

## Introduction

### Background

#### Delta Wing at High Angle of Attack

- The position of the leading edge vortex (LEV) changes with wing's posture change, and the break and recovery of LEV happen
- Unsteady phenomenon to affect the stability and the maneuverability such as Wing rock phenomenon exists

Unsteady flow field at high angle of attack should be researched

#### Dynamic Wind Tunnel Testing

- Experiment that simulate model motion and measure unsteady flow using a manipulator
  - Aerodynamic force and moment measurement
  - Flow visualization (laser light sheet method etc.)
  - Change of pressure field measurement
- "Unsteady Pressure Sensitive Paint"

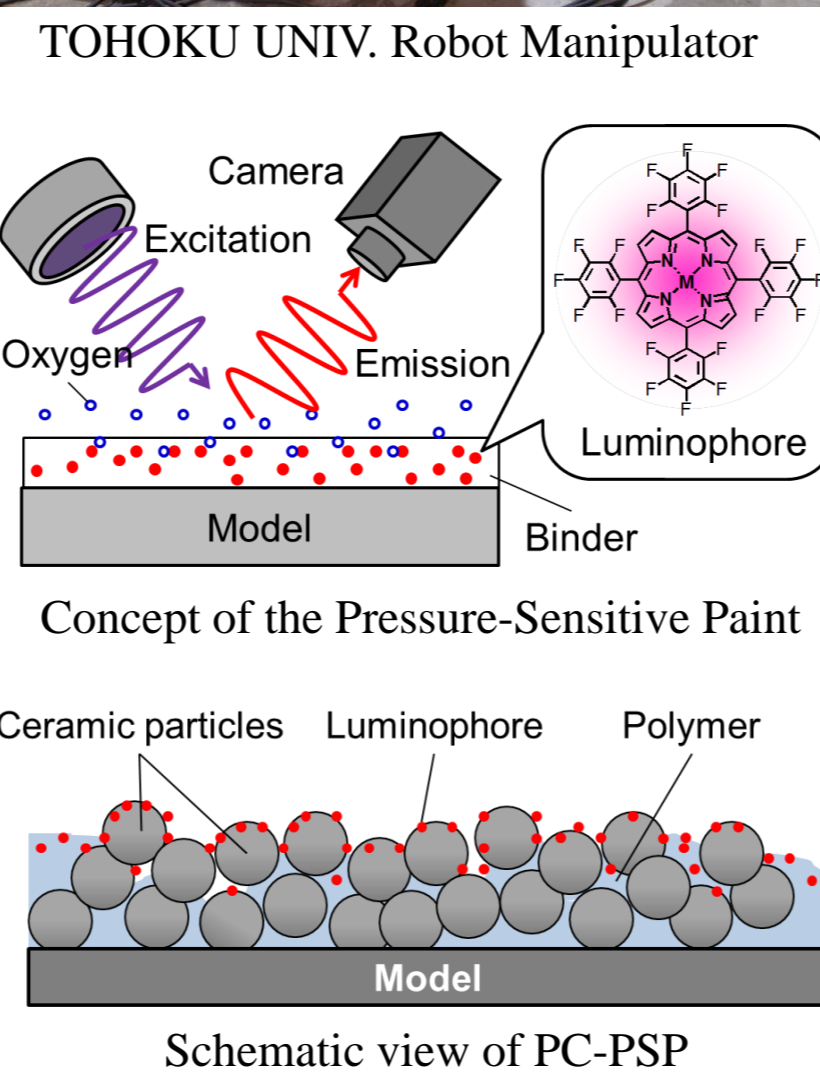
#### Pressure Sensitive Paint, PSP

$$\frac{I_{ref}}{I} = A(T) + B(T) \frac{P}{P_{ref}}$$

- A pressure measurement technique based on the oxygen quenching of luminescence
- Requirements for PSP characteristics to be applied to unsteady and low-speed flow
  - Fast response time
  - High pressure sensitivity, Low temperature sensitivity
- Polymer/Ceramic PSP (PC-PSP)
  - Can change its characteristics by types of polymers, particles and contents



