

Special project

DESIGN OF A PROPULSION MODEL
FOR
HUMAN POWERED BIONIC BOAT

By

Nikhil Rane

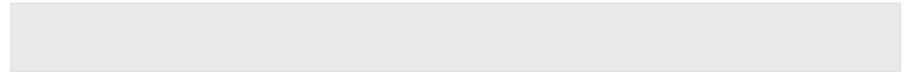
Guide: Prof. V. P. Bapat

IDC, IITBombay
India

Approval Sheet

The Special Project titled
'Design of a propulsion model
for a human powered bionic boat'
by
Nikhil Rane
is approved
for the partial fulfilment of the requirement
for the degree of
Master of Design in Industrial Design

Project Guide



Chairperson



Internal Examiner



External Examiner



Date



Acknowledgement

I wish to thank my guide Prof. V. P. Bapat for his guidance and wholehearted support throughout the project.

I thank the IDC faculty for their precious time and suggestions which were very useful for providing a correct direction to the project.

I wish to thank my colleagues Prashant Vetoskar and Abhijeet Kumar who worked on parallel projects and shared their time and provided valuable inputs.

Last, but not the least, I sincerely thank all my fellow students who were very supportive and accomodating.

Contents Page

Abstract	1
Introduction	2
Data Collection	3
Inferences	9
Selection Of Preferred Propulsion Mechanism And Fish Type	10
Analysis And Modeling Of Selected Propulsion Mechanism	12
Concepts For Propulsion Mechanisms	16
Scale Model For The Propulsion Mechanism	20
Proposed Applications and Boat Forms	22
Conclusion	23
References	24

Abstract

This project was envisaged with the intention of exploring the bionic mechanisms for locomotion in fishes and to analyze and thereby develop a model of fish propulsion. It is a part of the ongoing research of prof. V. P. Bapat, and is guided by him.

The work done so far by other students through previous projects has given a certain direction to the research. A scale model of one fish propulsion type has been previously tested.

The project focuses more on development of an appropriate mechanism for subsequent building and testing of a scale model to verify and evaluate the nature of the movement obtained with reference to the bionic principles involved.

It is observed that most bionic research in this area focuses on development of electrically powered craft. This project however focuses on developing a mechanism for pedal powered boats for leisure and recreational activities, sports, etc.

The approach has been to develop a mechanism which conveys the essence of the action with correct proportioning and becomes an integral part of any boat form developed for it

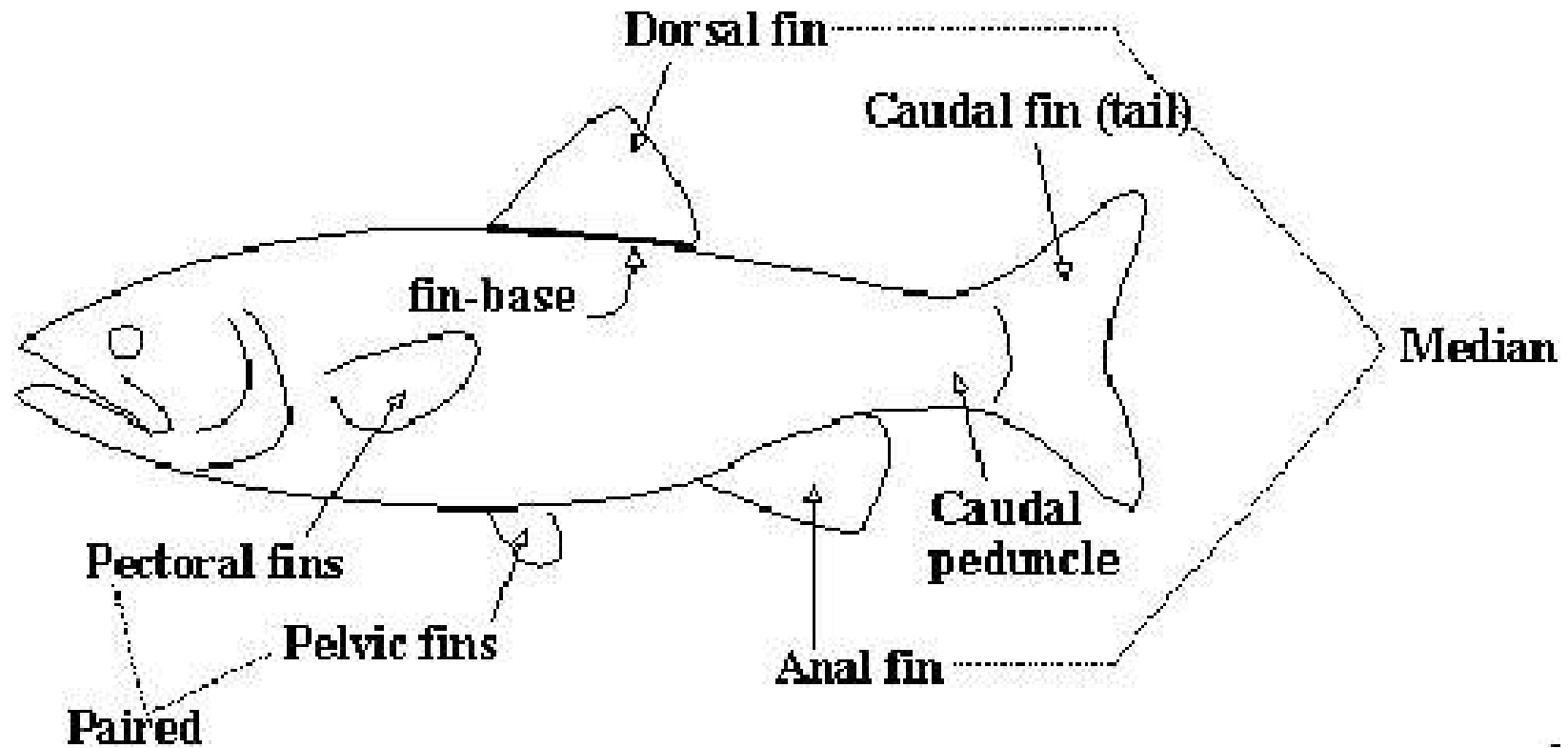
Introduction

Fish have been the subject of a lot of research all over the world for developing marine craft and products based on their structure, swimming characteristics and unique features. The vast area of bionics has been instrumental in helping us to understand and apply our knowledge of their activity to develop robot submarines, boats and the like. The navy and other defence establishments have been at the forefront of this area of work.

However much lesser work has been carried out to find applications for human powered boats and craft for recreational use and sport activity. It is this area that I wish to address through this project. The scope of the project is identification of a fish and locomotion mode type for study and adapting its propulsion methods and form for the development of a mechanism for future development of a bionic boat. It focuses on devising a simple, efficient and inexpensive mechanism for propulsion.

The approach begins by examining the previous project work done in IDC on design of a human powered bionic boat and study of various types of fish and fish motions.

