Flow Interactions and Control

Date: 04 MAR 2013

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Air Force Research Laboratory

Integrity ★ Service ★ Excellence

Report Documentation Page

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NAME: Douglas Smith

BRIEF DESCRIPTION OF PORTFOLIO:

Foundational research examining aerodynamic interactions of laminar/transitional/turbulent flows with structures, rigid or flexible, stationary or moving.

Fundamental understanding is used to develop integrated control approaches to intelligently modify the flow interaction to some advantage.

LIST SUB-AREAS IN PORTFOLIO:

Flow Physics for Control
Flow Control Effectors
Low Reynolds Number Unsteady Aerodynamics
Aeromechanics for MAVs

Overview

Interactions

Energy pathways

Transition

Energy

Reynolds No.

Unsteadiness

Time/length scales

Vortices

Bio-inspiration

Stability

Flexibility

Turbulence

Separation

Flow Control

Boundary layer

Kinematics

Simulations

Flight stabilization

Jets

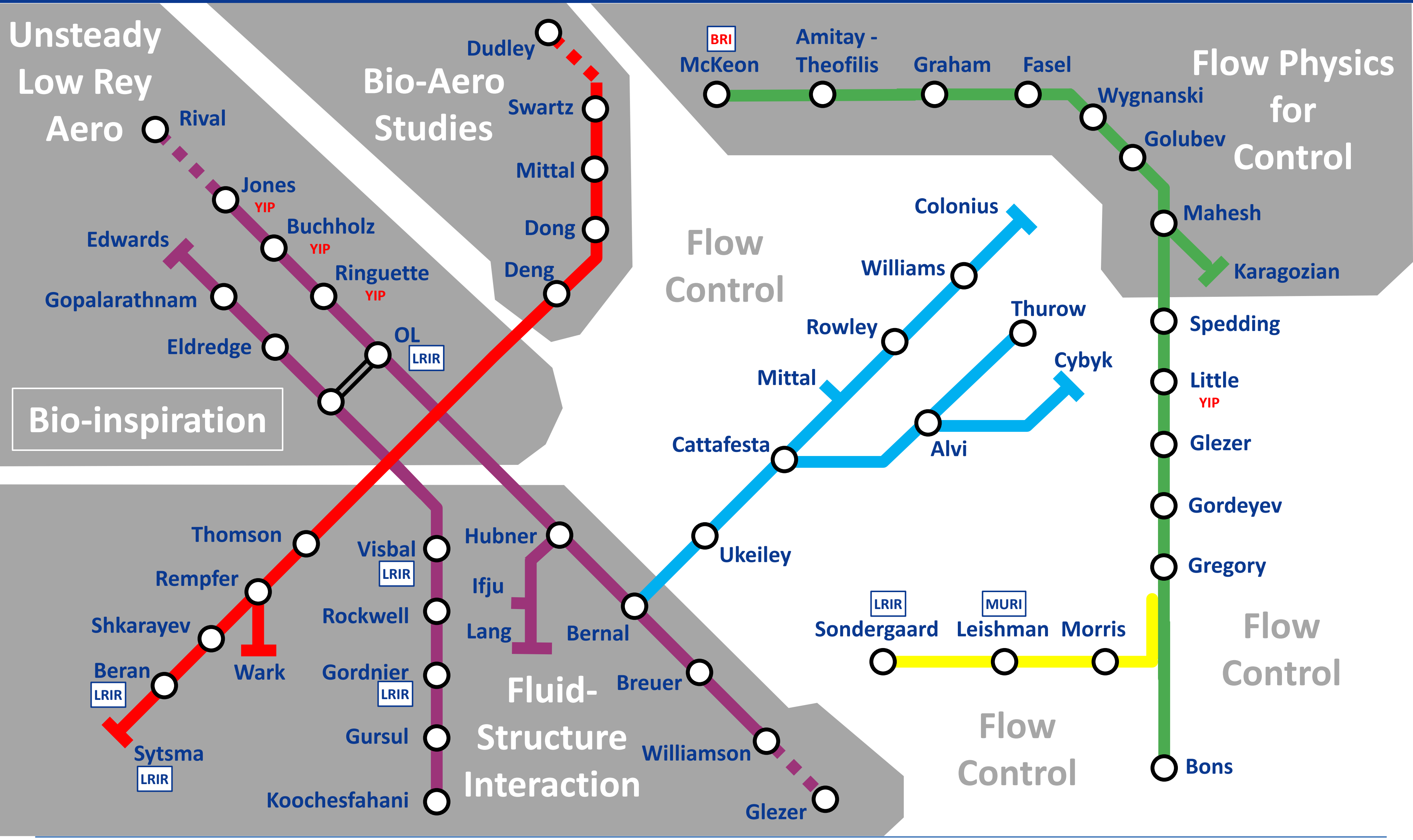
Shear layer

Wakes

Experiments

Modeling

Portfolio map



Key to Lines

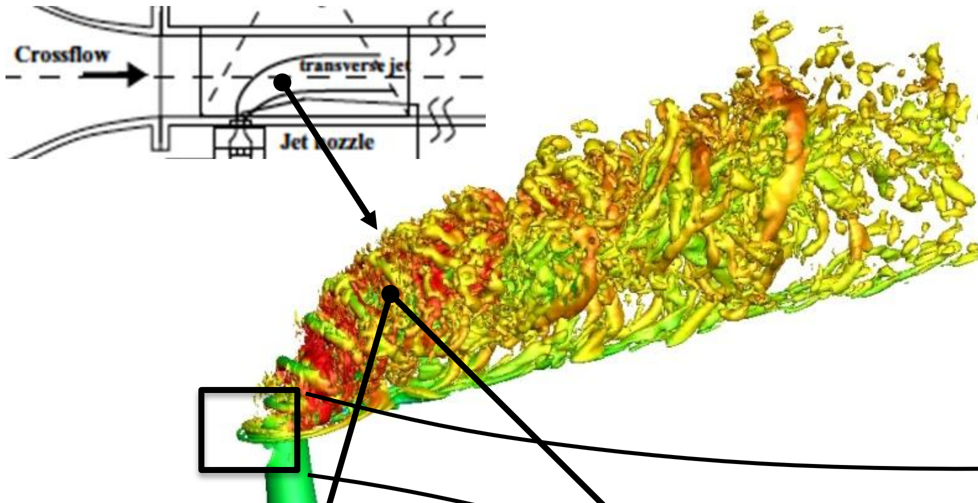
- Flow physics & Control
- Flow control collaboration
- Applied flow control
- Low Reynolds number unsteady aerodynamics
- Flight physics for MAVs

PI | Co-PI | 2013 New Start

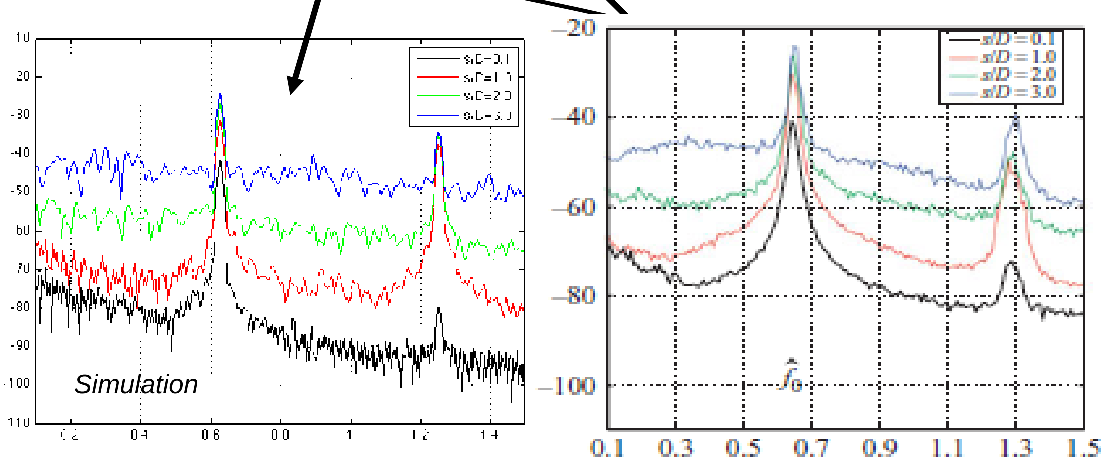
Study of Physics-based Control of Jets in Crossflow

