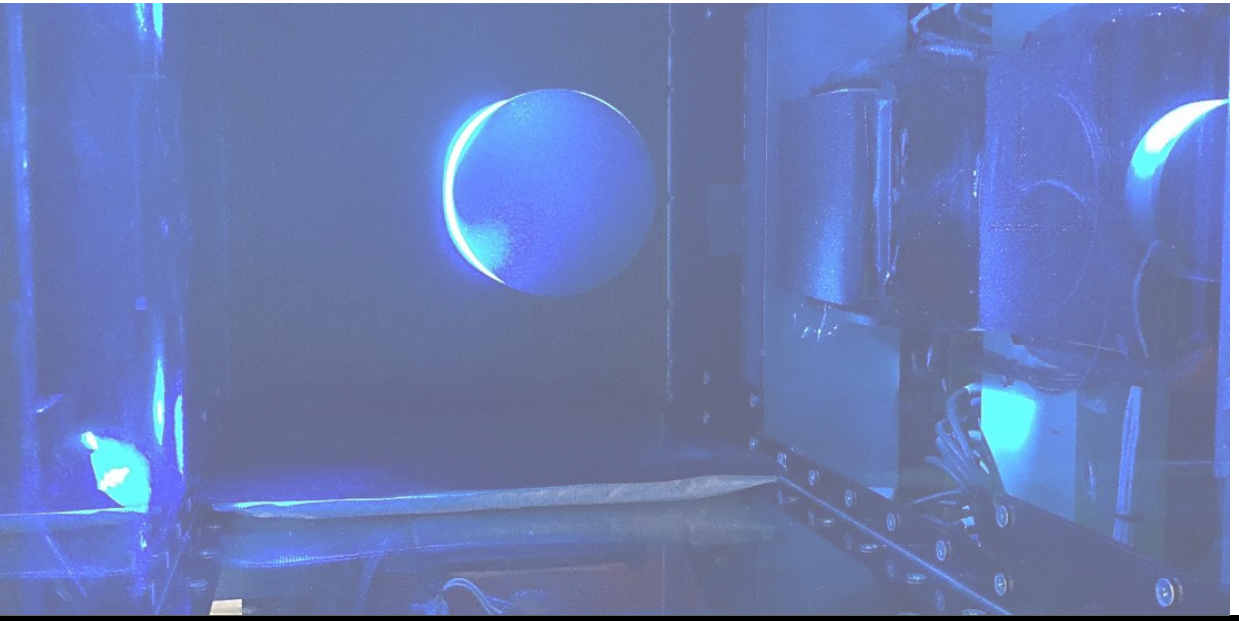
Experimental project for aerodynamic characteristics of cylinders with a low fineness ratio using IFS MSBS

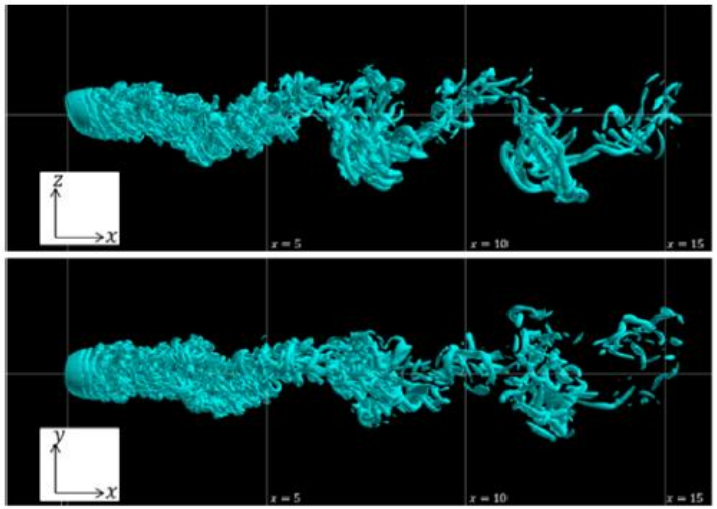


Masahide Kuwata[1,2]

[1]Institute of Fluid Science, Tohoku University
[2]Department of Aerospace Engineering, Tohoku University

Bluff Body : Re-entry capsule

Boeing's CST-100 in Earth orbit [1]



Wake structure of re-entry capsule [2]

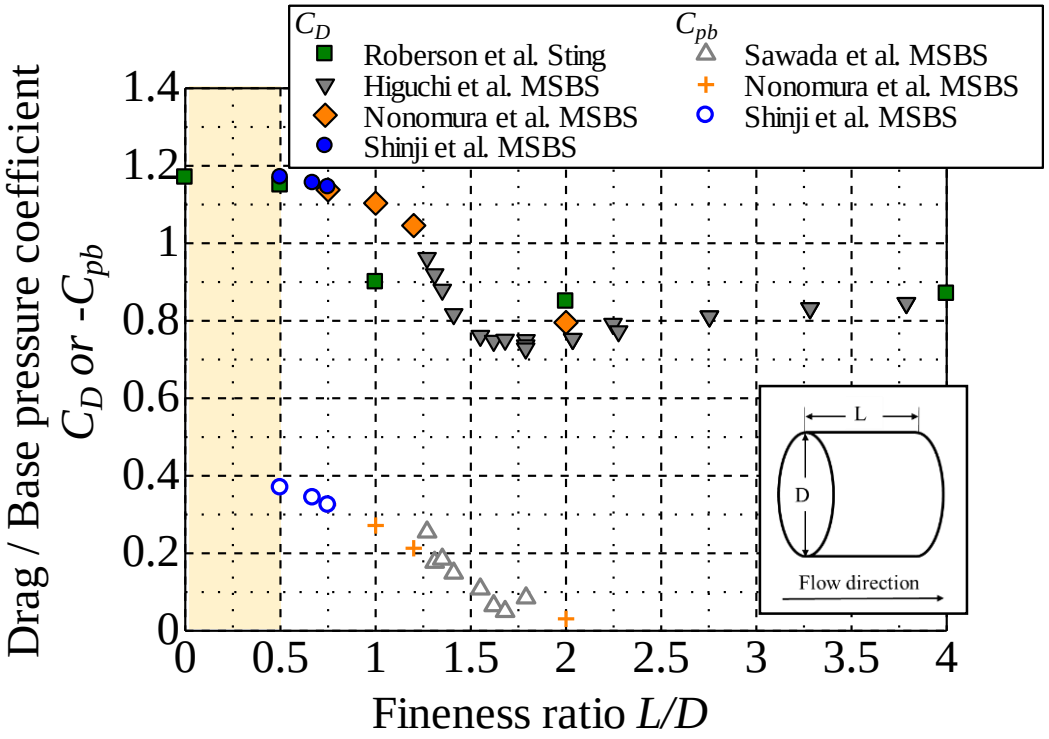
Re-entry capsule are used when returning people or samples from space to the earth

