VORTEX DYNAMICS AND FISH HYDRODYNAMICS: ROBOTUNA

by

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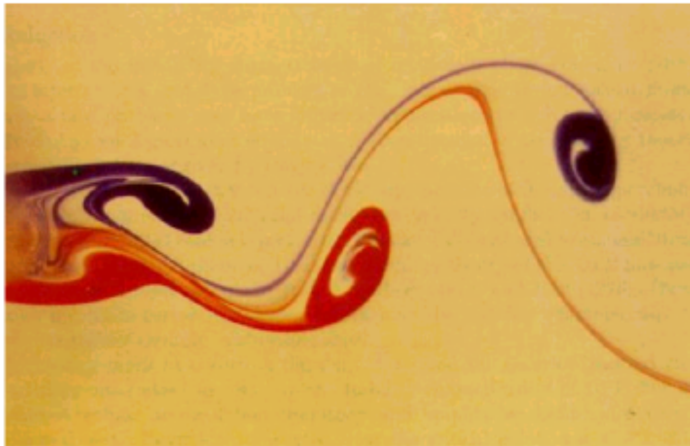
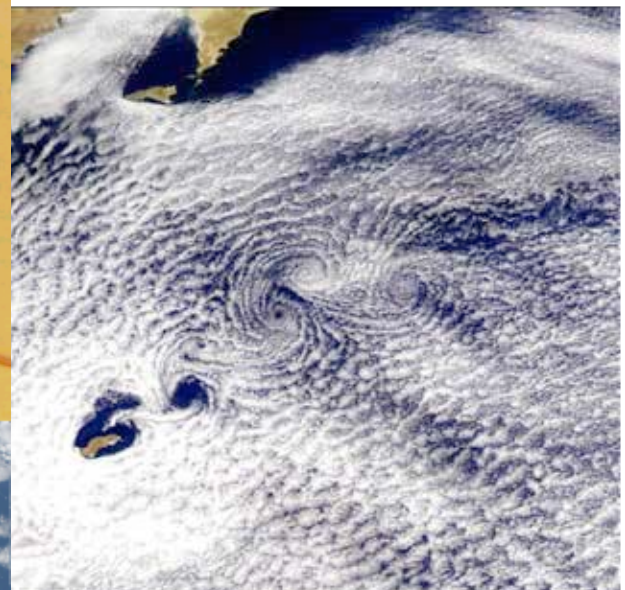
SEMINAR AT TRONDHEIM
FOR CARL LARSEN'S RETIREMENT

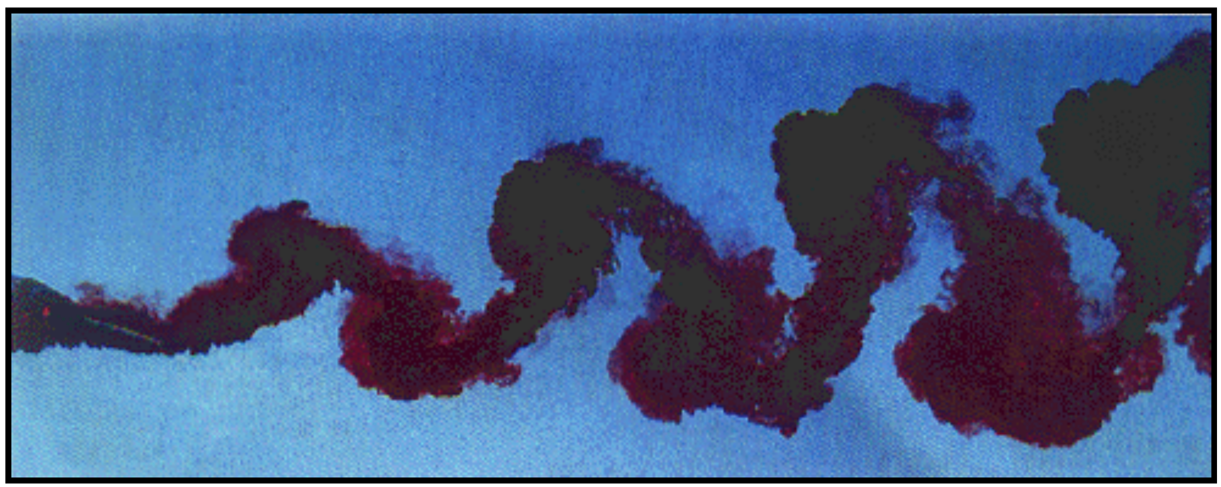
August 21, 2015





LEFT: Karman vortex street behind a cylinder (Re=150) and behind islands (Re=10^{11}) **f D/U = 0.20**

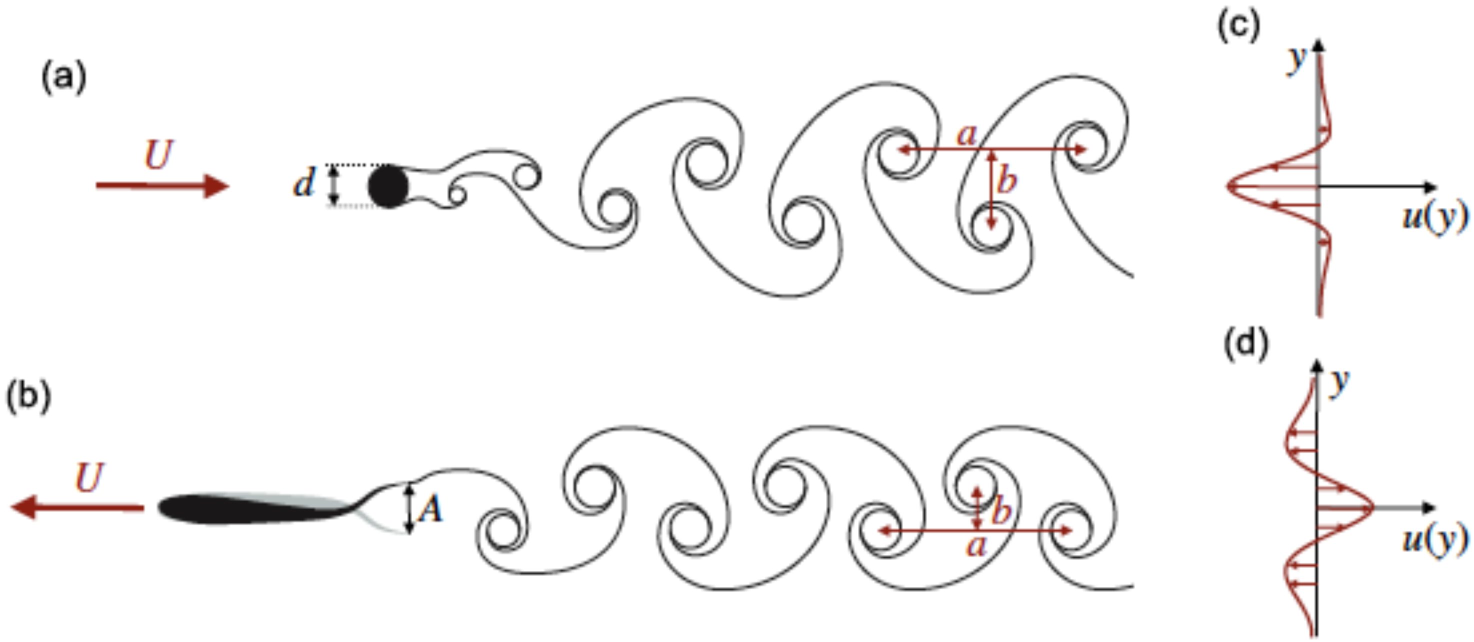
BELOW: Reverse Karman street behind a robotic tuna (Re=10^{4}) **f A/D = 0.30**



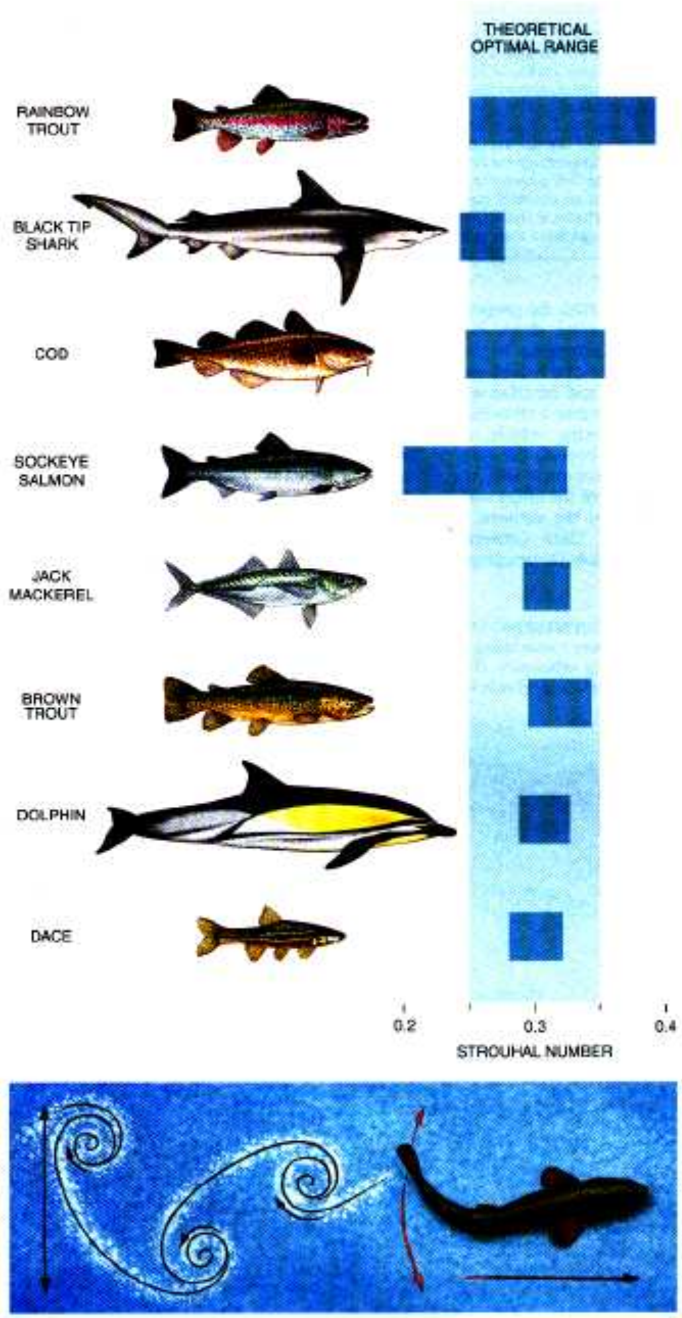
SWIMMING FISH
AND FLYING BIRDS
Why fish have no propellers?
Why birds flap their wings?

