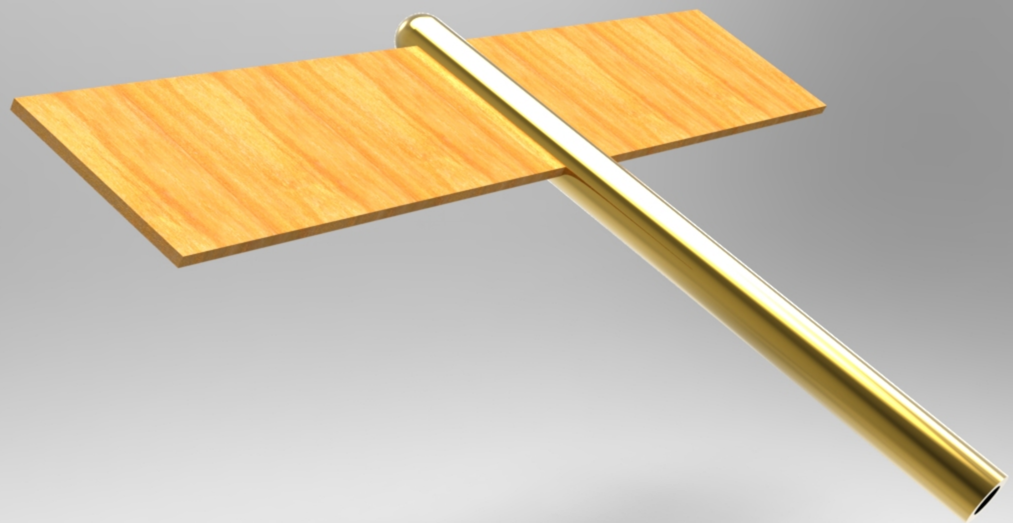
Boeing Higher Education Program Research Project



Data Assimilation Method for EFD/CFD Integration

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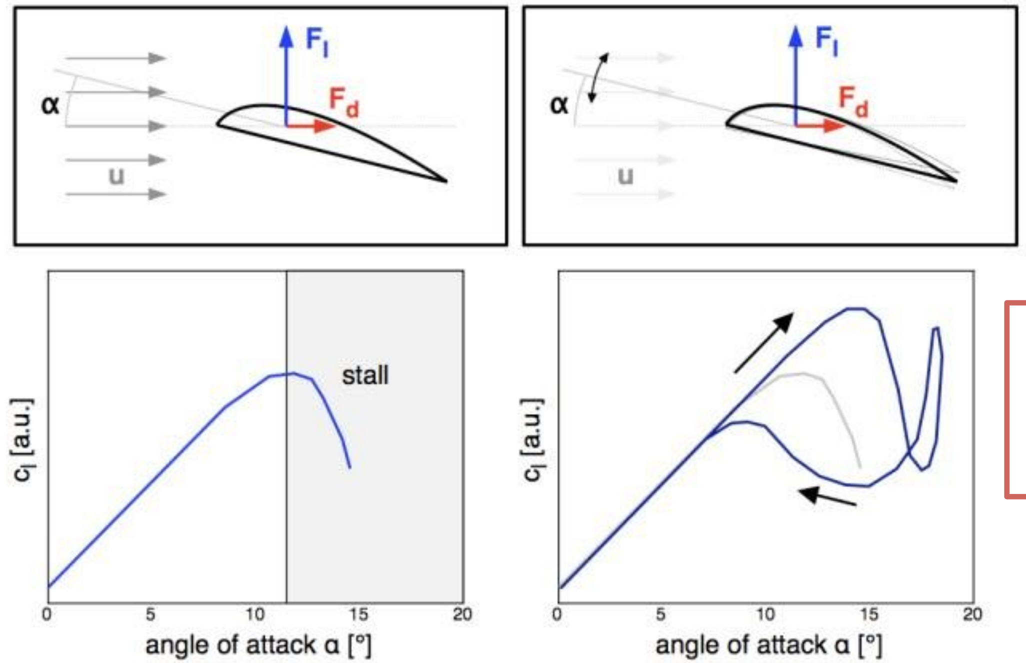
Background: Stall

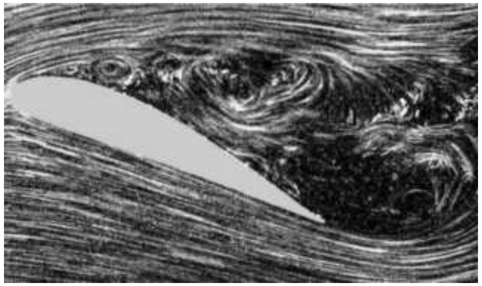
Air France Flight 447
（Airbus A330-200）

A section of the tail of Air France Flight 447

Background: Dynamic Stall Phenomenon

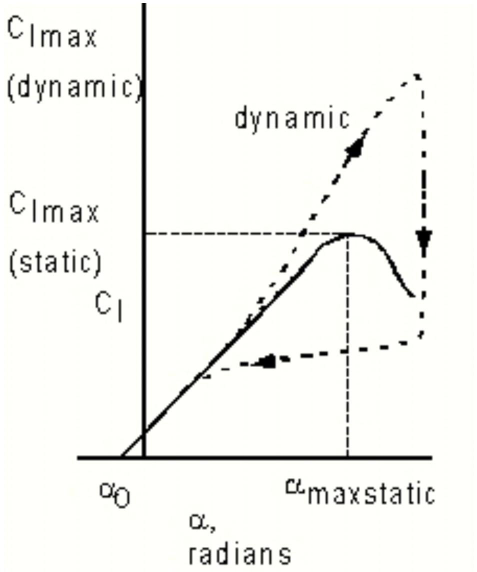
What is the Dynamic Stall Phenomenon?