- ✓ **Flat shape** : To reduce aerodynamic heating due to high entry speed
- ✓ **Dynamic instability** : aerodynamic forces cause pitching oscillation

It is necessary to understand the relationship between the wake structure and aerodynamic forces which induce pitching oscillation

[1]. spaceflightinsider.com, visited 2019/12/7.
[2]. Omichi et al., "Feature extraction technique for large time-series data and its application to wake flow analysis of a re-entry capsule", 50th Fluid Dynamics Conference, Japan, 2019.

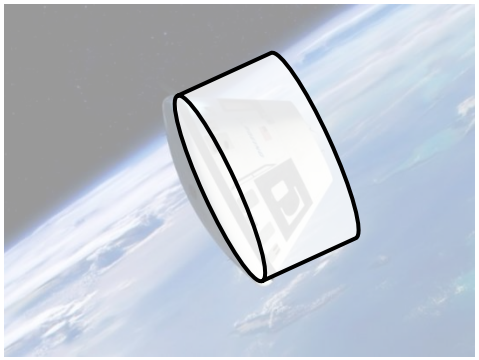
Aerodynamics of Circular Cylinder



C_D & -C_{pb} vs Fineness ratio (L/D) of circular cylinder

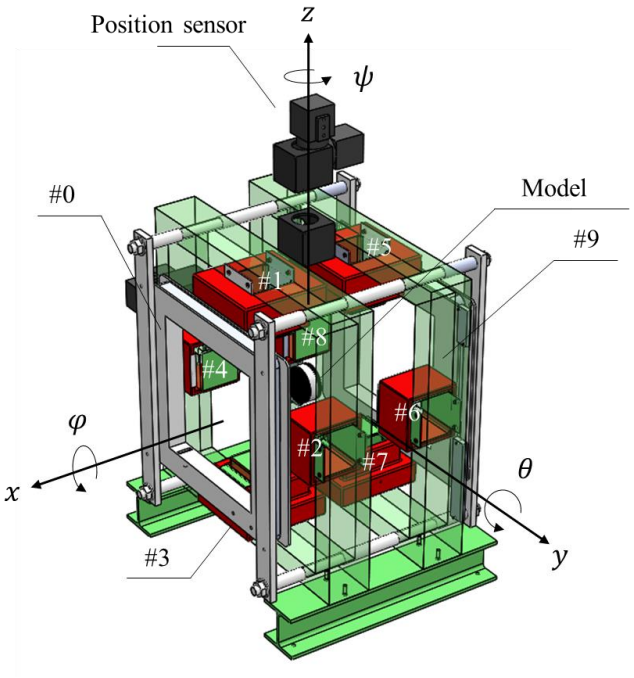
Re-entry capsule

Low-fineness-ratio circular cylinder

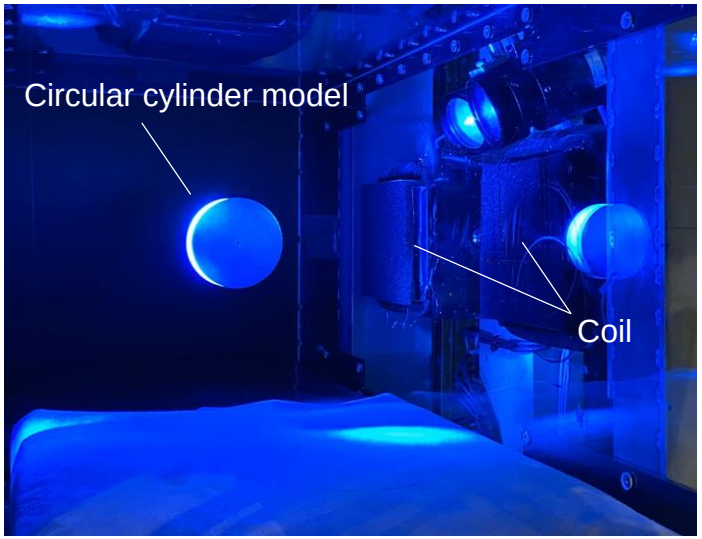


Evaluate aerodynamic characteristic of circular cylinders with $L/D \leq 0.5$ to estimate aerodynamic characteristics of a re-entry capsule

Magnetic Suspension and Balance System



0.3 m MSBS



Magnetically supported model in the MSBS

- ✓ Magnetically support model in wind tunnel
- ✓ Measure aerodynamic force from magnetic force

