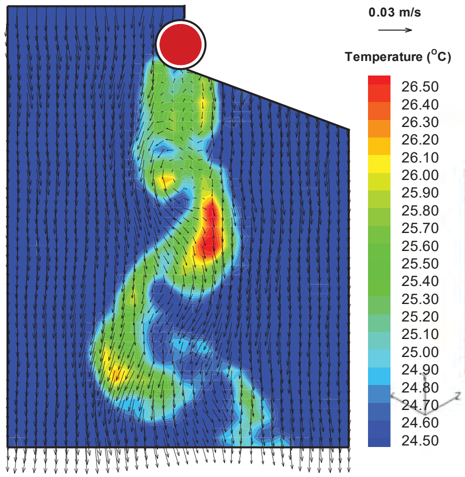
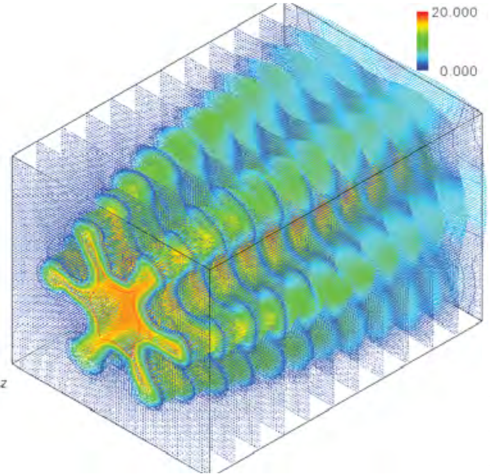
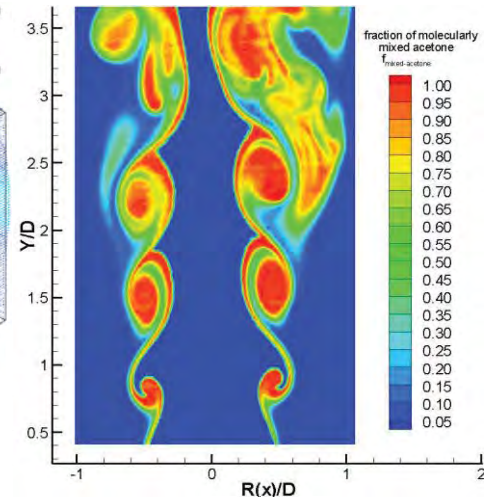


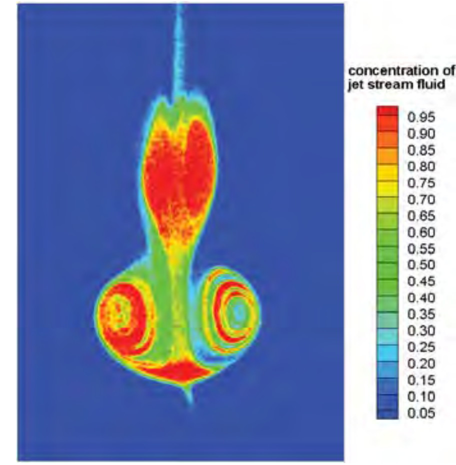

*MTV&T*




*Stereo PIV*




*PLIF*




*QD imaging*

# Summary of Recent Research Activities


**Dr. Hui HU**

*Martin C. Jischke Professor in Aerospace Engineering*

*Director, Advanced Flow Diagnostics & Experimental Aerodynamics Laboratory*

*Department of Aerospace Engineering,*

*Iowa State University, 2251 Howe Hall, Ames, IA 50011-2271*

*Email: huhui@iastate.edu*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- ***Development of advanced flow diagnostic techniques and instrumentation:***
  - ***Particle-based*** *flow diagnostic techniques:*
    - *Laser Doppler Velocimetry (LDV)*
    - *Particle Image Velocimetry (PIV) techniques: 2-D PIV, Stereoscopic PIV, Dual-plane Stereoscopic PIV.*
  - ***Molecule-based*** *flow diagnostic techniques:*
    - *Planar Laser Induced Fluorescence (LIF)*
    - *Molecular Tagging Velocimetry (MTV) /Molecular Tagging Thermometry (MTT)*
    - *Pressure Sensitive Paint (PSP) / Temperature Sensitive Paint (TSP)*
    - *Digital Image Projection (DIP)*

- ***Fundamental studies of complex thermal-flow phenomena:***
  - *Icing physics and anti-/de-icing; aircraft icing ; aero-engine icing; wind turbine icing.*
  - *Heat transfer of gas turbines ;film cooling; trailing edge cooling;*
  - *Spray flow characterization ; liquid fuel atomization of gas turbines*
  - *Wind turbine aeromechanics; wind farm aerodynamics and wake interference.*
  - *Bio-inspired flows, bio-inspired aerodynamic designs for UAS /UAV applications.*
  - *Low-speed aerodynamics, laminar boundary layer flow transition and flow control.*
  - *Microfluidics, micro-flows and micro-scale heat transfer.*
  - *Wind engineering, flow-structure interactions of built structures with strong winds.*

# Research Portfolio

***Advanced Flow Diagnostic Technique Development and Instrumentation***

*Icing Physics, Aircraft icing and de-/anti- icing technologies*
*(Funding Source: NASA, FAA and NSF)*

*Liquid Fuel atomization and spray flow characterization*
*(Funding source: NSF, DoE,UTAS, Honeywell )*

*Wind Energy and Wind Turbine Aeromechanics*
*(Funded by NSF, DoE,)*

*Bio-inspired aerodynamics and bio-inspired MAV /UAV/UAS designs*
*(Funding source: AFOSR/ARO, NSF)*

*Microfluidcs & Nanofluidics, Micro-scale heat transfer*
*(funding source: NSF/AFOSR)*

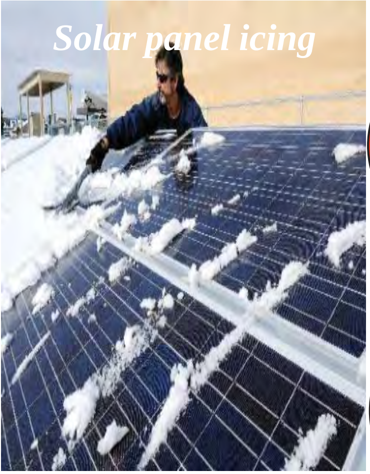
*Wind Engineering, and Flow Structure Interaction (FSI)*
*(NSF / NOAA)*

*Cooling Technology & Heat Transfer of Gas Turbines*
*(funding source, AFOSR, DoE, GE)*

# ISU Research Initiative for Icing Physics and Anti-/De-icing Technology








*NDE, MEMS sensors for in-flying icing detection*

*Experimental aerodynamics & wind tunnel testing*

*CFD &multiphase modeling*

*UAS/MAV, Rotorcraft, wind turbine, power lines*

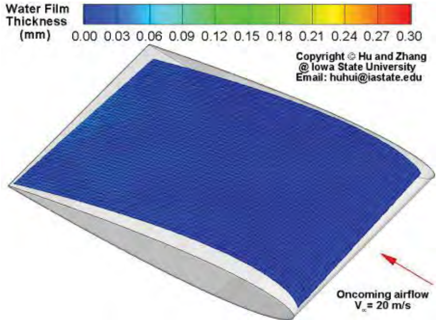
## *Center for Icing Physics & Anti-/De-icing Technology*

*Syetem design and MDO for anti-/de-icing strategy*

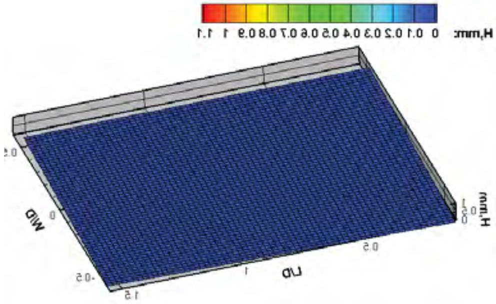
*Aero-structure designs for icing mitigation & protection.*

*Smart materials, Micro & Nano Mechanics*

*Super-hydrophobic coatings and surface engineering*

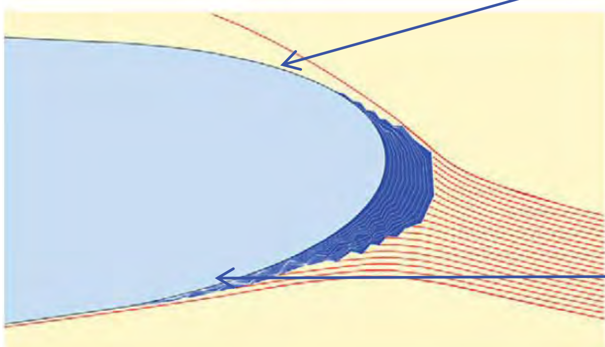





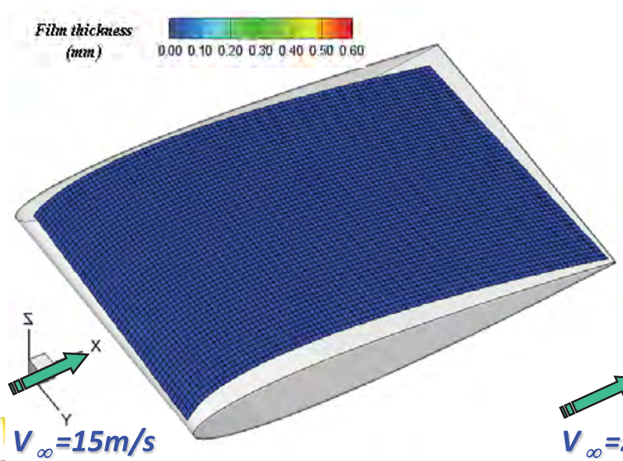


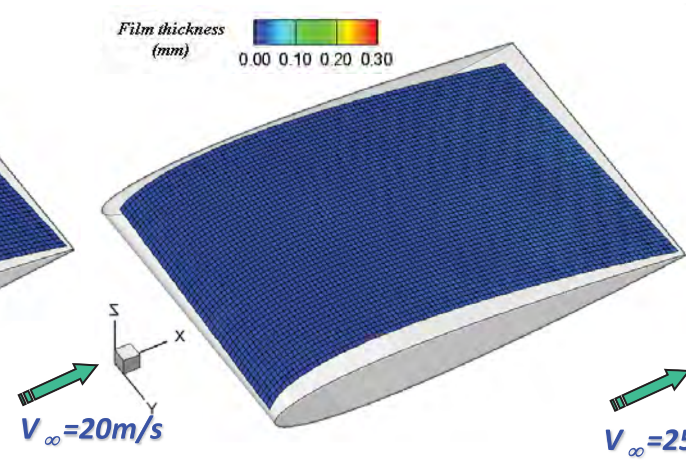
# Aircraft Icing Physics and Anti-/De-Icing Technologies (Funded by NASA, NSF, DoD)

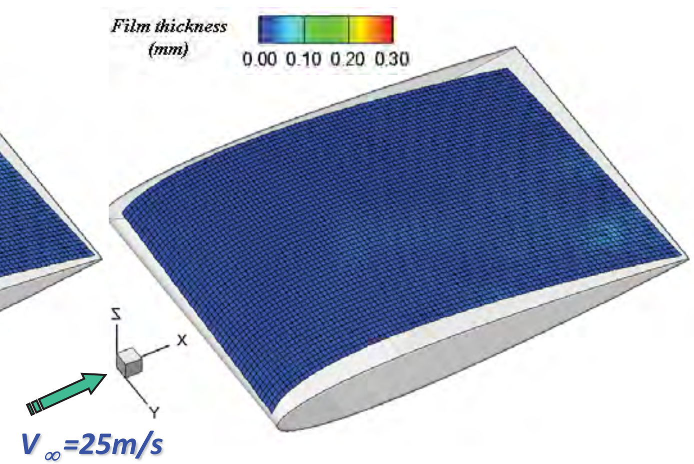
- *Test Conditions*
  - *Oncoming airflow velocity :* $V_{\infty} \approx 35$ m/s
  - *Angle of attack of the airfoil:* $\alpha \approx 5$ deg.
  - *Airflow Temperature :* $T \approx -8$ °C.
  - *Liquid water content (LWC) :* LWC =3.0 g/m$^3$
  - *Image acquisition rate* $f$ = 150Hz, 10X replay