Dynamic stall is a non-linear unsteady aerodynamic effect that occurs when airfoils rapidly change the angle of attack.

The airflow separation on top of the wing is in reality dynamic and always changing, and during these beyond the critical angle of attack, where the airflow is less separated than in the steady state.



Dynamic Stall of an Airfoil

Background: EFD & CFD

Experimental Fluid Dynamics (EFD)

Advantage

Practical flow ⇨ credible

Disadvantage

- Expensive
- Long experimental time
- Information limited
- Different from the real flight (Wall & Support eq.)

complementary

Computational Fluid Dynamics (CFD)

Advantage

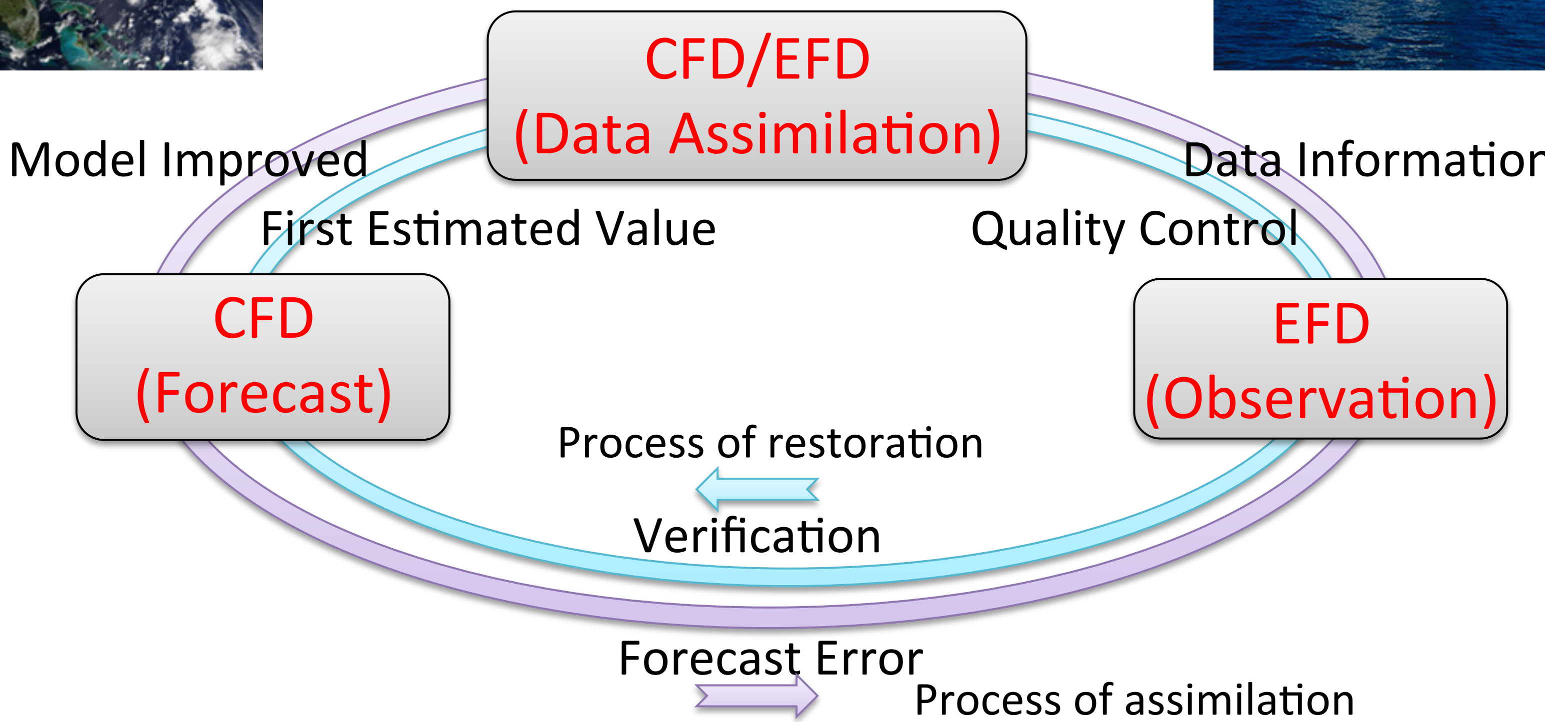
- Low computational cost
- Big information content

