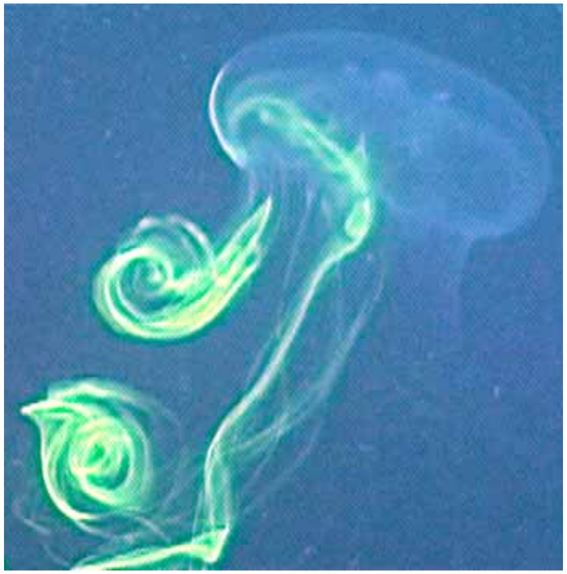
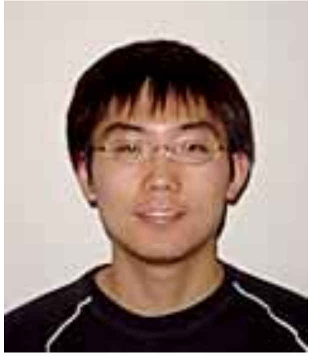
The geometry of bio-locomotion and sensing in fluids



