SIMULATION OF PLANAR WAVE FLAGELLAR PROPULSION OF NANOROBOTS USING COMSOL

Nikhil Londhe[1], R. Majumdar[1], J.S. Rathore[1], N.N. Sharma[1]
1.Department of Mechanical Engineering
Birla Institute of Technology and Science, Pilani 333031, India

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Presented by Rwitajit Majumdar at the 2011 COMSOL Conference

Typical μorganism

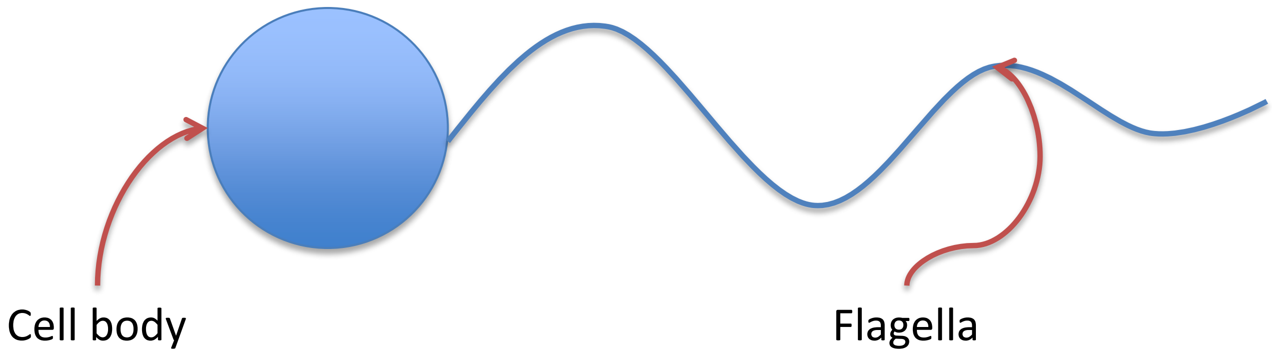
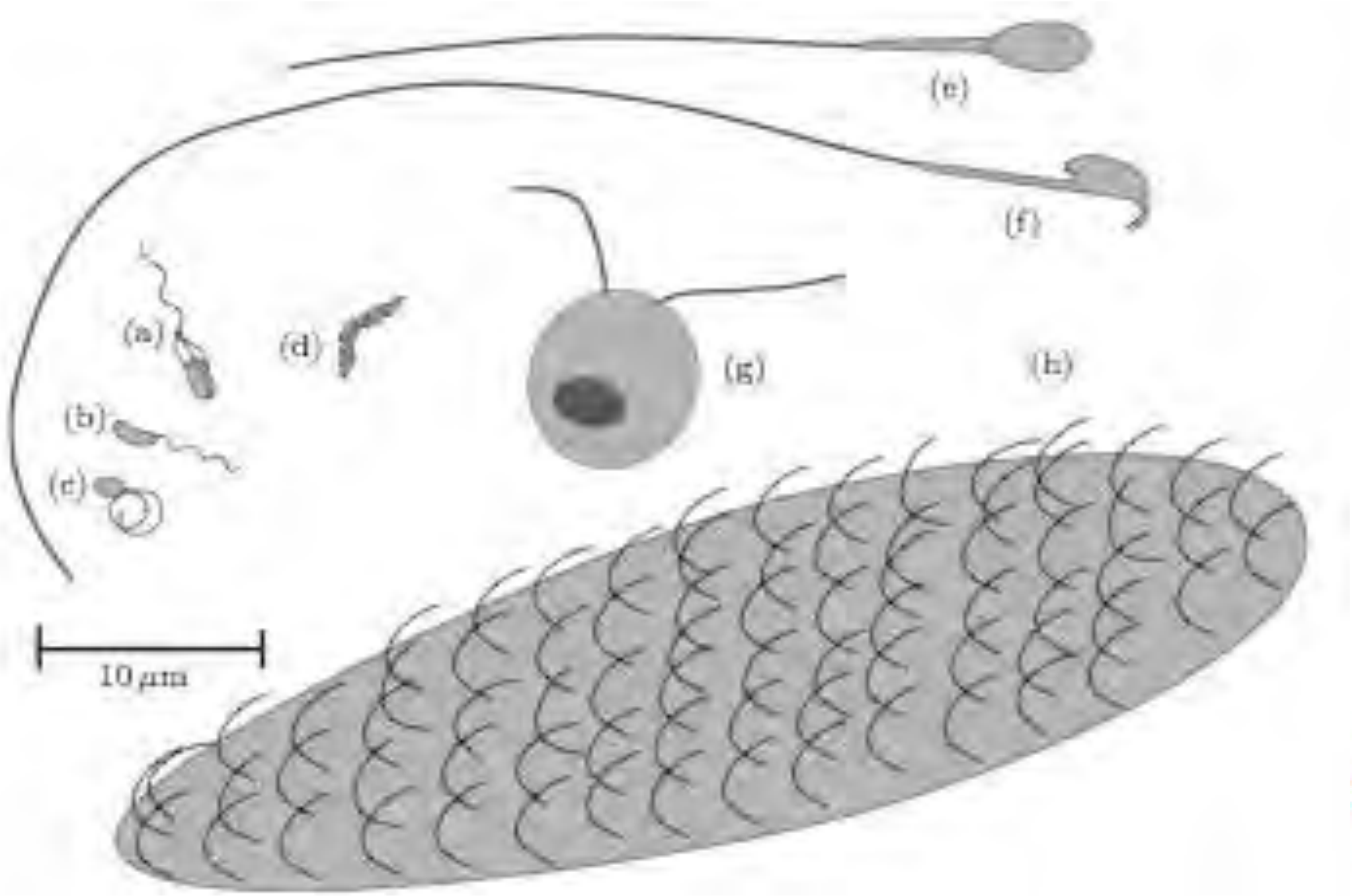