NASA F/A-18 HARV



Schematic view of PC-PSP

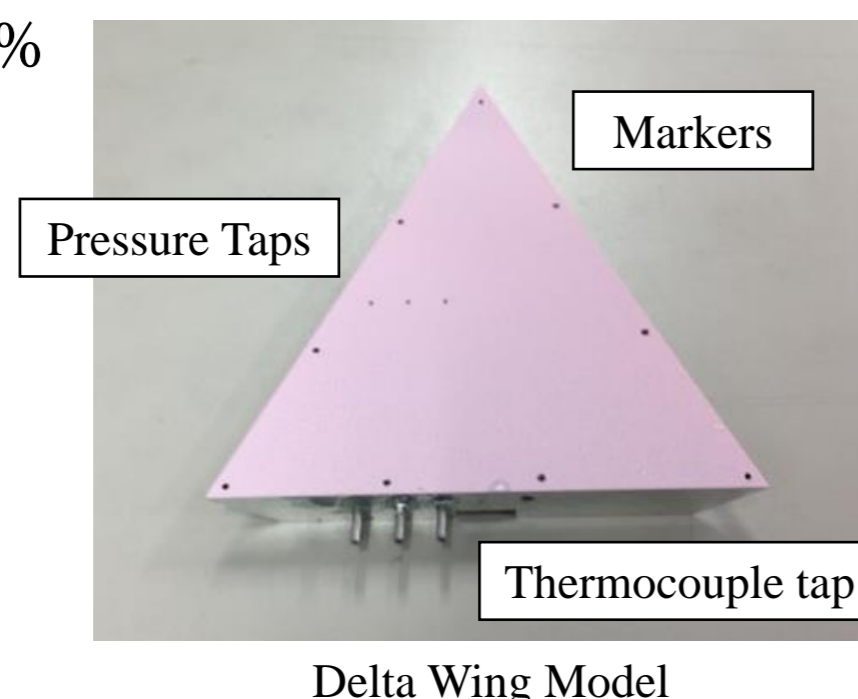
### Objective

- To evaluate the applicability of the measurement method to low-speed flow by new PC-PSP
- To measure unsteady pressure field of upper surface of forced rolling delta wing by PC-PSP, consider its dynamic flow field