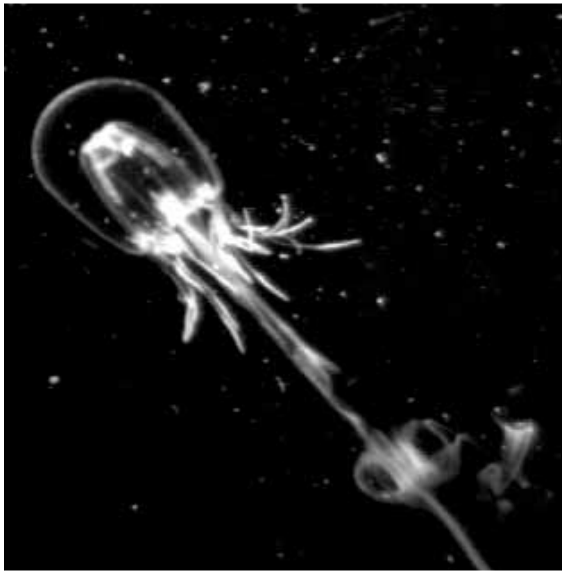
Dabiri Group

Caltech

Kakani Katija

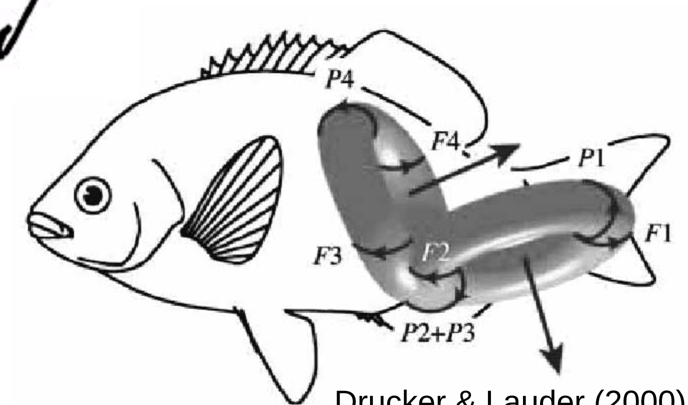


Jifeng Peng

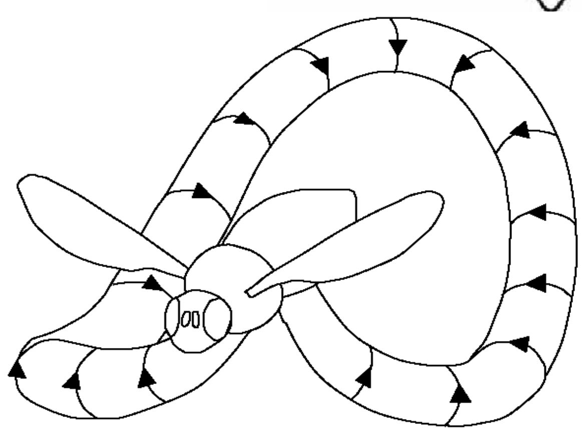


Engineering Motivation: Transportation, environmental sensing technologies inspired by *biological designs*

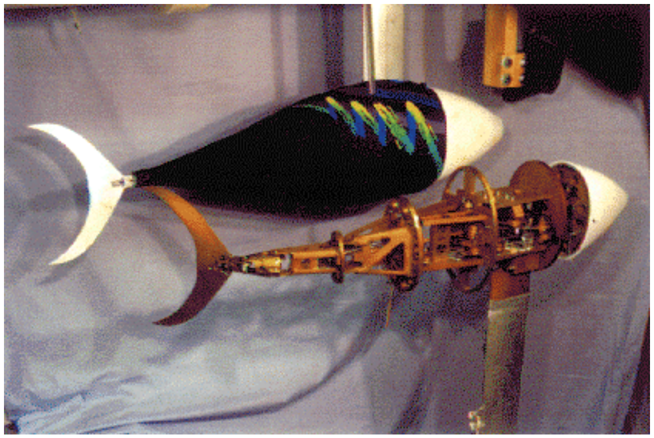
Rayner (1988)



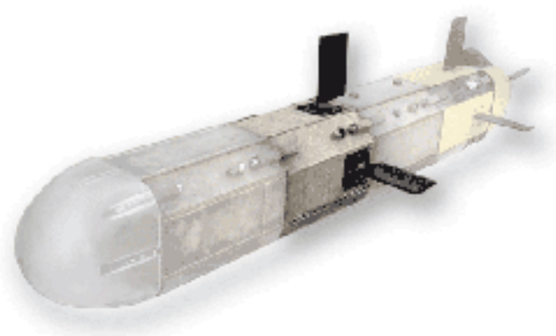
Drucker & Lauder (2000)



Dickinson & Gotz (1996)



