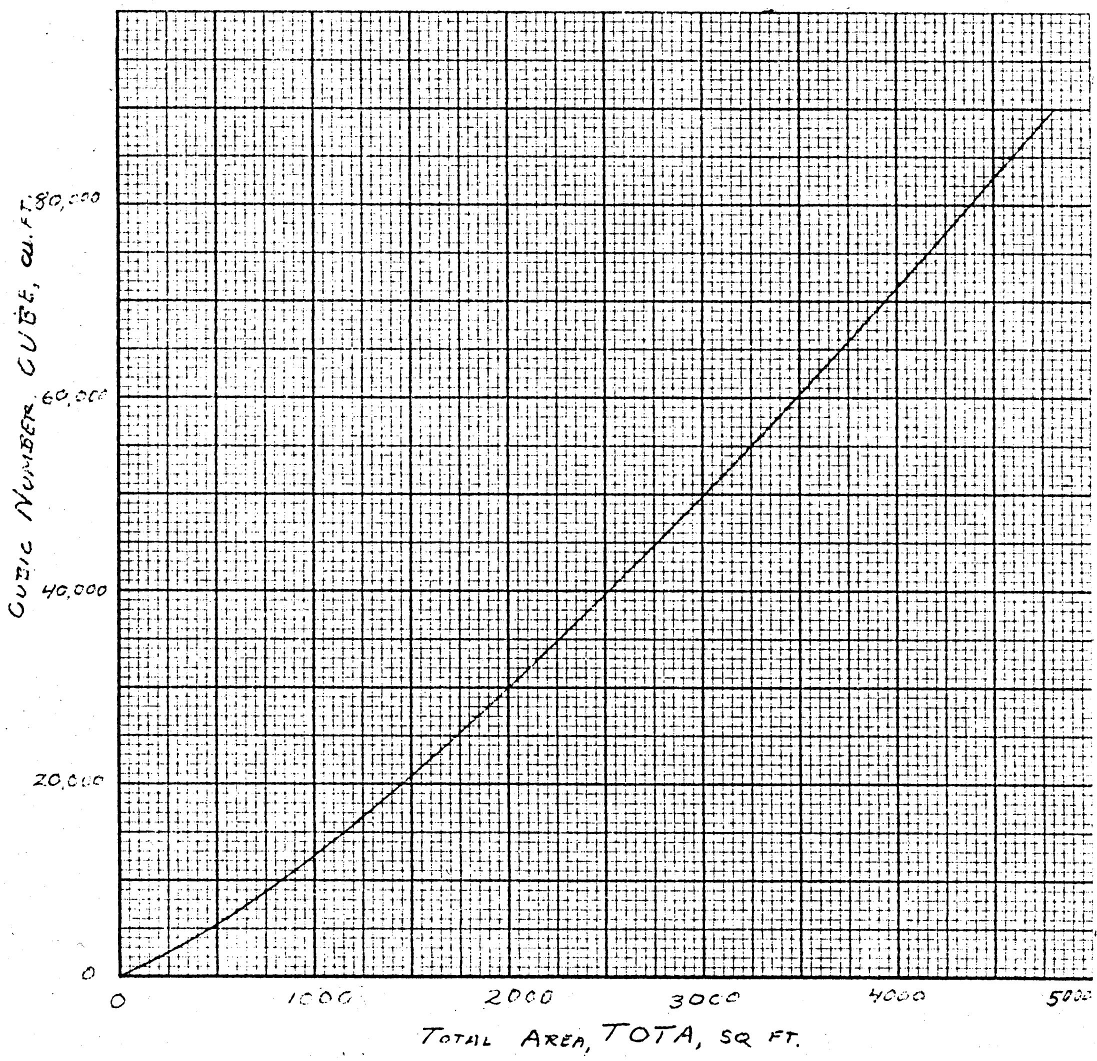


Figure 3.5.2-I

Cubic Number (CUBE)

vs.

Total Area (TOTA)

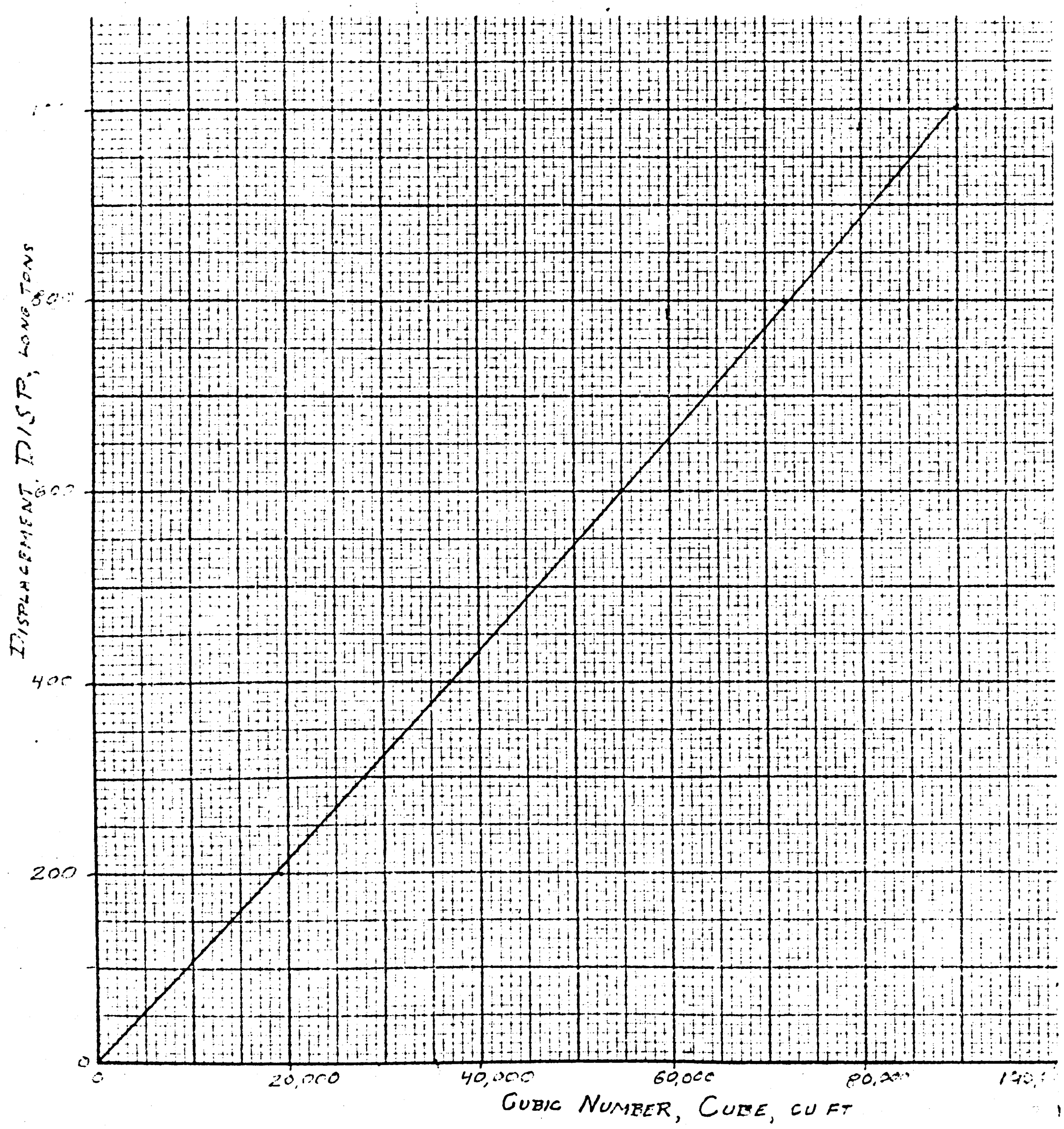


<u>Figure 3.5.2-II</u>

Displacement (DISP)

vs.

Cubic Number (CUBE)



3.5.3 (Continued)

A simple procedure for optimizing the proportions is as follows:

1. A vessel length is selected for a given displacement using a tentative value of $\frac{LWL}{\nabla^{1/3}}$ * = 4.25 (Ref.3-Geroult).

2. From the LWL, displacement, and shaft horsepower, an estimated steaming speed can be arrived at by one of several accepted methods, such as Geroult's curve of $R_c$ vs. $\frac{V}{\sqrt{L}}$.

3. The value of $\frac{V}{\sqrt{L}}$ derived in 2. above, is entered in Geroult's graph, and the minimum value of $\frac{LWL}{\nabla^{1/3}}$ was checked.

4. If this minimum value differs from the 4.25 tentative value, the calculation may be recycled to check on the optimum value.

After obtaining the optimum length, then beam and depth are easily obtained from the cubic number and the B/D relationship.

To obtain draft and midsection area, the prismatic coefficient, ($C_P$), may be selected from one of the accepted curves of optimum $C_p$ versus speed-length ratio. In the range of fishing vessel performance characteristics, $C_P$ is not of vital importance (Ref.3-Doust).

By conventional methods, the balance of the vessel characteristics are established pending preparation of the preliminary sketches.

3.5.4 Stability and Motion

Certain minimum standards of stability are necessary for the safety of the vessel. No international standards have been established as to the minimum stability suitable for fishing vessels, expressed as metacentric height (GM) but Takagi (Ref.2) suggests minimum GM standards for light and loaded condition as functions of freeboard, beam, and height of CG above CB. The minimum GMs offer a relatively simple check of stability and were used in this study.

With respect to icing, no vessels have been lost in recent years on Georges Bank because of over-icing. For this reason, no ice loading allowance has been made in assigning a value to GM.

Motion has a considerable effect on the comfort and efficiency of the crew. Studies by Möckel and others (Ref.2, 3) have established

* In naval architecture, the symbol Δ refers to displacement in long tons, the symbol inverted ∇ refers to displacement in cubic feet. The term $\frac{LWL}{\nabla^{1/3}}$ is a measure of the fullness of a vessel; it is sometimes symbolized by Ⓜ, spoken of as a "circle M".

3.5.4 (Continued)

on the basis of subjective judgements by crew members that a vessel can be too stiff or too tender for comfort and working efficiency. Optimum values of GM lie between 2.0 feet and 3.0 feet for rolling comfort, regardless of vessel size (Ref. 2 - Mockel).

Pitching is of much less significance to the crewmen. The major consideration here is the accelerations generated, although, again, the picture is not at all clear. Although fishermen objected to vessels with accelerations above .25g to .35g (Ref. 2 - Vossers), it has been shown (Ref. 2 - duCane) that high speed power boat accelerations of up to 4g do not cause distress to the passengers. It is quite possible that there is an accumulative effect from constant and frequent repetition of the accelerations and that sitting or standing still on a speed boat is not exactly comparable with moving and working on a fishing vessel. An unknown, but quite possibly important, damping effect on pitching may result from the warps of a stern trawler restricting heaving of the stern.

It is significant that the very narrow World War I subchasers (13' beam on 110' length over all) were known as exceptionally comfortable boats at sea. This undoubtedly stemmed from the low resistance to rolling of the very narrow beam, and the high inertial damping of the rather high freeboard.

Except for ascertaining that the GM is within the acceptable range of values, there does not seem to be a great deal of need to compromise other design characteristics to achieve small gains in comfort. The assumption made here is that a normal hull form of adequate stability has comfortable motions.

3.5.5 Arrangement

For ease in planning, the arrangement above the main deck may be considered relatively independent of that below the main deck. Although certain accommodations between the two must be made, major distributions of each are independent of the other. These will therefore be considered separately.

Below Deck

The major consideration below deck is the distribution of the variable weights so that the best available trims are obtained over the widest loading variations to be met with in practice. A prime trim requirement is that the propeller be adequately submerged in the water at

3.5.5 (Continued)

all times to perform with acceptable efficiency; this requirement is not as important where the propeller is shrouded in a nozzle. For this reason, most variation of trim will be concentrated forward, but here again if a vessel trims too heavily by the bow, she may be difficult to steer, especially in a quartering sea.

The major weight variables are ice, fish, fuel, water. The variability of the weights are presented schematically in the graph, Figure 3.5.5-I. An analysis of the variations in weight and the position of these items, compared with the desired trims at various degrees of loading, will assist in the below deck arrangement.

The fish hold must obviously be located near the center of the vessel because of the large weight variation in the catch. With the new, light-weight engines, the engine room may be located forward or aft of the fish hold.

The advantages of the engine room aft, with the crew's accommodations forward, is that noise and fumes are reduced in the accommodations, and there is no shaft hump through the fish hold. Drawbacks are that the exhaust stacks and access companionways may constitute obstructions on the afterdeck, and space may not be used quite as efficiently due to the fining up of the hull as it tapers into the propeller aperture.

On the other hand, the engine room forward has ready access directly from the quarters (of a stern trawler), and keeps the entire after part of the vessel clear for the fishing operation. Drawbacks are that the shaft passes through the fish hold, possibly creating an obstruction to transverse passage in the hold and to en route servicing of the shaft, and required additional shaft length and fittings, and the accommodations are more readily subject to noise and vibration from the machinery.

The determination of below deck arrangement of fish hold, fuel tanks, etc., is largely a mathematical matter. The location of the engine room and accommodations, however, is more subjective and will reflect the experience and attitudes of the vessel owner and skipper.

Above Deck

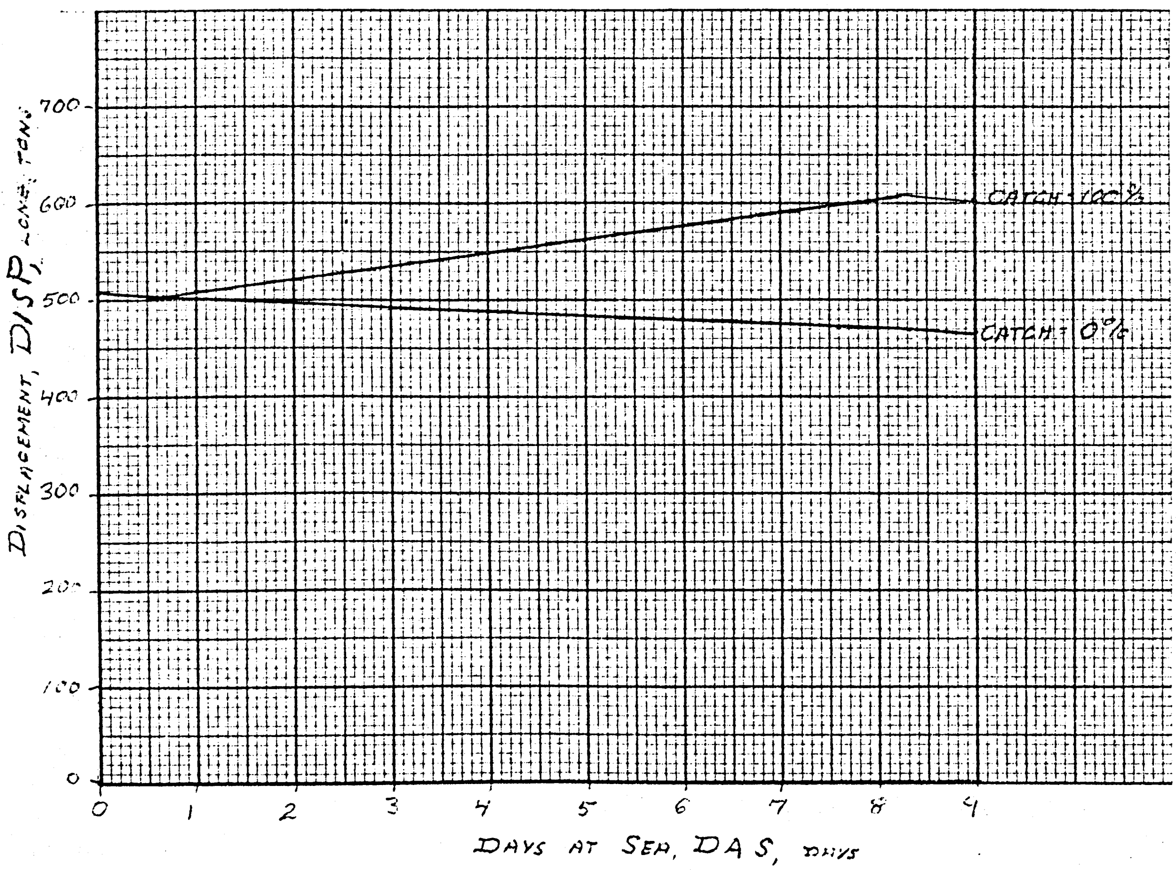
Of course the fundamental consideration here is whether a vessel is to be a side trawler or stern trawler. This is discussed later in Section 3.6.1. If the stern trawler configuration has been selected, then the only decision remaining are the location of the pilot house and the distribution of the fishing and processing gear.

3.5.5 (Continued)

With respect to the pilot house, in either type of vessel, it seems advisable to have maximum visibility in all directions. This is partly a matter of safety, as several New England fishing vessels have been lost by being run down from astern. Perhaps more important in this day of increasing use of pilot house controls of deck machinery, is the need for the captain to be able to con his vessel at the same time that he has maximum visibility of the entire scope of operations on deck. The location of the pilot house can thus be of great importance, and should be located with the assistance of the captain.

Figure 3.5.5-I

Displacement (DISP) Variations
vs.
Days at Sea (DAS)



3.6.0 Major Trade-offs

In the optimizing process much of the fundamental vessel, with associated gear and methods, was quite explicitly defined by the nature of the fishery itself and the constraints recorded in Section 1.4.0. Nevertheless, certain innovations have either been adopted by some fishermen in the Georges Bank fishery, have found acceptance in other similar fisheries, or have otherwise demonstrated their usefulness in ordinary commercial practice. Following are discussions of those alternatives for which valid data, knowledgeable opinion, or experimental information are available. Obviously, such a list is subject to expansion as fishing and vessel technology advance. Nevertheless, for the purposes of this study, these alternatives were considered to combine practicality and potential profitability to a high degree.

In evaluating these trade-offs, the only measure used has been an improvement of return on investment. Figure 3.6.0-I is a generalized flow chart for evaluating trade-offs.

3.6.1 Stern vs. Side Trawling

The stern trawler is rapidly moving into the fisheries and replacing the side trawler. This is a fairly recent development since World War II, begun principally in England, and with each country producing its own variations. These variations, particularly noticeable in deck equipment and gear handling methods, have aroused considerable controversy, but this does not minimize the impact of the stern trawler concept on the fishing fleets of the world. It is perhaps an even greater revolution in the fisheries than that resulting from the introduction of the diesel engine.

It is probably safe to say that the stern trawler configuration will completely replace the side trawler in most sizes, as rapidly as new vessels replace old. The choice is still a moot one, however, among those contemplating the smaller size of vessel.

Although stern trawlers have been designed and built as small as 28' LOA, there is a body of opinion which considers the small stern trawler to be less desirable than the small side trawler. It is difficult to obtain explicit reasons for this opinion, but it may be a combination of the inertia of tradition and the reports of some of the rather expensive growing pains of early stern trawlers.

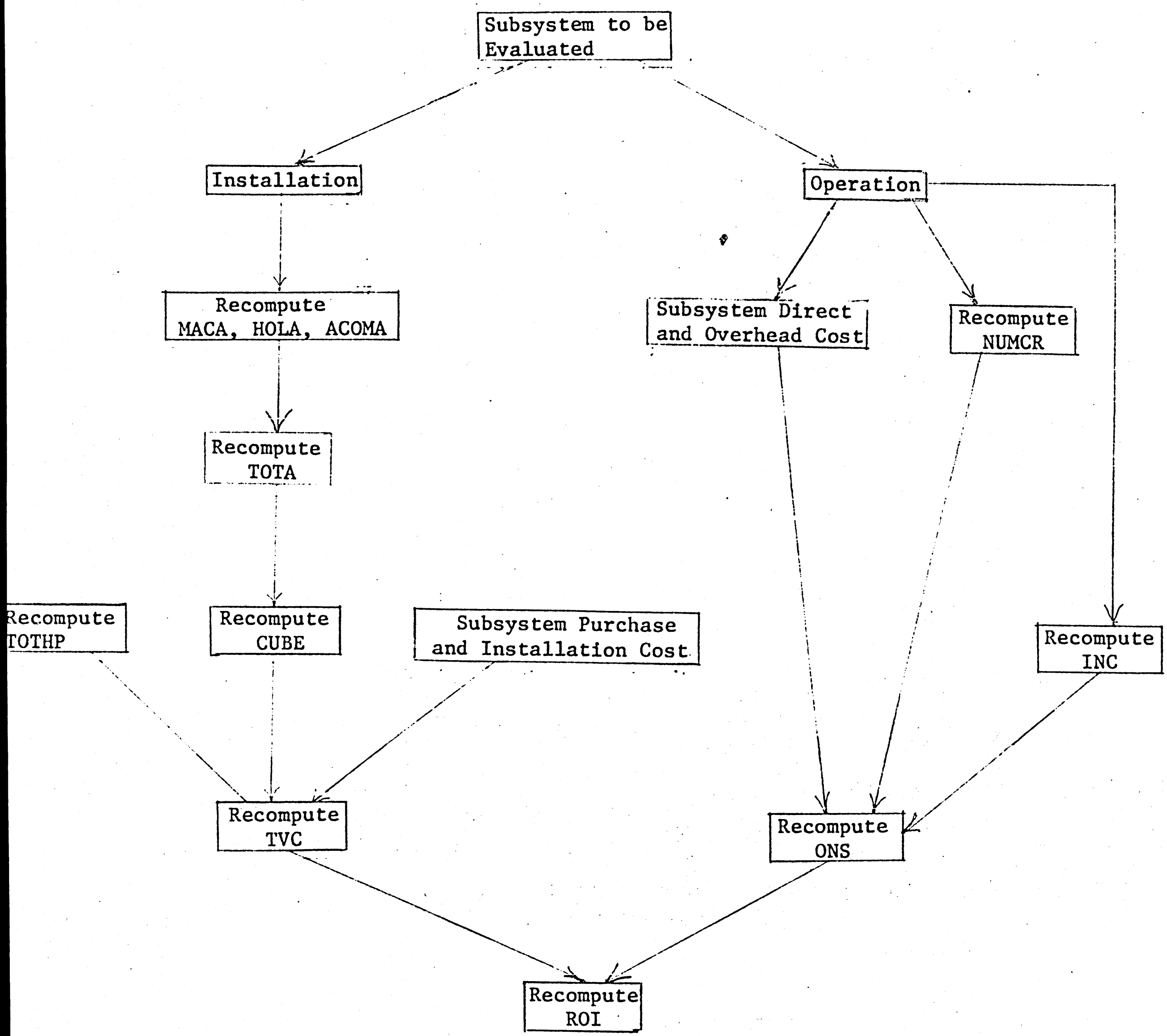
The fact remains that opinion is by no means unanimous as to the advantages of the stern trawler configuration in the smaller sizes.

Dr. Frederick Bell, of the Federal Reserve Bank of Boston, (Ref. 19) in 1966 endeavored to make a logical and valid comparison be-

Figure 3.6.0.-I

FLOW CHART

for SUBSYSTEM EVALUATION




Referring to the detail flow chart, equations, and definitions, in Section 8.1.2, recompute only those values above which are affected by introducing the subsystem under study.

The method of subsystem evaluation noted here may be applied to existing vessels and designs as well as to vessels in the preliminary design stage.

3.6.1 (Continued)

tween side trawling and stern trawling. At that time, there were no data available from the Georges Bank fishery as no U. S. stern trawlers were then fishing. The basic assumptions made by Dr. Bell were that a stern trawler cost 20% more than a side trawler of the same size, and the stern trawler was able to land 20% more fish, partly because a Canadian study indicated that the stern trawler was able to shoot and haul its nets in considerably less time than the side trawler.