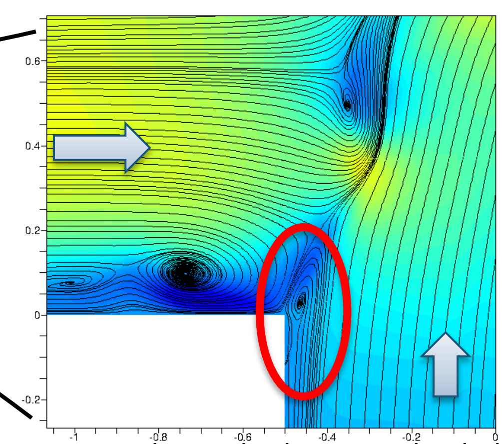
K. Mahesh, Minnesota & A. Karagozian, UCLA

Controlled transverse jet mixing requires understanding fundamental instabilities and their response to jet excitation



- Is it possible to simulate/predict the instability behaviors for different jet velocities?
- What is the fundamental mechanism for the transition between behaviors?



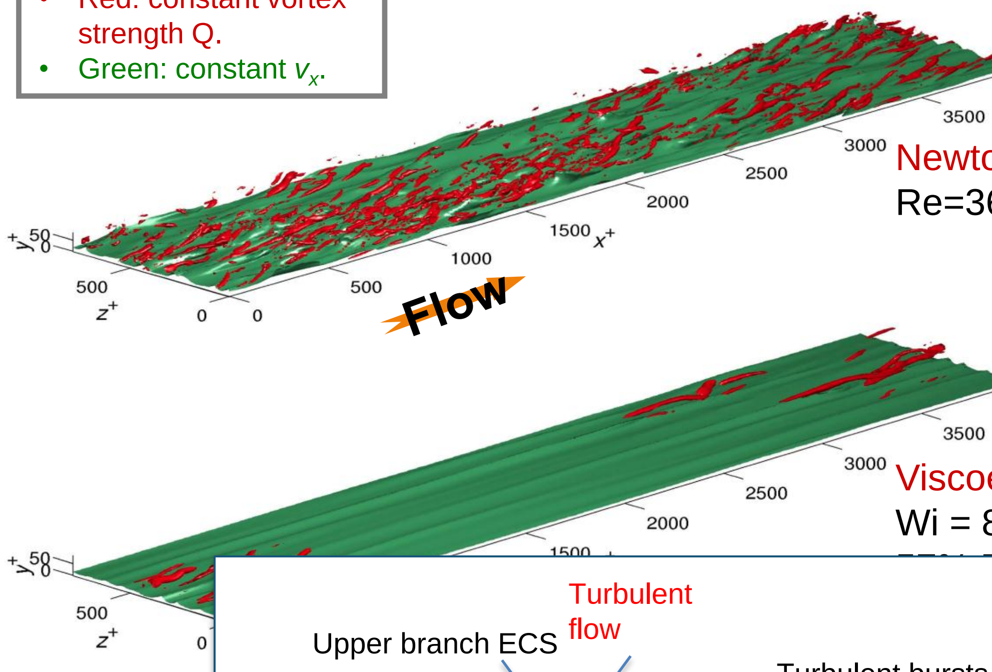


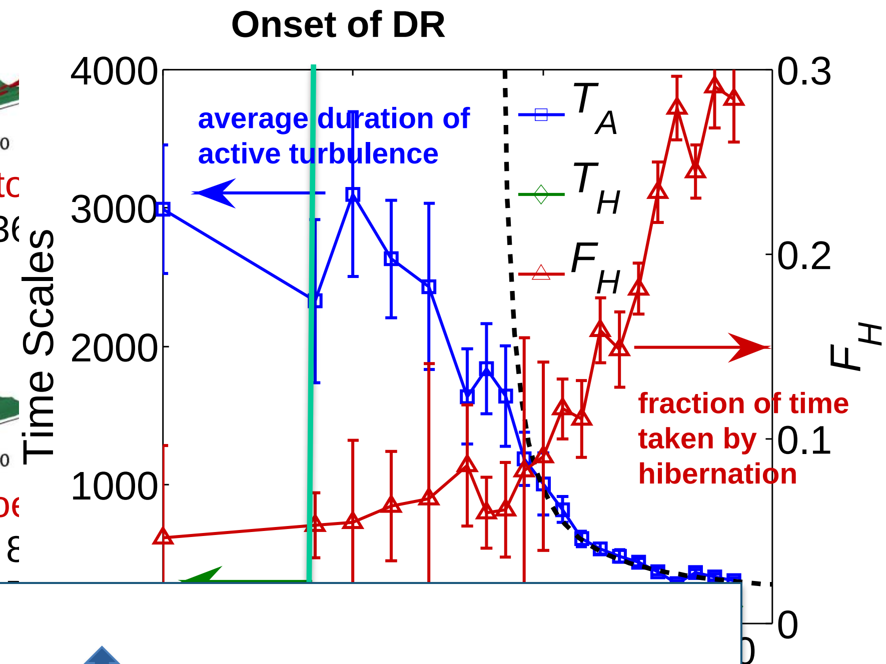
Spectra inside nozzle shows similar behavior to spectra along upstream shear layer

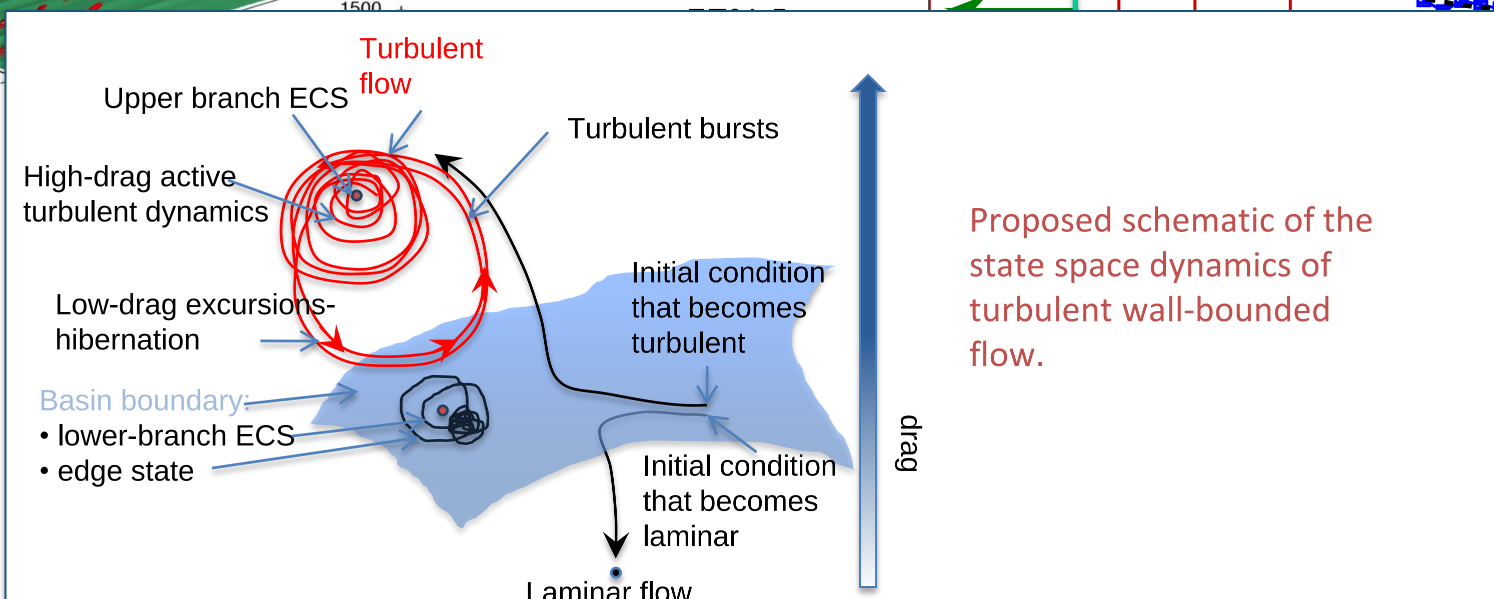
Exploiting the nonlinear dynamics of near-wall turbulence for skin-friction reduction

M. Graham, Wisconsin

- Red: constant vortex strength Q.
- Green: constant v_x.



