



Integrity ★ Service ★ Excellence

Flow Interactions and Control

08 MAR 2012

**Dr. Douglas Smith
Program Manager
AFOSR/RSA**

Air Force Research Laboratory

Report Documentation Page			Form Approved OMB No. 0704-0188		
Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.					
1. REPORT DATE 08 MAR 2012	2. REPORT TYPE		3. DATES COVERED 00-00-2012 to 00-00-2012		
4. TITLE AND SUBTITLE Flow Interactions And Control			5a. CONTRACT NUMBER		
			5b. GRANT NUMBER		
			5c. PROGRAM ELEMENT NUMBER		
6. AUTHOR(S)			5d. PROJECT NUMBER		
			5e. TASK NUMBER		
			5f. WORK UNIT NUMBER		
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Air Force Research Laboratory,Patterson AFB,OH,45433-			8. PERFORMING ORGANIZATION REPORT NUMBER		
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)			10. SPONSOR/MONITOR'S ACRONYM(S)		
			11. SPONSOR/MONITOR'S REPORT NUMBER(S)		
12. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release; distribution unlimited					
13. SUPPLEMENTARY NOTES					
14. ABSTRACT					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT Same as Report (SAR)	18. NUMBER OF PAGES 27	19a. NAME OF RESPONSIBLE PERSON
a. REPORT unclassified	b. ABSTRACT unclassified	c. THIS PAGE unclassified			



2012 AFOSR SPRING REVIEW



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

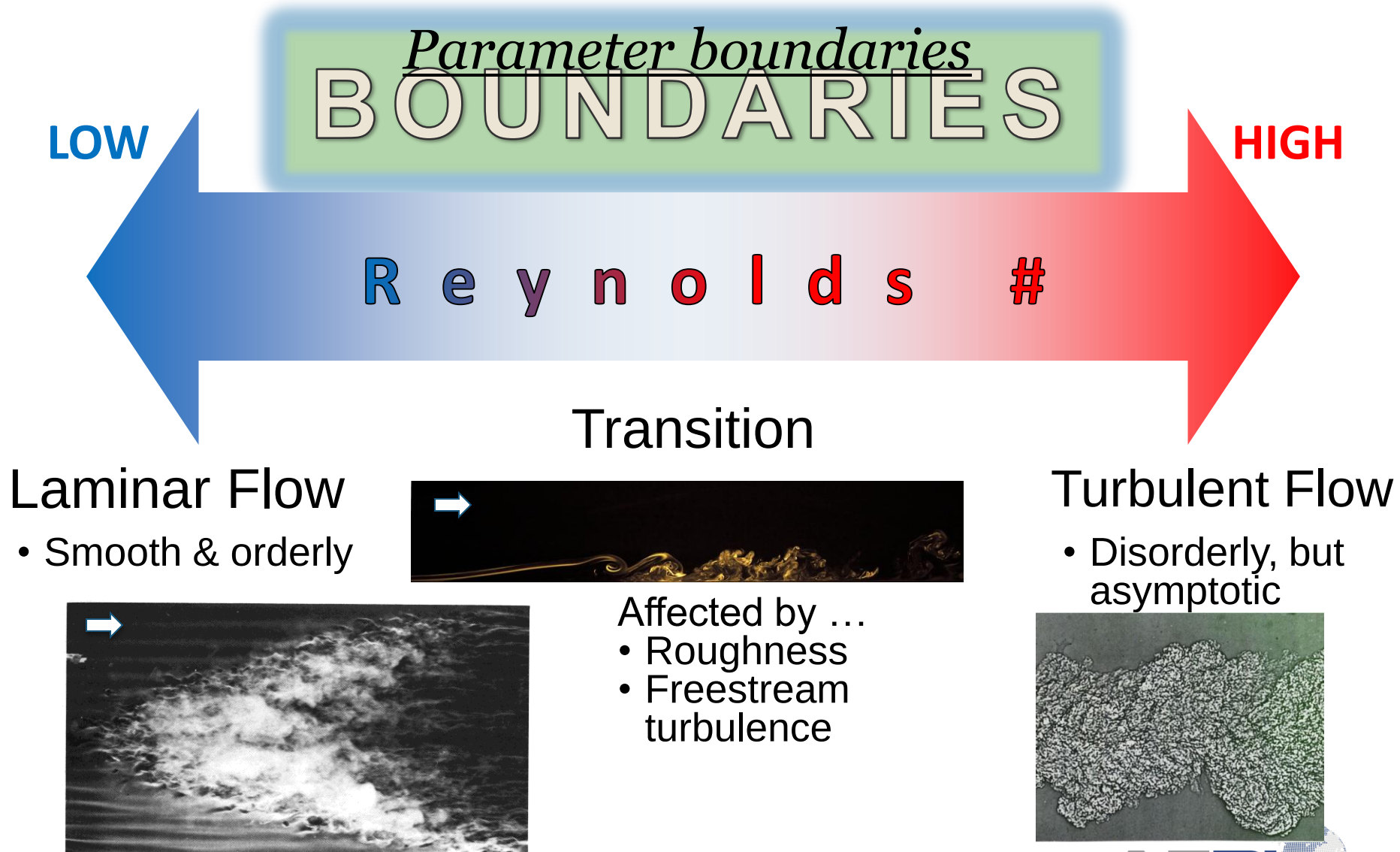
Flow Control Effectors

Low Reynolds Number Unsteady Aerodynamics

Aeromechanics for MAVs



Inspiration ...

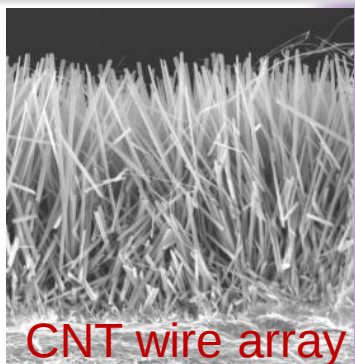




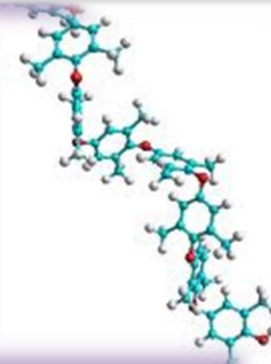
Inspiration ...

Disciplinary boundaries

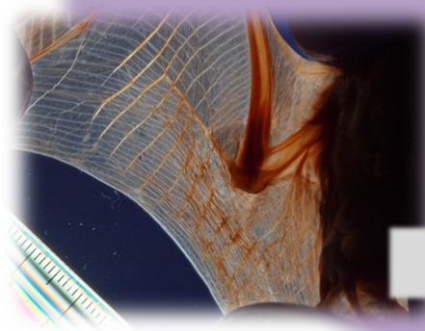
Novel Materials



Chemical Interactions



Flow Physics



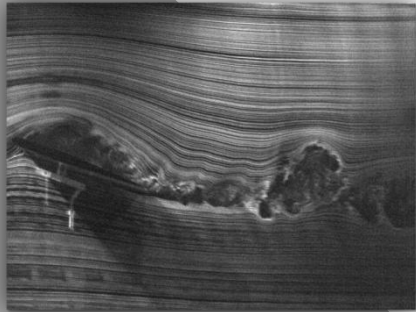
Biology



Energy

Scientific Challenges

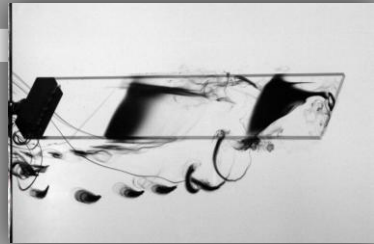
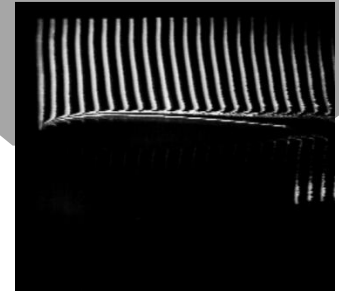
Unsteady
Low Rey
Aero



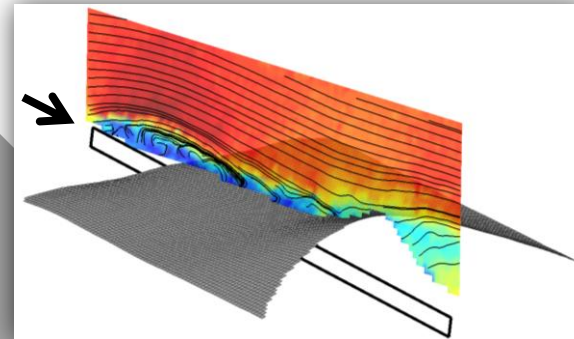
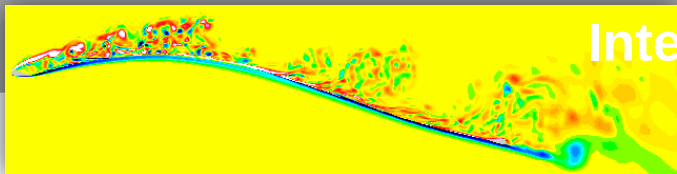
Flow
Control



Flow Physics
for
Control



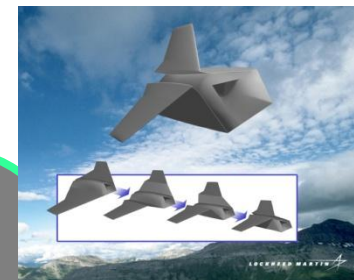
Fluid-
Structure
Interaction



Flow
Control



Opportunities ...