Disadvantage

Computational accuracy relies on the scheme and mesh

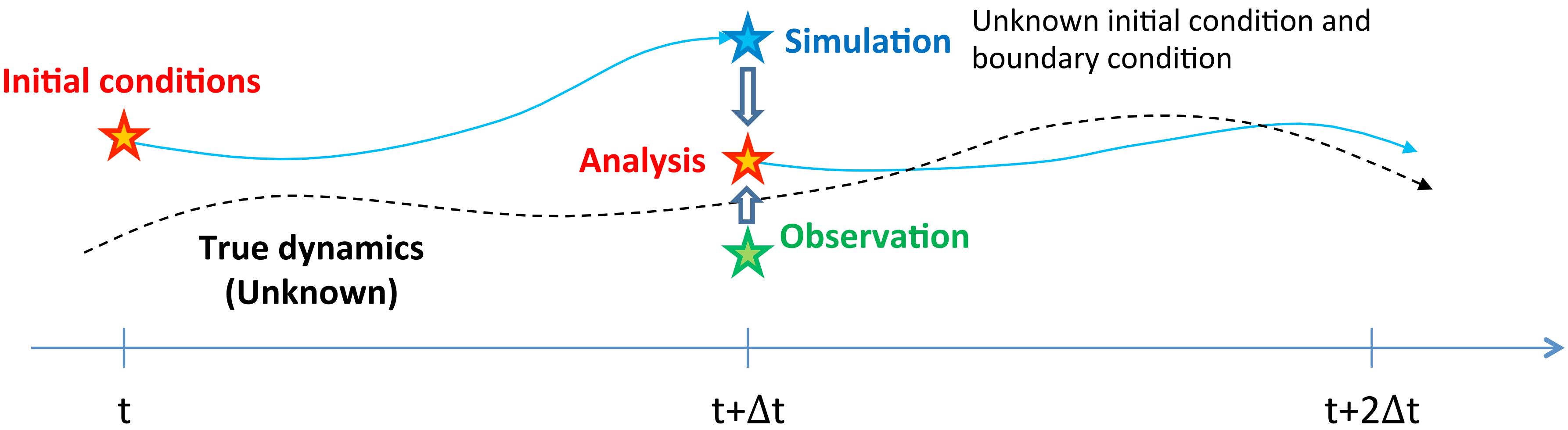
Background: Data Assimilation

Data assimilation is an analysis technique in which the observed information is accumulated into the model state by taking advantage of consistency constraints with laws of time evolution and physical properties.



Background: Data Assimilation

Basic Approaches
- Retrospective assimilation: EnKF(Ensemble Kalman Filter)
- Sequential assimilation: 4D-Var(4-dimensional Variational Assimilation)