Brief Study of Fish Nomenclature¹



Fish Propulsion Systems¹

There are two broad categories

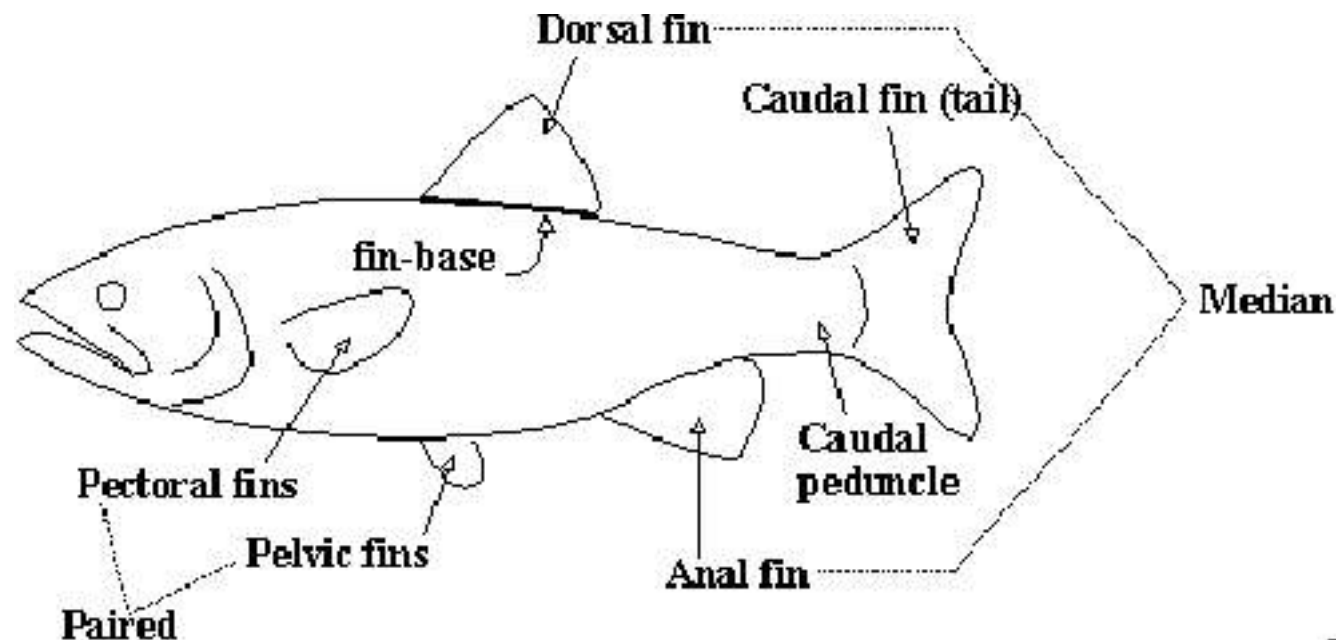
1. Body/Caudal Fin [BCF] Propulsion

The elements used in BCF propulsion are caudal fin and caudal peduncle

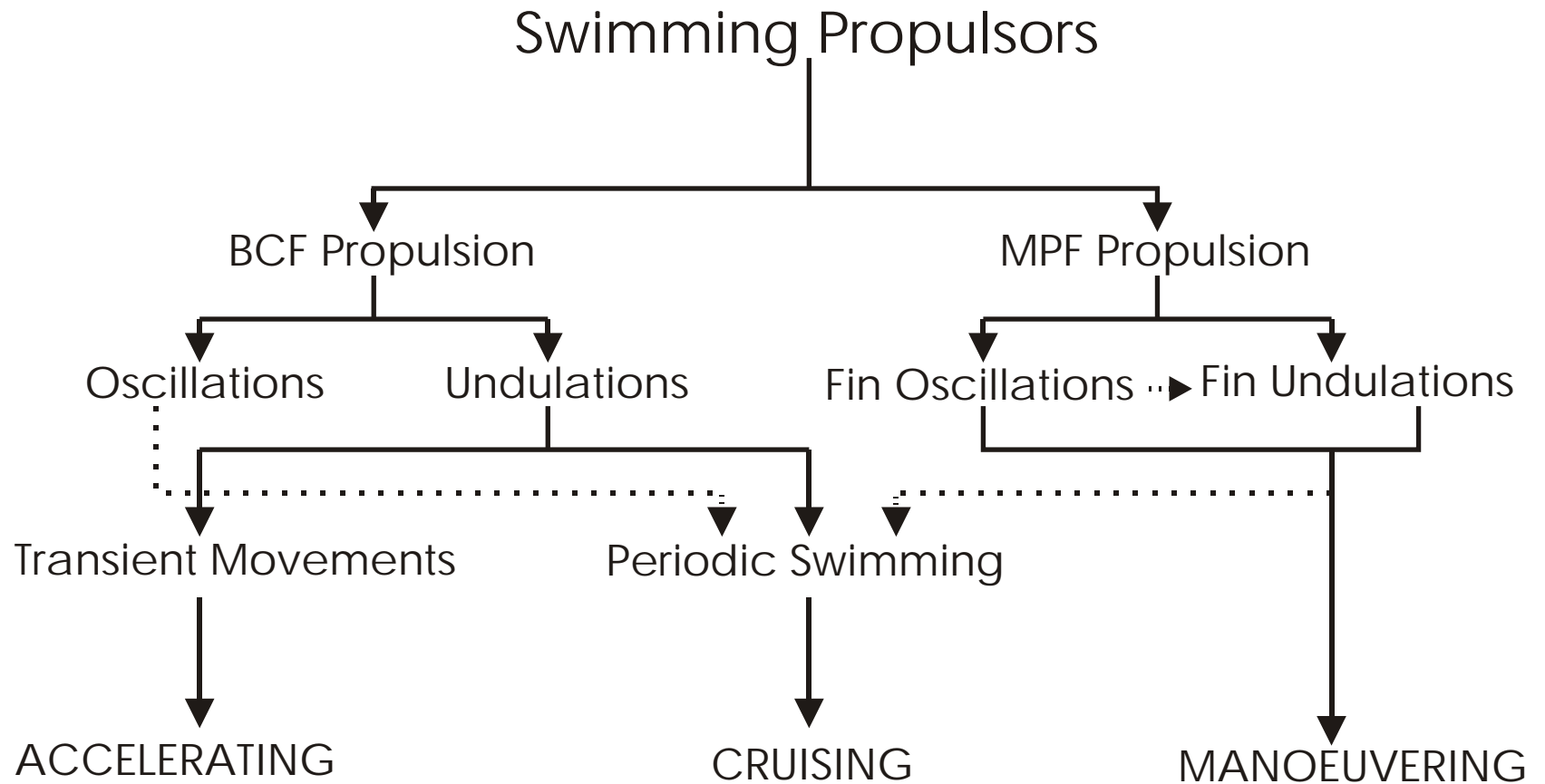
2. Median/PairedFin [MPF] Propulsion

The elements used in MPF propulsion are Median (dorsal and anal) fins and paired (pectoral and pelvic) fins