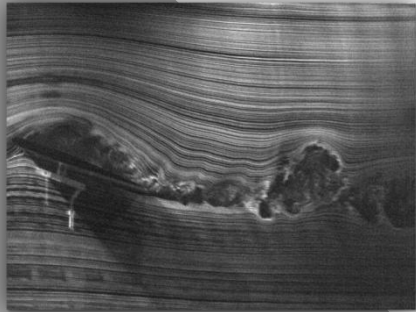
- Create opportunities in
 - ✓ Gust tolerance/mitigation
 - ✓ Agility
 - ✓ Hover
 - ✓ Integrated lift & thrust
- Reconfigurable aircraft
- Coordinated flight, swarming
- Drag reduction, Enhanced efficiency



Require an understanding of aerodynamic-structure interactions and control.

Scientific Challenges

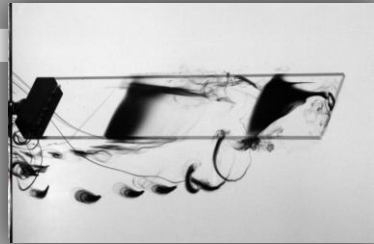
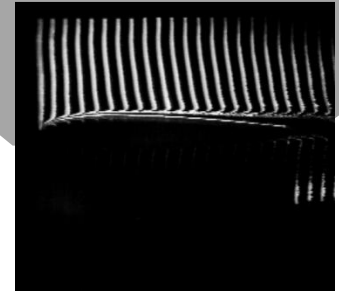
Unsteady
Low Rey
Aero



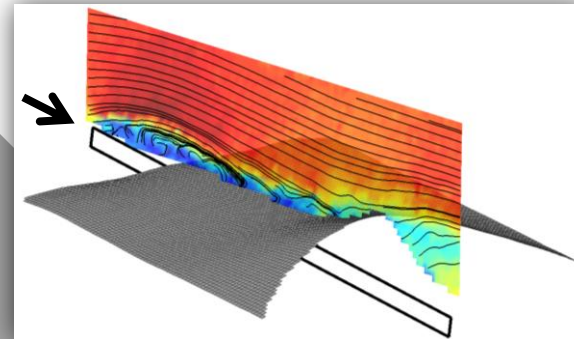
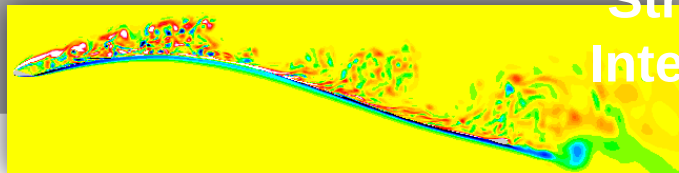
Flow
Control