Since Dr. Bell's study, one stern trawler has been groundfishing for one year, and Ocean Research Corporation has completed its study on fishing vessel costs (Ref. 81).

The ORC cost study indicated quite conclusively that construction costs of both stern and side trawlers are virtually the same, as indicated in Table 3.6.1-I. The question in comparing costs is whether in fact equal vessels are compared. As a rough comparison, cubic number $^{N}LWL$ = LWL x Beam x Depth to Main Deck, is accepted as the most accurate of the readily available cost parameters. This is reasonable, in that the structural size and weight of the vessel are approximately proportional to the cubic number. Except in special cases, the basic equipment is roughly similar for both side and stern trawlers and the cost would in turn be approximately proportional to cubic number.

If construction costs of the two types are equal, the problem of comparison is considerably simplified because it to some degree removes the need for quantifying the parameters used in the comparison. In other words, if all advantages are qualitatively on the side of the stern trawler, then the stern trawler may be said to be the superior configuration, without actually being able to state the measure of superiority.

As to the improved productivity, there seems little doubt that stern trawlers do in fact land more fish. However, whether this is a result of functional improvement, such as faster net handling or ability to fish in worse weather, or because a stern trawler is apt to attract more able skippers and crews and is likely to be somewhat better equipped, is not clearly understood.

From the reports of fishermen, there seems no doubt that the stern trawler can continue to fish in weather which causes the side trawler to cease operations. This will increase the hours during which the net is on the bottom.

Another increase of net time on the bottom may be due to somewhat improved conditions for hauling and shooting the trawl. This would seem to be indicated by the statement of one owner of both kinds of vessels

Table 3.6.1-I

RELATIVE PRICES OF U.S. FISHING VESSEL TYPES

| Type | Const. Material | Avg. Ratio of $\frac{\text{Low Bid}}{N_{LWL}}$ | Number of Boats in Sample | Relative Cost, Stern Trawler = 100 |
|---|---|---|---|---|
| Stern Trawlers | Steel | 16.48 | 8 | 100 |
| Side Trawlers | Steel | 17.00 | 4 | 103 |
| Side Trawlers | Wood | 10.90 | 4 | 66 |
| Scallopers | Wood | 15.50 | 5 | 94 |
| Shrimpers | Steel | 14.60 | 2 | 89 |

Explanation of Table:

This comparison is based on the average value of $\frac{\text{Low Bid}}{N_{LWL}}$, or dollar per cubic foot of block, for each type. The vessels selected for rhe comparison were quite evenly distributed over a relatively narrow range of sizes ($N_{LWL}$ = 18,000 to 41,000) so the effect of size should be small.

The values of $\frac{\text{Low Bid}}{N_{LWL}}$ can be used for rapid estimating of the cost of the various types of fishing vessels by multiplying the cubic number (= $N_{LWL}$ = LWL x Beam x Depth) by these values. The resulting figure will be a roughly estimated price as of July 1, 1967, of a vessel of the particular type with average specifications, power, and outfit.

Source: "Fishing Vessel Construction Costs and the U. S. Fishing Vessel Construction Differential Subsidy", Ocean Research Corporation, 1967.

3.6.1 (Continued)

that whereas shooting and hauling in 30 fathoms of water took 15 minutes for a side trawler, for the stern trawler it was only 12-13 minutes in 40 fathoms of water (see Appendix 8.1.5 for further discussion of handling time). It might be added that this particular owner has no doubts about the success of the stern trawler.

Additional factors tending to improve the overall productivity of the stern trawler include the ability to use net reels rather than heaving the net manually, the larger and more protected deck space available for handling gear and processing fish, the potential ability to fish by virtually any known method in addition to bottom and midwater trawling, such as long lining, seining and pot fishing, and the ability to provide somewhat more comfortable living accommodations for the crew.

In the light of the equality of construction cost, the quantitative advantages and qualitative advantages, and the success of the stern trawler in other fleets as measured by its popularity, it was decided to adopt the stern trawler configuration for the optimum design.

It may be appropriate to close this section with a portion of a news story from the March, 1968, edition of "Fishing News International":

> "CREWS PREFER THE
> STERN TRAWLERS
>
> The addition of stern trawlers to the deepsea fishing fleet of Newfoundland has made it increasingly difficult to man the older-type side trawlers.
>
> A number of ships have been tied up since before Christmas because crews just will not sail on them as long as work is available aboard the more comfortable stern trawlers which can carry larger payloads with resultant higher earnings for the crews."

### 3.6.2 Controllable Pitch vs. Solid Propeller

The controllable pitch propeller is one in which the blades of the propeller can be altered from a maximum pitch ahead through neutral pitch, to a maximum pitch astern. Perhaps the major advantages from the fisherman's standpoint of the controllable pitch propeller is that it permits selection of an optimum pitch to suit virtually any condition, it permits instantaneous "vernier-type" speed and direction control, and it allows "inching" without stalling the engine. The disadvantages, as compared with the solid propeller, are that it involves a considerably greater number of moving parts in the propeller and shaft system, and the additional cost is considerable. The cost of a controllable pitch propeller, complete from the engine coupling and including shaft, sailing clutch, propeller controls, is approximately 40% more than for a conventional solid propeller drive system.

When propulsion conditions are approximately constant throughout the use cycle of a vessel, there is little need for a controllable pitch propeller. Although the free-running speed and resistance of a fishing vessel shows relatively little change, with load variations, the hydrodynamic difference between the steaming condition as 10 to 12 knots and the towing condition at 3 or 4 knots is considerable. For a solid propeller designed for optimum free-running, the efficiency will drop 50% to 60% when towing at a speed of 25% of the free-running value.

Under the best conditions, then the solid propeller cannot be expected to function with top efficiency in both free-running and dragging situations. This poor performance when towing may be aggravated by cross-wind, waves, and currents to a point where, in the author's experience, the propeller blades are beginning to cavitate and VT has dropped virtually to zero.

To make full use of the available SHFHP over the wide variety of conditions under which a trawler must function requires a controllable pitch propeller. It is accordingly included in the Optimum Vessel.

### 3.6.3 Kort Nozzle

The Kort nozzle is a device for improving the thrust of a propeller. In essence, it consists of an annular ring fitted closely around the propeller. The proportions and shape of the nozzle is such that for a given shaft horsepower it provides a greater thrust with a smaller diameter propeller.

Nozzles may be either fixed, in which case the steering is done with a conventional rudder, or the nozzle itself may be steerable which directs the propeller slipstream thrust in the direction of turning.

3.6.3 (Continued)

Nozzles are fairly expensive, and steerable nozzles are of course more so. One of the latter may be expected to cost approximately $10,000 to $12,000 installed, for a vessel in the general size range under discussion in this study.

Besides improving thrust, the nozzle has other advantages, Perhaps of most importance to the fishermen, it tends to shield the propeller from entanglement by warps or other gear hanging over the side. It also has a small effect in damping out pitching, reducing amplitude and increasing the period (Ref. Taylor Model Basin). The nozzle also acts to limit ventilation of the propeller, important in vessels with wide variations of trim and when pitching heavily, i.e. when the wave length approximately equals the vessel length.

Although the nozzle is expensive, it requires virtually no maintenance once installed, being a heavily built and sturdy piece of equipment. Since the first cost can be depreciated over the entire life of the vessel, the added advantages of increased thrust, improved steering and position holding,and propeller protection are increasing the popularity of the nozzle. Quantatively, "Principles of Naval Architecture" (Ref.101) states that when $B_p$ (Taylor propeller coefficient) is equal to or greater than approximately 100, a nozzle should be used. Since a trawler, when dragging, can have a $B_p$ of 1000 or more, there is no question that on propulsions grounds, a nozzle is indicated.

As to whether the nozzle should be steerable, replacing the conventional rudder, this decision requires a fairly subjective judgement. However, one owner has expressed his satisfaction with the steerable nozzle, and since the turning characteristics of a fishing vessel while towing, whether side or stern trawling, are rather unfavorable, the added maneuverability stemming from the directed propeller slipstream is considered to be worth the extra expense.

3.6.4 Boxing of Fish vs. Bulk Stowing

Under the present system of purchasing fish, and the unloading of fish from the vessels, there is little incentive to improve quality of the catch by boxing at sea. Boxes utilize appreciably less of the hold volume (23 to 24 lb./cu. ft for boxed fish vs. 30 to 32 lb./cu. ft for bulk fish). In addition, the extra work of packing fish in boxes prior to stowing below means additional labor cost per unit weight of fish, labor time which is not rewarded by higher prices (Ref. 98-(o)).

Nevertheless, as has been demonstrated in other countries, fish boxed at sea are of higher quality, and maintain their quality longer than fish stored in bulk. This results not only from total elimination of crushing, but also because the fish are stored in easily cleaned, relatively germproof containers, and hence maintain their low bacteria count for a longer period of time, and the fish are handled fewer times.

For purposes of comparison, a vessel with a 200,000 lb. capacity of fish would require 2,000 cu. ft more fish hold volume to store an equal amount of fish, and at a cost for boxes of approximately $20,000 initially, and a replacement cost/year of $5,000 at a 25% replacement rate.

There is no indication that revenue would show an appreciable increase per pound of fish for this extra expense and the additional labor involved. For this reason boxing at sea is not considered for the Optimum Vessel. It should be noted, however, that the move toward more rigid Federal control of fish quality may well make boxing at sea desirable if not mandatory.*

### 3.6.5 Untended Engine Room

The untended engine room may be defined as an engine room which requires no attention during a voyage, which could in fact be locked or sealed. Maintenance requirements, and control operations normally performed by an engineer in the engine room, are carried out automatically during the voyage. The entire propulsion and auxiliary complex is monitored to indicate trouble spots by means of visual and sound warnings; in vessels of fishing vessel size the monitoring console and all operating controls are located on the bridge. All maintenance measures would be carried out between voyages by trained, shoreside personnel whose services might be contracted for on an annual basis.

The benefits of the untended engine room are: No engineers are required on board, since all controlling and monitoring of the machinery is carried out from the bridge or by automatic instrumentation within the engine room; main and auxiliary machinery systems are at the direct fingertip control of the officer on the bridge; there would be more rapid response to trouble from the monitoring instrumentation than from a human monitor.

In the event of a component failure, the location and approximate nature of the trouble would be indicated on the monitoring console and the officer on watch would take corrective action, if neccessary entering the engine room to make an on-the-spot inspection and if possible a diagnosis and repair. If the cause and solution of the problem were not immediately apparent, the officer could communicate by radio-telephone with the maintenance personnel on shore for advice on correcting the difficulty. In extreme cases,maintenance personnel could be flown to the vessel with the parts necessary for correction of the trouble.

Untended engine rooms have been common in yachts of small and moderate size for many years. In addition, many different types of untended power installations are in regular service, such as emergency power plants, automatic pumps,etc. Recently, untended engine rooms have moved into

* The Whitefish Authority reports an increase in unloading rate of 1.59 to 2.65 times of boxed over bulk fish, and a reduction in unloading crew size by a fact of from .31 to .47.

3.6.5 (Continued)

Mississippi River towboats, and have been studied for fishing vessels (Ref. 98-p). There is no reason to believe, therefore, that there are any mechanical or practical blocks to adoption of the untended engine room concept to fishing vessels.

On many hard-working fishing vessels the engineer spends a percentage of his time assisting in the actual fishing operations. The percentage of time contributed by the engineer to the fishing operation allows the optimization process to ignore the fact that people come in units, and not fractions, with the engineer filling in the curve between the unit crew numbers. Therefore, the omission of one or two engineers may not actually afford a proportionate increase in the shares for the crew remaining.

Because there is no clear cut economic advantage, supported by statistical data, for the untended engine room, this feature is not included in the Optimum Vessel. Nevertheless, for the owner who wishes to consider this feature, a cost of $13,000 to $16,000 has been reliably estimated for the installation of the automatic devices, monitoring instrumentation, and remote control, necessary to provide an untended engine room. No additional space requirements would be necessary in the vessel to accommodate this equipment.

3.6.6 Anti-Rolling Devices

Perhaps more than any other type of seagoing vessel, commercial fishing demands virtually continuous work on deck. While fishing, half the crew is on deck-watch at any time and under normal catching conditions is working virtually the entire time.

The high accident rate for fishing vessels is second only to coal mining (Ref.15). This is easy to understand when one considers that fishing is carried out on the rolling deck of a vessel, day and night, in all kinds of weather and temperatures, hooking and unhooking doors weighing from 1200 to 2000 pounds, 300 to 400 times each trip, processing fish with extremely sharp knives, and generally working around on a footing made hazardous by fish, gurry, fishing gear, cables, etc.

The hazards of fishing can be mitigated and the comfort of the crew increased, by reducing the effect of rolling. This reduction may consist of reducing the rolling angle and/or increasing the rolling period. Devices available to reduce the effects of rolling may be active, such as anti-rolling fins or activated flume stabilizing tanks, or passive, such as passive stabilization tanks, bilge keels, or stabilizing planes (the "flopper stoppers", popular on the West Coast). For a fishing vessel, which spends

3.6.6 (Continued)

its working time at relatively low speeds, devices such as anti-rolling fins requiring forward motion are not practical.

Recently, the anti-rolling tank has received a good deal of notice for all types of vessels. These tanks may be of the active or passive type; in the passive type the fluid contained in the tank flows naturally from side to side;in the active type the fluid is forced against its natural inclinations by means of pumps or air pressure. The theory of the anti-rolling tank is that the flow of water in the tank can be brought 90° out of phase with the rolling of the vessel, yet maintain the same period. The result, ideally, is that the mass of fluid in the tank is moving to the side of the vessel rolling upwards and away from the side of the vessel rolling downward. The effect is to reduce the roll angle by about 50% for passive tanks, and as much as 85% for the active type (Ref. 101).

The reduction in roll for the stabilization tank is impressive. Nevertheless, they require considerable space and weight of fluid (1/2% to 2% of the total displacement of the vessel). In some cases fuel is used, but this then eliminates this fuel as a realistic supply for the machinery, unless it is replaced with water.

Bilge keels are the traditional method of limiting the effects of roll. They accomplish this by increasing the amount of sea water which must be moved by the vessel as it rolls, leading to reduced angle and increased period. Bilge keels are trouble-free, and reasonably effective, reducing the roll by up to 50% (Ref. 101), but they have drawbacks. They result in some increase of resistance at steaming speeds, particularly if there is much change of trim. Where gear is handled over the side, they may constitute a hazard to the gear itself. Nevertheless, bilge keels of the most efficient type, which will fit within the docking rectangle of the vessel, are very likely worth the modest expense and the small increment of resistance when steaming. Bilge for the Optimum Vessel are described in Section 4.2.0.

Another development which shows considerable promise are the "flopper-stoppers" used on the West Coast (Ref. 102). These are metal planes suspended well out from the side of the craft in a horizontal plane. They offer excellent promise where they do not interfere with the fishing operation. Combining simplicity and low cost, they are undoubtedly well worth consideration for all fishing vessels for reducing roll angle and increasing the rolling period. Date published in the above reference gives sizes and weights of planes for vessels up to about 90' LOA. "Flopper-stoppers" for the Optimum Vessel are described in Section 4.2.0.

### 3.6.7 Shipboard Fish Meal Plant

Small fish meal plants for shipboard installation have been receiving increased attention, especially in the Gulf of Mexico shrimp fleet. These plants are intended to increase the profit by turning the waste of the fishing operation (offal, trash fish, etc.) into a relatively dry meal, high protein, for use as a supplement in animal and poultry feeds and perhaps eventually as raw material for fish flour for human consumption.

If a fish meal plant will increase the ROI of the Optimum Vessel, then it is worth while installing. From that point of view, the ROI was recalculated to include installation and operation of a fish meal plant, and storage of the meal, and compared with the ROI without the fish meal plant.

The following assumptions were made - a) 20% of the catch is trash fish, b) 5% of the edible catch is offal, c) the stowage factor for fish meal is 80 cu. ft. per ton, d) 50% by weight of fish meal is protein, e) the selling price of fish meal is \$2.00 per percentage point of protein per ton, f) the output of the plant in fish meal by weight is 20% of the input by weight, and g) it will require one extra man per watch to maintain and operate the plant, including sacking and stowing the finished meal. Therefore,

$$\text{edible CATCY} = 3800 \text{ lb.}$$

$$\text{trash fish CATCY} = .20\ (1.25)\ 3800 = 950 \text{ lb./cycle}$$

$$\text{offal CATCY} = .05\ (3800) = 190 \text{ lb./cycle}$$

$$\text{total convertible fish/cycle} = 950 + 190 = 1140 \text{ lb./cycle}$$

total convertible fish, (short) tons/12 hrs

$$= \frac{12 \times 60}{119} \times \frac{1140}{2000} = 3.45 \text{ tons/12 hrs}$$

$$\text{fish meal yield, lb./cycle} = .20 \times 1140 = 228 \text{ lb. cycle}$$

$$\text{fish meal landed per trip, tons} = \frac{228}{2000} \times 78.1 = 8.9 \text{ tons/trip}$$

$$\text{fish meal landed per year, tons} = 3.63 \times 31.82 = 283.3 \text{ tons/yr}$$

landed value (income), fish meal/yr

$$= 283.30 \times 50 \times \$2.00 = \$28,330$$

The deck area of a typical fish meal plant suitable for handling 3.45 tons of fish per 12 hours is 38.1 sq. ft.; allowing for working space, the required operating deck area was set at 70 sq. ft. Hold area required, at 80 cu. ft./ton and a hold depth of 10' = 71.2 sq. ft. Two extra men will require an increase of 142 sq. ft. in accommocation area,

3.6.7 (Continued)

and an additional 80 HP is required to operate the plant. The plant itself lists at $19,500, and 20% was allowed for installation costs, for a total cost of $22,800.

The table below summarizes the results of the calculations, and compares the vessel without the fish meal plant to the vessel with the plant.

| | Without plant | With plant |
|---|---|---|
| TOTA | 3,187.3 | 3,472.9 |
| TOTHP | 1,185 | 1,265 |
| NUMCR | 16 | 18 |
| CUBE | 53,315 | 60,070 |
| TVC | 835.6 | 949.6* |
| INC | 1,117.82 | 1,146.1 |
| ONS | 223.1 | 213.7 |
| ROI | 26.7% | 22.5% |

This comparison, based on the assumptions stated initially, clearly indicates the installation and operation of a shipboard fishmeal plant will reduce the ROI when fishing at the optimum level. As the conditions of operation of the vessel changed, however, a shipboard fishmeal plant may well become economically desirable.

3.6.8 Shipboard Irradiation

The use of sub-atomic radiation to pasteurize and sterilize food products is advancing rapidly, and holds out great promise. Fish such as haddock, exposed to radiation of approximately 250,000 rads (radiation absorbed dose) will remain fresh, on ice, two to four times as long as without irradiation. (Ref. 103). The advantage of irradiating the fish at sea, immediately after catching, is that a much smaller (and thus less expensive) dose is effective because the bacteria count is low. The cost per pound of irradiating fish at sea has been estimated at $.02 (Ref. 104), based on the cost of the irradiator and the necessary additional labor.

The promise inherent in irradiation should motivate fishing vessel owners to keep in mind the possibility of future installation of the necessary facilities. For this study, however, a shipboard irradiator was not given consideration, on the following grounds:

1. There is no existing design for a shipboard irradiator combining satisfactory equipment weight with production rate. The experimental units so far produced have a weight of 34,000 lbs. and a production rate of 360 pounds

* TVC includes an extra $22,800 for cost of fishmeal plant, installed, as well as additional cost resulting from increased CUBE and TOTHP.

pounds per hour (Ref.103). The considerable weight consists largely of lead shielding necessary to protect personnel from the high energy gamma radiation of the Cobalt-60 source. The specific weight may be expressed as $\frac{\text{Equip.Weight, lb.}}{\text{Hourly production, lb.}}$ or 94.5 for present equipment. Even if the specific weight could be cut in half, the equipment weight required to process each thousand pounds of fish per hour will be 94,500 lb.

2. Additional labor requirements may be considerable. Apart from that necessary to load and unload the irradiator, preliminary packing of the fish in plastic film and then the containers for irradiation will require labor above that required for simply iced fish. The decision must also be made whether to reduce labor costs but increase irradiation costs by irradiating the whole fish, or to filet the fish first and thus increase labor costs, but reduce treatment costs.

3. Other uncertainties pertaining to irradiation are: (1) whether lower energy radiation, such as beta rays (from Caesium) or even X-rays, may not be adequate for treating fresh-caught fish, with greatly reduced shielding and safety requirements; (2) approval by the Food and Drug Administration of all varieties of fish produced on Georges Bank; (3) the design of high-rate producing units and ancillary packaging, etc., equipment.

On the basis of the tradoff constraints set forth in Section 1.4.0, irradiation at sea was not due for consideration. Nevertheless, its potential for the future seemed to warrant this discussion.

### 3.7.0 Crew

As noted in the constraints, Paragraph 1.4.0, the crew situation, with respect to the optimum fishing vessel, will be essentially the same as it is now on the Boston fishing fleet. In other words, demonstrated maximum rates of production per man will be utilized, and the existing lay system of payment, with minimum daily pay for "brokers", will be used.

### 3.7.1 Crew Requirements

The labor demands on a fishing vessel may vary considerably in the course of the fishing year. Pounds of fish caught may vary in the proportion of one and two in the course of a year, and certain species of fish,

3.7.1 (Continued)

such as whiting, red fish, and flounder require no processing labor, while others such as haddock, cod, etc., require gutting and cleaning.

The assumption made in this study is that a constant level of effort will be required during the fishing year. In other words, the crew is sized to process the catch of each drag before the next drag is hauled, with adequate time out for the hauling and shooting process. Since, under the lay system, labor costs are dependent upon the landed value of the fish, and not upon the number of crew members, the exact number is important primarily as it affects the size of accommodations and hence the cost of the vessel, with a small difference in operating cost reflected in insurance, overhead, etc.

The best available data (unpublished) on the level of productivity of the processing crew gives values of approximately 6.25 lb. per man per minute of processing. This is based on studies which indicate that a four-man crew, made up of one ripper, two gutters, and one icer, can consistently handle a maximum of 4,000 pounds of fish per catch. In another study, a ripper was timed at a rate of approximately 10 fish per minute, or 20 pounds, the fish being 2 lb. haddock; this gives a team rate of 5 lb./man/minute.

The Technological Laboratory of the Bureau of Commercial Fisheries in Gloucester, Massachusetts, has been experimenting with improved processing arrangements for fishing vessels. Their developmental work has been sufficiently demonstrated to include the gear on the Optimum Vessel. The primary function of this processing system is to increase productivity per man by reducing the physical effort presently required in stooping, bending, etc., involved in the present processing methods. The productivity per man is estimated to be increased by 30% to a rate of approximately 8.1 lb./man/minute, when the system is used. In addition, this improved processing system should significantly lengthen the healthy and efficient life of the fisherman by reducing the motions required of the body (Ref. Pg. 79, World Fishing, June 1967). A processing rate of 8 pounds per man per minute has been used in this study, to reflect the increased rate of the BCF-developed deck processing equipment.

The assumption in sizing crews is that there is sufficient flexibility in the labor distribution to fit a continuous curve of labor requirements rather than a stepped curve. If there were not this flexibility, the program would be required to reject decimal parts of people and round off to the next highest whole number.

The method of obtaining the crew size is to assume one non-processing officer per watch, at least part of one engineer and one man per watch for each 8.0 pounds of fish caught/minute, plus one cook for the whole vessel.

