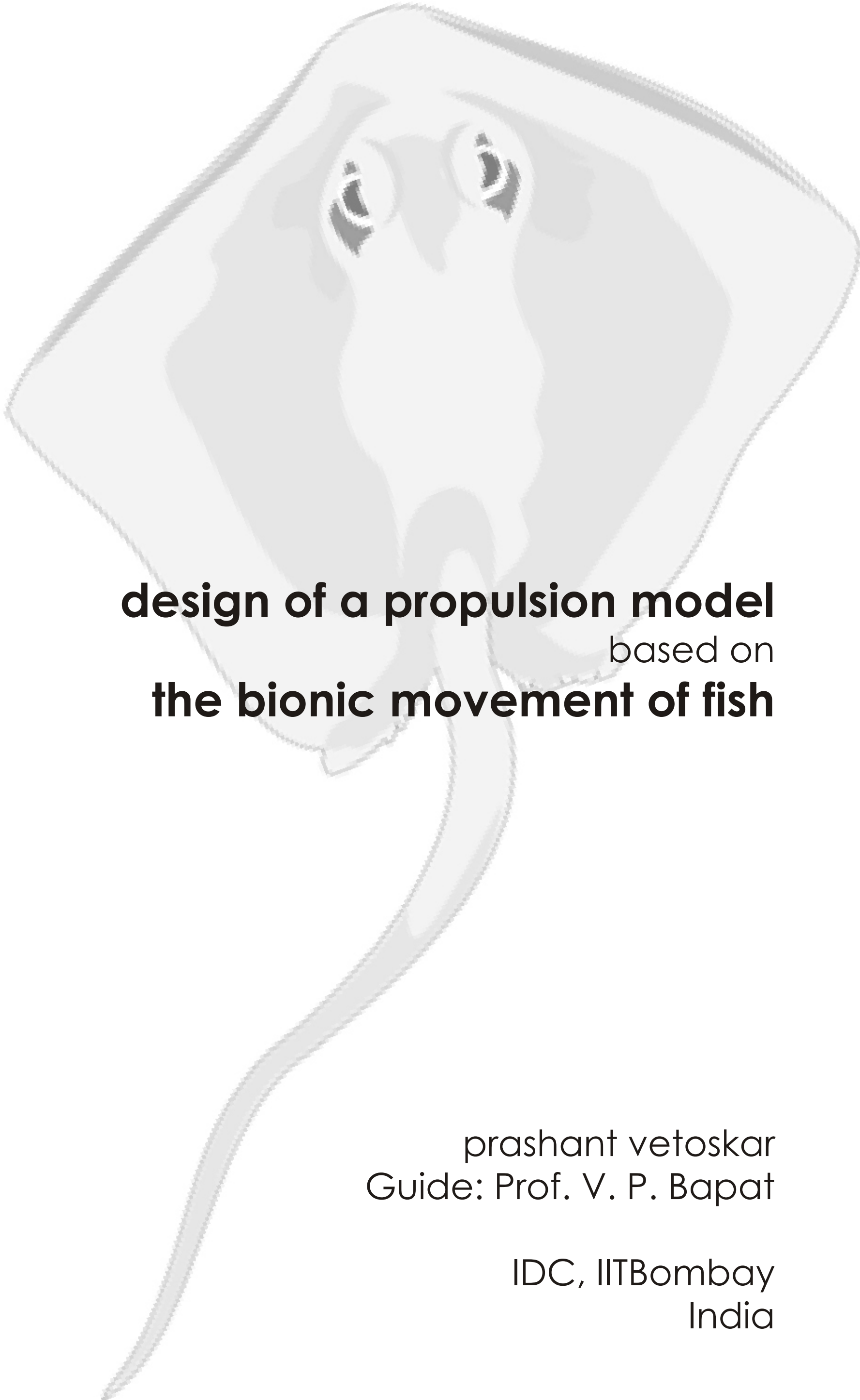

design of a propulsion model
based on
the bionic movement of fish

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India

Approval Sheet

The Special Project titled
'**Design of propulsion model based on the bionic movement of fish**
by **prashant vetoskar**
is approved for the partial fulfilment of the requirement for the degree of 'Master of Design'

Project Guide ______________________

Chairperson ______________________

Internal Examiner ______________________

External Examiner ______________________

Date ______________________

Introduction

The oceans and seas are the most ecologically diverse places on our planet, and yet we know very little about them. Man made systems developed for ocean exploration, up to this point, have been very limited in their capabilities. For our engineering solutions to become better suited to marine exploration, we must look to nature for inspiration. While man made marine systems, such as submarines and ships, have been optimized over the years to perform long range cruising, they lack the agility and maneuverability of biological systems. A good measure of the maneuverability for water borne systems is turn radius. The minimum turning radius for a fish is 0.00-0.47 body lengths, while for sea-lions it is about 0.09-0.16 body lengths. In contrast, rigid-body submarines have a turning radius of 2-3 body lengths. In general the performance of man-made systems, constructed from rigid members with propulsion from propellers, fall far short of biological systems.

The most common method of underwater propulsion is the propeller. Propellers are often shielded in part by the body of the vessel, reducing their efficiency. Also, boats have a large frictional resistance to overcome since they are submerged in a viscous fluid. They also have to produce enough power to carry added mass along with them. More efficient means of propulsion would benefit these vessels. This project aims at developing a more efficient propulsion method. other methods of propulsion are being studied based on successful natural systems.

Using designs based on fish swimming modes has proven to be a sound design method, having the benefit of millions of years of evolutionary design. Biophysical systems that have been modeled for propulsion designs include thunniform motion (MIT's Robotuna) and rigid foil flapping (MIT's Penguinboat).

Objective

The objective of the project is to emulate the rajiform motions of ray fishes. More specifically, the scope of the project will include building a mechanical model capable of reproducing the propulsion required for straight-line swimming modes of rays.
The intention is to create a simple mechanism rather than using hgh tech electronics as the aim is to make this technology available for purposes that don't require expensive equipment.
conceptualization of the situation where this mechanism could be applied to in different types of boats with different purposes.

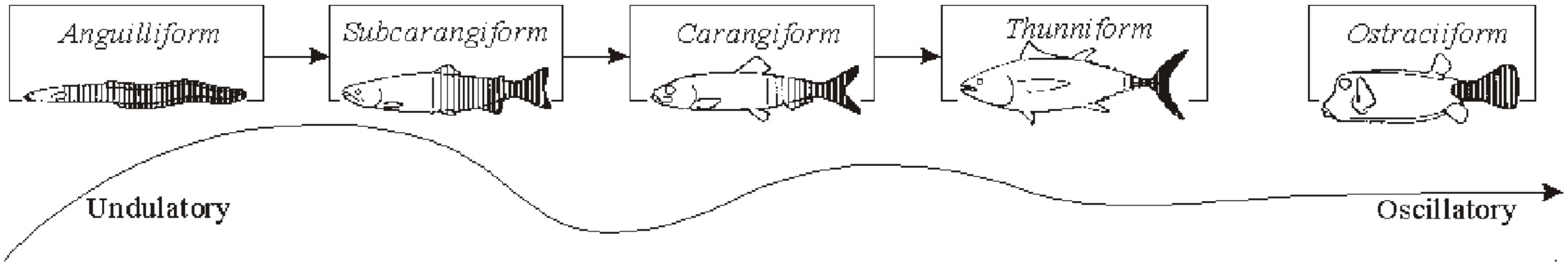
types of motion used by fish in propulsion

There are two basic methods used by fish for propulsion. One method uses mainly the fish **body and the caudal fin (BCF)**, while the other method uses mainly the **medial paired fins** (pectoral and pelvic) **(MPF)**.

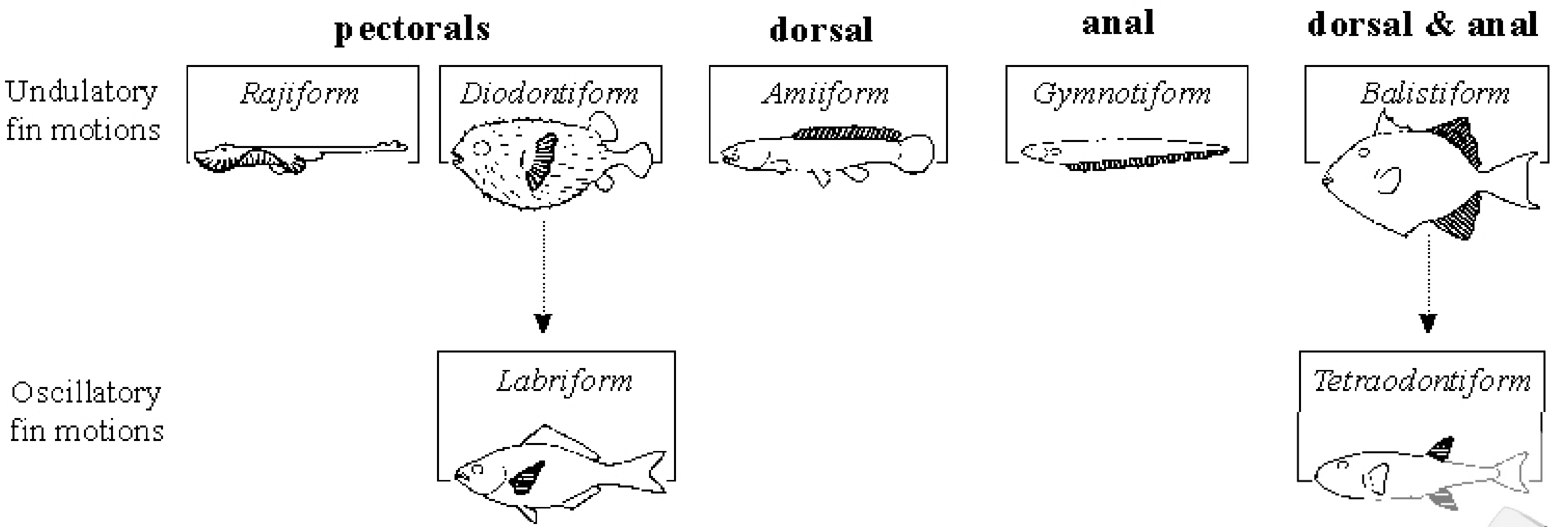
Most fish use a combination of the two methods to propel themselves. BCF propulsion is most efficient for swimming at a constant velocity over distance, while MPF propulsion is better for maneuvering and turning the fish. Undulating fins are used by many fish as auxiliary propulsors, as well as for maneuvering and stabilization. They can also provide adequate thrust to be used as the sole means of locomotion, at generally low speeds.