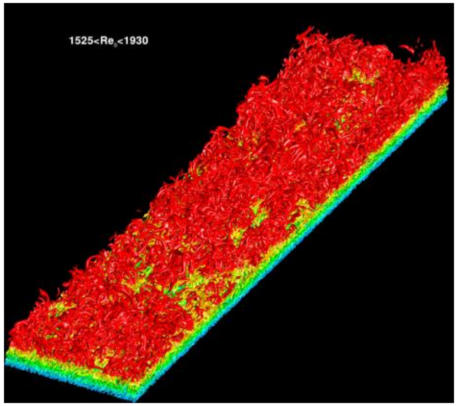




Proposed schematic of the state space dynamics of turbulent wall-bounded flow.

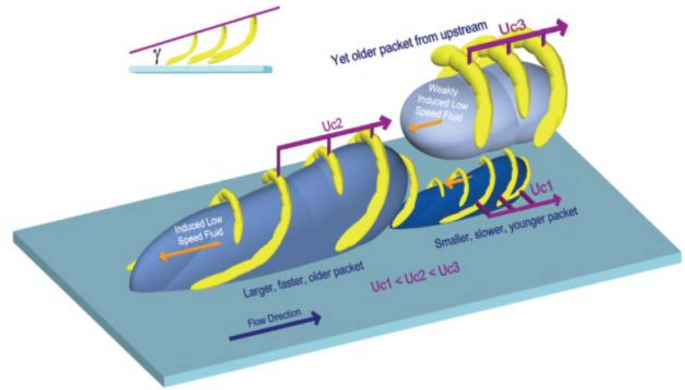
(BRI) Wall Turbulence With Designer Properties: Manipulation of Energy Pathways

McKeon & Tropp, Caltech & Goldstein, UT-Austin & Sheplak, Florida

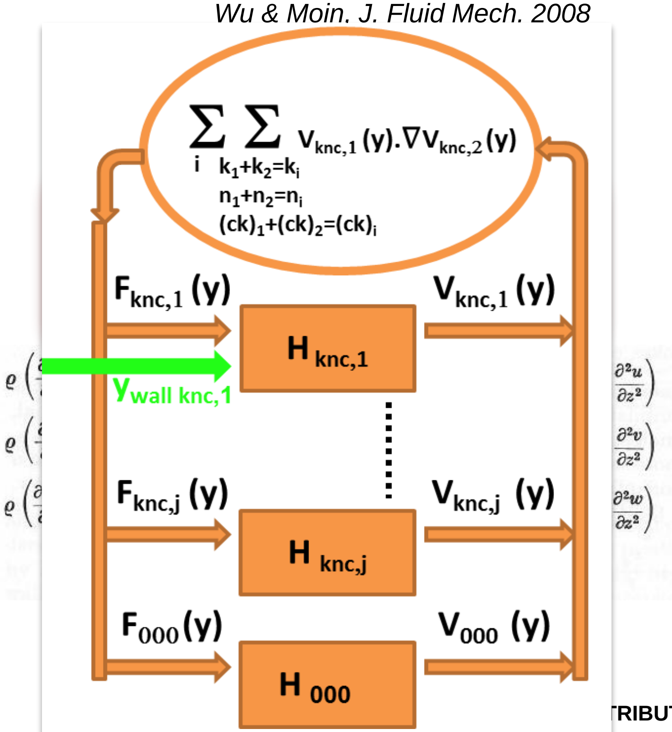


Wu & Moin, J. Fluid Mech. 2008

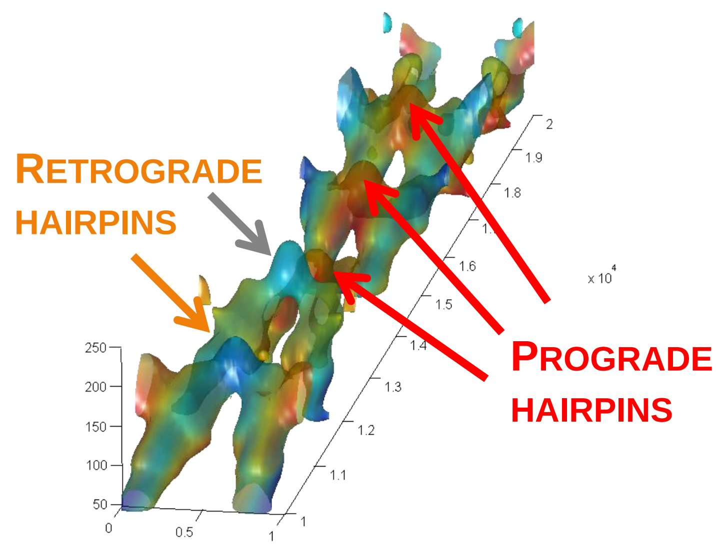
Decreasing complexity



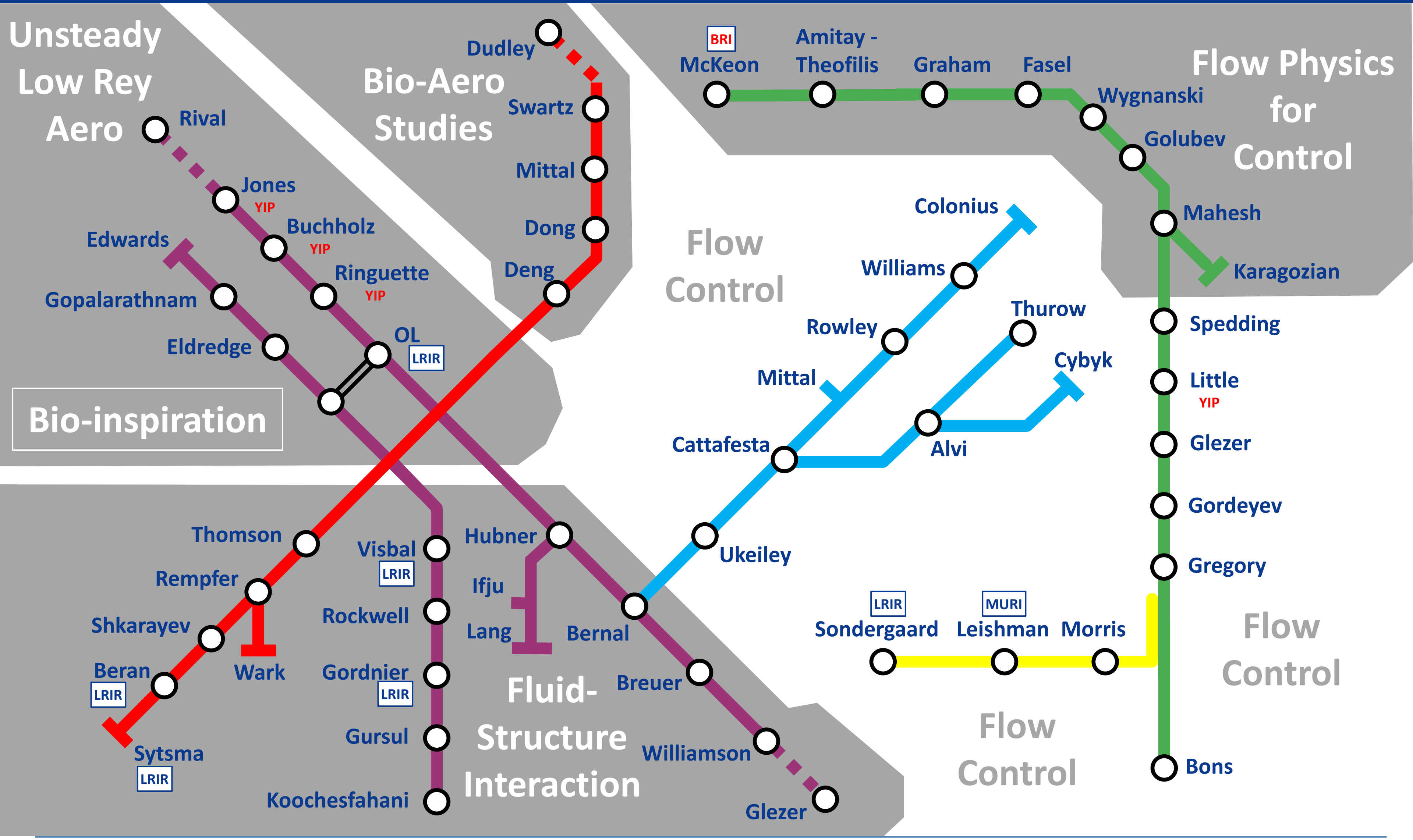
Adrian, Meinhart & Tomkins, J. Fluid Mech. 2000



