Active Flow Control – A Tool to Improve System Efficiency

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Flow Control

**Flow control:** Any mechanism or process through which the flow is caused to behave differently than it normally would.

**Flow control mechanisms**
- Passive:
  - Turbulators / surface roughness
  - Unsteady blowing
  - Oscillating ribbon or flap
  - Internal and external acoustic excitations
  - Oscillating surface
- Active:
  - Synthetic jets ($f_{act} \sim 10 f_{natural}$, $l_{jet} \sim 0.01 l_{char}$)

**Applications**
- Aerodynamic performance and flight control (manned and unmanned aerial vehicles)
- Internal flows (separation, head losses)
- Heat transfer control (electronic/film cooling)
- Mixing enhancement (combustion, noise)
- Renewable energy (wind turbine blades)
**Synthetic Jet**


**Orifice size:**
Length: O(mm)
Width: less than 1mm

**Operating frequencies:**
O(100Hz)-O(10KHz)

- Zero-net-mass-flux (ZNMF)
- Allows momentum transfer to the flow
- Diaphragm and cavity are driven near resonance
- Small electric power input
- No plumbing or any mechanical complexity is needed

The interaction of the synthetic jet with a cross flow can form a quasi-steady recirculation region
⇒ Improve aerodynamic performance of lifting surfaces.
Past and Ongoing Research at FCRL

- 2-D Circular Cylinder
  - baseline
  - w/control

- Separation Control on 2-D Airfoils
  - baseline
  - w/control

- Stingray UAV
- Mini Stingray
- Cessna 182

- Mini UAV
- μUAV
- NAVs

- Active Electronic Cooling

- Active Control of Particle-Laden Jets

UAVs - Applications

Police, Fire and Rescue Support

Chemical-Biological Monitoring

Disaster Management

Caves
Flying BAGEL Model: Design

- Ducted fan configuration
- A single moving part – fixed pitch propeller
- Flow control on the stator blades
- Two mini UAVs were built:
  - Flying model
  - Stationary model
The “Flying Bagel” Mini UAV

MOVIE
Micro Flying BAGEL

MAVs are limited to 6”×6”×6” and a gross takeoff weight of 100gr.

Active Flow Control

- Flight control is achieved by active control of the flow over the stators.
- Two 20mm 3kHz piezo-discs are installed in each stator (~0.2W each).

➢ Technical support from the CATS in hardware and software.
➢ Closed loop control will be provided by the CATS
Flow Field over the Stator - PIV

Baseline

Actuated

Synthetic Jet Only
Design and Fabrication of UAVs with Synthetic Jets

- Design and Fabrication of Cessna 182 RC model with Synthetic Jets Instrumented Wingtips for Roll and separation Control

Cessna RC Model (1/6.65 of Original Cessna 182)  Cessna Wing tip with synthetic jet actuators
Flight Control and Flow Control on a Cessna 182

Ciuryla et al., Journal of Aircraft, March 2007

Wing span = 18in
Wing chord = 2.5in
Re = 150,000
f_{act} = 1,100 Hz (f_{char} = 50Hz)
Flight Control Using Synthetic Jets

- Proportional separation and roll control authority at a wide range of $\alpha$.
- Roll moments are comparable to conventional ailerons.
- Small-scale synthetic jets yield a global effect.
- Flight tests of a 5ft RC model are underway (electronics designed by CATS).
- Flight tests with flow control are planned for fall 2007.
The angle of attack was increased slowly from $0^\circ$ to $\sim 8^\circ$ (until flow separated)

The RMS output of the shear stress sensor was monitored, and when RMS threshold was reached – the synthetic jets were activated by the computer.

**RMS_{threshold} = 0.5V**

- Onset of Separation
- Automatic Activation of SJ
- Complete reattachment
- Roll torque reading

**RMS_{threshold} = 0.25V**

- Roll torque Reading

**RMS_{threshold} = 0.1V**

- Roll torque reading
Active Control of Sprays

Explore the feasibility of using active flow control on sprays using synthetic jet actuators.

Applications

– Spray Cooling (cooling of electronics components)
– Agriculture (applying pesticides)
– Homeland Security (subways, trains, planes, etc.) - Sarin gas attack on the Tokyo subway in 1995

Global behavior

PIV
Velocity field
RMS levels
Direction (vectoring)

Detailed characteristics

Shadowgraphy & PTV
Droplet size
Droplet distribution
Droplet concentration
Droplet velocity

Use active flow control on sprays to improve the performance of spray cooling
**Experimental Setup – Spray Facility**

Air-assisted atomizing water spray

\[
\frac{Q_a}{Q_w} = \text{air to water flow rate ratio}
\]

\[
\frac{Q_a}{Q_w} \text{ can be varied by:}
\]

(i) the air pressure,
(ii) the water intake level WRT the spray nozzle level, \( L_w \).

**Flow control module**

- Water reservoir
- Water level meter
- Valve
- Flow meter
- Air filter
- Air desiccant
- Compressed air
- Synthetic jets
- Enclosure
- Atomizing spray nozzle
- Air siphoned in
- Water
- Pump
- Damper
Movies of Ramped and On-Off Flapping

Ramped flapping

On-off flapping

Spray
Spray Cooling

Three flow control schemes: (i) all 4 jets on, (ii) ramped flapping, and (iii) on-off flapping

\[
H/d_s = 35.3 \\
Q_s/Q_w = 166
\]

\[\Delta T = T_s - T_\infty (^{\circ}C)\]
Conclusions

- Synthetic-jet-based active flow control can be used for flight control of small-size UAVs, in lieu of (or in addition to) conventional control surfaces.

- Synthetic jets can be used to control sprays
  Global and detailed spray characteristics were modified such that the efficiency of spray cooling was improved.
Questions?