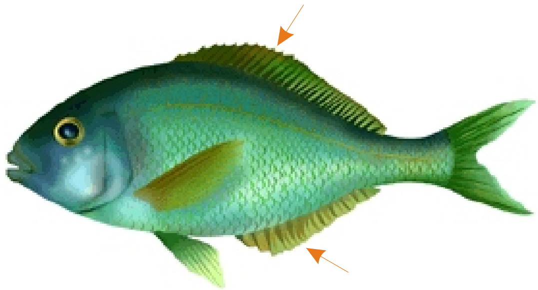
This report will be studying the M.P.F. Type of propulsion and selecting one of the types of M.P.F propulsion for the development of the mechanism.

Types of B.C.F propulsion

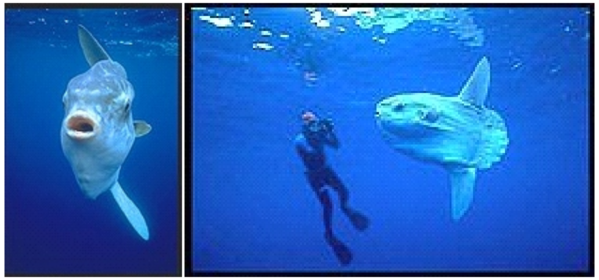


Types of M.P.F propulsion

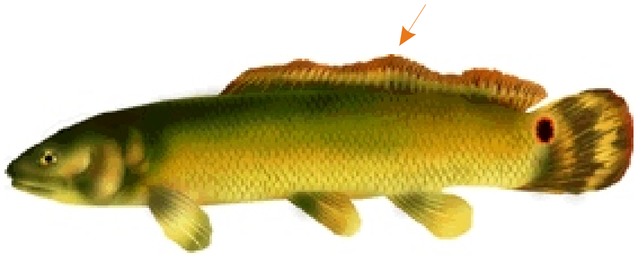




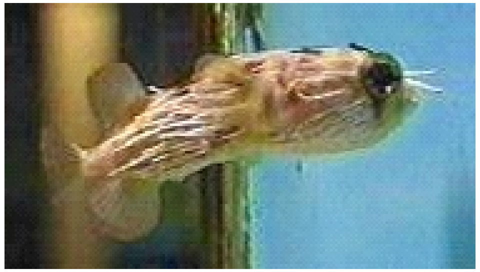
Labriform mode



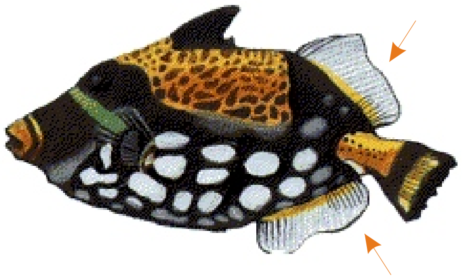
Tetraodontiform mode



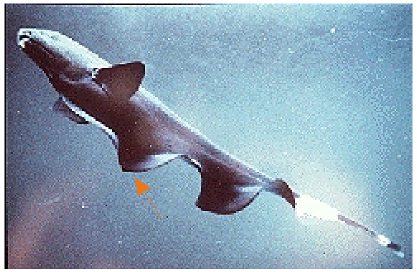
Amiiform mode



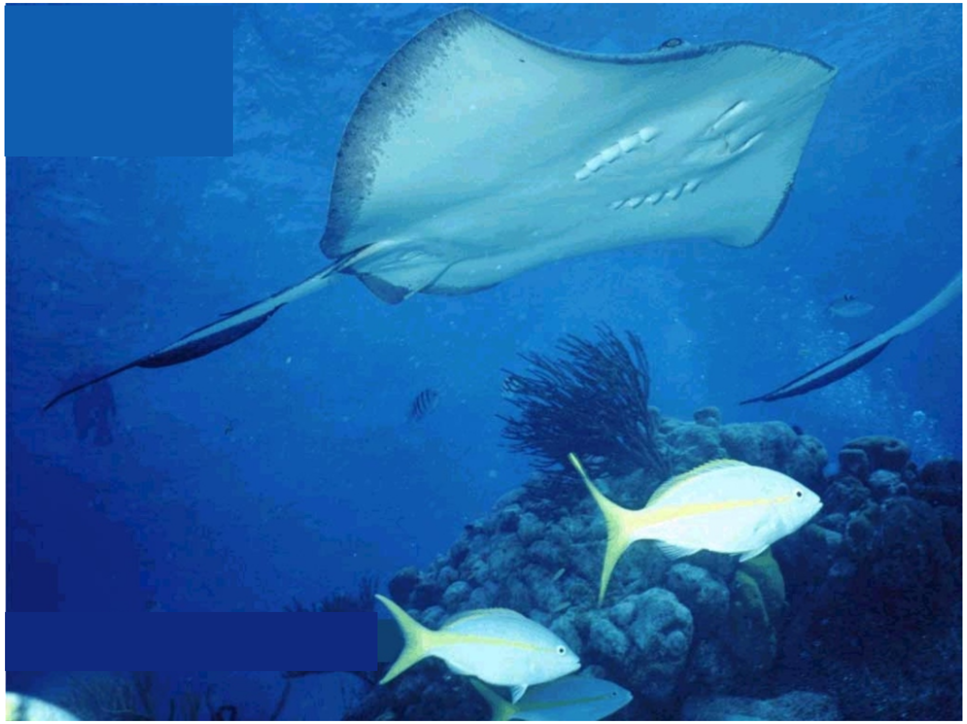
Diodontiform mode



Balistiform mode



Gymnotiform mode

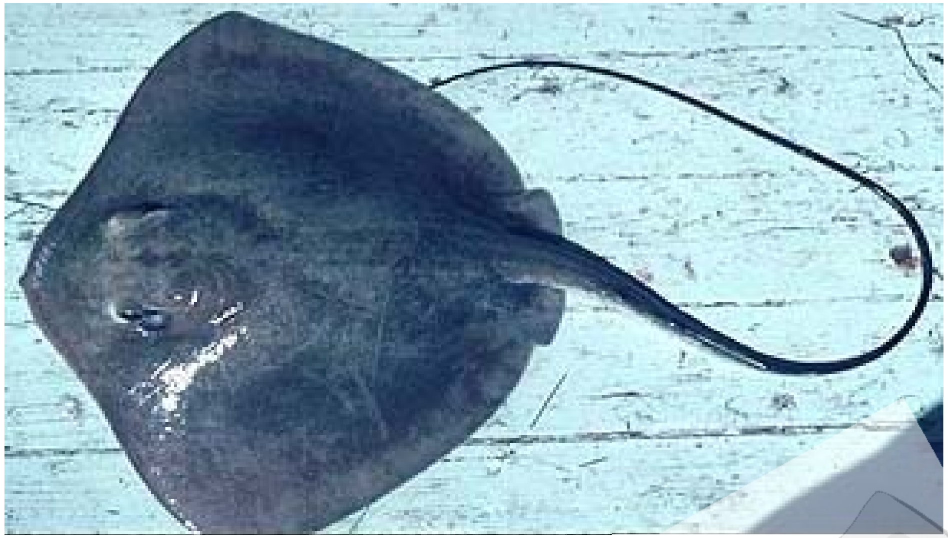


Rajiform mode

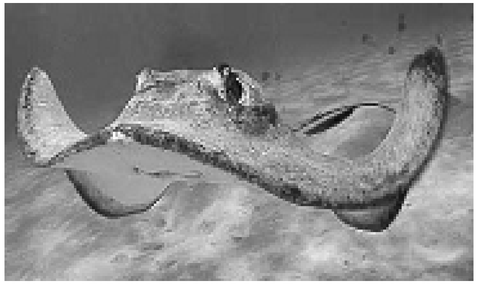
Selection of type of motion

Rajiform fishes, or rays, appear to be more efficient swimmers compared with other types of motion, a vessel using this motion for propulsion may also be more efficient, depending on the implementation. Rays are swift, silent swimmers. These are also desirable qualities , enhancing their ability to perform environmentally sensitive missions such as wildlife observation in addition to increasing their range.