A UNIVERSAL FREQUENCY OF SWIMMING

CYLINDER, St=0.20
FOIL, St=0.30



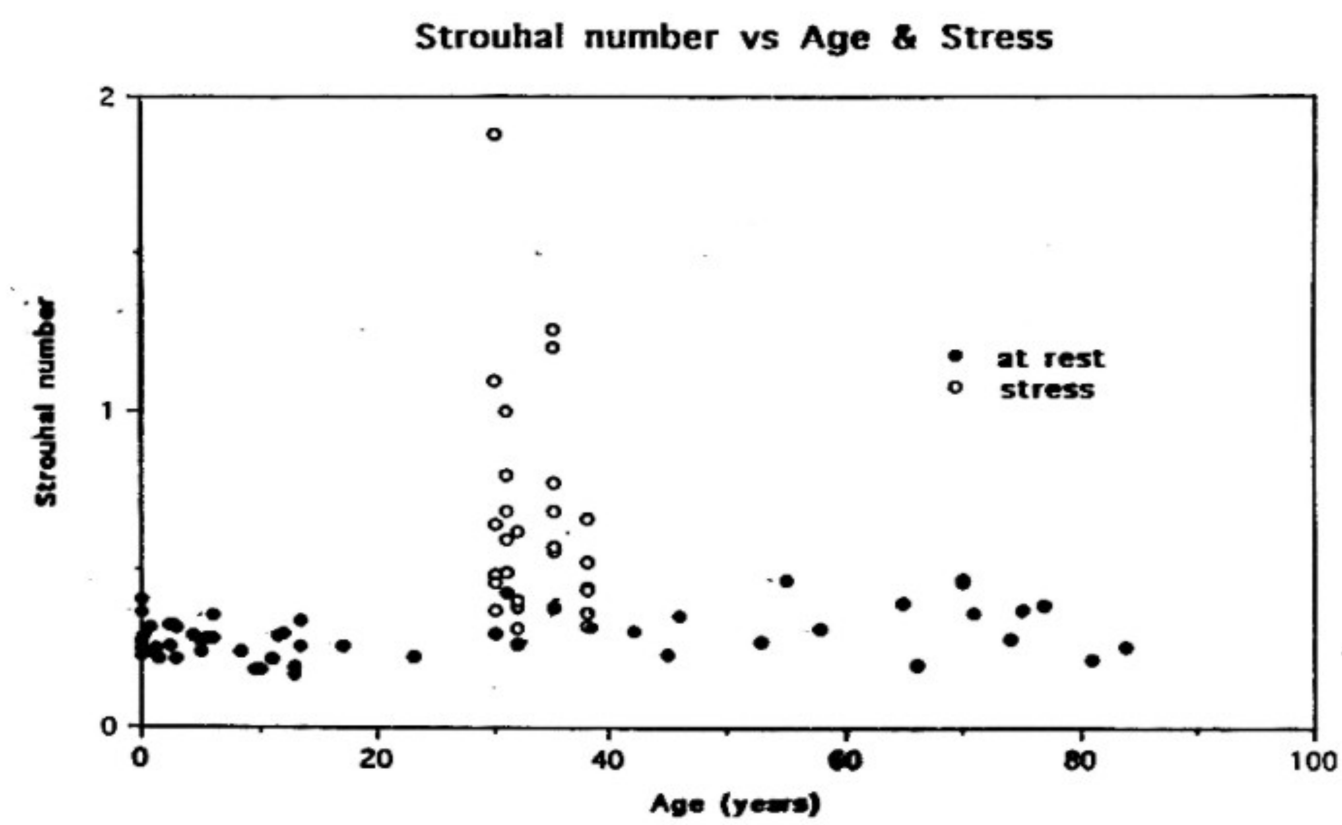
ALL FISH FLAP THEIR TAILS AT NON-DIMENSIONAL FREQUENCY CLOSE TO 0.30



FISH OF ALL KINDS flap their tails to create vortices that produce a jet of high propulsive efficiency. Key parameters describing the jet are related in a ratio known as the Strouhal number, defined as the product of the frequency of tail flapping (*yellow arrows*) times the jet's width (*purple*), divided by the fish's speed (*red*). A Strouhal number between 0.25 and 0.35 is a hallmark of efficient swimming.

$$St = fA/U = 0.30$$

STROUHAL NUMBER FOR THE HEART



DYNAMIC FILLING CHARACTERISTICS
OF THE LEFT VENTRICLE

STROUHAL NUMBER FOR BIRDS

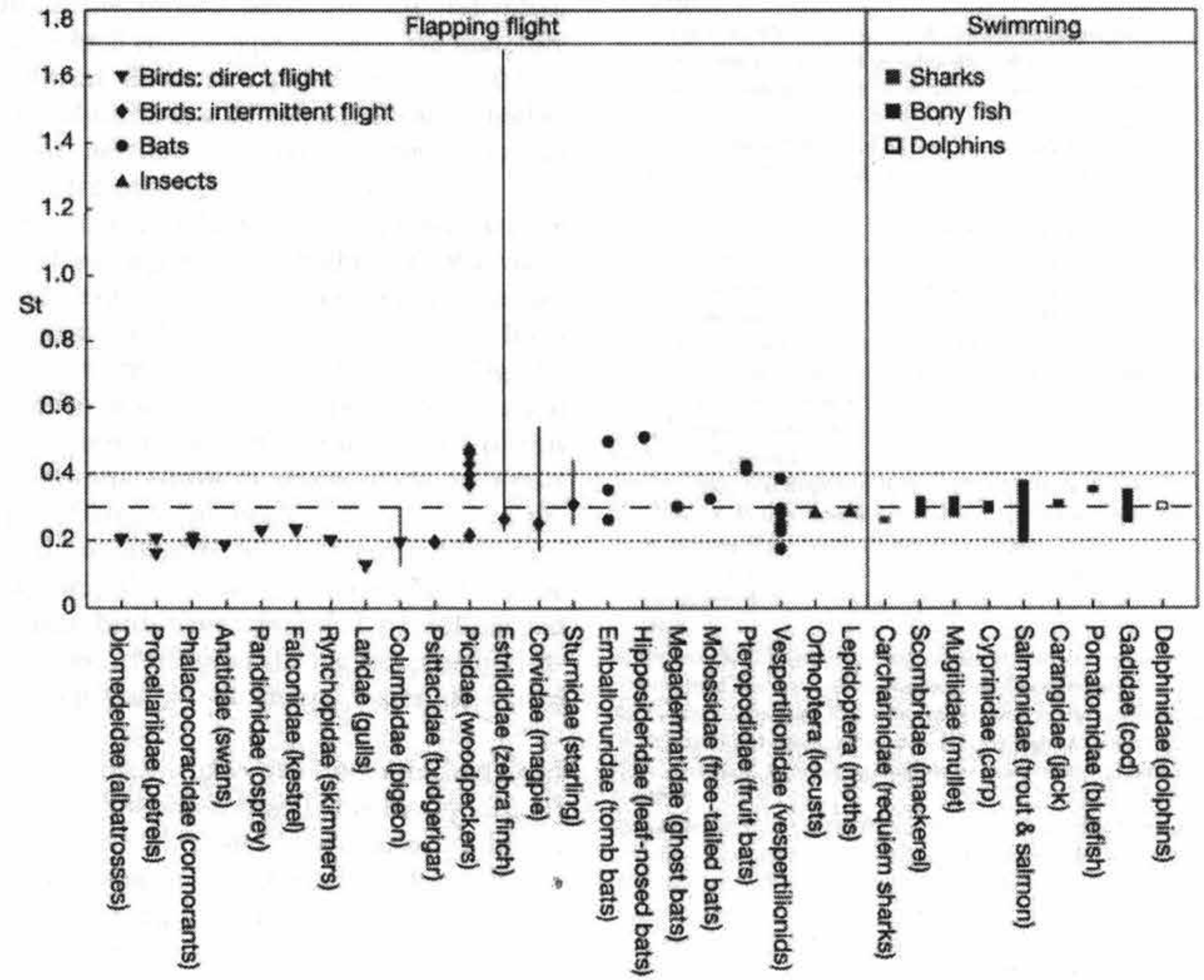


Figure 2 Strouhal number for 42 species of birds, bats and insects in unconfined, cruising flight. Published ranges[3,4] of St in cruising fish and dolphins are included for comparison. Dotted lines mark the range $0.2 < St < 0.4$, in which propulsive efficiency usually peaks; dashed line marks the modal peak at $St = 0.3$. Unbroken lines indicate the range of variation in St across other non-zero flight speeds, where such data exist.