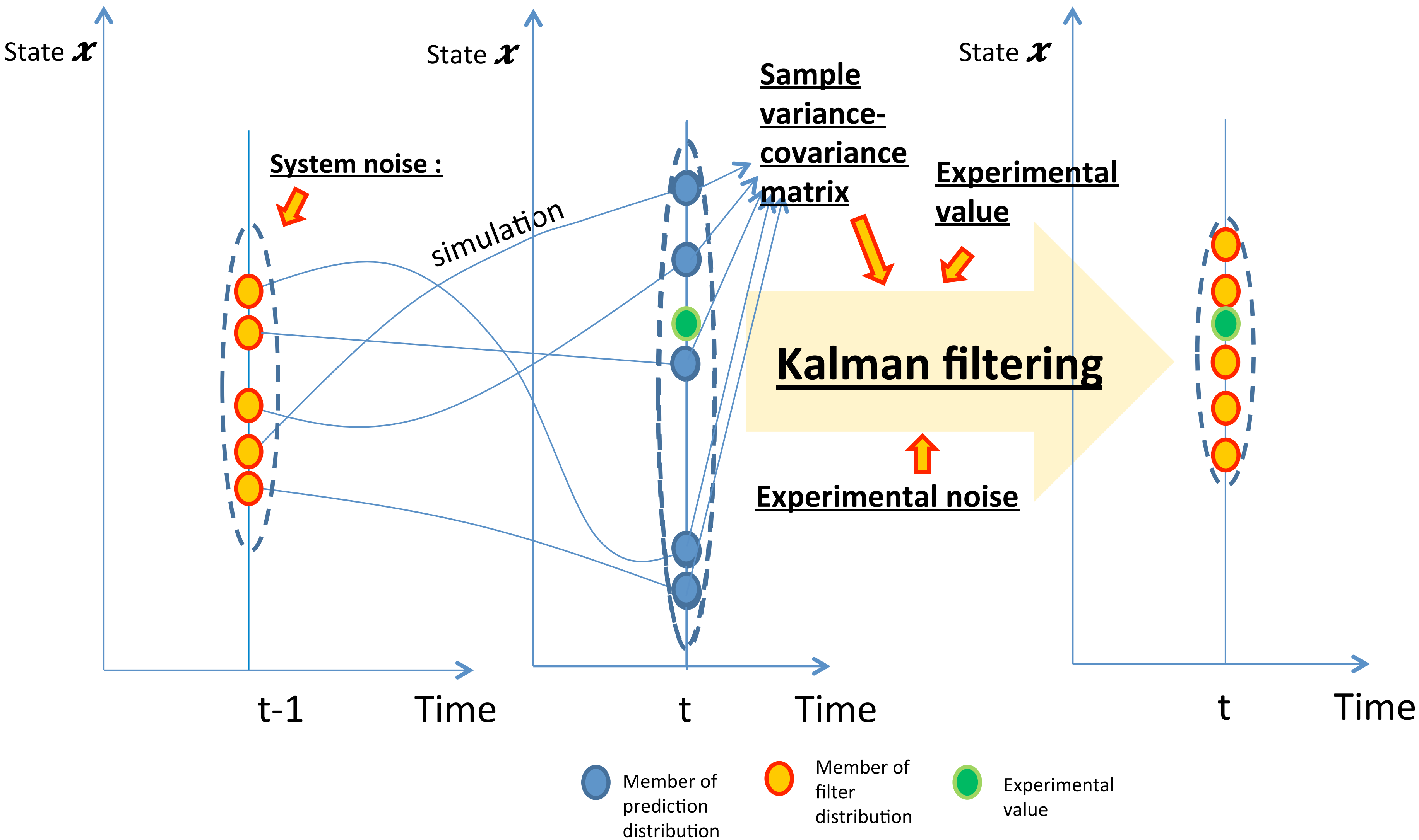


Schematic of data assimilation (JAXA,Kato)

Data assimilation
Reduce the numerical error (uncertainty) by using observation (measurement)

Background: Data Assimilation

Procedure of EnKF

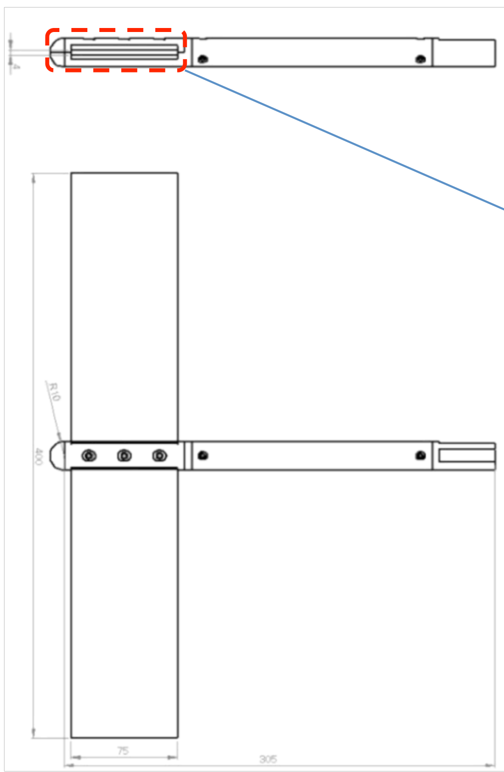


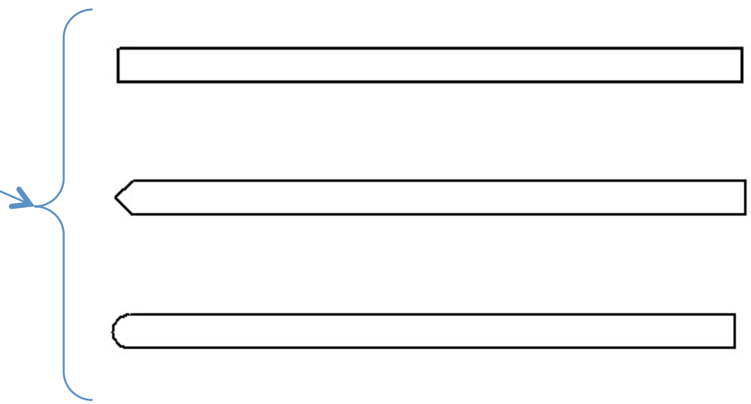
Objective

Make the numerical simulation become high-precision using Data assimilation method to understand the Dynamic Stall phenomenon

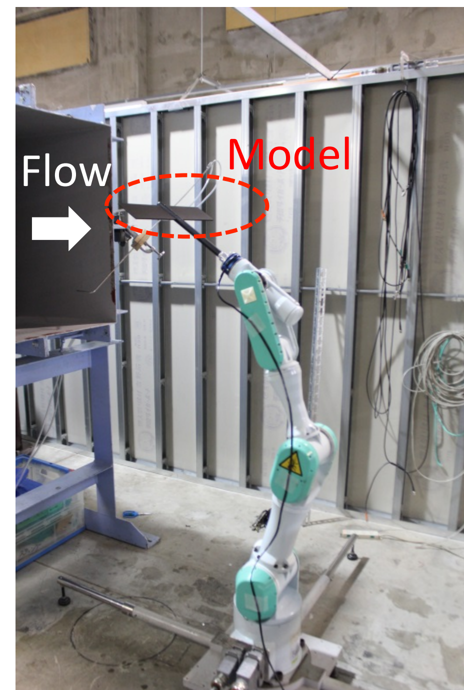
Experimental Set-up

- ✓ Facility: Open-type Low-turbulence Wind Tunnel
- ✓ Measurement: Force (Robotic Arm PA10)
- ✓ Sting: Robotic Arm PA10 (Mitsubishi Heavy Industries), Degree of freedom=7
- ✓ Model : rectangle wing (Aspect Ratio= 5<400/75<6)
  leading edge= Quadrangle, Triangle, Rotundity
- ✓ Experimental conditions:
  steady : 0°~ 10°(1°changed per case)
  unsteady : frequency=0.5, 1.0, 1.5, 2.0, 3.0 Hz ,amplitude=2, 4 deg