Decreasing complexity



Portfolio map



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- Flight physics for MAVs

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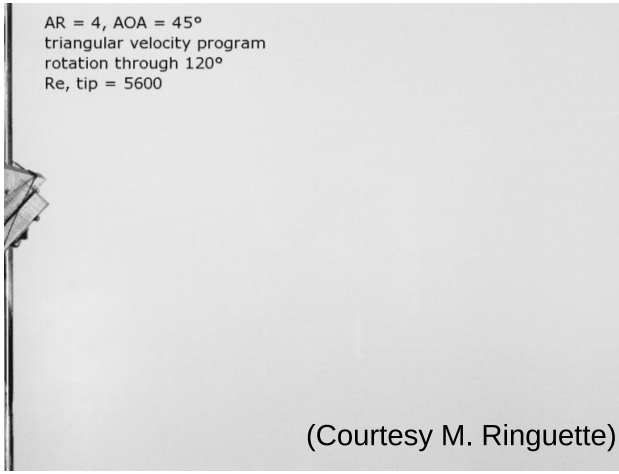
Biological Inspiration

Biological Inspiration

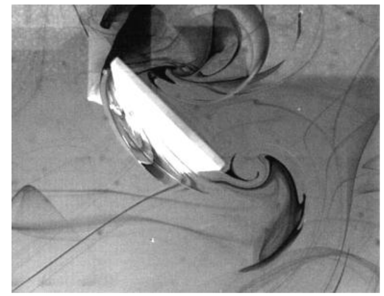
From Nature – Attenborough's Life Stories – Life on Camera
Courtesy of WETA

M. OL, AFRL/RQ



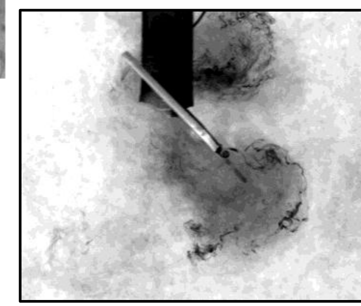
(Courtesy M. Ringuette)

Case-study: Re effects on hovering plate



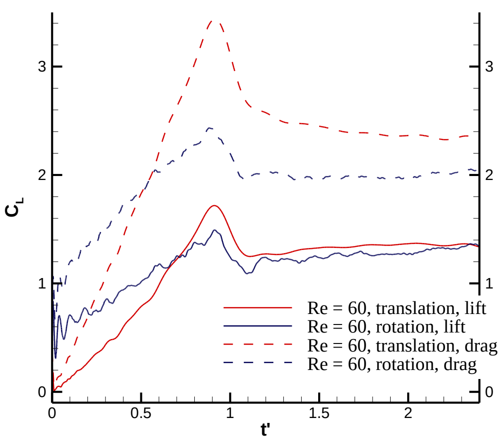
Re 300

Hovering plate at 45° incidence , rectilinear motion: LEV and TEV production at semi-stroke extremum, but no vortex stability. Vortices at Re = 10,000 almost indistinguishable from Re = 300



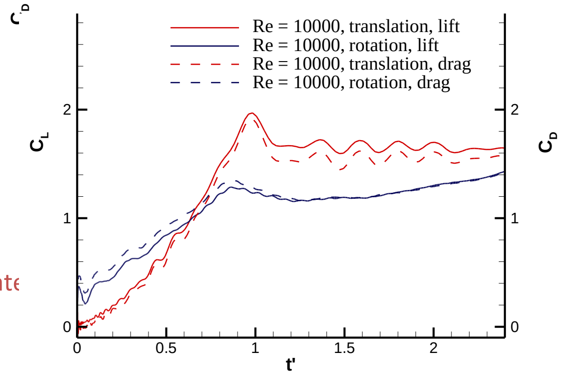
Re 10,000

Case-study: rotation vs. translation impulsive-start



Rotating AR=2 plate vs. Translating AR=4 plate
Acceleration is linear ramp over 1 chord

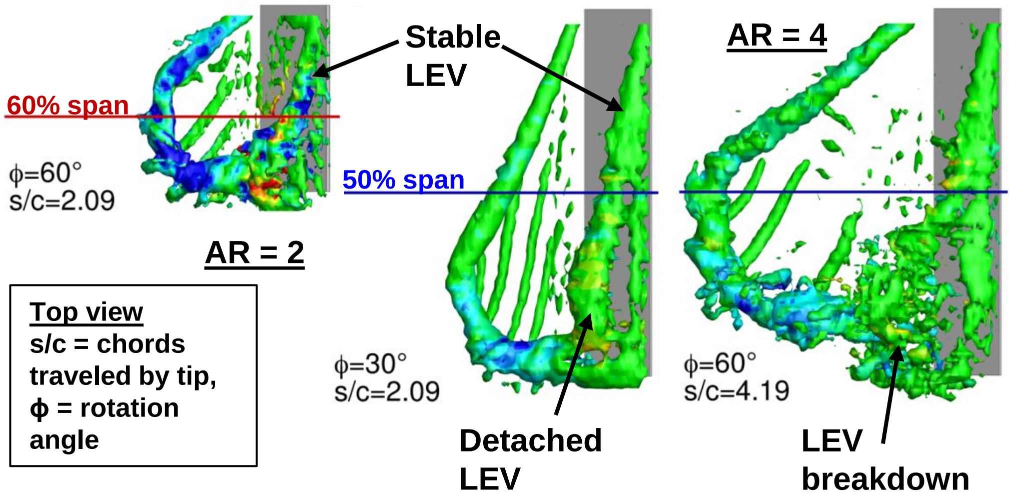
At Re = 10000, lift an drag histories are mutually similar, and net aero force is wall-normal. At Re = 60, viscous effects tilt the net aero force aft, far more so for translation than for rotation. This might explain benefits of insect-type flapping at very low Re



Role of Leading Edge Vortex

Flapping-Wing Vortex Formation and Scaling

M. Ringuette (YIP 2010), Buffalo

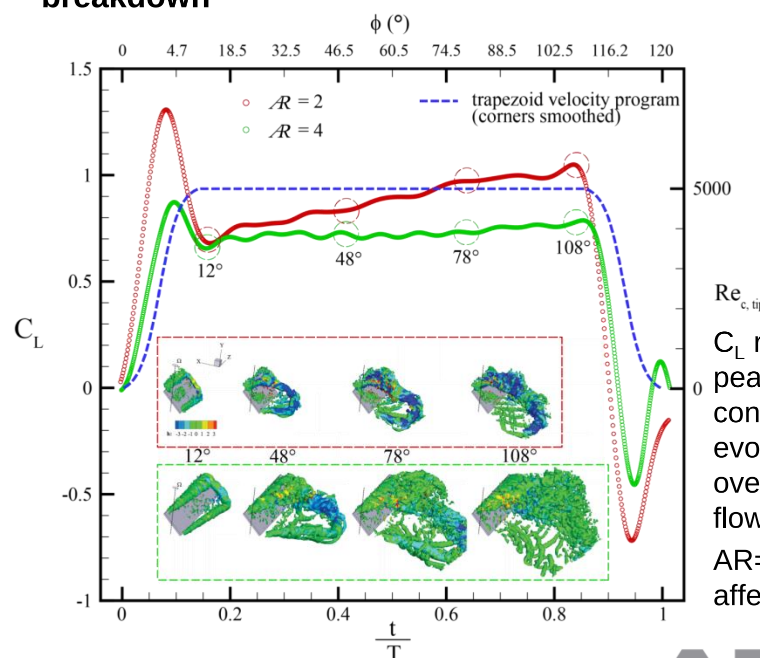


For both ARs, **stable LEV** over inboard ~50-60% span

AR-effects:

outboard LEV detaches for AR = 4

AR = 2 stays close to plate



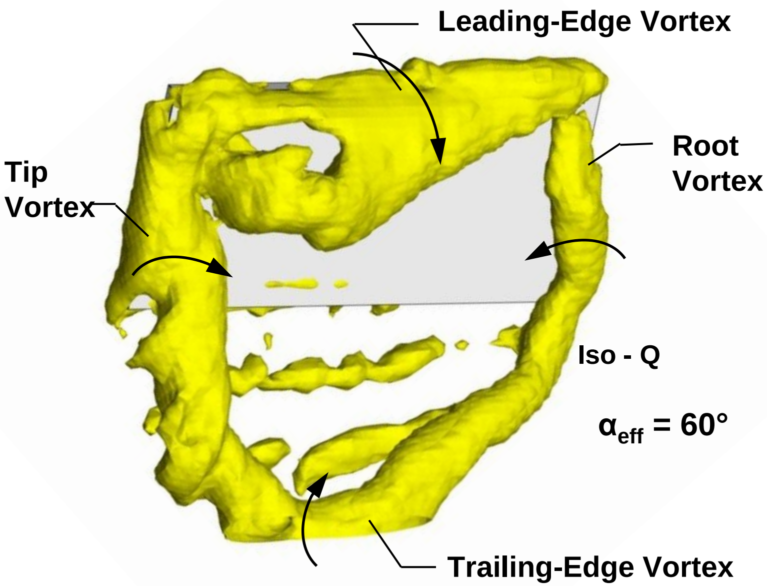
C_L rise after initial peak due to continual evolution of overall vortex flow.

AR=4 breakdown affects C_L growth.

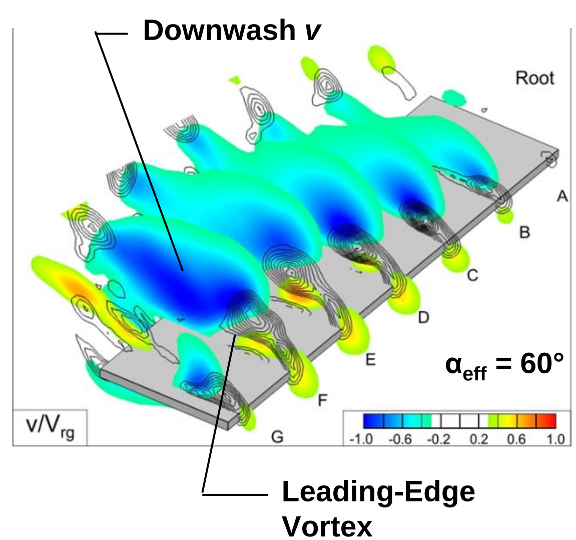
Flow Structure and Loading on Revolving-Pitching Wings

D. Rockwell, Lehigh

VORTEX SYSTEM ON ROTATING WING



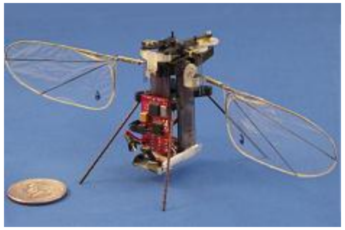
DOWNWASH IN RELATION TO LEADING EDGE VORTEX



High-Resolution Computational Studies and Low-Order Modeling of Agile Micro Air Vehicle Aerodynamics

J. Eldredge, UCLA

AeroVironment
'Nano Hummingbird'



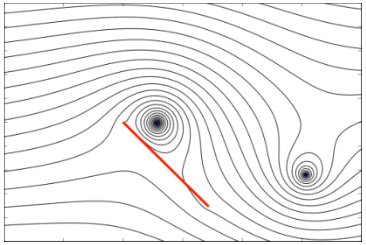
UMD/Daedalus (ARL/MAST)

Linear Quasi-Steady Wingbeat-ave'd → Flight Ctrl → Reduced Maneuverability

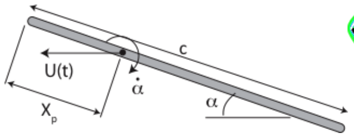
Develop low-order models that can capture the critical phenomena for agile maneuvering with fla

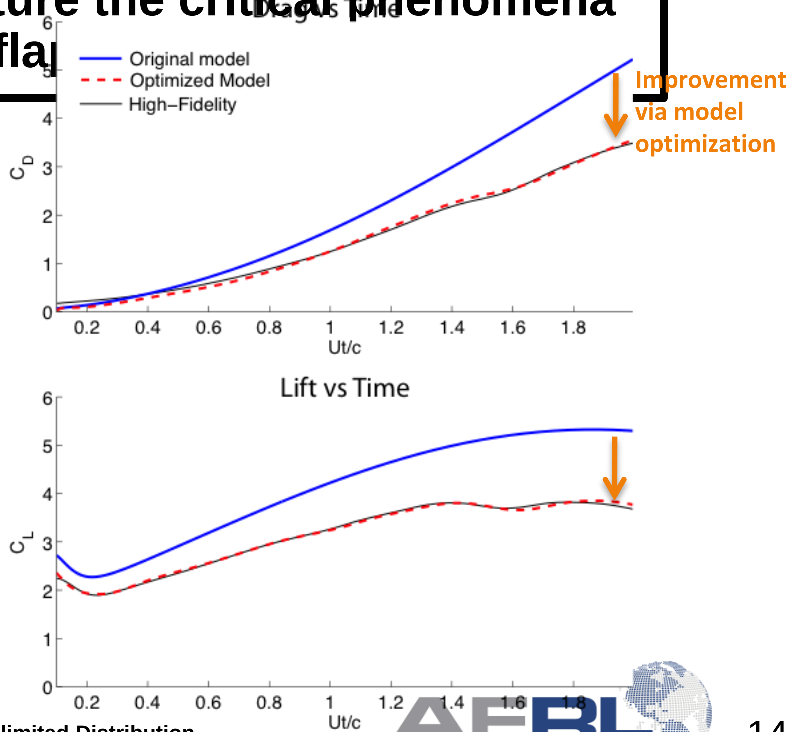
Experimental flow viz (Granlund et al., AFRL)