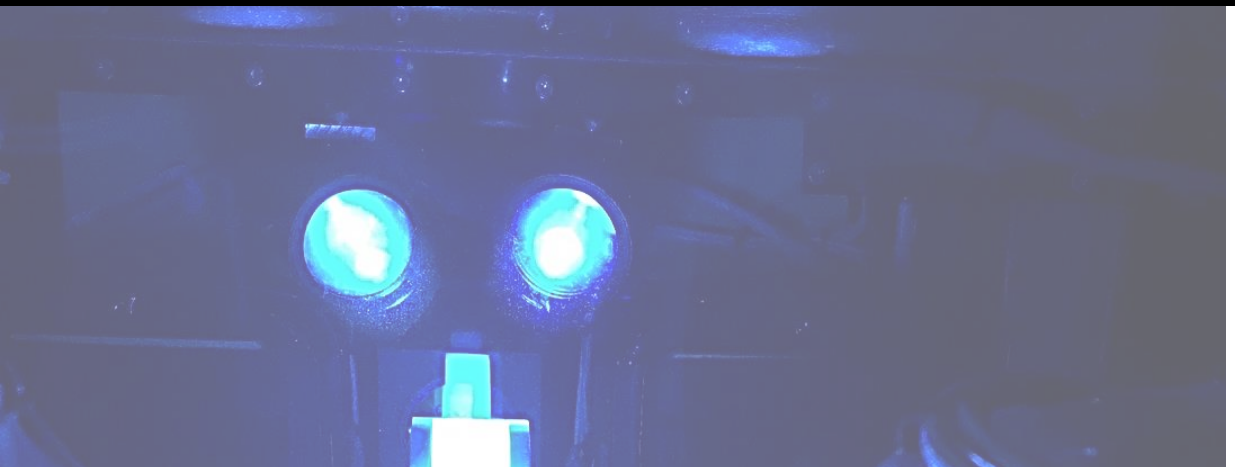
MSBS can evaluate aerodynamic forces and torques acting on a model without support interference

Objectives

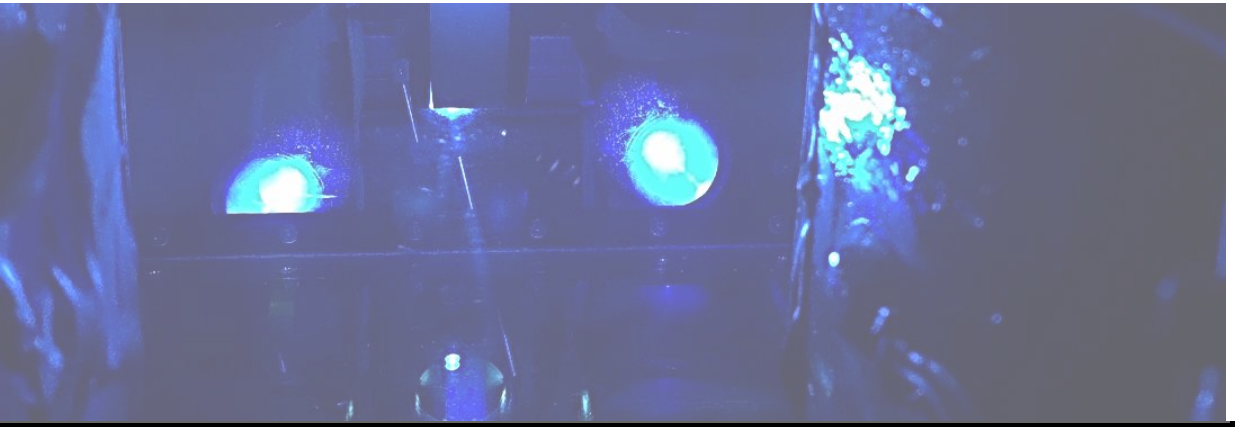
Evaluate aerodynamic characteristics of a low-fineness-ratio circular cylinders toward the effective development of the re-entry capsule