MIT RoboTuna



Nekton Oscillating Foil Thruster

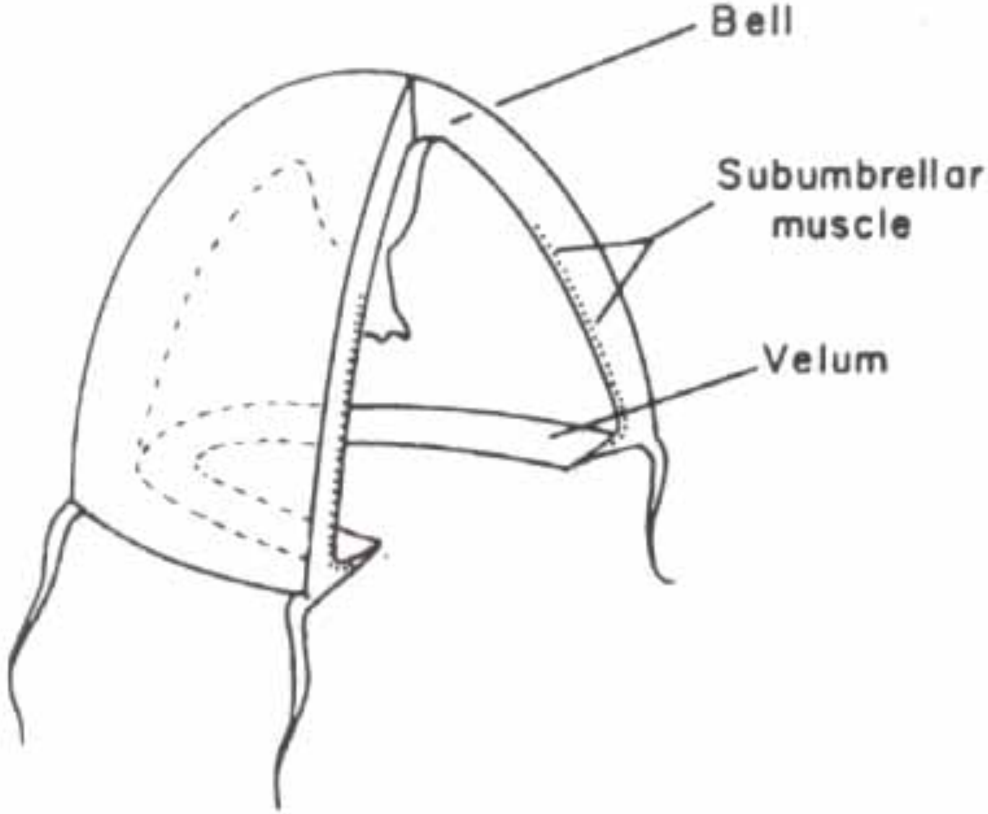
Key Distinction

Goal is to extract *governing fluid mechanics principles*, not blind copying

Emphasis is on *wake vortex dynamics*

Model System/Testbed: Jellyfish

simple body/flow geometry
(radial symmetry)



Daniel (1983)

Model System/Testbed: Jellyfish

wake kinematics vary with changes in bell morphology, scale across species

Dabiri et al. (*J. Exp. Biol.*, 2005)

Model System/Testbed: Jellyfish

wake kinematics vary with changes in bell morphology, scale across species

Dabiri et al. (*J. Exp. Biol.*, 2005)

Model System/Testbed: Jellyfish

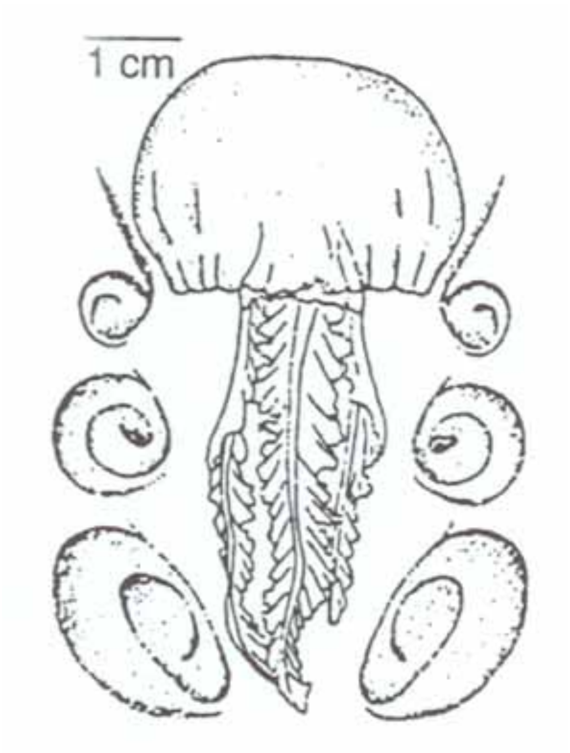
wake kinematics vary with changes in bell morphology, scale across species