Low-order model streamlines



High-fidelity results



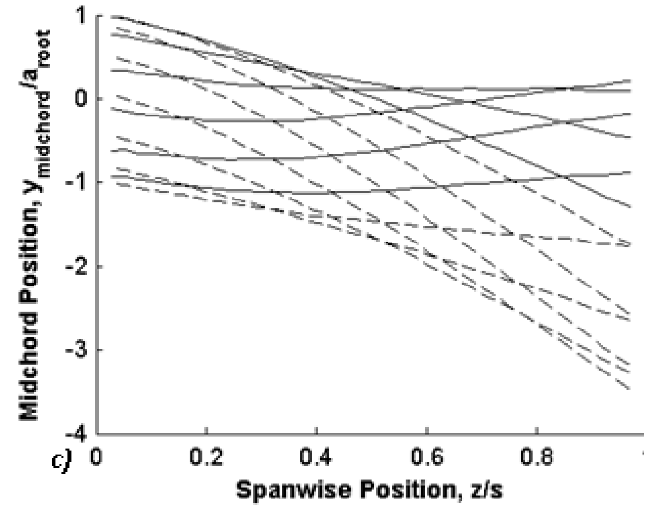


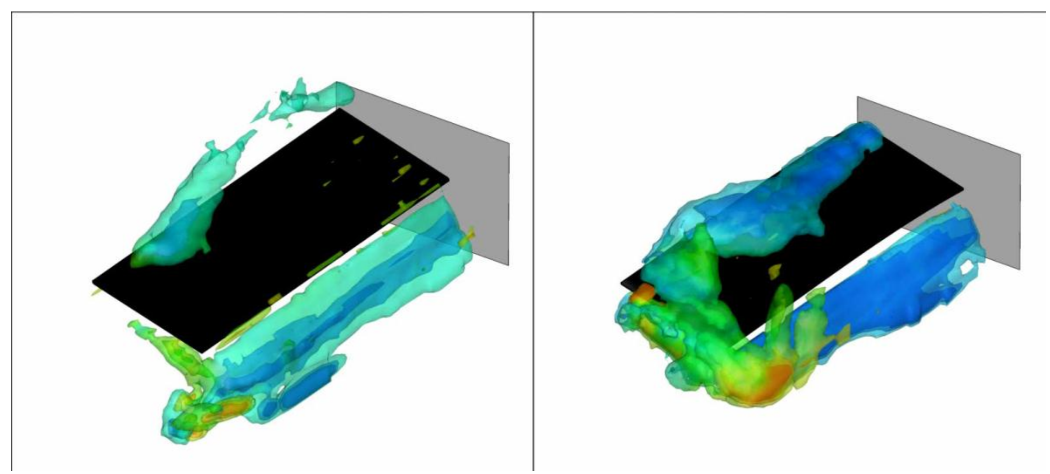
Control of Low Reynolds Number Flows with Fluid-Structure Interactions

I Gursul, Bath

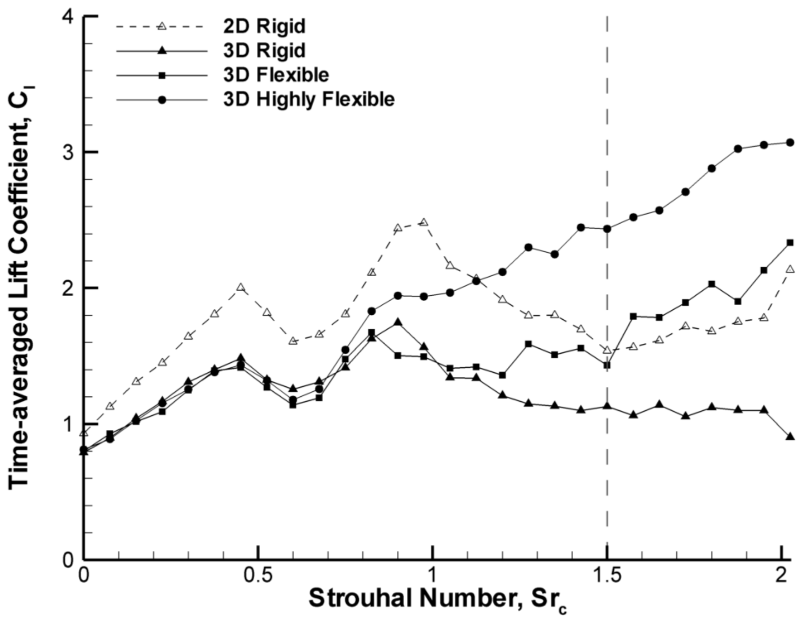
- Conventional flow control techniques are not practical for MAVs (weight limitation, insufficient space for actuators)
- Attempt to exploit aeroelastic vibrations of flexible wings
- Excite the fluid instabilities with structure

Wing deformation measurements





Time-averaged lift measurements



$\alpha=15°$ post-stall

Sr=1.5 resonance frequency

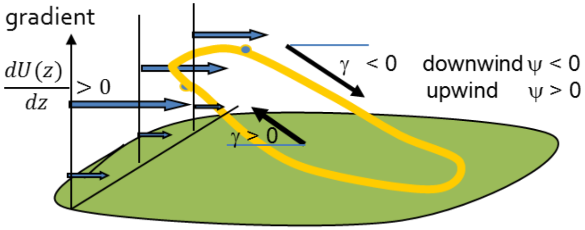
$CL_{flexible}/CL_{rigid} \cong 2$

Understanding the Flow Physics of Energy Extraction from Gusting Flows to Enhance MAV Performance

D. Williams, IIT & T. Colonius, Caltech

Background

Energy extraction from spatial & temporal velocity gradients requires correct trajectory relative to wind gradient



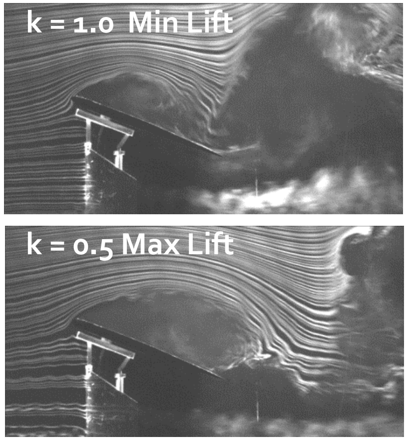
Conditions for positive "dynamic soaring" thrust and energy extraction $\frac{T}{m} = \frac{dU(z)}{dz} V \sin(\gamma) \cos(\psi)$

	$\frac{dU(z)}{dz}$	$V \sin(\gamma)$	$\cos(\psi)$
Upwind	+	+	+
Downwind	+	-	-

$U_\infty(t)$ is at the same peak value for both images, but lift is different

LEV structure controls L'

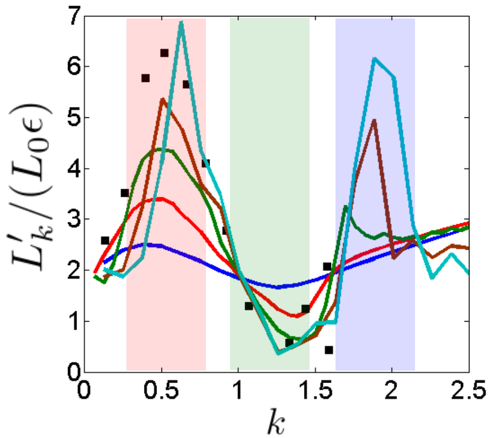
Deeper insight obtained from numerical simulations shown in next slide



Lift fluctuations for different Reynolds numbers

AOA=15°
ε = 0.05

Simulation
Re=100
Re=200
Re=300
Re=400
Re=500
Experiment
Re=57000 ■



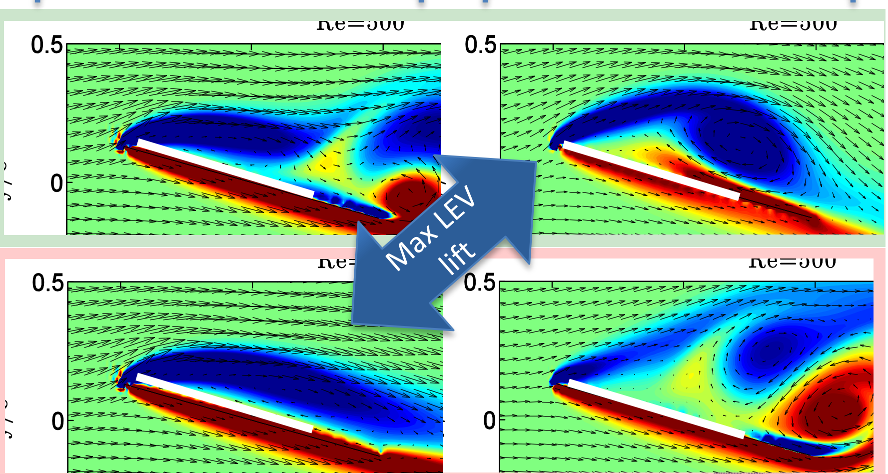
Instantaneous flow structure (vorticity) on flat-plate airfoil @ Re=500

at maximum of U_∞ (max quasi-static lift)

at minimum U_∞ (min quasi-static lift)