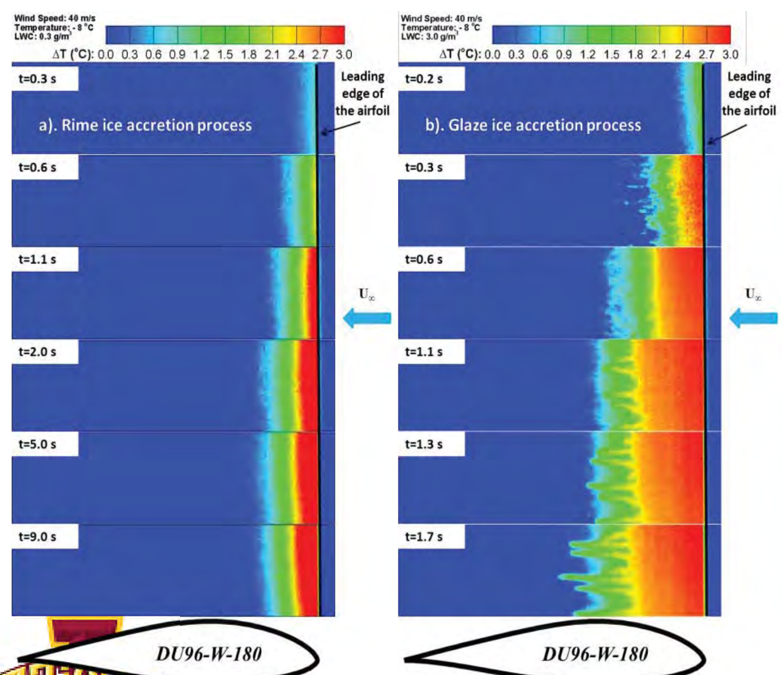


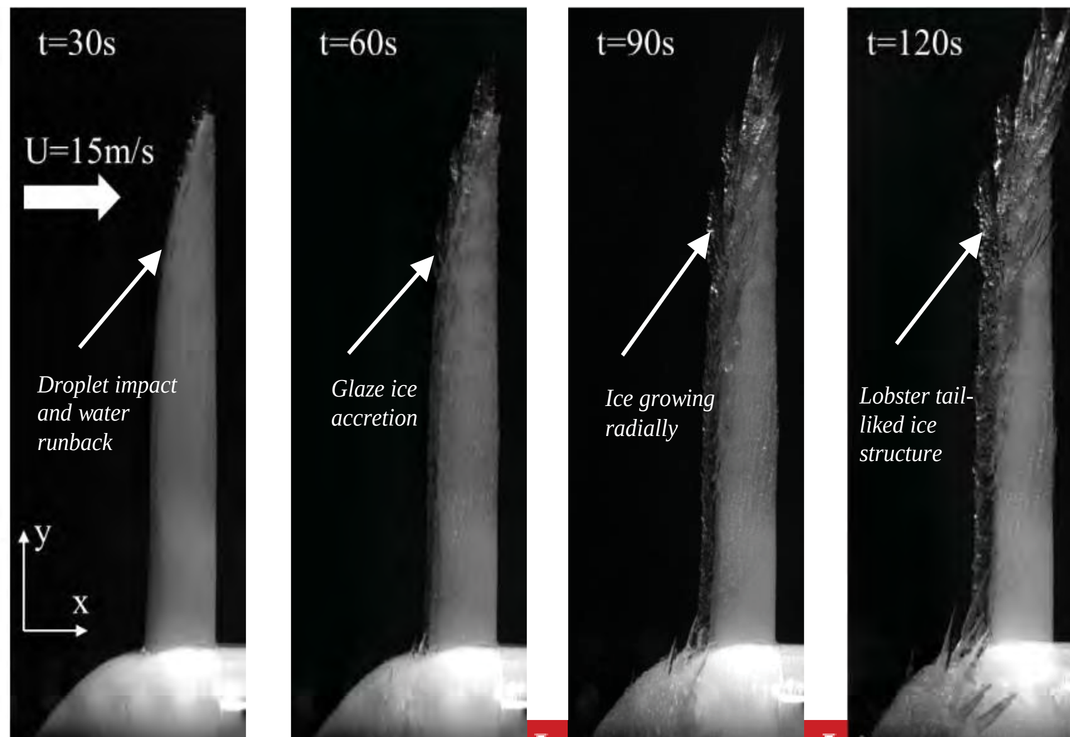



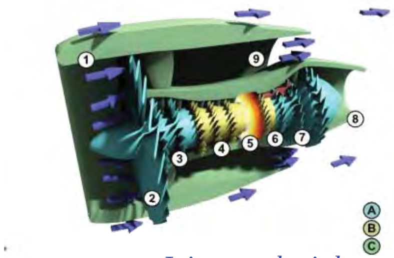

*(Waldman R. and Hu H., 2016, Journal of Aircraft, Vol.53(2), pp369~377)*

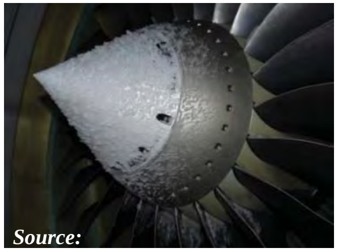
# Wind Turbine Icing and Anti-/De- Icing Techniques (Funded by NSF, DoE)



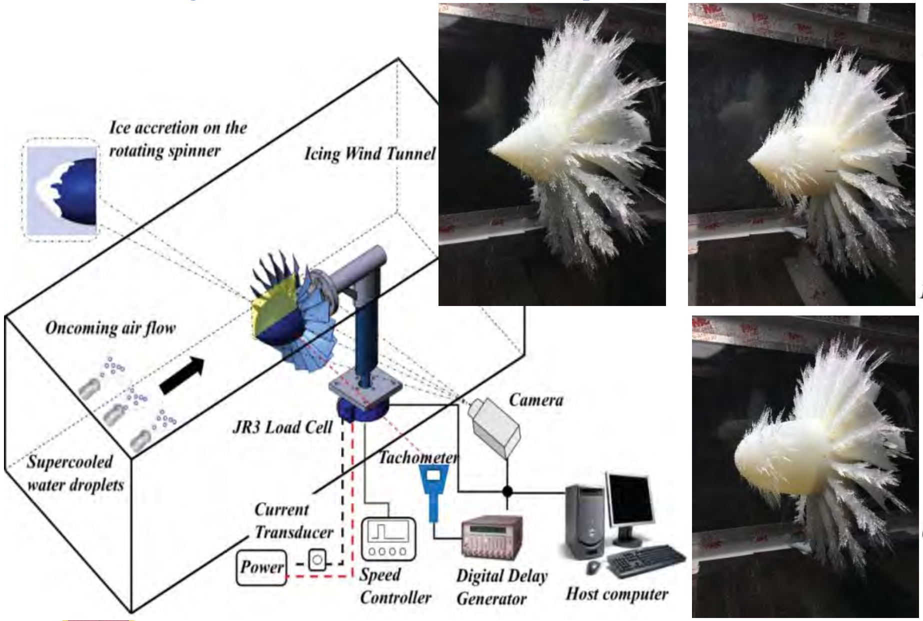
# Aero-engine ice and Anti-/De-icing






Icing on the inlet and spinner of aero-engines


- Aero- engine icing event hits an AirBridge Cargo-operated Boeing 747-8F on 07/31/2013 to cause power loss.

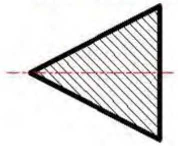



Rolls-Royce | Pratt & Whitney (A United Technologies Company) | GE Aviation

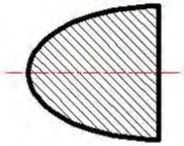
- RR Trent-XWB

- PW 1000G

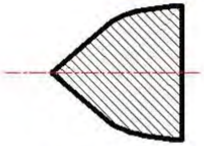
- GE 90



- Conical



- Elliptical



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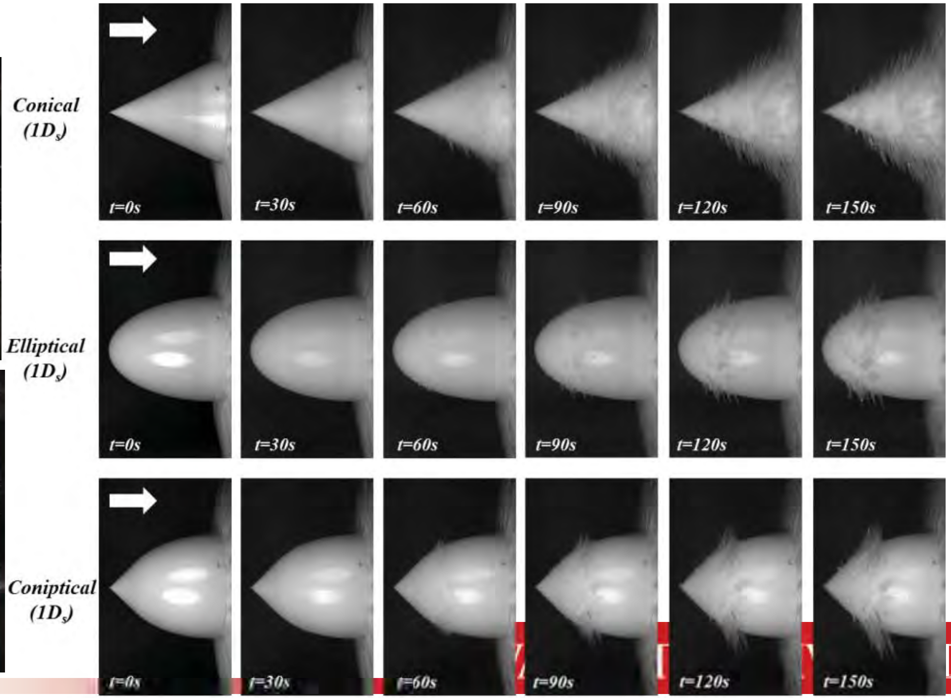
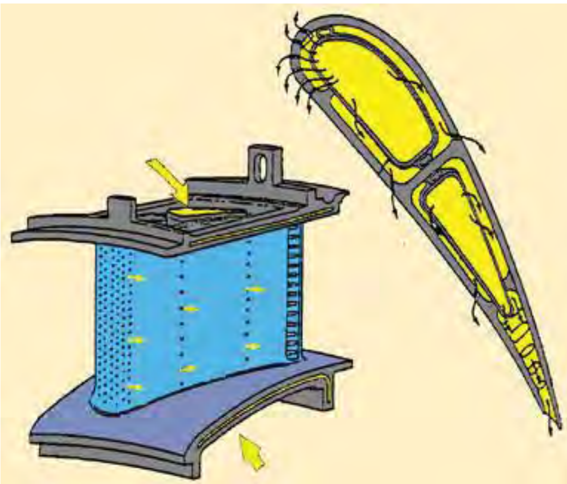
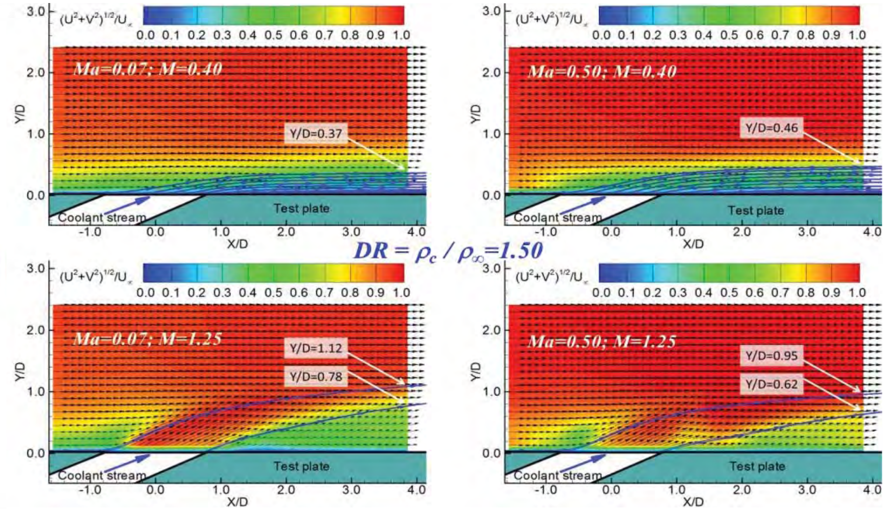
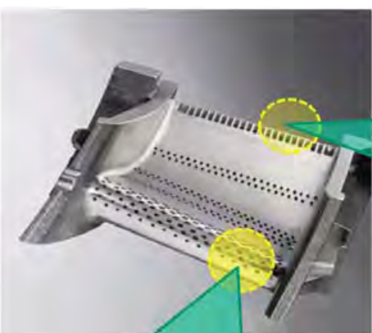


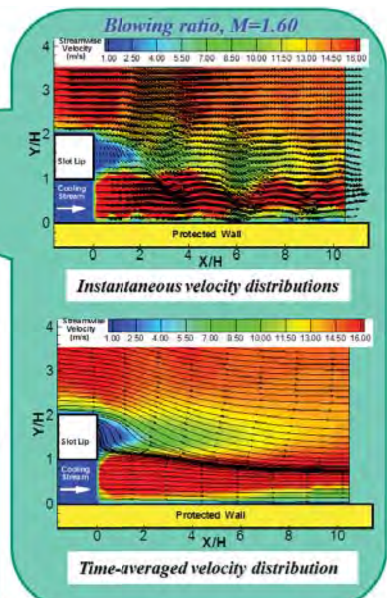
# Heat Transfer of Gas Turbines and Cooling Technology (Funded by GE and DoE)