1. **Aerodynamic force measurement by MSBS**

2. **Flow visualization by PIV technique**

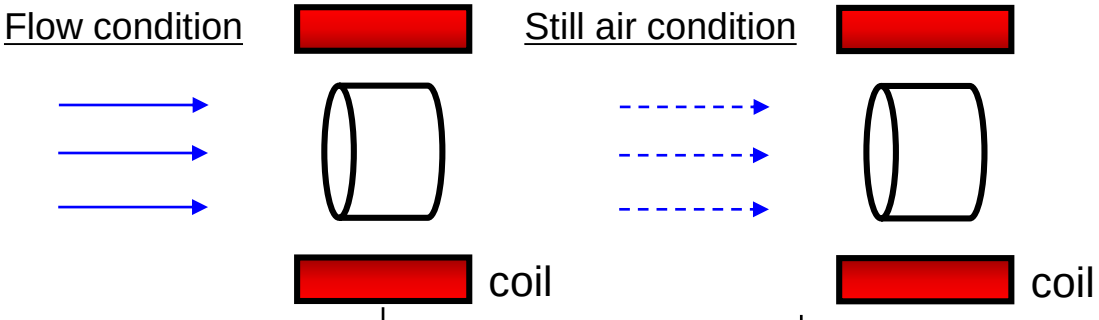


1 Aerodynamic force measurement by MSBS



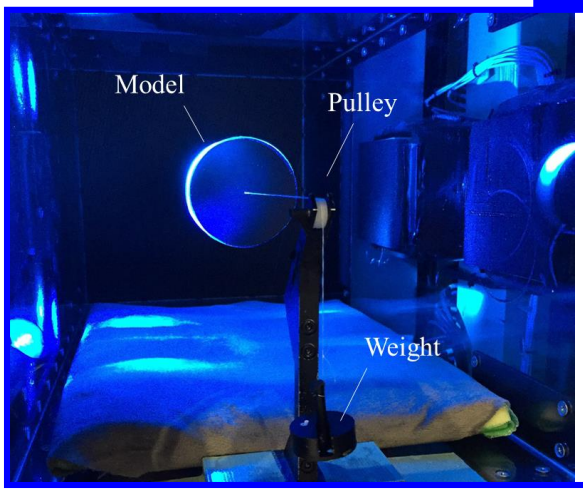
Force Evaluation by MSBS

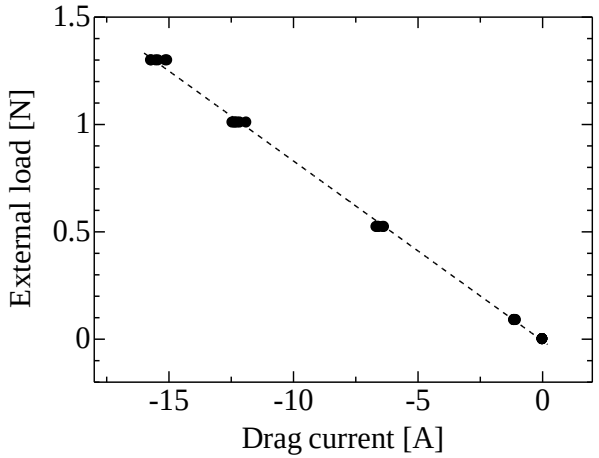
How to measure the aerodynamic force



$$F_{aero} = M_x \frac{\partial h_x}{\partial x} \left(I_{flow} - I_{still\ air} \right)$$

Aerodynamic force | Calibration constant | Measured coil current



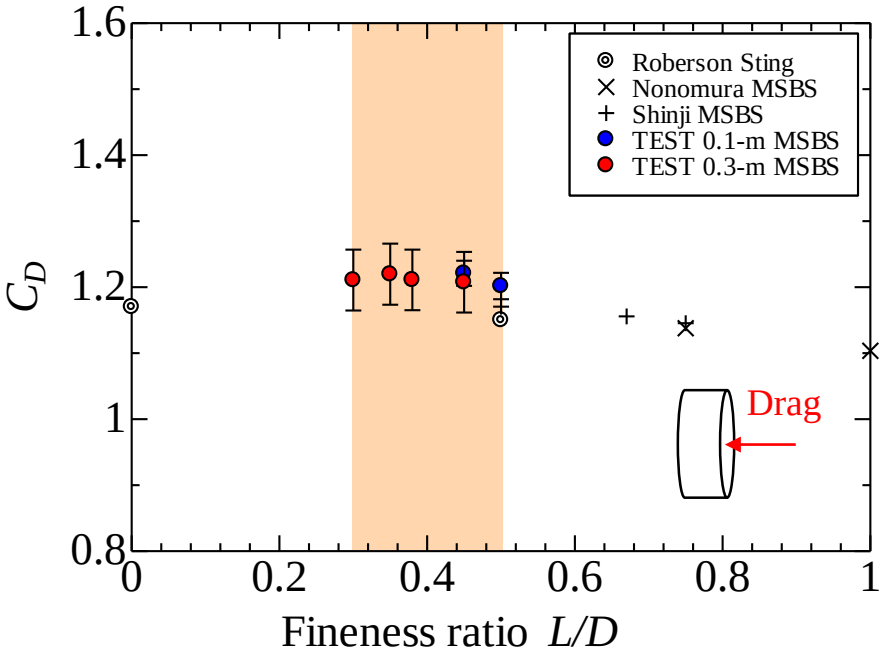


$$F_{drag} = C_{drag} I_{drag}$$

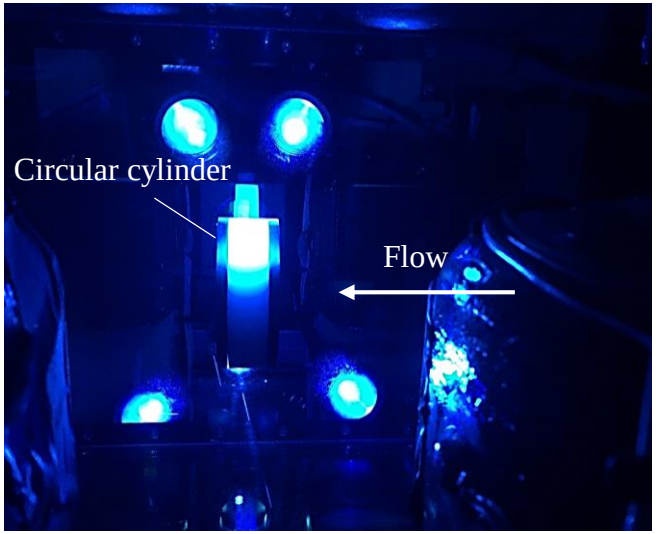
Changing load

Changing Coil current

Result : Steady Aerodynamic Characteristic



Drag coefficient C_D vs Fineness ratio (L/D)



Magnetically supported model with L/D=0.30

Drag coefficients were almost constant in $0.3 \leq L/D \leq 0.5$

Length of a circular cylinder with low fineness ratio
does not affect steady aerodynamic characteristics