Flow Physics
for
Control

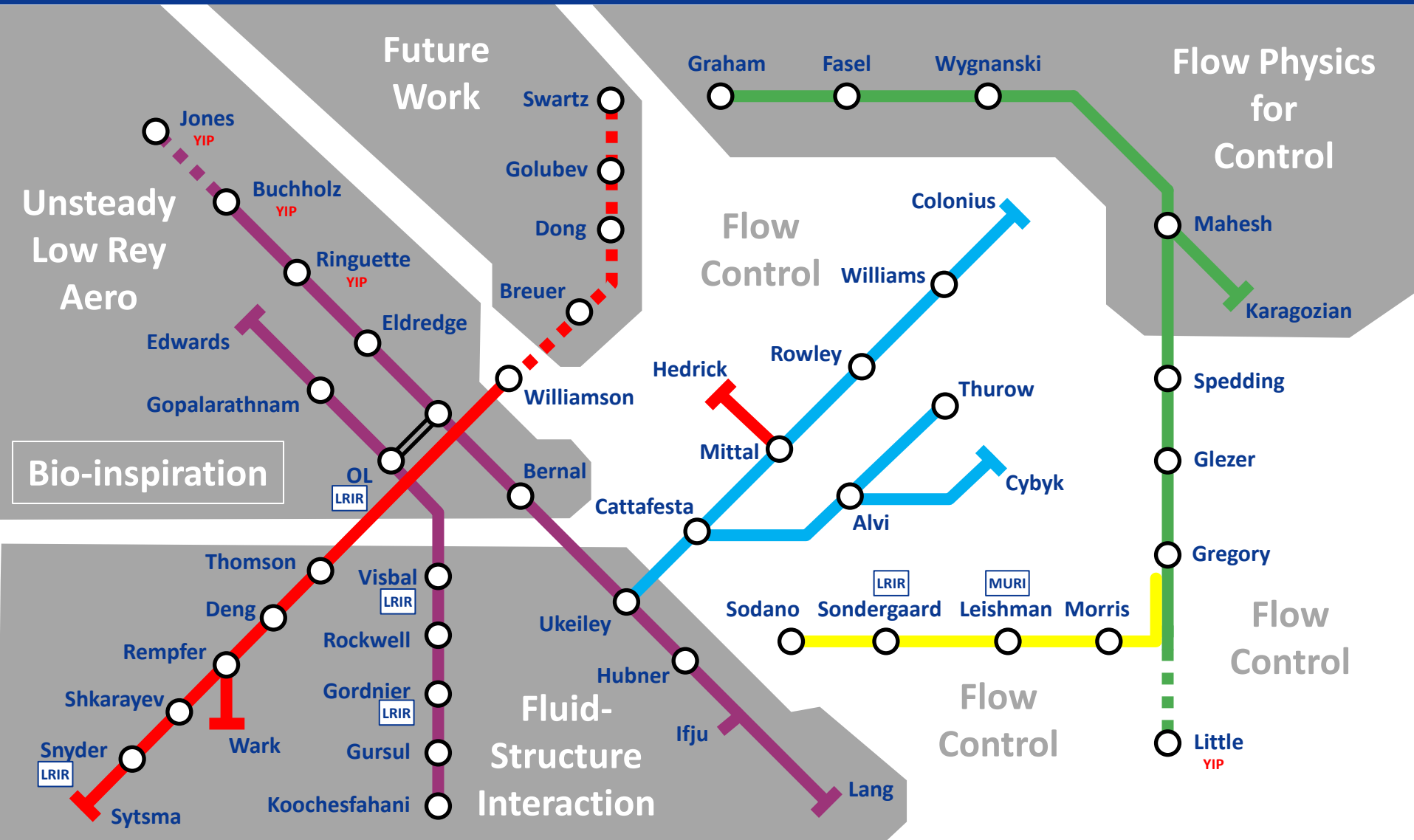


Fluid-
Structure
Interaction



Flow
Control

Portfolio map



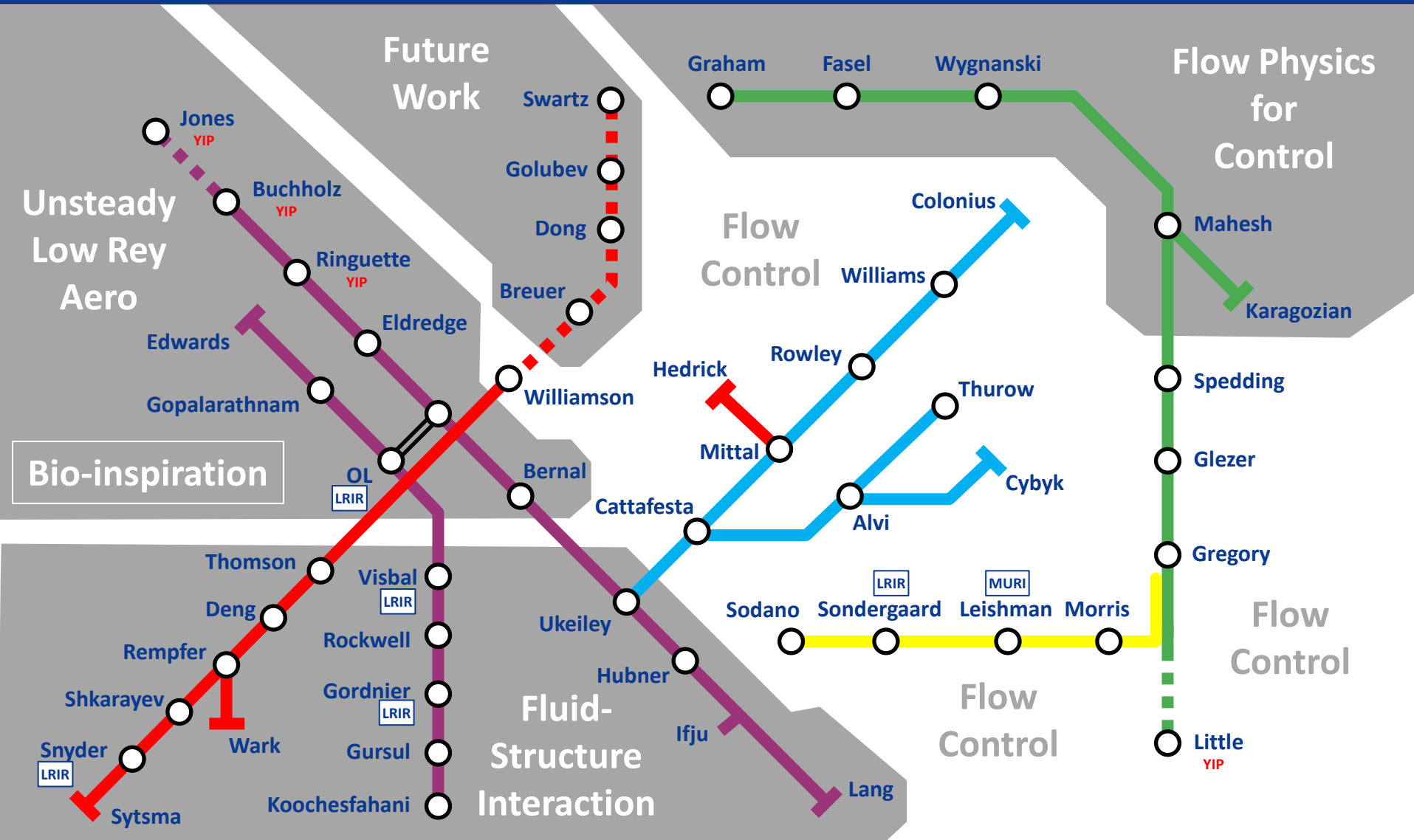
Key to Lines

- Flow physics & Control
- Flow control collaboration
- Applied flow control

- Low Reynolds number unsteady aerodynamics
- Flight physics for MAVs

- PI
- Co-PI
- 2012 New Start

Portfolio map





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

M. Graham, Wisconsin

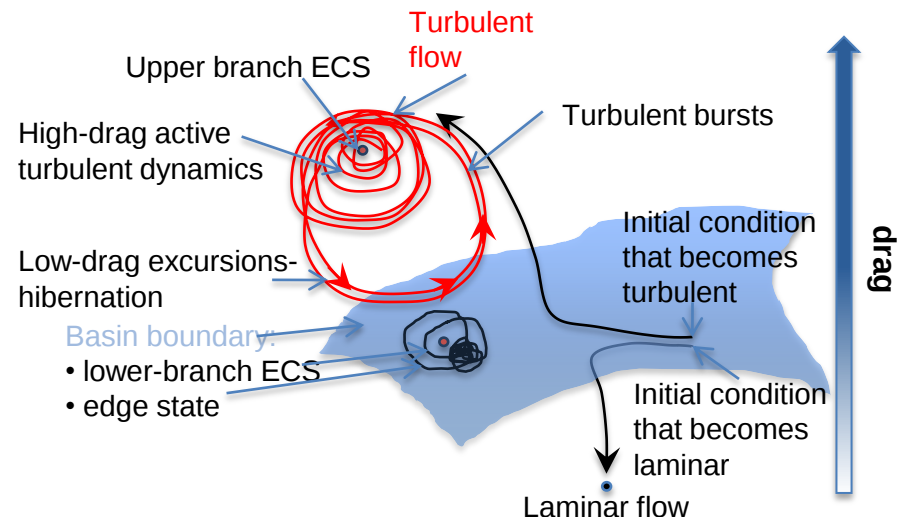
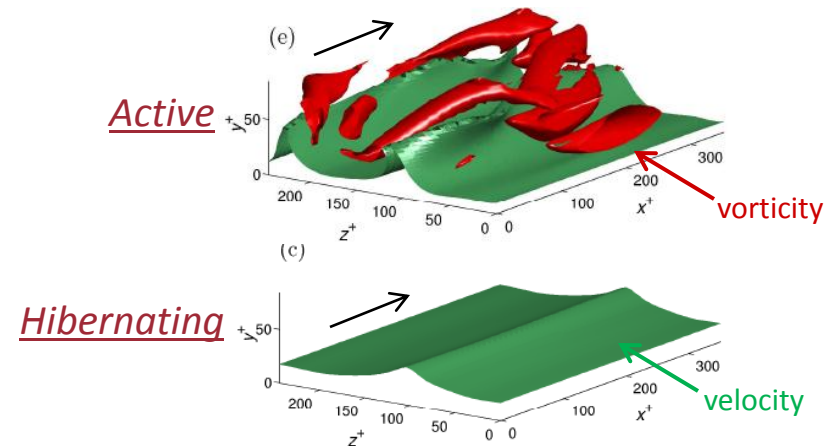


Background and objective

- Drag in many aerodynamic flows is dominated by near-wall turbulent flow structures
- Approaches to skin-friction reduction often focus on manipulation of these structures via suction/blowing or topography (riblets)
- In liquids, dramatic changes in these structures and corresponding high levels of drag reduction (>70%) can be achieved by adding long-chain polymers.
- Recent discoveries:
 - polymer stresses suppress normal “active” turbulence” but do not affect intervals of “hibernating” turbulence that exhibit very low skin friction,
 - hibernating turbulence intervals are found occasionally ***even without polymer additives***.

⇒ Goal: Exploit these observations to develop new boundary control schemes to make these low-drag intervals more frequent and thus reduce overall drag in aerodynamically important flows.

Recent results



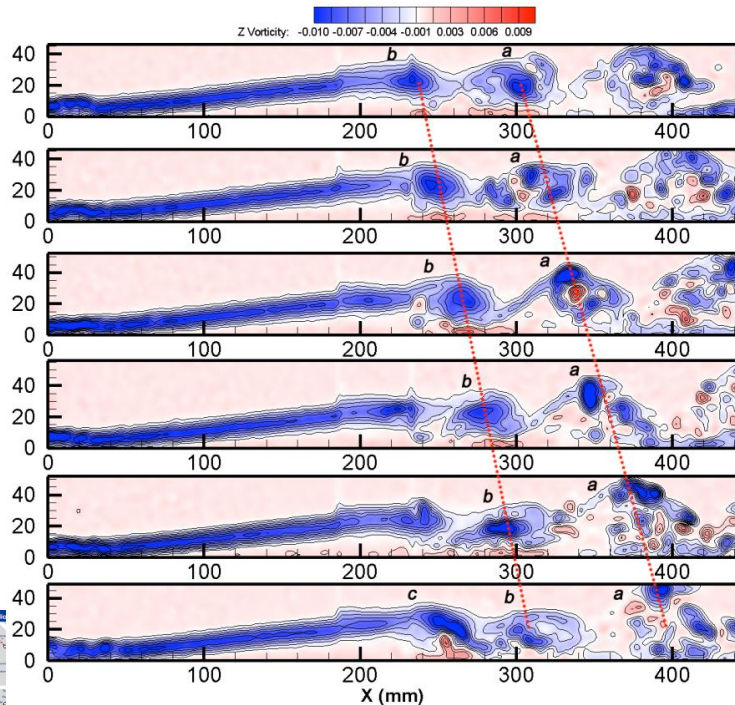
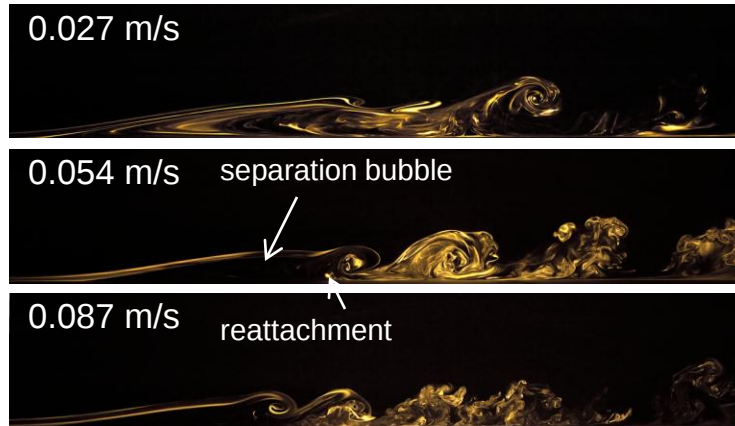
Proposed schematic of the state space dynamics of turbulent wall-bounded flow.





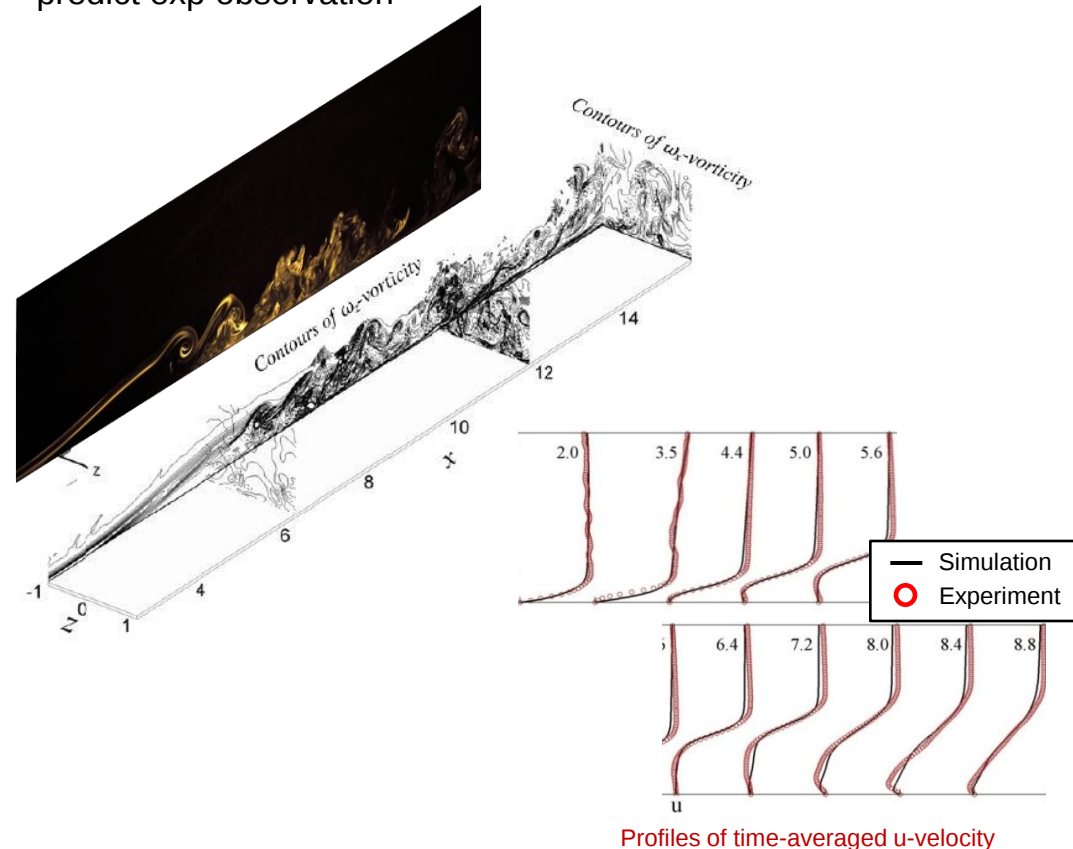
Control of boundary-layer separation for lifting surfaces