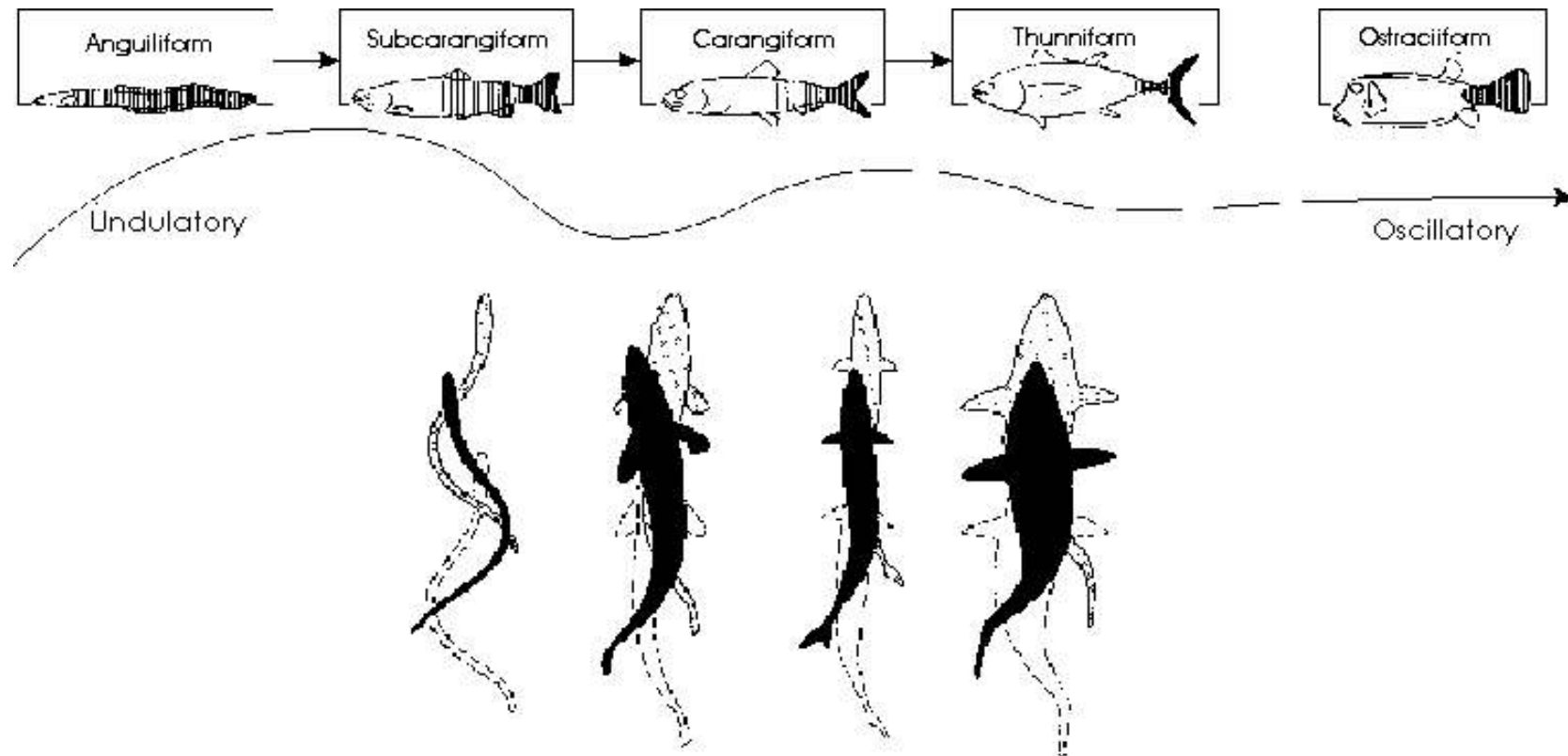
The above elements are shown in the figure below



Relation Between Swimming Propulsors and Swimming Functions²








Body/Caudal Fin [BCF] Propulsion¹



A greater number of fish (about 85%) rely on BCF modes for propulsion employing MPF modes for maneuvering and stabilization. The BCF mode of propulsion is therefore selected for further study to select a single mode of locomotion for bionic study and modeling.

Examples of Various BCF Modes Of Locomotion¹

Anguilliform mode		Spiny eel
Sub Carangiform mode		Trout
Carangiform mode		Clupea
Thunniform mode		Skipjack Tuna
Ostraciiform mode		Longhorn

Comparison Of Various BCF Modes Of Locomotion

Locomotion Mode	Body Movement	
Anguilliform mode	100%	<ul style="list-style-type: none"> Flexible, elongate fish e.g., eels Involves entire length of the body Relative inefficient High speed is impossible Hold body rigid to slow down or stop
Sub Carangiform mode	50 – 66%	<ul style="list-style-type: none"> Use caudal fin Waves less extreme than in eels 1/2 - 2/3 of musculature involved Large, well-developed, flexible caudal fins e.g., salmon, trout, minnow, carp, cods
Carangiform mode	33%	<ul style="list-style-type: none"> Only posterior part of fish flexes Last 1/3 of body undulates Caudal fin stiff and deeply forked More laterally compressed and deeper bodied, Fins stiffened by spines e.g., herrings, mackerels, jacks
Thunniform mode	20%	<ul style="list-style-type: none"> most efficient locomotion mode Highest speed Thrust generated by a large, lunate, stiff caudal fin with a narrow caudal peduncle e.g., tuna
Ostraciiform mode	<10%	<ul style="list-style-type: none"> No lateral flexure Propulsion comes from “wagging” the caudal fin Vary greatly in body shape Slow swimmers Rely on armor, spines, and toxins for protection

Inferences

1. Propulsion modes range from full body motion to only caudal fin oscillations
Implications
 - Boat design based on ratio of dead wt. to propulsion mechanism
 - Design of flexible boat members in case of anguilliform mode
2. Boat design if integrated with the bionic propulsion mechanism design might lead to better propulsion efficiency
3. Some methods are better for acceleration, some for steady, fast swimming and some for maneuvering
4. Innovative applications based on
 - Speed v/s Maneuverability need (Rescue vessels, Water races, Rafting)
 - Critical v/s Leisure need (Navy, Amusement parks, Lake rides)

BIONICS

Selection of Preferred Propulsion Mechanism and Fish Type

Examples

Based on the comparison of the various BCF modes of locomotion and the inferences drawn from them, the 'THUNNIFORM' mode is selected for further analysis and modeling

Tuna

The Thunniform mode is the most efficient mode of locomotion.

Mackerel

Thunniform swimmers among fish utilize only about 1/5th of their body for movement, yet they are able to achieve high speeds and good cruising.