Trailing edge cooling

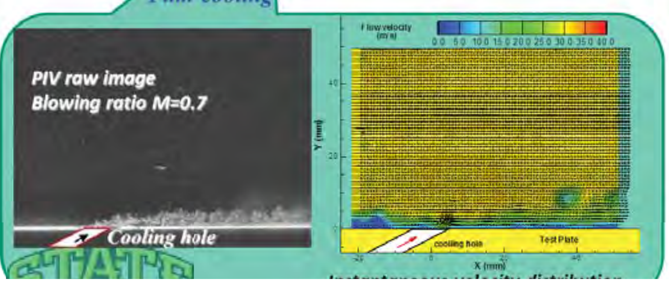


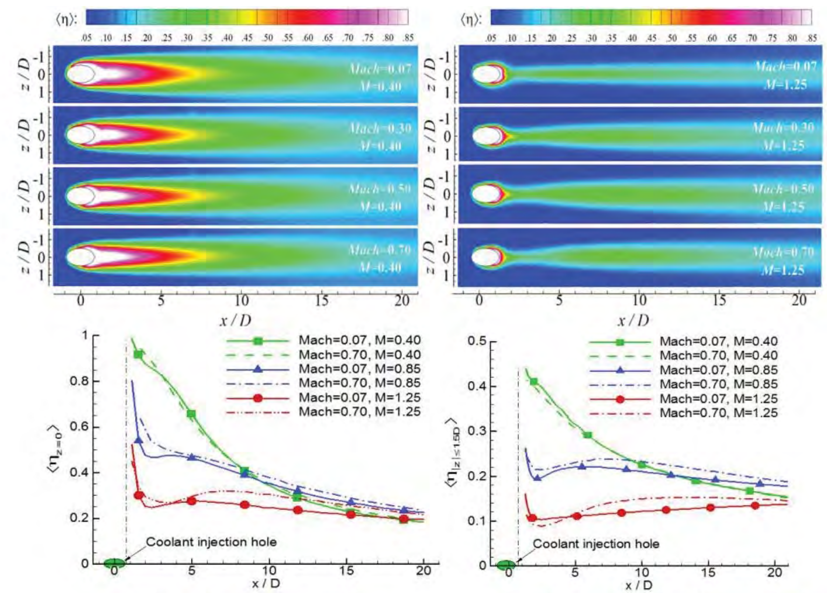

Instantaneous velocity distributions

Time-averaged velocity distribution

- Heat transfer
- Mass transfer
- Momentum transfer
- ....

Film cooling



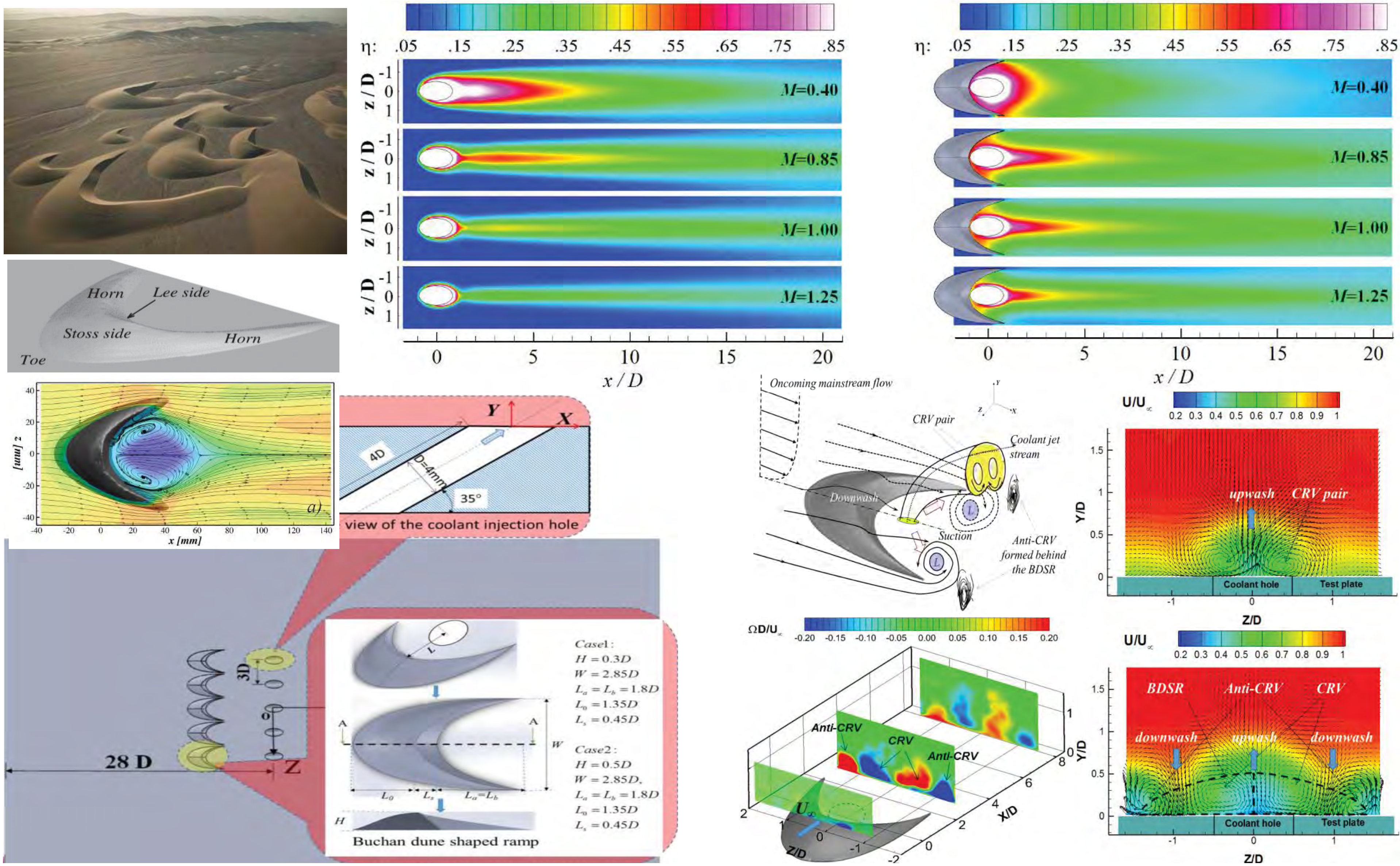




Centerline cooling effectiveness profiles

Laterally-averaged cooling effectiveness profiles

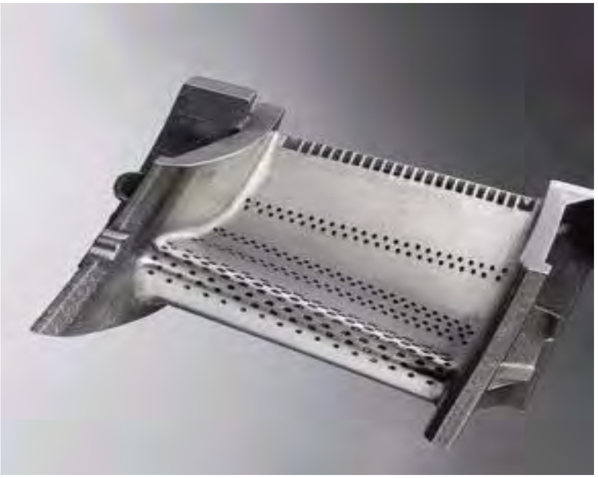
- (Zhou, Johnson & Hu, AIAA Journal of Propulsion and Power, 2016)

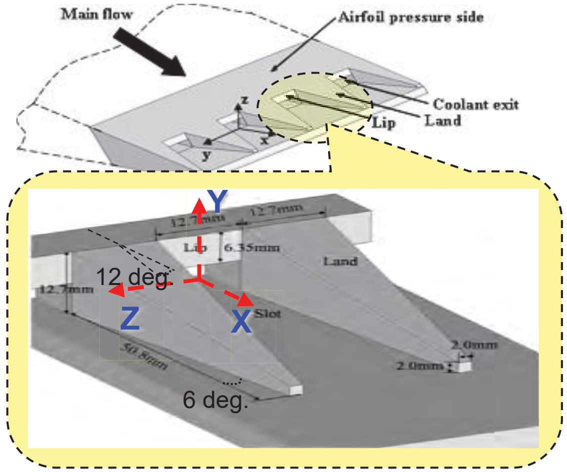
# Barchan-Dune-Inspired Design for Improved Film Cooling Effectiveness (USA Patent Pending)

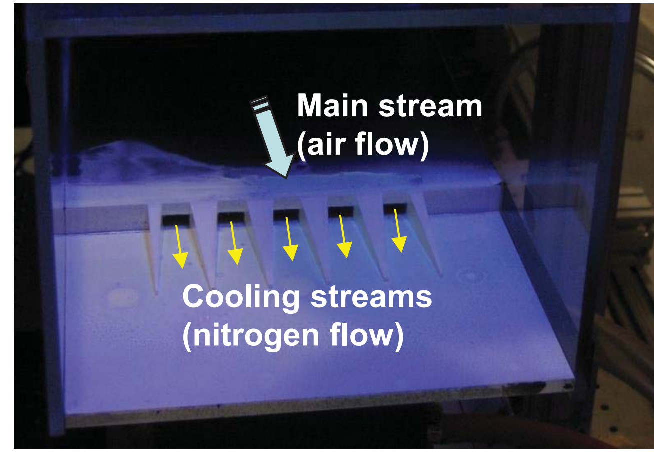



- *(Zhou & Hu, International Journal of Heat and Mass Transfer, Vol. 103(12), 2016. pp443–456.)*

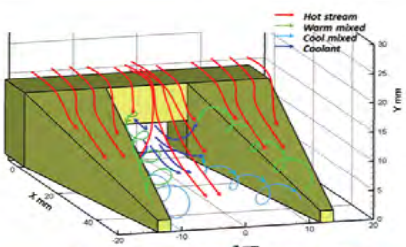
# Characterization of Trailing Edge Cooling of Turbine Blades