Fig1: Schematics of a micro organism

Spectrum of flagellated motion



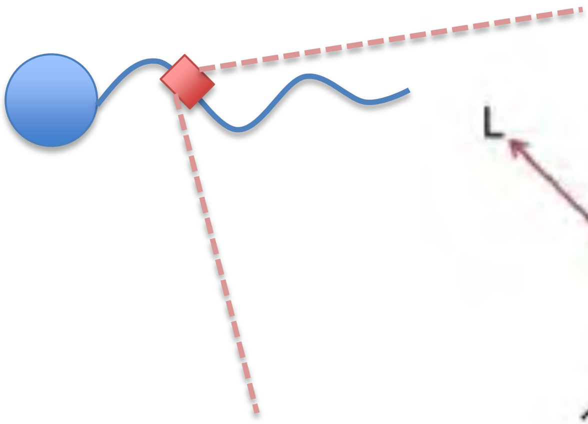
Review by Eric Lauga and Thomas R. Powers

The hydrodynamics of swimming microorganisms - 2008

Background

- Sir James Gray
  - Resistive Force theory
    - 1955
- Dr. K. E. Machin
  - Elasto-hydrodynamics
    - 1958

Elemental Modeling



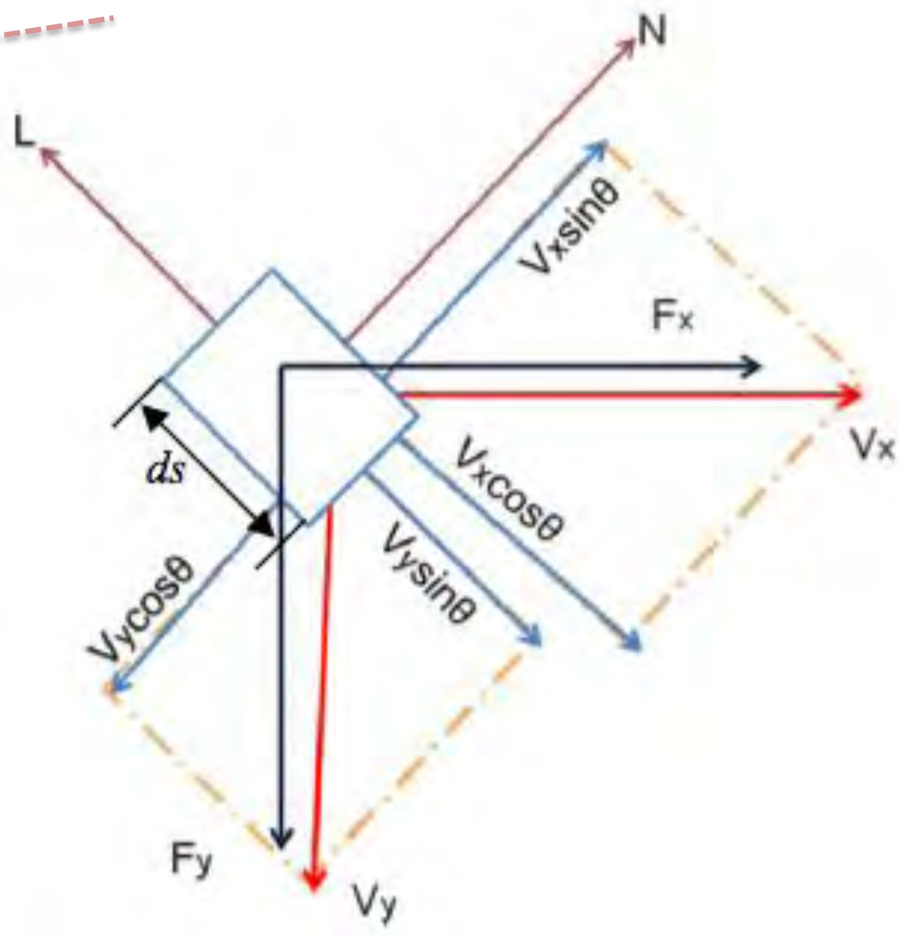


Fig 3: FBD of the tail element

Governing Equation

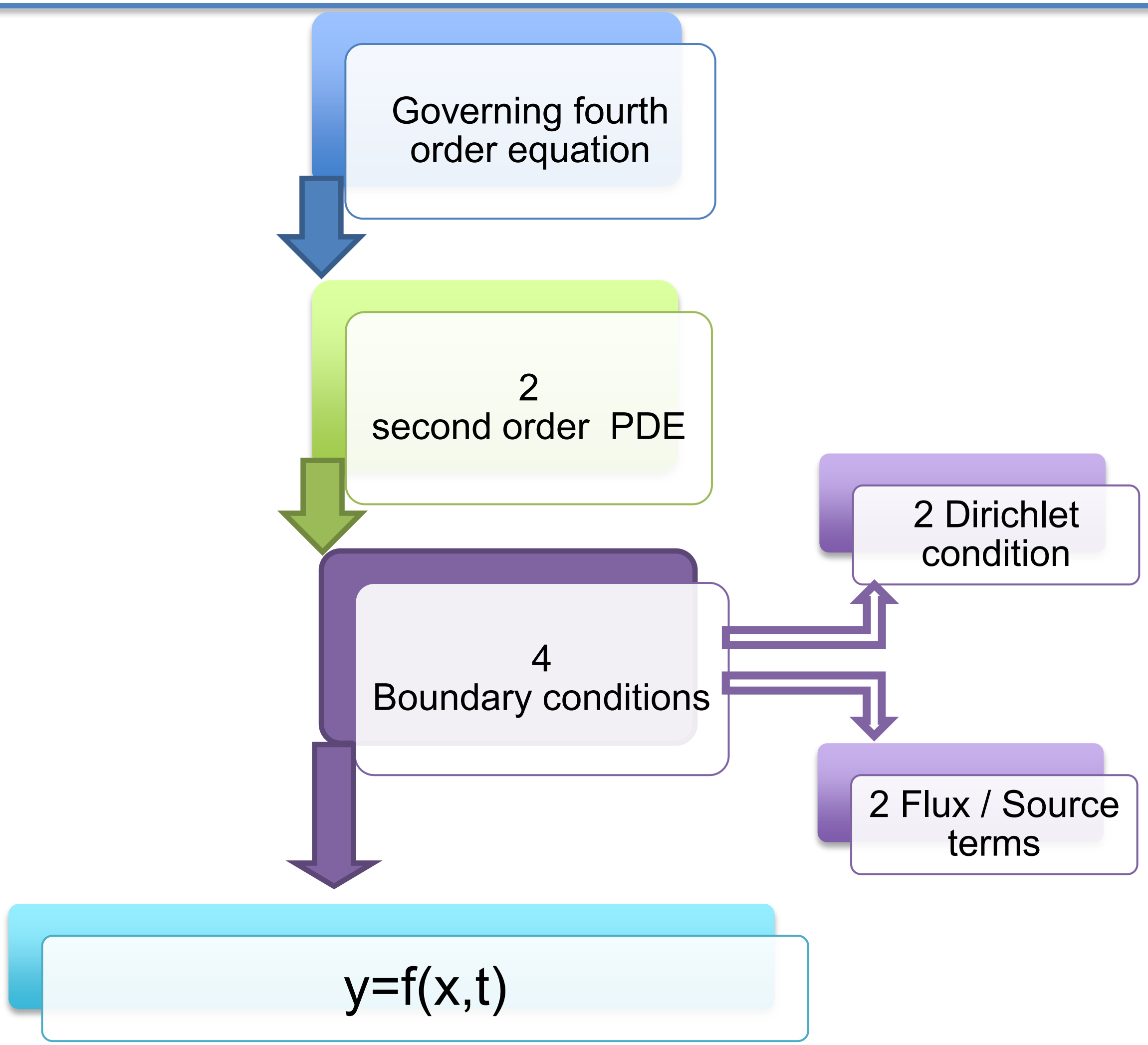
Transverse velocity

$$EI(x)\frac{\partial^4 y}{\partial x^4} = -\frac{4\pi\mu}{2-\log(\mathrm{Re})}\frac{\partial y}{\partial t}$$

Euler-Bernoulli beam equation

Drag coefficient

Algorithm to solution



Remapping Governing Equation

Damping Coefficient (d_a)

Source Term (f)

$$[0]\frac{\partial^2 u}{\partial t^2} + \begin{bmatrix} -C & 0 \\ 0 & 0 \end{bmatrix} \frac{\partial u}{\partial t} + \nabla . \begin{bmatrix} A\dfrac{\partial p}{\partial x} \\ \dfrac{\partial y}{\partial x} \end{bmatrix} = \begin{bmatrix} 0 \\ p \end{bmatrix}$$

Mass Coefficient(e_a)

Conservative Flux (Γ)