### 3.7.2 Accommodations

In order to standardize on the accommodation needs for all vessels, accommodation spaces for the Optimum Vessel will be as proposed to the International Labor Organization at its fiftieth session in Geneva in 1966 (Ref. 11) were used. On the basis of these recommendations, hypothetical accommodations were worked out and the square foot required per crewman was estimated. This gave a figure of 71.0 sq. ft. of deck space per man for berthing, sanitary, galley, mess, and storage.

Modern fishing vessels are being built with accommodations which would do credit to a yacht. When one considers that this vessel may be the home of the crew for up to 300 days/year, during which the crew will be on watch approximately half the time, one can readily understand the motivation behind this trend to making the off-watch hours as pleasant as possible.

### 3.8.0 Economics

The sole criterion of success in a fishing vessel is stipulated in this study to be Return on Investment (ROI). This is specifically defined as noted below to fit the present customs and methods of the Boston Fish Pier:

DEFINITION OF RETURN ON INVESTMENT (ROI):

$$\text{ROI (Before taxes, \%,} = \frac{\text{Owner's Net Share}}{\text{Investment}} \times 100$$

Where:

"Owner's Net Share" = "Gross Revenue" minus "Costs"

"Gross Revenue" = All income to vessel (assumed to be solely from sale of catch).

"Costs" = Joint Share + Crew Share + Captain's Share + Vessel Share

Where:

Joint Share = Wharfage, Exchange Fees, Bonuses to Engineer and Mate, Instrument Rental, Lumpers, Ice, etc.

Crew Share = 60% Net Stock
= 60% (Gross Stock - Joint Share)
= Fuel + lube oil + icing up + provisions + cook + water + crew lay.

Captain's Share = 4% Net Stock

3.8.0 (Continued)

Vessel Share = Insurance + payroll taxes + maintenance and repair + management (shoreside overhead) + depreciation (investment straight-line depreciated over 20 years).

"Investment" = Total cost of vessel and gear less construction differential subsidy.

At the time of preparing this study, new legislation was pending regarding a simplified and revised method of assigning construction subsidy percentages. Currently, these percentages are calculated individually for each vessel, based on U. S. bids and estimated foreign costs and vary widely; the subsidy equals in dollars the difference between foreign and domestic costs up to a maximum of 50% of the total cost of the vessel.

Because of the present lack of a fixed system of subsidies, in this study Return on Investment is based on an Owner's investment equal to the total vessel cost.

Note that the crew share is a percentage of the gross stock (after deducting minor joint expenses), and is, therefore, independent of crew size. The lay system is not used in all ports. The assumption is probably valid, however, that regardless of what method of labor payment is used, the eventual distribution of the gross income to labor over an extended period of time probably differs very little from port to port, regardless of the system used.

## 4.0.0 The Optimum Design

In this section is described the Optimum Georges Bank fishing vessel as derived in the course of this study.

It must be stressed that fishing and the design of fishing vessels are far from being exact sciences. The procedures used in deriving this optimum design, including the assumptions, statistical values, etc., are based on many variables. Some of these variables may be considered as rigorously defined, but many can only be described as defined "according to the best available data". The optimum fishing vessel described in this section does, however, fit fairly well into the matrix of the U.S./Canadian Georges Bank fishing fleet. As might be expected, no startling departures from present practices developed. It is entirely reasonable to expect, therefore, that a vessel built to this design would be a successful financial venture, perhaps the most successful possible under the conditions for which it was designed.

The existence of this optimum design does not, however, imply that other vessels of quite different characteristics cannot be very successful commercial fishing operations, also. If the given circumstances are different from those upon which this study is based, then the vessels with optimum earning characteristics will also very likely be quite different.

The "Optimum Vessel" is in a sense a trial horse. As such, it reflects whatever errors and gaps there may be in the basic data from which it was derived, and whatever erroneous assumptions stem therefrom. However, the general approach is sound, and lends itself well to future correction and refinement. It is our hope that skippers, vessel owners, naval architects, and others associated with the industry, will have the opportunity to experiment with this program, and will avail themselves of it. Although the program is lengthy and seems very complicated, it is in reality nothing but a long string of arithmetic, any small section section of which can be explained easily in practical, everyday terms. Those who do experiment with the program will not only be gaining a greater insight into their profession, but can also help in the advancement of fishing technology by suggesting refinements to the program by commenting on the basic data used and the results derived, and perhaps by providing hard data in areas where it is now so lacking.

### 4.0.1 Vessel Selection Procedure

Investment in a vessel must be based on as much and as "hard" information as possible. In those areas where such information is lacking, however, the investor must make the best value judgements he can, based on whatever information is available, on logic, and on sound and prudent business principles.

4.0.1 (Continued)

The final selection of an Optimum Vessel in this study was made from the investor's point of view. Although return on investment, ROI, was the keystone in the decision-making, some judgements were made beyond the scope of the complete program.

The selection philosophy was essentially that the Optimum Vessel must include a fair degree of adaptability to changing economic and resource conditions. This philosophy dictated that borderline vessels which were limited in the directions in which they could adapt be excluded from selection.

Figure 4.0.1 is a graph of maximum ROI for a wide range of net sizes, expressed as headline length (HL), at four towing speeds, 1.5, 2.5, 3.5, and 4.5 knots. As the result of observing movies of groundfish trawls in action (Ref.95), a minimum effective towing speed of 2.5 knots was stipulated and the towing speed of 1.5 knots was eliminated from further consideration (based in part on watching a skate swim out of the trawl after having been captured).

In line with the principle of avoiding a borderline vessel, the Optimum Vessel should be designed for operation at above the borderline towing speed of 2.5 knots. However, the greater the towing speed, the lower became the maximum ROI. Thus, whereas the maximum ROI at 2.5 knots was 33%, the maximum ROI at 3.5 knots was only 21%.

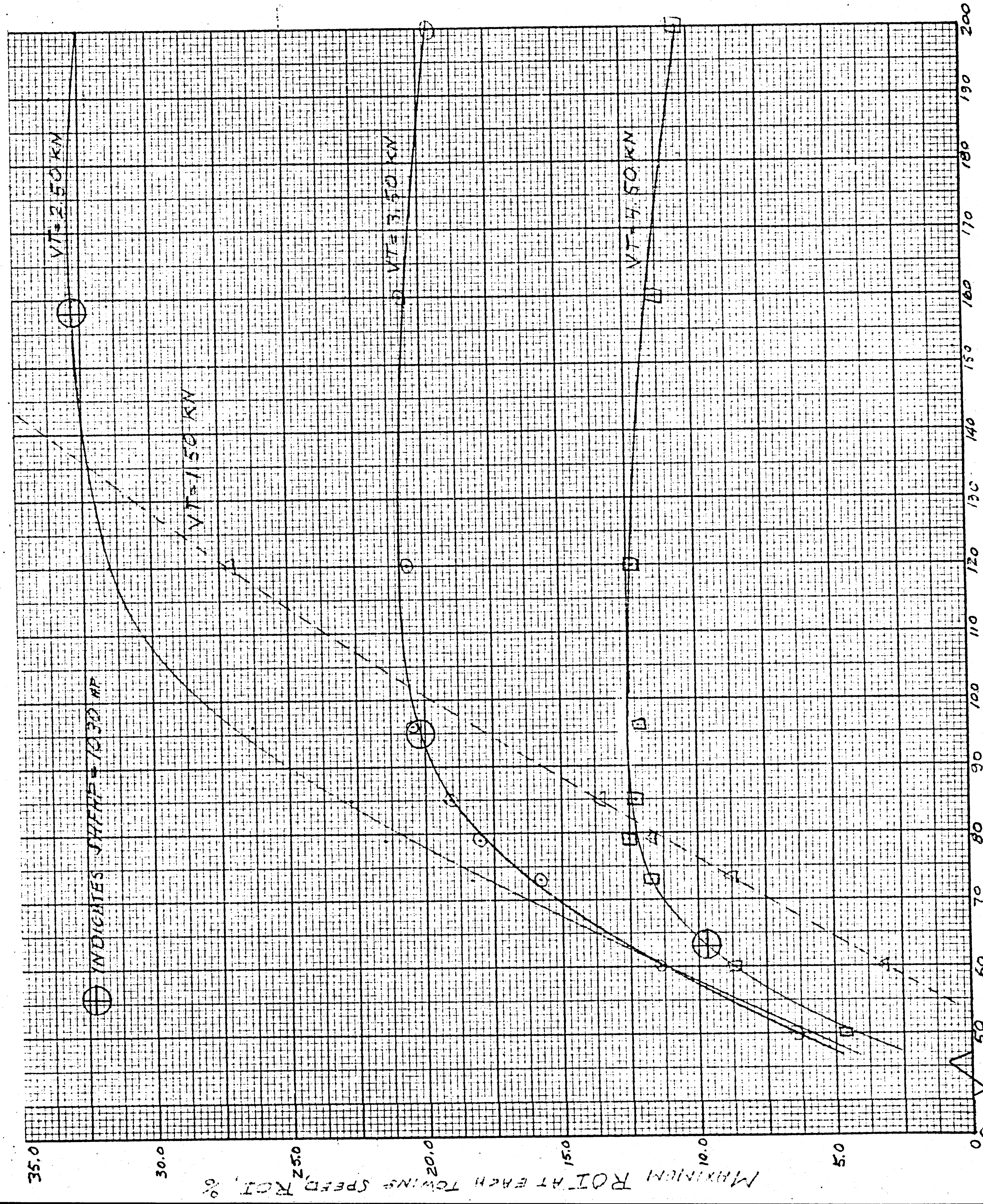
It was noticed that a curve of SHFHP slightly above 1000 passed through or close to the peaks of the curves of ROI (see Figure 4.0.1-I). This suggested that 1000 hp might be close to an optimum horsepower (although it should be noted that the optimum vessels computed for each point on the SHFHP curve would have different characteristics).

As is required so often in naval architecture, a compromise was effected. It was accordingly decided that the Optimum Vessel of this study was to be one with approximately 1,000 horsepower, towing a net of 120' HL at a speed of approximately 3.0 knots. As such, it would be able to tow a wide range of net sizes at speeds from 2.5 knots upward (at full power), and would be operating at or near the peak ROI values for each speed.

Table 40.1-I gives the pertinent computer output data for the vessel and its operating characteristics. Figure 4.0.1-II is a plot of the Curves of Form, presenting the more important hydrostatic data. Figures 4.0.1-III, IV, V, and VI (Plans 6801-1, 2, 3, 4) delineate the major external and internal details of the vessel. Included as Appendix 8.5.0 is an example of the actual computer output description of a vessel.

Figure 4.0.1-I

Maximum Return on Investment (ROI)
vs.
Headline Length of Net (HL)
at
Various Towing Speeds



## Table 4.0.1-I

## Characteristics of Optimum Vessel*

### Geometrical Characteristics

| | |
|---|---|
| Length, Waterline | = 116.0' |
| Length, Overall | = 125.2' |
| Beam | = 28.7' |
| Designed Draft @ Station 5 | = 12.5' |
| Depth from Main Deck | = 16.0' |
| Cubic Number | = 53,315 cu. ft. |
| $\Delta$, at Designed Draft | = 593.3 Tons |
| $C_p$ at Designed Draft | = 0.608 |
| $C_B$ | = 0.507 |
| $C_X$ | = 0.834 |
| $V_S$ | = 12.5 kn |

### Functional Characteristics

| | |
|---|---|
| Continuous Shaft Horsepower of Main Engine | = 1030 |
| Auxiliary Generator | = 112.9 |
| Trawl Winch | = 110** |
| Size of Fish Hold | =11,986 cu. ft. |
| Number of Crew | 16 |
| Accommodations Available | 19 |
| GM at Departure | = 2.12' |
| GM at arrival with full load | = 2.69' |
| Trim, at departure | = 0 |
| Trim at arrival, with full load | = 0 |
| $\Delta$ at departure | = 507.4 Tons |
| $\Delta$ at arrival, with full load | = 600.6 Tons |
| FO Capacity | = 50.6 Tons |
| FW Capacity | = 7.4 Tons |

* See Section 4.0.1 for explanation of procedure for selection of Optimum Vessel characteristics, and Appendix 8.5.0 for computer output.

** See Appendix 8.3.0.

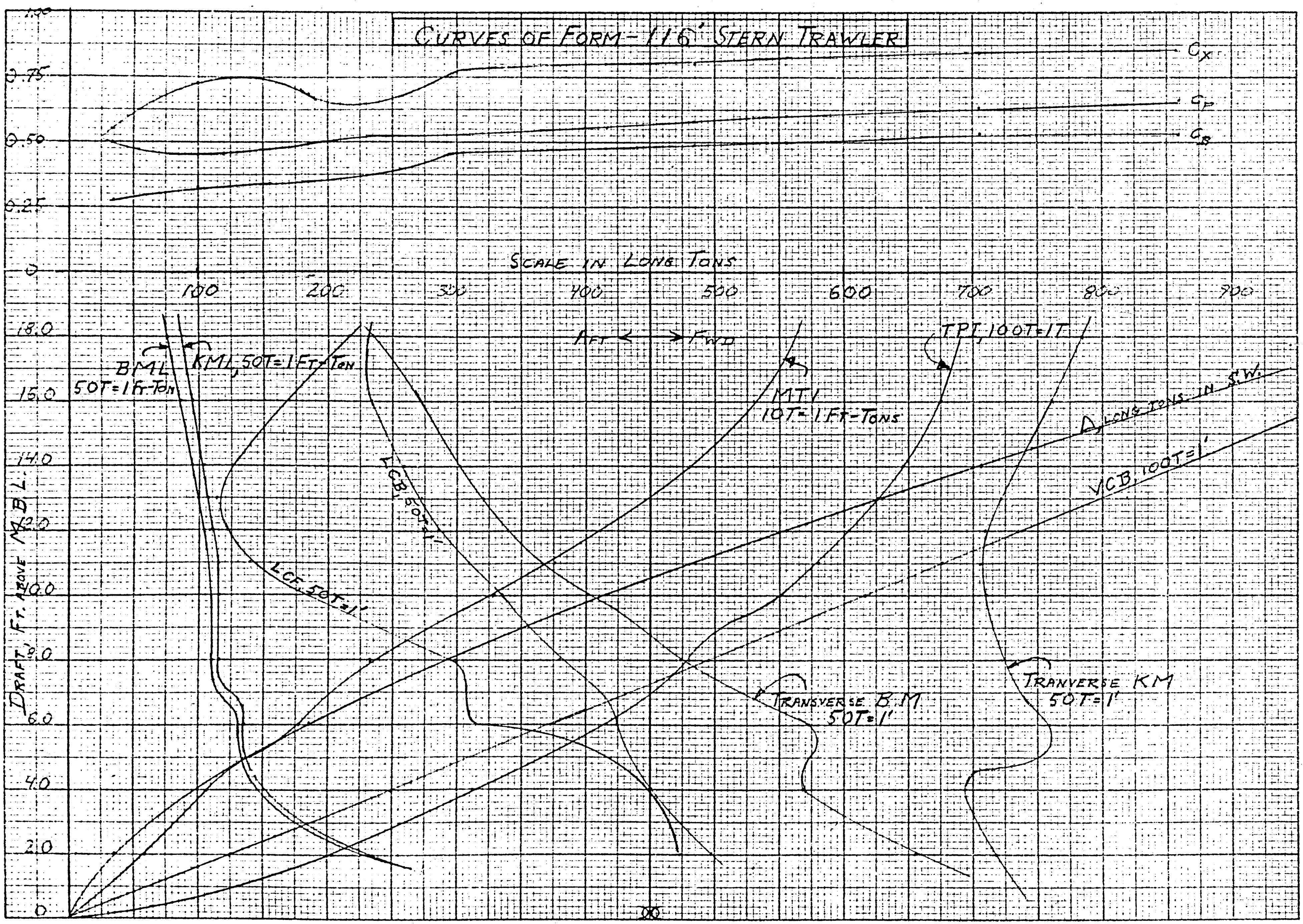
4.0.1-I (Continued)

Operational Characteristics:

| For net with headline length of, ft. | 120 | 96 | 85 (#45-A) | 79 (#41) |
|---|---|---|---|---|
| Towing speed, knots | 3.00 | 3.49 | 3.78 | 3.99 |
| Days at sea per trip | 9.0 | | | |
| Days fished (gear in use) | 6.43 | | | |
| Days to and from grounds | 1.25 | | | |
| Days lying to, dodging, etc. | 1.32 | | | |
| Time in port between trips, days | 2.00 | | | |
| Number of trips per year | 31.82 | | | |
| Time to complete one fishing cycle, min. | 119.0 | | | |
| Time gear fishing, min. | 90.0 | | | |
| Time shooting gear, min. | 5.0 | | | |
| Time retrieving gear, min. | 16.0 | | | |
| Time handling gear on deck, min. | 8.0 | | | |
| Catch per cycle (haul), lb. | 3800 | 2840 | 2400 | 2190 |
| Cycles per trip | 77.0 | | | |
| Catch per trip, lb. | 297,710 | 222,000 | 187,700 | 171,200 |
| Catch per year, lb. | 9,473,040 | 7,070,000 | 5,970,000 | 5,450,000 |

Economic Characteristics:

| For net with headline length of, ft. | 120 | 96 | 85 (#45-A) | 79 (#41) |
|---|---|---|---|---|
| Total vessel cost | $ 835,550 | | | |
| Owner's investment | $ 835,550 | | | |
| Total income at $.118 per pound | $ 1,117,820 | $ 834,900 | $ 705,000 | $ 643,000 |
| Owner's net share | $ 223,100 | $ 134,000 | $ 93,200 | $ 73,400 |
| Return on investment | 26.7% | 16.0% | 11.1% | 8.8% |
| Crewmen's earnings | $ 37,600 | $ 27,100 | $ 22,400 | $ 20,020 |




**This esoteric collection of curves describes to the naval architect the important vessel characteristics affecting speed, motions, safety, etc.**

Figure 4.0.1-II Curves of Form - Optimum Fishing Vessel

## 4.1.0 General Arrangement

Once the stern trawler configuration has been settled upon (see Section 3.6.1),and the computer program has produced the characteristics of the Optimum Vessel, there are relatively few major decisions to be made as to the general arrangement of the vessel.

Below decks, the engine room was placed forward because of the several advantages of this arrangement (see Section 3.5.5) and because one of the primary disadvantages, the raised shaft hump in the hold, could be avoided due to the size of the vessel. As a consequence, the center of the hold is fairly close to the center of flotation, which affords excellent trimming conditions under all expected loading. Splitting the fuel tankage forward and aft of the hold provides further opportunity for the skipper to make fine adjustments to his trim according to the situation at any given moment.

The stern trawler configuration requires that the working area on the main deck be located aft. Conventionally, the quarters, bridge, etc., are located forward of a bulkhead about at the midpoint of the vessel. In this design, an effort was made to move as much of the quarters as possible as far aft as possible in order to minimize the pitching accelerations. The layout resulting is thus not symmetrical, and the accommodations in general use during the day (galley and mess) are placed along the port side fairly well aft. This also brings the bridge well aft where motion is less and where excellent visibility of all fishing operations is provided. The skipper's cabin is aft, quickly available to the working deck and the bridge.

The bridge itself is short fore and aft, and wide athwartship. This permits the controls for both the fishing operation and for conning the vessel to be located very close to each other. At the same time, there is ample room for instrumentation, chart work, etc.

The unusual location of the stack, forward of the bridge, deserves some comment. As a bar to forward visibility, it is probably not important; it will be as narrow as possible and is so far forward that it should not offer more obstacle to vision than a mast a few feet forward of a bridge. There is also the possibility of soot, smoke, and fumes from the exhausts interfering with work on the bridge. The height of the stack and the distance from the bridge should make this unlikely, but if it became a problem the stack could be raised even more and a "wing" fitted near the top to force air currents in a vertical direction to carry the exhaust products clear of the bridge.

Note that the forward part of the working area of the main deck, forward of the bridge, is uncovered. The opening would make it easier to convert the vessel to long-lining, or to seining in the European style, and even for trawling there may be a preference for open air. If desired, however,there is no reason this area could not be enclosed to any desired

4.1.0 (Continued)

degree, with permanent or removable surfaces, with hatches in the upper deck to facilitate icing, unloading, etc.

The offcenter deck layout makes it possible to locate the trawl winches well forward. The warps, instead of being led along the deck, are carried overhead out of the way and with fewer bends.

The concept of the offcenter deck layout is not new (Ref.3), but it is unusual and the possibility of potential advantages motivated its adoption for the Optimum Vessel. The more conventional symmetrical arrangement could just as easily be incorporated on this vessel.

## 4.2.0 Hydrodynamics

Although a method of optimizing the vessel's geometry, from the standpoint of performance, is described in Section 3.5.3, the temptation to carry this out for the Optimum Vessel was resisted. It was felt that better use could be made of the program, and a more acute critical analysis of its virtues and faults if the Optimum Vessel were designed according to the unchanged output of the computer program. Although individual preference on the part of owners, skippers, and naval architects may dictate different proportions of hull, etc., nevertheless the vessel, as it has emerged, is well within the range of variations to be found in this type and size of vessel.

Major matters of hydrodynamic concern are the resistance to forward motion when steaming, stability from a safety standpoint, the motions in pitch and roll, and the steering and turning characteristics.

Steaming speed for this vessel, at full rated continuous horsepower will be about 12.5 knots. A larger value of Ⓜ than 4.25, i.e. a longer LWL, would increase this speed somewhat for the same displacement and horsepower (Ref.3-Geroult); this would be one of the prime areas of subsystem optimization which the naval architect would investigate, and check with tank tests, as noted in Section 2.5.0. Within this length limitation, however, the other proportions and coefficients, as given in Table 4.0.1-I, are favorable to efficient steaming.

The selection of the double chine hull form calls for some explanation with respect to resistance. There is an impression that this type of hull has higher resistance than a round bilge hull. Although greater care must be taken in designing a chine hull to avoid as much as possible the flow of water across the chines, it has been demonstrated (Ref.105) that there need not be an appreciable difference in resistance if sufficient care is taken in designing and tank testing the chine hull.

4.2.0 (Continued)

The advantages of the chine hull are that it is less expensive to build (the saving, perhaps 2% to 3% of the total vessel cost, may be better invested in a controllable pitch propeller or a nozzle), and the chines assist in reducing rolling angle and increasing the period by entraining more water than would a round hull. It should be pointed out, however, that within the characteristics given in Table 4.0.1-I it would be entirely possible to design either a round hull or a single chine hull.

Stability is adequate for all conditions, according to the standards suggested by Takagi (Ref.2). However, the values of GM also lie within the area of maximum crew comfort, as reported by Vossers (Ref.2). The GM values may therefore be said to lie within the range of optimum values, to the extent that these values can be determined.

To further assist in attaining the most comfortable rolling motions, bilge keels will be fitted as suggested in Ref. 2. The keels will extend from Station 4 to Station 6-1/2 and will be 24" deep and of the "buttressed" type. The keels will in general be located at the lower chine, but the exact location will depend on flow lines established from the tank tests.

In addition, stabilizing planes, known as "flopper stoppers" and used extensively on the West Coast of the U. S., are suggested as a simple and inexpensive means of further increasing the comfort of the vessel. Although there is no known installation of these planes in vessels of this size, extrapolating from catalog data suggests that planes of 1,000 sq. in. area, weighing about 150 lb. each, would be suitable. There seems to be no functional reason why these planes couldn't be safely handled, and they are, therefore, included on the Optimum Vessel, suspended from the mast well forward, clear of all fishing gear.

Pitching is difficult to correct to any great degree because the longitudinal stability is so much greater than the transverse. (The longitudinal GM approximately equals the LWL of the vessel, whereas the transverse GM is on the order of 2' to 3'.) Factors which might have an appreciable effect on damping out pitching are the downward force of the warps at the stern when towing, and the effect of the stabilizing planes in the fore part of the vessel. Perhaps the best way to avoid troubles from pitching is to locate those functions of the vessel which are sensitive to pitching as far aft as possible.