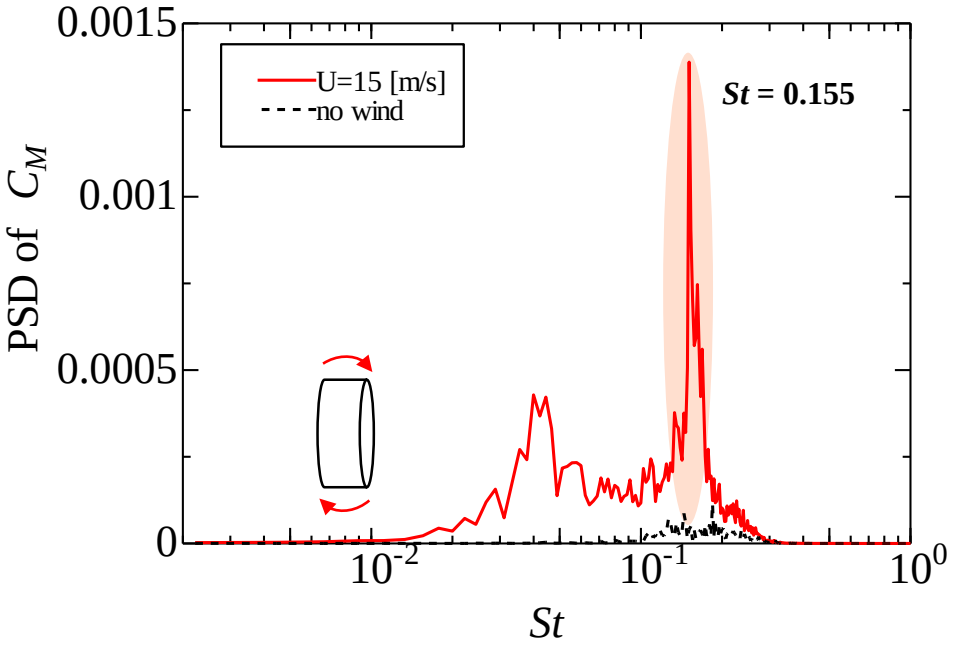
Result : Unsteady Aerodynamic Characteristic

✓ What aerodynamic forces / torques oscillate the Re-entry capsule…?

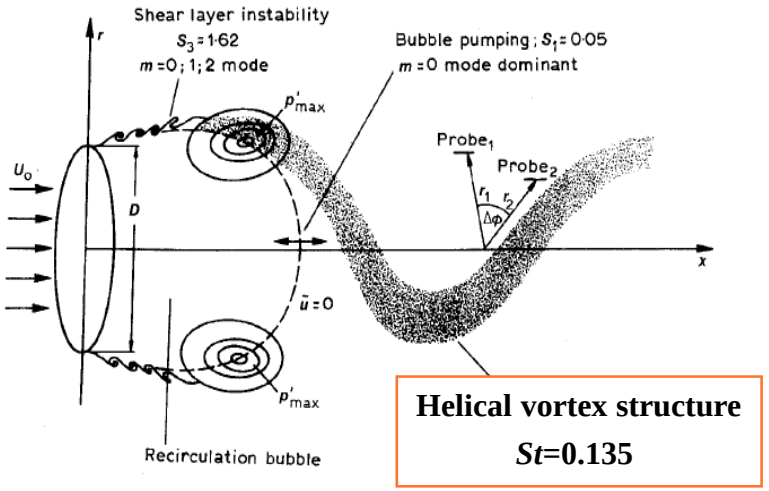
Frequency analysis is applied to aerodynamic force data

Strouhal number $St = \frac{fD}{U}$ Non-dimensional frequency

f : frequency [Hz], D : model diameter [m], U : flow velocity [m/s]

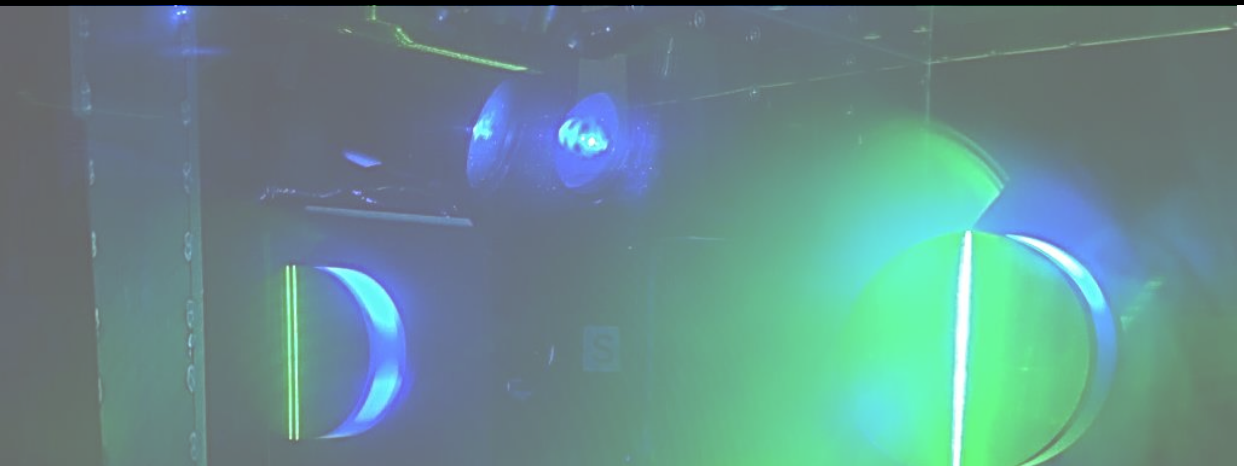


PSD of C_M (L/D=0.30)



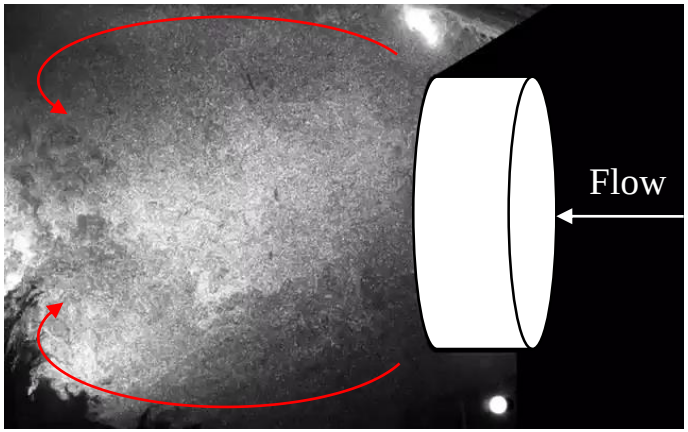
Helical vortex structure
St=0.135

Disk wake structure (E. Berger, 1990)