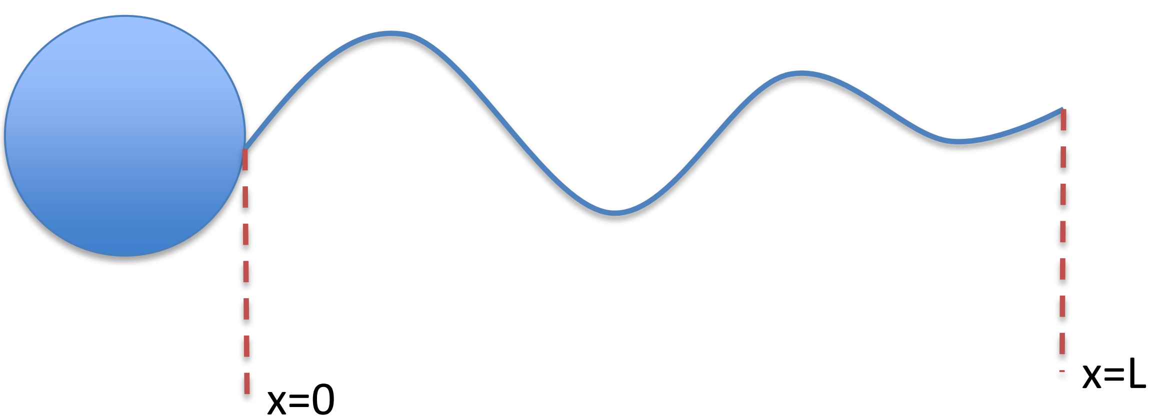
Dirichlet condition

- The head and tail is connected and is fixed

$$y = 0$$

- Bending moment vanishes at the distal end

$$\frac{\partial^2 y}{\partial x^2} = 0$$



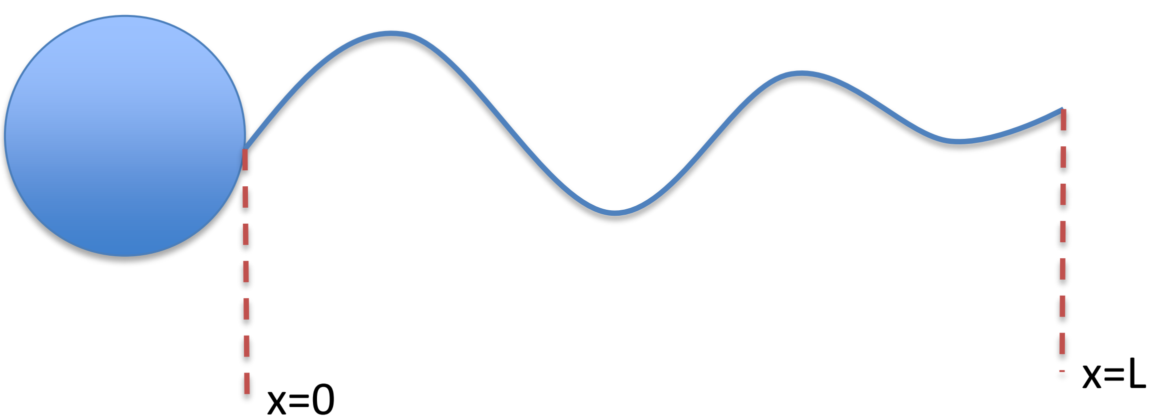
Natural Boundary Condition

- Slope at the proximal end

$$\frac{! y}{! x} = G \sin ! \, t$$

- Shear stress vanishes at the distal end

$$\frac{!^{3} y}{! x^{3}} = 0$$



Parameters