H. Fasel, Arizona



Investigating the transition process of separation bubbles in the presence of freestream turbulence

- Experimental observations → description of bubble behavior
- Simulations require that freestream turbulence is included to predict exp observation

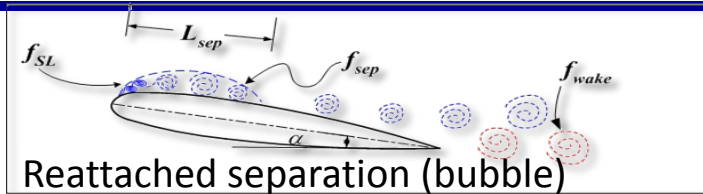


Profiles of time-averaged u-velocity

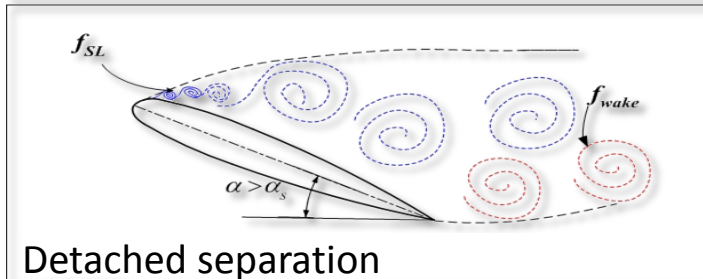


AN INTEGRATED STUDY OF SEPARATION CONTROL

L. Cattafesta (FSU), R. Mittal (JHU), & C. Rowley (Princeton)



Reattached separation (bubble)



Detached separation

- 1) Investigate nonlinear interactions between these phenomena
- 2) Leverage nonlinear interactions for effective control strategies

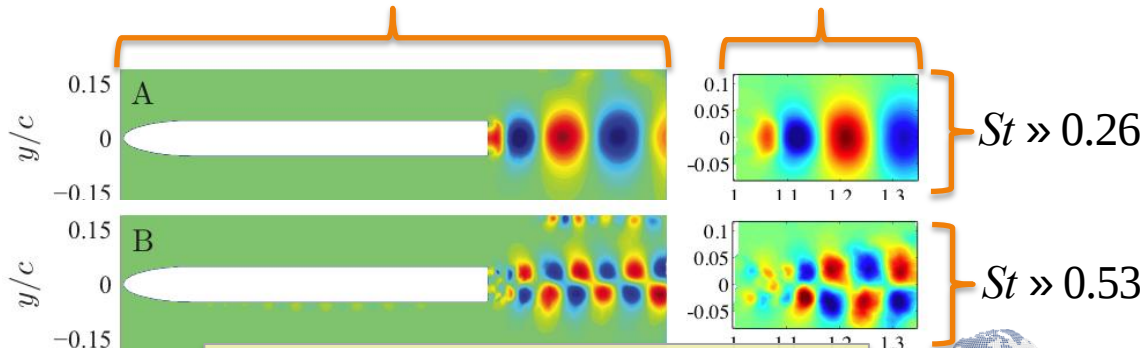
SB/wake mode ($f = 4.45$)

SL mode ($f = 8.90$)

DYNAMICAL ANALYSIS

SIMULATED

EXPERIMENTAL



Fixed frequency structures similar

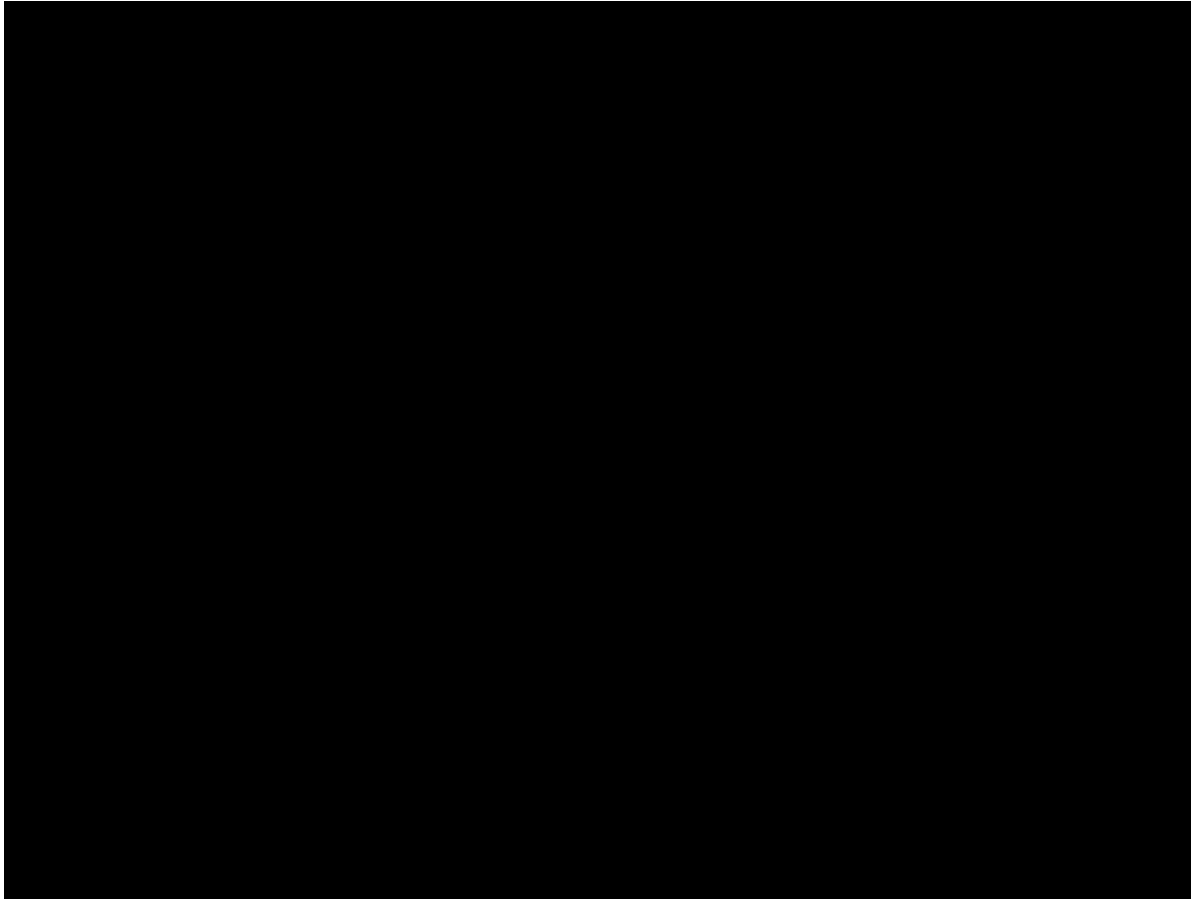
Oscillating structures

DISTRIBUTION A:



Rotorcraft Brownout – Advanced Understanding Control and Mitigation

G. Leishman, Maryland



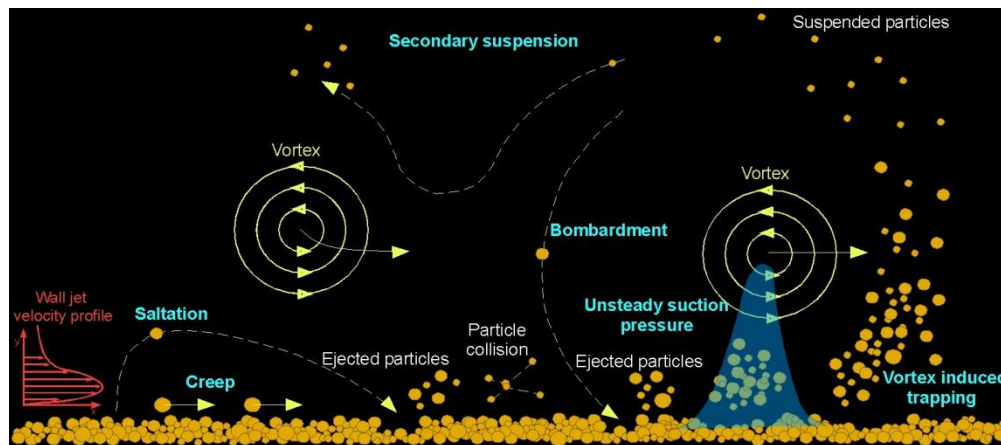


Rotorcraft Brownout – Advanced Understanding Control and Mitigation

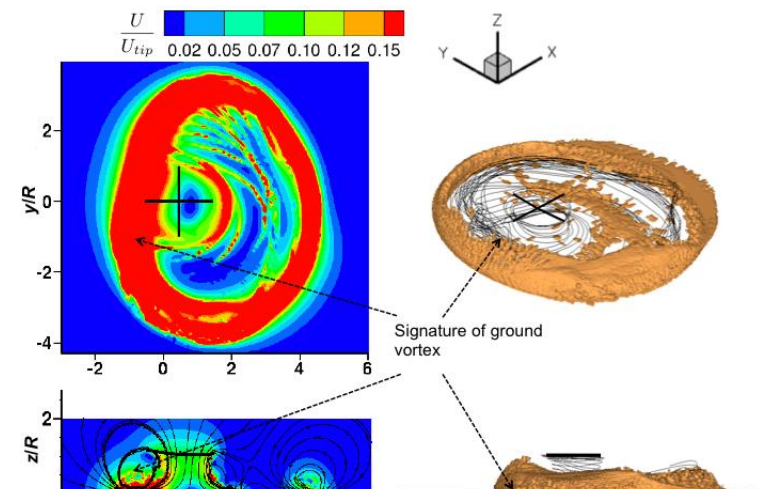
G. Leishman, Maryland



- Rotor wake dynamics “in ground effect” is at the root of the problem
- Unsteady, 2-phase, 3-dimensional fluid dynamics problem
- Wake impinging on the ground creates:
 - Transient excursions in flow velocities
 - Unsteady shear stresses and pressures
 - Secondary vortical flows and local regions of flow separation
 - Turbulence