J. O. Dabiri, S. P. Colin, J. H. Costello (*J. Exp. Biol.*, 2006)

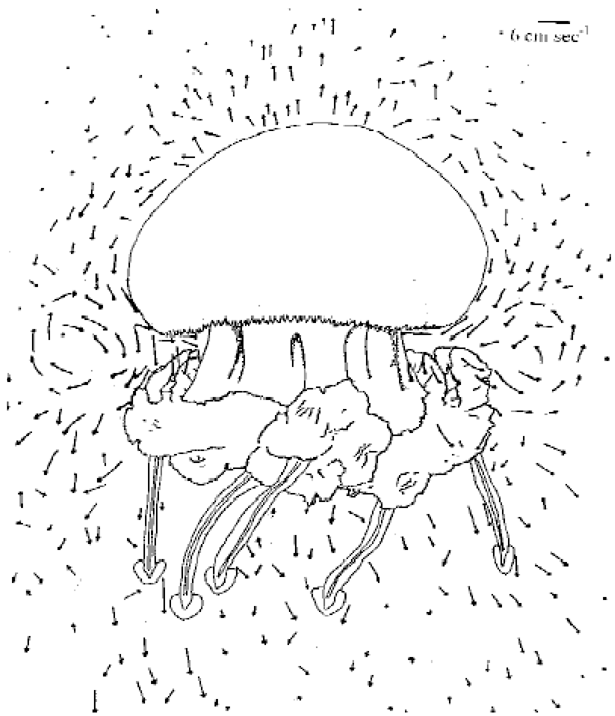
Project Problem:

How to **quantify** these flows **non-invasively**?

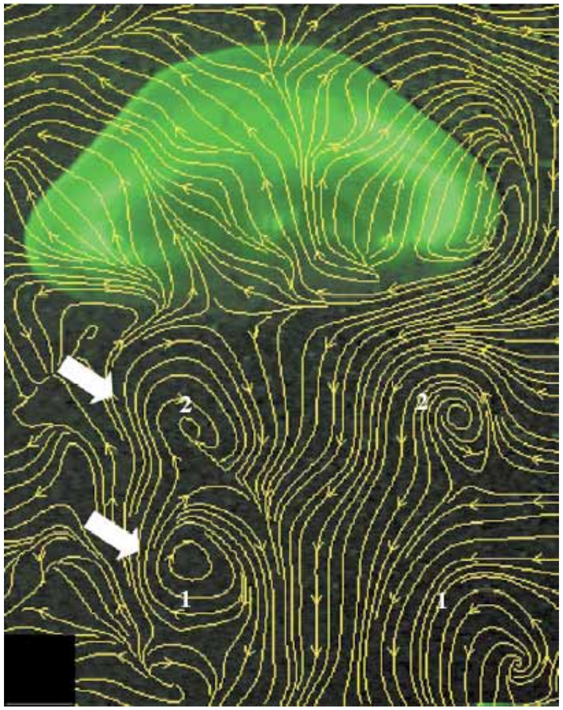
Previous States-of-the-Art



Ford et al., 1997



D'Ambra et al., 2001



Dabiri (2005)

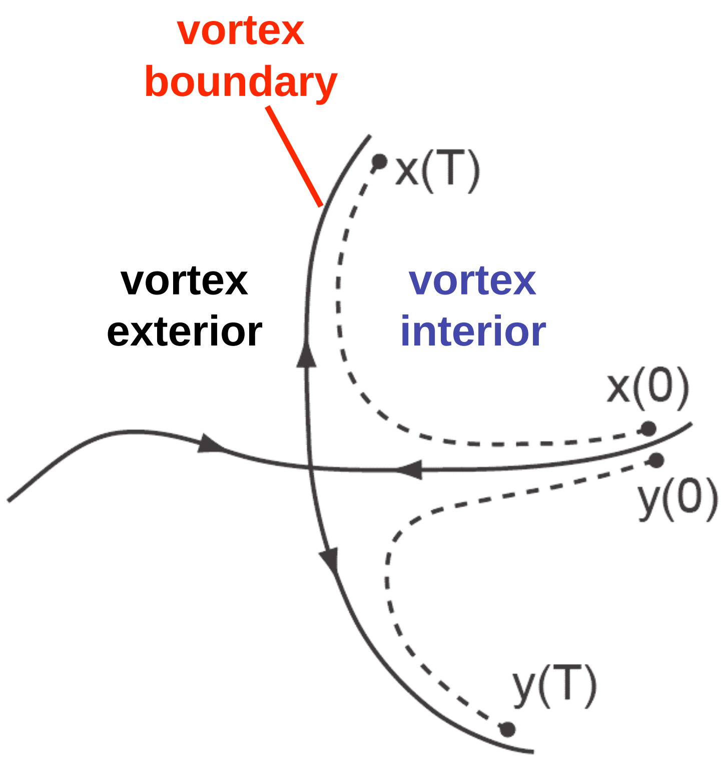
Existing methods are limited to flows with weak time-dependence