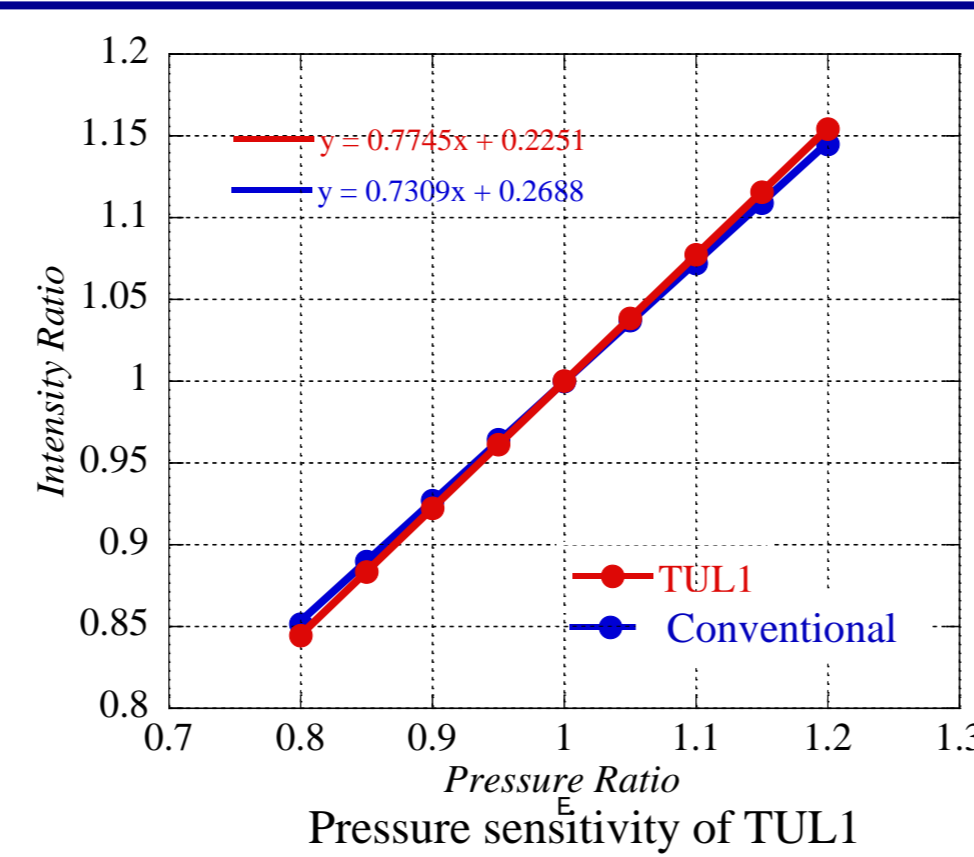
## Experimental Method

#### Wind Tunnel and Model

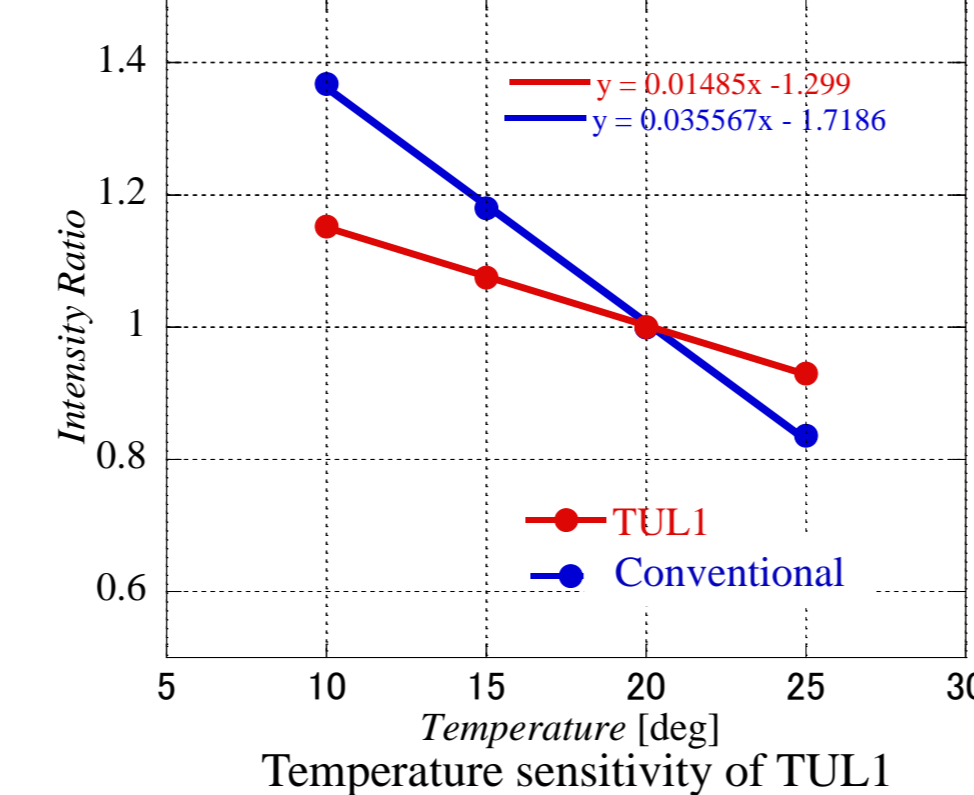
- Small Low Turbulence Wind Tunnel (TOHOKU UNIV.)
  - Opposite side distance : 290 [mm]
  - Turbulence intensity : 0.06 %
- Robot Manipulator "PA10"
- Delta Wing Model
  - Sweep angle : 65 [deg]
  - Code length : 100 [mm]
  - Thickness : 10 [mm]
  - Sprayed PC-PSP
- PC-PSP "TUL1"
  - Optimized for unsteady and low-speed flow experiment
  - Near the atmospheric pressure, higher pressure sensitivity and Lower temperature sensitivity than conventional one
  - Sufficient fast responsibility (Cut-off frequency is 2[kHz])