Sharks

Marine Mammals

Advantages of Thunniform mode

High aspect ratio of 4.5 - 7.5 leads to improved efficiency

Higher degree of stiffness leads to higher thrust generation capability

Well stream lined body reduces pressure drag

Optimized for high speed swimming in calm waters for long durations

Disadvantages of Thunniform mode

this action is not suited for

Slow swimming

Turning maneuvers

Rapid acceleration from start is not possible

Poor working in turbulent waters

The MACKEREL has been chosen as the fish type to study for its locomotive mechanism and propulsion abilities. There are several varieties of mackerel around the world. The most popular varieties are explained below



Narrow-barred (spanish) Mackerel³
OTHER NAME: Spaniards, Tanguigue
SPECIES: *Scomberomorus Commersoni*
SIZE: 10-30 pounds, sometimes exceed 120 pounds



Spanish Mackerel
OTHER NAME: Sierra
SPECIES: *Scomberomorus Maculatus*
SIZE: Common 1-3 pounds, maximum potential over 10 pounds



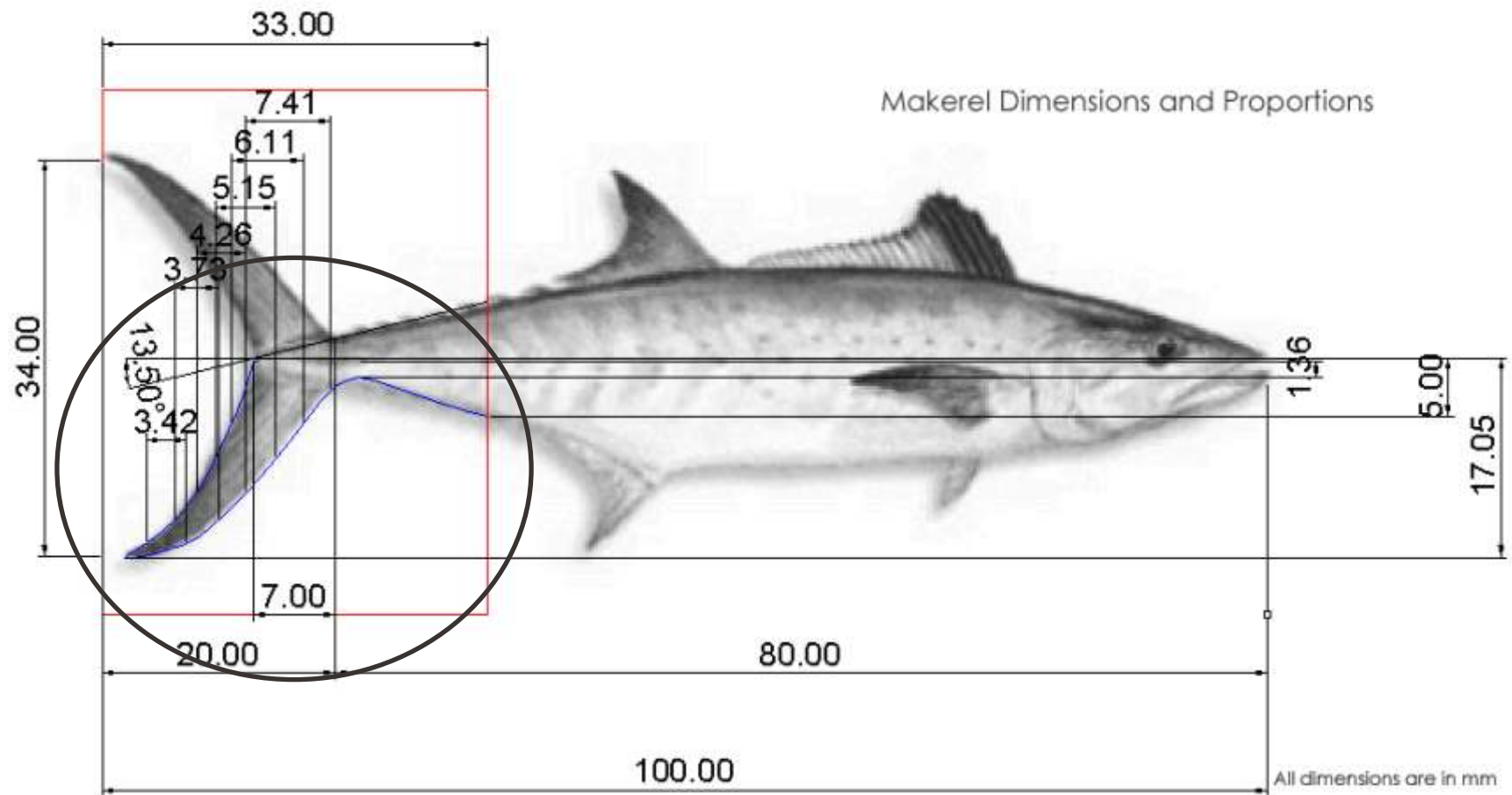
King Mackerel
OTHER NAME: Kingfish, Sierra, Cavalla
SPECIES: *Scomberomorus Cavalla*
SIZE: 4-50 pounds, possibly weight 100 pounds



Cero Mackerel
OTHER NAME: Painted, Mackerel, Pintada
SPECIES: *Scomberomorus Regalis*
SIZE: Average 1-5 pounds, max. approaches 20 pounds

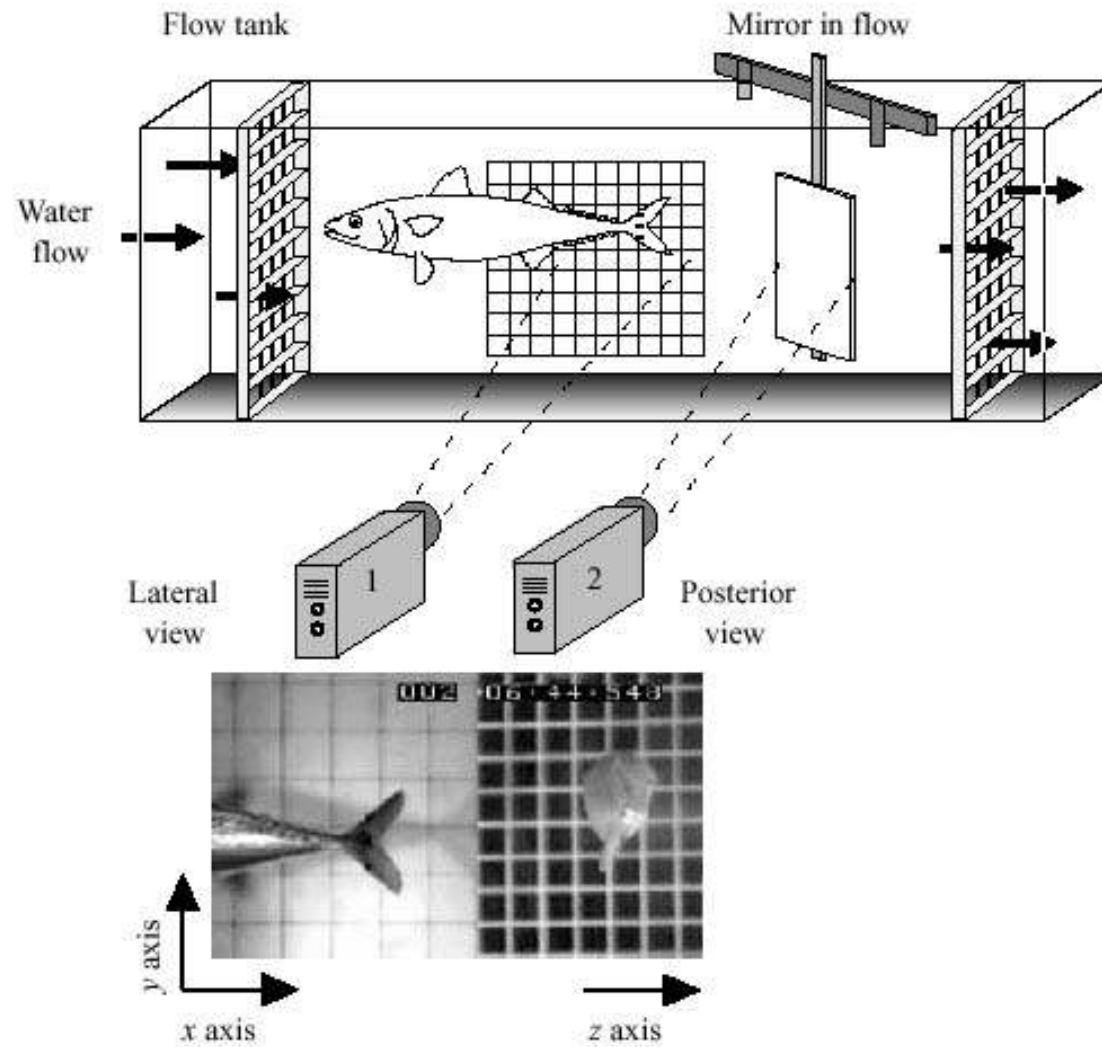
Analysis and Modeling of Selected Propulsion Mechanism