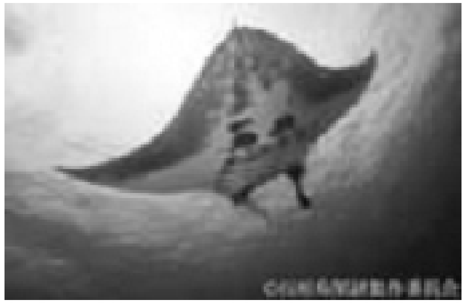
Rajiform mode is found in fish such as rays, skates and mantas, characterised by *very large, triangular-shaped and flexible pectoral fins*. *Their swimming involves the passing of vertical undulations along the pectorals, that may also be flapped up and down, and has been likened to the flight of birds. The amplitude of the undulations increases from the anterior part to the fin apex and then tapers again towards the posterior.*



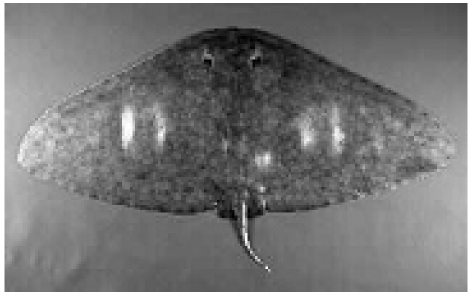
A)



(B)



(C)



. **Southern Stingray, Manta and Widewing Butterfly Ray**

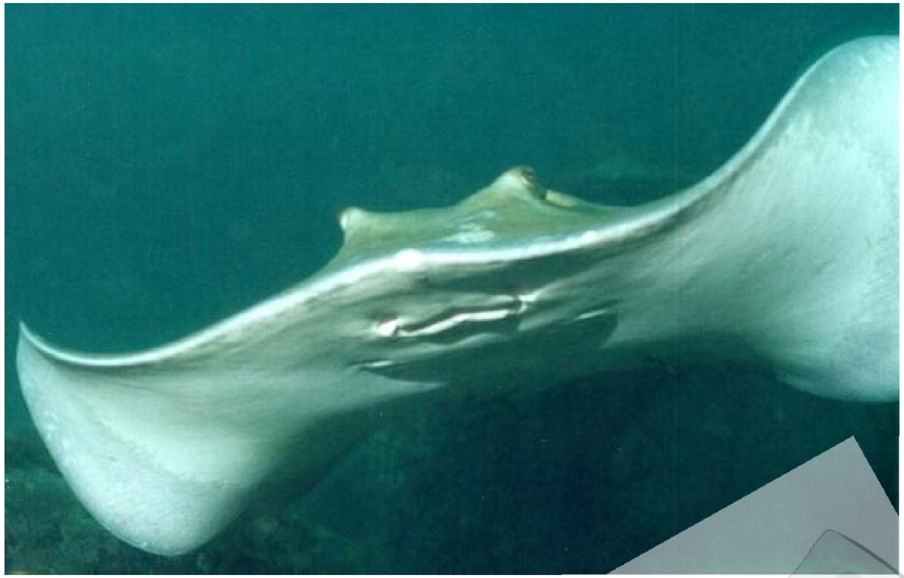
Understanding the nature of Rajiform motion

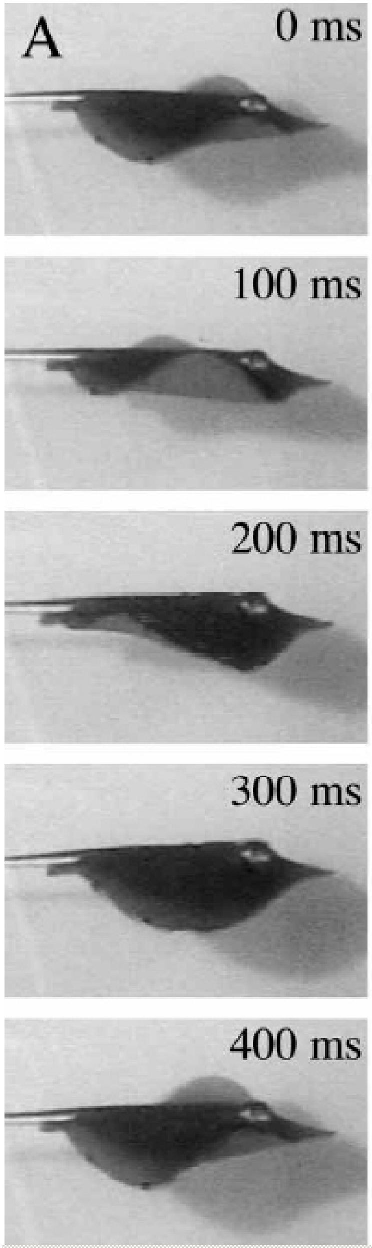
Rajiform motion, named after the rays which use it, includes oscillatory and undulatory swimming modes. Some rays, such as *Dasyatis americana* (Southern stingray), undulate their pectoral fins in a nearly sinusoidal wave to create a net thrust. Others, such as the Manta ray, use strictly oscillatory motion, or flapping, to propel themselves in a straight line. The ray we are using as our template is the *Gymnura micrura*, or smooth butterfly ray, which uses both forms of locomotion.

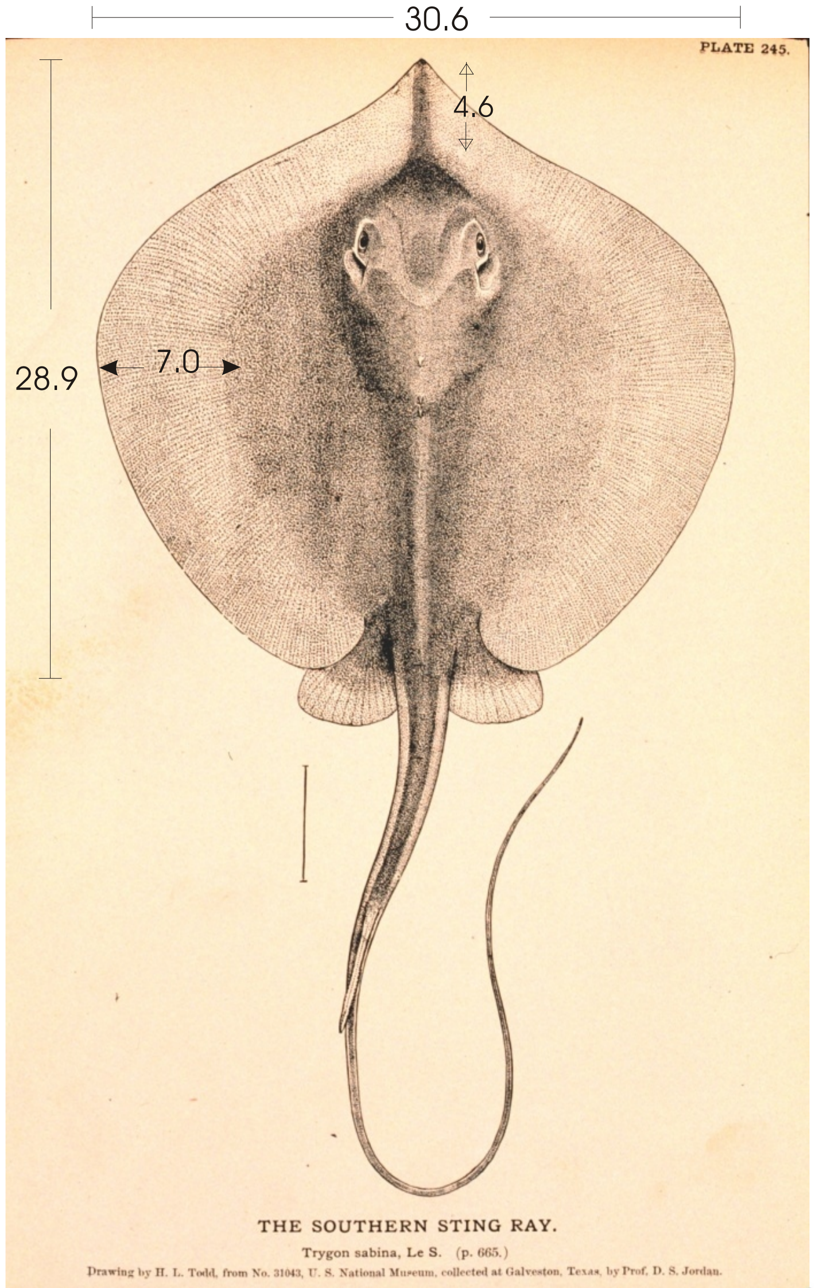
Undulatory motion is a wave generated along the pectoral fins which propagates backward at some phase velocity. Undulations vary from about 1.2 to 2 wavelengths along the fin for rays. The Southern stingray is shown undulating through the water in **Figure 1(a).**