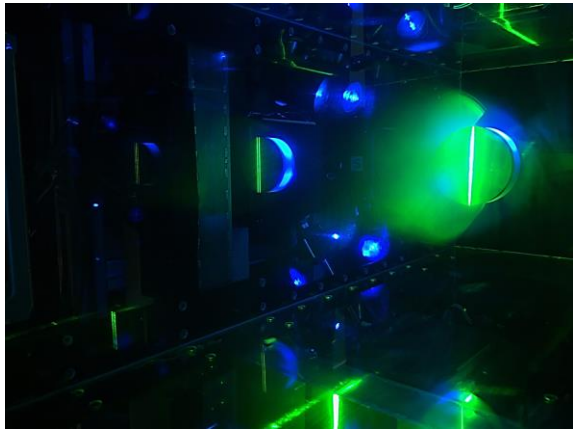


❷ Flow visualization by PIV technique

Outline of Flow Visualization



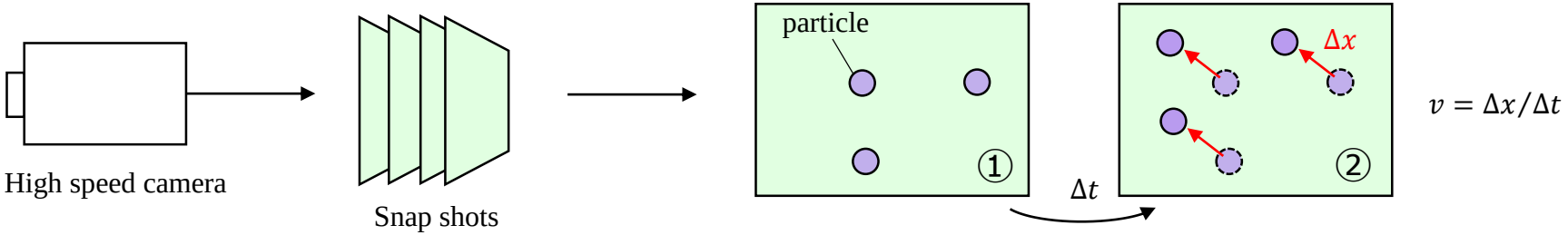
Particle visualized by YLF laser



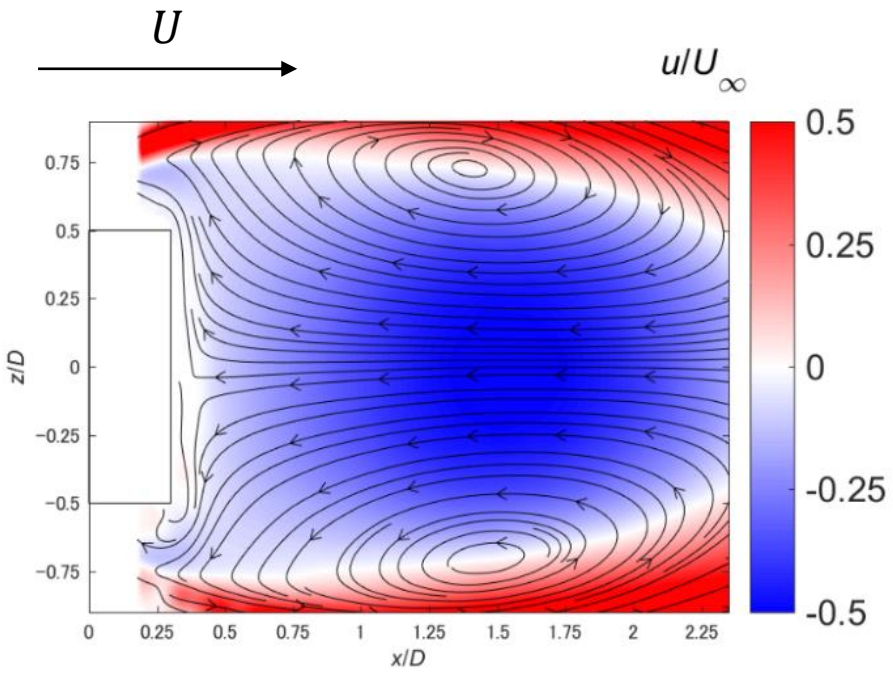
Laser sheet in the wake of circular cylinder

Particle Image Velocimetry : PIV

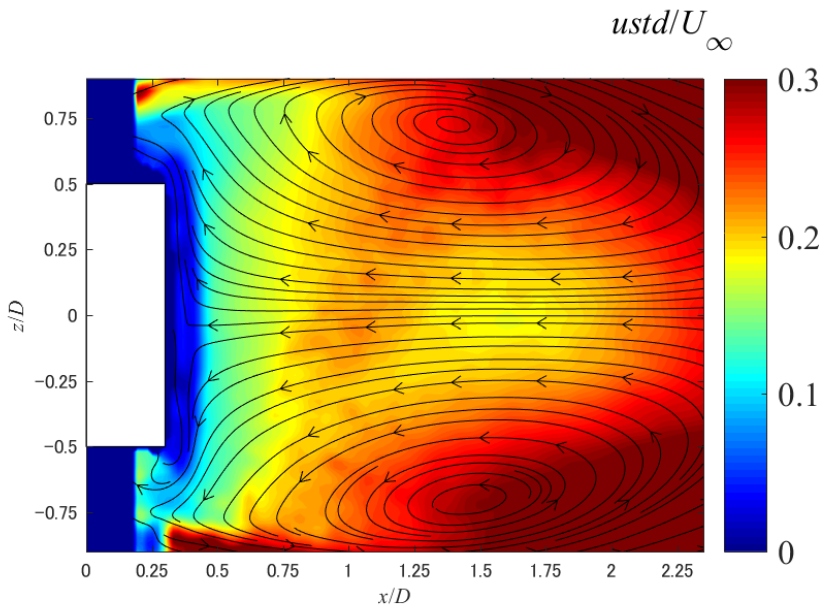
- ✓ Optical method of flow visualization, using tracer particle and strong laser sheet
- ✓ Flow velocity can be calculated by observation of tracer particle