Summary of the six sediment mobilization, uplift, and suspension mechanisms observed from a bed below a rotor: creep; modified saltation, vortex-induced trapping, unsteady suction pressure effects, secondary suspension, particle bombardment/splash



Simulated dust clouds using a Lagrangian free-vortex rotor wake method and Lagrangian sediment particle tracking method ($\sim 10^{12}$ particles) along with contours of induced velocity on the ground (note high 3-dimensionality) for a dynamic simulation of a helicopter landing over a surface covered with a sediment bed

; dist

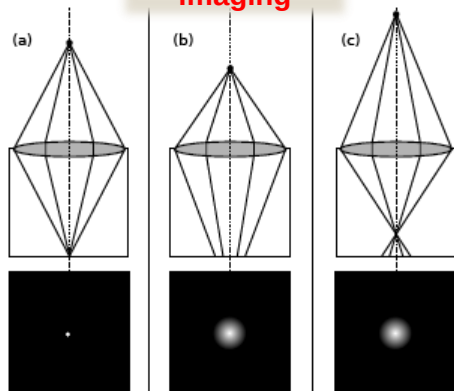


Development of a Compact and Easy-to-Use 3-D Camera For Measurements in Turbulent Flow Fields

B Thurow, Auburn



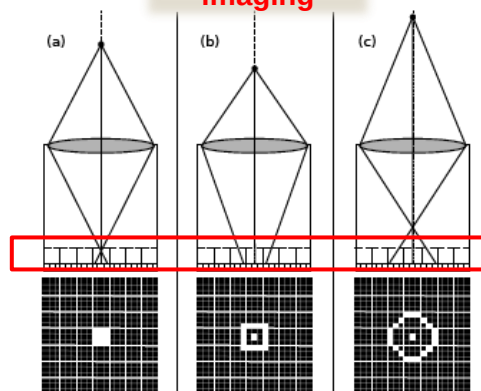
Conventional imaging



Conventional 2-D Imaging Systems

- 2-D information neglects inherent 3-D nature of turbulent flows
- Camera integrates angular information, which leads to depth-of-field and blur
- Reduced aperture (restricted angular information) leads to low signal levels

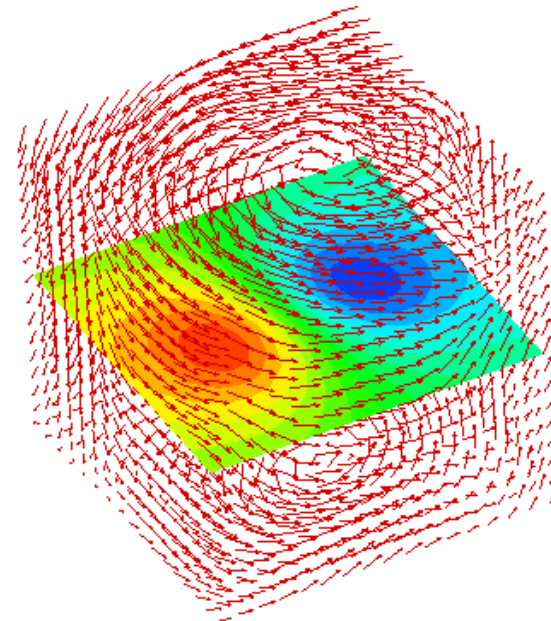
Plenoptic imaging



Lense-

Lightfield Imaging

- Plenoptic camera records both the position and angle of light rays that enter the camera
- Eliminates the need for complex, expensive multi-camera arrangements
- Dense sampling of 3-D scene



Near



Mid



Far





Biological Inspiration



Courtesy of Breuer & Swartz, Brown

DISTRIBUTION A: Approved for public release; distribution is unlimited.



Challenges & Questions

CHALLENGES

Unsteady, periodic flow-fields

Three-dimensional flow-fields

Low Reynolds number flows

Laminar-transitional flows

Separation & Leading-edge vortices

Wing kinematics

Wing flexibility

QUESTIONS

To what extent can the flow be treated as quasi-steady?

Can the flow be treated as 2-D along the span of the wing? What can we learn from these 2-D treatments?

How good are inviscid approximations?

How well must these flows be resolved?

Why separated flow? Do LEVs have universal formation scaling?

How sensitive are the aerodynamics to the kinematics? Rectilinear vs flapping?

What is the role of flexibility in modifying aerodynamic efficiency?



Bio-Inspired Aerodynamics



HIGH

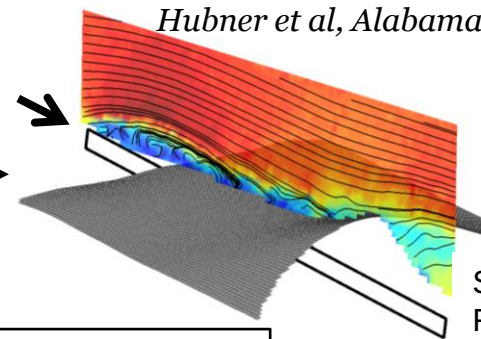
Bio-Inspired Flight



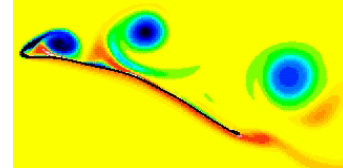
3D aero-elastic, dynamic flight
Neuro-physiological control
Evolutionary biology

Aerodynamics & Flexibility

Wing Structure

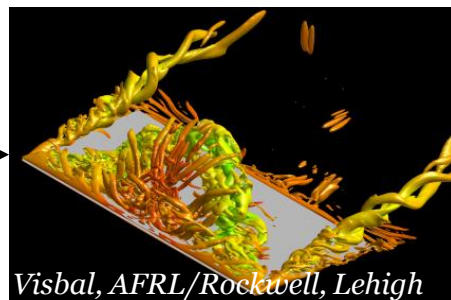


Gordnier, AFRL

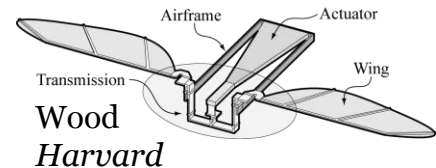


Surface flexibility/compliance
Flow induced vibrations
Natural, passive flow control

Hi-fidelity Simulations



3D/wing tip effects
Transition to turbulence



Rigid Wing Aerodynamics

Starting/stopping transients
Leading edge vortex formation
Universal scaling

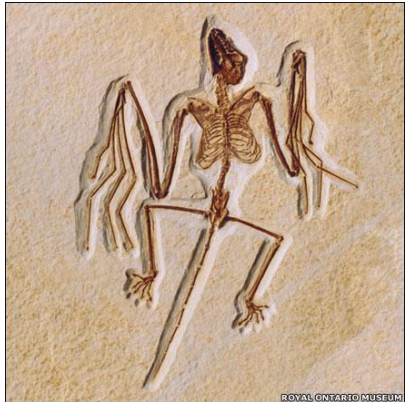


DISTRIBUTION A: Approved for public release; distribution is unlimited.