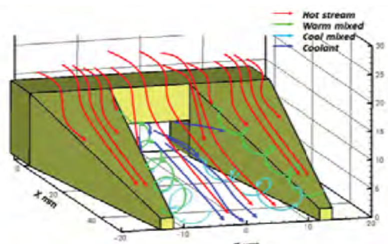




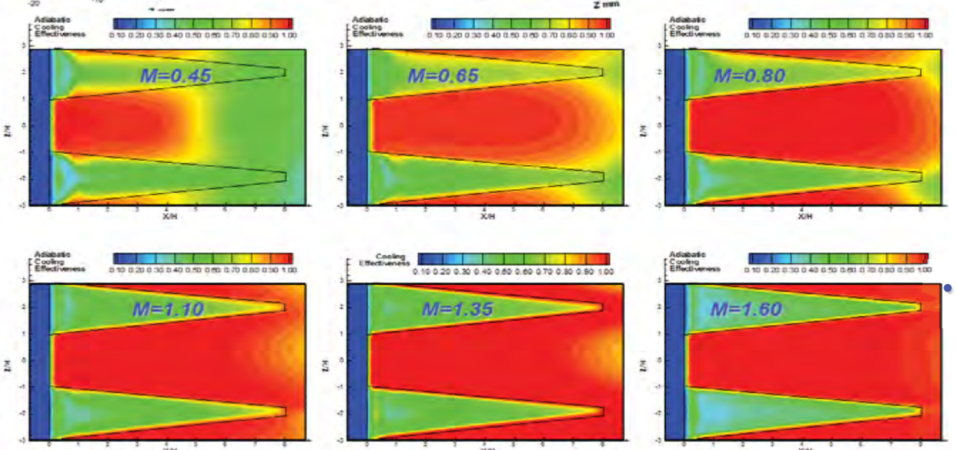




*At a lower blowing ratio, M < 1.0*

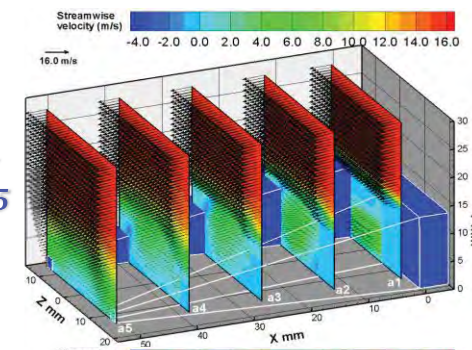


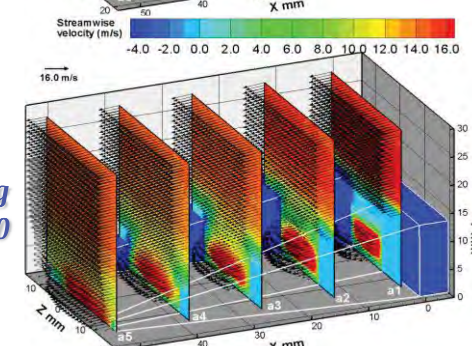

*At a higher blowing ratio, M > 1.0*


- *Low blowing ratio, M=0.45*

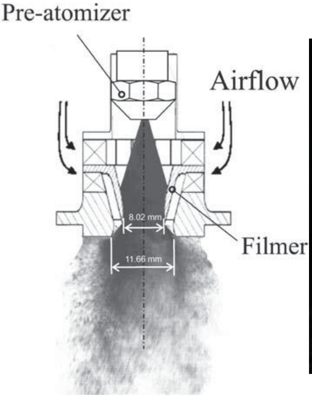


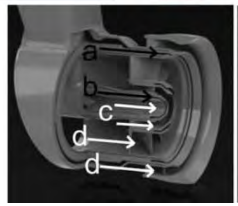

- *High blowing ratio, M=1.60*

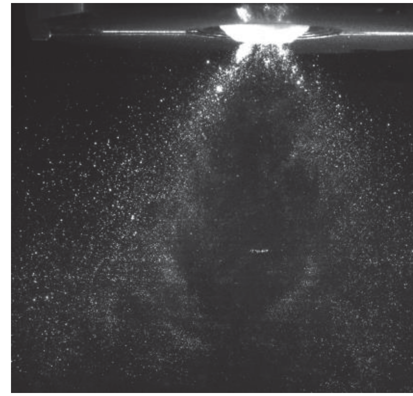


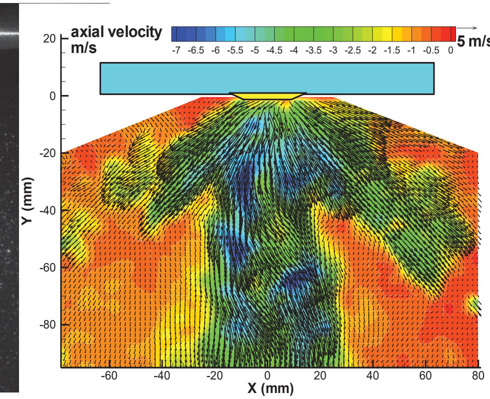

- *(Yang and Hu, AIAA J. of Power and Propulsion, Vol.27, No.3, pp700-709, 2011)*

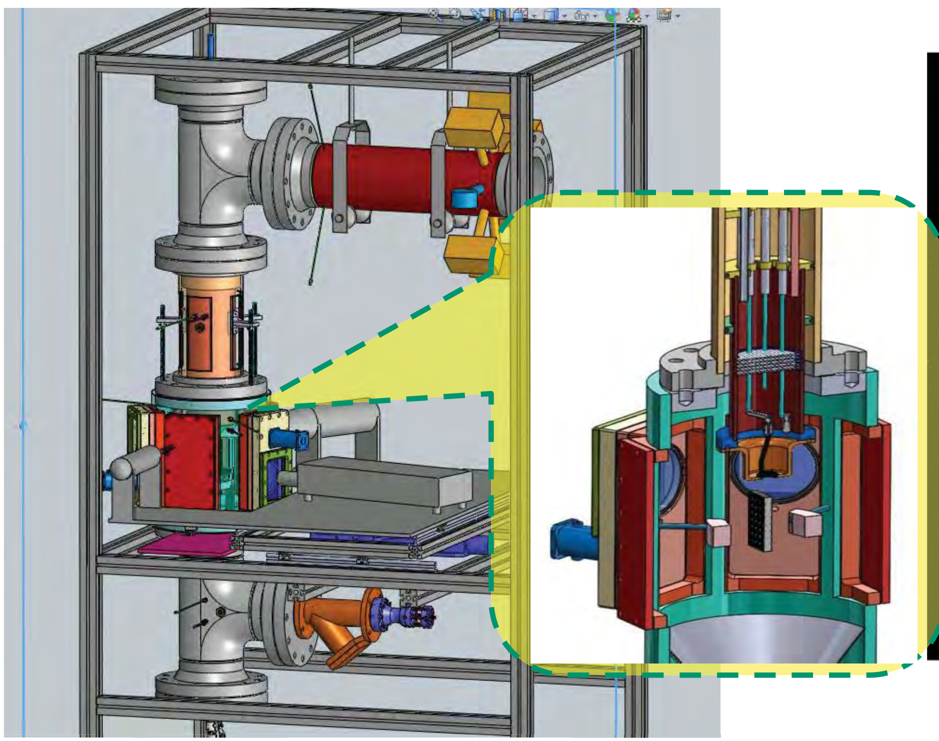
# Characterization of Liquid Fuel Injectors/Atomizers of Gas Turbines
# ( Funded by DoE, NSF, UTAS, Honeywell)



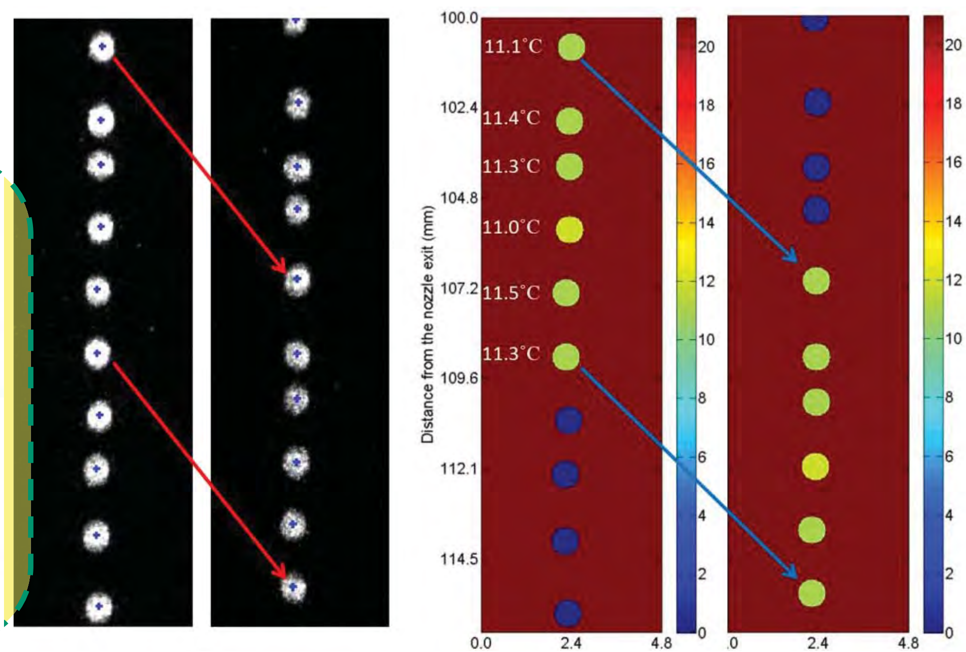





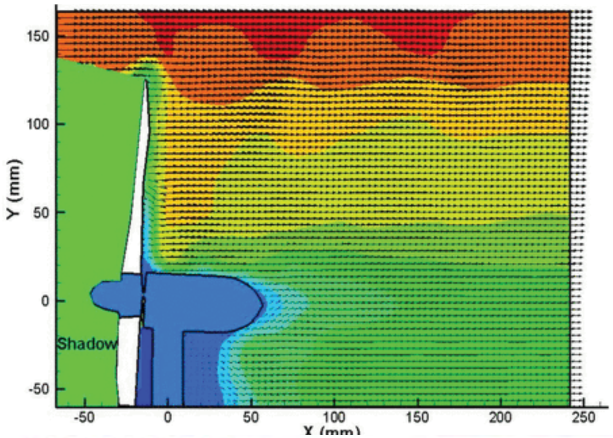
*High-pressure fuel spray test rig (~250psi, i.e., 15atm) @ Iowa State University*

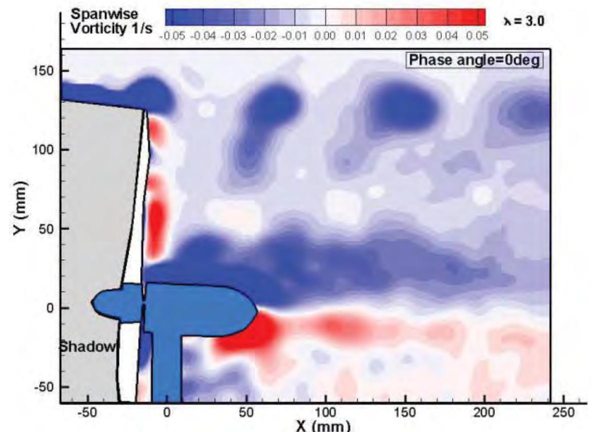


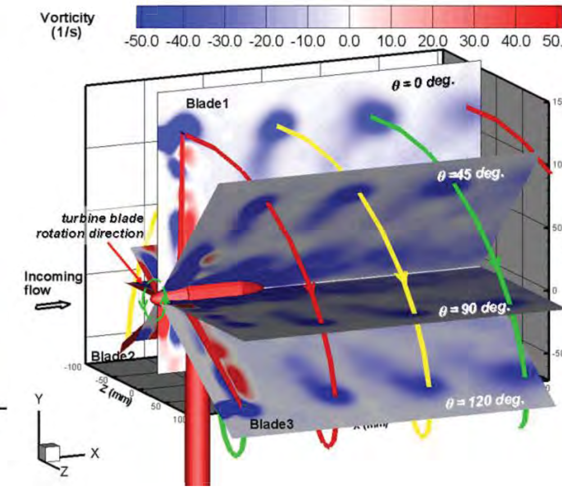

*Simultaneous measurements of droplet size, velocity and temperature of "in-flight" droplets using MTV&T technique*

- *(Hu et al. 2015, Experiments in Fluids)*

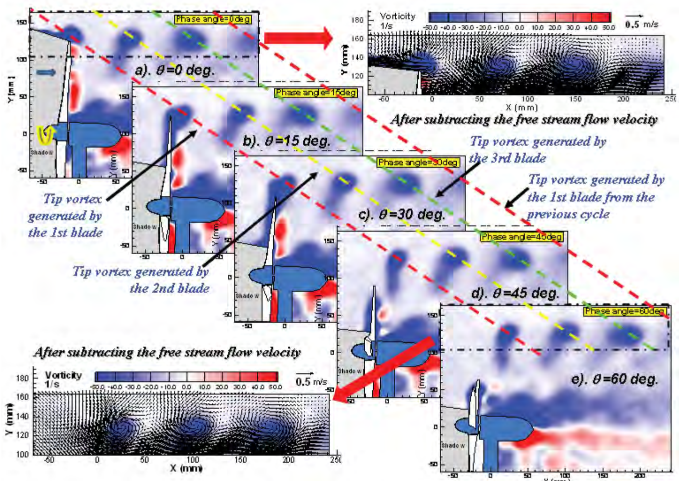
# Wind Turbine Aeromechanics and Near Wake Vortex Structures (Funded by NSF, IEC, IAWIND, DoE)