Mean Velocity Distribution



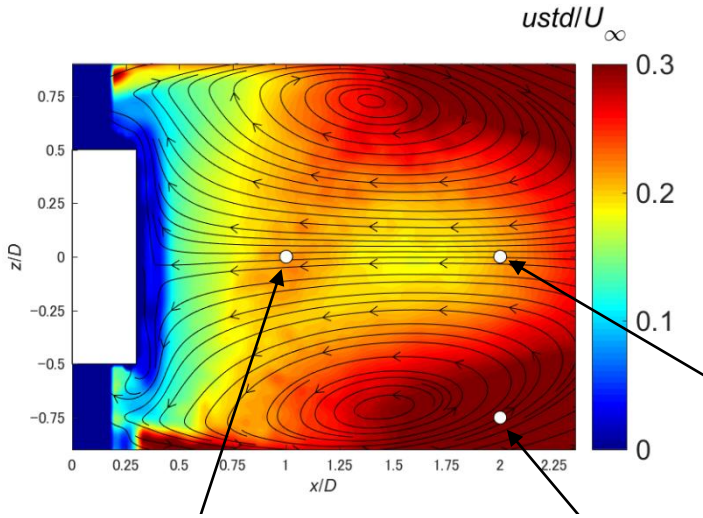
Mean Velocity distribution of U component (U_∞=10 m/s)



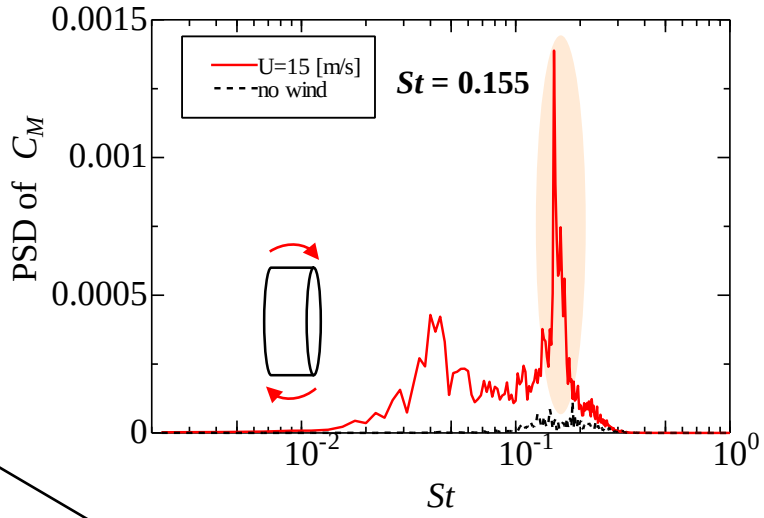
STD distribution of U component (U_∞=10 m/s)

- ✓ A pair of a counter-rotating recirculation zone is formed in the wake
- ✓ Large velocity fluctuation is observed behind the center of the recirculation zone

Unsteady Aerodynamic Force and Wake



STD of velocity component of L/D=0.30 (U_∞=10 m/s)



PSD of C_M (L/D=0.30)

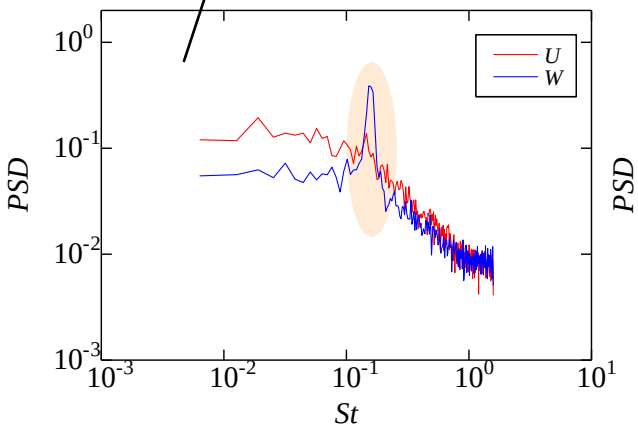


Fig. PSD of velocity (x/D , z/D)=(1.0 , 0.0)

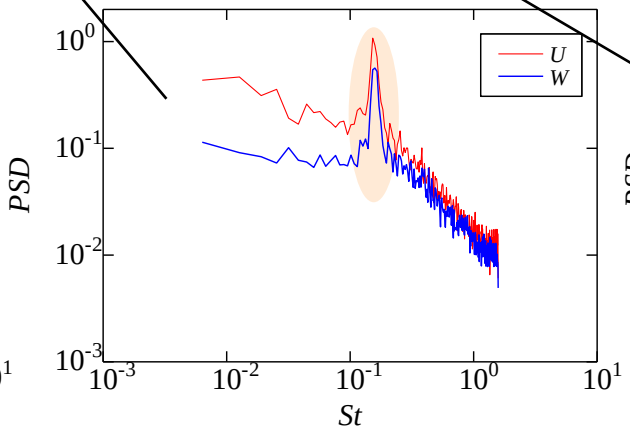


Fig. PSD of velocity (x/D , z/D)=(2.0 , -0.75)