Delta Wing Model



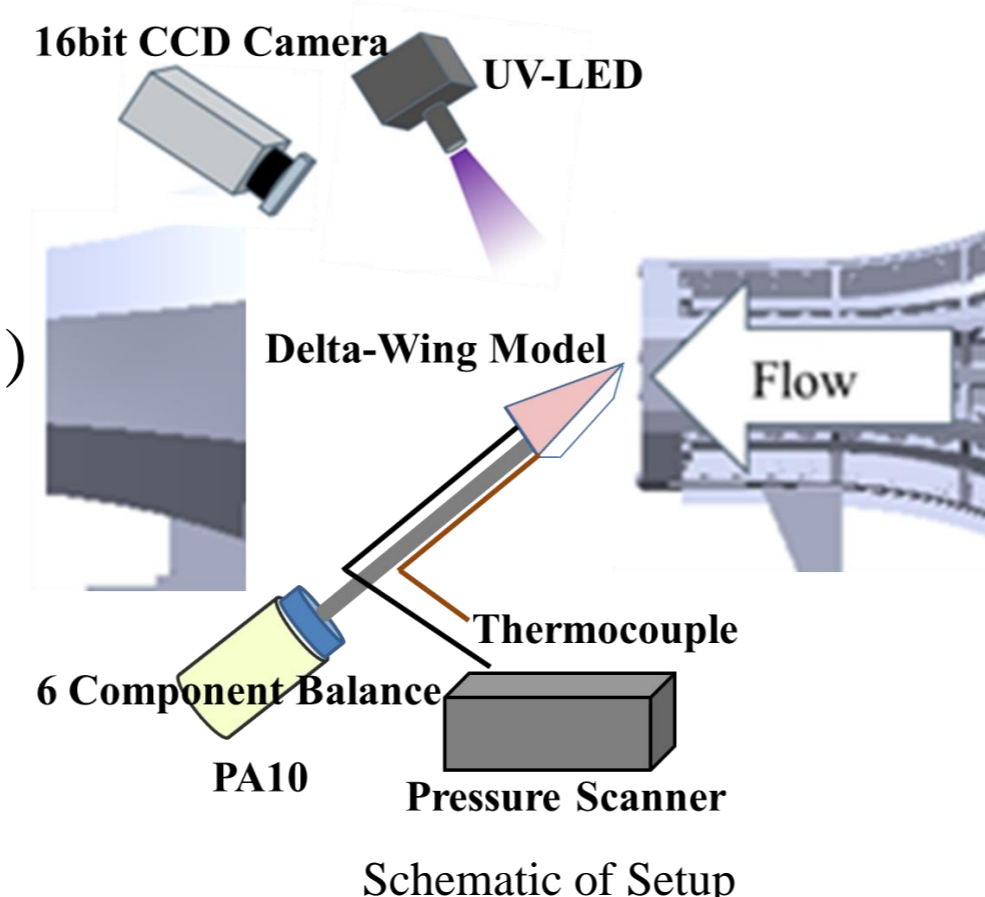
Pressure sensitivity of TUL1



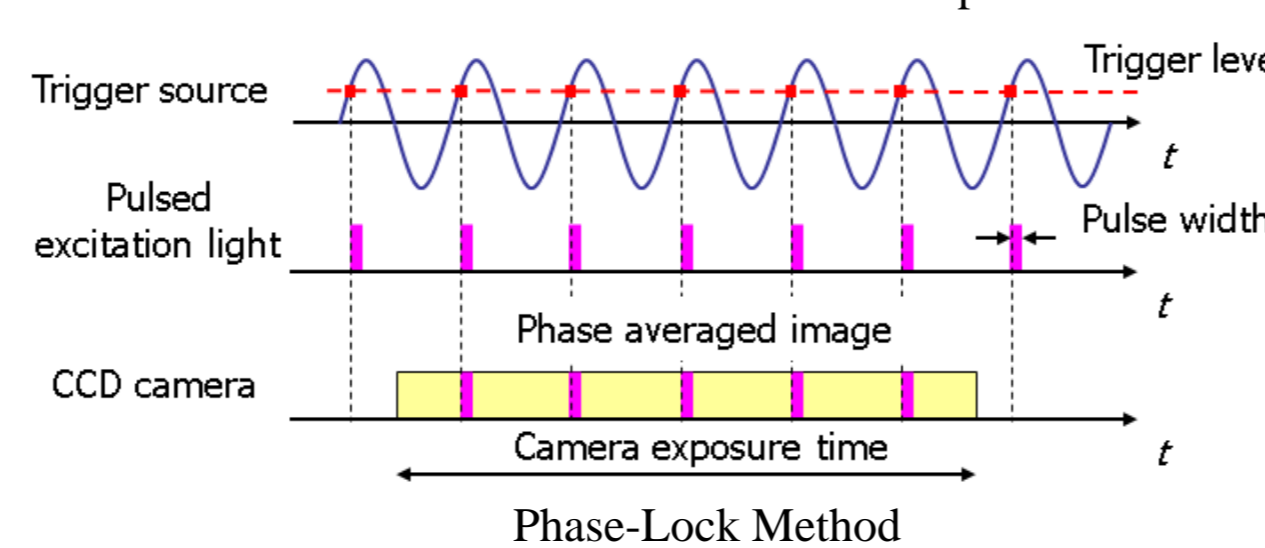
Temperature sensitivity of TUL1

#### Experimental Setup

- Reference Pressure measurement
  - Pressure scanner "Net Scanner System 9116"
- PSP figure measurement
  - UV LED
  - 16bit CCD camera (105mm lens, 650±40 nm Band-Pass filter)
- Force measurement (Rolling moment)
  - 6 component balance "IFS-90M31A50-I50"
- Phase-Lock Method
  - It is effective to obtain high-SNR images for unsteady PSP measurement and similar to stroboscopic photography.
  - Trigger signal is produced at determined phase
  - Excitation light is synchronized to the trigger signal
  - PSP luminescent intensity is summed up