Lagrangian solution: **Finite-time Lyapunov exponent field**

For small times ΔT, nearby particles $\mathrm{x}(t)$ and $\mathrm{y}(t)$ in the flow will separate as

$$\delta = x(t+\Delta T) - y(t+\Delta T) \sim e^{\sigma \Delta T}$$

σ is the finite-time Lyapunov exponent



See Haller (2000 – 2005); Shadden et al. (2005, 2006)

Lagrangian solution: **Finite-time Lyapunov exponent field**

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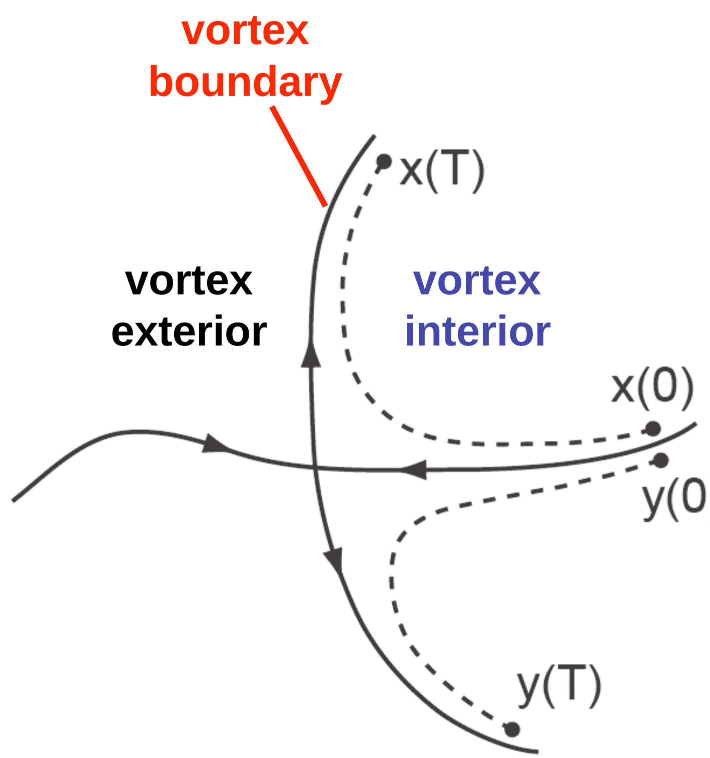
σ is the finite-time Lyapunov exponent

Key observation:

Level sets of large $\|\sigma\|$ in $\sigma(\mathbf{x})$ indicate boundaries of flow regions with distinct behavior, e.g. the vortex wake