ROBO-TUNA & ROBO-PIKE

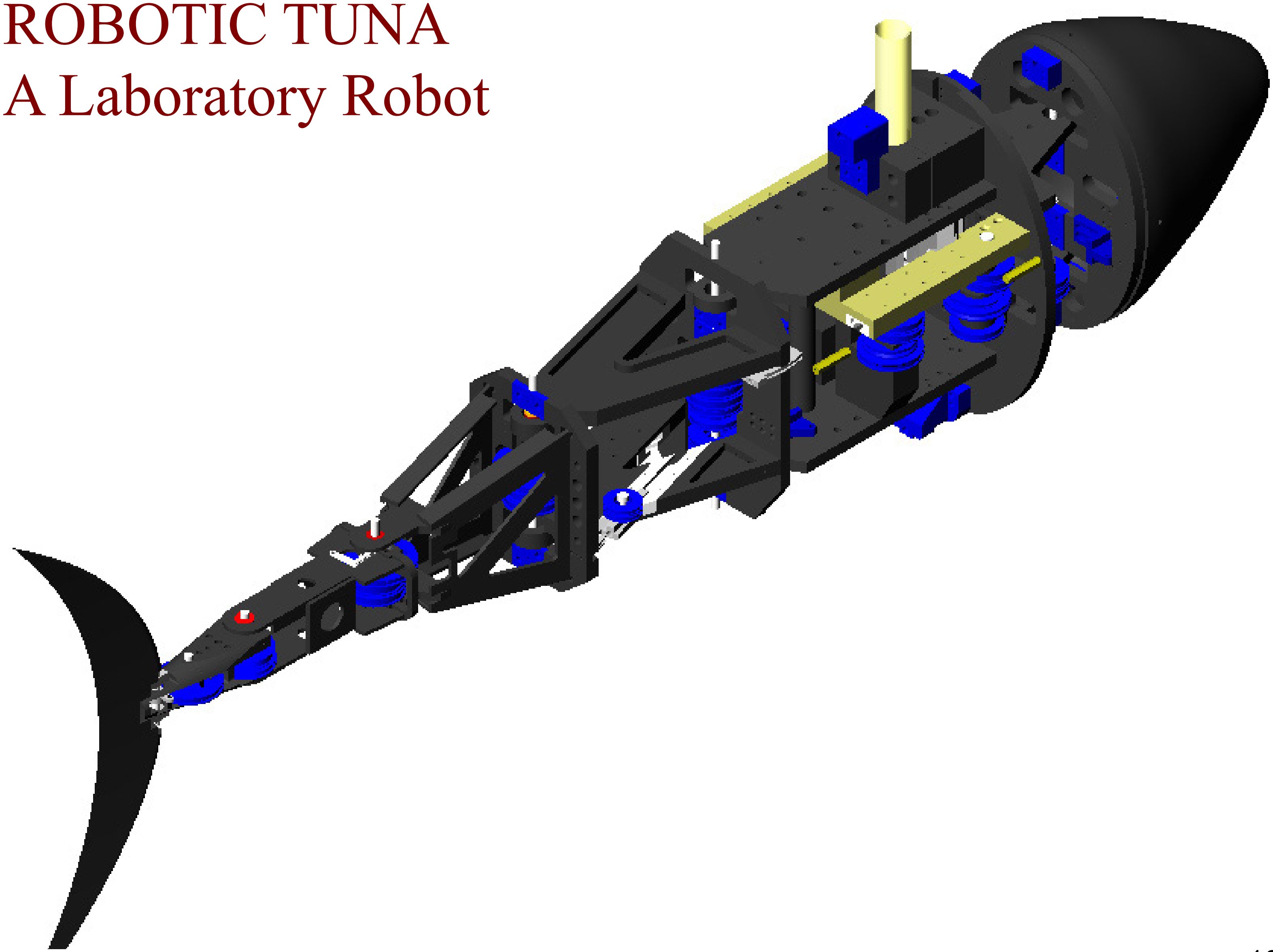
Optimal Propulsion

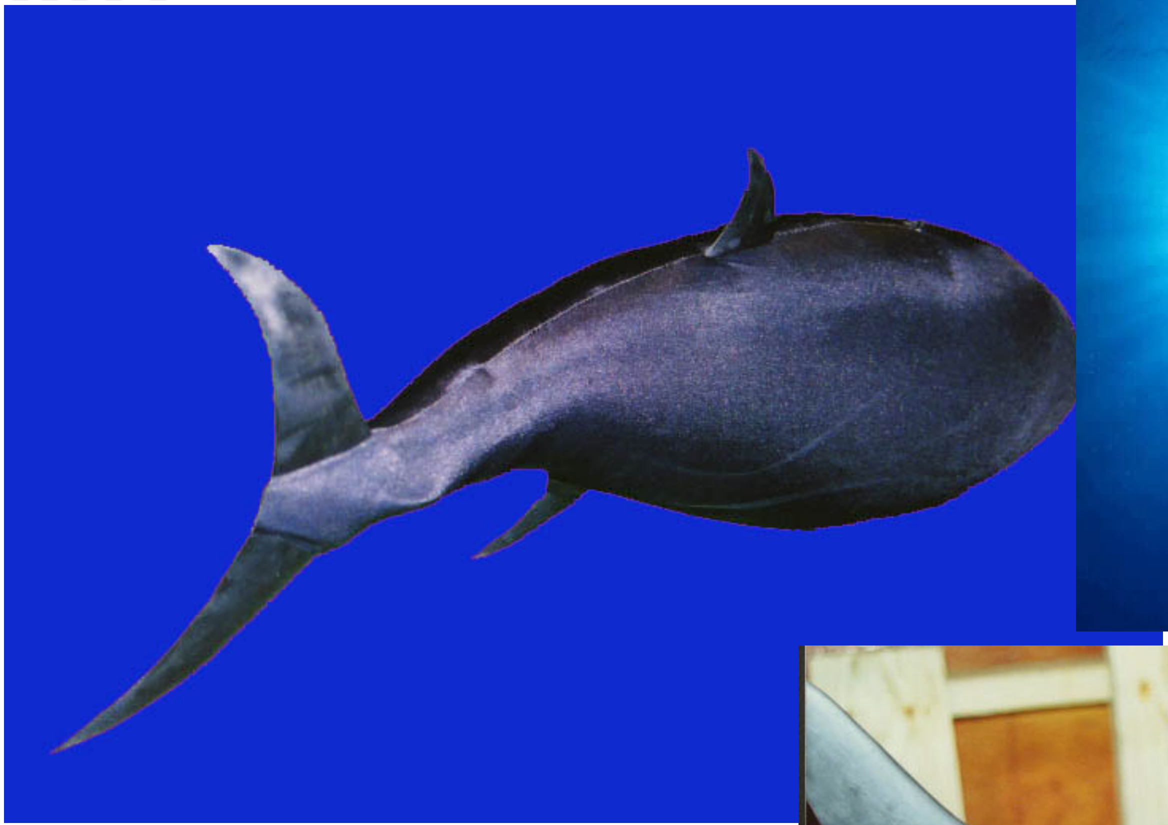
Turbulence Reduction

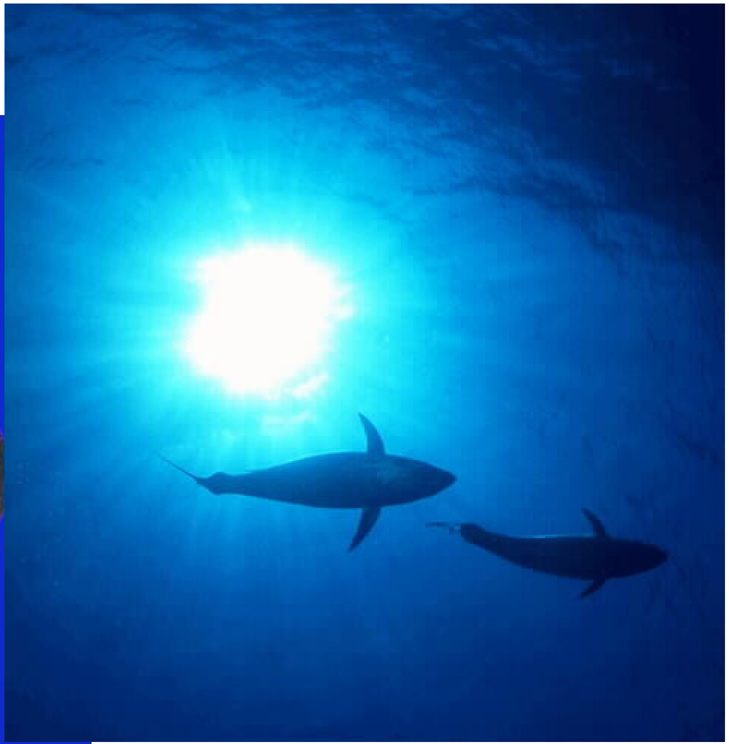
Vorticity Control

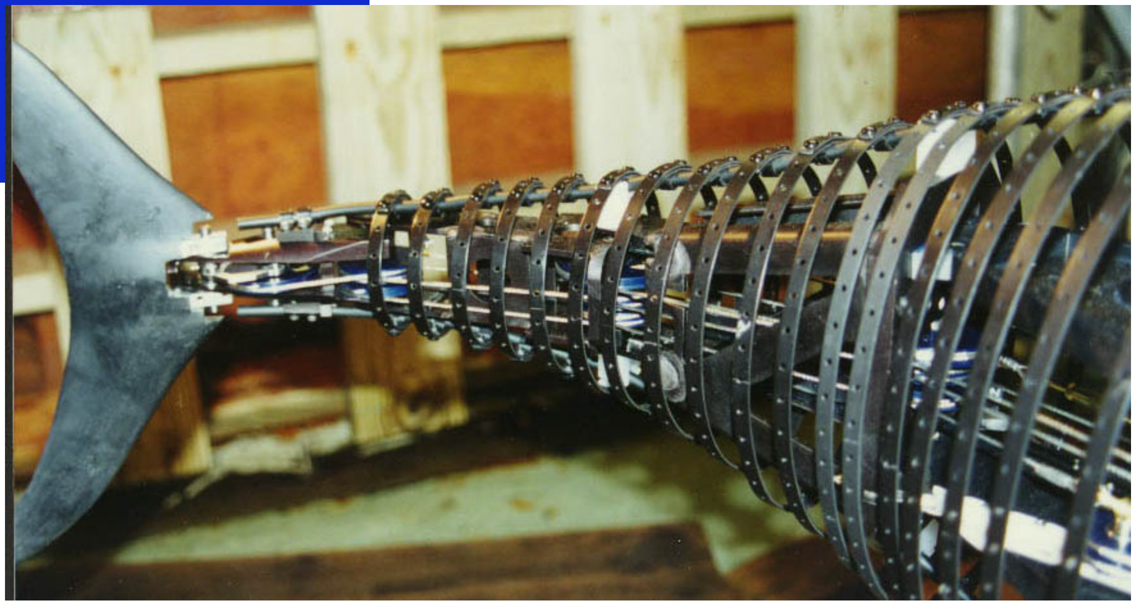
Super-maneuverability

ROBOTIC TUNA
A Laboratory Robot









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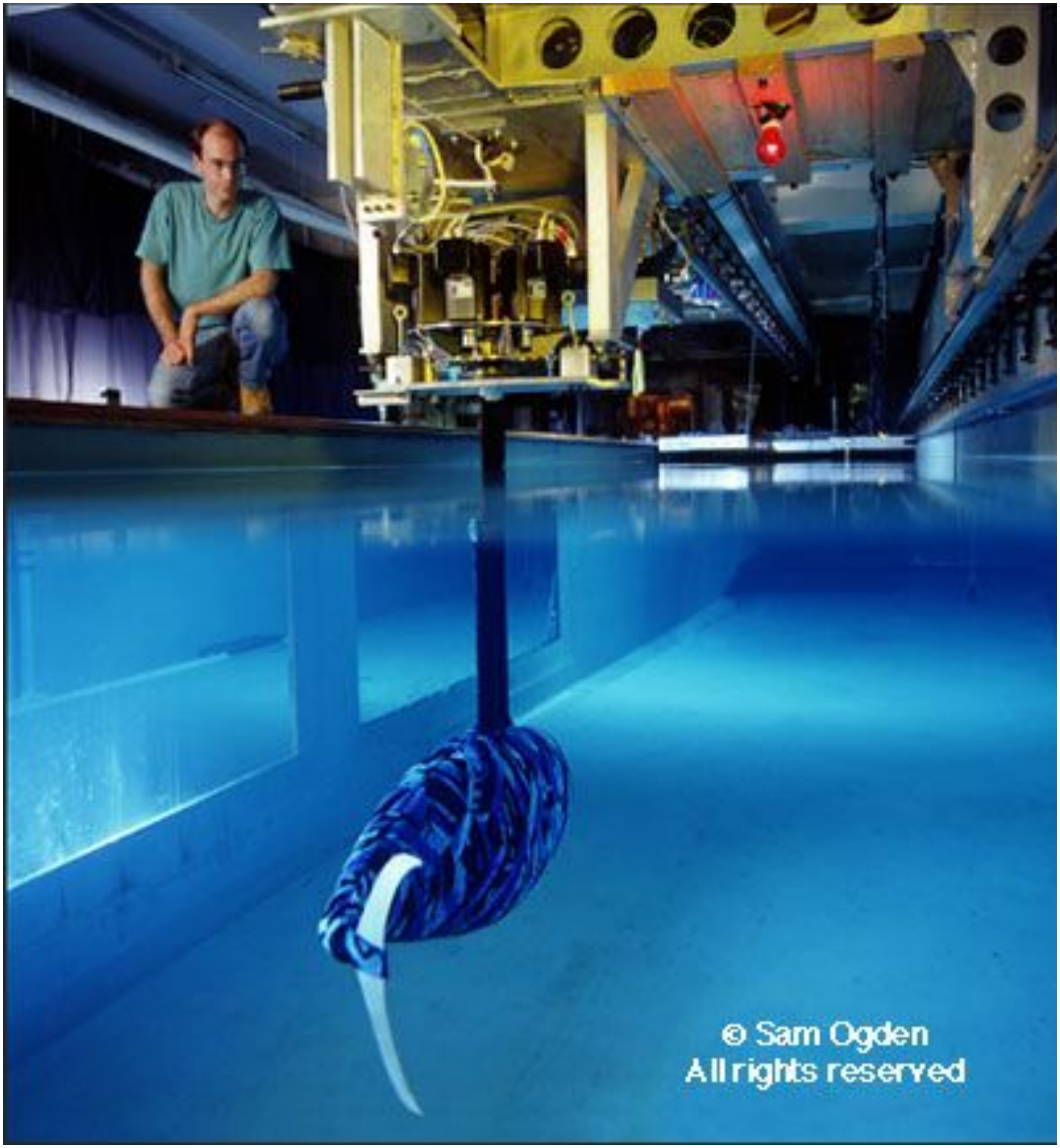