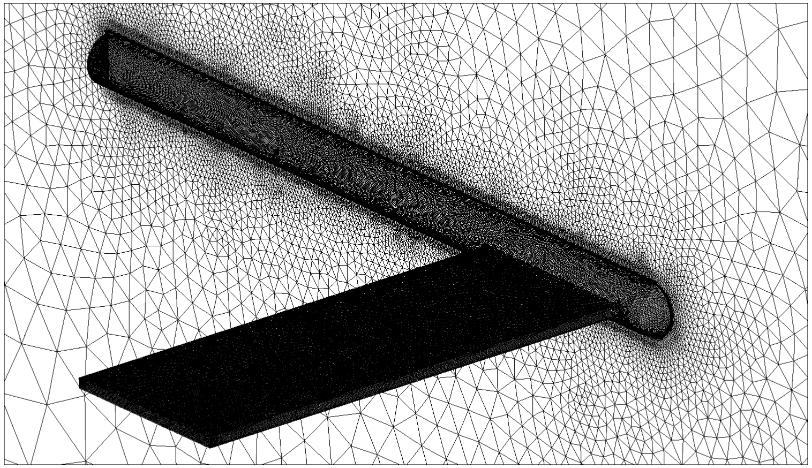
Three different kinds of Leading Edges



Computational Fluid Dynamics

✓ Method

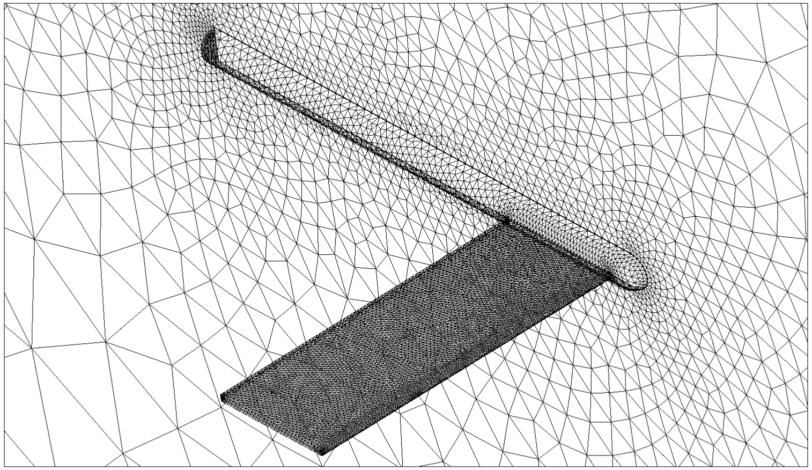
Scheme for advection term	SLAU
Reconstruction method	Green-Gauss based Least Square
Time integration method	LU-SGS
Viscous model	SST/ Laminar



Fine grid

✓ Calculation Condition

Mach number M_∞	0.044
Angle of attack α (deg)	0°~10°
Aspect ratio	400/75
Reynolds number Re	7.6e4
Grid number	Fine:5,986,903 Coarse: 1,023,896
Calculation steps	30,000