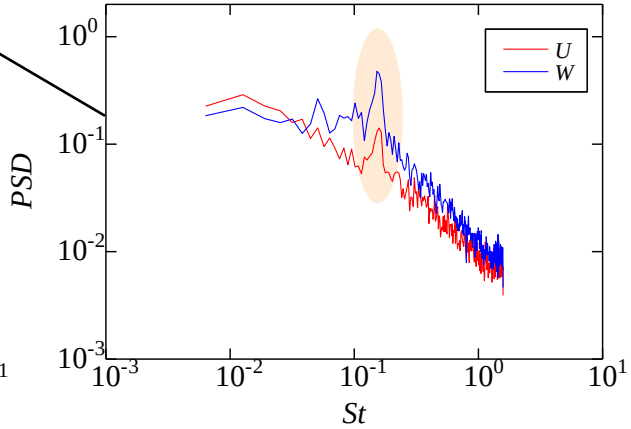
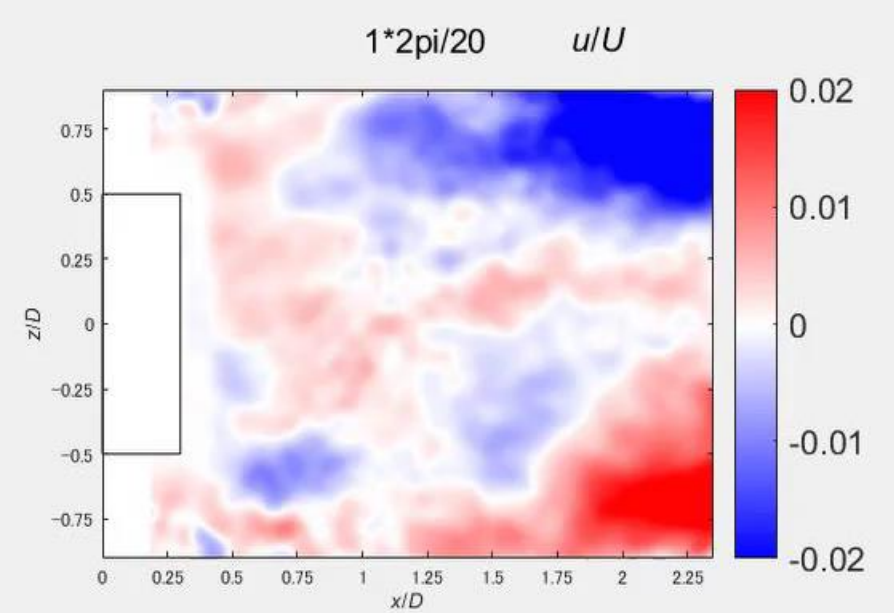


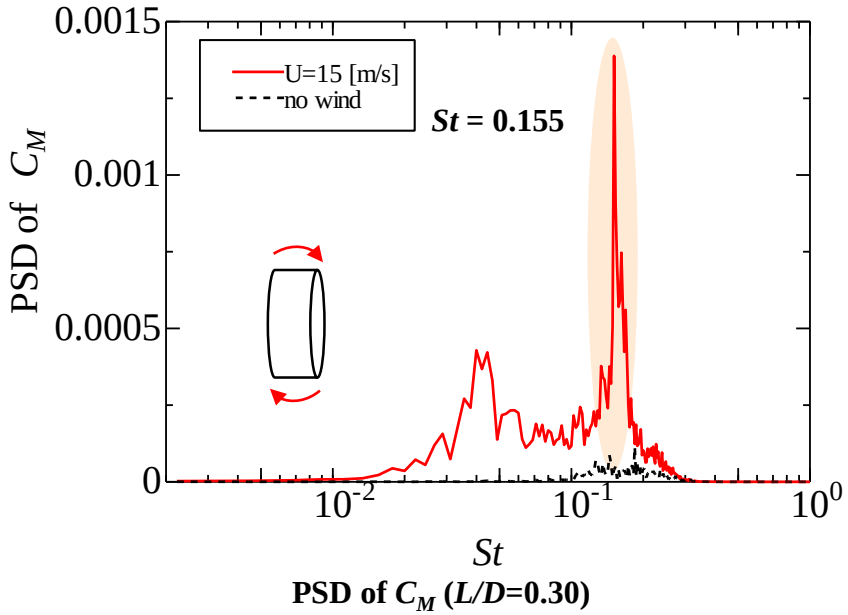
Fig. PSD of velocity (x/D , z/D)=(2.0 , 0.0)

Specific frequency fluctuation (*St* = 0.155) was also confirmed in flow field

Unsteady Aerodynamic Force and Wake



Phase averaged velocity component of *St*=0.155



PSD of C_M (L/D=0.30)

Flow separation (*St*=0.155)

- ✓ Flow separation at leading edge occurs in *St* = 0.155
- ✓ Forced oscillation in pitching moment is caused at *St* = *O* (0.1)

Flow separation is closely related to unsteady aerodynamic torque acting on a low-fineness-ratio bluff body

Summary

Evaluate aerodynamic characteristics of a low-fineness-ratio circular cylinders toward the effective development of the Re-entry capsule

1 Aerodynamic force measurement by MSBS

Steady aerodynamic characteristic

- ✓ Drag coefficient of a circular cylinder with fineness ratio *L/D*=0.30~0.50 is almost constant

Unsteady aerodynamic characteristic

- ✓ *St*=0.155 fluctuation is observed in aerodynamic torque acting on a low-fineness-ratio circular cylinder

2 Flow visualization by PIV technique

- ✓ Flow separation (*St*=0.155) is closely related to unsteady aerodynamic torque acting on a low-fineness-ratio bluff body