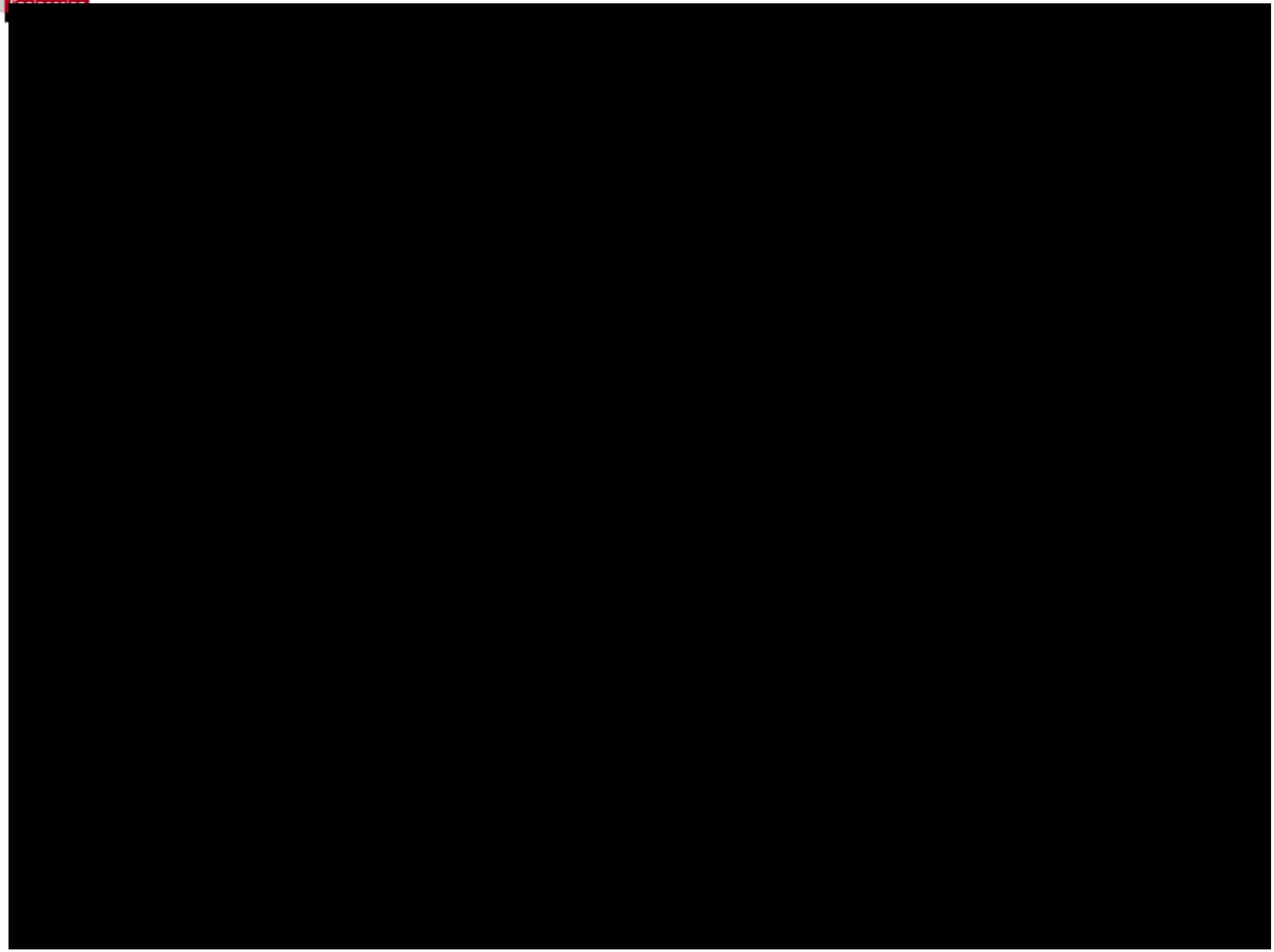

VORTICITY CONTROL

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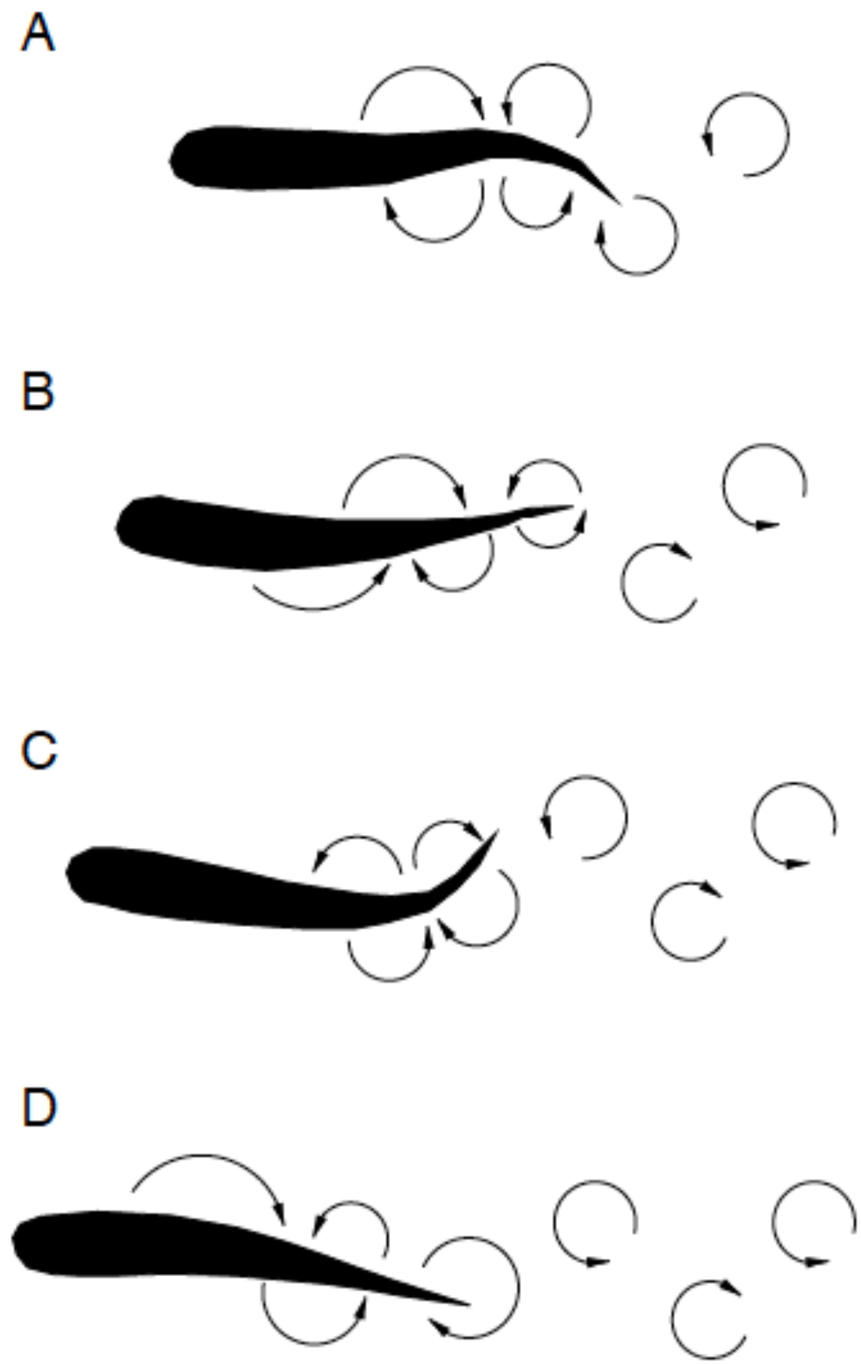
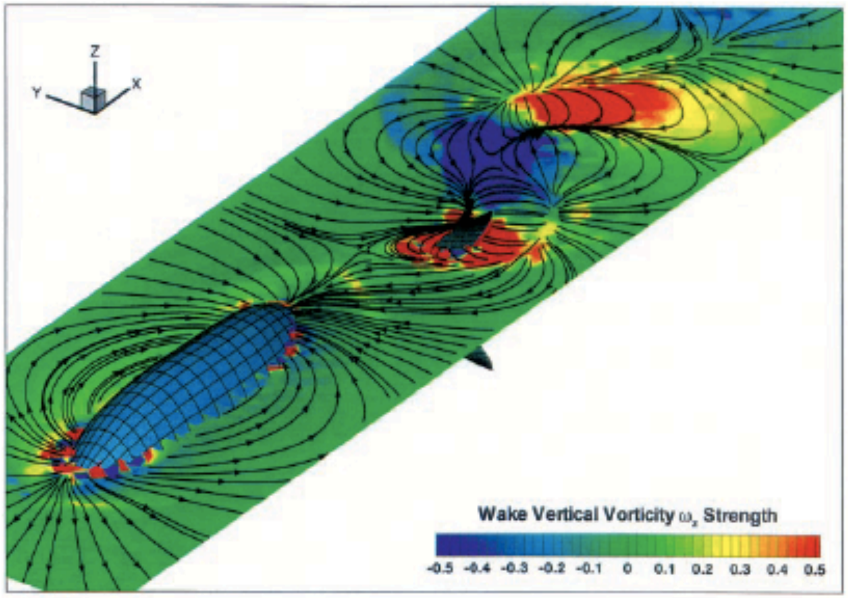
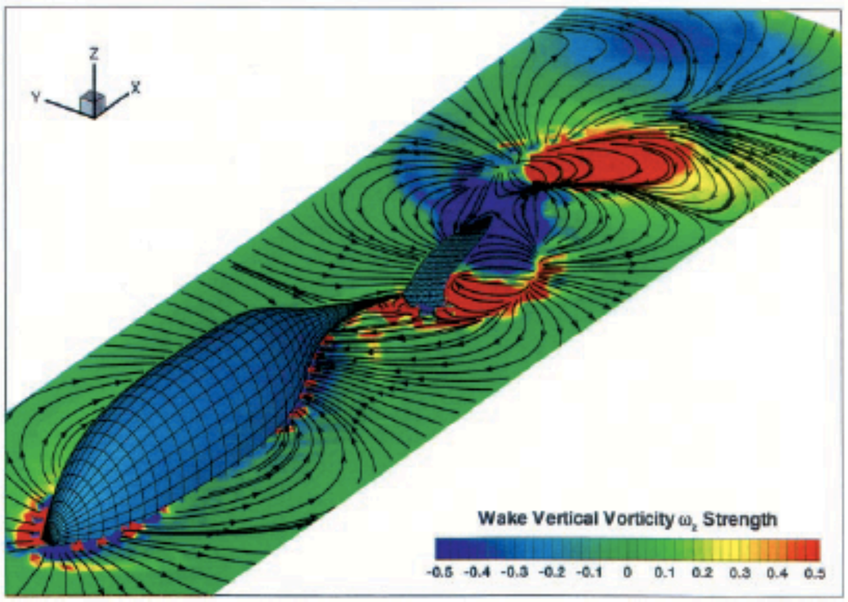
VORTICITY CONTROL IN SWIMMING FISH