The steering and turning of vessels raises some contradictions. The vessel with good directional stability, i.e. steering, characteristics is also more apt to have the poorest turning, i.e. maneuvering, characteristics. This is further complicated by the restrictions on turning imposed by the warps.

4.2.0 (Continued)

In order to improve turning qualities when towing, the forefoot has been kept quite deep, with little drag (18") to the keel, a steering nozzle is specified for the propeller, and the gallows on each quarter are set up so as to swing inboard when they are on the outside of a turn, thus moving the weathercocking force farther forward and giving the nozzle more turning leverage. The braces for the gallows will be spring or hydraulically loaded to return them to the outboard position when the turn is completed.

The steerable nozzle has the effect of increasing the turning force by directing the propeller slipstream in the direction of the turn. This feature of the nozzle is also very useful for steering when going astern.

The deep forefoot is frequently suggested as being the cause of wild steering with a following sea. However, it also moves the turning axis and the turning center of pressure farther forward and thus provides a greater lever arm for the turning force provided by the nozzle (or rudder). The result is a greater turning moment and better turning responsiveness. The drag of keel is approximately half that suggested by Doust (Ref.106) but since it will not alter, as the vessel will trim level or by the stern, it seemed to be adequate for providing suitable directional stability.

The deep forefoot has the added advantage of providing a more balanced lateral plane relative to the above-water profile which is concentrated forward. This balance will help the vessel lie to more steadily.

4.3.0 Structure

The basic structure of the Optimum Vessel will be welded steel, with scantlings in accordance with an accepted classification, such as American Bureau of Shipping ✠A1. Finish will be the best available, applied after sand blasting the steel. A 15" x 15" box keel will be fitted to provide resistance to drift and to rolling. The fish hold is insulated with 8" rigid foam overhead and 5" rigid foam on sides and deck; the foam is covered with plywood, sheathed in turn with adequately thick fiberglass reinforced resin. Stanchions, pen boards, shelves, etc., will be aluminum, and every crevice will be filled or filletted to prevent bacterial growth.

4.4.0 Machinery

Machinery will be as noted on plans, with all installations in accordance with best accepted practice. Electrical systems will, in general, be 110 VAC. Hydraulic system, powering all fishing gear, will be 1500 - 2000 psi, driven by its own engine but capable of being driven from the main engine in an emergency. Controls for fishing gear and machinery will be located on the bridge.

## 4.5.0 Crew

The 16-man crew set by the computer program is quartered on one deck and in conformity with the standards proposed by the International Labor Organization (Ref.11). 19 berths are provided, to accommodate observers or guests; these are not intended for steady use, however, as it is not considered likely that a larger working crew would be required for other types of operations.

In order to attract young, trained, and stable crewmen to this vessel, it is proposed that everything be done which will enhance comfort, cleanliness, and pleasure for the 300 days or so each year that the full-time fisherman spends at sea. The following features would, therefore, be incorporated in the Optimum Vessel:

1. Heat insulation throughout on all surfaces bounding the accommodations, including the engine room overhead and casing.

2. Sound insulation between the engine room and casing and the accommodations. Sound transmission between cabins should also be kept to a minimum through high-mass, or spring supported, partitions.

3. Deck, wall, and overhead surfacing which will be pleasing to the eye, easy to clean, and long lasting.

4. An efficient hot water heating system, perhaps utilizing engine cooling water, with a stand-by auxiliary oil burner.

5. A forced ventilation system to all quarters. (Because of the relatively low temperatures encountered on the Georges Bank, air conditioning should not be necessary.)

6. A public address system, with keyed outlets in each cabin and compartment, suitable for communication and for the distribution of recorded or radio music, etc.

7. A pleasant and roomy mess/lounging area, located where vessel motion is low, with cushioned benches, buffet for snacks, and facilities for movies, TV, etc.

8. A decor throughout the accommodations which is esthetically pleasing yet, in view of the long work hours, does not impose unnecessary cleaning and tidying loads on the crew members.

4.5.0 (Continued)

9. A vestibule arrangement which provides changing and clean-up facilities so that it is never necessary for the crew to wear oilskins, boots, etc., to their quarters.

Similar efforts should be made with respect to the working conditions. Looming large in this connection is safety; fishermen have one of the poorest safety records in U. S. industry (Ref.15). Carrying the trawl warps overhead from the winches to the gallows will remove one source of hazard. The use of a hydraulic boom for handling nets, cod end, etc., will do away with several pieces of gear now used for these functions. These measures, plus following well established rules for shielding rotating machinery, painting danger areas, etc., should help to reduce the loss of time through accident.

As to comfort and convenience of the working conditions, the stern trawler with its working area aft has less motion and dryer decks than the conventional side trawler. In addition the measures taken to reduce rolling will improve working comfort, as will the use of the BCF processing system at waist height as developed at Gloucester.

Shelter may be provided by closing in the forward part of the working deck area, as described in Section 4.1.0, and further effects of environment may be minimized by forced ventilation, and radiant and/or hot air heating for winter operations.

Lighting of the accommodations and working areas should receive careful consideration. Lighting of public spaces and staterooms should follow the best standards for standby and functional light levels and concentrations. For the working areas, use of line - or plane - source, instead of the conventional point-source, lighting should be investigated for elimination of shadows and for evenning out of the light intensity levels in the working areas; carefully located fluorescent or mercury-vapor lamps are suggested.

Of particular interest from several points of view is the decking material. It should be non-slip and easy underfoot, for the comfort and safety of the crew. Yet it should also be free of crevices and easy to clean in order to reduce bacterial contamination of the fish. A trowelled-on type of deck surfacing would seem to be preferable to the block type, at least from the standpoint of cleanliness.

Further possibilities exist for making fishing more attractive to the labor market, although this is not properly the subject of this study. Among these are: Providing for rotating of crew members by hiring an extra deckhand so that every tenth or eleventh trip each man could stay ashore for a trip, yet would share in the lay for that period; making it possible for crewmen to take along wives or a child for a trip once a year, or so.

## 4.6.0 Fishing Gear

Several items of the fishing gear on deck and in the hold deserve mention. These are suggested as realistic possibilities for consideration.

1. Towing Gear - The two hydraulic winches, with level-winding and warp-metering devices, will be entirely enclosed and operable either from the bridge or from the winches themselves. Each will have a capacity of about 800 fathoms of 1" 6x19 aluminized plow steel warp. The warps will be led overhead through pipes where possible, directly to the gallows frames. These will be of fairly conventional design, but fitted with retractable braces to permit the outside gallow to swing inboard when turning, and return automatically to the towing position when the turn is completed. The bulwarks will be set inboard, from the gallows to the stern, to provide a pocket into which the doors will seat and be secured with a chain strap.

2. Net Reels - These have the advantage of greatly reducing the deck space required for hauling, and of making it possible to have a spare net available for immediate use. It is suggested that the two reels carry one larger and one smaller net, as suggested in Tactics, Section 4.7.0.

3. Hydraulic Boom - The boom affords complete access to all parts of the after deck by one piece of equipment. Operable from the bridge or from its own base, it can be used for any lifting or hauling work required. The boom shown on the drawings would desirably have a capacity of 5,000 lb. or so, at an 18' radius, with a maximum capacity of 8000 - 10,000 lb. The cod end would be brought to the ramp by the net reel, at which time the boom would take over. A catch within the limits of the boom would be picked up and emptied into the sorting hopper; a larger catch would be dragged, not lifted, up the ramp and split while it lay there.

4. Processing Gear - This is as designed and tested in use by the BCF Technological Laboratory at Gloucester, Massachusetts. The fish are emptied into the sorting hopper, which raises the fish hydraulically to the level of the ripper's waist. The ripper(s) deposit them on a conveyor which carries them to the gutters. The gutters toss the fish into the washer,from which they are conveyed to a chute into the hold.

5. The Hold - The hold will have a conveyor installed overhead, fed by the chute from deck, and reversible to enable carrying fish to both ends. It will be possible to barricade the conveyor at any point to permit feeding fish, via a movable chute, to any pen. The ice may possibly be stowed on shelves in the outboard row of pens on each side; as the fish are laid in place, ice may be spilled out over them and spread with pushers. Unloading could be done as it is now, but Stonely and Hopkins (Ref. 99) demonstrate that a vacuum air pump system mounted on the dock might be the least expensive and quickest way to unload.

4.6.0 (Continued)

Electronic outfit should be the best available for the purpose. Appendix 8.4.0 gives a suggested list of electronics for any Georges Bank vessel.

4.7.0 Tactics

Ths study suggests the possibility of developing fishing tactics on the grounds which will help improve the overall landing.

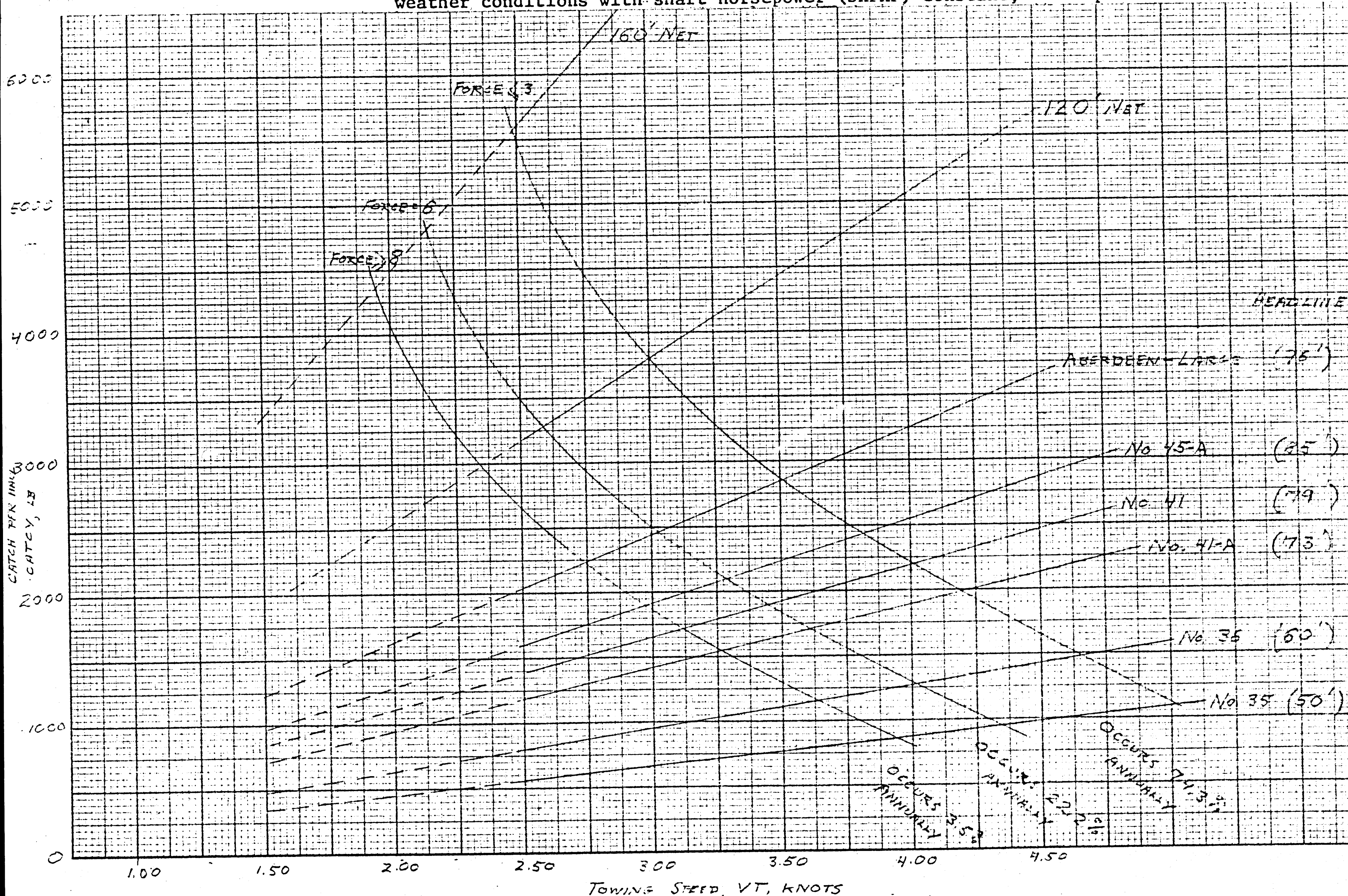
"Tactics" may be described as short-term reactions taken to minimize adverse effects of an external change and/or maximize the beneficial ones. An example of a tactical approach to fishing is reaction to a change in the weather. Figure 4.7.0-I shows the catch per cycle for a vessel with 1030 shaft horsepower using different nets. As discussed in 4.0.1, a minimum towing speed of 2.5 knots is assumed and fishing is assumed to terminate when conditions exceed Beaufort Force 8 (Ref.2-Möckel).

Let us picture a vessel fishing with a 120' net in force 3 conditions. The weather worsens until the vessel's towing speed is reduced to 2.5 knots. Rather than discontinue fishing because of insufficient speed, a shift is made to an Aberdeen-Large net and fishing is continued at the new towing speed of 2.92 knots. If the weather conditions do not worsen,the catch per cycle will continue at approximately 2380 lb./cycle, a reduction from the initial 3800 lb./cycle, but an improvement over the cessation of fishing activity altogether. If conditions worsen beyond force 8,fishing will cease regardless of the net in use because of the violent motions of the vessel. Conversely, if conditions improve, the captain should shift back to the 120' net as soon as he feels a towing speed in excess of 2.5 knots can be maintained.

Present practice appears to be to use a net small enough to permit towing at a reasonable speed up to the time fishing must cease altogether. This means that most of the time, in good weather, the engine is throttled back to less than full power. The ideal arrangement is to have nets such that full SHFHP may be used at all times under all fishable weather conditions.

## Figure 4.7.0-I

Catch per Cycle (CATCY) vs. Towing Speed (VT) for various weather conditions with shaft horsepower (SHFHP) constant, 1030 hp.



## 5.1.0 Income Sensitivity Analysis

A sensitivity analysis was performed in order to measure the effect of varying certain of the values considered constant. Values for which no change is expected in the near future (i.e. specific fuel consumption) were not analyzed.

Those values which were analyzed were: price/lb of fish, POB, catch rate, Q, and total vessel cost, TVC. Because of time constraints, the sensitivity of ROI to variations in time spent/fishing cycle, ITF and time spent in port between trips, TIP (i.e. crew rotation), and variations in the type and operation of the prime mover could not be tested.

The income that a vessel's catches produce may be affected by either a change in the gross catch rate or by a change in the unit price of the catch. In order to judge the sensitivity of return on investment, ROI, to changes in income, INC, returns on investments were computed for vessels whose income had been altered by -40%, -20%, 20% and 40%. These results are shown on Figure 5.1.0-I. Assume an initial return on investment of 30%. If income should decrease by 20% (INC'=.80 INC), then the new return on investment will be 21.1%. This is shown as path A on the curve.

The curve indicates that a decrease in income will cause a smaller percentage change in ROI than an increase will, but in either case the percentage change in ROI will exceed the percentage change in income. It may also be seen that high values of ROI are less sensitive to changes in income than lower ones on a percentage basis.

The vessels achieving larger ROIs have a smaller percentage of their income used for the vessel share and insurance than vessels achieving lower ROIs. These costs will remain fixed despite income variations, and are basic reason for increasing sensitivity to income variation with decreasing return on investment.

## 5.2.0 Total Vessel Cost Sensitivity Analysis

The analysis of the sensitivity of return on investment to variations in total vessel cost indicates that ROI is sensitive to TVC variations. As shown in Figure 5.2.0-I, this sensitivity is biased in that a decrease in TVC will cause a greater percentage difference in ROI than an increase will; however, in all cases the percentage change in ROI exceeds the percentage change in TVC. The percentage change in ROI is lesser for large values of ROI than it is for small ones.

Figure 5.1.0-I

Sensitivity of ROI to Changes in Gross Revenue

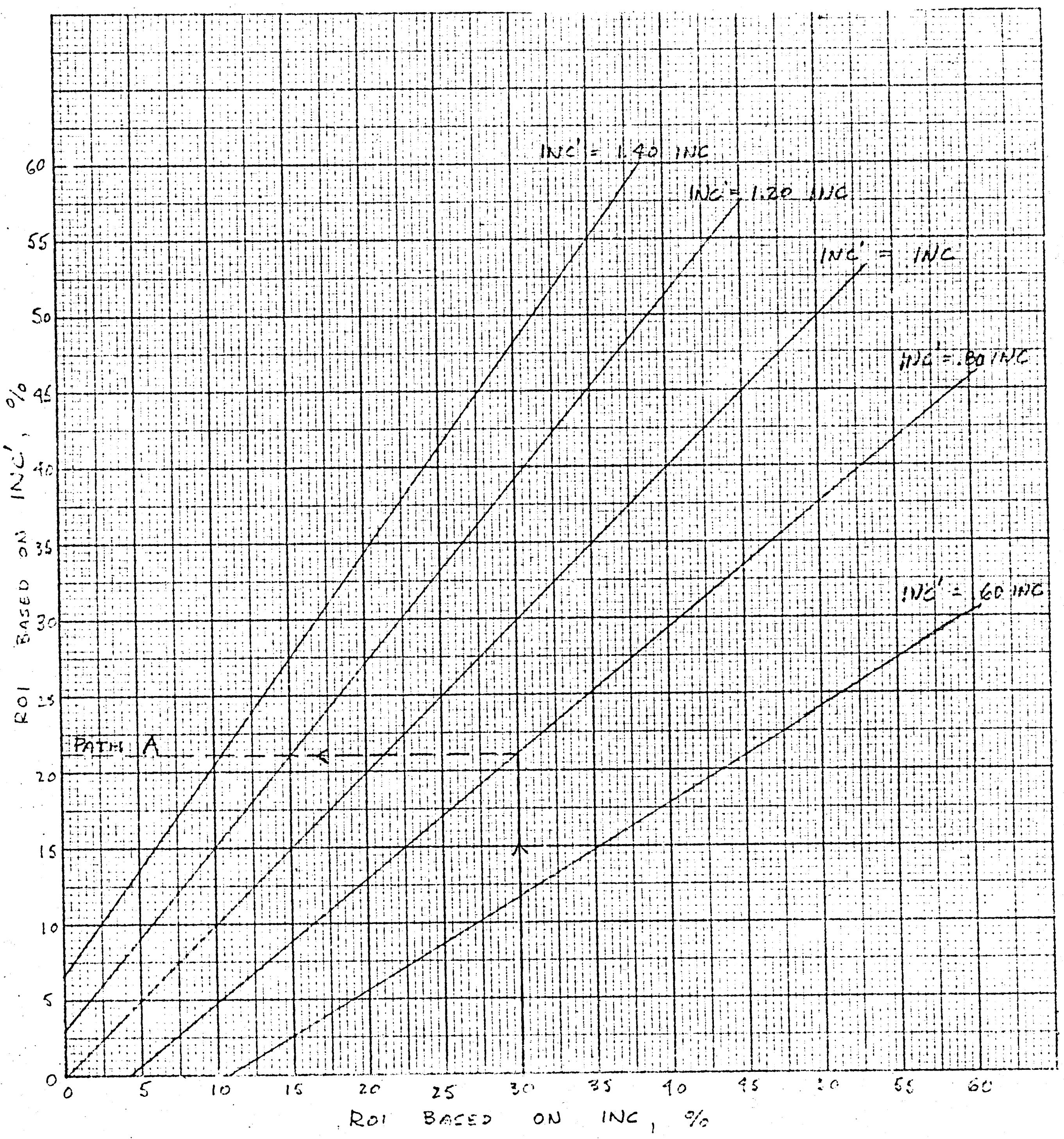
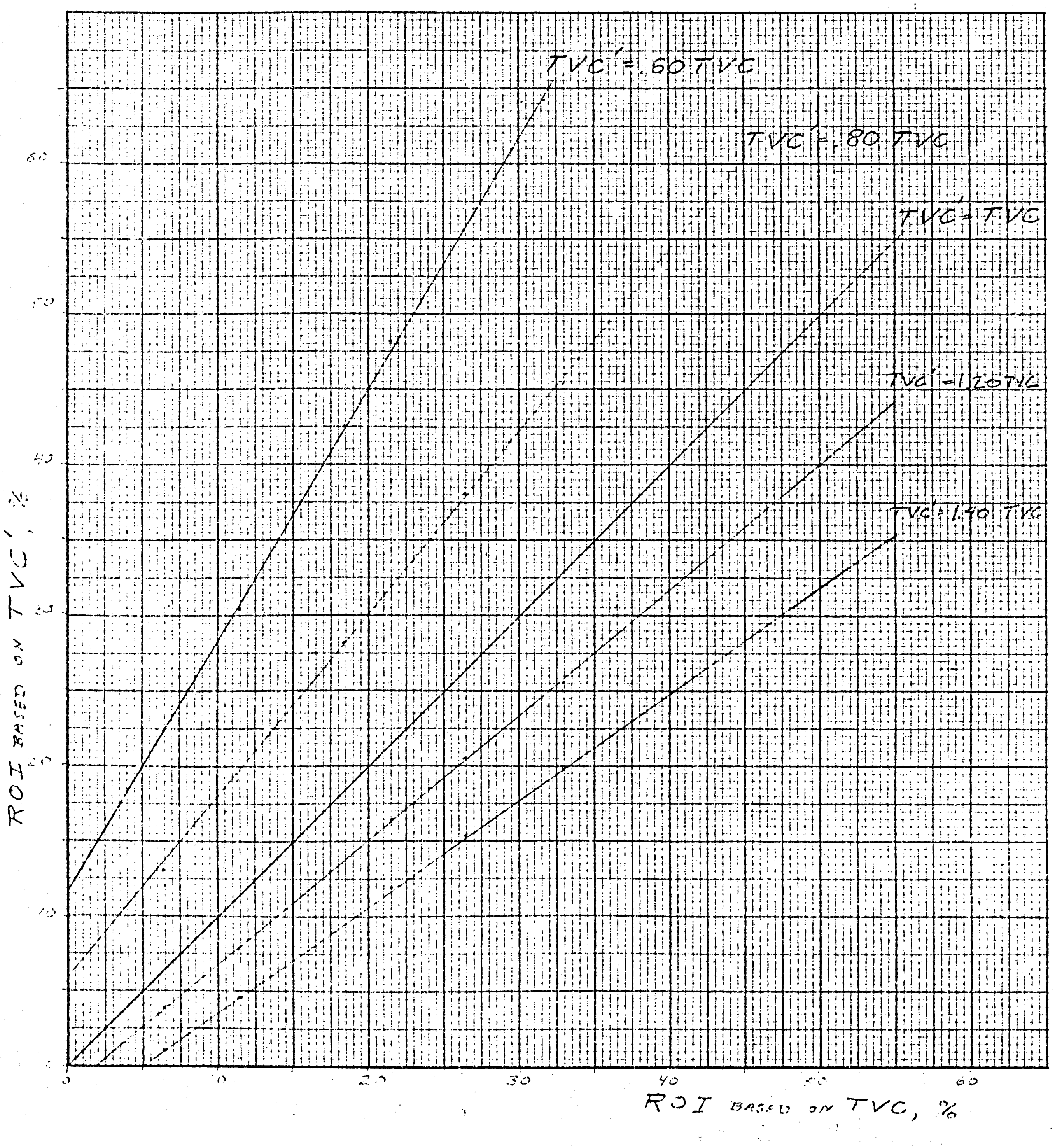


Figure 5.2.0-I

Sensitivity of ROI to Variations of Total Vessel Cost



## 6.0.0 Conclusions and Recommendations

### 6.1.0 Conclusions

6.1.1 The functional and mathematical model, and its computer program, provide a convenient and quick method for evaluating all aspects of a particular fishery. As applied to the Georges Bank fishery, the program gives very good agreement when the actual landings of high-performance Boston vessels are compared with landings predicted by the program for these vessels. (See Figure 6.1.1-I). Refinements, revisions, and new technological changes may easily be introduced into the model and program. With demonstrated ability to portray one fishery, the same model may be applied to other fisheries with appropriate changes.