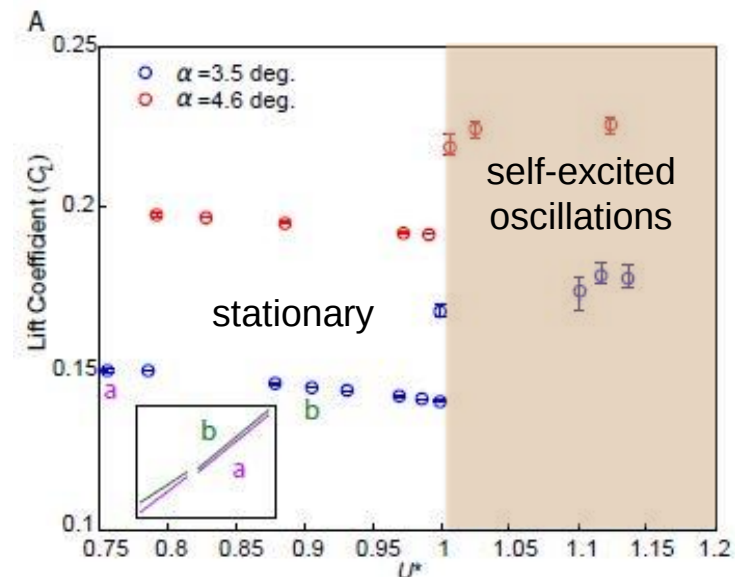
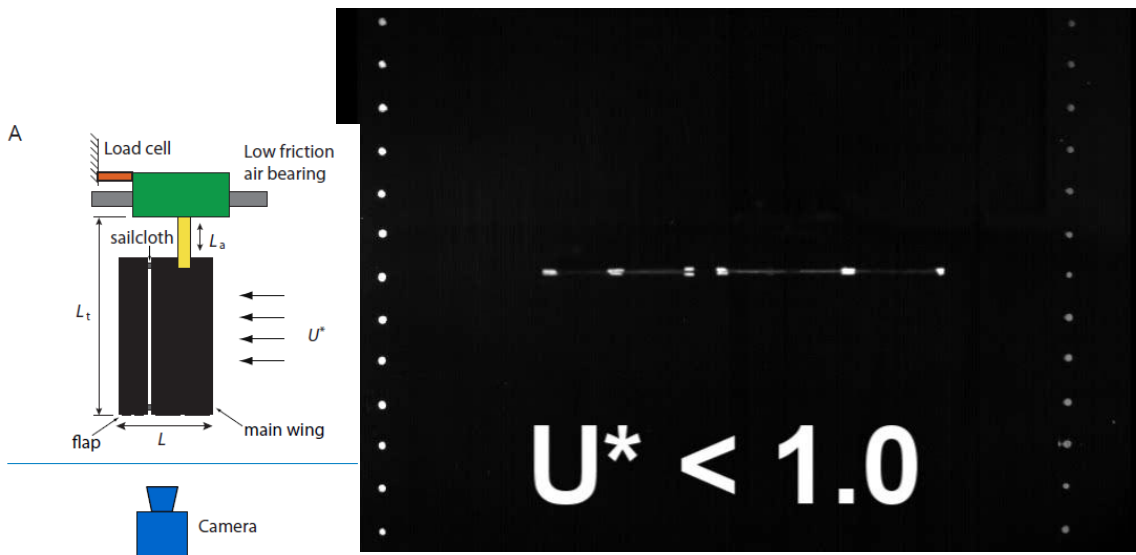
From Gliding to Powered Flight



Onychonycteris finneyi

50 million years ago bats evolved from gliding to powered flapping flight. BUT...

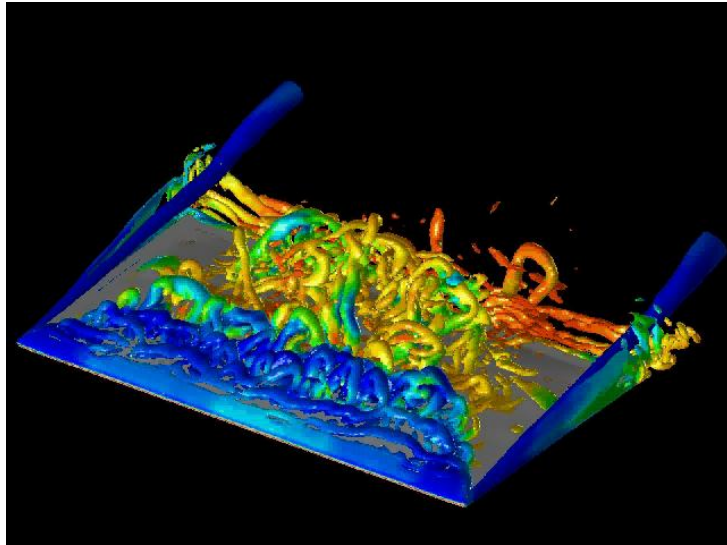
- What pressures led from passive gliding to powered flight?
- What is the role passive wing deformation or motion in biological flight?



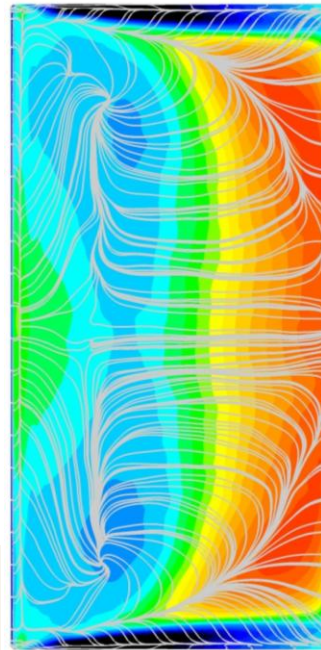


Effect of Membrane Flexibility on Leading Edge Separation

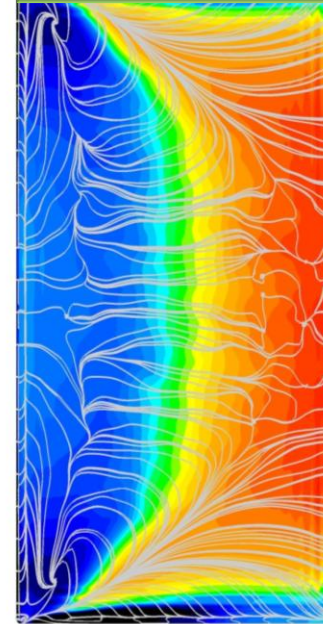
R Gordnier, AFRL/RBAC



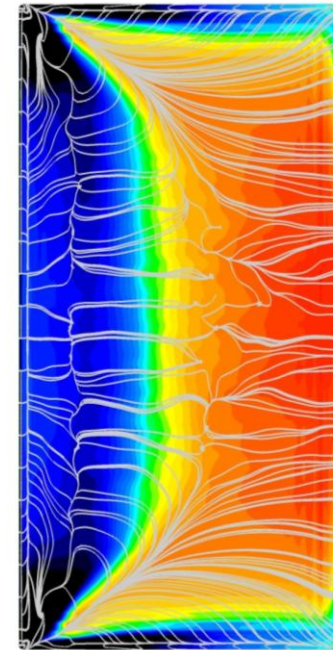
Rigid, Flat Wing



Rigid, Cambered Wing



Flexible Wing



Membrane Flexibility:

- ✓ Reduces the extent of leading edge separation
- ✓ Enhances lift at the cost of increased L/D
- ✓ Reduces nose down pitching moment

	C_L	C_D	L/D	C_{my}
Rigid-Flat	0.965	0.235	4.112	-0.160
Rigid-Cambered	1.020	0.269	3.794	-0.140
Flexible Membrane	1.024	0.262	3.903	-0.122





Control of Low Reynolds Number Flows with Fluid-Structure Interactions

I Gursul, Bath

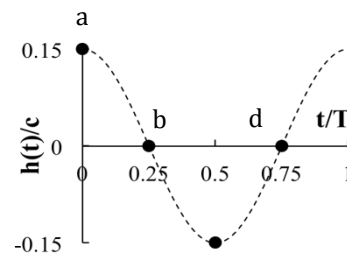
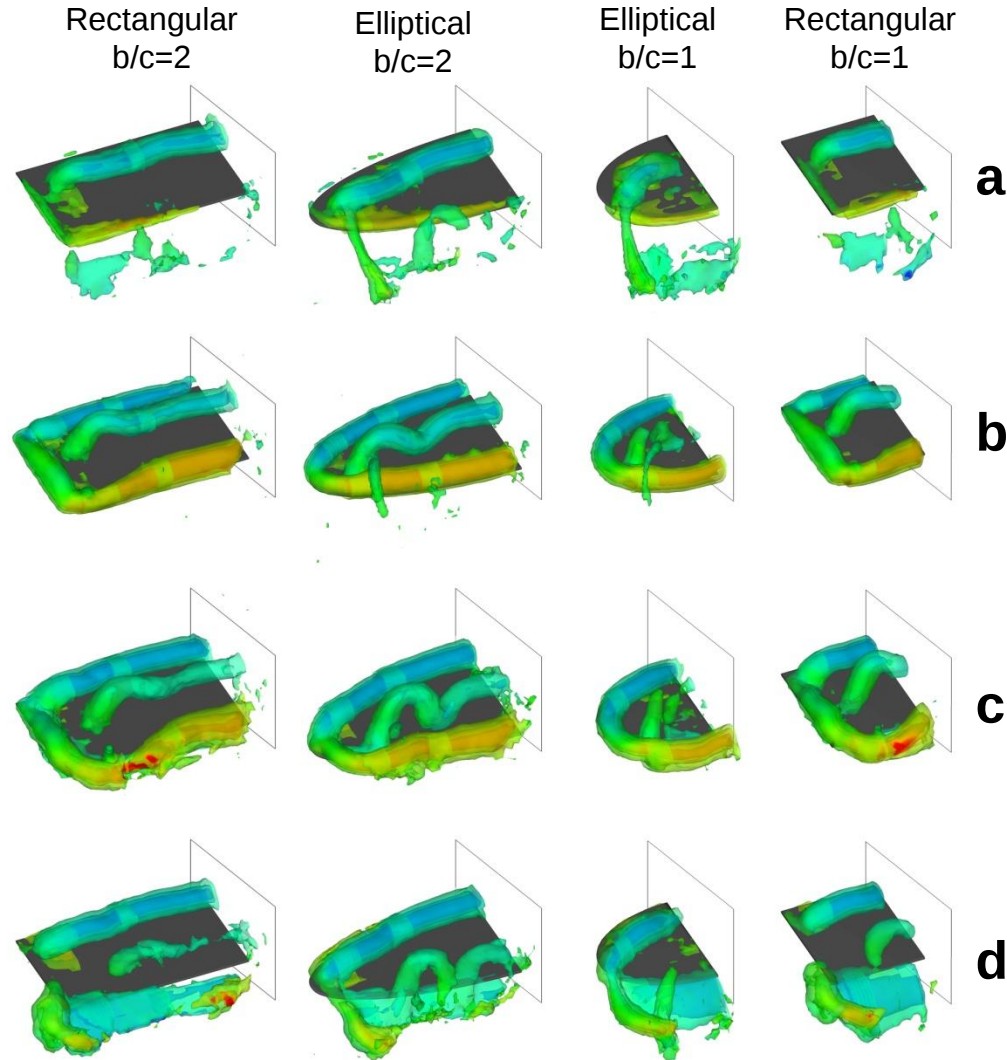


Objectives:

- (i) exploit fluid-structure interactions to delay stall and increase lift of airfoils and wings at low Reynolds numbers
- (ii) improve maneuverability and gust response of MAVs.