Parameters	Expression/Value	Description
Re	0.0001	Reynolds's Number
μ	0.001 Ns/m^2	Viscosity
C	$\frac{-4\pi\mu}{2-\log(Re)}$	Drag Coefficient
ω	100 rad/s	Forcing frequency
G	4E-9	Slope amplitude
A	1E-22 Nm^2	E*I
l_0	$\left(\frac{A}{C\omega}\right)^{0.25}$	Characteristic length
L	10*l_0	Total length

General Settings

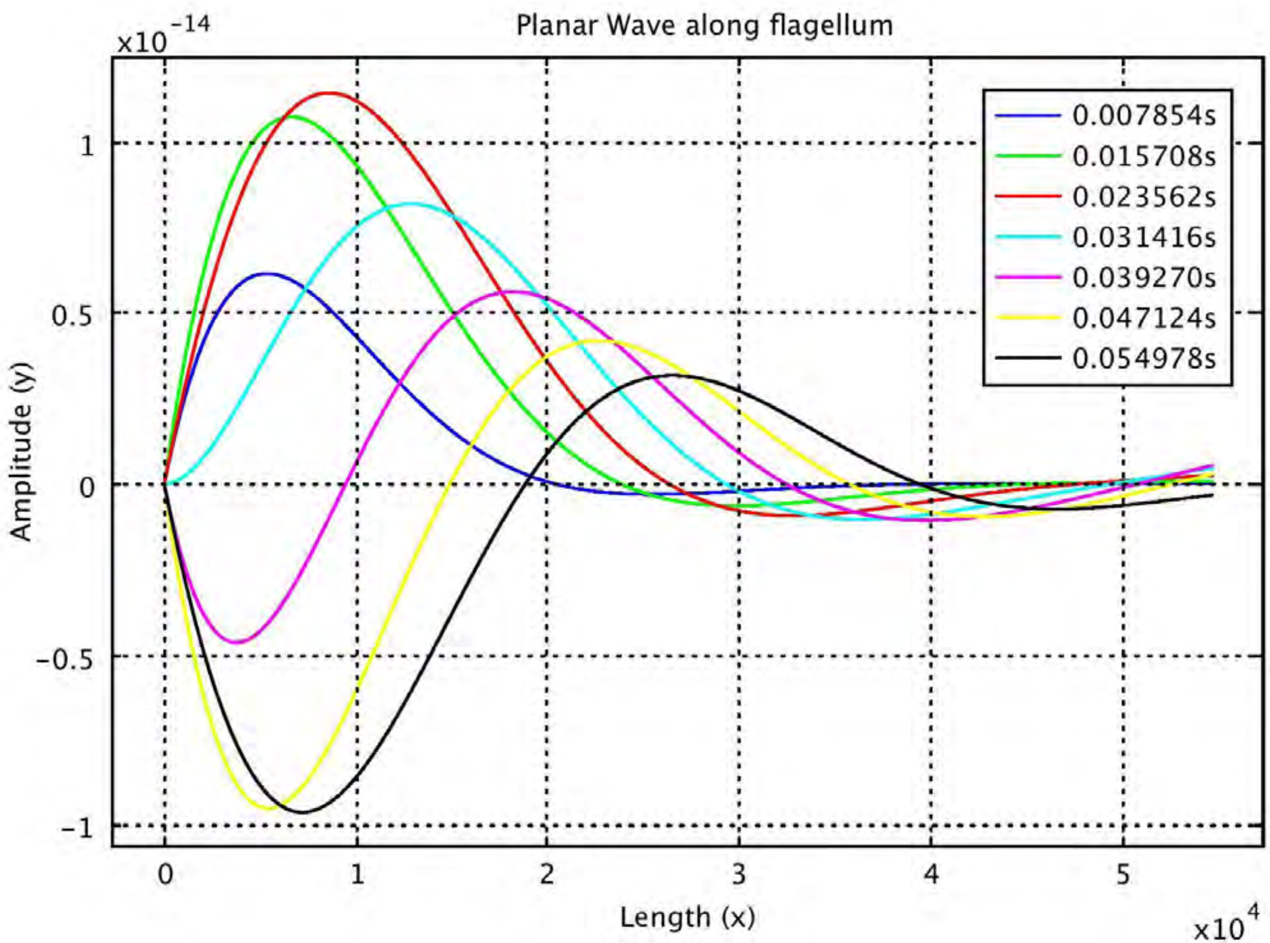
Geometry
Dimension: 1D
Scale: nanometers
Total Length: 54650 nm

