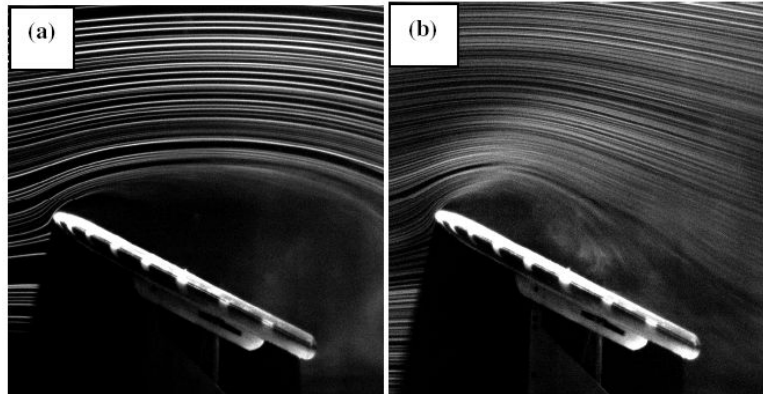


Illinois Institute of Technology Research Scholarship  
 Final Report  
 Wesley Kerstens  
 August 27, 2010

The research scholarship has provided me with an excellent opportunity to begin the process of earning a PhD in mechanical and aerospace engineering. The funding allowed me to undertake a substantial portion of research without additional work requirements. I would like to express my deepest gratitude to the source of the funding.

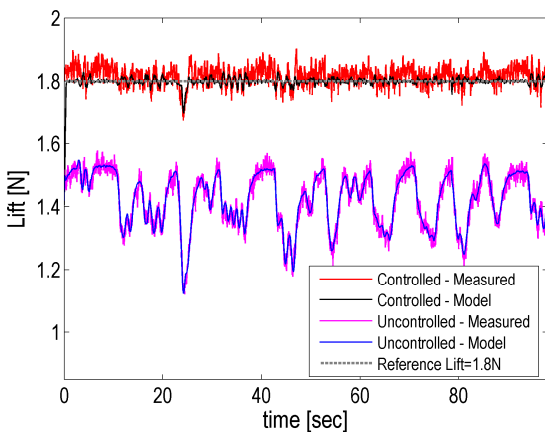
During the time I was receiving the scholarship I was able to complete a fair amount of course work towards my degree. Courses completed were: Fundamentals of Fluid Mechanics (MMAE 510), Experimental Methods in Fluid Mechanics (MMAE 516), Perturbation Methods (MMAE 508), Engineering Analysis II (MMAE 502), Modern Control Systems (MMAE 543), research credit hours (MMAE 591) and as of this fall 2010 semester I am enrolled in Continuum Mechanics (MMAE 507), Computational Fluid Dynamics (MMAE 517) and more research credit hours (MMAE 591). The scholarship enabled me to complete much more course work and research without having to hold down another job during the semester.

The research completed during the scholarship has provided insight into the fundamental flow physics in using active flow control. Active flow control is a means of controlling the fluid flow, over the suction surface of a wing in my research, which requires an external energy source. The form of active flow control used is a pulsed-blowing type, valves within a pressurized plenum are pulsed producing jets of air that have the ability to reattach a separated flow over the wing.



**Fig. 1** Smoke wire visualization of the flow over the mid-span of the wing at  $U=5\text{m/s}$ . (a) natural flow. (b) forced reattachment using active flow control forcing. (From Publication [7])

Working with a group for the Technical University of Berlin (Jens Pfeiffer and Dr. Rudibert King), we



**Fig. 2** Controlled and uncontrolled lift time series showing the substantial reduction in lift fluctuations, using active flow control, due to a time varying incident velocity (from Publication [8])

were able to model the lift response of the wing to the pulsed-blowing jets. Using these models robust closed loop controllers were synthesized that enabled us to maintain a nearly constant lift force during a longitudinally oscillating velocity. The modeling of the lift response showed a time delay in response to actuation. This time delay was found to be related to the separated flow's response to actuation. This time delay limits the range of possible frequencies that can be controlled using active flow control. The result is interesting in its own right, but the way in which we discovered it is also interesting. In approaching the experiments from the control theory community's point of view, we were lead to a fundamental, fluid dynamic, limitation.