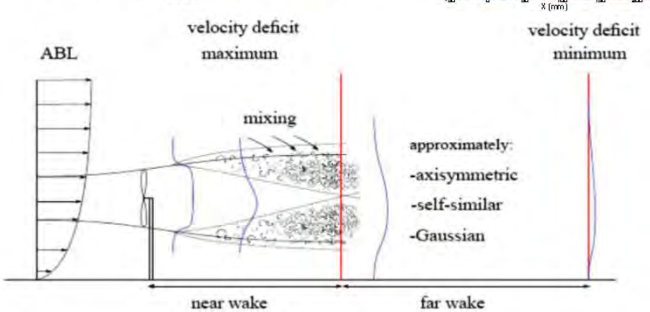


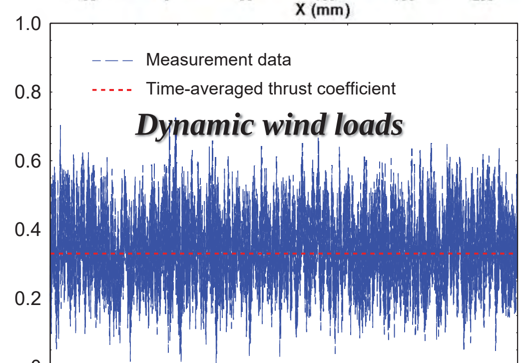



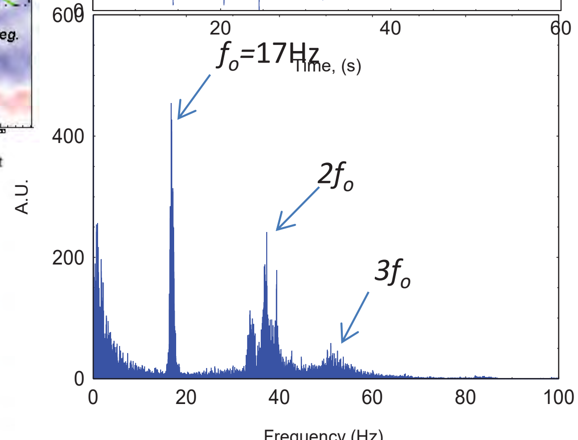



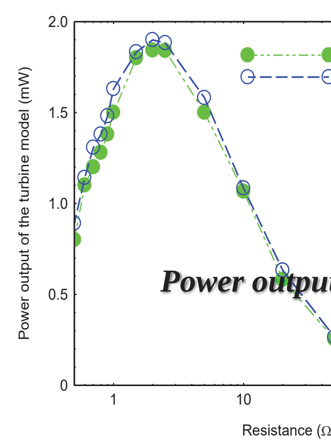

*3-D wake vortex structures*

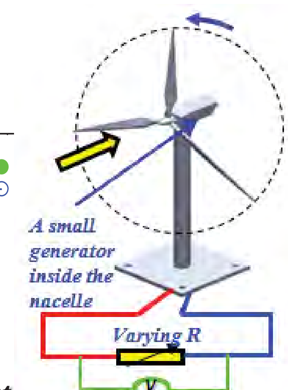



*( Hu et al. Exp. Fluids, 2011)*

*Currently funded by DoE and IAWIND*

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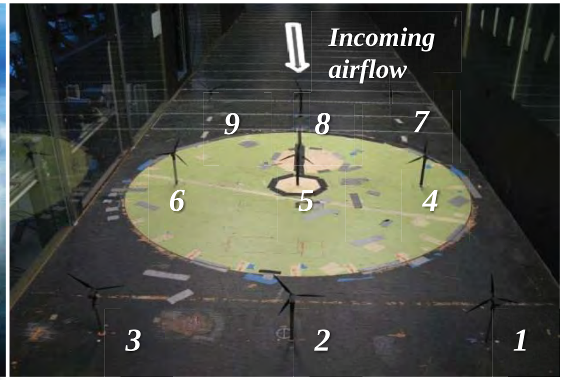
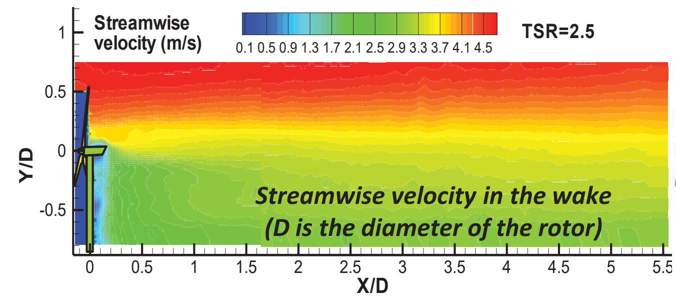
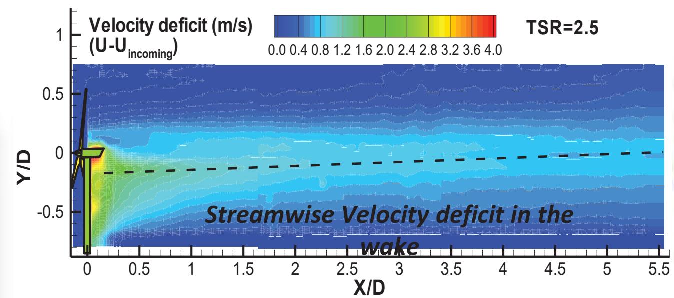
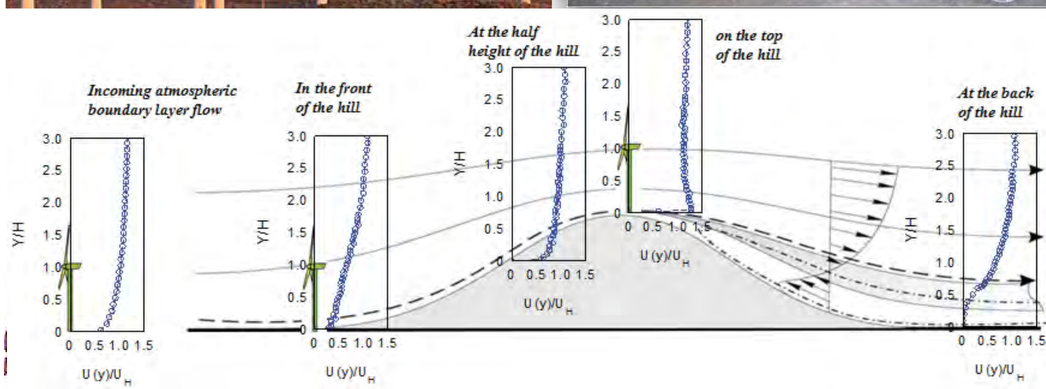
# Wind Turbine Aeromechanics over Complex Terrains
# (Potential Funding Sources : NSF, DoE,)

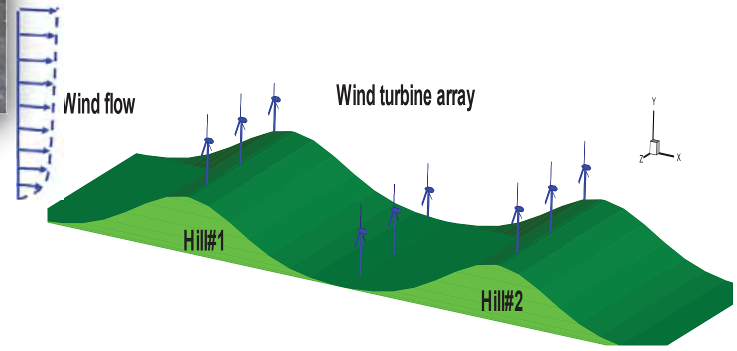






*Currently funded by DoE and NSF*

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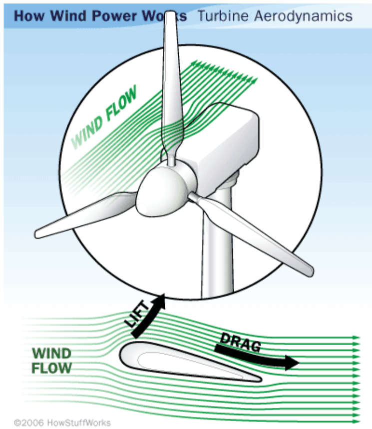
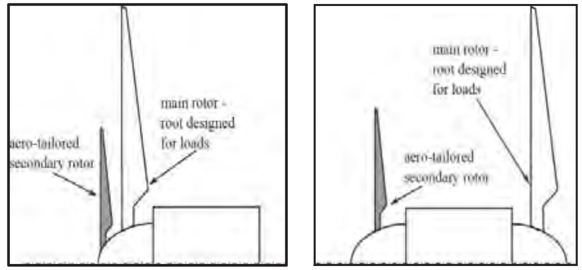
# Novel Wind Turbine Designs for Improved Performance and Durability (Funding Sources : NSF, IEC)

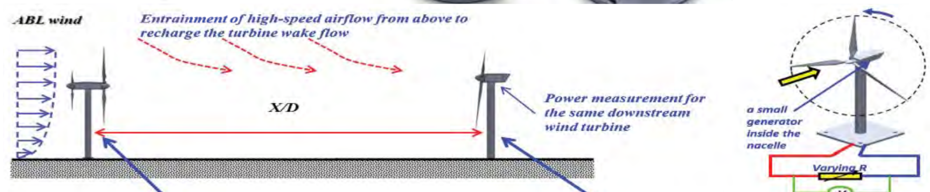


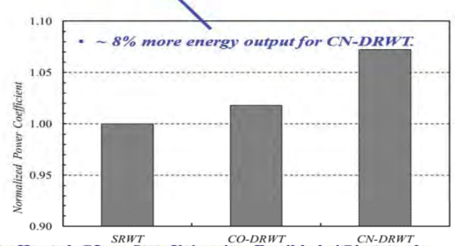



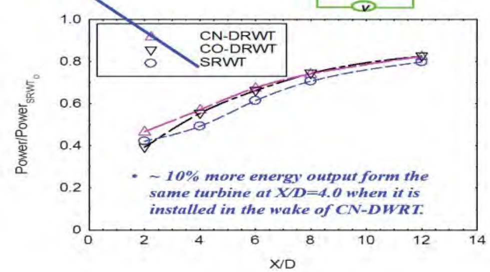

Two DRWT concepts

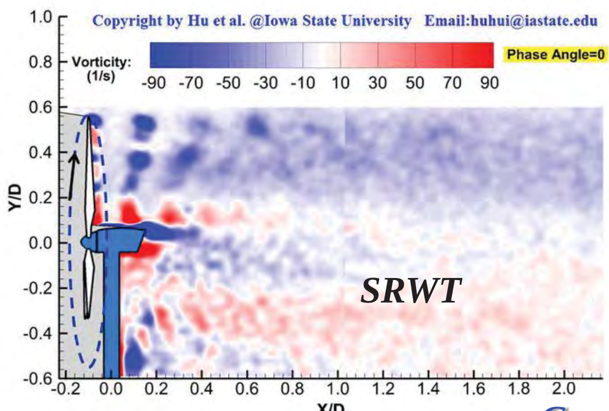
- $H_{hub}$ = 225mm
- $D_{main\ rotor}$= 140mm
- $D_{2nd\ rotor}$= 70mm

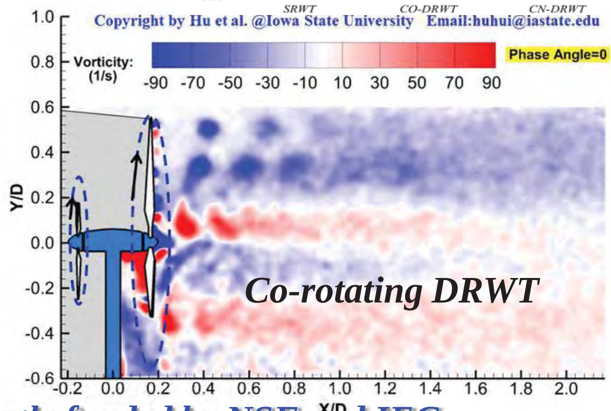
*1:350 scale ratio to simulate a 2MW turbine with diameter of 90mm*

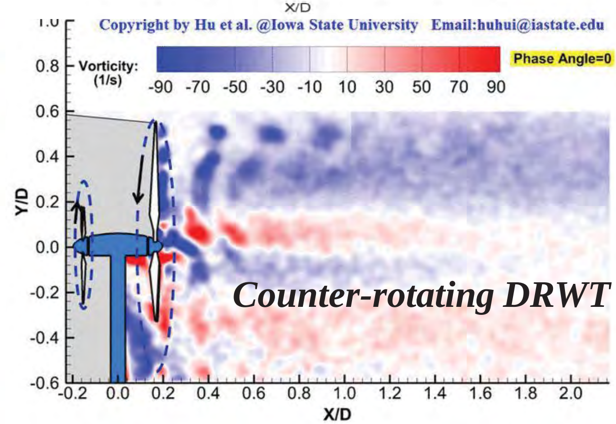


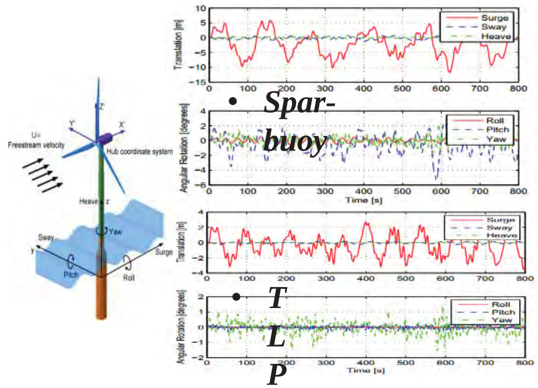



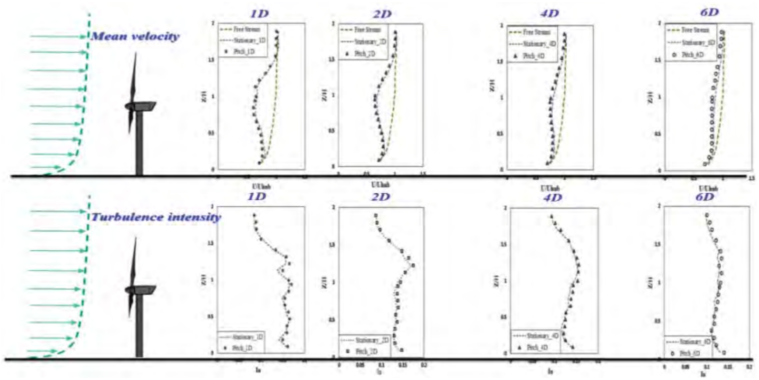



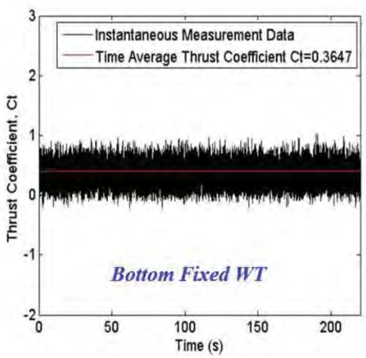



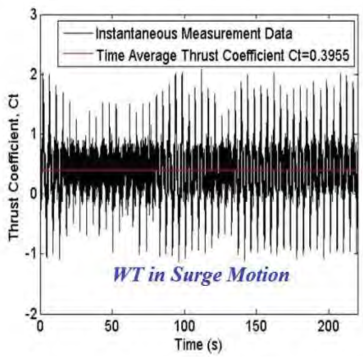

*Currently funded by NSF and IEC*

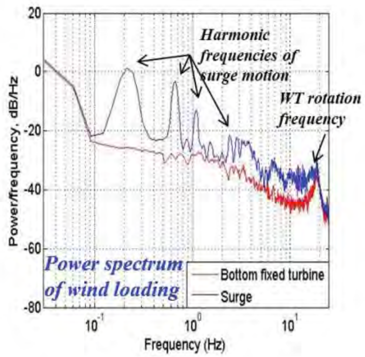
# Effects of Base Motion on the Aeromechanic Performance of Floating Offshore Wind Turbines