Fish chosen for study - Spanish Mackerel



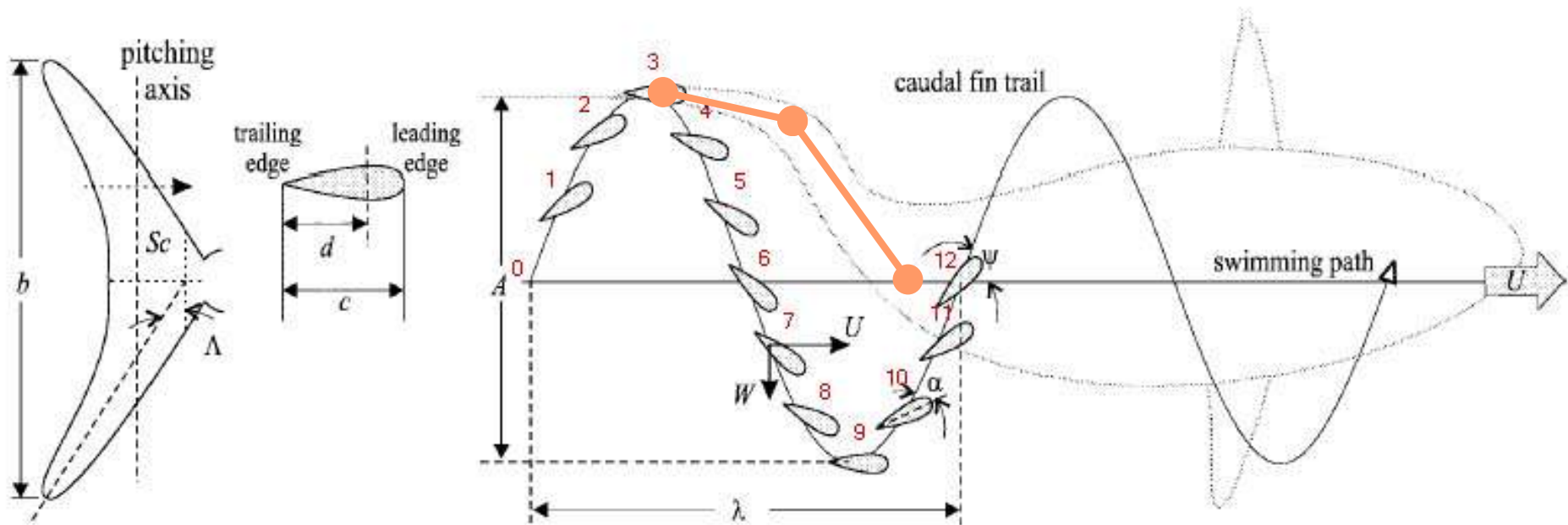
Approxiamately 1/3rd of the body is involved in propulsive movement

Schematic Drawing Of A Flow Tank And Videotaping Methods For Understanding A Mackerel's Swimming Characteristics⁴



BIONICS

Lunate undulatory movement and Swimming path Characteristics



Thunniform Locomotion

In Thunniform locomotion, two joints, one at either end of the caudal peduncle, permit flexion of the peduncle and the caudal fin. Nesting of the myomeres is extreme and the myosepta are extended into powerful tendons which insert either on peduncular vertebrae or the caudal fin itself, allowing the peduncle to be oscillated rapidly while keeping the angle of attack (α) of the caudal fin optimized. Thunniform swimmers are the fastest fish (again at sustained cruising) but are not well designed for rapid starts