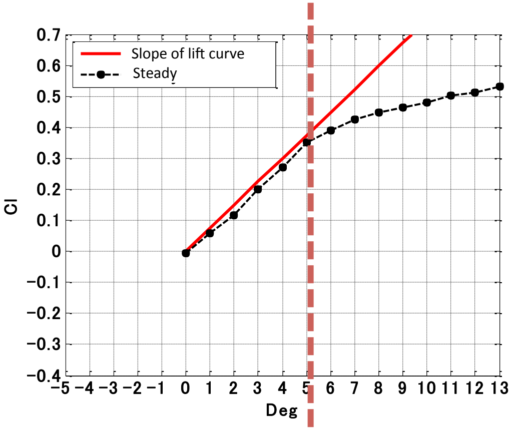


Coarse grid

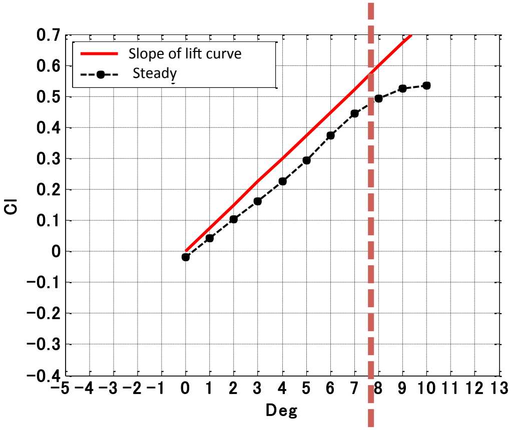
Results

EFD: Steady Motion

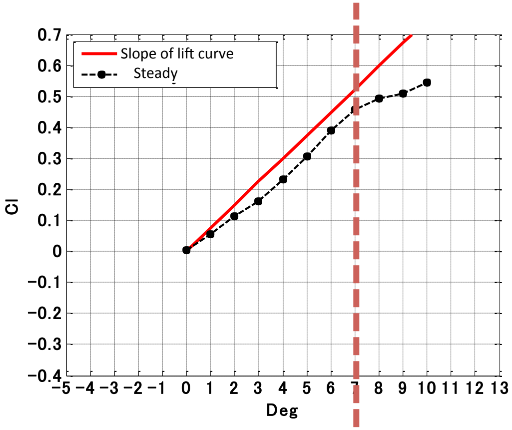
Leading Edge: Quadrangle



Leading Edge: triangle



Leading Edge: Rotundity



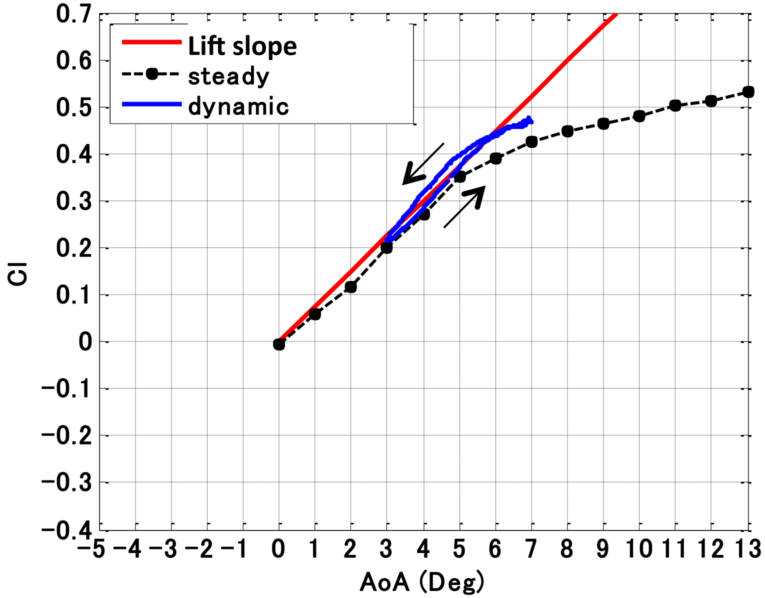
Leading edge	Flow separation of AoA [degree]
Quadrangle	5
Triangle	8
Rotundity	7

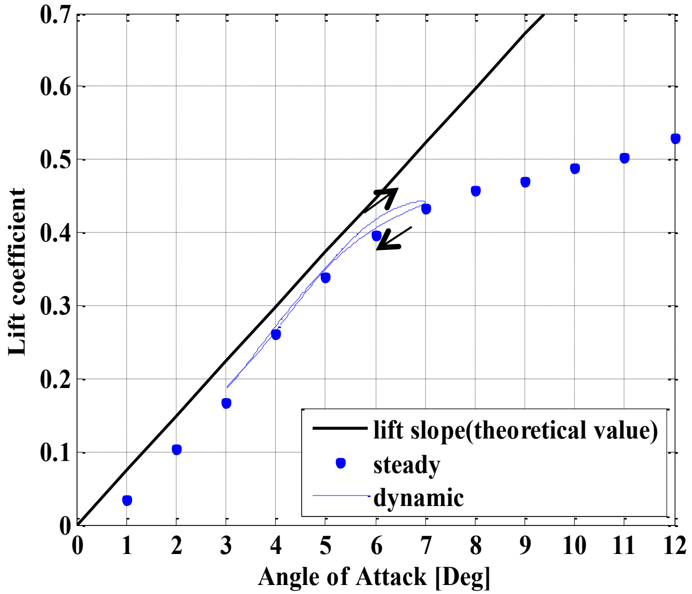
Purpose of Steady motion: Find the flow separation of AoA ➡ Unsteady motion
Compare with numerical simulation