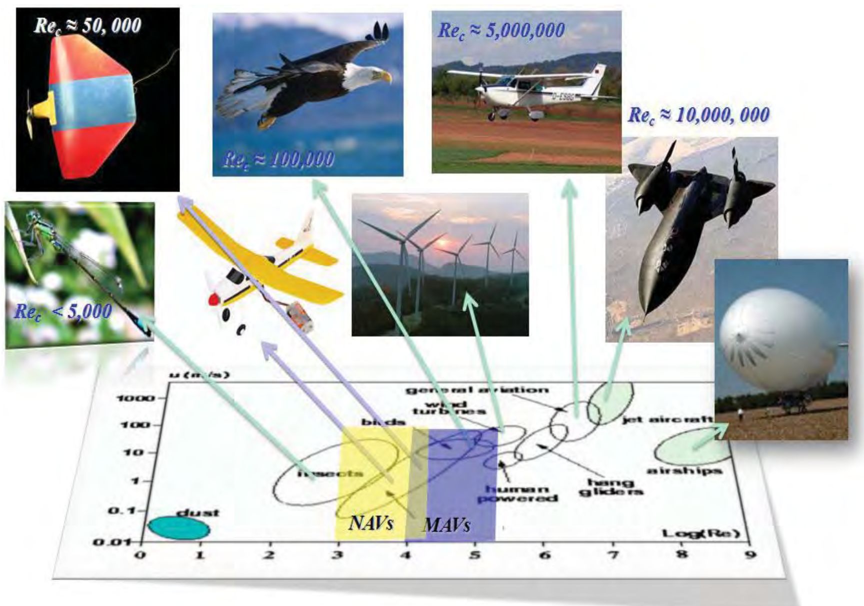



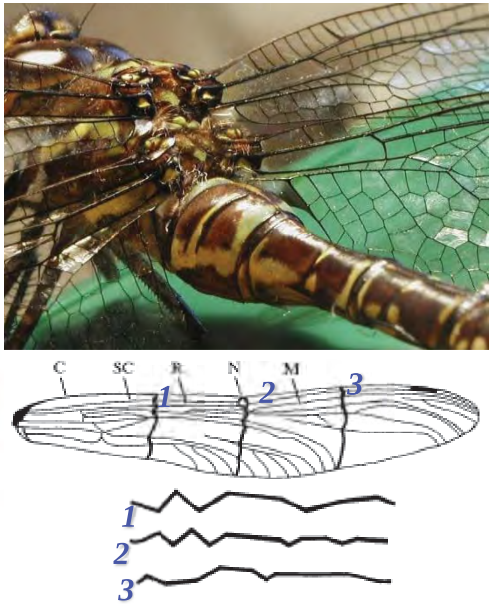



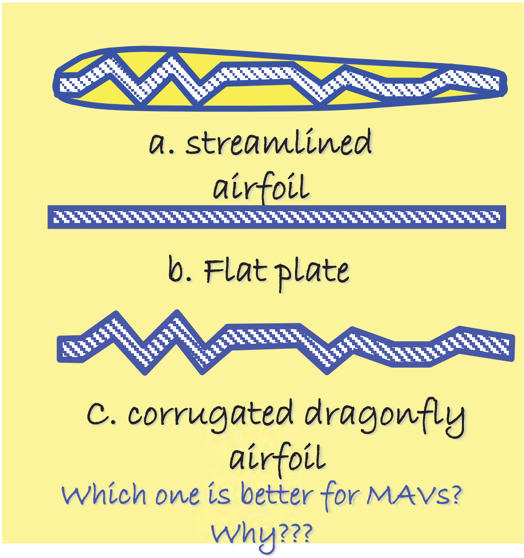

- *Surge motion*
- *Pitch motion*
- *Heave motion*

- *(Khosravi, Sarkar, Hu., AIAA-2015-1207)`*

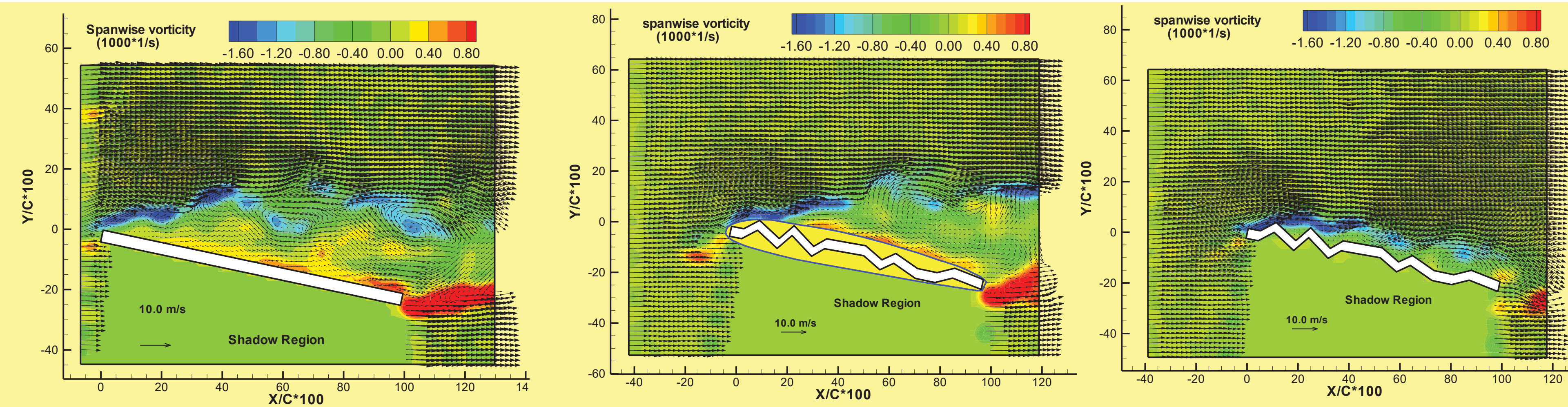
# Unsteady Aerodynamics and Bio-Inspired MAV/UAV/UAS Designs
# (Funding Sources : NSF, AFOSR/ARO)



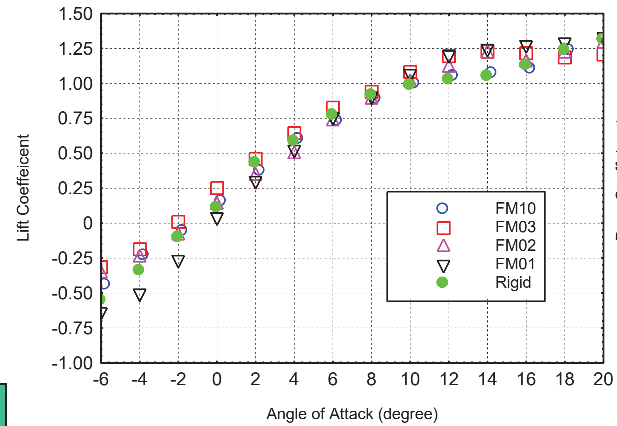



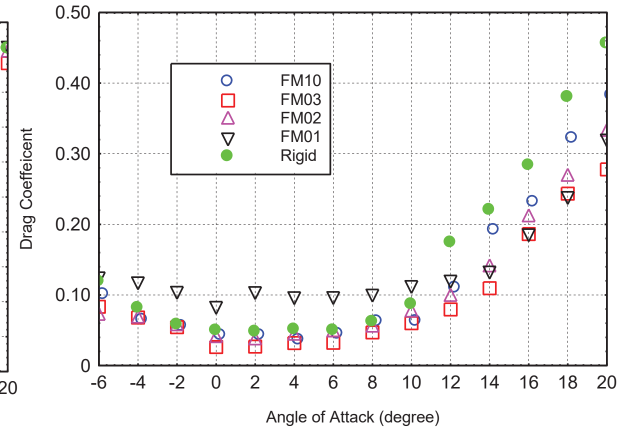

*AOA = 12.0 deg., Re=58,000*

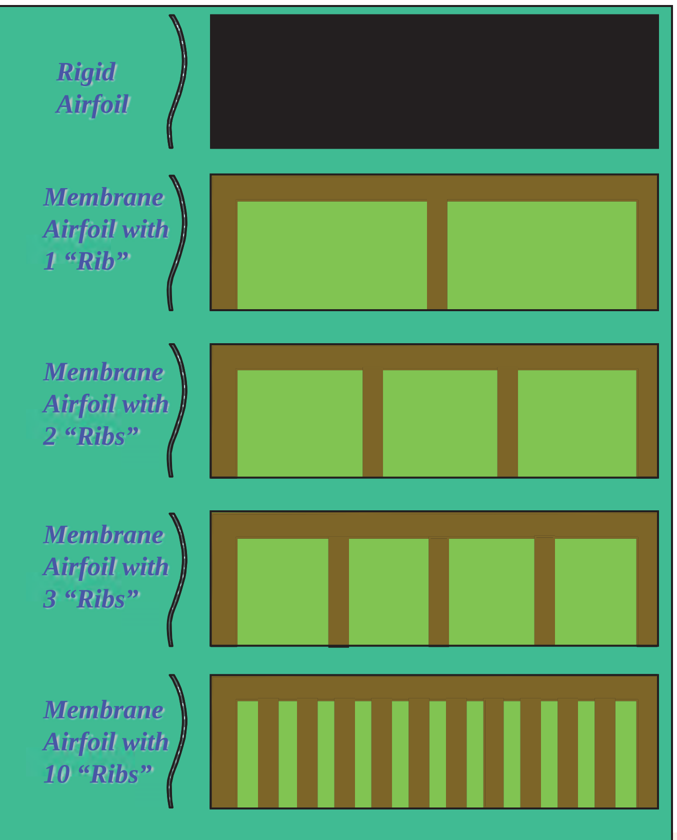


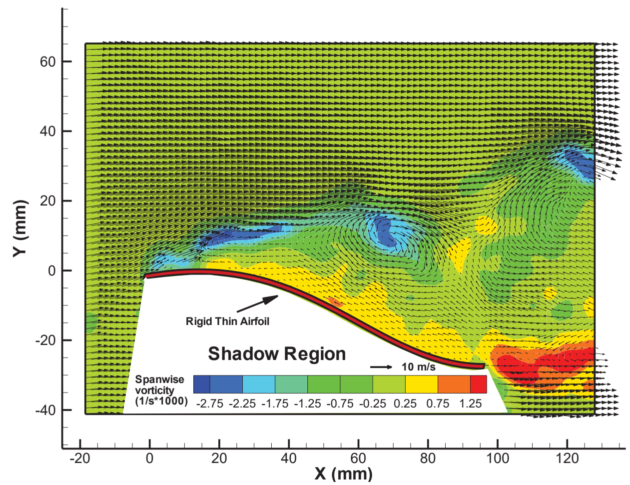

- *(Murphy JT, Hu H,, Experiments in Fluids, Vol. 49, No.2, pp531-546, 2010.)*

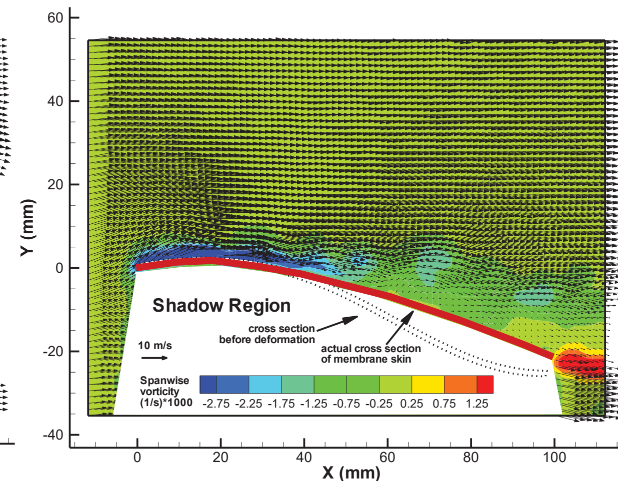
# Bio-Inspired Aerodynamics Design for MAV/UAV/UAS Applications (Funded by NSF, AFRL)