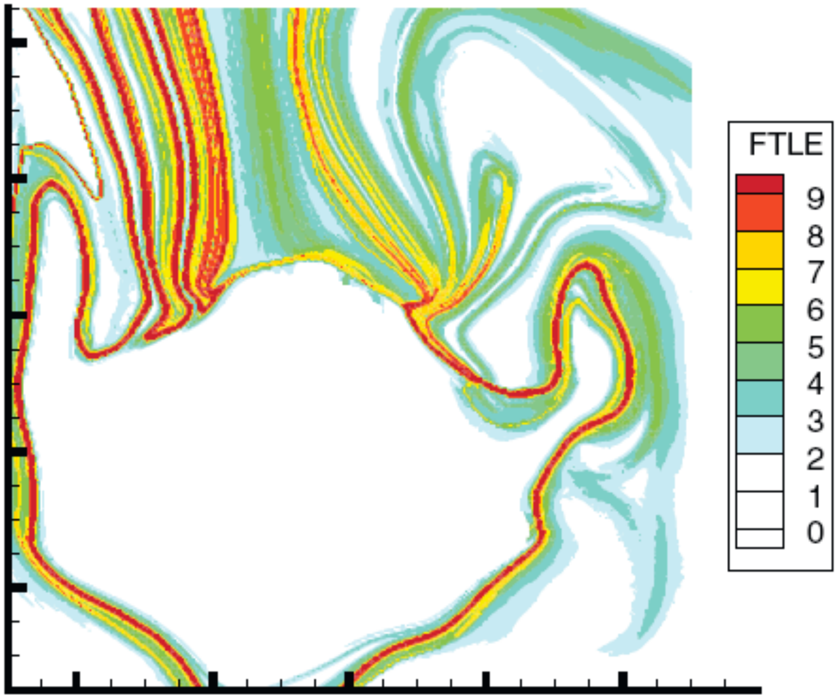
"Lagrangian Coherent Structures (LCS)"

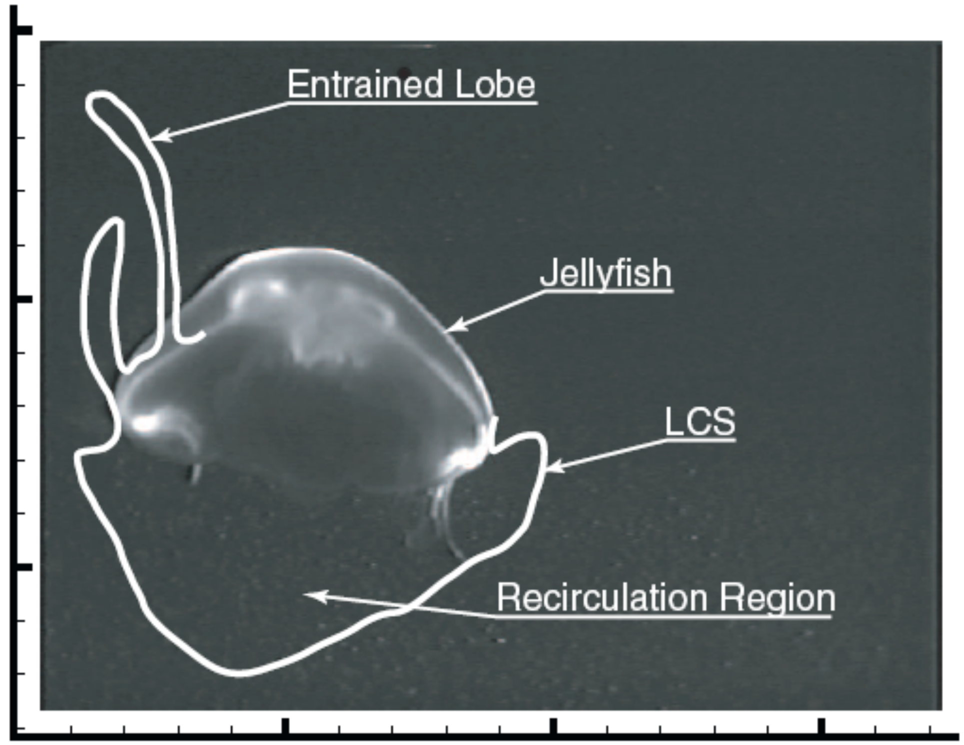


Analysis requires *no periodicity*, admits chaotic advection…

See Haller (2000 – 2005); Shadden et al. (2005, 2006)