Max LEV at minimum U_∞ suppresses quasi-static fluctuations

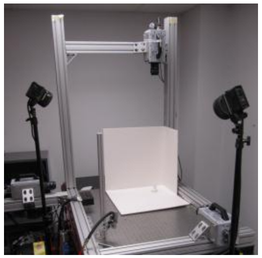
Max LEV at maximum U_∞ enhances quasi-static fluctuations

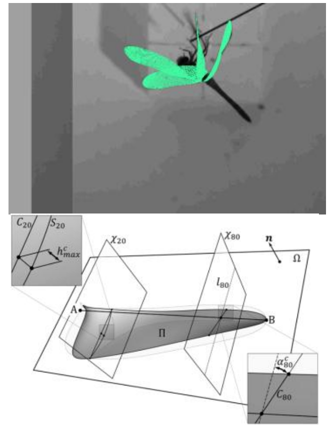


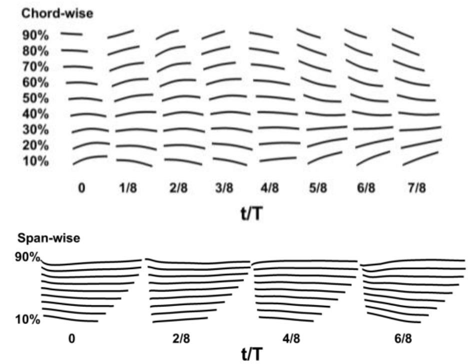
Physics-based morphology analysis and adjoint optimization of flexible flapping wings

H. Dong, UVa & M. Wei, NMSU

- 3D physics-based morphology analysis of flexible flapping wings



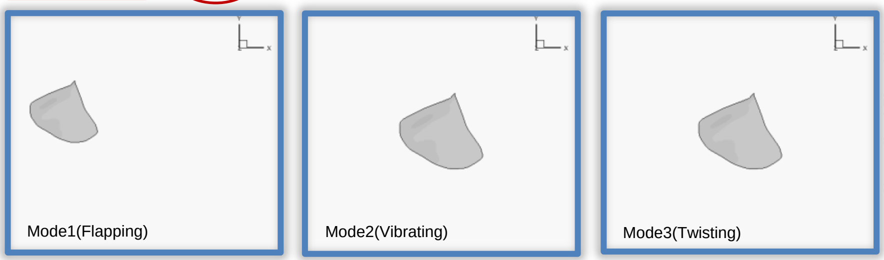


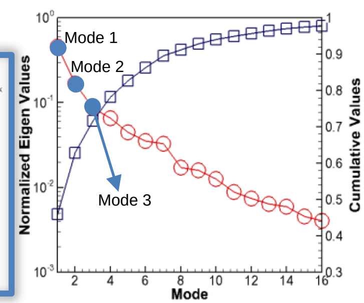


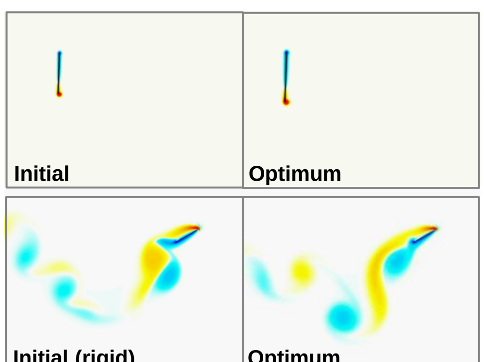
Quantifying wing morphology in chord-wise and span-wise

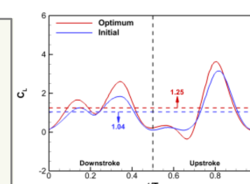
- Wing gaits analysis using SVD (Singular Value Decomposition)

Snapshots of wing location → $A_{3m\times n} = U_{3m\times 3m} S_{3m\times n} V^T_{n\times n}$



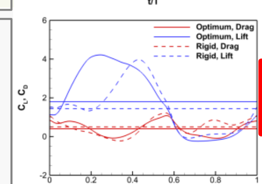






$\overline{C_L}$ increased by 25%

Hover

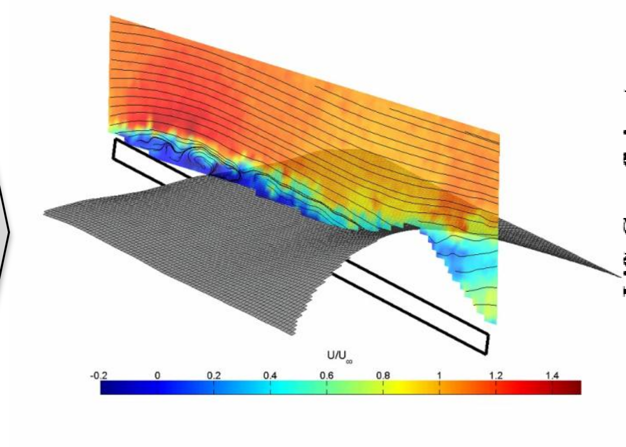


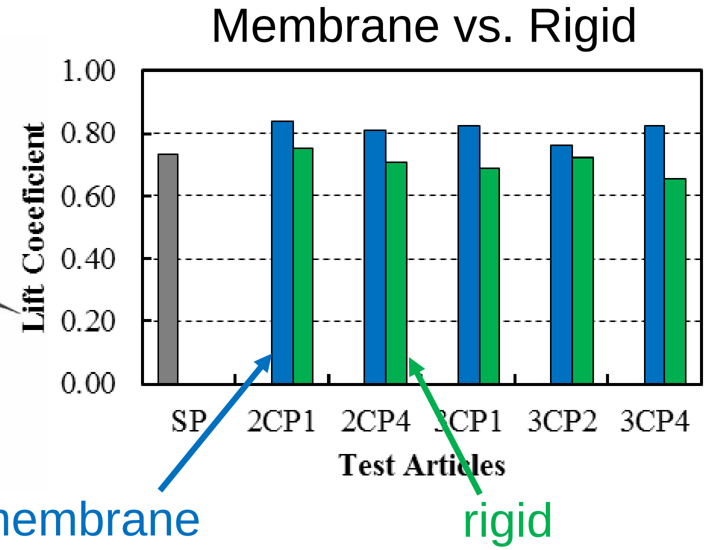
$\overline{C_L}/\overline{C_D}$ increased by 53%

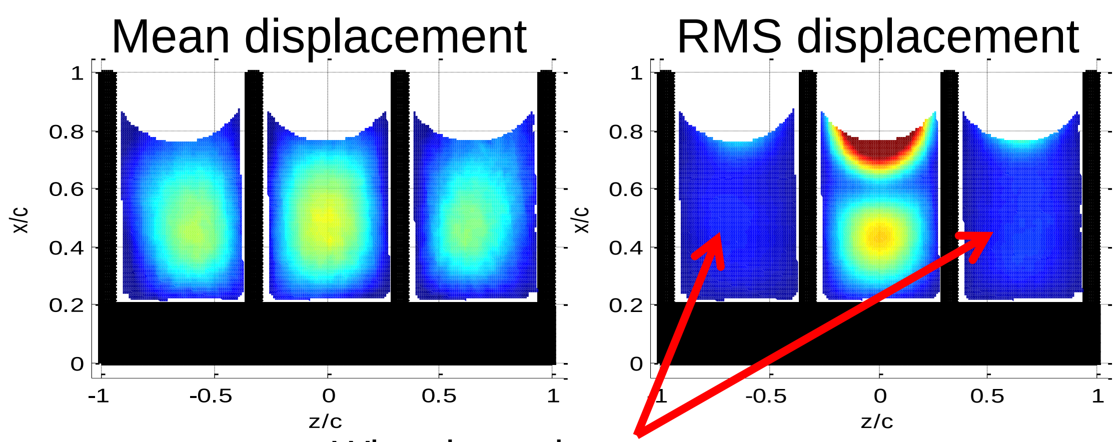
Cruise

Time-Dependent Fluid-Structure Interaction & Passive Flow Control of Low Reynolds Number Membrane Wings