6.1.2 Up to a limiting size, a larger net will produce a higher ROI than a smaller one. (See Figure 4.0.1-I). This statement presumes that both nets are towed at the same speed (that best suited for the particular fish being harvested) and that the towing vessel is the optimum one in each case for the net and speed. It is possible to say, for instance, that a vessel selected by this program to tow a 100' net at 3.5 knots will produce a higher ROI than a vessel selected to tow an 80' net at the same speed.

6.1.3 It is in general more profitable to tow a large net slowly than a small net fast. Note on Figure 4.0.1-I the three points for performance with 1030 SHFHP. However, (See Section 4.0.1 and Ref.78) the percentage of the fish population in the path of the net which is actually trapped is a function of the speed of towing (as well as other factors not yet clearly understood) from which it may be concluded that for a given fish population below a certain towing speed few or no fish will be caught, whereas above some other towing speed the catch rate will not materially alter.

6.1.4 Productivity may be increased by the ability to change nets to suit wind and weather conditions. (See Section 4.7.0). Net reels would facilitate, but not be essential, for the net-changing operation.

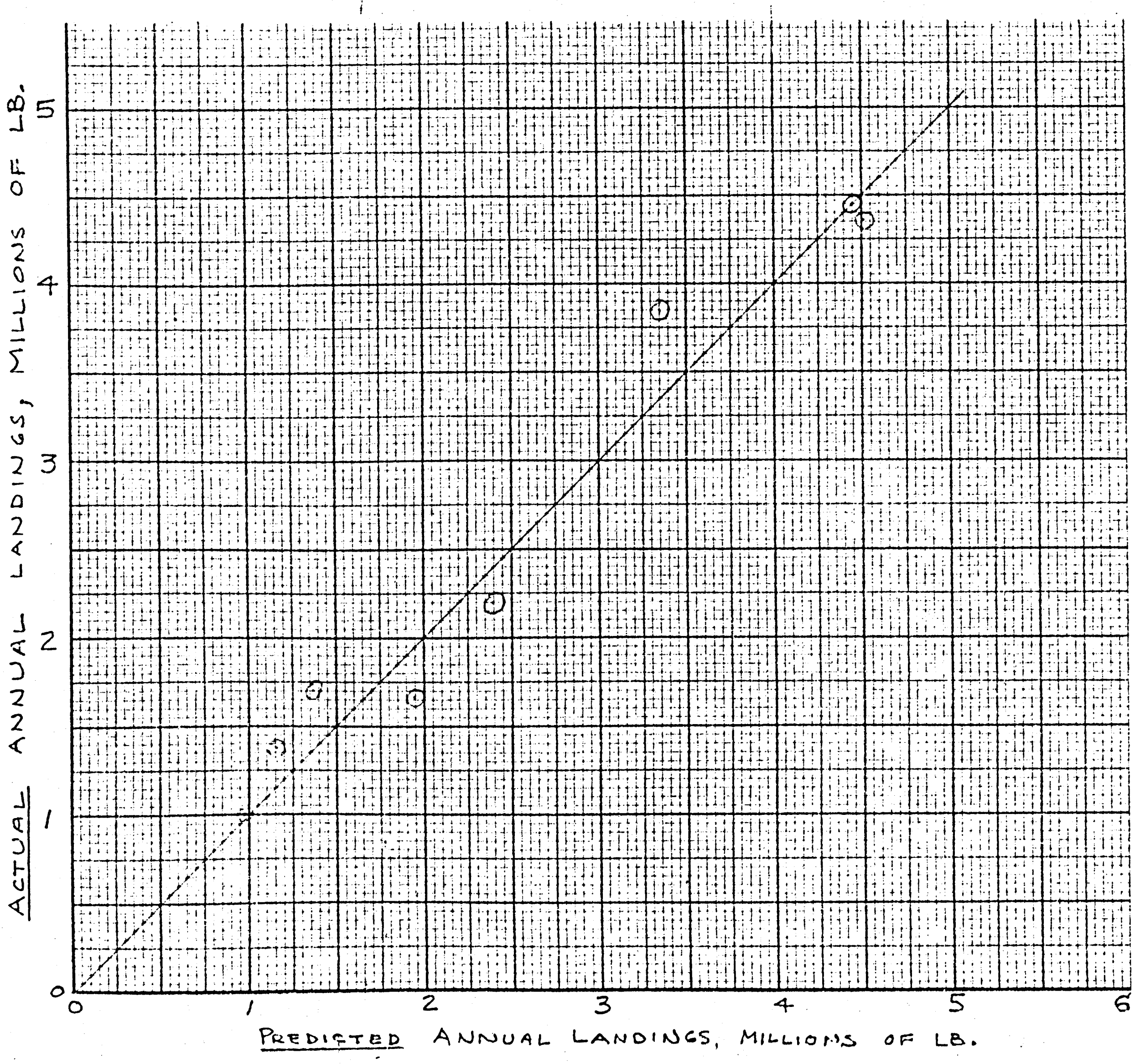
6.1.5 The prominence of towing speed in this study suggests the desirability of equipping fishing vessels with speedometers to indicate speed through the water. Accurate sailboat speedometers can be had from $100 to $300.

6.1.6 The stern trawler, with an initial cost approximately the same as the side trawler, (Table 3.6.1-I), has a greater efficiency, in part because of reduced net handling times (Table 8.1.5-I), more comfort for the crew, and the ability to fish in worse weather (Section 3.6.1).

Figure 6.1.1-I

Actual Annual Landings
vs.

Predicted Annual Landings



6.2.0 Recommendations

The recommendations listed below were gathered during the course of this study. They were finally selected and edited so as to be of help in paving the way for future extensions of this study, to suggest means for enhancing the effectiveness of future research into fishery gear and operations, and to suggest some specific ways, revealed by the study, in which the Georges Bank fishing operation may be improved.

6.2.1 That other fisheries, preferably now relatively unexploited, be modeled and investigated with the computer in order to optimize the fleets to come. These might include the Maine northern shrimp fishery, the Alaska groundfish fishery, or the Florida and Alaska scallop resources.

6.2.2 That this study be expanded to investigate the following additional aspects of the Georges Bank fishery:

a. Scallop fishery
b. Flatfish fishery
c. Herring fishery
d. Longlining
e. Variation of fishing tactics, such as longer or shorter tows.
f. Possibility of increasing DAS by having entire or partial crew rotation each voyage.

6.2.3 That a national fishery data center be established with, for all fisheries, uniform formats designed to provide all useful data, a single storage center with reasonably rapid retrieval, a uniform method of dealing with confidential data.

6.2.4 That the methodology and model used in this study be made available to Georges Bank vessel skippers and owners, naval architects and other industry people, either in the form of a deck of punched cards for individual use (with trained assistance) or as a set of graphs plus written instruction for their use.

6.2.5 That the push for future investigations should be aimed at unravelling the complex biological, mechanical, and oceanographic relationships involved in the net/fish/environment system. The aim should be to provide the skipper with information as to the best gear to use and course to sail in order to maximize his catch.

## 7.0.0 BIBLIOGRAPHY


1. "Fishing Boats of the World - 1" FAO-UN, London, 1955.

2. "Fishing Boats of the World - 2" FAO-UN, London, 1960.

3. "Fishing Boats of the World - 3" FAO-UN, London, 1967.

4. "Trawler Design Factors and the Decision to Build", Doust, (unpublished paper), Canadian Atlantic Offshore Fishing Vessel Conference, Montreal, Canada, 1966.

5. "Pulling Power of Stern Trawlers", Bulletin of the Japanese Society of Scientific Fisheries, Vol. 32, No. 6, 1966.

6. "Pulling Power of Large Stern Trawler Operating at Rough Sea", Bulletin of the Japanese Society of Scientific Fisheries, Vol. 33, No. 10,1967.

7. "Resistance of Trawlnet", Bulletin of the Japanese Society of Scientific Fisheries, Vol. 33, No. 2, 1967.

8. "Relations Between Horsepower of Trawlers Main Engine and Trawl Winch and Fishing Gear", Bulletin of Tokai Regional Fisheries Research Laboratory, No. 47, August, 1966, Japan.

9. "Trawl Warp Tension Meter", Bulletin of Tokai Regional Fisheries Research Laboratory, No. 47, Japan, August, 1966, Japan.

10. "Method of Computation for Seeking the Suitable Size of Trawl Gear to the Horsepower of the Main Engine of a Trawler", Bulletin of Tokai Regional Fisheries Research Laboratory, No. 47, Japan, August 1966.

11. "Accommodation on Board Fishing Vessels", Report VI, International Labor Conference, 50th Session, Geneva, Switzerland, 1965.

12. "Computer Techniques Can Determine Least Cost Ship", Murphy, Sabat, and Taylor; Maritime Reporter/Engineering News, New York, December, 1963.

13. "Research and Development Progress Report", The White Fish Authority, London, England, 1966-67.

14. "Optimization Methods Applied to Ship Design", Mandel and Leopold, SNAME Transactions, Vol. 74, 1967.

15. "An Economic Study of the Boston Large Trawler Labor Force", Norton and Miller, USDI-BCF Circular 248, Washington, D. C., May, 1966.

16. "Shrimp Trawlers, An Analysis of Evolution", C. W. Bond, SE Section, SNAME, Miami, Florida, June, 1967.

17. "Comparative Testing of Midwater Rigs on Small Draggers", A. Holmsen, University of Rhode Island Occasional Paper, Kingston, R.I., March, 1967.

18. "The Groundfish Industries of New England and Canada", Lynch, Doherty, Droheim, (Bureau of Business Research, Boston College), U.S.D.I. Circular 121, Washington, D. C., June, 1960

19. "The Economics of the New England Fishing Industry", Bell; Federal Reserve Bank of Boston, 1966.

20. "ICNAF Summary, 1965", International Commission for the North Atlantic Fisheries, Nova Scotia, Canada, 1965.

21. "ICNAF Vol. 14, for the year 1964 Statistical Bulletin", Nova Scotia, Canada, 1966.

22. "ICNAF Vol. 15, for the year 1965 Statistical Bulletin", Nova Scotia, Canada, 1967.

23. "Trends in the Marine Fisheries of the Continental Shelf of the Eastern United States", H. W. Graham, American Fisheries Society Transactions, Vol. 97, No. 1, January 1968.

24. "Recent Trends in the Fisheries of the Northwest Atlantic", Activities Report, Vol. 19, No. 1, Spring 1967; H. W. Graham.

25. "Fluctuating Fish Prices, an Adverse Factor in the Industry", H.Lampe, Maritimes (U.R.I.), Vol. VIII, No. 4, Autumn 1964.

26. "North Atlantic Trawl Nets", R. A. Bruce, BCF Exploratory Fishing and Gear Research Base, Gloucester, Mass., USDI Leaflet 600, Washington, D. C., August 1967.

27. "Fishing Vessel Data", Fujinami and Antunes, FAO Fisheries Report No. 28, October 1965.

28-A. "Economic Aspects of Small Boat Fishing", Proskie, Conference of the Design, Construction, and Operation of Small Fishing Vessels, St. John, Newfoundland, May 1965.

28-B. "Fishing Vessel Design and Some Related Technical and Economic Factors", D. J. Doust, Conference of the Design, Construction, and Operation of Small Fishing Vessels, St. John's, Newfoundland, May 1965.

29. " The Development of Beam Trawling in the North Atlantic", R. Symonds and H. Trowbridge, NE Section, SNAME, January 1947.

30. "FAO Catalogue of Fishing Gear Designs", Rome, Italy, 1965.

31. "Costs and Earnings of Selected Fishing Enterprises - Atlantic Provinces, 1964", J. Proskie, Canadian Atlantic Offshore Fishing Vessel Conference, Montreal, Canada, February 1966.

32. "New England Fisheries - Annual Summary", J. O'Brien, USDI-BCF, 1966.

33. "Recent Development and Research in Fisheries Economics", F. W. Bell, and J. E. Hazelton, 1965.

34. "Translation on USSR Fishing Industry and Marine Resources", Clearinghouse, JPRS No. 43812, U. S. Department of Commerce, December 1967.

35. "Economic Impact of the Abolition of Meatless Fridays", F. W. Bell, New England Business Review, December 1967.

36. "Some economic Considerations Relating to Canadian Atlantic Offshore Fishing Vessels", J. Proskie, Canadian Atlantic Offshore Fishing Vessel Conference, Montreal, Canada, February 1966.

37. "Fisheries of the United States", Bureau of Commercial Fisheries, U. S. Department of the Interior, Washington, D. C., 1963.

38. "The Practical Application of Economics to Merchant Ship Design", H. T. Benford, Marine Technology, Vol. 4, No. 1, January 1967.

39. "Great Lakes Ore-Carrier Economics and Preliminary Design", Dr. O. Krappinger, Marine Technology, Vol. 4, No. 2, April 1967.

40. "University of Rhode Island Agricultural Experimental Station Bulletins No. 379 and No. 380", J. Farrell and H. Lampe, June 1965.

41. "On the Rational Selection of Ship Size", H. T. Benford, SNAME Transactions, Vol. 75, 1967.

42. "A Fishing Technologist's Viewpoint on a Canadian Designed Stern Trawler", W. W. Jonson, Canadian Atlantic Offshore Vessel Conference, Montreal, Canada, February 1966.

43. "Some Hydrodynamic Characteristics of Three Hull Designs for a Canadian Designed Stern Trawler", Strazak and Ferguson, Canadian Atlantic Offshore Vessel Conference, Montreal, Canada, February 1966.

44. "Crew Accommodation in Trawlers", W. J. Milne, Canadian Atlantic Offshore Vessel Conference, Montreal, Canada, February 1966.

45. "A Skipper's Viewpoint on Offshore Fishing Vessels", M. Rodgerson, Canadian Offshore Vessel Conference, Montreal,Canada, February 1966.

46. "Steel Stern Trawlers", J. Marsters, Canadian Atlantic Offshore Vessel Conference, Montreal, Canada, February 1966.

47. "A Market Development Plan for the New England Groundfish Industry", USDI-BCF Circular No. 53, July 1958.

48. "Weight, Cost and Design Characteristics of Tankers and Dry Cargo Ships", Johnson and Rumble, Rand Corporation.

49. "A Modern Production Tool", Honsinger, Maritime Reporter/Engineering News, New York, November 1965.

50. "Automation of the A. J. McAllister", Maritime Reported/Engineering News, New York, January 1, 1968.

51. "Improvement in Fish Handling at Boston Fish Pier", Study by Bio-Dynamics, Inc., Cambridge, Massachusetts, 1965.

52. "Cruise Report M V Delaware, Cruise 67-10", USDI, BCF, December 1967.

53. "Fishery Industrial Research, Vol. 4, No. 1", USDI, BCF, Washington, D. C., 1967.

54. "Modern Deep Sea Trawling Gear", J. Garner, The Fishermen's Library, Fishing News Ltd., London, 1967.

55. "North Atlantic Type Otter Trawl Gear", B. Knake, Fish and Wildlife Service,Fishery Leaflet 445, Washington, D. C., May 1958

56. "Modern Fishing Gear of the World", FAO-UN, London, 1959.

57. "Exploiting the World's Fish Resources - The Outlook for the New England Fisheries", A. Holman, University of Rhode Island "Maritimes", 1967.

58. "Fisheries of the United States, 1966", United States Department of the Interior, Bureau of Commercial Fisheries, CFS 4400.

59. "Cruise Report,M.S. Delaware, Cruise 68-3", USDI-BCF, April 1968.

60. "Trawls", Zebrowski, Polish translation of NSF/USDI, OTS 60-32500, Warsaw, Poland, 1953.

61. "Relative Catching Efficiency of a 70' Semiballoon Trawl and a 94' Eastern Fish Trawl", W. Persyra, et al, Fishery Industrial Research, Vol. 4, No. 1, USDI-BCF, Washington, D. C., 1967.

62. "Fishery Products Reports", Daily New England Market News Service, Bureau of Commercial Fisheries.

63. "Earnings of Nova Scotia Fishing Vessels", Proskie, Fisheries of Canada Report, Vol. 24, No. 4, October 1967.

64. "Stern Trawling", edited by G. Ward, London, 1964.

65. "Cruise Report, M. V. Delaware, Cruise 65-6", USDI-BCF,

66. "Annual Earnings of Boston Fishermen in 1964", P. V. Mulkern, U. S. Department of Labor, Boston, Massachusetts, February 1966.

67. "Gulf of Mexico Shrimp Trawl Designs", USDI-BCF Leaflet 394, Washington, D. C., September 1951.

68. "Methods of Net Mending in New England, Part I", USDI-BCF Leaflet 241, Washington, D. C., July 1963.

69. "Assembly Methods for Otter Trawl Nets", B. Knake, USDI-BCF Leaflet 437, Washington, D. C., 1963.

70. "Double-Rig Shrimp Trawling in the Gulf of Mexico", B. Knake et al, USDI-BCF Leaflet 470, Washington, D. C., September 1958.

71. "Sea Scallop Boats and Gear", J. A. Posgay, Fishery Leaflet 442, U. S. Fish and Wildlife Service, Woods Hole, Massachusetts, July, 1963.

72. "Use of an Electrical Attracting and Guiding Device in Experiments with a Fish Pump", Keith Smith, BCF, USDI Vol. 17, No. 2, Washington, D. C., February 1955.

73. "Observations on Trawl-Door Spread and a Discussion of Influencing Factors", Wathne, USDI Commercial Fisheries Review, October 1959.

74. "Mechanical De-Icing and Weighing Groundfish at the Dock in New England", Peters, Slavin and Linda, BCF, Fishery Industry Research, Vol. 2, No. 1, Washington, D. C., September 1962.

75. "Trawler Operation in the North Sea", B. Noetzel, USDI TT66-57058, Warsaw, Poland, 1967.

76. "Psychosociological Problem of Work in the Fisherman's Occupation", A. Polanska, TT66-57060, USDI, 1964.

77. "Preliminary Examination of the Operation of B-23 Trawlers on the Fishing Grounds of the Northwest African Shelf", J. Swiniarski, TT66-57063, USDI, 1965.

78. "Modern Fishing Gear of the World - 2", P. Crewe, C. Hamuro, J. Verhost, A. Maton, FAO, London, 1964.

79. "Report of the Lectures of the FAO/USSR Seminar/Study Tour", A. Friedman, W. Dickson, FAO-UN, Rome, 1967.

80. "Diesel and Gas Turbine Catalog", 1967.

81. "Fishing Vessel Construction Costs and the U. S. Fishing Vessel Construction Differential Subsidy", by Ocean Research Corporation for the Bureau of Commercial Fisheries, 1967.

82. "Efforts and Landings of Large and Medium Trawlers Operating in the Boston Fleet for 1964-1966", Bureau of Commercial Fisheries,Proprietary.

83. "Fishery Statistics of the United States, 1964", Statistical Digest No. 58,USDI-BCF, Washington, D. C. 1964.

84. "Fishery Statistics of the United States, 1965", Statistical Digest No. , USDI-BCF, Washington, D. C., 1965.

85. "ICNAF Statistical Bulletin Vol. 16, for the Year 1966", Halifax, Canada, 1968.

86. "Modern Principals in Projecting and Design of Vessels", Dir. Sverre Møller, paper presented at meeting of Scandinavian Naval Architechts, Aalborg, Denmark, October, 1965; Norwegian Fishing and Maritime News, Vol. 13.

87. "Results of the Joint USA-USSR Groundfish Studies - Part I", (a) Comparative Fishing Experiments, Hennemuth, 1968; (b) Part II - Groundfish Survey from Cape Hatteras to Cape Cod, M. D. Grosslein.

88. "The West German Research Vessel WALTHER HERWIG", E. D. McRae, Jr., USDI-BCF Circular #266, Washington, D. C., September 1967.

89. "Cruise Report - M. V. Delaware , 65-3, Pelagic Oceanic Explorations", USDI-BCF, May 1965.

90. "Cruise Report-M.V. Delaware - 65-13 - Pelagic Oceanic Explorations", USDI-BCF, December 1965.

91. "Cruise Report-M.V. Delaware - 66-8 - Industrial Fish Explorations", USDI-BCF, October 1966.

92. "Design of the M.V. Delaware II", Keith Smith, USDI-BCF Circular 273, Washington, D. C., October 1967.

93. Torrey (England) Research Station: a) "Take Care of Your Catch"; b) "Road Transportation of Frozen Fish"; c) "The Protection of Wood in Fish Rooms"; d) "Handling Sea-Frozen Fish"; e) "Improving the Quality of Whiting"; f) "The Hauling of Wet Fish During Distribution"; g) "Handling and Preservation of Fish"; h) "The Principles of Scientific Cleaning for the Fish Industry".

94. "Fishes of the Gulf of Maine", Bigelow and Schroeder, Fisher Bulletin No. 74, Fish and Wildlife Service, Vol. 53, (Contribution No. 592, Woods Hole Oceanographic Institution), Washington, D. C., 1953.

95. "Underwater Gear Studies No. 4", Bureau of Commercial Fisheries Exploratory Fishing and Gear Research Base, Gloucester, Massachusetts, 16mm. black and white sound film.

96. "The Systems Approach to Fisheries Development", Dr. J. L. McHugh, Deputy Director, Bureau of Commercial Fisheries, Undersea Technology, January, 1968.

97. "The Royal Canadian Navy's Application of Method Study to Ship Design", K. Farrell, R. Judge, I. Engh, at Eastern Canadian Section of SNAME, January, 1965 - printed in Marine Technology, July, 1967.

98. White Fish Authority - London, England: a) "Summarized Report of a Study of the Operation and Performance of the Trawl Winch on a Large Stern Trawler" Bulletin No. 1, April 1964; b) "Warp Load Meters for Stern Trawlers", Bulletin No. 6, December, 1964; c) "Trawl Gear Investigations", Bulletin No. 10, May 1965; d) "Performance of a Japanese Trawl", Bulletin No. 12, July 1965; e) "Fish-Washer Development", Bulletin No. 14, September 1965; f) "Super Chilling", Bulletin No. 16, November 1965; g) "Warp Load Meters for Seine Net Vessels", Bulletin No. 17, December, 1965; h) "Product Development", Bulletin No. 19, April 1966; i) "Automatic Data Logging", Bulletin No. 20, June 1966; j) "Measurement of Power", Bulletin No. 21, September 1966; k) "Prepackaged Wet Fish - Progress Report on Market Trials", Bulletin No. 22, November 1966; l) "Hydraulic Winch Transmission for Seine

98. (Continued)

Netting (Fly Dragging)", Bulletin No. 23, March 1967; m) "Progress in Transfer of Catches at Sea", Bulletin No. 24, April 1967; "Speed, Hold Capacity and Other Design Parameters of Freezer Trawlers", 1968; "Progress Report on Trials of Boxing at Sea", October 1967; "Design Study for Unmanned Engine Room for Stern Freezer Trawlers;January, 1968.

99. "Fish handling on Board and Fish Unloading Methods", D. R. Stonely and R. D. B. Hopkins, Canadian Atlantic Offshore Fishing Vessel Conference, Montreal, Canada, February 1966.