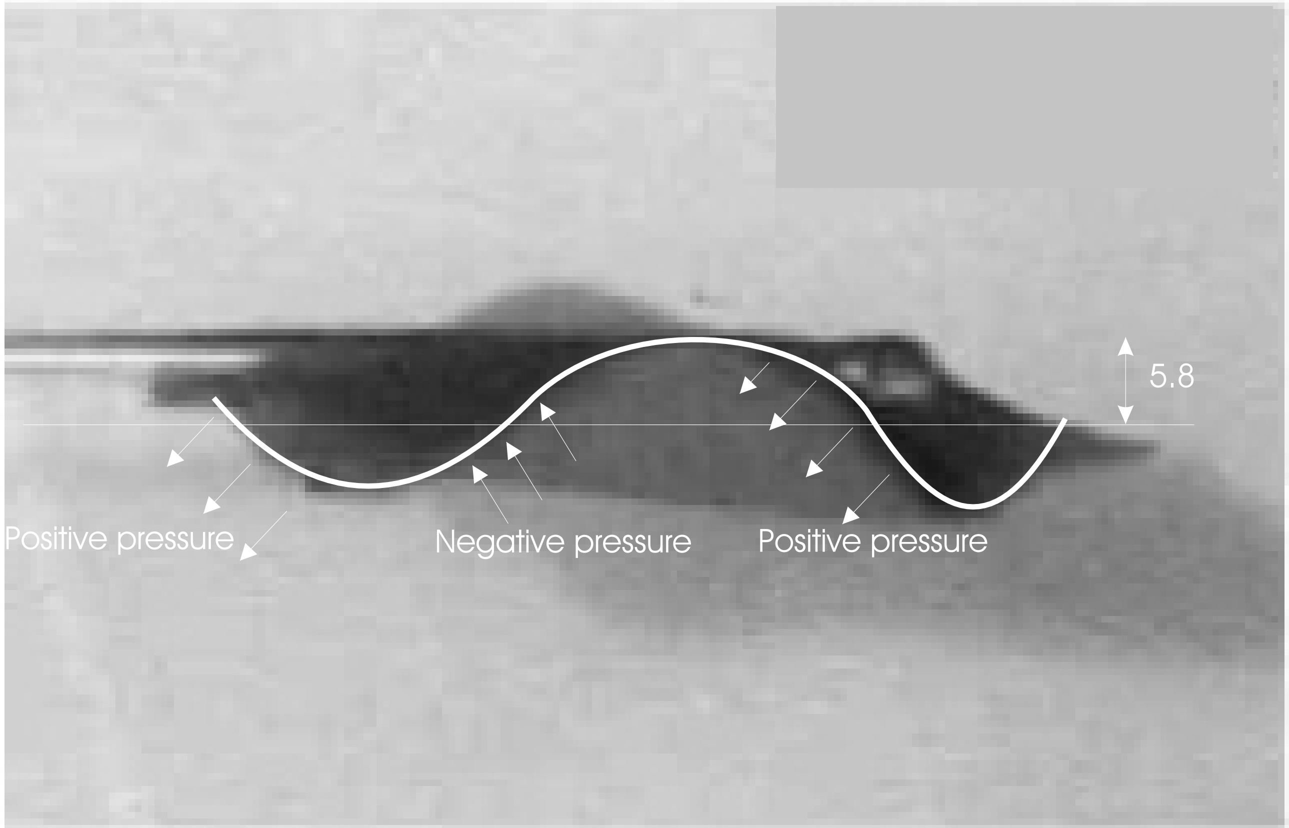
Oscillatory motion, as shown in **Figure 1(b)**, is similar to the flapping mode used by birds. The entire fins oscillate up and down, with the angle of attack of the leading edge changing through the stroke to give a net forward thrust. This motion is usually characterized by a half wavelength along the fin.

The *G. micrura* has a nearly diamond-shaped disk 16 cm long, with a mean span of 29 cm. It uses a **combination of undulatory and oscillatory** motion to propel itself at about 0.9 m/s. The widewing butterfly ray shown in **Figure 1(c**) is about five times the size of *G. Micrura*.



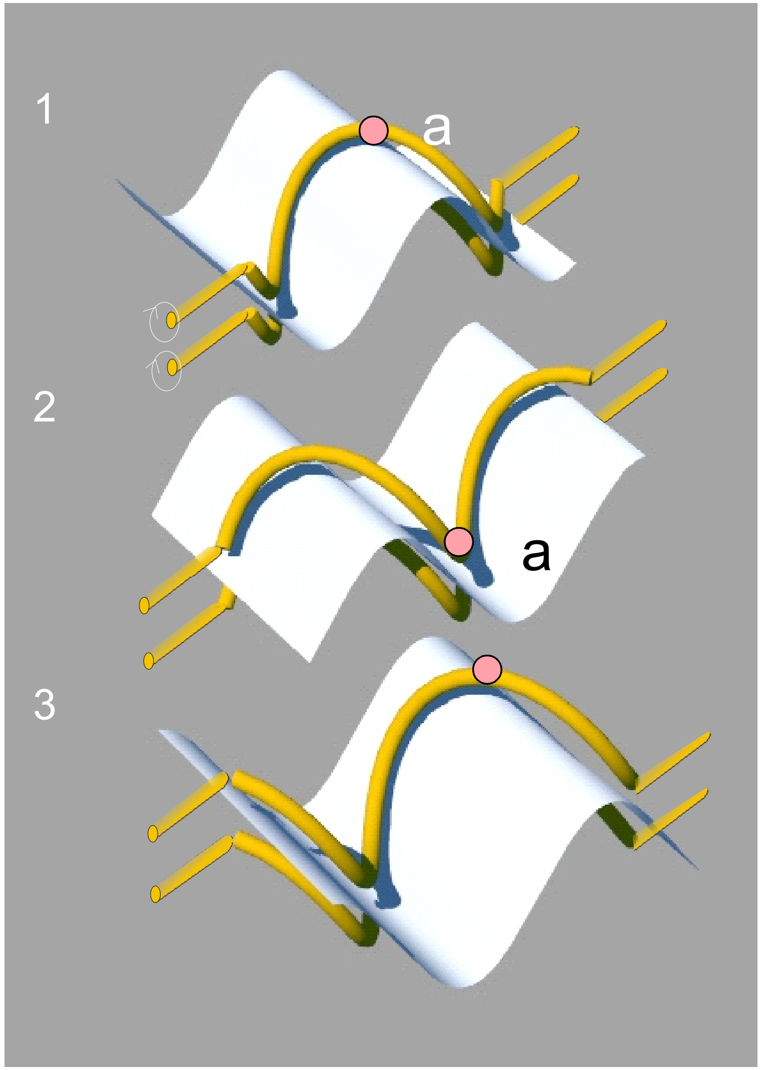

A
0 ms
100 ms
200 ms
300 ms
400 ms


30.6
PLATE 245.
4.6
28.9
7.0
THE SOUTHERN STING RAY.
Trygon sabina, Le S. (p. 665.)
Drawing by H. L. Todd, from No. 31043, U. S. National Museum, collected at Galveston, Texas, by Prof. D. S. Jordan.


5.8
Positive pressure
Negative pressure
Positive pressure

Model Parameters

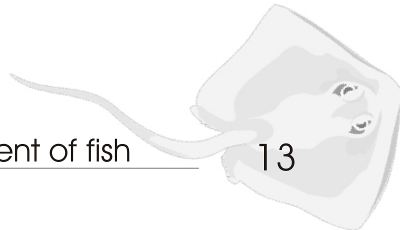
	non-dim	dim
Scale factor, S_F		
Disk Length, L_D		28.9cm
Disc width (root of fin), W_D		29.5 cm -
Fin width, W_F		14.5 cm
Fin beat frequency, f		1.29 Hz
Mid disc amplitude	0.20 (A/W_D)	5.8 cm
Wave speed at 1/3 span	2.73 (c/L_D)	
Wave number	0.63 (L_D/ë)	



Concept 1

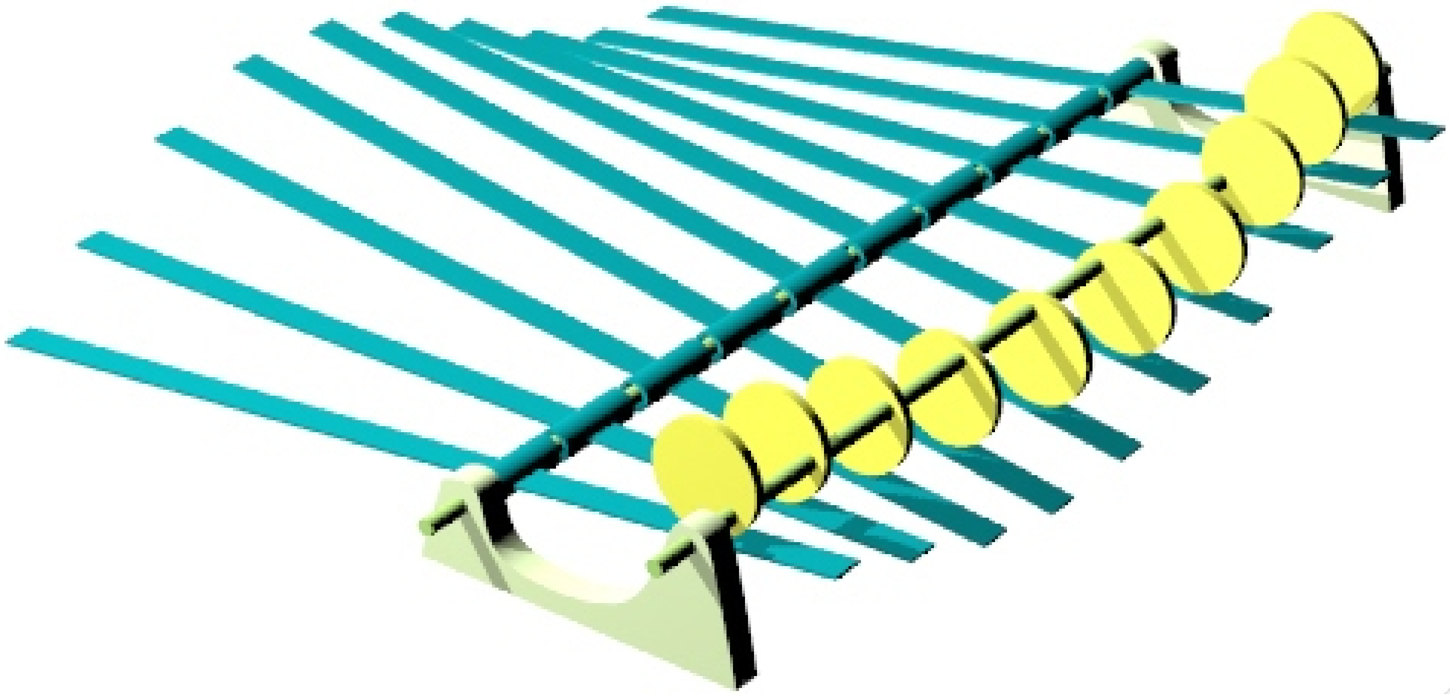
This concept uses two parrallely placed spiral springs that are rotated individually about their central axis and are moving in phase. The rotation creates a sinusoidal wave that travels from one end to the other. This sinusoidal wave is translated to a slippery surface sandwitched between the two spirals.