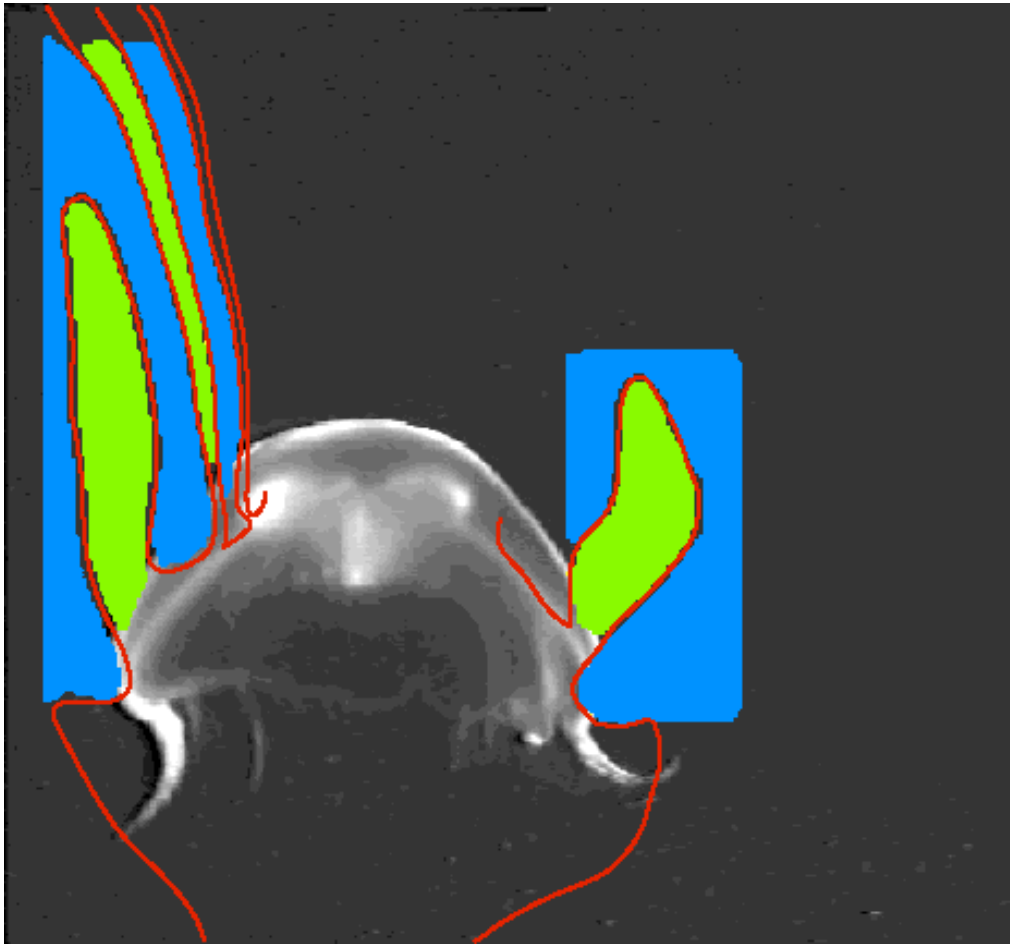
Preliminary results: Forward time calculation (stable manifold)





Shawn Shadden

Preliminary results: Forward time calculation (stable manifold)



Red boundary dictates both transport and propulsion

Project Goals

1. **Combine existing measurements and dynamical systems theory (e.g. transport in Poincare maps) with new LCS calculations conducted during the project to *compute transport rates in a free-swimming jellyfish*.**

<u>If time permits</u>

2. **Implement new theory to *compute swimming forces* based on evaluation of the LCS geometry**
3. ***Manipulate live jellyfish* to determine dependence of flow geometry on animal behaviors (e.g. swimming frequency)**

For more info:

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