100. "New England Groundfish Industry - A Systems Approach", Litton Industries for National Council on Marine Resources and Engineering Development, 1967.

101. "Principles of Naval Architecture (Revised), SNAME, New York, 1967.

102. "West Coast Fishermen Swear by Stabilizers", National Fisherman, February, 1966.

103. "Shipboard Irradiator Studies", J. W. Slavin et al, USDI, BCF, Gloucester, Massachusetts, 1966.

104. "Cost-Benefit Study of Selected Products", Daniel Yankelovich, Inc., for Atomic Energy Commission, 1966.

105. "Lines and Model Test Results - 47'-6" LWL Double Chine Work Boat", L. A. Baier, University of Michigan for General Motors Detroit Diesel Engine Division, 1946.

106. "Stern Trawler Designs", G. E. Kristinsson and D. J. Doust, Marine Technology, April, 1968.

107. "Basic Naval Architecture", (5th Edition) K.S. Barnaby, London, 1967.

## 8.0.0 Appendices

Following are more detailed descriptions of selected portions of the study:

### 8.1.0 Model and Program Descriptions

The generalized Fishery Resource Development Model, Fishery Flow Chart (Figure 2.0.0-I) formed the basis for modelling of a Georges Bank fishing system. This was then linearized, expanded, and quantified to form the Flow Charts (Sections 8.1.1 and 8.1.2) by use of the rationale contained in Sections 8.1.3 - 8.1.7. The form of flow chart used in 8.1.2 presents the operation in linear form and also provides cross-guidance to all inter-relationships.

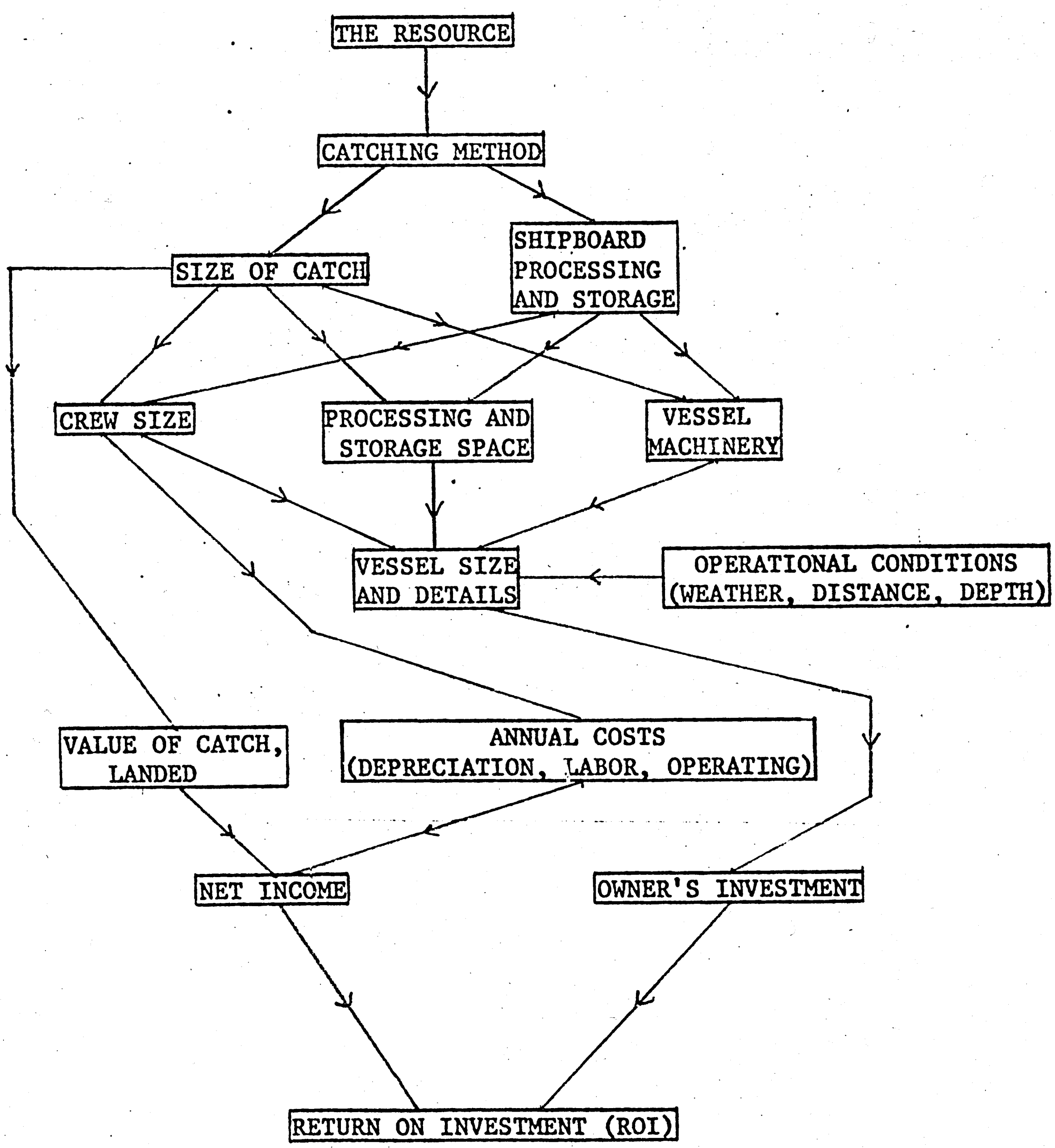
Associated with the flow chart are definitions of the items and the mathematical expressions used to find them. The essentially straightforward progression from one unit to the next as shown on the flow chart belies the complexity of both the fishery and the modelling problem. For example, return on investment (No. 61 on the Flow Chart) is a function of seven independent variables and nine semi-constants (units for which a single numerical value has been used, but which is in fact a variable).

In summary, Appendix 8.1.0 is a presentation of the relationships existing between various units, the reasoning for the quantification of these relationships, and the definition of the units.

Figure 8.1.1-I

**FLOW CHART**

Condensed Fishery Model



## 8.1.2 Flow Chart of Computer Program, with Definitions and Quantifications

| Step No. | Operation | Quantity is also used to find: | Where: |
|---|---|---|---|
| 1. | START | | |
| 2. | READ HL,L | EFFHP (9)<br>A (7) | HL=Length of headline of net, ft.<br>L=Stretched length of net, ft., exclusive of cod end. (8.1.3-6) |
| 3. | SET ITR | WINHP (13)<br>ITC (22) | ITR=Time required to recover net, min., from beginning to haul to hook-up of door.<br>= 8.0, 12.0, 16.0, 20.0 |
| 4. | SET VT | EFFHP (9)<br>WINHP (13) | VT=Towing speed of vessel, kn.<br>= 2.5, 3.5, 4.5 |
| 5. | SET WATER | WINHP (13) | WATER=Depth of Water, fathoms<br>= 100.0 |
| 6. | SET CRFC | Q(8) | CRFC=Catch rate factor change, $lb./min/ft^2kn.$<br>= 0 |
| 7. | COMPUTE A | EFFHP (9) | A=Functional area of net sq. ft.<br>$= .055\ (HL)^2$ |
| 8. | COMPUTE Q | CATCY (24) | Q=Catch rate of net, lb./min.<br>= .0178 (A) (VT) (8.1.3-a) |
| 9. | COMPUTE EFFHP | WINHP (13) | EFFHP=Power required to pull net, exclusive of doors and warps, hp.<br>$= \frac{[.47A + .0746(HL)\ (L)]\ 1.667\times1.689(VT)^3}{550}$<br>(8.1.4) |

8.1.2 (Continued)

| Step | Box | Used in | Definition |
|---|---|---|---|
| 10. | COMPUTE SHFHP | largest is used for TOTHP (15) TVC (45) | SHFHP=Main Engine continuous shaft horsepower required to move vessel/system at VT, hp. $=21.3325(EFFHP)^{.726}$ (8.1.4) |
| 11. | COMPUTE CRUHP | (largest of 10 and 11 as above) | CRUPH=Main Engine continuous shaft horsepower required to move vessel at 10.0 kn., hp. $=169.0 + 2.22\ (HL)$ |
| 12. | COMPUTE GENHP | AUXHP (14) | GENHP=Vessel's generator rated continuous horsepower, hp. $= .0093427(SHFHP)^{1.68711}$ (8.1.4) |
| 13. | COMPUTE WINHP | | WINHP=Vessel's trawling winch rated horsepower, hp. $= 4.0 \times EFFHP \times \left[\frac{.1775 \times Water}{VT \times ITR}\right]$ (8.1.4 and 8.3.0) |
| 14. | COMPUTE AUXHP | | AUXHP=Vessel's total auxiliary horsepower, hp. = WINHP + GENHP |
| 15. | COMPUTE TOTHP | TVC (45) | TOTHP-Vessel's installed horepower, hp. = SHFHP + AUXHP |
| 16. | COMPUTE MACA | TOTA (36) | MACA=Floor area of machinery room, sq.ft., $= .20979\ (TOTHP)^{1.16239}$ (8.1.6) |
| 17. | SET DAS | TRIPS (56) EXPEN (62) | DAS=Days at sea per trip, days = 4, 6, 8, 10 |
| 18. | COMPUTE DAYF | NUMCY (23) | DAYF=Average days fished per trip, days = 0.83 (DAS-1.25) |

| Step No. | Operation | Quantity is also used to find: | Where: |
|---|---|---|---|
| 19. | SET ITF | ITC (22)<br>CATCY (24)<br>WC (31) | ITF=Time net on bottom, min.<br>= 90 (8.1.5) |
| 20. | SET ITS | ITC (22) | ITS=Time required to shoot net, from unhooking doors to net on bottom, min.<br>= .05 WATER (8.1.5) |
| 21. | COMPUTE ITM | | ITM=Time required to manually handle net on deck, from hooking to unhooking doors.<br>= 8 (8.1.5) |
| 22. | COMPUTE ITC | | ITC=Time of a fishing cycle, min.<br>= ITS + ITF + ITR + ITM |
| 23. | COMPUTE NUMCY | | NUMCY=Number of fishing cycles per trip<br>= DAYF (24 x 60)/ITC |
| 24. | COMPUTE CATCY | WC (31) | CATCY=Catch per fishing cycle, lb.<br>= Q(ITF) |
| 25. | COMPUTE TRIPC | YRCAT (57) | TRIPC=Catch per trip, lb.<br>= NUMCY (CATCY) |
| 26. | COMPUTE HOCU | HOLS (28) | HOCU=Volume of fish caught per trip, cu.ft<br>= TRIPC/30 |
| 27. | SET PW | | PW=Factor allowing for working space in hold<br>= 1.30 |
| 28. | COMPUTE HOLS | | HOLS=Volume of hold, cu. ft<br>= HOCU (PW) (8.1.6) |
| 29. | COMPUTE HOLA | TOTA (36) | HOLA=Floor area of hold, sq. ft<br>$= .50993(HOLS)^{.82605}$ (8.1.6) |

| Step No. | Operation | Quantity is also used to find: | Where: |
| --- | --- | --- | --- |
| 30. | SET PPM | | PPM=Fish Processing rate, (sorting, gutting, icing) lb./man/min. = 8.0 |
| 31. | COMPUTE WC | NUMCR (34) | WC=Crew required per watch to process fish, men/watch = CATCY/PPM(ITF) |
| 32. | SET ISEAL | NUMCR(34) | ISEAL=Engineers per watch, men/watch = 1 |
| 33. | SET MATE | | MATE=Deck Officers per watch, men/watch = 1 |
| 34. | COMPUTE NUMCR | ONS (60)<br>EXPEN (62)<br>CRERN (63) | NUMCR=Total crew of vessel, men = 2 (WC + ISEAL + MATE) + 1 (8.1.6) |
| 35. | COMPUTE ACOMA | | ACOMA=Area required for total accommodations of crew, sq. ft = 71.0(NUMCR) (8.1.6) |
| 36. | COMPUTE TOTA | | TOTA=Representative total area of vessel,sq.ft = MACA + HOLA + ACOMA |
| 37. | COMPUTE CUBE | TVC (45)<br>DEPTH (43) | CUBE=Cubic no. of vessel, cu. ft $= 1.7586(TOTA)^{1.28045}$ (8.1.6) |
| 38. | COMPUTE DISP | LWL (40) | DISP.=Displacement of vessel, long tons $= .0071808(CUBE)^{1.03827}$ (8.1.6) |
| 39. | SET ALPH | | ALPH=Length/Displacement ratio=$\frac{LWL}{\nabla^{1/3}}$ = 4.25 |
| 40. | COMPUTE LWL | TIP (55) | LWL=Length on waterline of vessel, ft $= ALPH\ (DISP(35))^{1/3}$ |

| Step No. | Operation | Quantity is also used to find: | Where: |
|---|---|---|---|
| 41. | COMPUTE LOA | OINV (46) | LOA=Length over-all of vessel, ft.<br>= 1.08 LWL |
| 42. | SET BETA | BEAM (44) | BETA=Beam/Depth Ratio<br>= 1.80 |
| 43. | COMPUTE DEPTH | | DEPTH=Depth of vessel to Main Deck, ft.<br>$= \left[\frac{CUBE}{LWL(BETA)}\right]^{1/2}$ |
| 44. | COMPUTE BEAM | | BEAM=Beam overall of vessel, ft.<br>= BETA (DEPTH) |
| 45. | COMPUTE TVC | ONS (60) | TVC=Total Vessel cost, thousands of dollars<br>$= 1.25(.008481 \times CUBE + .048(TOTHP)^{1.175}+20.0)$<br>(8.1.7) |
| 46. | COMPUTE OINV | ONS (60)<br>ROI (61) | OINV=Owner's investment, thousands of dollars<br>= TVC (8.1.7) |
| 47. | COMPUTE FA | GAL (53) | FA=Fuel consumed by main engine during transit, jogging, etc., gal.<br>$= [1.581 + .1291(DAS - 1.25)]$ SHFHP |
| 48. | COMPUTE FB | GAL (53) | FB=Fuel consumed by main engine during shooting, gal.<br>= .00043916(SHFHP)(ITS) NUMCY |
| 49. | COMPUTE FC | GAL (53) | FC=Fuel consumed by main engine during fishing, gal.<br>= .00087833(SHFHP)(ITF)(NUMCY) |
| 50. | COMPUTE FD | GAL (53) | FD=Fuel consumed by main engine and trawl winch during recovery, gal.<br>= .00017566(SHFHP)(ITR)(NUMCY) +<br>.00087833(WINHP)(ITR)(NUMCY) |

| Step No. | Operation | Quantity is also used to find: | Where: |
|---|---|---|---|
| 51. | COMPUTE FE | GAL (53) | FE=Fuel consumed by main engine during time net on deck, gal. = .00017566(SHFHP)(ITM)(NUMCY) |
| 52. | COMPUTE FF | | FF=Fuel consumed by auxiliary generator during trip, gal. = 24(DAS)(.0527)(GENHP) |
| 53. | COMPUTE GAL | EXPEN (62) | GAL=Fuel consumed during trip, gal. = FA + FB + FC + FD + FE + FF |
| 54. | COMPUTE CAP | | CAP=Fuel capacity of vessel, gal. = 1.4 (GAL) |
| 55. | COMPUTE TIP | | *TIP=Time in port between trips, days = 10.68 - .0876(LWL) (8.1.5) |
| 56. | COMPUTE TRIPS | EXPEN (62) | TRIPS=Number of trips per year $= \frac{350}{(DAS + TIP)}$ |
| 57. | COMPUTE YRCAT | | YRCAT=Annual vessel catch, lb./yr = TRIPS (TRIPC) |
| 58. | SET POB | | POB=Average price of catch per lb.,dollars/lb. = .118 |
| 59. | COMPUTE INC | | INC=Annual gross revenue, thousands of dollars = YRCAT(POB)/1000 (8.1.7) |
| 60. | COMPUTE ONS | | ONS=Owner's net share, thousands of dollars = INC - (.685(INC) + .0975(TVC) + .4(NUMCR) + .05(OINV)) (8.1.7) |
| 61. | COMPUTE ROI | | ROI=Owner's return on investment, % $= 100 \left(\frac{ONS}{OINV}\right)$ (8.1.7) |

* Minimum TIP = 2.00

| Step No. | Operation | Quantity is also used to find: | Where: |
|---|---|---|---|
| 62. | COMPUTE EXPEN | | EXPEN=Annual expenses to be deducted from crew's share, thousands of dollars $= \text{TRIPS}\ (.02 + .00012\ \text{GAL} + .004(\text{NUMCR})(\text{DAS}) + .035\ \text{DAS})$ (8.1.7) |
| 63. | COMPUTE CRERN | | CRERN=Annual earnings of crew without bonuses, thousands of dollars $= \frac{.595\ \text{INC} - \text{EXPEN}}{\text{NUMCR}}$ (8.1.7) |

64. RETURN TO STEP 3, Repeat for all values of ITR

65. RETURN TO STEP 4, Repeat for all values of VT

66. RETURN TO STEP 14, Repeat for all values of DAS

67. RANK ALL ROI'S in descending order

68. Print RANK ROI, ITR, VT, DAS, TIP for all

69. Print RANK and all output for every 8th vessel (1st, 9th, etc.) or as directed

70. STOP

71. END

8.1.3 Catching Sub-System

a) Catch Rate Coefficient

For round fish, (Haddock, cod, etc.) the catch rate of a net is taken to be directly proportional to the volume of water swept passing through the trawl net. Therefore, the catch rate will be a function of the mouth area of the net and the rate at which it moves through the water. Based on confidential and detailed actual catch records, using a known net and towing speed, a catch rate coefficient, lb. caught per square foot of net mouth, in one minute at one knot, lb. catch/$ft^2$/knot/min., was calculated. The total catch per minute equals the catch rate coefficient times net area, A, times towing speed, VT.

b) Net Mouth Area

The mouth of a trawl net is assumed to have the shape of an ellipse. In actual use the height of the trawl net opening (minor axis) will decrease with increasing speed unless additional buoyancy is added to on the headling (Figure 39, Ref. 78). It is assumed that the headline height is kept constant for all speeds through the use of such lifting devices, (dynamic floats, kites, etc.) as are required. See Table 8.1.3-I for net sizes.

Therefore, $A = \pi \times \frac{l}{2} \times \frac{h}{2}$ where:

A = Effective mouth area of trawl net, sq.ft

l = horizontal dimension of net opening, major axis, ft

h = vertical dimension of net opening, minor axis, ft

Because of catenarity, l is assumed equal to 70% of the headline length. Height, h, was set equal to 12.7% of the headline length, HL, (Ref. 52).

then $$A = \pi \times \frac{.70(HL)}{2} \times \frac{.127(HL)}{2}$$

$$= .055\ (HL)^2$$

where HL = length of headline, ft.

8.1.4 Trawling Sub-System

a) Towing and Main Engine Power Requirements

The tension in the towing warps is the sum of the drags of the net, warps, doors, and miscellaneous gear. Measurements by Dickson (Ref.

Table 8.1.3-I

Principal Dimensions of Nets

| Name of Net | HL, Headline (Headrope) Length, ft | Footrope (Groundline) Length, ft | L, Length to aft end of belly, feet |
|---|---|---|---|
| No. 35 | 50 | 70 | 66 |
| No. 36 | 60 | 80 | 71 |
| No. 41-A Yankee | 73 | 94 | 77 |
| Granton | 78 | 118 | 104 |
| No. 41 Yankee | 79 | 100 | 80 |
| No. 45-A | 85 | 116 | 90 |
| Aberdeen - Large | 96 | 121 | 101 |
| 120' Net * | 120 | 152 | 127 |
| 160' Net * | 160 | 202 | 169 |
| 200' Net * | 200 | 253 | 211 |

* Hypothetical Nets

8.1.4 (Continued)

78), and others reported in Ref. 54, show that the drag of the net, alone, is equal to about 60% of the total warp tension.

Studies by Crewe (Ref.78) show that the resistance of a net at A = 0' is considerable. This suggests that trawl net resistance can be separated into two components, which might be termed Friction Drag (for the net at A = 0), and Form Drag (the resistance increment added by the opening of the mouth).

A Form Drag equation was derived of the type:

$$C_D = \frac{D}{AV^2}$$

where D = Form Drag of Net, lb.

A = Mouth Area of Net, $ft^2$

V = Towing Speed, knots

From Crewe (ref.78, Figure 38), it is seen that the drag due to form at A = 334.5 sq. ft, i.e., difference between total drag and zero mouth area drag, for a Granton net towed at 3.5 knots is 0.86 tons, giving a value for $C_D$ = .470.

The friction drag coefficient was derived of the type:

$$C_F = \frac{F}{AV^2}$$

where F = Friction Drag of Net, lb. at A = 0

A = Planiform Area of Net, $ft^2$

V = Towing Speed, knows

By analyzing the Granton net, it was found that the planiform area term could be expressed as a function of headline length, H., and stretched length of the net, L, wings to after end of belly. Since several commonly used nets have variable length cod ends, the characteristic length was chosen to after end of belly instead of overall. Crewe (Ref.78) gives zero mouth area drag of 3.32 tons for a Granton net towed at 3.5 knots, producing $C_F$ = .0746.

8.1.4 (Continued)

Since warp tension is taken to be equal to 1.667 (1/.60) times the sum of form and friction drag, the total tension in the warp may be calculated. The equation for EFFHP, the power required by the warp tension, is of the type:

$$EFFHP = \frac{D \times V \times 1.689}{500}$$

where D = total horizontal warp tension, lb.

V = towing speed, knots

EFFHP = horsepower required to pull net

(warp scope of 3:1 is assumed)

Note that since $D = f\ (HL, L, V^2)$ the power required to pull the net system, EFFHP, is a function of HL, L, $V^3$.

Having found the power required to pull the net, the power required to drive the net/vessel system, SHFHP, may now be found. While several methods exist (see Ref. 79, Friedman and Dickson), of comparing thrust required and thrust available for a net/vessel system, they are quite complex and presuppose intimate knowledge of vessel and engine characteristics. For this study, a relationship was developed which directly relates the power required to overcome the warp tension to the vessel shaft horsepower required to move the system. EFFHP and SHFHP figures were taken for three trawlers under similar operating conditions. (Table 3, Ref. 5, A, B, D-MARU, 13 data points), and a curve of SHFHP vs. EFFHP was drawn, Figure 3.5.1-I

In some cases, the power required to drive the net/vessel system is insufficient to drive the vessel at an acceptable transit speed, arbitrarily set at 10 knots. By knowing the general range of vessel characteristics generated for any given net (determined by the computer program FISH) it was possible to calculate the approximate horsepower required to achieve the transit speed. This horsepower was then related back to the net size with the equation:

$$CRUHP = k + m\ (HL)$$

where CRUHP = Horsepower required to achieve a transit speed of 10 knots

k,m = constants (k = 169.0 and m = 2.22 in this study)

HL = length of headline of net, ft

8.1.4 (Continued)

The main engine horsepower is the larger of the two horsepowers, SHFHP and CRUHP.

b) Auxiliary Power Requirements

For this study, the horsepower of the auxiliary generator, (GENHP), was related to main engine horsepower, SHFHP, on the basis of all available data. An actual design would require a calculation of the specific loads in order to size the generator. For purposes of estimation, however, the formula derived from data for existing vessels was found useful and reasonably accurate. The equation is of the type:

$$GENHP = k\ (SHFHP^{n})$$

where k, n = constants (k = .0093427 and n = 1.68711 in this study)

It might be expected that the exponent, n, would be unity, i.e., expressing a linear relationship between SHFHP and GENHP. The fact that n is greater than 1.0 is taken to indicate that as vessels become larger, a greater proportion of electrical power is required and/or less of it is generated by power-takeoff devices from the main engine.