EFD: Unsteady Motion

Leading edge : Quadrangle

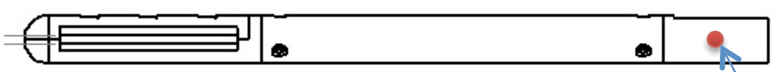
α_0=5deg Amp=2deg f=0.5Hz

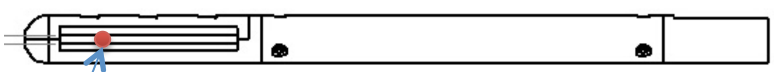




before

after

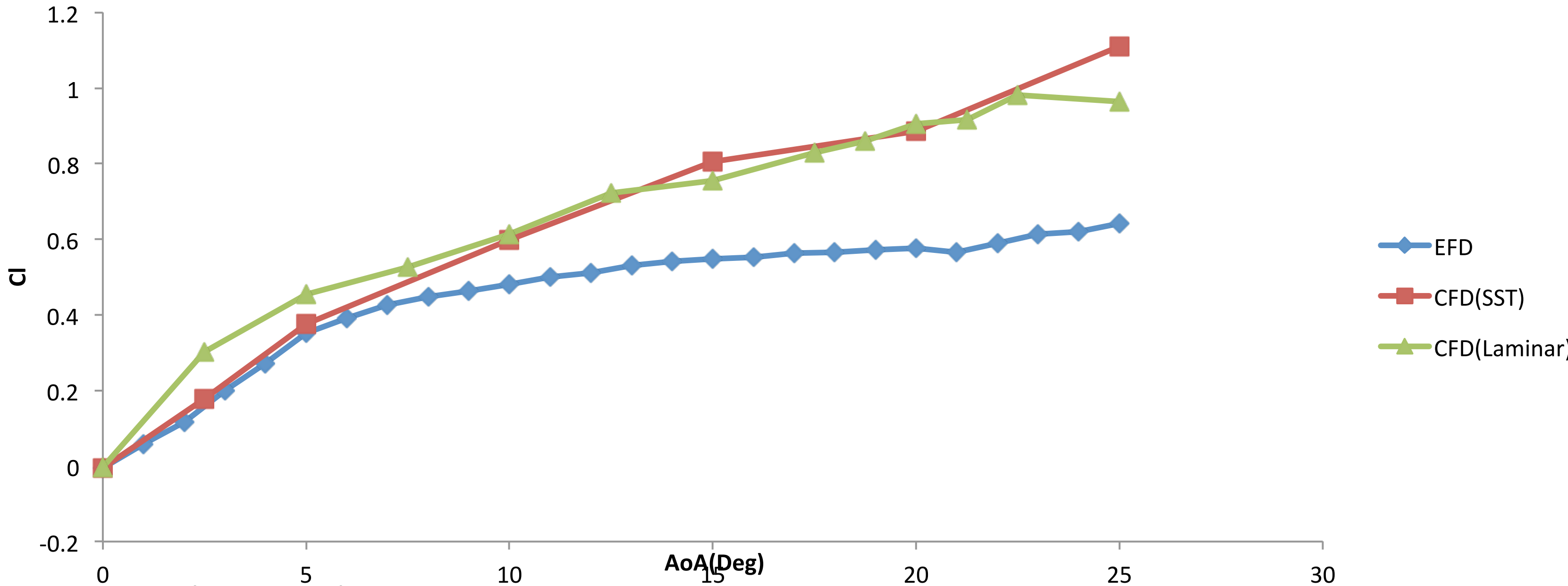




Axis

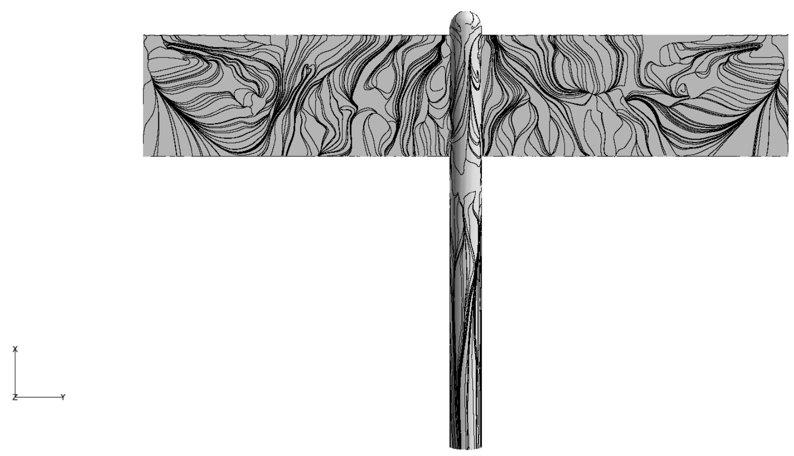
CFD: Quadrangle

Quadrangle



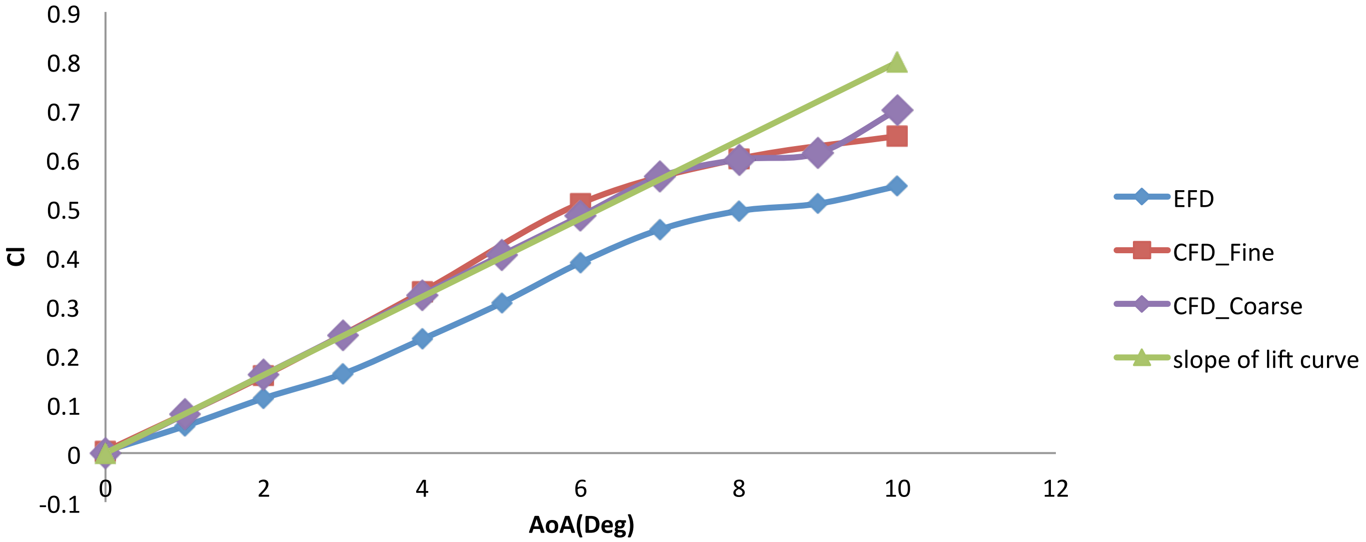
Visualization (AoA=5°)