Schematic of Setup



Phase-Lock Method

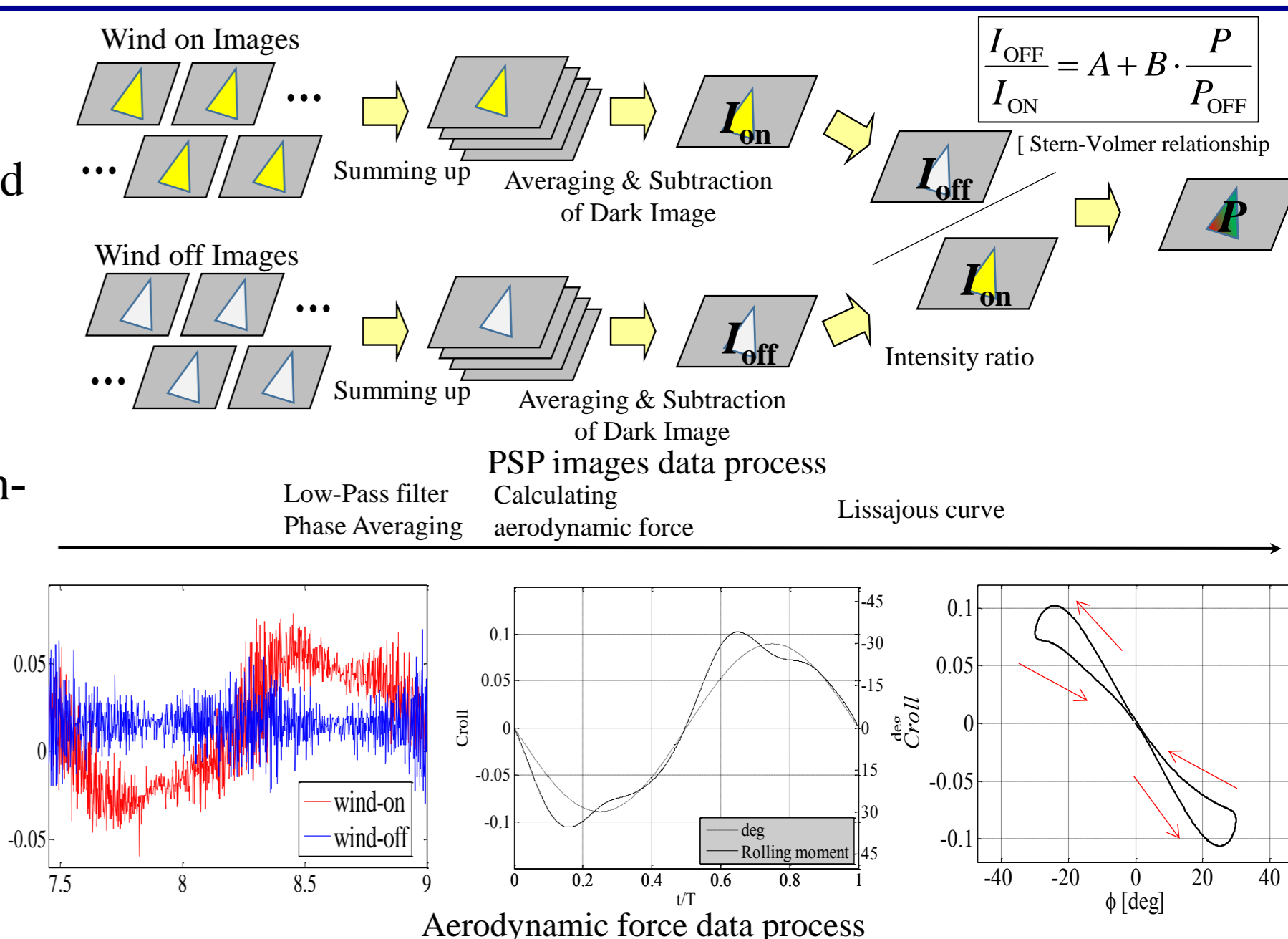
#### Test Conditions

- Steady testing
- Unsteady (Forced roll oscillation) testing

| Angle of attack | Flow velocity | Oscillation frequency | Dimensionless frequency | Roll amplitude |
|-----------------|---------------|-----------------------|-------------------------|----------------|
| 35 [deg]        | 30 [m/s]      | 0.1(steady), 1.0 [Hz] | 0.0003(steady), 0.003   | ±30 [deg]      |