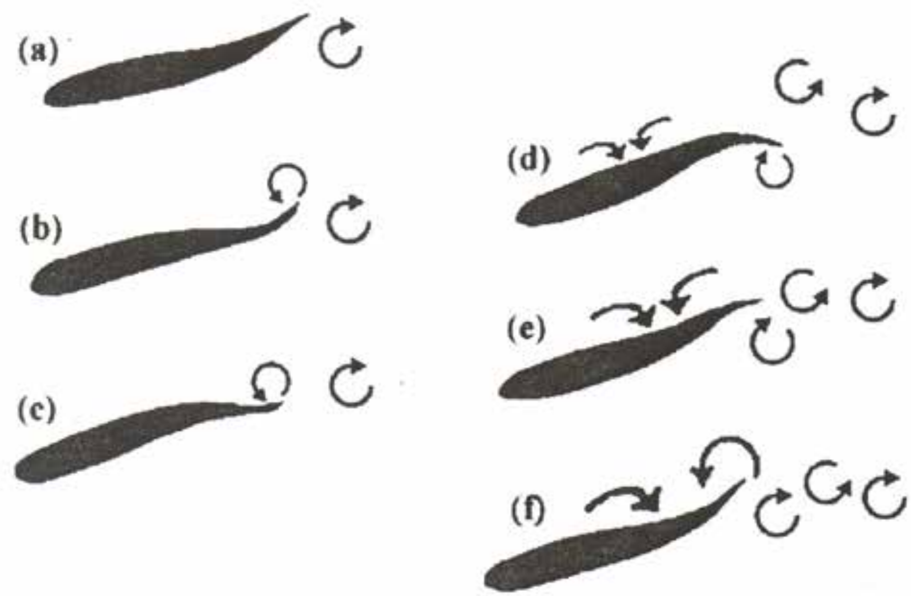


FISH:

VORTICITY CONTROL

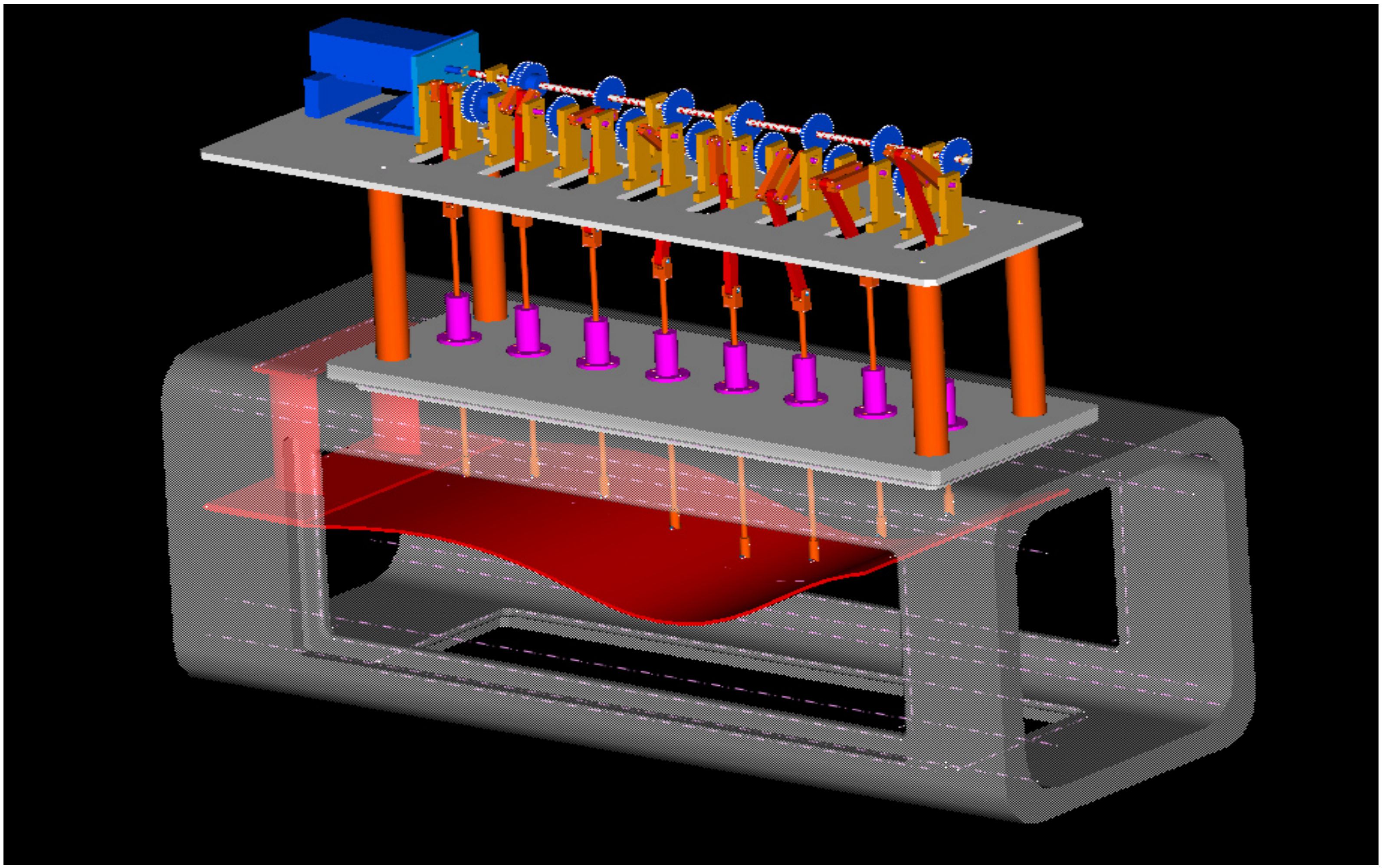






TURBULENCE REDUCTION IN FISH SWIMMING

Waving Plate Apparatus



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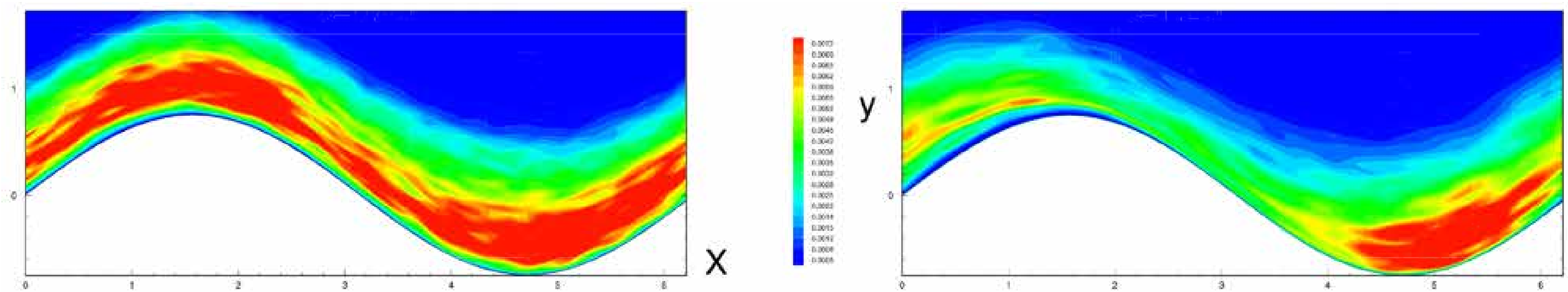
Turbulence Suppression in Wavy Fish-Like Swimming Motions: CFD Results