The horsepower ratings of trawl winches, WINHP, showed wide variation among similar existing vessels. The horsepower required to recover the net is a function of total net system drag and the desired speed of recovery, expressed as a function of the time required for recovery, a 3:1 warp scope, and the depth of the water.

$$WINHP = EFFHP \left[\frac{k \times Water}{V \times ITR}\right]^{3} \times 4 \quad \text{(See Footnote)}$$

where V = towing speed, knots

ITR = time to recover net system, (time from doors on bottom to doors ready to be hooked up, min.)

Water = depth of water, fathoms

k = a constant (k = .1775 in this study)

NOTE: Study of winch horsepower requirements, subsequent to the final computer run, showed that the horsepower required to haul up the dead weight of warps, doors, etc., is largely relative to the hydrodynamic resistance of the net at low speed. WINHP as defined above is based on the resistance (EFFHP). WINHP is too low at slow retrieval speeds and too high at high retrieval speeds. The relative effect on ROI and on vessel size would be very slight, so the winch horsepower of the Optimum Vessel has been increased without altering other characteristics. See Appendix 8.3.0 for further discussion.

## 8.1.5 Chronological Relationships

For this study the following definitions were made:

ITR = Time to recover net system (time from doors on bottom to doors ready to be hooked up), minutes.

ITM = Time to manipulate net system (time to hook up doors, dump cod end, rig for shooting, unhook doors), minutes.

ITS = Time to shoot net system (time from doors unhooked to net system on bottom), minutes.

Bell (Ref. 19), has data on net handling times for side and stern trawlers and Heinsohn (Ref. 2) has a complete time record for a large stern trawler in Iceland waters. In addition, an experienced fisherman, owner of both side and stern trawlers, gave the following information on handling times; side trawler in 30 fathoms - 15 minutes; stern trawler in 40 fathoms - 12 to 14 minutes. Breaking down the times into the various operations, and adjusting the side trawler times to 40 fathoms gives the results in Table 8.1.5-I.

Table 8.1.5-I

Net Handling Times
New England Fishing Vessels

| Operation | | Stern Trawler | Side Trawler |
|---|---|---|---|
| Hauling, from bottom to gallows | ITR | 3 min. | 4 min. |
| Hook up doors | ITM | 2 min. | 3 min. |
| Handle and empty net | ITM | 4 min. (with net reel) | 5 min. |
| Unhook doors, rig for shooting | ITM | 2 min. | 2 min. |
| Shooting, to fishing position | ITS | 2 min. | 3 min. |
| | | 13 min. | 17 min. |

For correcting the data to 100 fathoms, ITM = 8 was held unchanged, $ITS_{100} = 2.5 \times ITS_{40} = 5$, and ITR was varied over a range of values from 8 minutes to 20 minutes. Ordinary practice is to average 10 trawls of 2-hours duration per day, with the remaining four hours per day being devoted to shifting, dodging, net mending and other miscellaneous tasks; 83% of the

8.1.5 (Continued)

time spent on the fishing grounds is, therefore, used for trawling operations. Transit time to the grounds was assumed to be a constant 15 hours each way (150 miles at 10 knots), or 1.25 days/trip.

An analysis of the Boston large and medium trawler fishing efforts showed a strong correlation between vessel size and time spent in port between trips (see Figure 8.1.5-I). Undoubtedly a principal reason for this relationship is weather. A small vessel, anticipating a bad sea, will remain in port or cut short a trip because it would be unable to trawl even if on the grounds; the large vessels exhibit relative immunity to this problem. A minimum of two days in port per trip was assumed for the large vessels. Figure 3.1.5-I is a representation of the time distribution for a vessel over a year.

From the data and assumptions explained above, a series of curves were constructed for various nets in common use, as well as three hypothetical nets, Figure 8.1.4-II, relating towing speed and SHFHP, towing speed and catch per cycle, and WINHP and time to complete a fishing cycle, ITC. By using these curves, and by computing the number of fishing cycles per trip based on 90-minute tows and hauling times as previously derived, it is possible to predict an annual catch for a known vessel if the number of trips per year is known.

An analysis of the efforts and landings data for Boston large and medium trawlers (Ref. 82) indicated that in most cases the landings predicted by the model exceeded the actual landings; however, for eight vessels, the predicted and actual landings agreed quite well and in three cases, the actual landings exceeded the predicted landings. The implication is that while the majority of the Boston vessels do not perform as well as predicted, there are vessels that do.

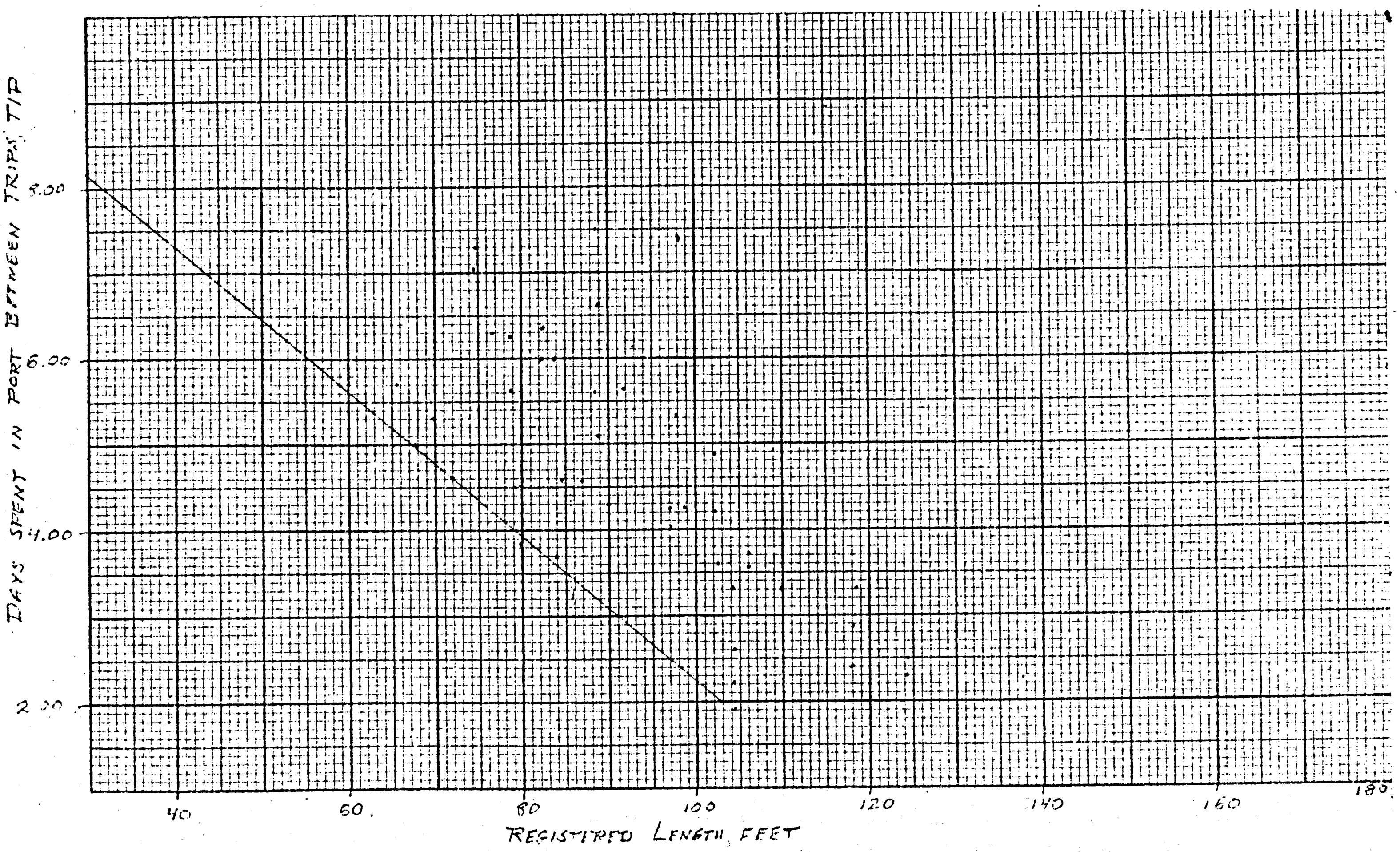
The reason for wide variability in the performance of the Boston fleet is not readily apparent. The most likely reasons are a high proportion of non-fishing time and a low catching rate, the former caused by frequent breakdown, inefficient deck layout, and advanced age of crew, and the latter partially by the skill of the captain in finding fish.

8.1.6 Vessel Characteristics

The size of the vessel may be determined by the space required for the catch, the machinery, and the crew. By analyzing a number of foreign and domestic trawler designs, it was possible to relate the floor area of the engine room to the total horsepower installed within it; that

Figure 8.1.5-I

Time in Port (TIP) vs. Registered Length




The plotted points represent the time in port for 56 large and medium Boston trawlers. Average annual time in port between trips (TIP) was calculated from BCF data for 1964, 1965, 1966 for each vessel by the following formula:

$$TIP = \frac{365 - 15 - DASYR}{TRIPS}$$

where: 15 = assumed days per year in shipyard for normal maintenance

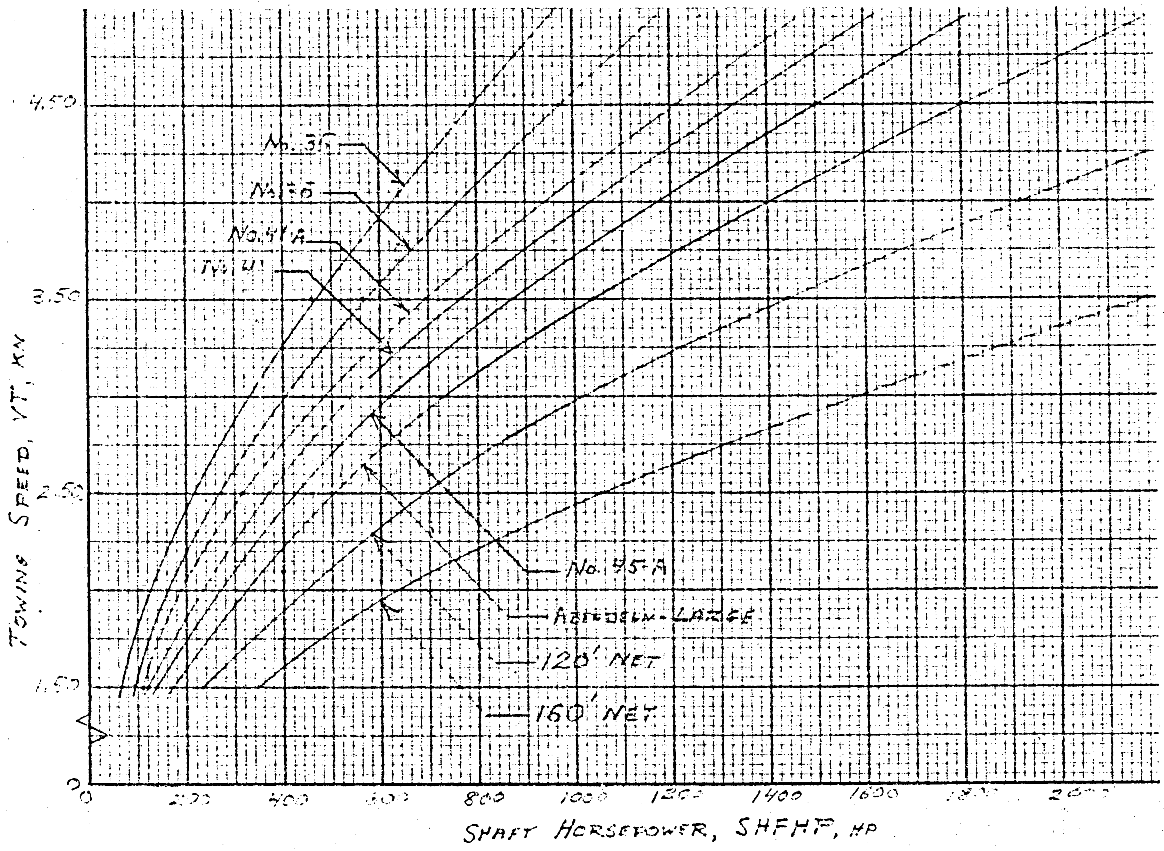
DASYR = Days at sea per year

TRIPS = Number of trips per year

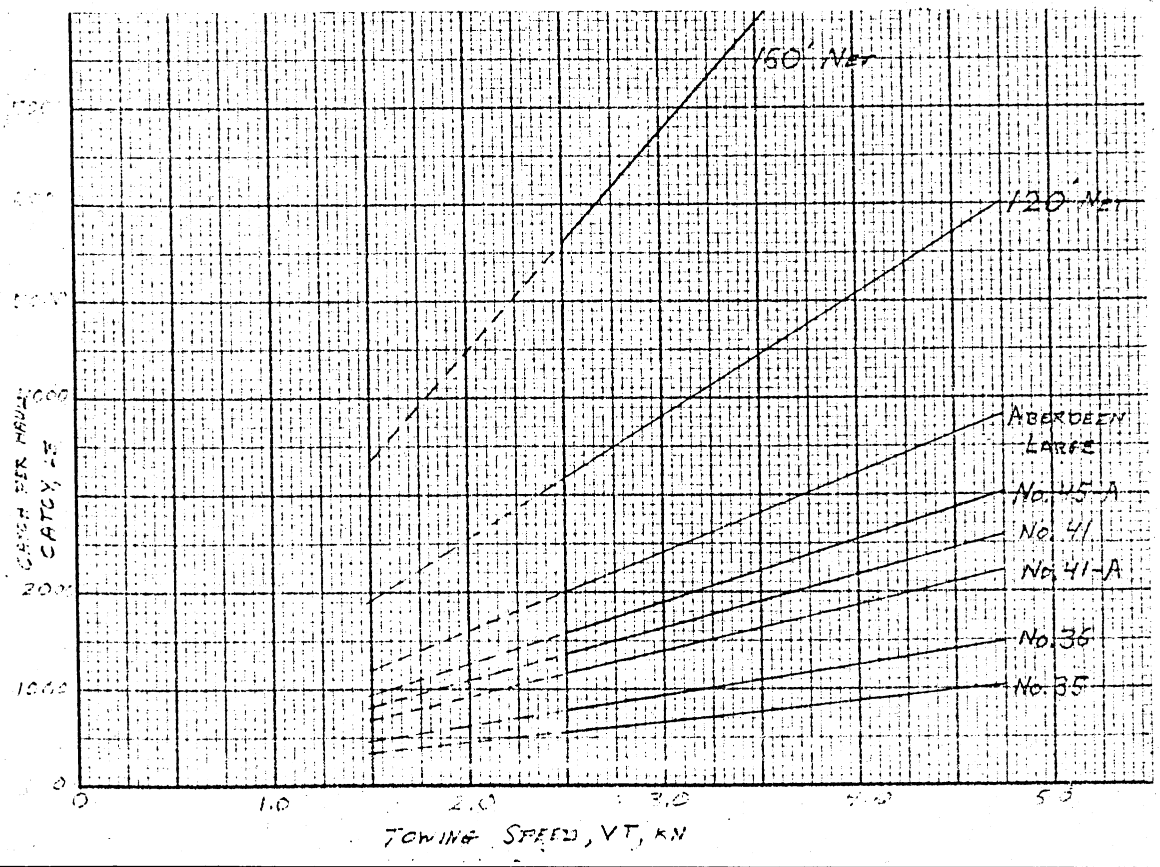
The least value of TIP for the three years was used in the plot. The curve was drawn as an envelope representing the minimum average, i.e. sustainable, time in port between trips.

Figure 8.1.4-II

Towing Speed (VT) vs. Shaft Horsepower (SHFHP)




Catch per Cycle (CATCY) vs. Towing Speed (VT)



8.1.6 (Continued)

is, the sum of the main engine and auxiliary horsepower. Because the original designs were in keeping with good, modern marine practice in allotting sufficient space within the machinery box for working, gear storage, and miscellaneous pieces of auxiliary machinery, the empirical relationship which was derived allots sufficient space for these functions. The equation is

$$MACA = k\ (TOTHP)^n$$

where MACA = Floor area of machinery box, sq. ft

TOTHP = total horsepower installed within the engine room
k, n = constants (k = .20979 and n = 1.16239 in this study)

The size of the vessel's crew will determine the size of the accommodation space. Prior to the advent of stern trawlers and the use of modern remote control deck machinery, the crew size was determined on the basis of the various operations required to shoot and haul the trawl. Modern design and technology have reduced the number required for this operation considerably. For this study, the rate at which the fish can be processed, the time trawled per cycle, and the cycle catch are used to determine the size of the working crew. Studies by Mr. A. Bezanson of the BCF Technological Laboratory in Gloucester, Massachusetts indicate that a sustained rate of 8.00 lb./man for gutting may be expected if efficient equipment, of the type developed at that laboratory, is installed. The total size of the crew is determined by the addition of one deck officer per watch, and one engineer per watch, and one cook, to the deck hands required to process at the predicted catch rate.

The attraction and retention of trained crews is becoming a serious problem of the Boston trawler fleet. In terms of arduousness of services and time away from home, a parallel may be drawn with the military sea service which, in recent years, has vastly increased habitability standards to help overcome this same problem. The standards for accommodations tentatively recommended by the International Labor Organization (Ref. 11), were adopted for this study as being reasonable and acceptable to good crews. The relationship between size of crew and accommodation area required was based on these standards and a study of modern vessels.

$$ACOMA = k\ (NUMCR)$$

where ACOMA = floor area of accommodations space, sq. ft

NUMCR = number of crew, officers, and cook

k = constant (k = 71.0 in this study)

8.1.6 (Continued)

The size of the fishhold is a function of the size of the expected trip catch and the additional space required for working area. A stowage factor of 30 lb. of fish per cubic foot is commonly used in the U.S.A.,32 lb. in the U.K; this allows for ice (about half th[illegible] of fish), space for pen boards, etc. An additional 30% was allotted to working space, large trips, etc. By analyzing a number of foreign and domestic trawler designs, the floor area of a fish hold was related to its volume.

This equation is of the type:

$$\text{HOLA} = k\,(\text{HOLS})^n$$

where HOLA = floor area of fishhold, sq. ft

HOLS = size of fishhold, cu. ft

k, n = constants (k = .50993 and n = .82605 in this study)

The areas of the major space components, MACA, ACOMA, HOLA, are added to give the total vessel characteristic area, TOTA. An analysis of foreign and domestic designs gave the relationship between TOTA and the cubic number of the vessel.

$$\text{CUBE} = k\,(\text{TOTA})^n$$

where CUBE = cubic number of vessel, LWL x Beam x Depth to Main Deck, cu. ft

TOTA = characteristic total area of vessel, sq. ft

k, n = constants (k = 2.03058 and n = 1.28045 in this study)

By the same method it was possible to relate vessel cubic number to vessel displacement.

$$\text{DISP} = k\,(\text{CUBE})^n$$

where DISP = displacement of vessel, long tons

CUBE = cubic number of vessel, cu. ft

k, n = constants (k = .0071808 and n = 1.03827)

By selecting an Ⓜ ratio, (Ⓜ $= \dfrac{L}{\nabla 1/3}$), ALPH, and a beam/depth

8.1.6 (Continued)

ratio, BETA, it is possible to obtain the length, beam and depth of the vessel from the cubic number and the displacement. Values of 4.25 and 1.80, respectively, were chosen to provide good powering characteristics (see Ref. 3a, b, c), stability and maneuverability, and general seakindliness. These dimensions may be tested for suitability and readjusted if necessary, holding cubic number and displacement constant.

The tankage requirements of the vessel were determined by assuming a mission profile with the following power requirements:

Main Engine

| | |
|---|---|
| Steaming | = 100% full power |
| Shooting | = 50% full power |
| Fishing | = 100% full power |
| Recovery and Manual Operation | = 20% full power |

Trawl Winch

| | |
|---|---|
| Recovery | = 100% full power |

Auxiliary Generator

| | |
|---|---|
| Continuous | = 100% |

A brake specific fuel consumption of .390 lb./hp-hr was selected (Ref. 80, pg. 18, 115). By summing the fuel consumed by each item, the fuel consumed during a trip is found. A reserve of tankage of 40% was added.

### 8.1.7 Economics

a) Total Vessel Cost

The method used to estimate total vessel cost was very similar to that used in Ref. 80. By analyzing foreign and domestic proprietary cost data it was possible to construct a series of cost curves for the major vessel groups. It was found that the costs of fishing gear (less winch), basic vessel structure, and miscellaneous costs are a function of the cubic number of the vessel, the electronic cost is approximately constant, and the machinery cost (with winch) is a function of total horsepower. An overhead rate was set at 25% of the total direct cost of material and labor.

8.1.7 (Continued)

$$TVC = 1.25\ (k\ (CUBE) + k_2\ (TOTHP)^n + k_3)$$

where TVC = Total vessel cost, thousands of 1967 dollars.

TOTHP = Total installed horsepower (main engine, auxiliary generator, and trawl winch).

$k_1$, $k_2$, $k_3$, n = constants ($k_1$ = .008481, $k_2$ = .048, $k_3$ = 20.0, and n = 1.175, in this study).

Note that this equation bears a resemblance to the 4-variable regression equation contained in Table IX-4 of Ref. 81. In the present case, however, the outfit number is considered to be a constant, and the LOA is not an independent variable, but rather a function of CUBE.

b) Owner's Investment

The relationship between total vessel cost and owner's investment is dependent upon the granting of a construction subsidy by the Maritime Administration and its acceptance by the prospective owner. While a logical, straightforward method of subsidy determination has been proposed, (see Ref. 81), the Maritime Administration has not yet accepted this proposal. It is also possible that the owner may not desire a subsidy. For these reasons, it was decided to set owner's investment equal to total vessel cost, i.e. with no construction subsidy.

c) Income

The gross income to the vessel for a year is a function of the quantity of fish caught and the unit value of the fish. The equation for the quantity of fish caught is:

$$YRCAT = TRIPC\ (TRIPS)$$

where YRCAT = Annual vessel catch, lb.

TRIPC = Vessel catch per trip, lb./trip

TRIPS = Number of trips vessel makes, trips/year

The average unit value of the fish was determined by dividing the 1966 total landing in dollars by the 1966 total landings in pounds for 11 large and 18 medium trawlers landing in Boston, where these figures were taken from Ref. 82. The value calculated was \$.118/lb. The income equation

8.1.7 (Continued)

is, therefore:

INC = YRCAT x POB/1000

where INC = Annual gross vessel income, thousands of dollars

POB = Price/lb. of fish, dollars/lb.
= $.118

d) Owner's Net Share

Under the Boston "lay" system, the Owner's Gross Share is equal to 40% of the vessel net income. The net vessel income is obtained by subtracting the Joint Share from the gross vessel income. A value of 4.5% of income was assumed for the Joint Share (Ref. 15). The Crew Share was set at 60% of the net vessel income, as provided by the lay arrangement. The vessel share was taken to be the sum of the hull insurance, 3.75% of total vessel cost per year for new vessels (Table VII-3, Ref. 19), straight line depreciation for 20 years, i.e. 5% of total vessel cost per year, and an annual maintenance and repair cost of 6.0% of total vessel cost for new vessels. The owner's net share is determined by subtracting the sum of the Joint, Vessel, and Crew Shares from the gross income, then subtracting the captain's share, which is 10% of the owner's gross share, (Exhibit VII-1, Ref. 19). The final equation is then:

ONS = INC - (.685 INC + .0975 TVC + .0500 OINV + .4 NUMCR)

where ONS = Owner's Net Share, thousands of dollars

.685 INC = Sum of Crew Share, Captain's Share, and Joint Share, thousands of dollars

.0975 TVC = Sum of Hull Insurance and Cost of Maintenance and Repair, thousands of dollars

.0500 OINV = Annual depreciation, thousands of dollars
= 5% of Owner's Investment

.4 NUMCR = Crew Insurance, thousands of dollars

e) Crew Expenses

Under the Boston Lay System certain expenses are subtracted from the crew share. These are fuel and lube oil costs, stores costs, and miscellaneous costs. Crew bonuses were not considered as one of these expenses.