When used in water this mechanism would be like the undulatory motion of the southern sting ray which propells it forward.

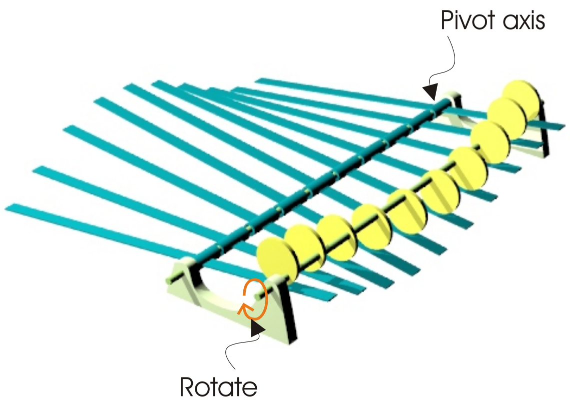


Concept 2

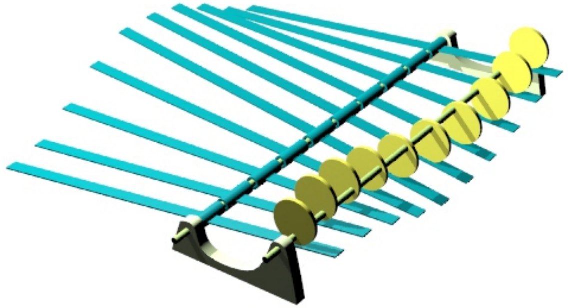
This concept creates the undulatory motion by the use circular cylinders attached eccentrically to a central rotating rod as shown in the 3d model. These cylinders, in turn, force the plates (that emulate the fins of a ray fish), to replicate that sinusoidal wave.