c/U = 0.4

c/U = 1.2

Zhang, 2000

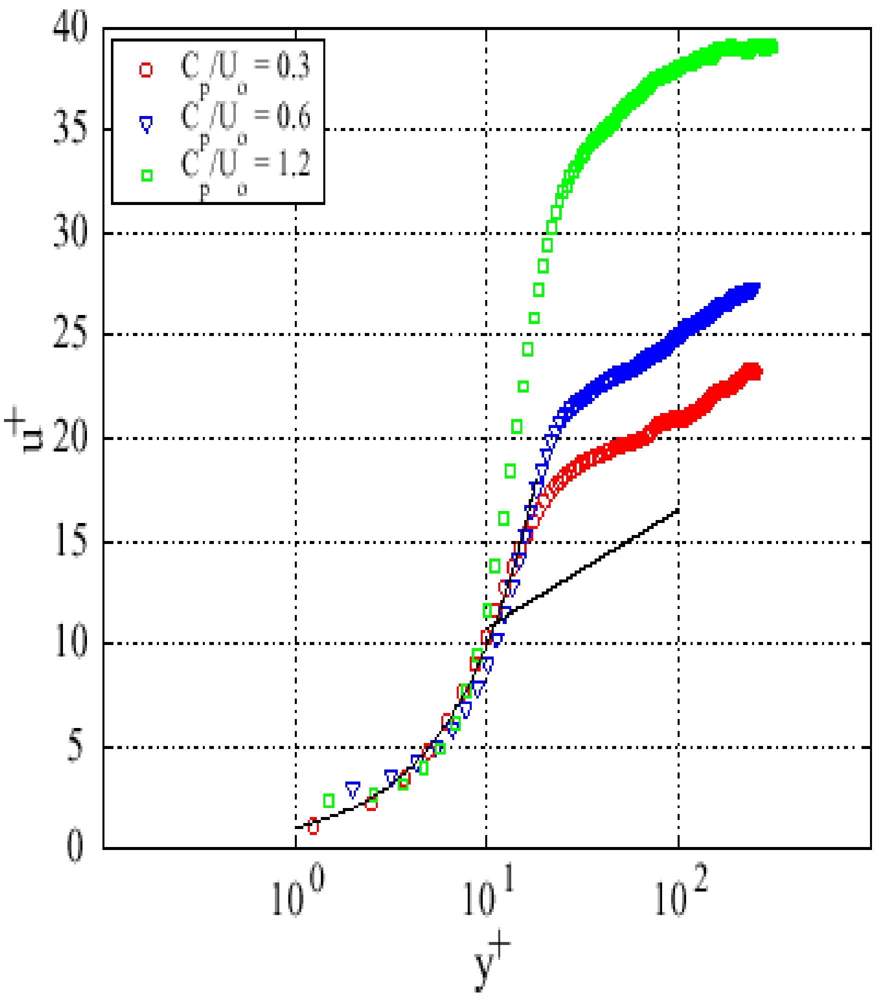
CFD WAVING PLATE: OPTIMAL SPEED 1.2 TIMES FISH VELOCITY

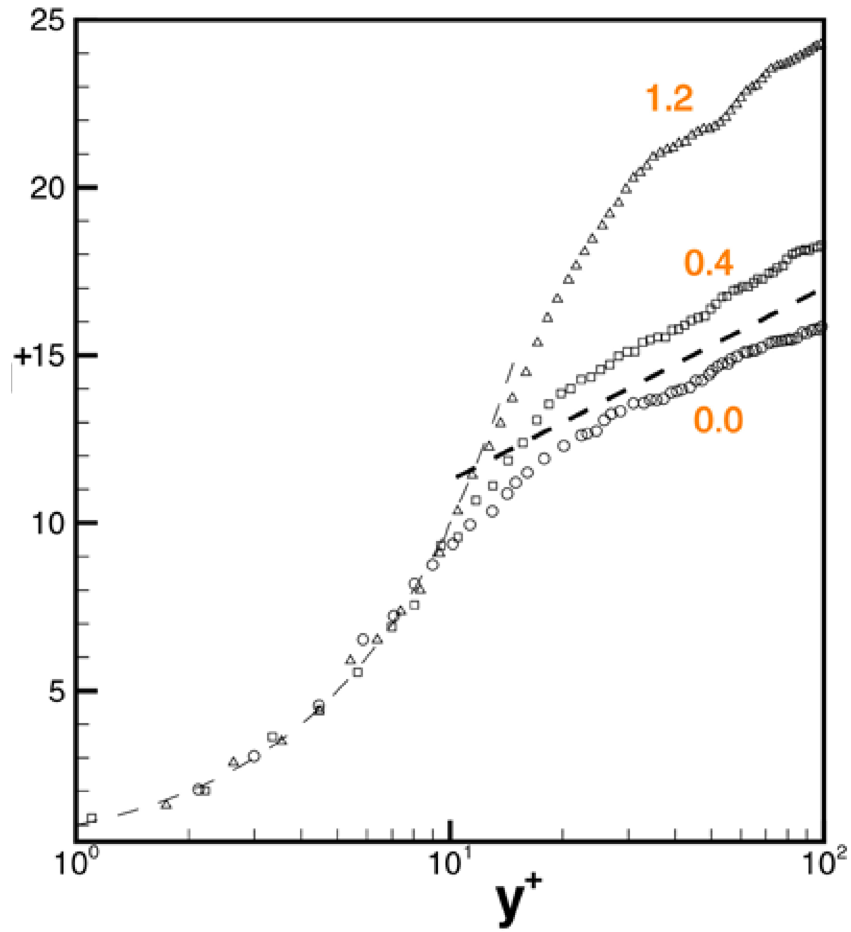
- Fp: pressure force
- Ff: friction force
- Ft: total force, Fp+Ff

- Ps: power for waving
- Pt: total power, Ps + U*Ft

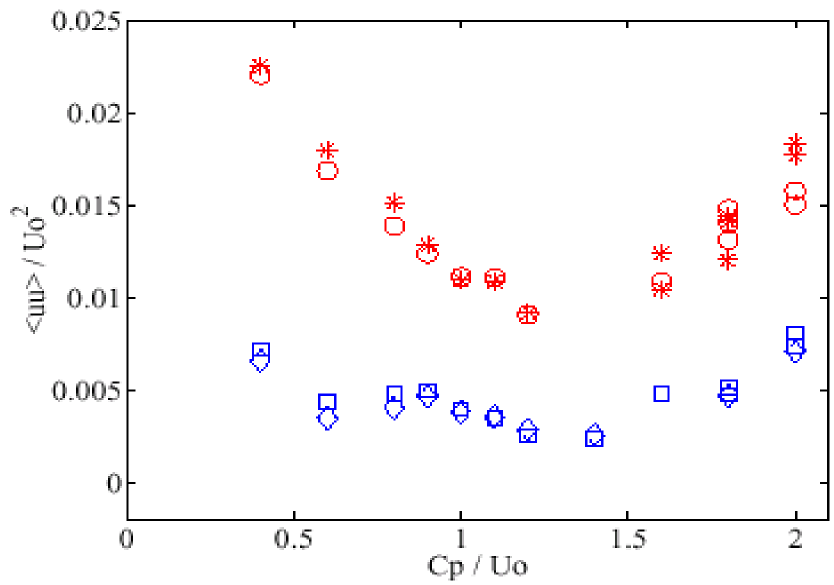
c/U	Fp	Ff	Ft	Ps	Pt
0.0	1.27	0.10	1.37	0.00	1.37
0.4	0.64	0.17	0.81	0.50	1.31
0.8	-0.30	0.18	-0.12	0.48	0.36
1.2	-0.15	0.15	0.00	0.35	0.35
2.0	-2.62	0.08	-2.54	9.70	7.16