8.1.7 (Continued)

A value of \$.12/gal of diesel oil was obtained as a representative figure for large quantity, on-site fueling rates. The cost of consumable stores was taken to be \$4.00/man/day at sea (Ref. 15). The cost of miscellaneous items such as ice, lumper fees, etc., was assumed to be \$35/day at sea/trip, (Ref. 15). A constant of \$20/trip was assumed for rag cost and cook's bonus (Ref. 15). The equation for the crew expenses is:

$$EXPEN = TRIPS\ (.020 + .00012\ (GAL) + .004\ (NUMCR)\ DAS) + .035\ (DAS))$$

where EXPEN = Expenses to be deducted from the crew share/year, thousands of dollars

f) Crew Earnings

The earnings of the crew were taken to be the Crew Share less Crew Bonuses, welfare funds, wharfage, etc., and crew expenses. The sum of bonuses, welfare funds, wharfage fees, etc., was assumed to be 0.5% of income (Ref. 15). Therefore, the equation for crew earnings is:

$$CRERN = \frac{.595\ (INC) - EXPEN}{NUMCR}$$

where CRERN = annual earnings of a crew member without bonuses, thousands of dollars/year

g) Return on Investment

For this study, the term "Return on Investment" (ROI) is taken to mean the return the owner might expect from the first year of vessel operation in relation to his original investment (for which commercial financing was not required). The equation for ROI is:

$$ROI = 100 \times \frac{ONS}{OINV}$$

where ROI = the annual percentage return on the owner's invested capital, %/year

## 8.2.0 Operator's Guide for FISH* Program

This program was written for use with an IBM 1130 computer, but can be used on any computer equipped with FORTRAN IV, with a card reader (for input of the program itself), a console keyboard and typewriter, and a line printer.

The program consists of a deck of computer cards (object deck). No data cards are required, although certain variables are entered with the console keyboard.

The program is executed by the use of a //XEQ FISH control card. The typewriter will give the program options available (amount of printed output desired, punch or print output, etc.) through use of the sense switches on the console. After selection of switch options, the user is requested to enter the net's headling length, (HL), and trawl net length, (L), in feet (excluding the cod end). The computer will then use the supplied data to arrive at the desired answers (solutions). One of the program options allows separate entry of trawling speed (VT), days as sea (DAS), hauling time (ITR) and catch rate change factor (CRCF); these are also entered at the keyboard, as requested by the typewriter. The computer will then determine the yields for the specific boat which fits the values entered.

To end operation (exit) of the program, the sense switch option 1 is turned on, and the end-of-file (EOF) console key is pressed, without entering any data.

*"FISH"is the title given to this program.

## 8.3.0 Discussion of WINHP

A further investigation of winch horsepower, subsequent to the start of the design of the Optimum fishing vessel disclosed that the calculated power of the trawl winch for the slower retrieval speeds was insufficient to raise the weight of the warps, doors, and net. A second term was added to the equation to reflect the work expended in lifting the gear. The weight of the net system is not a constant for each net, (a No. 41 towed at 4.5 knots will require considerably heavier warps than a No. 41 towed at 2.5 knots) but is more closely related to the vessel's shaft horsepower. A value of 24 lb. of net system per shaft horsepower was used. An overall system efficiency was determined by utilizing specifications and data from a recent stern trawler. The winch horsepower equation is of the form:

$$\text{WINHP} = \frac{1}{.35}\left[\frac{(24\ \text{SHFHP})(.1\ \text{WATER})}{550\ \text{ITR}} + \text{EFFHP}\left(\frac{.1775\ \text{WATER}}{\text{ITR x VT}}\right)^3\right]$$

8.4.0 **Electronic Outfit**

The following is a list of electronic gear considered to be the minimum for successful operation on the Georges Bank Fishery.

Decca Navigator: (Although Georges Bank lies in a weak signal zone between the New York and Nova Scotia sending area, the convenience and accuracy of this system suggest its use. It may replace the Loran).

Radar: 32 mi. to 48 mi. range, $\leq$ 1/2 mi. minimum range; $\geq$10" scope; large antenna. (There may be some advantage to having two displays, so that long and short ranges may be viewed at the same time.

Loran: "A" only.

Echo Sounder: 400 fathoms total range; recording type with white or gray-line bottom; 4-10 fathoms bottom-locked; balance in 50 fathoms steps.

Fish Finder: Fish lupe type; effective range $\geq$2000 yds; (trainable narrow-beam type may be worth extra cost in order to 1) detect bottom obstructions such as wrecks, and 2) locate fish in upper water and measure their density).

Radio telephone: 150 watts, 8-10 channel

Auto Pilot: Heavy duty for 120'-130' LOA, 600 L. Tons displacement; two fixed stations - forward and after end of pilot house (for steaming and fishing); one portable station for deck use.

Compass: A component of the auto pilot system.

Speedometer: Sailboat type; 0-12 knot scale for steaming; 0-4 knot scale for towing.

Environmental Instruments:

- Recording barometer
- Thermometers
  - Air, outside
  - Water, hull mounted
- Hygrometer
- Anemometer

8.4.0 (Continued)

In addition, the following items are considered to be highly desirable for increasing the efficiency of vessel and crew:

CB Radio: 5-watt, 23-channel

Radio Receiver: Broadcast and shortwave; tape recorder; sufficient power to drive through PA system.

Audio System: Hailer; fog horn (timer); PA system throughout vessel; internal intercom system.

## 8.5.0 Sample Computer Output for HL = 120, L = 127, IRT = 16, DAS = 9, VT = 3.0

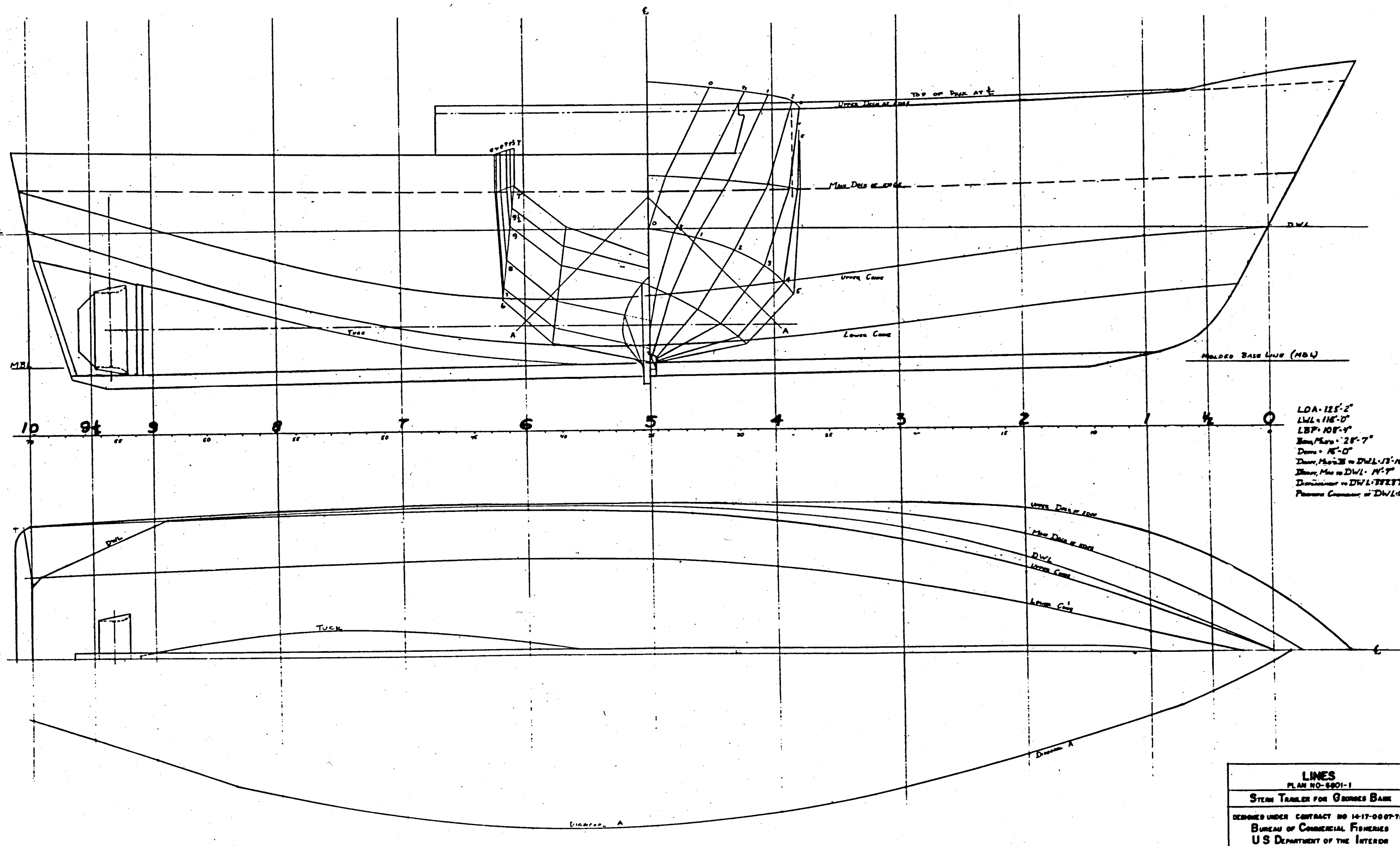
```
 FOR A HEADLINE OF     120.00  AND A LENGTH OF     127.00
THE FOLLOWING BOAT-CREW IS PROPOSED AS THE   1TH BEST POSSIBLE SYSTEM

  ROI=  25.85  VT= 3.0  ITR= 16  DAS=  9  DAYF=  6.43  DAYYR= 204

A=    792.  Q=    42.2  EFFHP=  208.5  SHFHP= 1030.0  TOTHP= 1185.3
  GENHP= 113.10  WINHP=  42.19  MACA=    784.   ITC= 119

ITF=  90  ITR=  16  ITM=   8  ITS=   5

NUMCY=  77  CATCY=  3806.3  TRIPC= 293089.  HOCU=  9769.6  HOLS= 12700.5  HOLA= 1251.6

 NUMCR= 16  ACOMA= 1136.0  TOTA=  3172.  CUBE=   53521.5   DISP=  582.9

  CRUHP=      435.400  SHFHP=    1030.032  THE LARGEST OF WHICH WAS USED TO CALCULATE TVC

LWL= 112.3  LOA= 121.3  DEPTH= 16.2  BEAM= 29.2  TVC=   837.815  OINV=   837.815

 TIP=  2.0  GAL=  10770.  CAP=  15078.  TRIPS=  31.81  YRCAT=  9325558.  INC= 1100.4  ONS=  216.6

 EXPEN=       70.10  CRERN=      36.53
```

**Notes:**

Optimum Vessel characteristics as used in the report were hand-calculated. Some slight variations will therefore be noted between this computer output and the characteristics in the text due to rounding, etc.

The agreement between the hand calculations and the computer output is generally good except for the vessel dimensions (LWL, LOA, Depth, Beam) which must represent a key-punching error as CUBE and DISPL are both very nearly identical. This difference will have no effect on the predictions, and in fact, vessels built to either dimensions should perform equally well.

WINHP used in the text was recalculated according to Appendix 8.3.0.




LOA = 125'-2"
LWL = 115'-0"
LBP = 108'-4"
Beam, Molded = 28'-7"
Depth = 15'-0"
Displacement to DWL

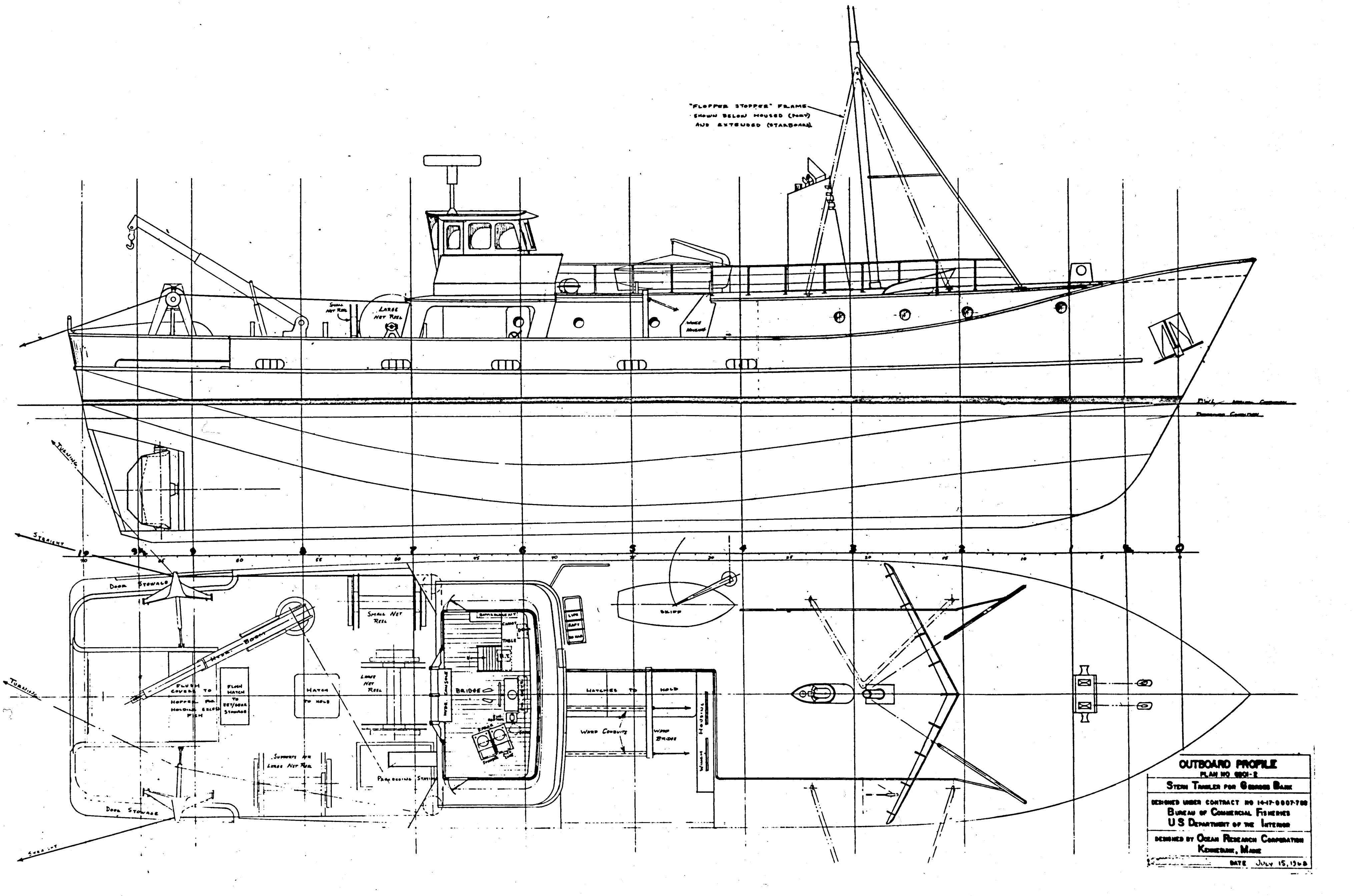
**LINES**
PLAN NO-6801-1

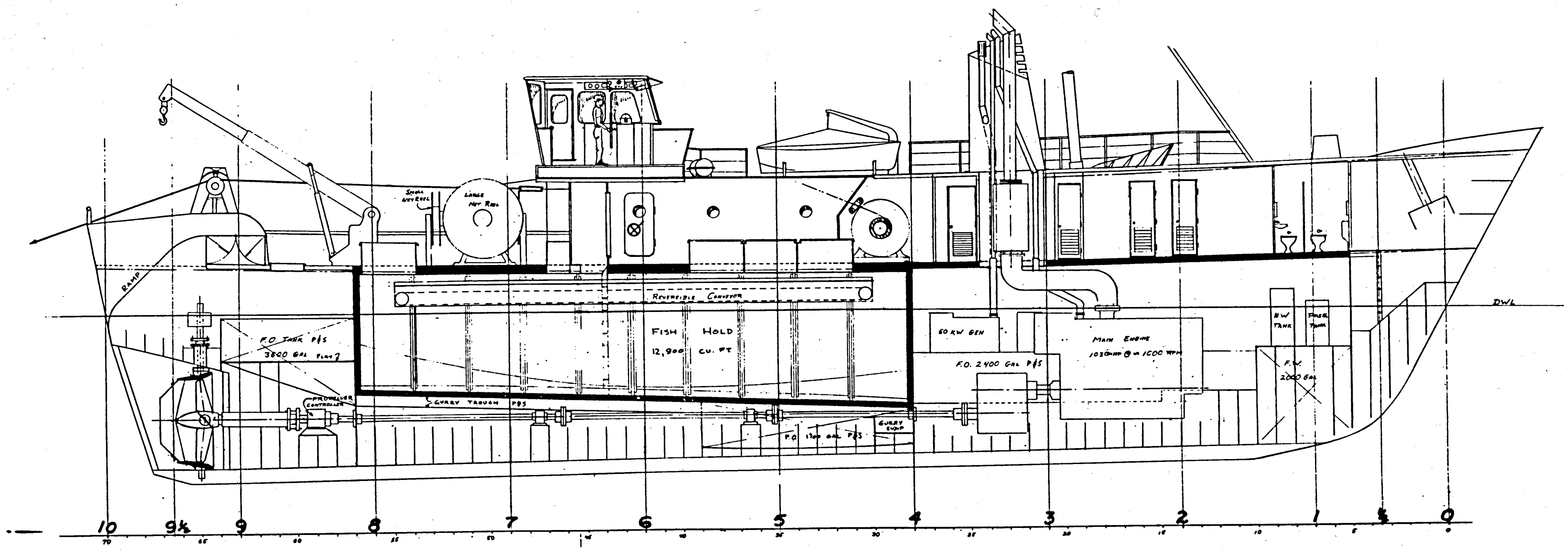
STERN TRAWLER FOR GEORGES BANK

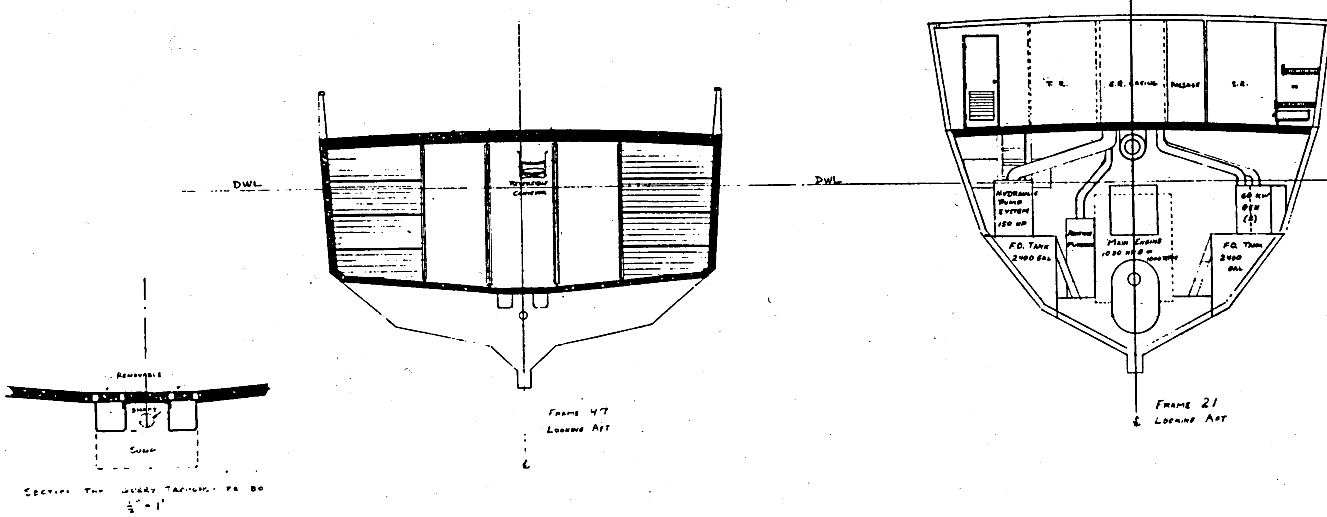
DESIGNED UNDER CONTRACT NO 14-17-0007-788
BUREAU OF COMMERCIAL FISHERIES
U S DEPARTMENT OF THE INTERIOR

DESIGNED BY OCEAN RESEARCH CORPORATION
KENNEBUNK, MAINE

| SCALE 1/16" = 1'-0" | DATE JULY 15, 1968 |
|---|---|


"Flopper stopper" frame
shown below housed (port)
and extended (starboard)
Small Net Reel
Large Net Reel
Winch Housing
Turning
Straight
Door Stowage
Hatch to hold
Bridge
Skiff
Hatches to hold
Warp Conduits
Warp Bridge
Processing Station
Supports for Large Net Reel
OUTBOARD PROFILE
Stern Trawler for Georges Bank
Designed under contract No
Bureau of Commercial Fisheries
U S Department of the Interior
Designed by Ocean Research Corporation
Kennebunk, Maine
Date July 15, 1968




**INB'D PROFILE & SECTIONS**
PLAN NO 6801-3

STERN TRAWLER FOR GEORGES BANK

DESIGNED UNDER CONTRACT NO 14-17-0007-780
BUREAU OF COMMERCIAL FISHERIES
U S DEPARTMENT OF THE INTERIOR

DESIGNED BY OCEAN RESEARCH CORPORATION
KENNEBUNK, MAINE

DATE JULY 15, 1968

(continued from inside front cover)

14. A Price Incentive Plan for Distressed Fisheries by A. A. Sokoloski and E. W. Carlson.

15. Demand and Prices for Shrimp by D. Cleary.

16. Industry Analysis of Gulf Area Frozen Processed Shrimp and an Estimation of Its Economic Adaptability to Radiation Processing by D. Nash and M. Miller.

17. An Economic Evaluation of Columbia River Anadromous Fish Programs by J. A. Richards.

18. Economic Projections of the World Demand and Supply of Tuna, 1970 - 90 by F. Bell.

19. Economic Feasibility of a Seafood Processing Operation in the Inner City of Milwaukee by D. Cleary.

20. The 1969 Fishing Fleet Improvement Act: Some Advantages of its Passage by the Division of Economic Research.

21. An Economic Analysis of Policy Alternatives for Managing the Georges Bank Haddock Fishery by L. W. Van Meir.

22. Some Analyses of Fish Prices by F. Waugh and V. Norton.

The goal of the Division of Economic Research is to engage in economic studies which will provide industry and government with costs, production and earnings analyses; furnish projections and forecasts of food fish and industrial fish needs for the U. S.; develop an overall plan to develop each U. S. fishery to its maximum economic potential and serve as an advisory service in evaluating alternative programs within the Bureau of Commercial Fisheries.

In the process of working towards these goals an array of written materials have been generated representing items ranging from iterim discussion papers to contract reports. These items are available to interested professionals in limited quantities of offset reproduction. These "Working Papers" are not to be construed as official BCF publications and the analytical techniques used and conclusions reached in no way represent a final policy determination endorsed by the U. S. Bureau of Commercial Fisheries.