Meshing
Discretized in 100 elements.

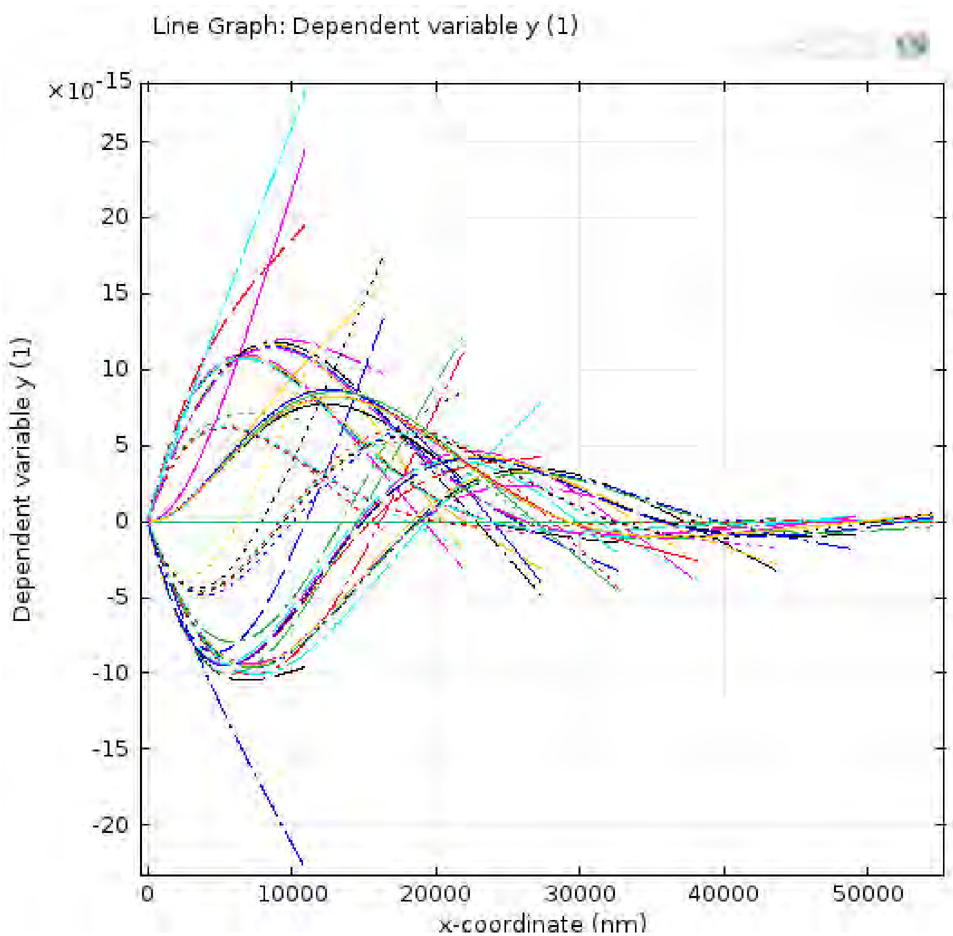
Solver settings
Time dependent solver
(0s : 0.007854s : 0.06283s)