The work has recently shifted slightly to enable small-unmanned aerial vehicles to fly longer by extracting energy from an unsteady flow, as opposed to damping the fluctuations caused by the unsteadiness. In a vertically gusting velocity field the

effective angle of attack changes as the relative angle of the velocity with respect to the wing changes. The lift force vector is always perpendicular to the instantaneous velocity vector. This means that when the effective angle of attack is increasing the lift vector tilts forward and creates a component of force that opposes the drag on the vehicle. By using active flow control and maneuvering the vehicle in response to gusting flows, we intend to show substantial reductions in energy requirements needed for small vehicles in gusting conditions. This work would also be applicable to wind turbine blades, creating the possibility of increasing the energy output of the turbines by utilizing the unsteady component of the wind that is currently not utilized to its full potential.

#### **Publications:**

- [1] David Williams, Gilead Tadmor, Tim Colonius, Wesley Kerstens, Vien Quach, Seth Buntain, "The Lift Response of a Stalled Wing to Pulsatile Disturbances" *AIAA Journal*. **47** (2009)
- [2] David Williams, Vien Quach, Wesley Kerstens, Seth Buntain, Gilead Tadmor, Clancy Rowley, Tim Colonius, "Low-Reynolds Number Wing Response to an Oscillating Freestream with and without Feed Forward Control," AIAA Paper 2009-143 (2009)
- [3] David Williams, Wesley Kerstens, Jens Pfeiffer, Rudibert King, Gilead Tadmor, Tim Colonius, "Closed-Loop Control of a Wing in an Unsteady Flow," AIAA Paper 2010-358 (2010)
- [4] David Williams, Seth Buntain, Vien Quach, Wesley Kerstens, "Flow Field Structures Behind a 3D Wing in an Oscillating Freestream," AIAA Paper 2009-3690 (2009)
- [5] David Williams, Gilead Tadmor, Tim Colonius, Seth Buntain, Vien Quach, Wesley Kerstens, "The Lift Response of a Stalled Wing to Pulsatile Disturbances," APS Abstract BAPS.2009.DFD.LD.7 (2009). <http://meetings.aps.org/link/BAPS.2009.DFD.LD.7>
- [6] Tim Colonius, David Williams, Gilead Tadmor, Wesley Kerstens, Seth Buntain, Vien Quach, "Scaling of Transient Lift Response to Actuation in a 3D Separated Flow," APS Abstract BAPS.2009.DFD.AD.6 (2009) <http://meetings.aps.org/link/BAPS.2009.DFD.AD.6>
- [7] David Williams, Wesley Kerstens, Jens Pfeiffer, Rudibert King, Tim Colonius, "Unsteady Lift Suppression with a Robust Closed Loop Controller". In R. King (Ed), *Active Flow Control II*, NNFM 108, Springer-Verlag, Heidelberg, Germany, 2010, pp.19-30
- [8] Wesley Kerstens, Jens Pfeiffer, David Williams, Rudibert King, Tim Colonius, "Closed Loop Control of a Wing's Lift for Gust Suppression," AIAA-2010-4969 (2010)
- [9] Quach, V., Kerstens, W., Williams, D., Tadmor, G. and Colonius, T., "Transient Response of a Wing to Arbitrary Actuator Input," ICJWSF Sep. 2010 [Accepted].
- [10] Wesley Kerstens, Jens Pfeiffer, David Williams, Rudibert King, Tim Colonius, "Closed Loop Control of a Wing's Lift for Gust Suppression," [Submitted for Publication]

#### **Presentations:**

- [1] Wesley Kerstens, "Closed Loop Control of a Wing's Lift for Gust Suppression," AIAA 5<sup>th</sup> Annual Active Flow Control Conference, Chicago, IL June 28-July 1, 2010