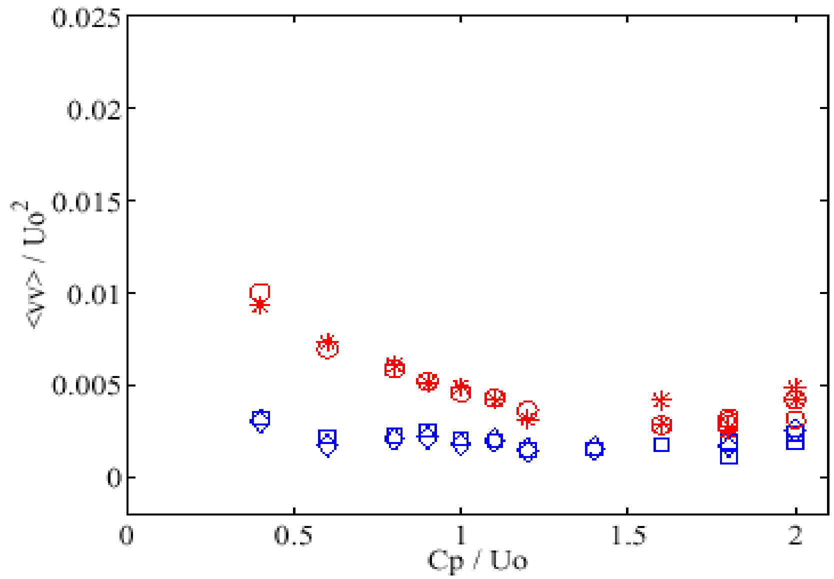
Effect of phase speed on BL



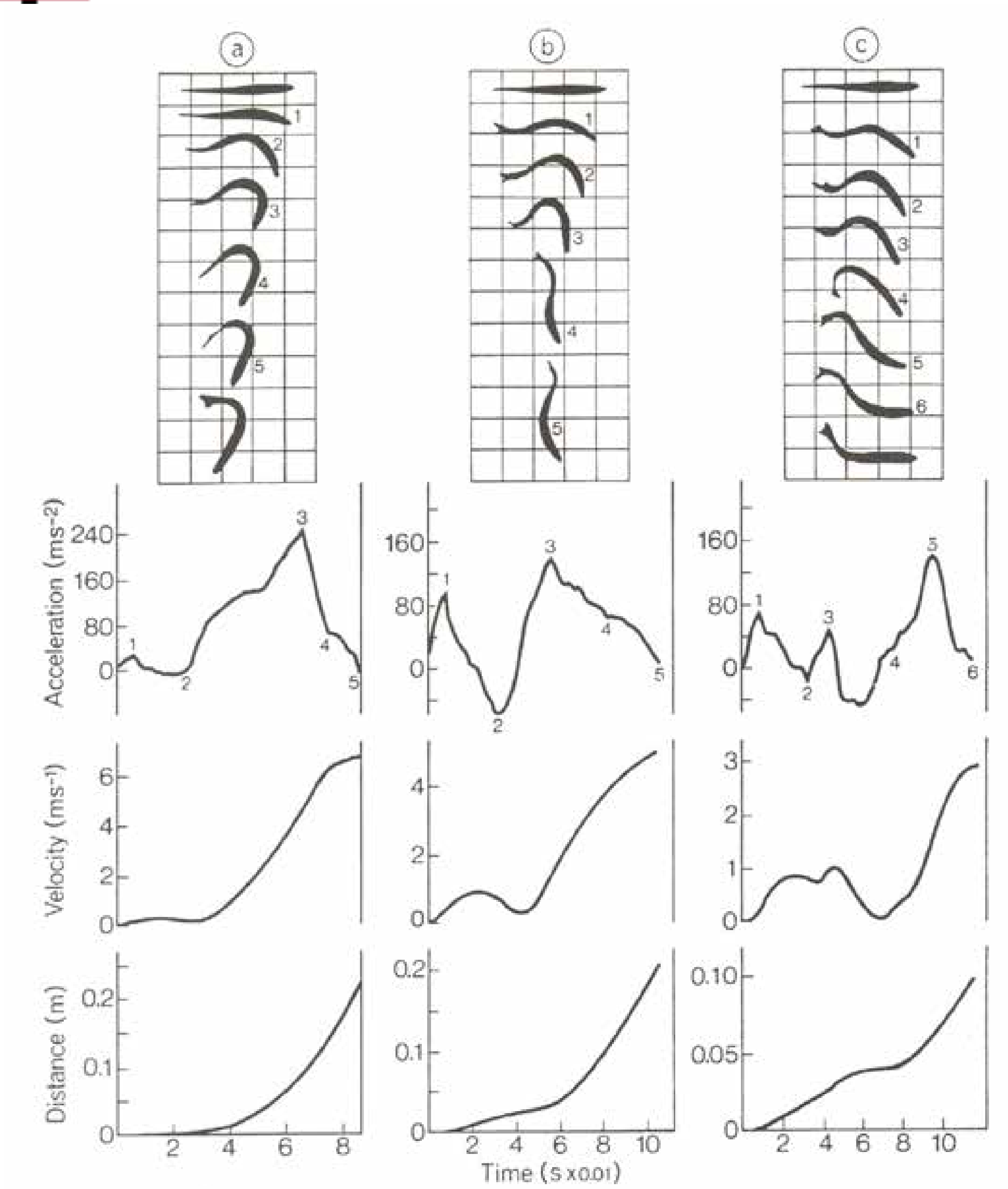


Turbulence Intensity



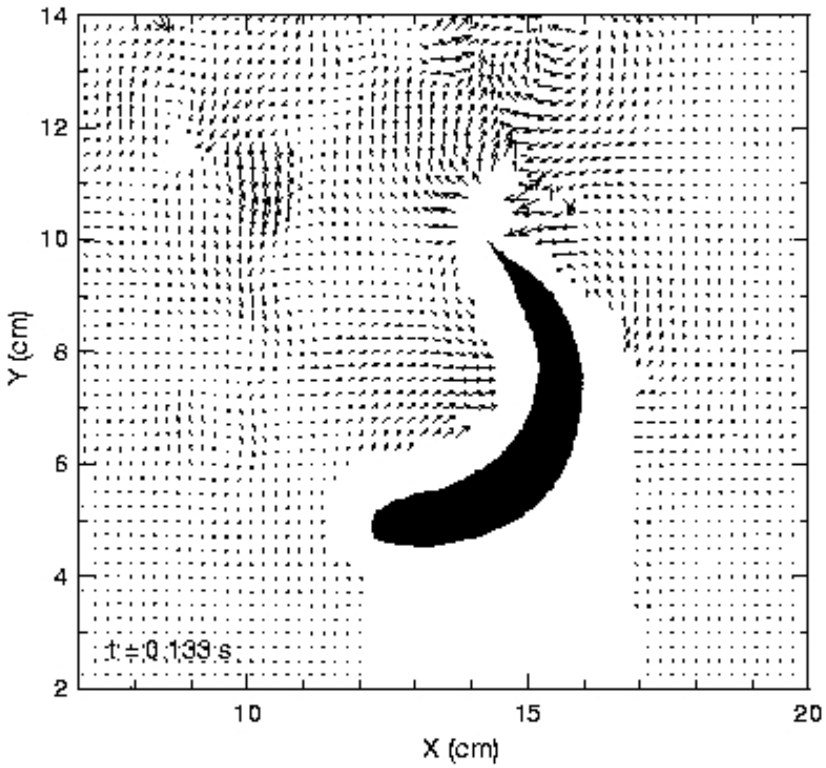


SUPER-MANEUVERABILITY

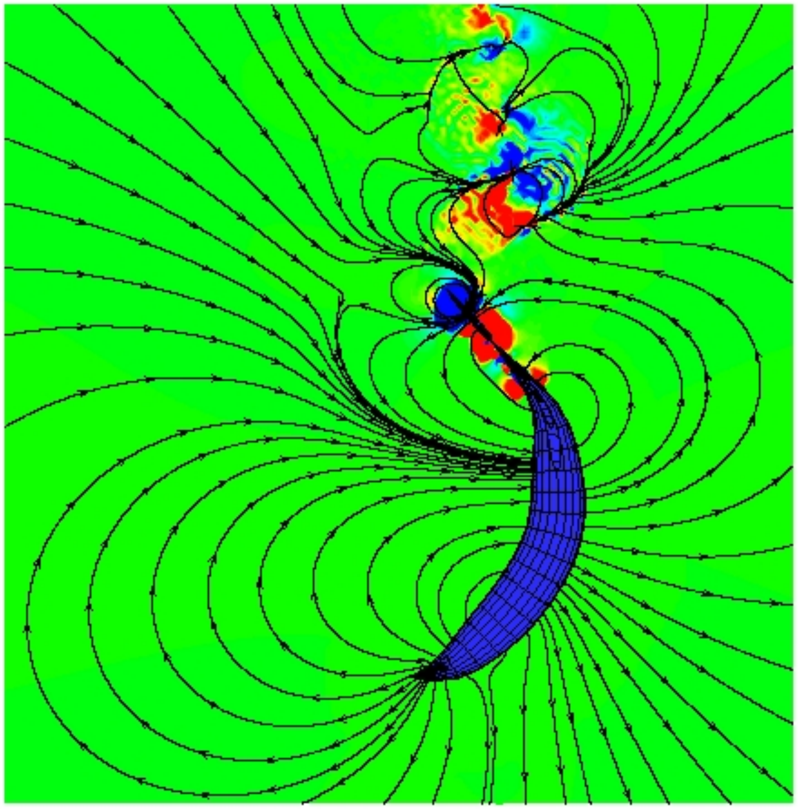


PIKE ACCELERATE WITH MAXIMUM ACCELERATION 25 g

Turning Maneuver Of Giant Danio

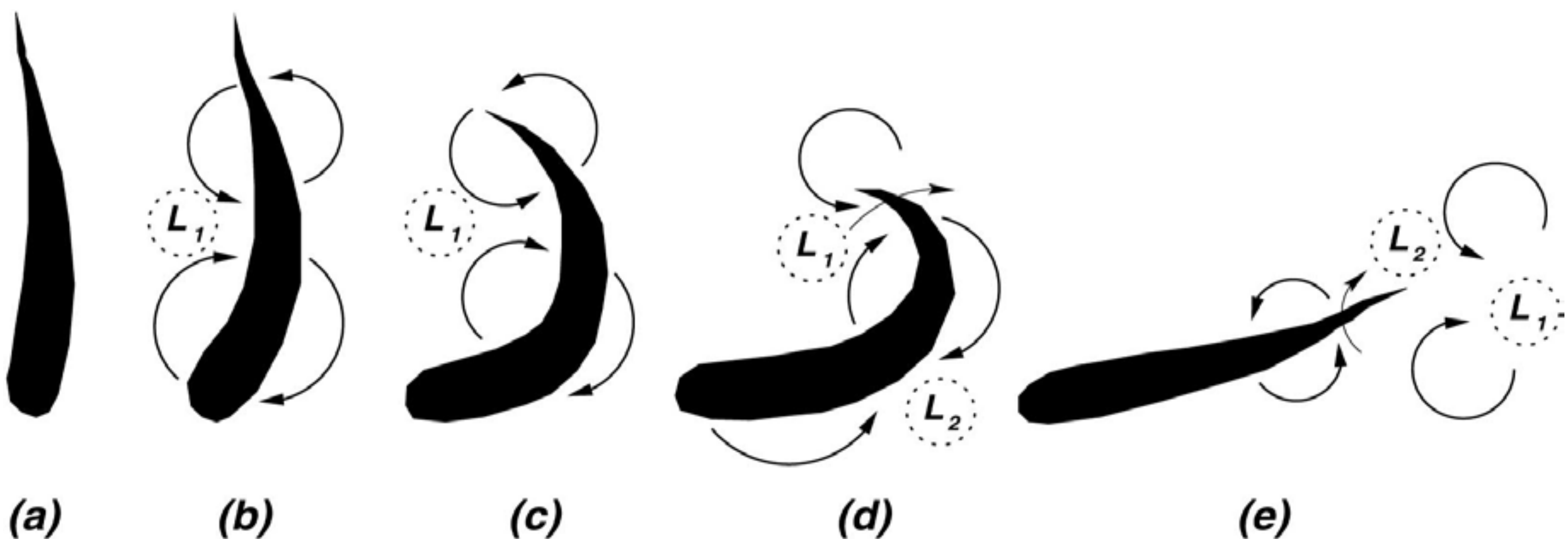


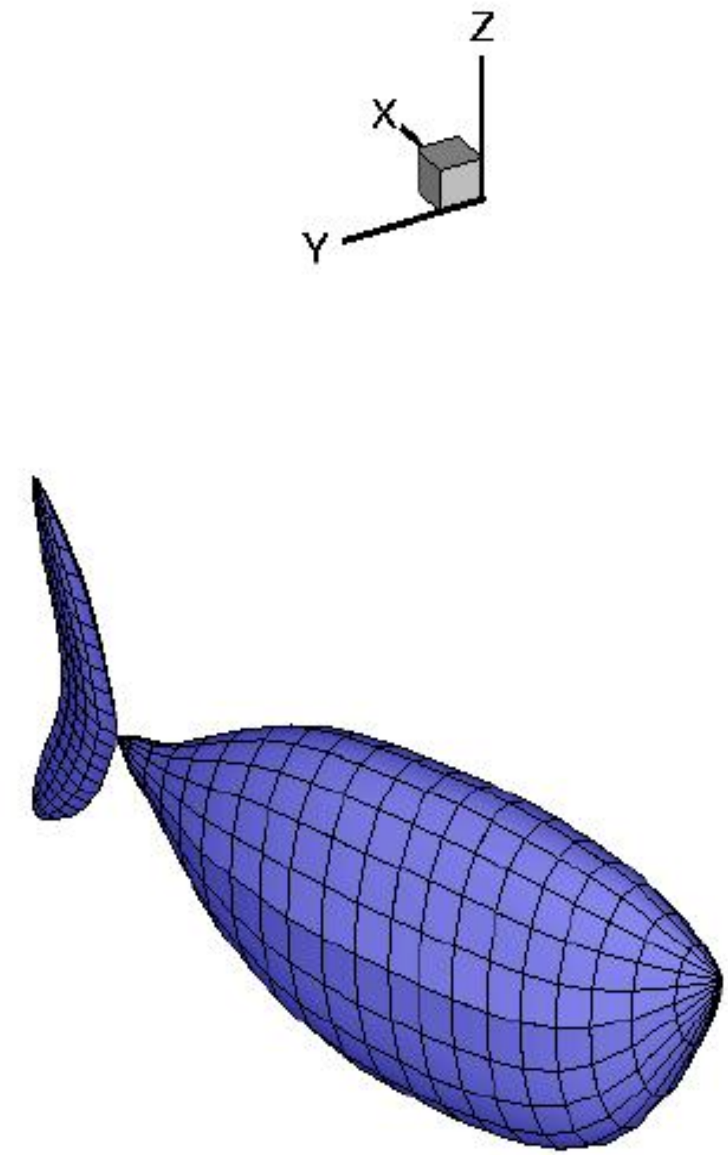
DPIV Image



Numerical Result

FAST-STARTING FISH
vorticity control





August 2015

Formation Number N

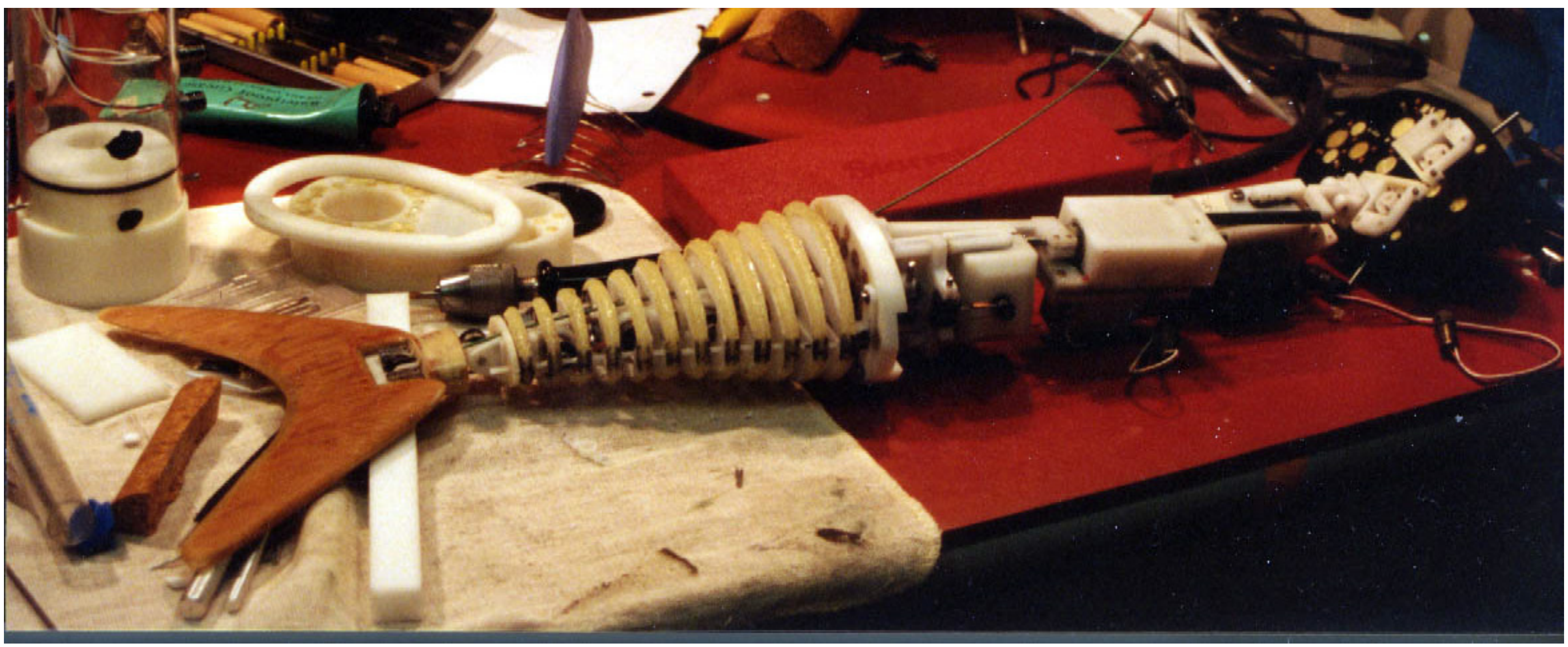
$$N = A/(U\,\tau)$$

A = Vortex ring size (Approx. 20% length)

