CHARACTERIZATION OF TYPICAL RESPONSE IN THE WAKE OF THE NACA0015 UNDER THE ACTION OF FLUIDIC VORTEX GENERATORS

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Order of Presentation

- Objectives
- Model, experimental setup, flow condition & fluidic vortex generator
- Background
- Results
  - Steady state characterization
  - Unsteady characterization & reduced order modeling
- Conclusion
Objectives

- Towards building a close loop flow control system - Identify the physics of the transient process of flow separation/attachment over a NACA0015
Model & Test Facility

- Closed loop tunnel
- Test section 2.4m by 2.6m
- Turbulence intensity = 0.4% at ~40m/s
- NACA0015 airfoil (baseline model)
  - Turbulated with 80micron grits
  - Equiped with pressure transducers at mid-span
  - Vortex generators installed (0.3c from leading edge) at central 1/3 of span
  - Test at Re=1million (40m/s)

Plan view of wing

External balance

NACA0015

Assembly of hotwire support and pitot tube

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Fluidic Vortex Generators

- Single row of 44 angled orifices
- Generate co-rotating vortices
- Design to operate up to sonic jet velocity
- In windon condition:
  - 7 msec for jet to be deployed
  - 9 msec for jet to be removed
Background

- Several studies were conducted in LEA concerning the efficiency of various jet actuator configurations in attaching separated flow over airfoils since 2000
  - Force balance, surface pressure data, surface flow visualization and PIV
    (documented in the thèse of S. Bourgois)
- EFFC 2005 showed that angled fluidic vortex generator in continuous mode was most efficient in attaching separated flow over NACA0015 up to 18deg incidence (Cl enhanced & Cd reduced).
  (documented in IUTAM 2006)
Background

(1) Find an efficient actuator configuration to attach separated flow over a wide range of incidences at Re~1million

(2) Find a suitable test condition to realize fundamental studies of the transient process of attachment and separation

(3) Build reduced order model of the condition described in (2)
Steady Characterization: Efficiency in terms of CL

CL estimated from integration of surface pressure distribution

(1) Better 2D estimate of CL
(2) Higher $C_\mu$ required to increase efficiency in post stall angles
Steady Characterization: Trace of longitudinal vortices

Flow
11deg, 3bar(supply)

Survey height = 3mm above airfoil surface

x/c=0.0286
x/c=0.154
x/c=0.286
x/c=0

Wave length reduced by ~1/2 as we survey towards trailing edge of the airfoil
Trace of the spanwise evolution of longitudinal vortices over the airfoil.

Steady Characterization: Spectral distribution in the wake

Spectral distribution \((St^*E_{uu})\) in the wake at \(x/c=1\) from the trailing edge

Without jet deployment

With jet deployment
Study conducted at the following conditions:
- 11deg incidence
- Jet deployed at a frequency of 1Hz
- Re=1mil (~40m/s)

Measurement technique
- Hotwire
- PIV

Test condition appreciation
- Movement of tuffs at 11deg (C:\test2007\Videos actuation)
- Movement of wake at 11 deg (C:\test2007\Videos actuation)
Unsteady Characterization

PIV window in wake

PIV window over airfoil

Jet position
Unsteady Characterization: Wake Survey

Wake survey at x/c=-1, using a single component hotwire
Unsteady Characterization: Wake evolution during jet deployment

Adimensionalized average velocity in x direction: $U/U_{\infty}$

Time (ms): 0.013
Unsteady Characterization: Wake evolution during jet removal
Evolution of the y-component of the velocity field during the process of jet deployment.

* Y component velocity becomes more –ve, indication of flow entrainment towards the wall
Evolution of the y-component of the velocity field during the process of jet removal.
1. **POD on time resolved assembled average**
   PIV velocity field (the evolution is represented by 40 time instant, each time instant is based on ensemble average of 300 snap shots)

2. Extract the first relevant number modes and compute \( a_i \)

3. **Solve the system of linear equations**
   \[ a_i = C_{ij} a_j + D_i b_i \]

4. **Simulate the dynamical system**

\[ u(X,t) = U_{\text{mean}} + \sum_{n=1}^{n_{\text{snap}}} a^{(n)}(t)\Phi^{(n)}(X) \]
Energy distribution of the eigen modes suggest 4 modes are sufficient to recover 99% of the flow characteristic.
Results : Unsteady Characterization

Plot of the temporal coefficients, $a_1(t)$

Base on the evolution of the first mode $T^+ \sim 10$
A robust fluidic actuator has been validated up to incidence of 22deg at Re~1 million

Flow response time in the wake was determined to be
- $T^+\sim10$ (~25msec) for reattachment over the airfoil
- $T^+\sim20$ (~50msec) for separation over the airfoil

A linear reduced order modeling has been realized
- Give possibility to explore other initial and actuation conditions
- Give further insight to the physics of actuator deployment and removal