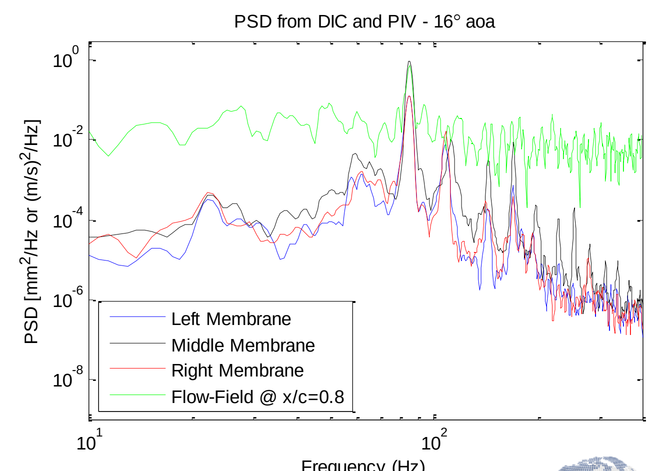
P. Hubner, A. Lang, Alabama & L. Ukeiley, P. Ifju, Florida







Wing tip vortices suppress oscillations

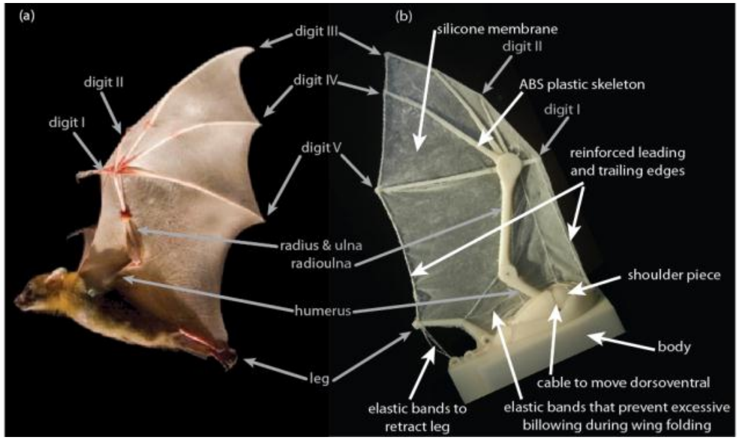


Aerodynamics and Mechanics of Robust Flight in Bats

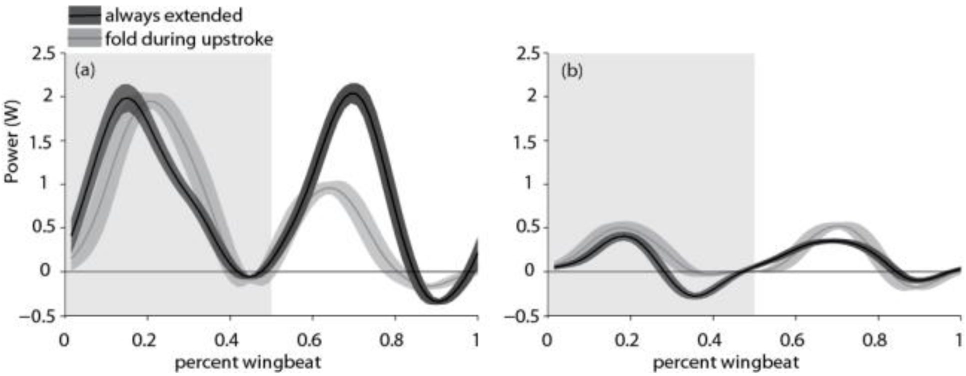
S. Swartz & K. Breuer, Brown

- Social animals are known to fly (birds & bats) or swim (fish) in large groups with diverse geometric arrangements
- May be fluid dynamic and energetic advantages depending on the circumstances
- For bats, little is known of the group flight dynamics

Flying bats generate wakes that may be sensed by other individuals to control spacing, reduce flight cost, and increase aerodynamic force production.



Cynopterus brachyotis, the lesser dog-faced fruit bat, and the robotic flapping wing based on its anatomy and flight behavior.



Flight power with and without wing folding, with respect to main flapping axis[(a), left] and front-back axis [(b), right]. Plots are mean and 95% CI for 160 wingbeats at 8 Hz and 60° stroke plane; grey shading is downstroke.

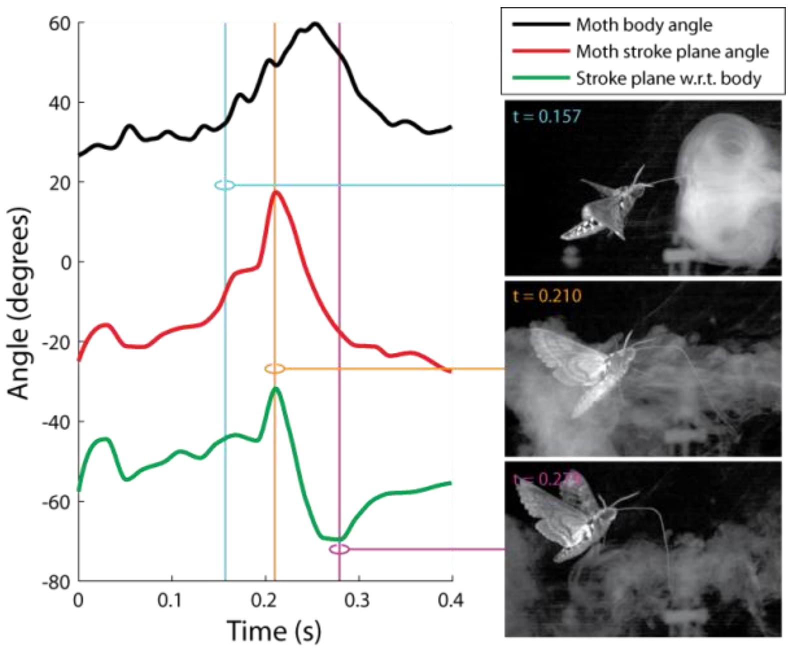
Biological Inspiration

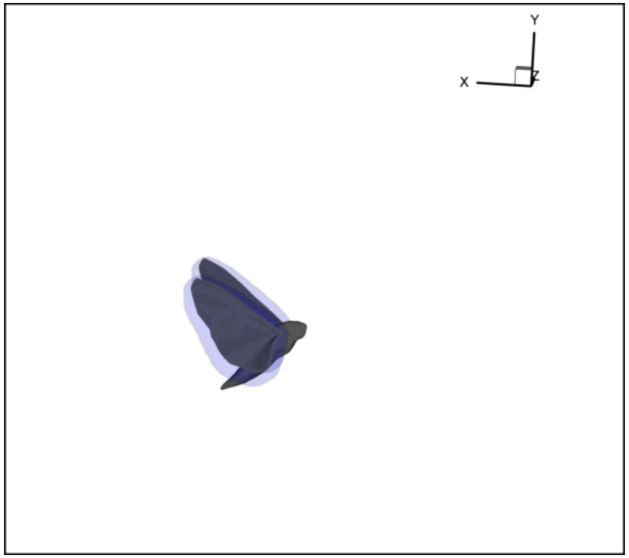
Courtesy of Breuer & Swartz, Brown

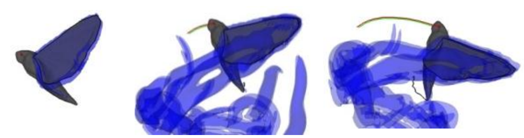
An Integrated Study of Flight Stabilization with Flapping Wings in Canonical Urban Flows

R. Mittal, JHU & Hedrick, UNC

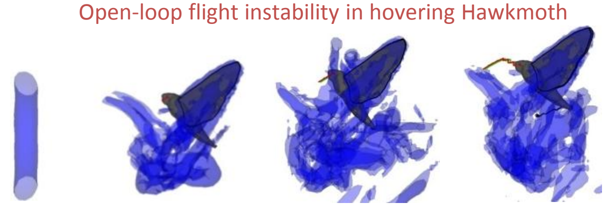
- Stabilization of flapping wing vehicles in complex flows is critical for effective operation of these vehicles.
- Study of flight stabilization in insects could lead to new insights for designing small, agile flying vehicles







Open-loop flight instability in hovering Hawkmoth



Active stabilization of Hawkmoth in vortex perturbation