Factors Affecting Thrust Development And Propulsive Efficiency

1. Aspect Ratio (AR) of the Caudal Fin

$$AR = b \times b / Sc$$

In thunniform swimmers, AR values range between 4.5 to 7.2

A high AR is desired

2. The shape of the Caudal Fin

defined by the sweepback angle and curvature of the leading edge

A curved leading edge is desirable

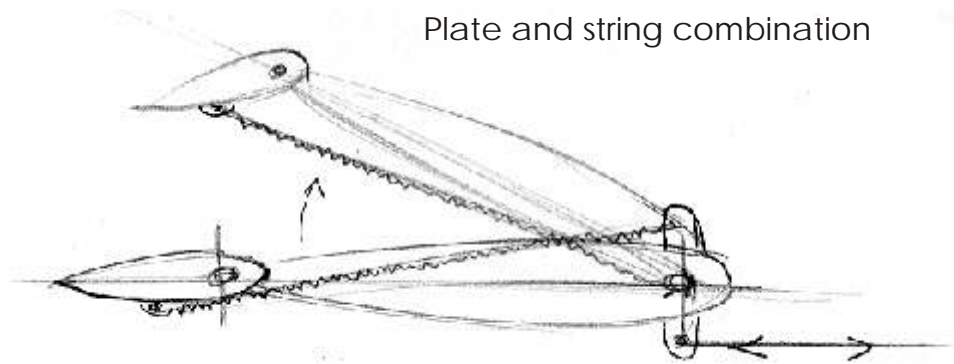
3. Fin Stiffness should be high

4. The oscillatory motions of the fin

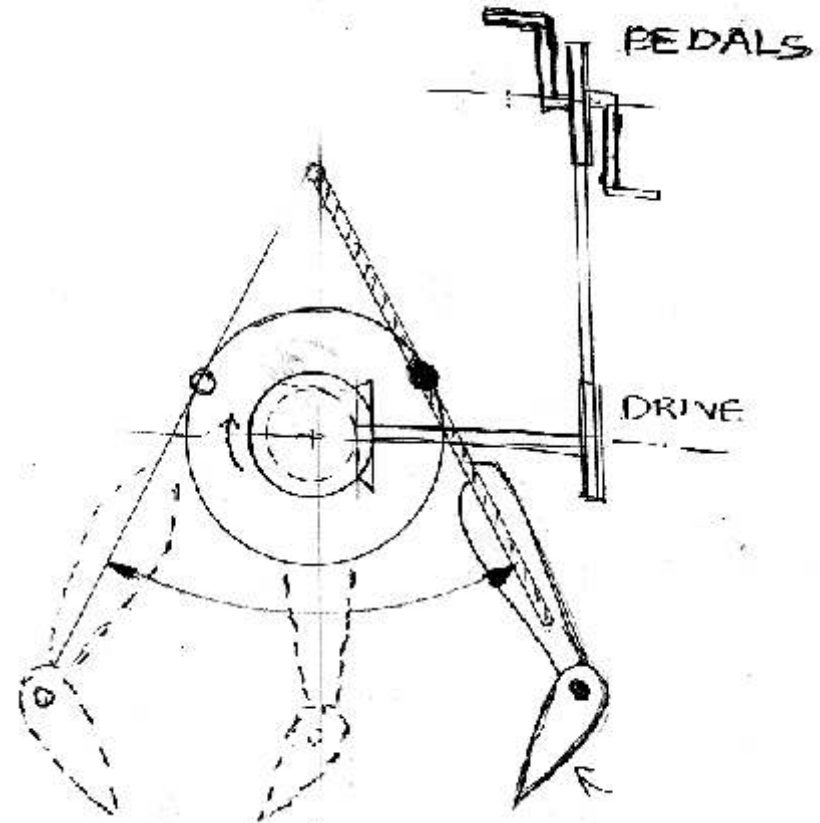
Concepts for Propulsion Mechanisms

1. Mechanical linkage systems with rotary and reciprocating inputs

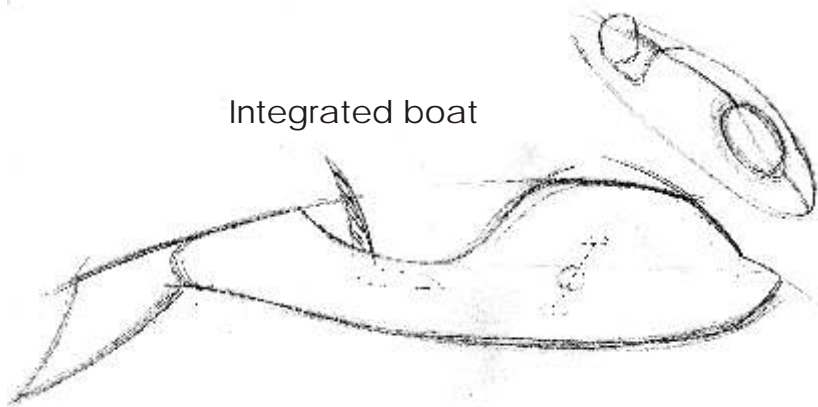
Plate and string combination



Oscillating lever mechanism

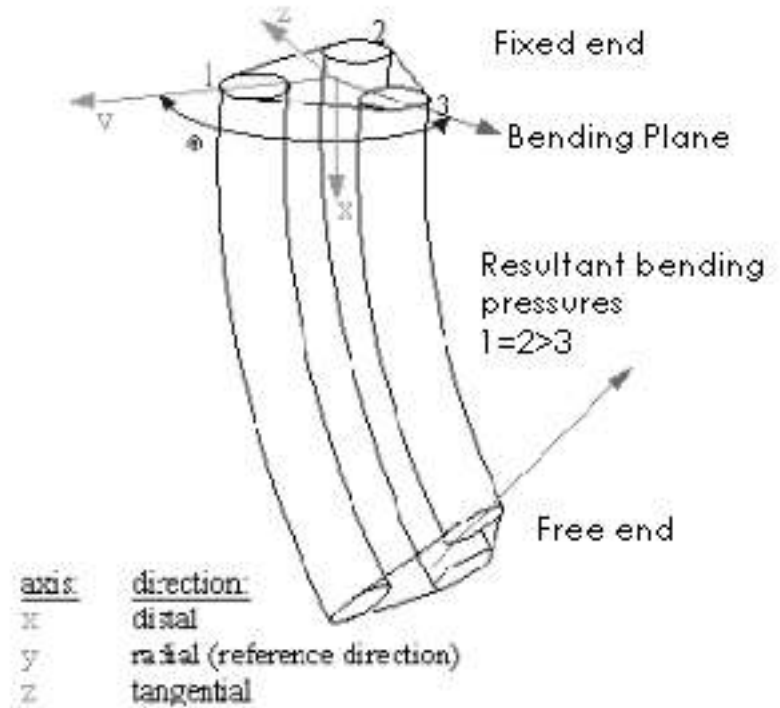
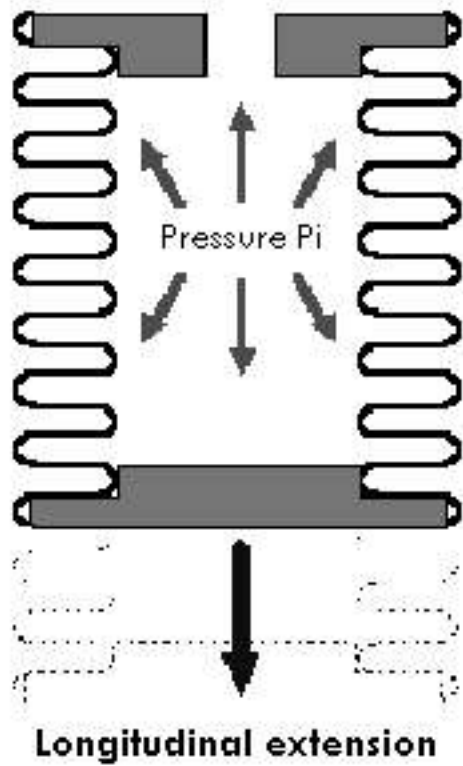