Meshing was done such that discreet time and space slicing was possible

Wave pattern



Parametric variation of length



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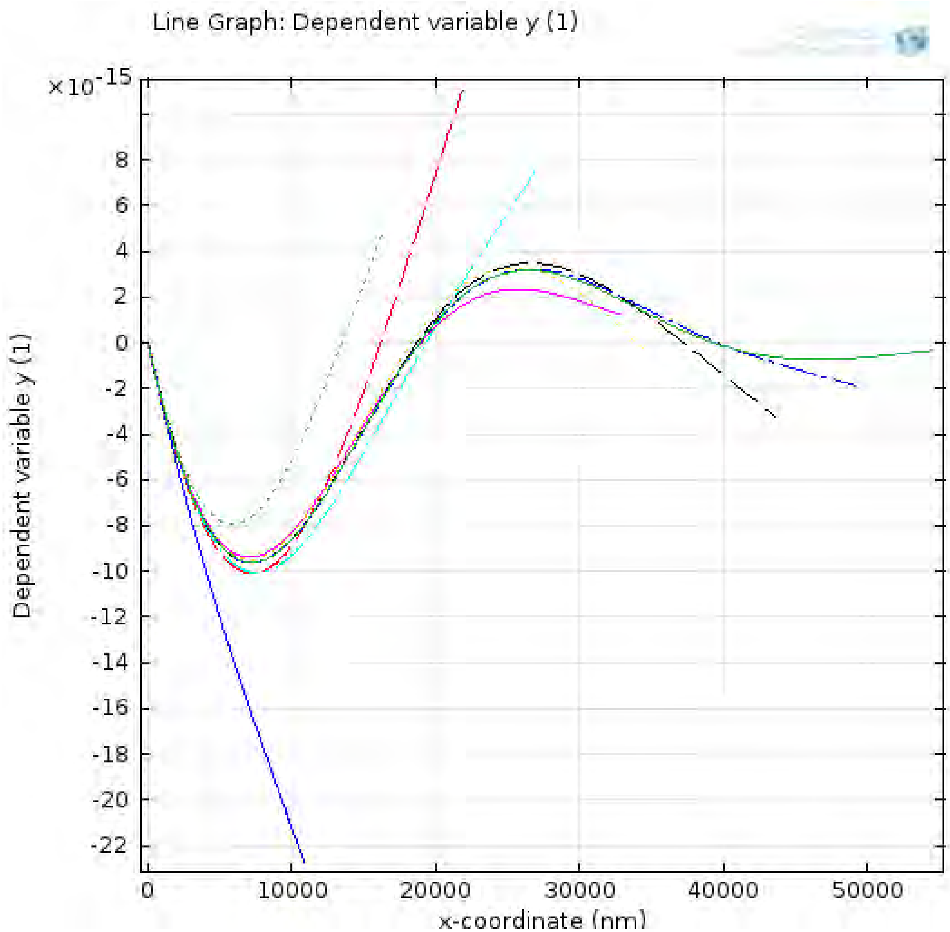
Last time impression for Parametric variation



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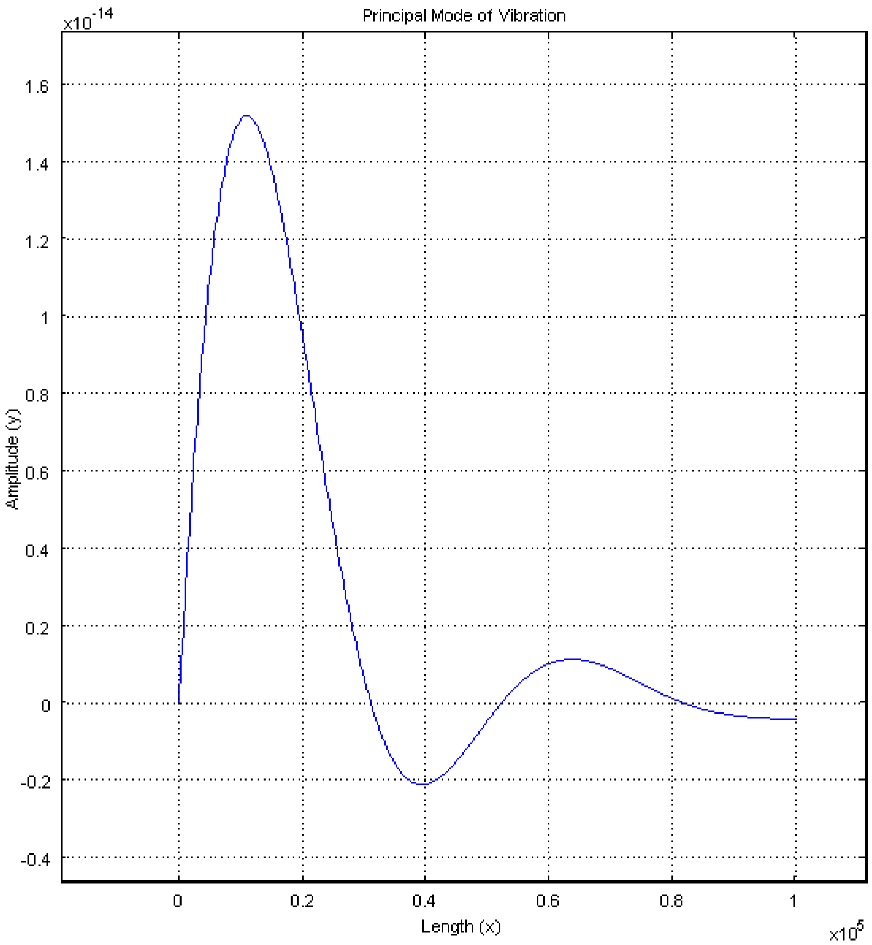
Waveform at a time instance