#### Data Processing

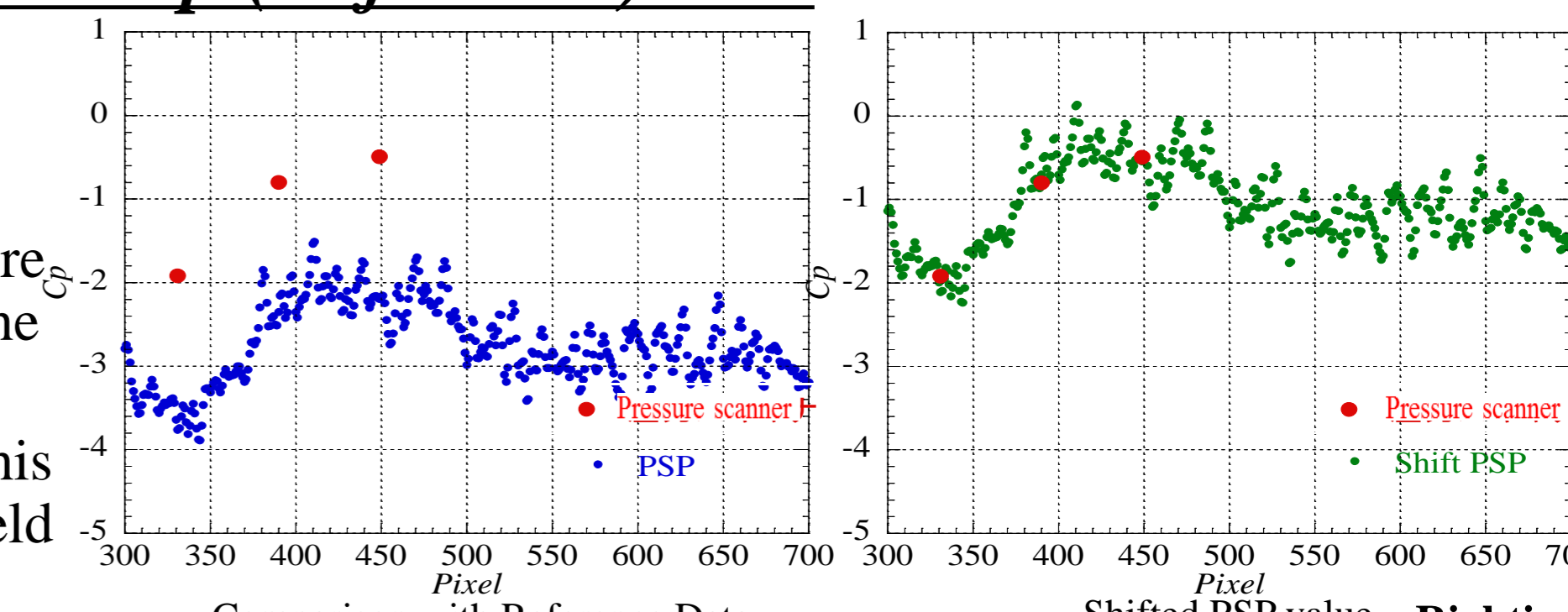
- Pressure from PSP figure
  - Summing up wind-on Images and wind-off Images
  - Averaging the intensity
  - Subtracting Dark images intensity from PSP images
  - Calculating the pressure by Stern-Volmer relationship
- Unsteady aerodynamic force
  - Subtracted wind-off data from wind on data
  - Low-Pass Filter
  - Phase averaging
  - Time drift correction