Integrated boat

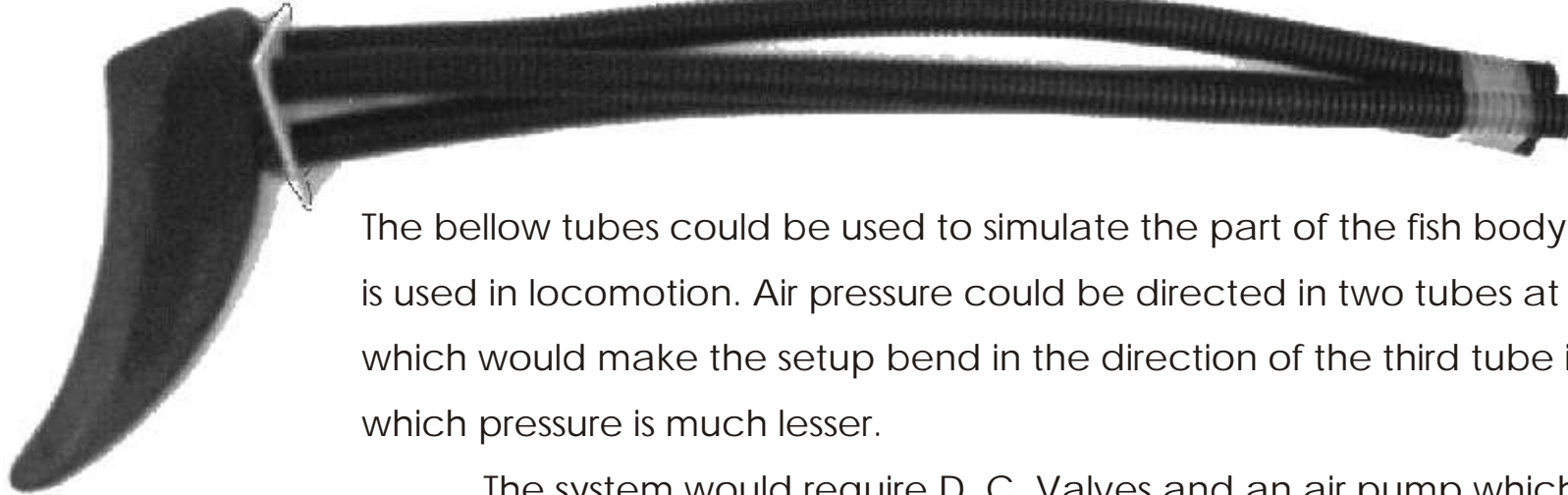


BIONICS

2. A fluid pressure system with 'bellow type' tubes to replace mechanical linkages



Flexible actuator bending due to pressure



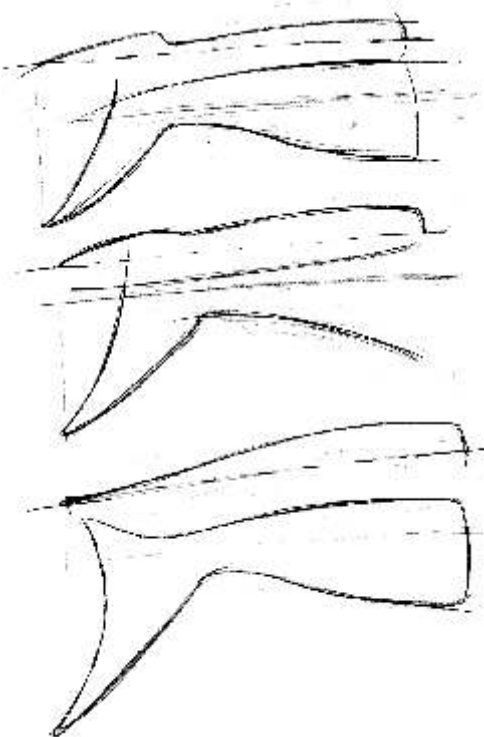
The bellow tubes could be used to simulate the part of the fish body which is used in locomotion. Air pressure could be directed in two tubes at a time which would make the setup bend in the direction of the third tube in which pressure is much lesser.

The system would require D. C. Valves and an air pump which would have to be operated by pedal power. This is a concept worth exploring as it mimics the natural muscle contraction principle in living beings.

To know the exact nature of the behaviour and viability of this, experiments must be conducted and construction of a control circuit must be designed.

It is also worth exploring the form which the concept should take by providing a rubbery outer to the bellow tubes and tail fin.

However, due to the complexity and precision involved in developing this, it lies beyond the scope of this study and is not explored further.



The comparison of the mechanical and fluid pressure systems brings to the fore the following interesting points

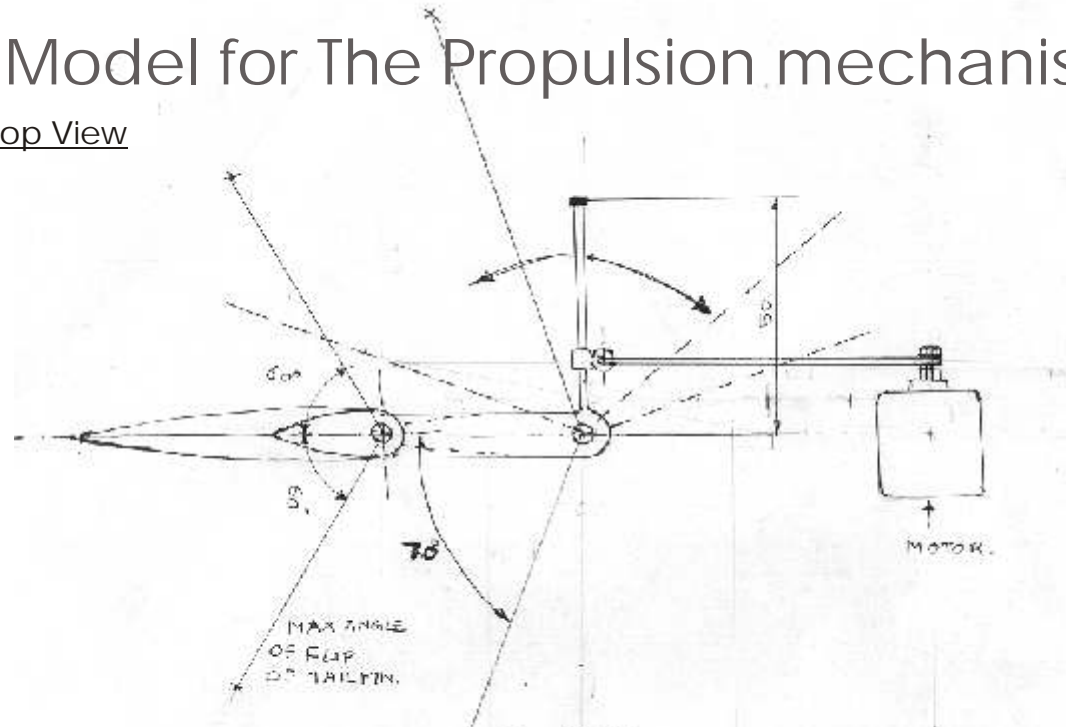
1. The mechanical systems are advantageous whenever linkages and subsystems are lesser in number and simple motions are involved
2. Fluid pressure systems excel where noiseless and smooth operation are of prime importance. Also complex systems can be handled with greater ease. However leakages in pressure lines and periodic inputs, if any are problem areas. Also control systems might be expensive
3. Fluid pressure systems, in spite of some drawbacks, appear to be more suited for application in the bionic modelling of fish propulsion. These systems, if coupled with flexible members can overcome the rigidity problems associated with mechatronic systems

The most important advantage that a fluid pressure system has is that they expend the exact amount of energy needed for a particular motion (in the form of opposing pressure) while mechanical systems might mean excess energy spent and thus become less efficient in such applications