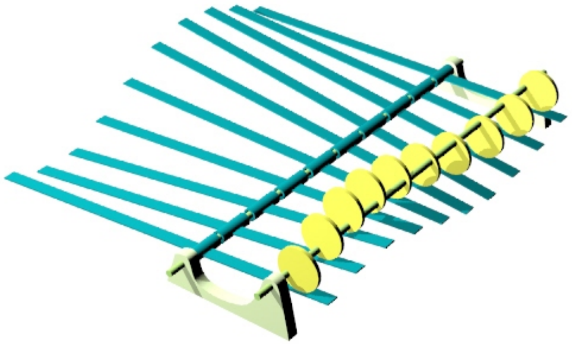
0^{0} rotation



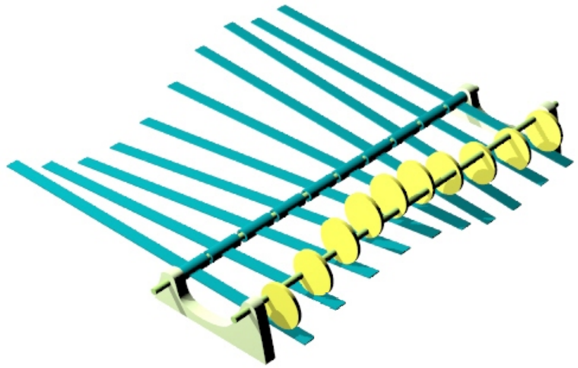
45^{0} rotation

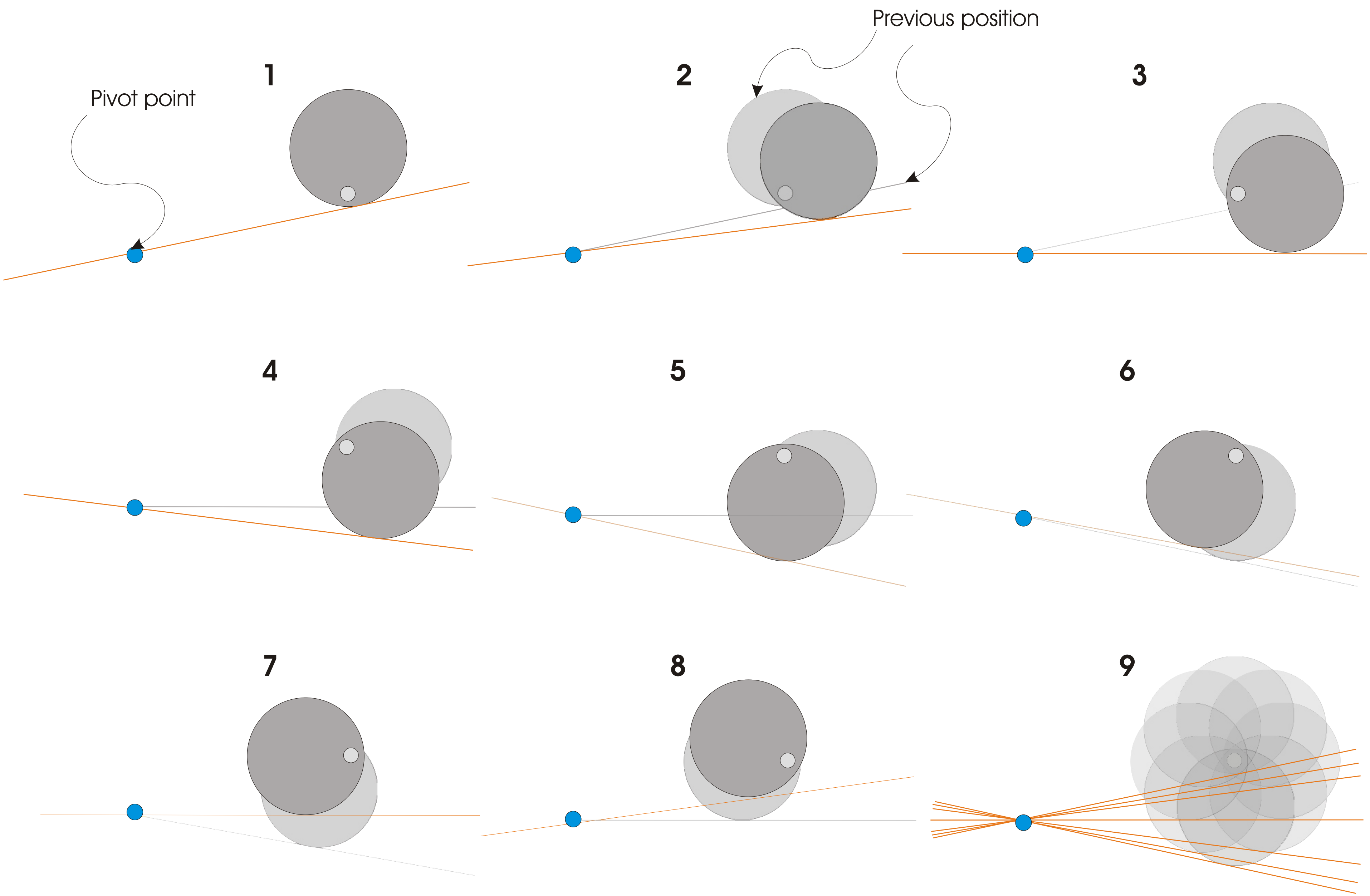


90^{0} rotation

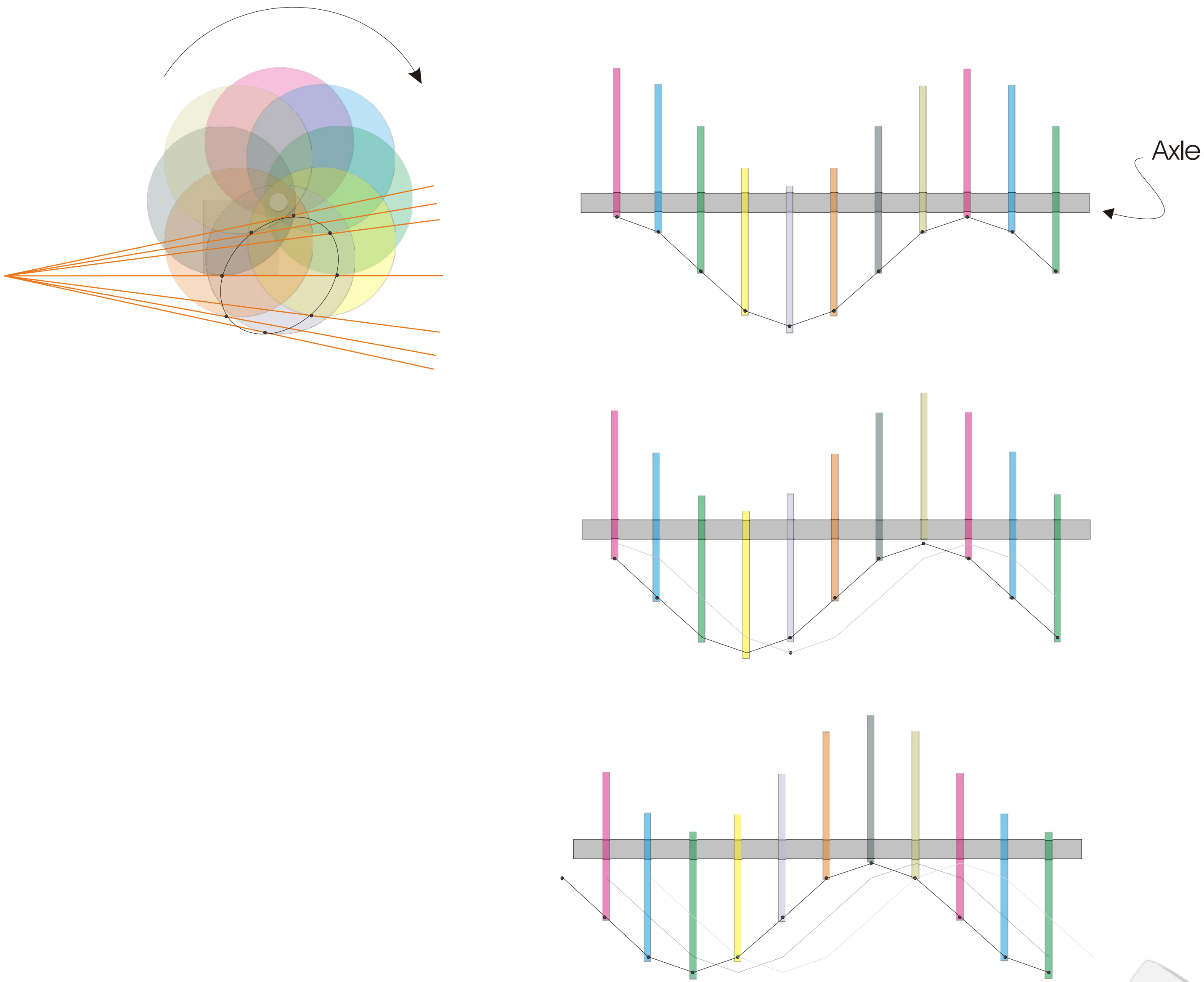


135^{0} rotation





Previous position
1
Pivot point
2
3
4
5
6
7
8
9



Concept 2 Design of a propulsion mechanism based on bionic movement of fish

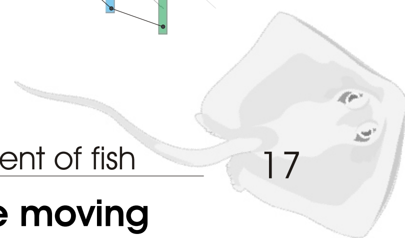
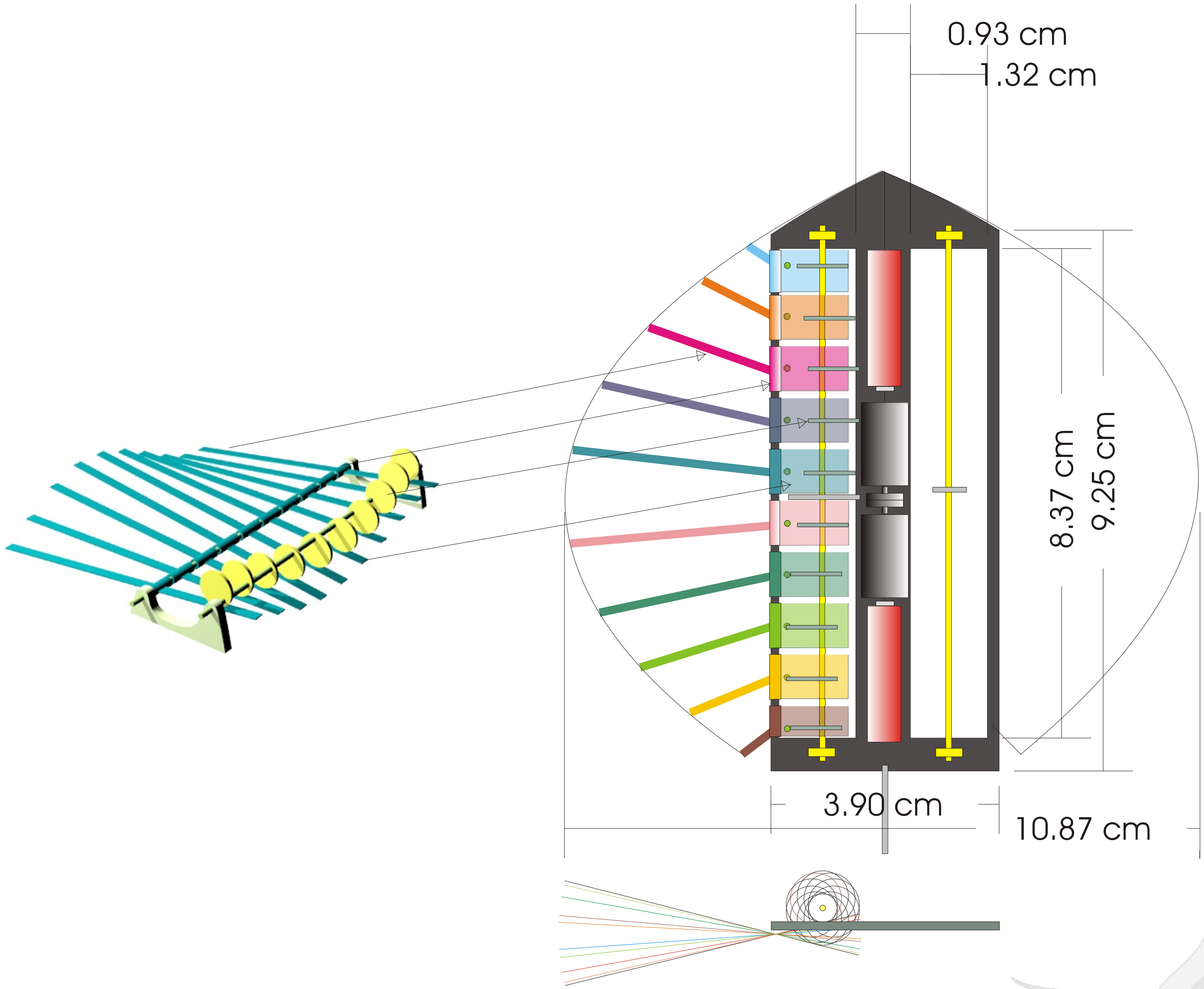
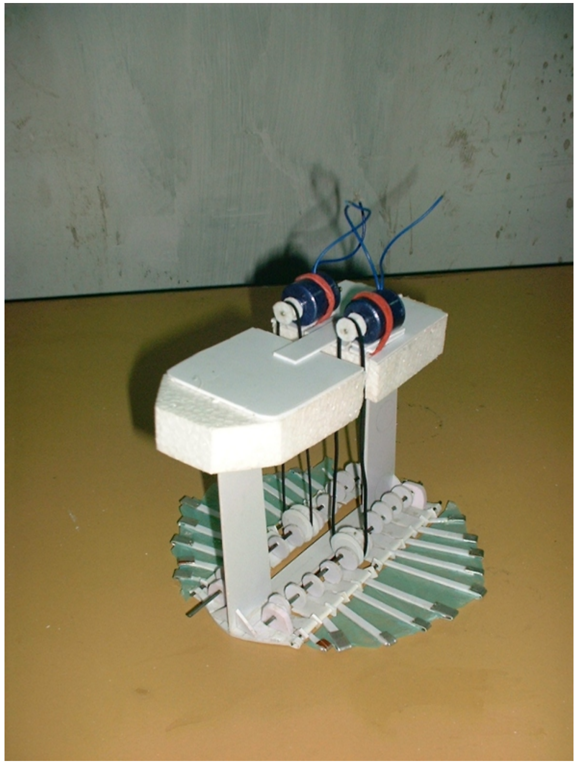
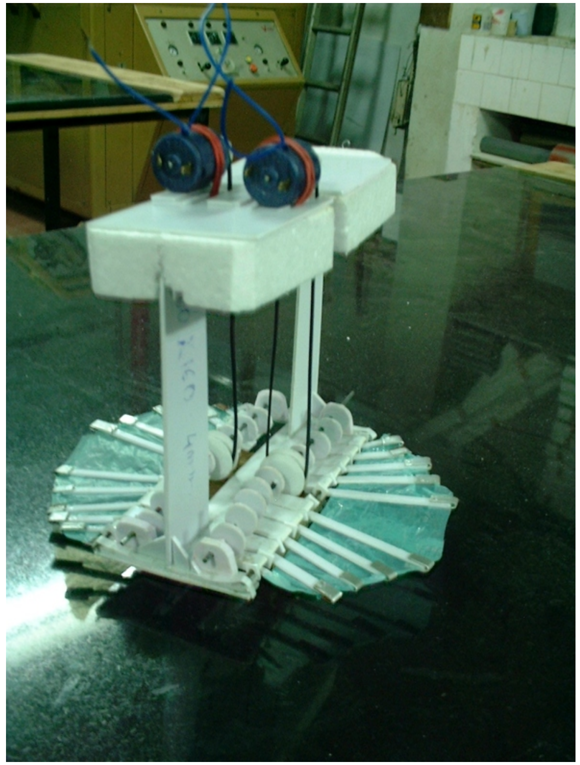
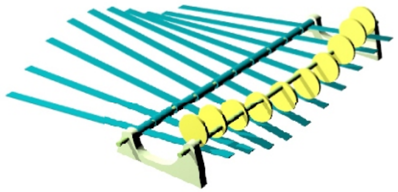