Approach:

- (i) simulate aerolastic vibrations by means of ***small-amplitude plunging*** oscillations of airfoils and wings
- (ii) develop flexible wings based on this knowledge.



DISTRIBUTION A: Approved for public release; distribution is unlimited.





Flapping-Wing Vortex Formation and Scaling

M. Ringuette (YIP 2010), Buffalo

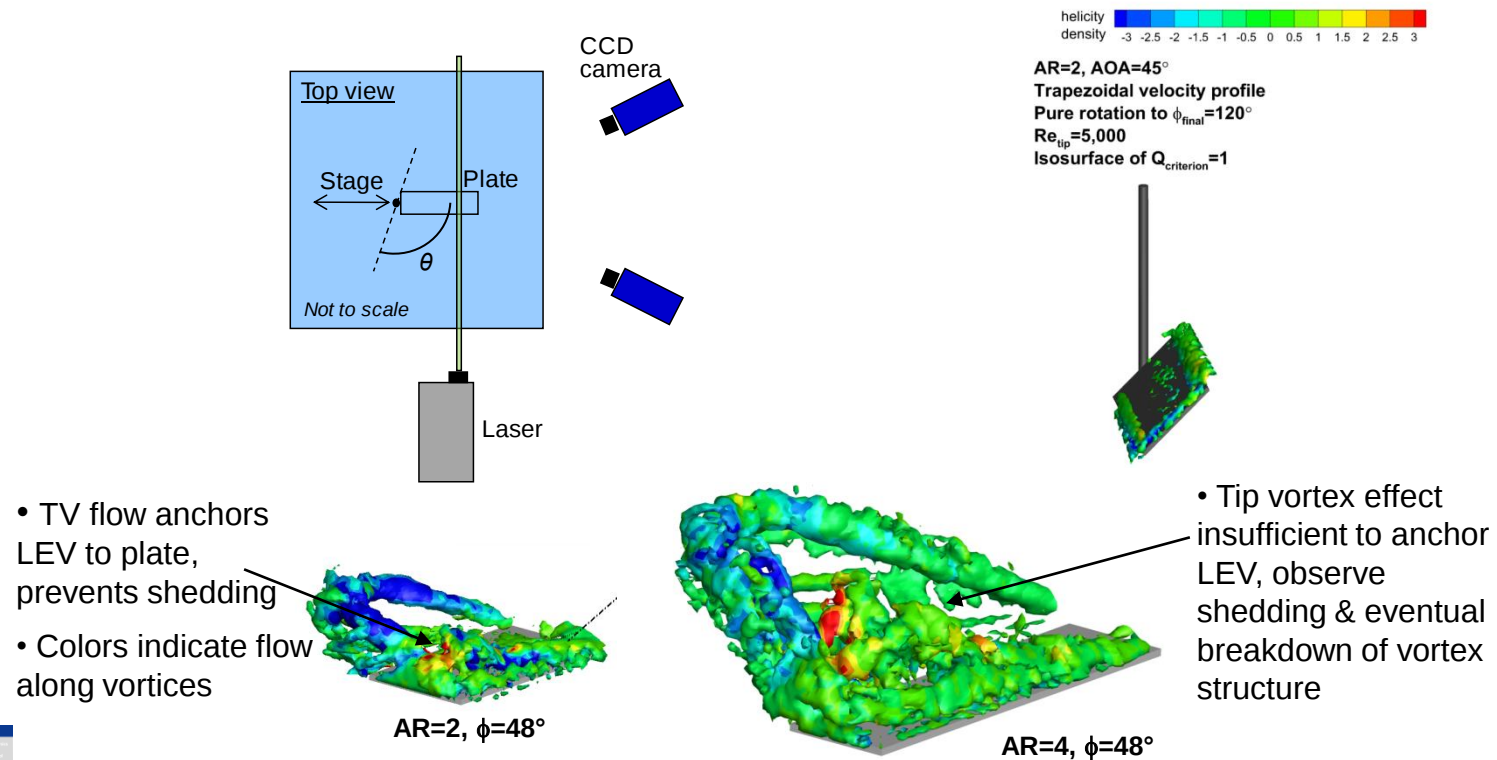


Objective ...

- find a scaling parameter connecting the vortex formation/strength to the kinematics, which should relate to important force features if a formation-parameter scaling holds

Approach ...

- characterize the general 3-D vortex topology
- track how the vortex loop evolves in space and time
- find the effects of non-dimensional parameters such as AR, Rossby no., on strength, vortex loop stability



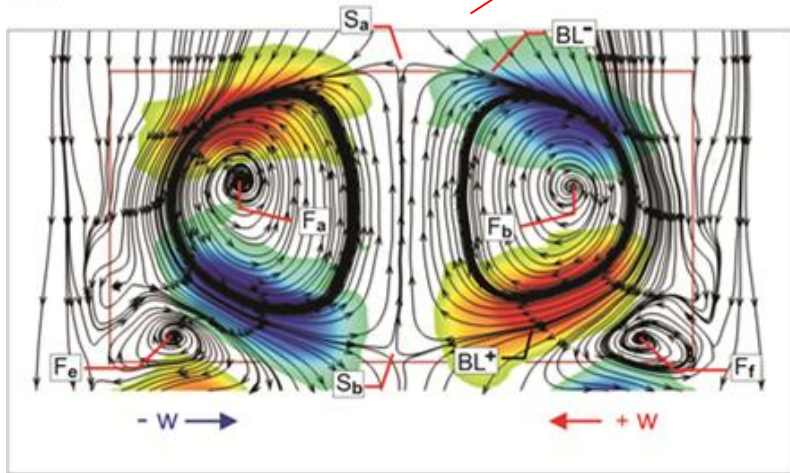
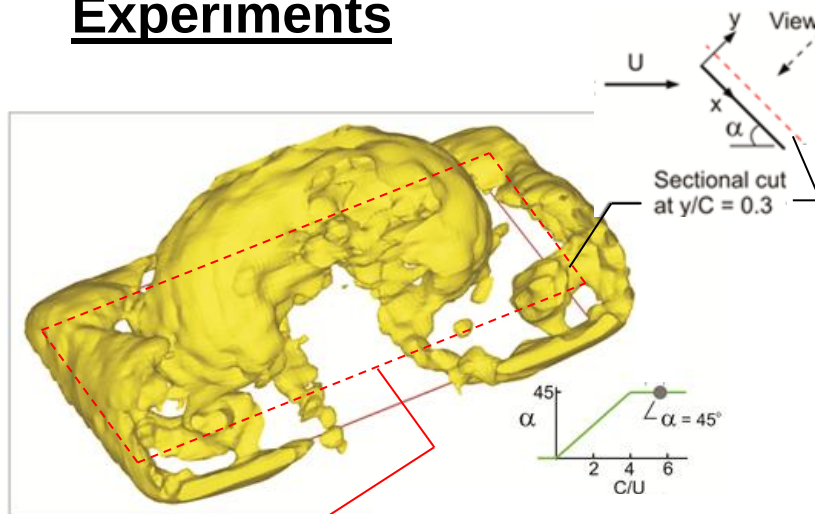


Three-dimensional Vortex Formation On A Pitching Wing



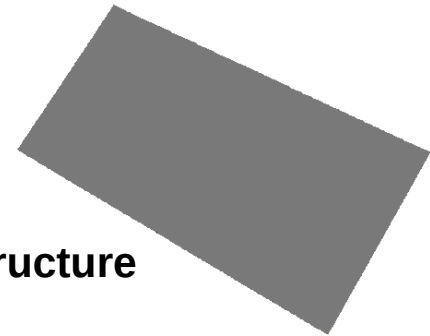
D. Rockwell (Lehigh) & M. Visbal (AFRL/RBAC)

