Summary of Recent Research Activities

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Advanced Flow Diagnostics and Experimental Aerodynamics Laboratory

- **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

- Liquid Fuel atomization and spray flow characterization (Funding source: NSF, DoE, UTAS, Honeywell)
- Icing Physics, Aircraft icing and de-/anti- icing technologies (Funding Source: NASA, FAA and NSF)
- Wind Energy and Wind Turbine Aeromechanics (Funded by NSF, DoE)
- Microfluidics & Nanofluidics, Micro-scale heat transfer (funding source: NSF/AFOSR)
- Wind Engineering, and Flow Structure Interaction (FSI) (NSF / NOAA)
- Bio-inspired aerodynamics and bio-inspired MAV /UAV/UAS designs (Funding source: AFOSR/ARO, NSF)
- Cooling Technology & Heat Transfer of Gas Turbines (funding source, AFOSR, DoE, GE)
ISU Research Initiative for Icing Physics and Anti-/De-icing Technology

Aircraft icing
Rotocraft icing
Aer-engine icing
Wind turbine icing

Solar panel icing

NDE, MEMS sensors for in-flying icing detection
Experimental aerodynamics & wind tunnel testing
CFD & multiphase modeling
UAS/MAV, Rotorcraft, wind turbine, power lines
Super-hydrophobic coatings and surface engineering

System design and MDO for anti-/de-icing strategy
Aero-structure designs for icing mitigation & protection.
Smart materials, Micro & Nano Mechanics

Center for Icing Physics & Anti-/De-icing Technology
- **Test Conditions**
  - Oncoming airflow velocity: $V_\infty \approx 35 \text{ m/s}$
  - Angle of attack of the airfoil: $\alpha \approx 5 \text{ deg.}$
  - Airflow Temperature: $T \approx -8 ^\circ C$.
  - Liquid water content (LWC): $LWC = 3.0 \text{ g/m}^3$
  - Image acquisition rate $f = 150\text{Hz}$, 10X replay
Wind Turbine Icing and Anti-/De- Icing Techniques
(Funded by NSF, DoE)

Droplet impact and water runback
Glaze ice accretion
Ice growing radially
Lobster tail-like ice structure
Aero-engine icing event hits an AirBridge Cargo-operated Boeing 747-8F on 07/31/2013 to cause power loss.

**Icing on the inlet and spinner of aero-engines**

**Rolls-Royce**

**Pratt & Whitney**

**GE Aviation**

- **RR Trent-XWB**
- **PW 1000G**
- **GE 90**

**Conical**

**Elliptical**

**Conical (1D)**

- $t=0s$
- $t=30s$
- $t=60s$
- $t=90s$
- $t=120s$
- $t=150s$

- **Conical (1D)**
- **Elliptical**
- **Conical**
Heat Transfer of Gas Turbines and Cooling Technology  
(Funded by GE and DoE)


- Heat transfer
- Mass transfer
- Momentum transfer
- Film cooling
- Trailing edge cooling
Barchan-Dune-Inspired Design for Improved Film Cooling Effectiveness
(USA Patent Pending)

Characterization of Trailing Edge Cooling of Turbine Blades

Main stream (air flow)
Cooling streams (nitrogen flow)

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, $M=1.60$

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

Dynamic wind loads

Power output

( Hu et al. Exp. Fluids, 2011)
Wind Turbine Aeromechanics over Complex Terrains
(Potential Funding Sources: NSF, DoE)

Off-shore wind farm

On-shore wind farm

Streamwise velocity in the wake
(D is the diameter of the rotor)

Streamwise Velocity deficit in the wake

Currently funded by DoE and NSF
Novel Wind Turbine Designs for Improved Performance and Durability
(Funding Sources: NSF, IEC)

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

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

Two DRWT concepts

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

Currently funded by NSF and IEC
Effects of Base Motion on the Aeromechanic Performance of Floating Offshore Wind Turbines

https://www.youtube.com/watch?v=7dkAXmXCcks

- Spar-buoy

- 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)

**Bat**

- **Rigid Airfoil**
- **Membrane Airfoil with 1 “Rib”**
- **Membrane Airfoil with 2 “Ribs”**
- **Membrane Airfoil with 3 “Ribs”**
- **Membrane Airfoil with 10 “Ribs”**

### Graphs

- **Lift Coefficient vs. Drag Coefficient**
  - Graph showing lift and drag coefficients for different configurations.
  - Different symbols represent different configurations: FM10, FM03, FM02, FM01, Rigid.

- **Angle of Attack vs. Lift and Drag Coefficients**
  - Plots showing lift and drag coefficients against angle of attack for various airfoils.

- **Shadow Region**
  - Comparison of rigid thin airfoil and flexible membrane airfoil at AOA=14.0 degrees.
  - Re=70,000

- **Spanwise Vorticity**
  - Comparison of vorticity for rigid thin and flexible membrane airfoils.

- **Actual Cross Section of Membrane Skin**
  - Images showing cross sections before and after deformation.

*(Murphy and Hu, Journal of Aircraft, 2008)*
Unsteady Aerodynamics and Bio-Inspired MAV/UAV/UAS Designs
(Funding Sources: NSF, AFOSR/ARO)

- Dragonfly flapping @ 30 ~ 100 Hz
- Fruit fly flapping @ 100 ~ 200 Hz
- In-Phase flapping
- Anti-Phase flapping
- Piezoelectric actuator-based flapping mechanism
  - Compact in size, simple structure
  - Much higher flapping frequency, f = 60~200 Hz

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

- Fruit fly flapping @100 ~ 200Hz
- In-Phase flapping
- Anti-Phase flapping
Flow-Structure interaction (FSI) of Buildings in Tornado-like Winds
(Funded by NSF, NOAA)

The world largest moving Tornado/Microburst Simulator

\[ D_{\text{tornado}} = 0.5 \text{m} \sim 1.5 \text{m} \]

- (Yang, Sarkar and Hu, Journal of Fluid and Structures, 2011)
Flow-Structure interaction (FSI) in Violent Microburst-like Winds
(Funded by NSF, NOAA)


ISU Microburst simulator
Flow Controls to Suppress Vortex-Induced-Vibrations (VIVs) of Bridge Cables

VIV of the stayed cables of a long-span bridge

- Cable-stayed bridge

- Speed ratio (Control parameter)
  - Wave propagation speed/Oncoming wind speed $c/U$: 0, 0.635, 0.667, 0.71, 0.834, 0.367
  - Oncoming wind speed $U$: 9.2 m/s
  - $D=100$ mm, $A=2.5$ mm, wavelength=13 mm, $N=4$

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