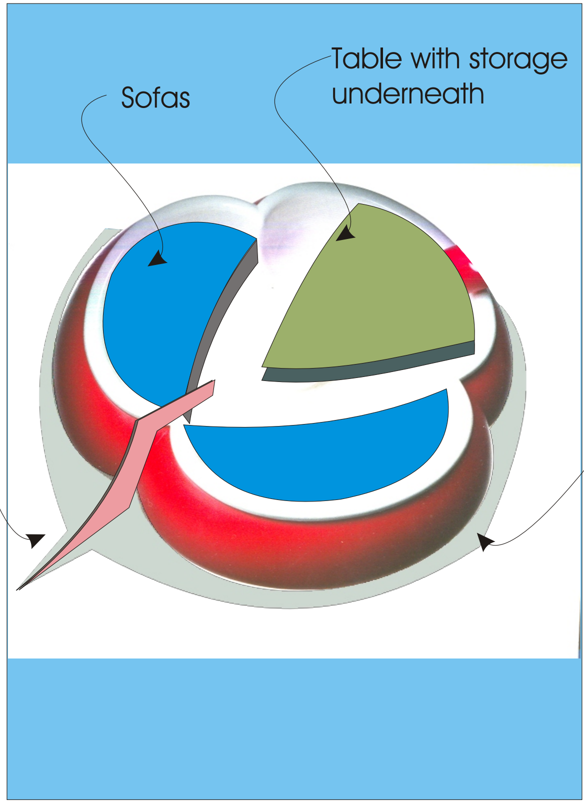
Diagram showing the sine curve moving


0.93 cm
1.32 cm
8.37 cm
9.25 cm
3.90 cm
10.87 cm



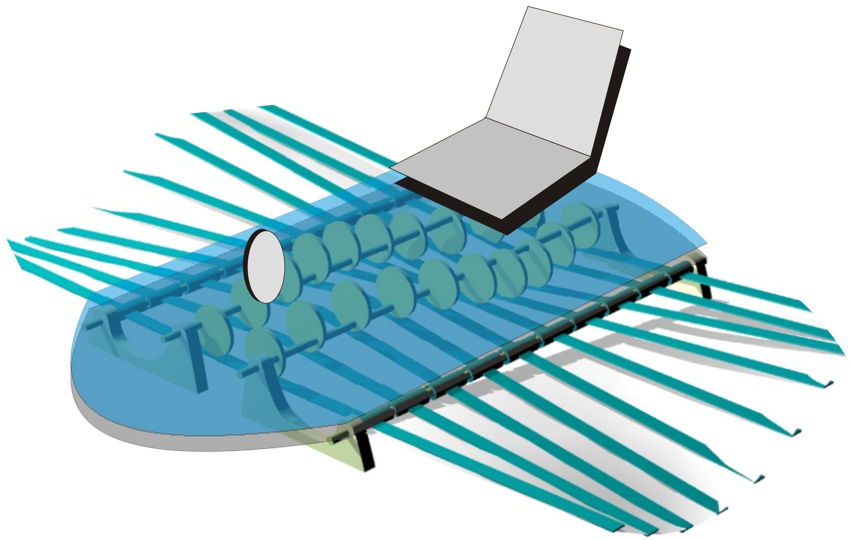






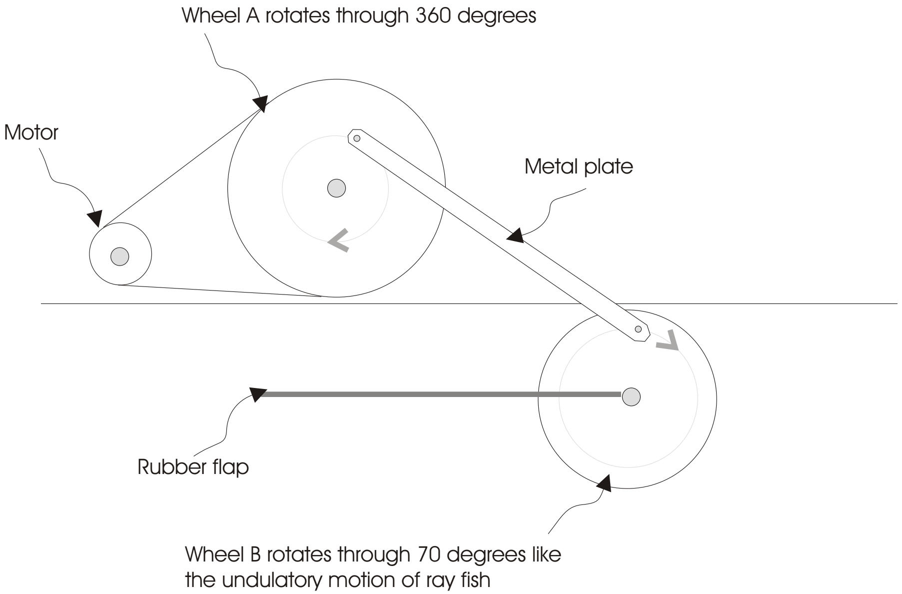
Leisure pad

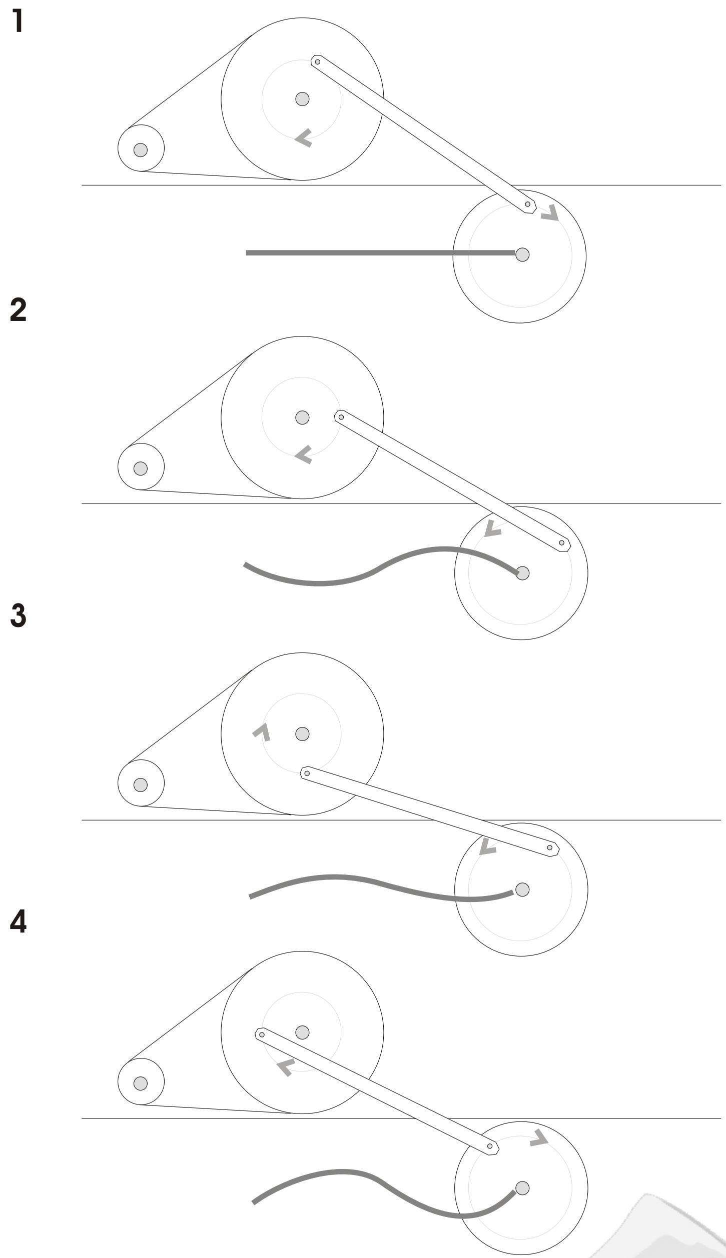
This concept is meant for a location like the backwaters of Kerela where there are these floating cottages... One could introduce these floating tubs for a couple. These would have facilities that will allow for a picnic in the middle of the water. Such a concept came from the swift and non jerky movement that is inspired by the ray fish.