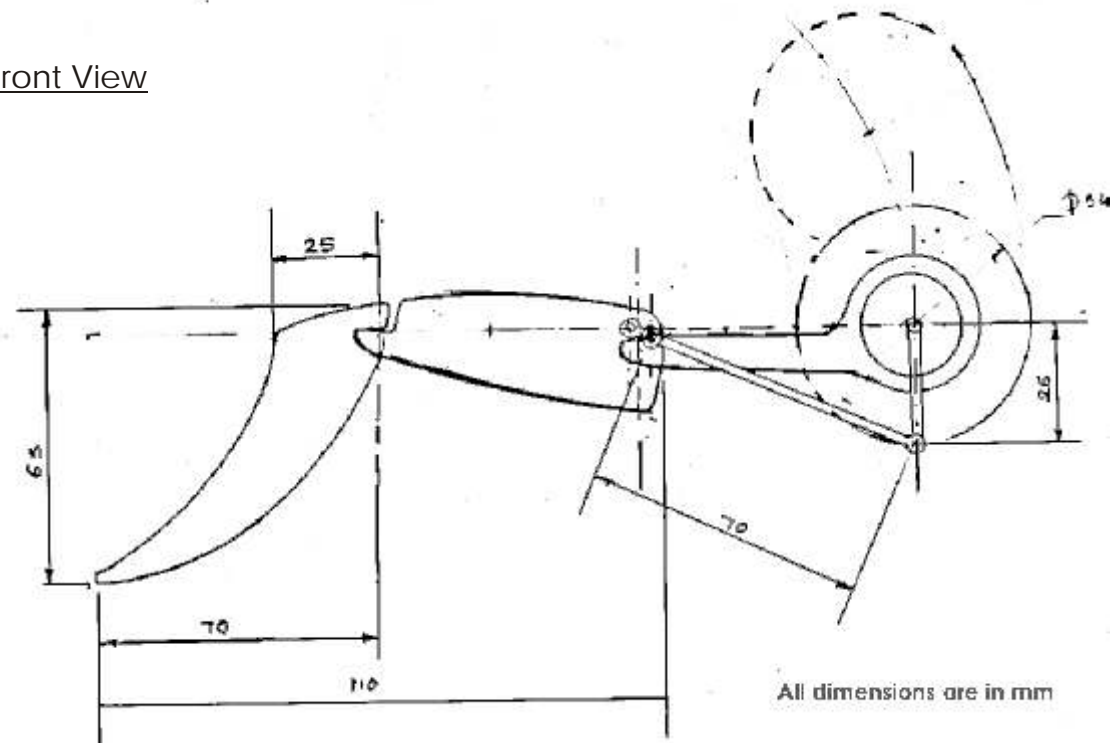
Scale Model for The Propulsion mechanism

Drawing for the Proposed Model

Top View



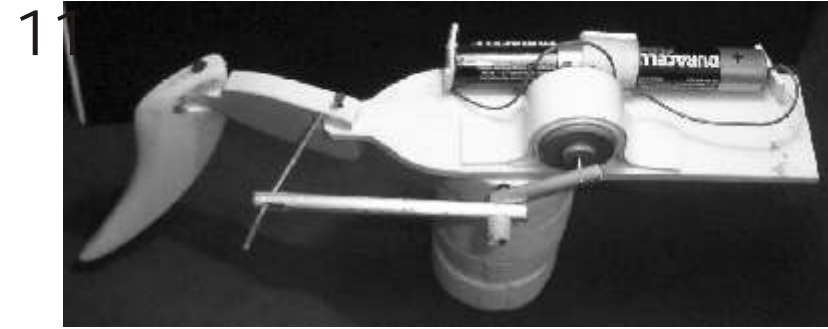
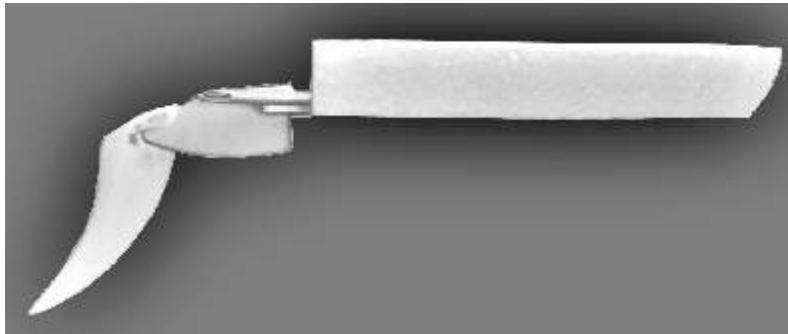
Front View



Scale: 1/10 of selected fish size
(Spanish Mackerel -average length 1000mm)

All dimensions are in mm

Scale Model Using Electric Motor To Simulate Pedal Power



1. Propulsion members moving left
2. Towards centre
3. Moving right

Proposed Applications and Boat Forms

The characteristics of the mechanism are

Fast Straight line motion

Sustained cruising

Slim and stiff body

Compact unit

Based on the above, the model seems to be most suited for boat forms like canoes, kayaks and small catamarans.

An interesting innovation might involve use of part of the boat form as the propulsion member, which means an integrated structure, composed of rigid surfaces for carrying a human and the drive and a flexible portion for the movement. This might help reduce turbulence and create a new aesthetic.

Other applications which must be considered are small and swift craft for naval use and unmanned craft for stealth operations.

Conclusion

The propulsion mechanism of the Mackerel is typical of thunniform mode of locomotion, i.e. Of fast , sustained swimming and cruising.

It is therefore necessary to understand its characteristics through its body proportions, its form and its habits.

The model developed is based on the proportions and structure of its caudal peduncle and caudal (tail) fin which are the portions involved in motion. This model, now mechanical in nature needs to be further refined through the following

Scaling up and scaling down the size of the model

Use of different materials to adapt the model to thunniform locomotion

Developing boat designs to complement the mechanism.

References

1. [Http://www.ece.eps.hw.ac.uk/Research/oceans/projects/flaps/swim.htm](http://www.ece.eps.hw.ac.uk/Research/oceans/projects/flaps/swim.htm)
[Http://www.ece.eps.hw.ac.uk/Research/oceans/projects/flaps/PBAprinc.htm](http://www.ece.eps.hw.ac.uk/Research/oceans/projects/flaps/PBAprinc.htm)
2. Miichael A., David Lane, Review of Fish Swimming Modes for Aquatic locomotion
IEEE Journal Of Oceanic Engineering, Vol 24, No 2, 1999
3. [Http://www.geocities.com/nauticaclub/spcmackerel.html](http://www.geocities.com/nauticaclub/spcmackerel.html)
4. Alice C. Gibb, Kathyrn A. Dickson, George V. Lauder, Tail [1999] Kinematics of the Chub Mackerel: The Journal of Experimental Biology 202,(2433-2447)

Useful Information Sources

1. Ashish Chandel, 2003, 'Design of Human Powered Bionic Boat, Special Project', IDC, IIT Bombay
2. Alexander R. M., 1968, 'Animal mechanics', D-517 IDC Library IIT Bombay
3. Carl Gans, 'Biomechanics', D-518, IDC Library IIT Bombay
4. MIT Robot Tuna (<http://web.mit.edu/towtank/www/tuna/brad/design.htm>)
5. PROTEUS The Penguin Boat (<http://web.mit.edu/towtank/www/flapfoil>)