*Rigid Thin Airfoil at AOA=14.0 degrees*

*Re=70,000*

*Flexible membrane Airfoil at AOA=14.0 degrees*

- *(Murphy and Hu, Journal of Aircraft, 2008)*

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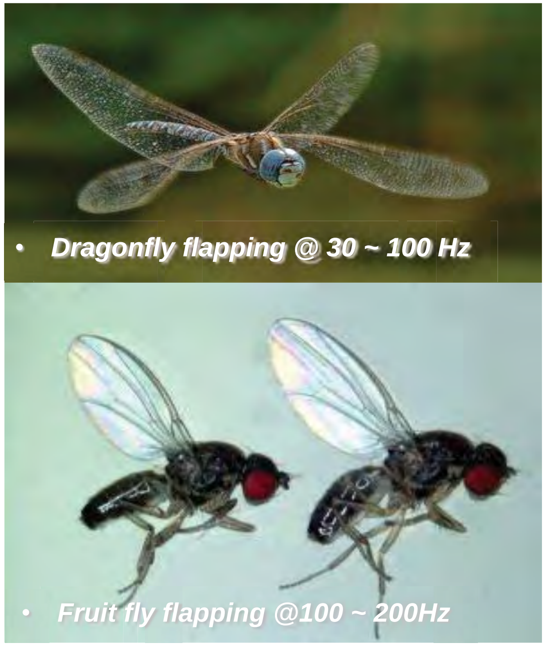
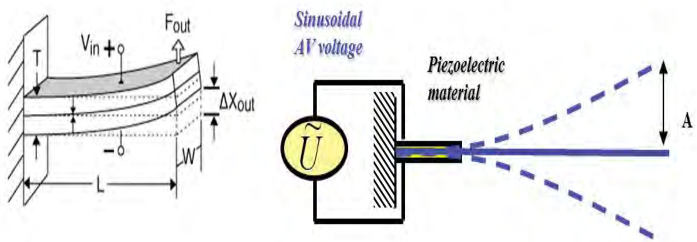
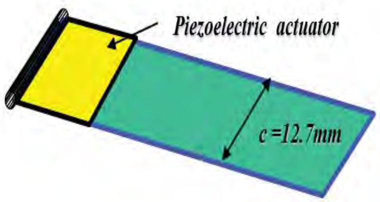
# Unsteady Aerodynamics and Bio-Inspired MAV/UAV/UAS Designs (Funding Sources : NSF, AFOSR/ARO)

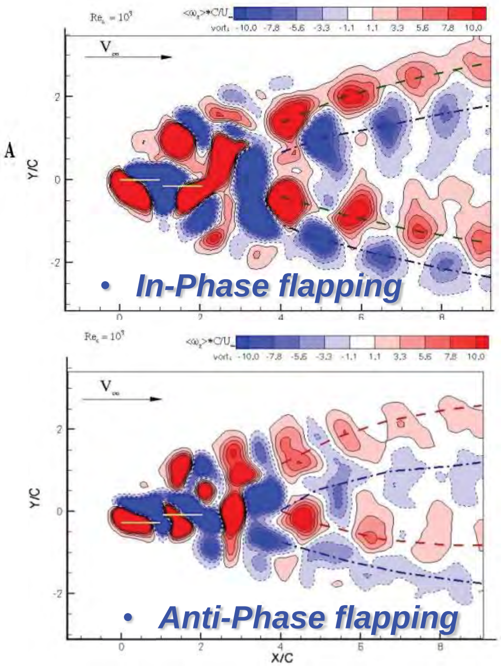


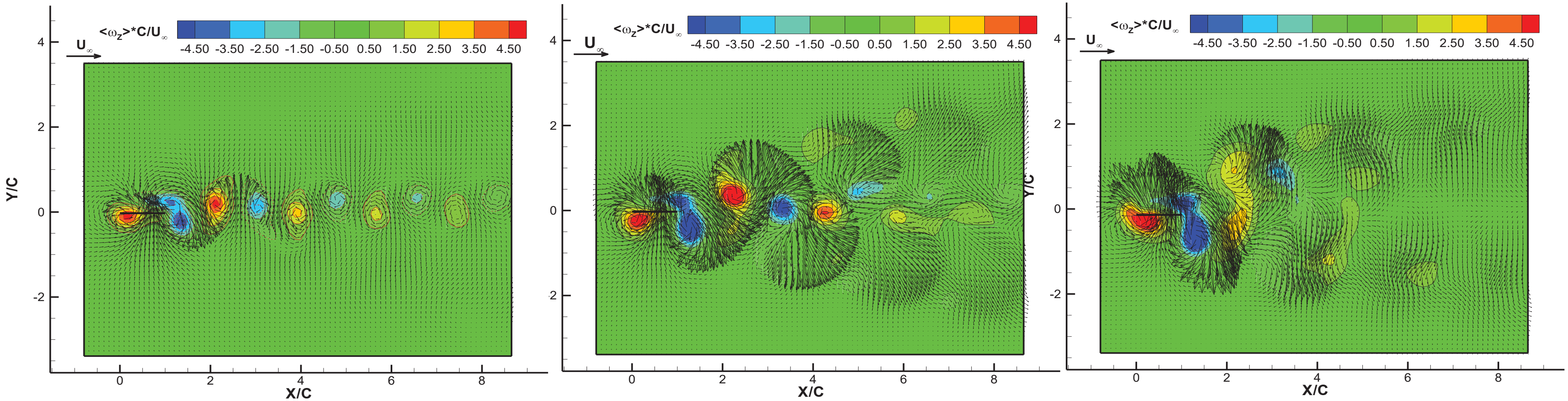




- Piezoelectric actuator–based flapping Mechanism
  - Compact in size, Simple structure
  - Much higher flapping frequency , f= 60~200Hz




- (Clemons, Igarashi and Hu, 2011, Exp. in Fluids)



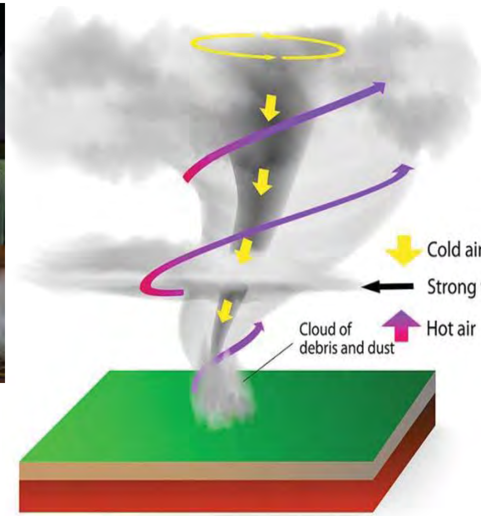

V=1.36 m/s, f=60Hz, A= 3.44 mm (h=0.27; k=3.52; J=1.70)

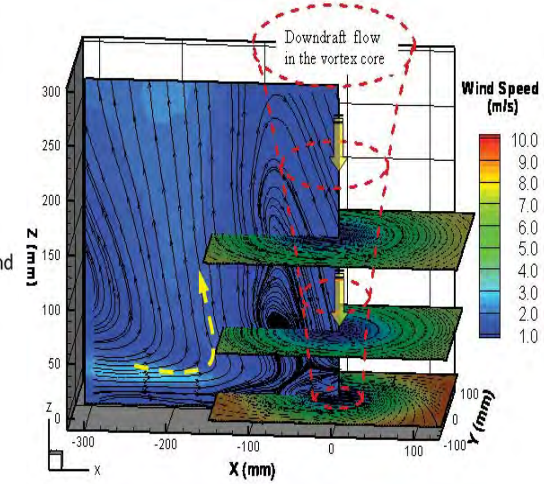
V=1.36 m/s, f=60Hz, A= 5.64 mm (h=0.44; k=3.52; J=1.03)

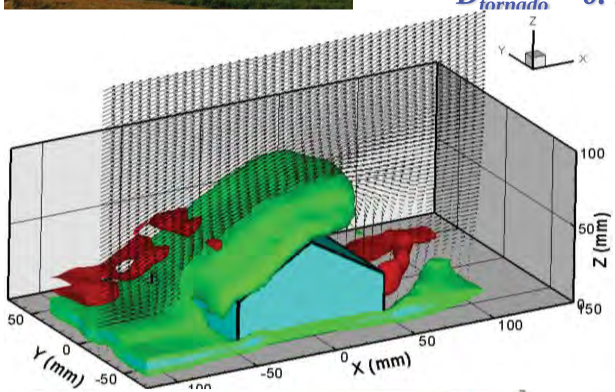
V=1.36 m/s, f = 60Hz, A= 8.20 mm (h=0.65; k=3.52; J=0.69 )

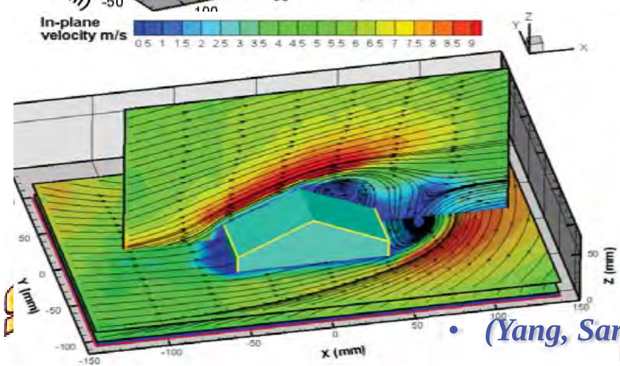
# Flow-Structure interaction (FSI) of Buildings in Tornado-like Winds
# (Funded by NSF, NOAA)

*The world largest moving Tornado/Microburst Simulator*
$D_{tornado}$ *= 0. 5m ~ 1.5 m*