## Results

#### Comparison with Pressure tap (Reference) data

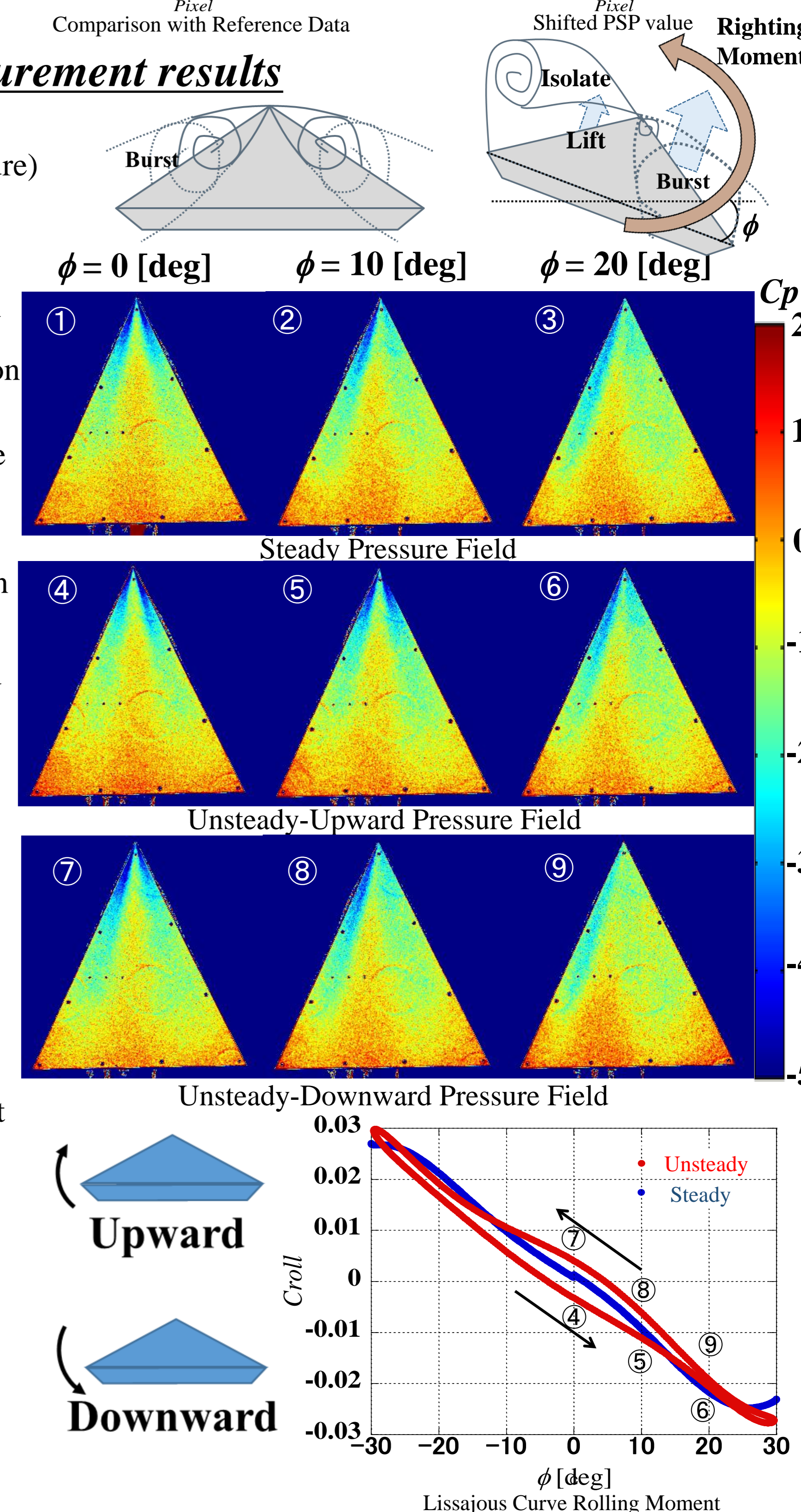
- Value of Pressure measured by PSP was shifted and it had a constant differential value
- Compared with reference pressure value, PSP data was following the tendency
- With reference pressure value, this method can measure pressure field of surface



Comparison with Reference Data

#### Steady and Unsteady measurement results

- Steady pressure field
  - Shown the suction (negative pressure) area caused by LEV
    - Symmetric suction area by LEV Vortex burst at trailing region
    - Asymmetric suction area by LEV LEV grown longer and isolated on the left side
    - LEV extended and bursted on the right side
- Unsteady pressure field
  - Compared with steady result, shown different view of pressure field by dynamic effect
    - Asymmetric suction area by LEV and dynamic effect of rolling
    - Delay of vortex burst on the right side
    - Delay of vortex recovery on the right side
    - Advance of vortex isolating
- Comparison with force measurement
  - PSP pressure data was compared with steady and unsteady result of force(rolling moment) measurement
  - Difference in right and left LEV structure produced the righting moment
  - Dynamic effect of rolling motion made the difference in upward and downward rolling moment. (Hysteresis)



## Summary

- Differential value of PSP and Pressure tap (Reference) is almost constant, therefore, correcting it can measure pressure field of surface quantitatively.
- Unsteady pressure field caused by LEV burst and recovery was visualized and measured by unsteady PSP.

## Future Works

- To measure velocity field of Delta wing surface by PIV, and we are considering that combine PIV and PSP analysis to observe the entire flow field three dimensionally.