Wave motion

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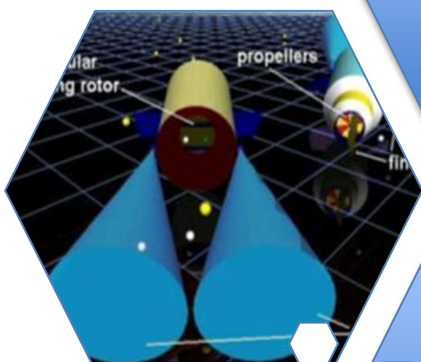
Application

medical technology

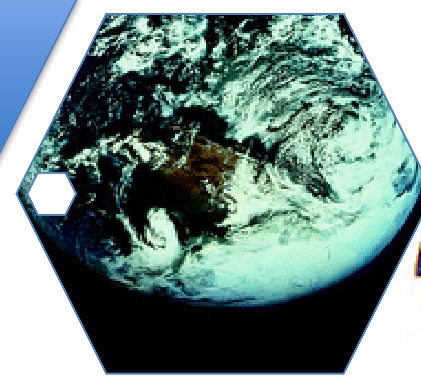


environment monitoring

http://xlink.rsc.org/?DOI=b704002d

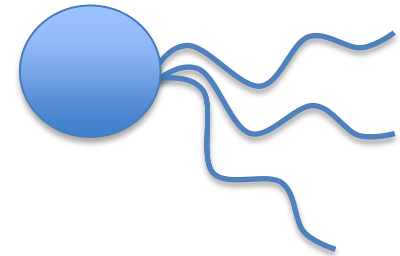
drug delivery

http://nanotechweb.org/cws/article/lab/32077

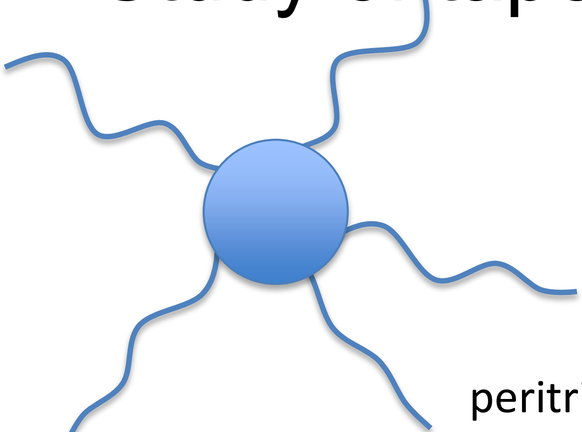


Future Scope - study

- Calculation of derived values
  - Velocity
  - Efficiency
  - Thrust force
- Parametric variation for optimization
- Study of tapered diameter flagella



lophotrichous



peritrichous

Input from day 1 of conference

- Using Matlab livelink for various parametric studies.
  - But for regular ones Comsol is simpler ☺

Future Scope – application of COMSOL

- Redefining the problem as a fluid-structure interaction problem
  - Study the wave patterns that the fluid would generate around the flexible filament.
- Particle tracing for swarm
  - Brownian motion study

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THANK YOU