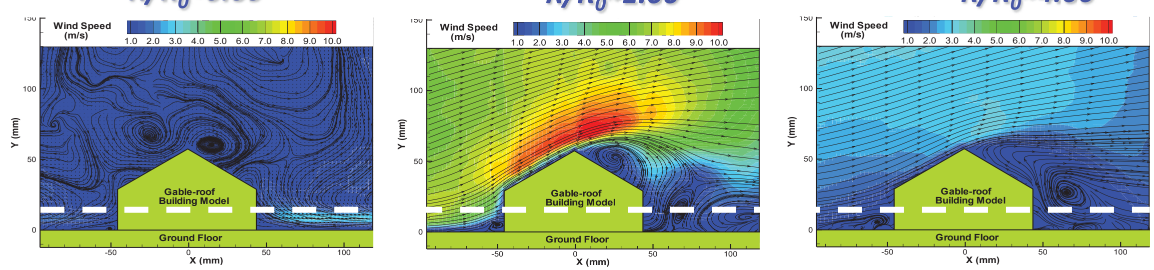


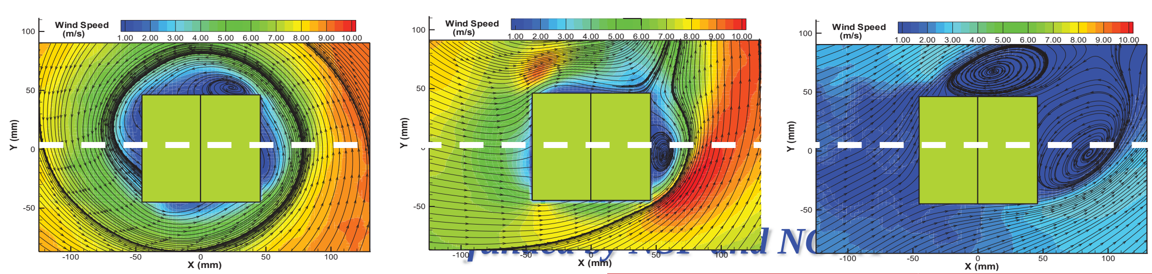




$R/R_0 \approx 0.00$ $R/R_0 \approx 1.00$ $R/R_0 \approx 4.00$




*Side view*




- *(Yang, Sarkar and Hu, Journal of Fluid and Structures, 2011)*

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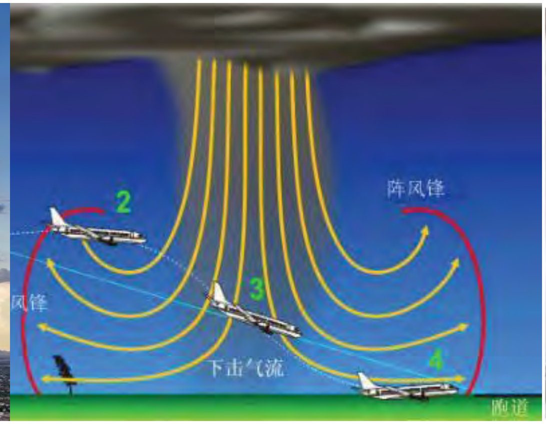
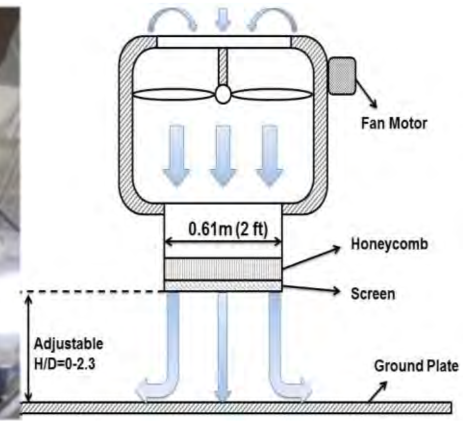
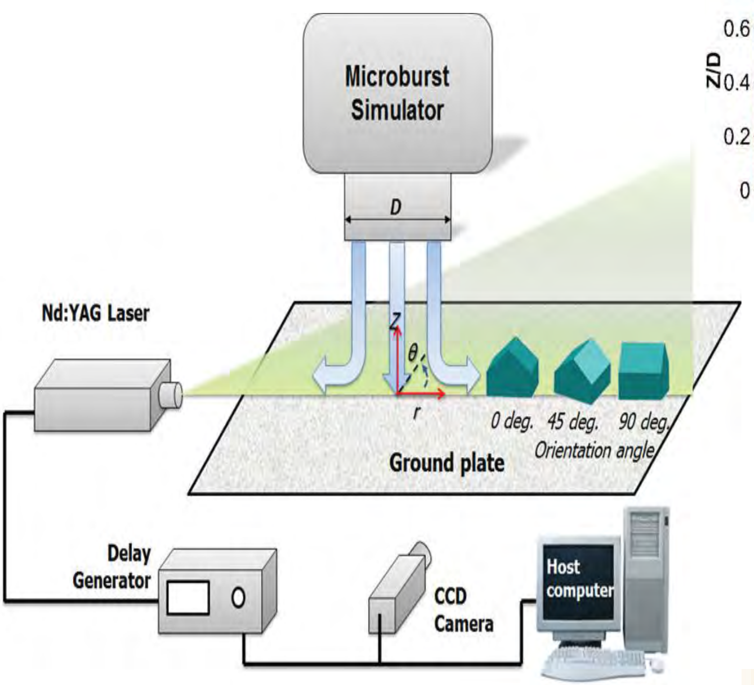
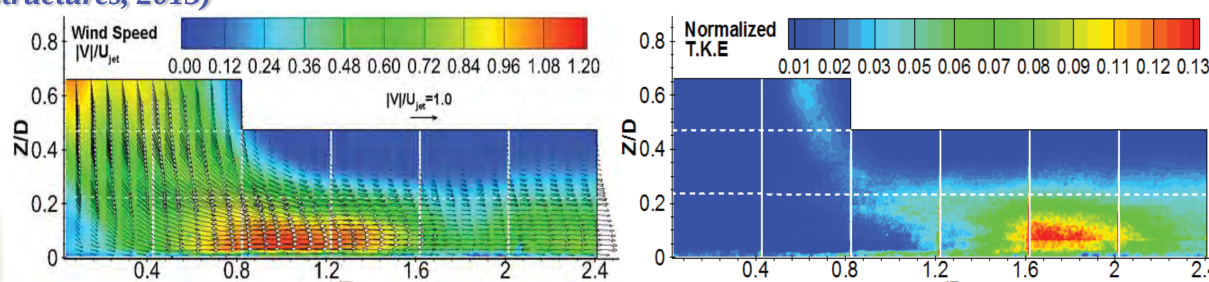
# Flow-Structure interaction (FSI) in Violent Microburst-like Winds (Funded by NSF, NOAA)

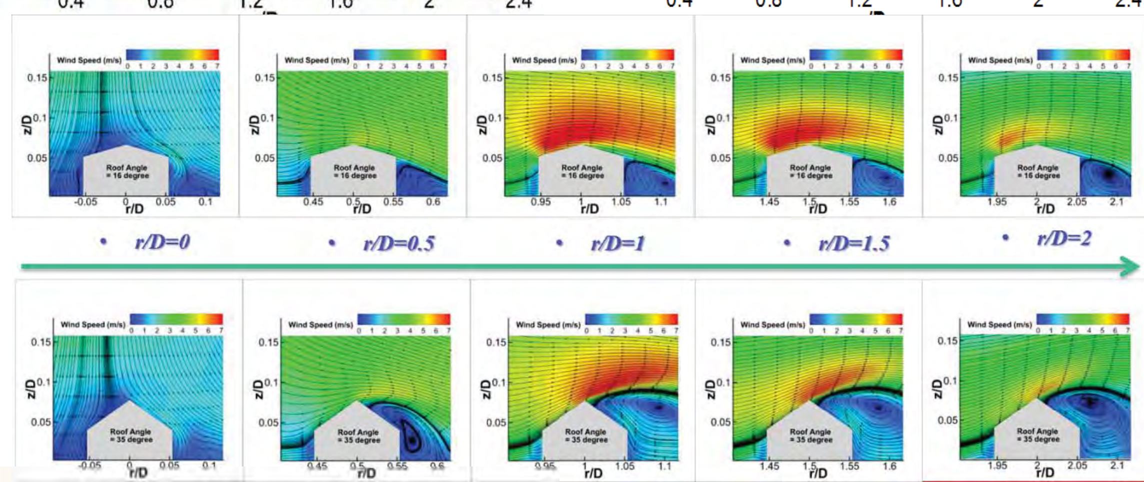


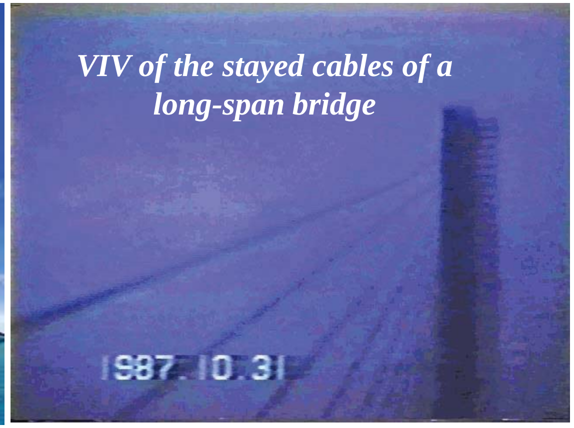

- *ISU Microburst simulator*
- *(Zhang, Sarkar & Hu, Journal of Fluid and Structures, 2013)*

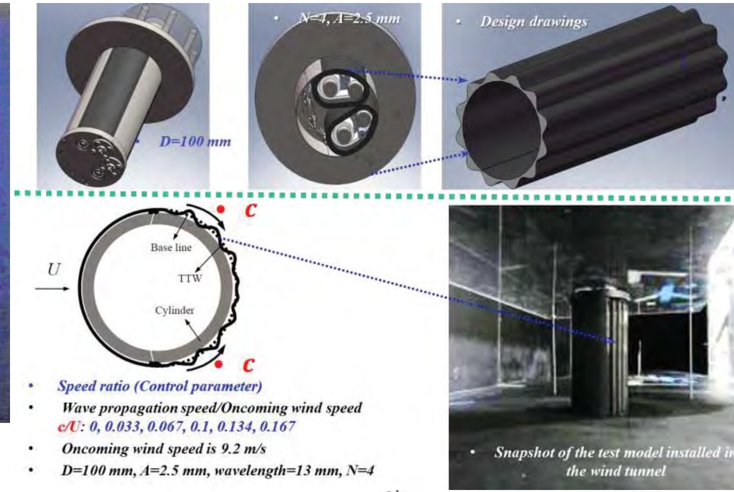


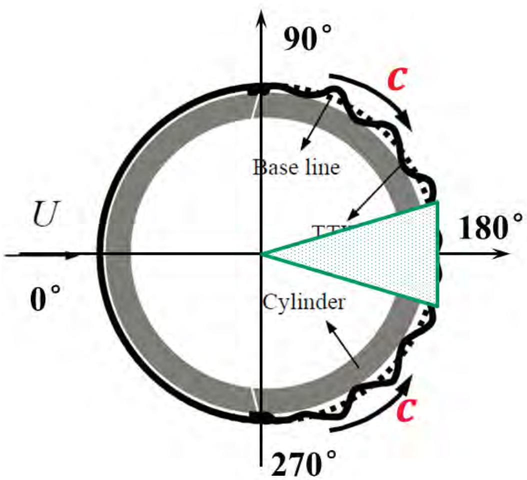



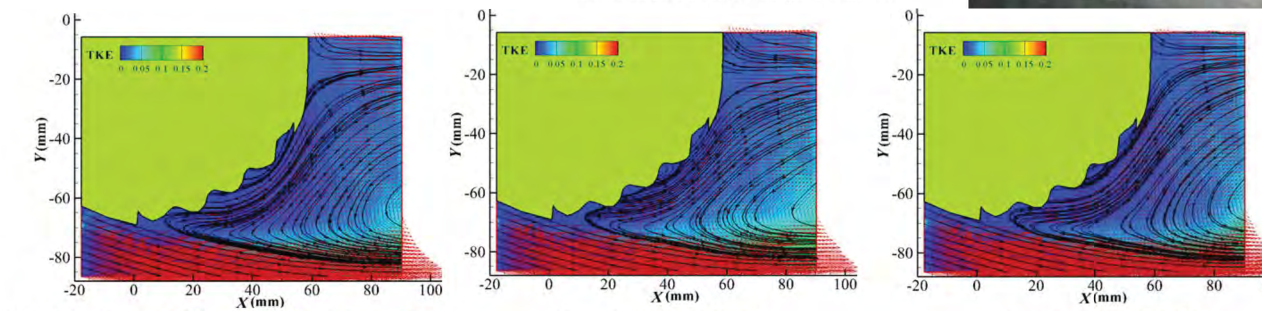
# Flow Controls to Suppress Vortex-Induced-Vibrations (VIVs) of Bridge Cables

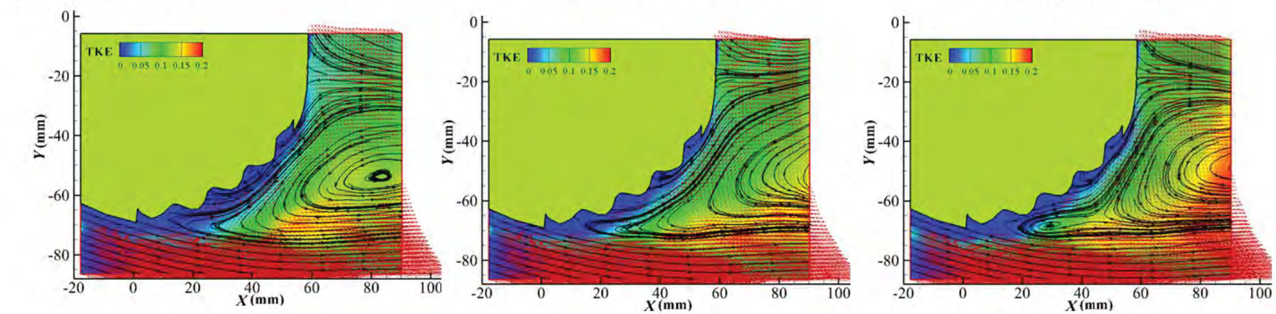




- Speed ratio (Control parameter)
- Wave propagation speed/Oncoming wind speed
  c/U: 0, 0.033, 0.067, 0.1, 0.134, 0.167
- Oncoming wind speed is 9.2 m/s
- D=100 mm, A=2.5 mm, wavelength=13 mm, N=4




Speed ratio = 0 (Baseline, No Control) | Speed ratio = 0.033 | Speed ratio = 0.067




Speed ratio=0.1 | Speed ratio=0.134 | Speed ratio=0.167

- (Chen, Li and Hu, Experiments in Fluids , 2011)

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- *Collaborators, postdocs, visiting scholars and graduate students:*
  - *Collaborators:* *P. Sarkar; P. Durbin; A. Rothmayer; M. Koochesfahani; ZJ Wang; R. Wlezien, S. Zhang*
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  - *Former Postdocs&Scholar:* *B. Johnson, W. Chen, W. Yuan, W.H. Ma; Drs. Z. Jin; H. Ma, Z. Yang*
  - *Former PhD Students:* *M. Zhang (PhD); M. Yu (PhD), Z. Yang (PhD); Z. Jin (PhD); N. Cooper (PhD)*
  - *Former MS Students:* *Dvorak; T. Grager; A.Kumar; H. Igarashi; L. Clemens; J. Murphy; K. Varma; M. Tamai.*

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