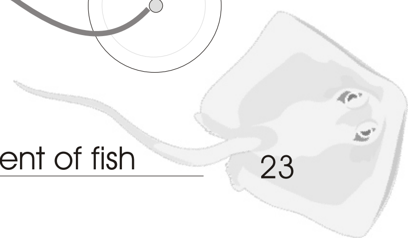


Water glider

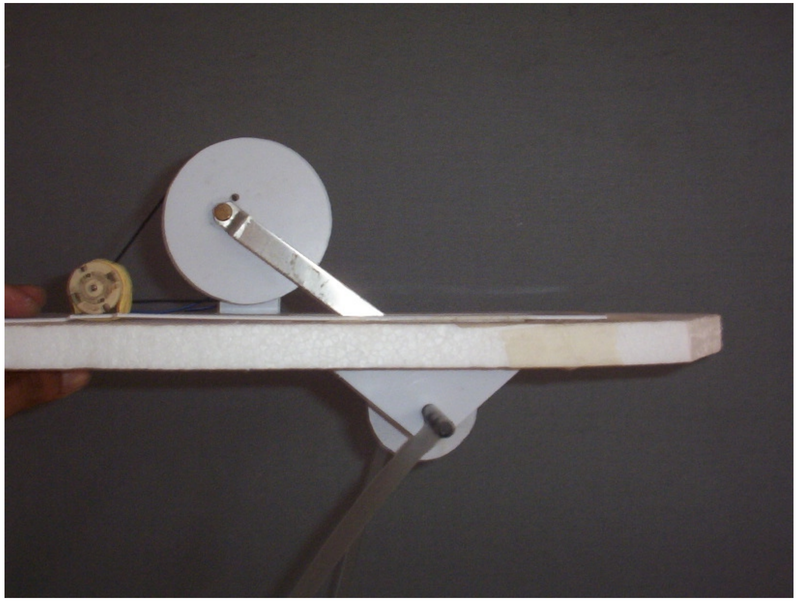
This water scooter tries to make visible the undulating fin mechanism of the ray fish rather than hiding it under, like in the leisure pad.
The smooth undulations can be seen on either side of the scooter while the rider sits in the center which is like the stiff part of the body of the ray fish. The swiftness without any turbulence and a nice easy going speed is good for locations which have a coral reef with lots of fishes that one can see without disturbing....since this mechanism has the least amount of turbulence as compared to the other fish movements.







Concept 4 Design of a propulsion mechanism based on bionic movement of fish



Model of the mechanism

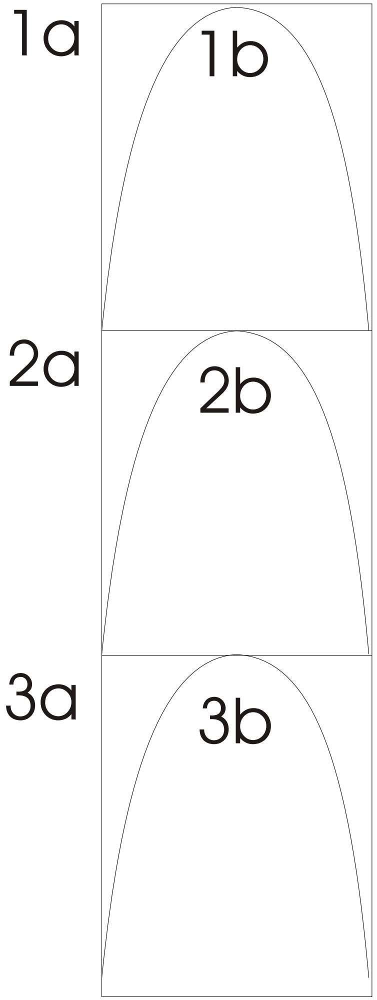
Model being tested in water tub

method
to keep one variable and mentain other parameters at constant

1. Shape of the fin member

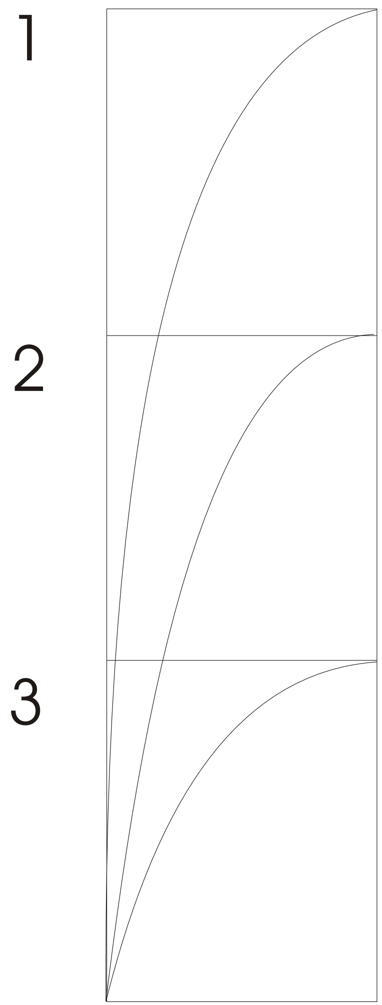
2. Thickness of fin member

3. Different materials...varying the elastic component



Length	Time a	Time b	Time c	Avrg time
1a	11	11.2	12	11.4
1b	9.3	9.6	10.3	9.73
2a	7.4	7.6	8.1	7.7
2b	7.8	8.2	7.6	7.86
3a	7.4	7.8	8.2	7.8
3b	8.4	9.2	8.8	8.8.

Experiment 1



Length	Time a	Time b	Time c	Avrg time
1	10.4	11.2	12	11.2
2	9.8	9.4	10	9.73
3	9.41	9.2	9.5	9.37

Experiment 2

Next step…

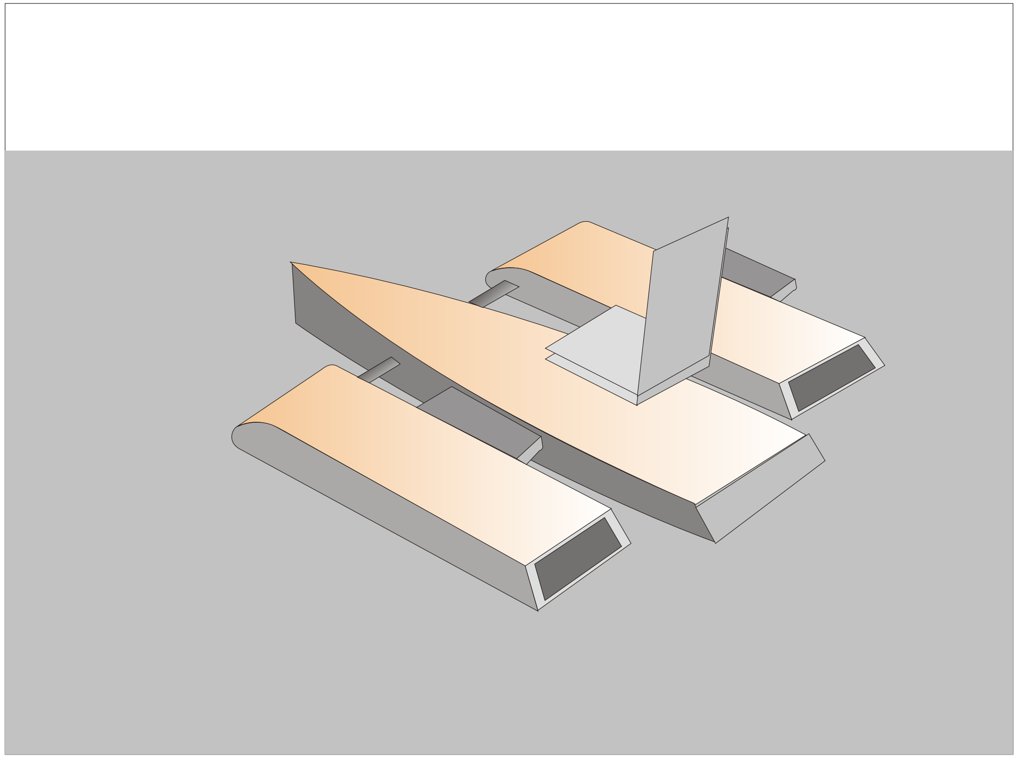
We know that changing the **fin size and shape** changes the speed, ie. the efficiency

Observing **the turbulence** would mean that the angle of the fin with the body could be studied to use the turbulence productively

Optimizing **material of fin** would again be an area to be explored

Model for such experiments have to be perfectly alligned, smooth moving, if care is taken initailly then the accuracy of time reading will be enhanced

The joint of the fin to the body can be designed so as to be easily attachable and changeable.



Summary

By understanding the nature of motion in fishes and the forces that cause it, we can develop mechanisms that are specific to a purpose. Not all kinds of propulsion need the conventional propeller based mechanism. And it might not be efficient in terms of where and how it is used.

The ray fish which has been studied and whos motion has been attempted to be emulated, is a silent smooth mover. It just glides inside the water with much less turbulence than other fishes. The movement is so graceful and effortless that it inspires a feeling of wonder. Its not only that the ray fish moves through water.. Importantly it also does it gracefully.

This project has been an elementary move in the direction to understand how we can benefit by studying nature. Capturing the exact motion was not the intention of the project but rather to adapt this nature of movement, simplify it, and make it easily available for use in water crafts.

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Decavitator: mark drela and students at iit

Useful websites

American museum of natural history (biomechanics) website

Http://ecomorphology.mlml.calstate.edu/Rosenberger2.pdf

Http://www.cnse.caltech.edu/index.html

IEEE journel of oceanic engineering (IEEEJOE_99.pdf)