Surface flow(Laminar)



Surface flow(SST)

CFD: Rotundity



Summary:

１. The fine grid and the coarse grid have almost the same results (Grid independence)

2. The CFD data is consistent with the slope of lift curve but different with the experiment data

Summary And Conclusion

1.Background: Dynamic stall, Data assimilation
2.Objective: Understand the dynamic stall phenomenon
3.Preparation:
EFD: Facility, Measurement, String, Model, Condition…
CFD: Method & Condition
4.Results:
EFD: Steady motion ⇒ Flow separation of AoA
Unsteady motion
CFD: Quadrangle, Rotundity steady computation & Visualization

Future Works

✓ EFD:

Flow Visualization& Force Measurement :

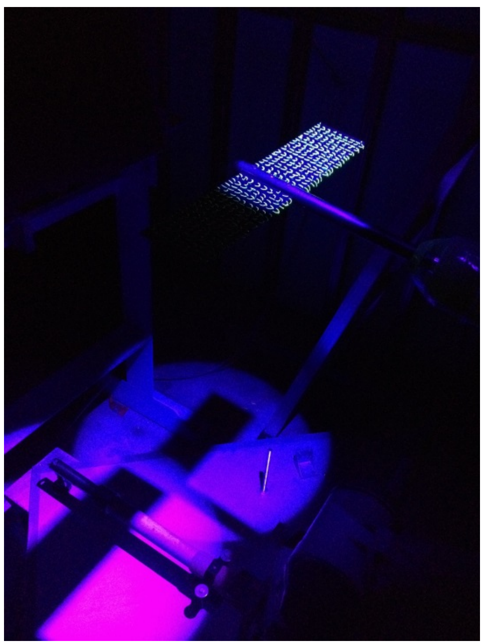
Fluorescent mini-tuft method ➡ Laser light sheet method(LLS)

✓ CFD:

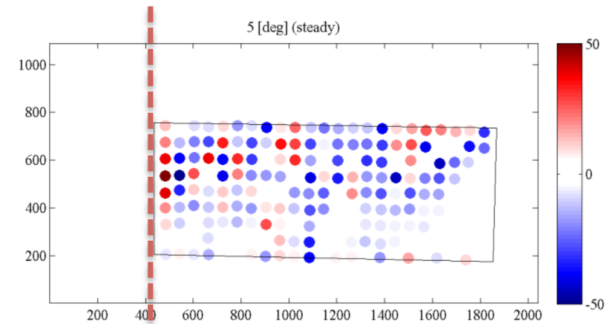
Carry out unsteady computation & find the optimized grid number for MPI

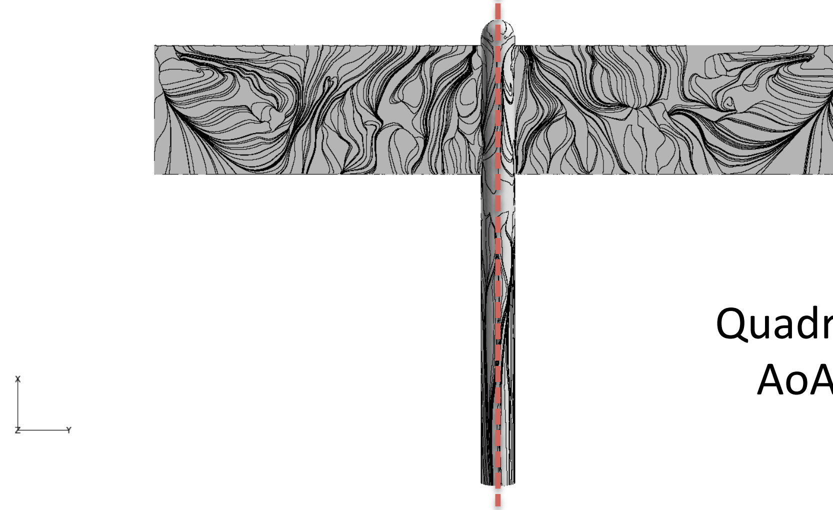
✓ Data assimilation:

Identical-twin experiments



Fluorescent mini-tuft method





Quadrangle
AoA=5°

THE END

Thank you for your attention!

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