Experiments

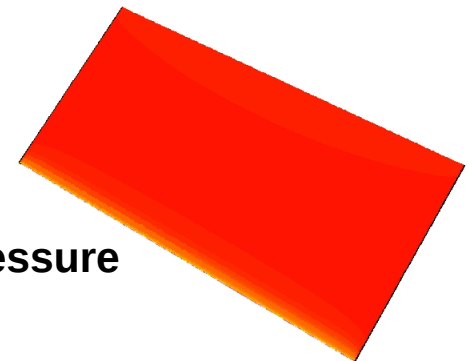


Simulations

Vortex structure



Surface pressure





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

J. Eldredge, UCLA



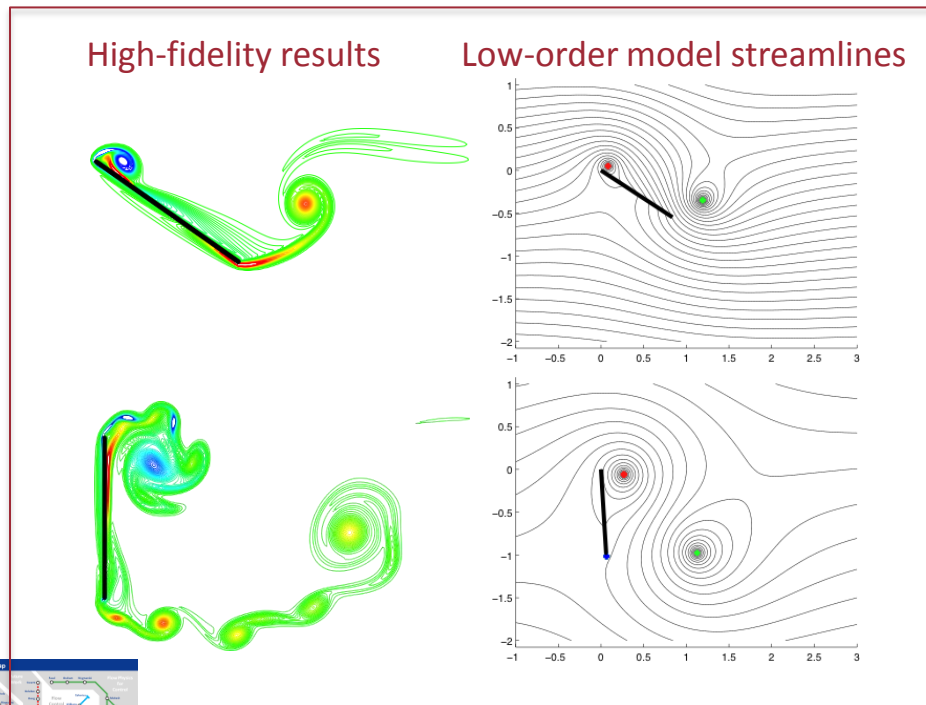
OBJECTIVES

- Develop **low-order phenomenological models** ($< \sim 10$ dof for flapping wing flight,
- Examining a progression of canonical wing motions, with both rigid and flexible wings.
- Simultaneously explore the physics of canonical wing motions using **high-fidelity numerical simulations**.

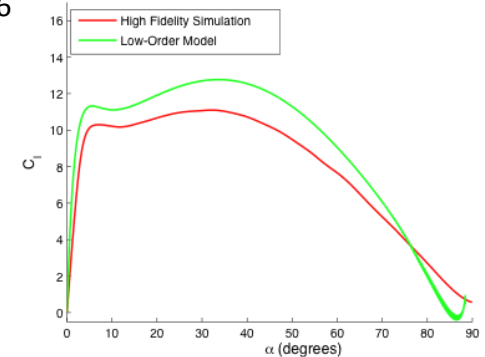
MAIN ACHIEVEMENTS

- Constructed a low-order model based on point vortex dynamics
- Successfully demonstrated that model captures force generated by a **2-d flat plate in pitch-up**
- High-fidelity simulation requires $\sim 1,000,000$ degrees of freedom; low-order model requires only 6

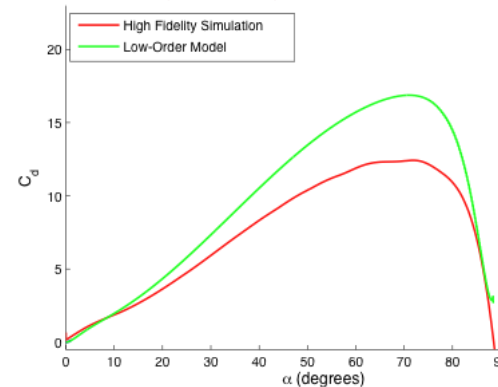
RAPID PITCH-UP



Lift vs Angle of Attack



Drag vs Angle of Attack





Energy Extraction From Unsteady Winds

Williams (IIT)/ Colonius (Caltech)

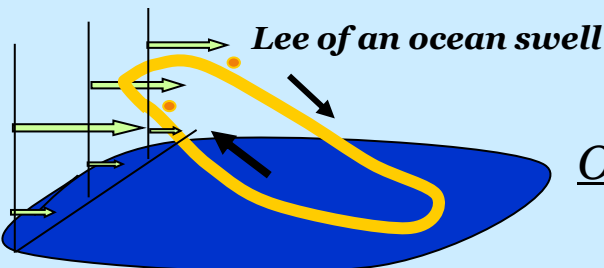
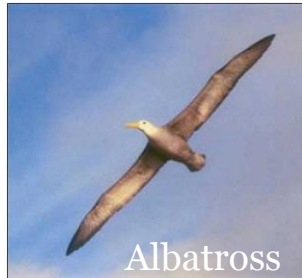


Albatross remains aloft indefinitely!

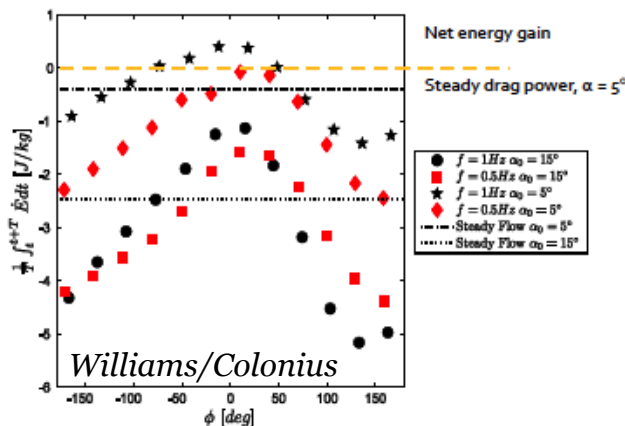
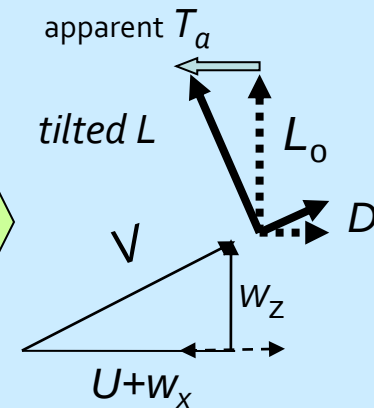
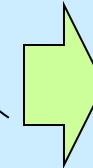
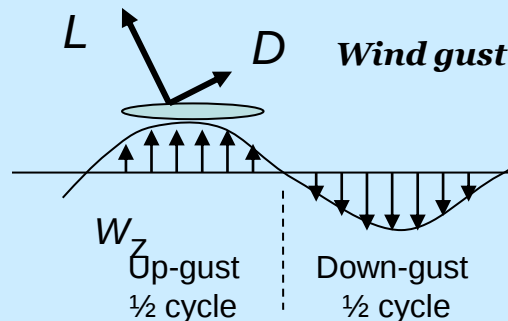
Model gliders flying at 400+ mph!!

How? ... DYNAMIC SOARING!!

Extracting energy from spatial velocity gradients in the wind.



OR



- Investigate unsteady and nonlinear phenomena relevant to gusts over wings
 - Without flow control can extract energy from flow
- Integrate active closed-loop flow with flight control
 - Demonstrate benefits of increased range and endurance by extracting energy from gusting flows



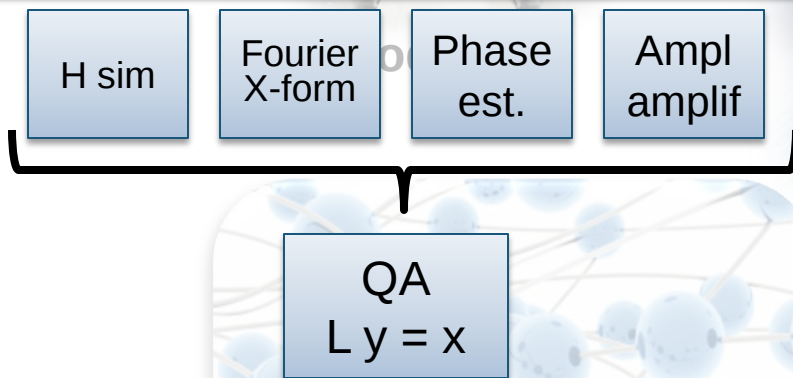
Transformational Computing in Aerospace Science & Engineering



To create transformational approaches in computing for aerospace science and engineering.

“How can we exploit quantum computing architectures specifically to advance aerospace computing?”

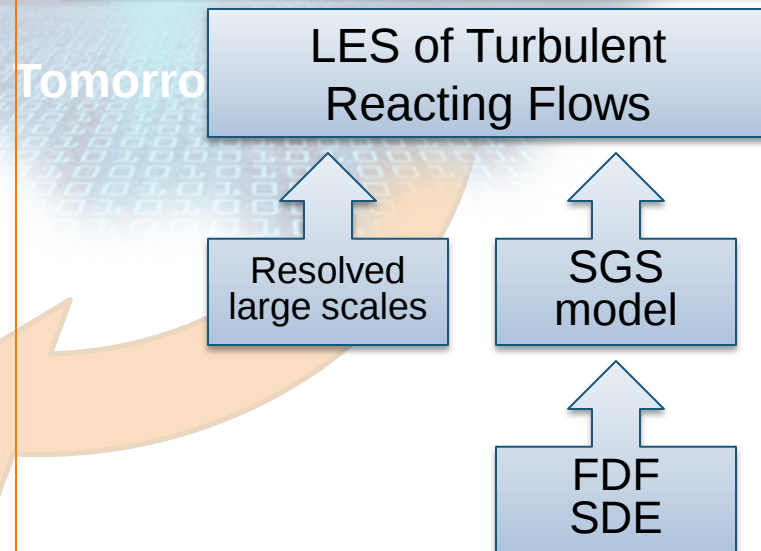
Applications of QC in Aerospace S&E *Meyer et al, UCSD*



Investigate QC improvements in...

1. Solving systems of ODEs
2. Optimization of (non)smooth fcns
3. Evolving the gnd state of a molecule

Quantum Speedup for Turbulent Combustion Simulations *Givi et al, Pitt*



- Develop quantum sim techniques for stochastic diff eqs (SDEs)