U = Average speed of maneuver

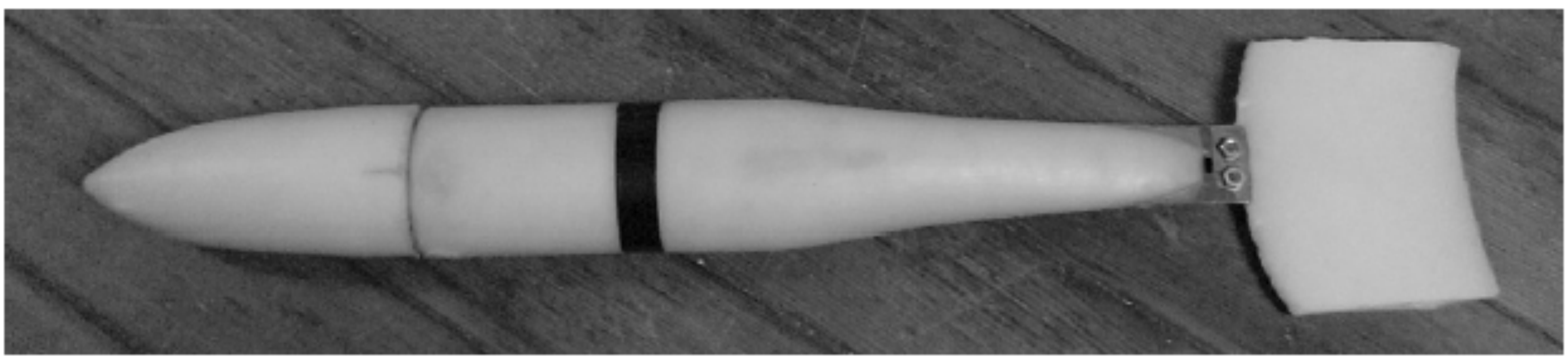
τ = Time to perform maneuver

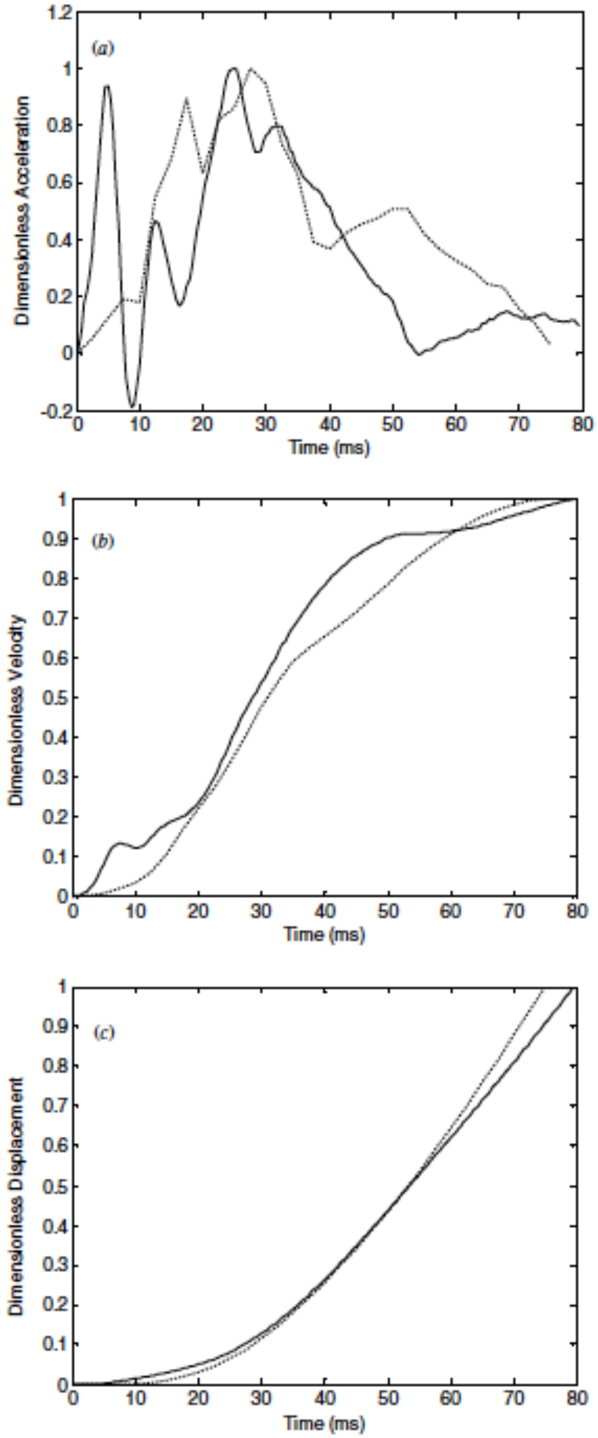
THEORY: Formation of ring is energetically optimal for N around 1/5 to 1/3



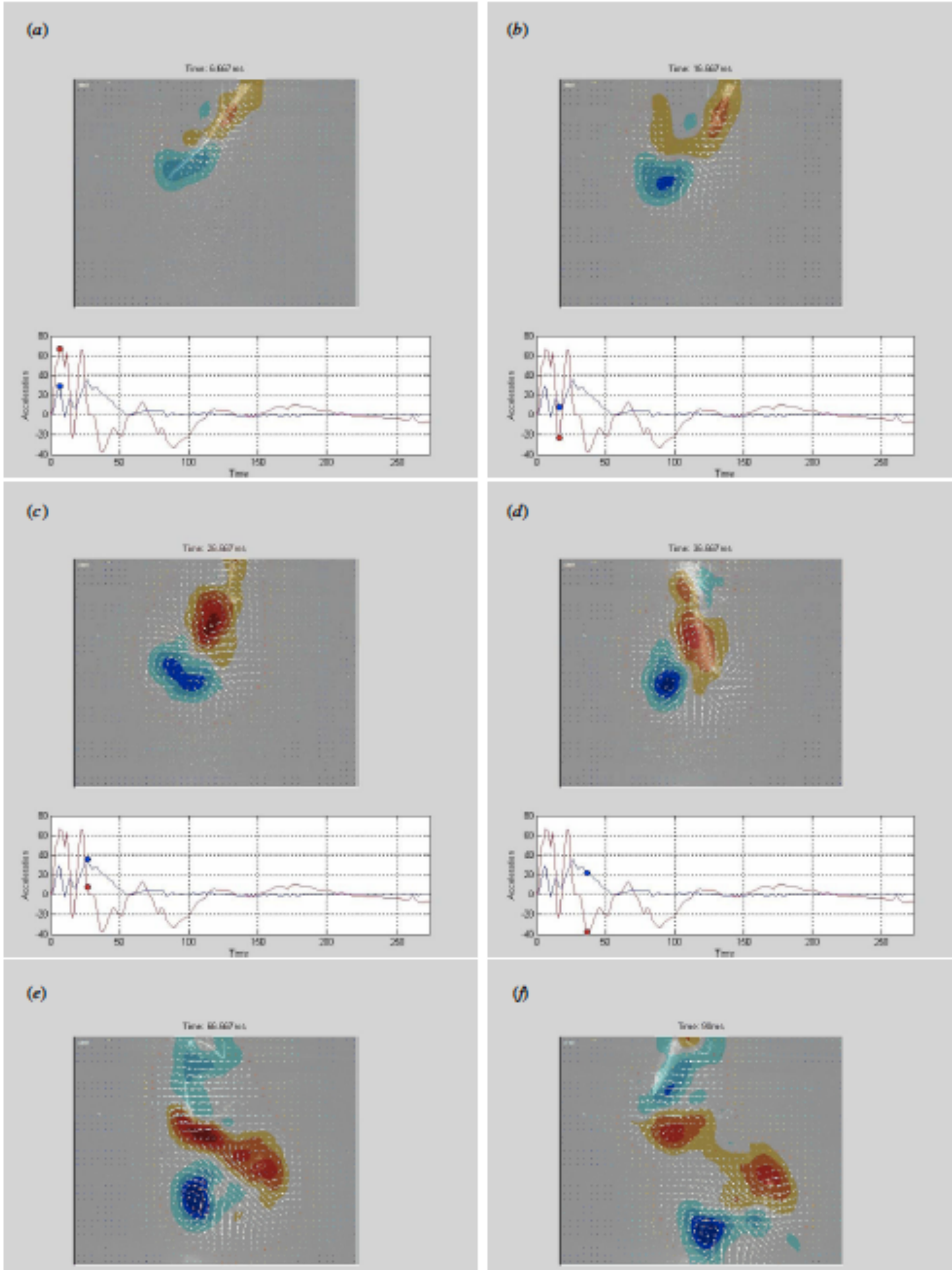
FAST-STARTING CHAIN PICKEREL

Beam length	l_{beam}	0.368 m
Beam height	b	0.0330 m
Beam thickness	h	0.001 27 m
Modulus of elasticity	E	200 GPa
Beam natural frequency scale	c	1.8
Fish length	l_{fish}	0.508 m
Fish maximum height	b_{fish}	0.0635 m
Fish material mass	m_{fish}	0.804 kg
Water density	ρ	1000 kg m^{-3}





PERFORMANCE
Robot
vs Fish



FISH
240 m/s^2

ROBOT
40 m/s^2