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Gusty wind disaster on engineering structures and transient characteristics of aerodynamic forces

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Extreme winds
(Tornadoes, downburst, gust front)

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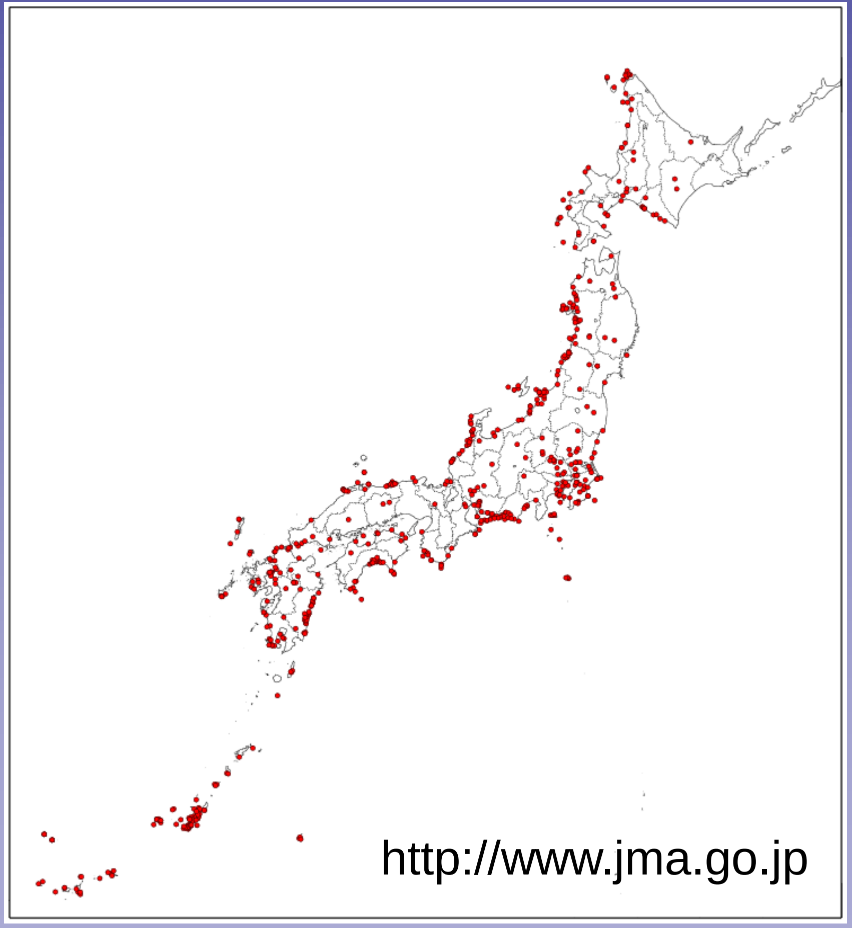
- 18.66 annually (leads to disaster)
- Up to F3 (less than 90 m/s)
  (JMA statistics)
- 1.4 annually per 10^4 km^2 (comparable with in Alabama and Missouri) (Niino et al., 1997)
- 8 tornaodes annually may cross railway tracks anywhere in Japan (Tamura, 2007)

- Wind loads, flying debris
- Safety level for high hazardous facilities, mass-, high-speed transports

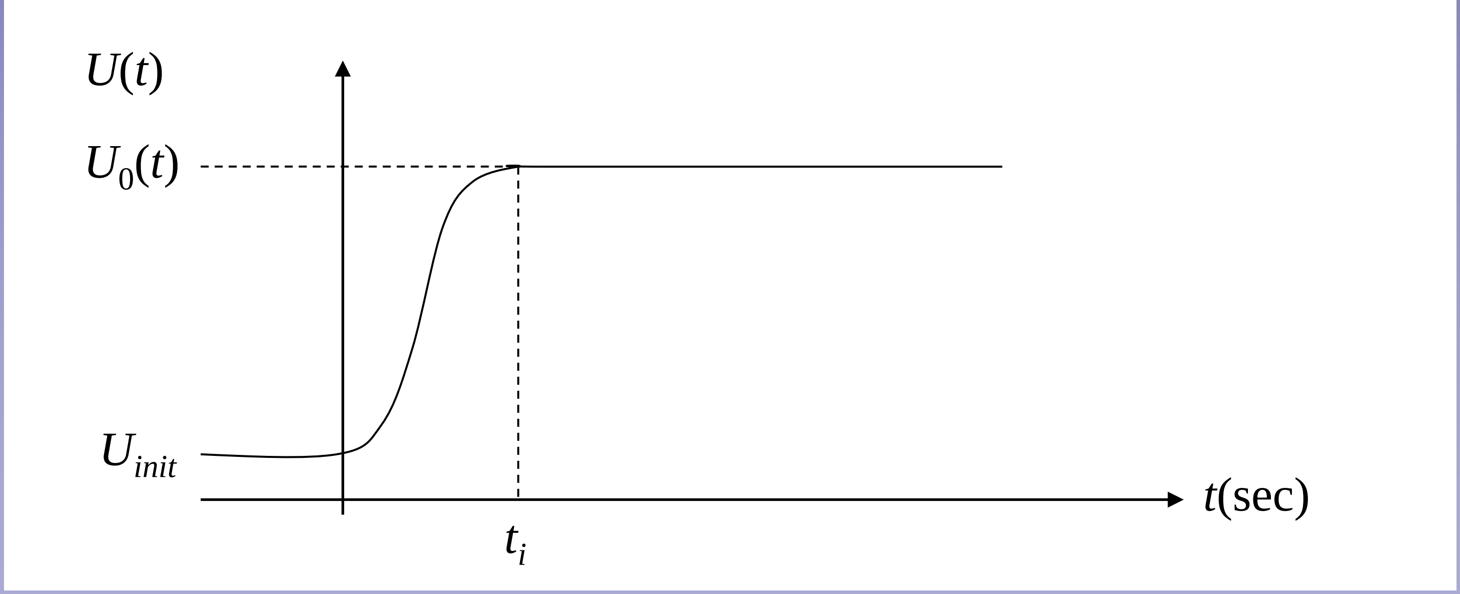
- Hard to be predicted



Winds induced by tornado passage

- Velocity increase in short time duration
  → like a step function

$$U(t) = U_0 \cdot 1(t) + U_{init}$$

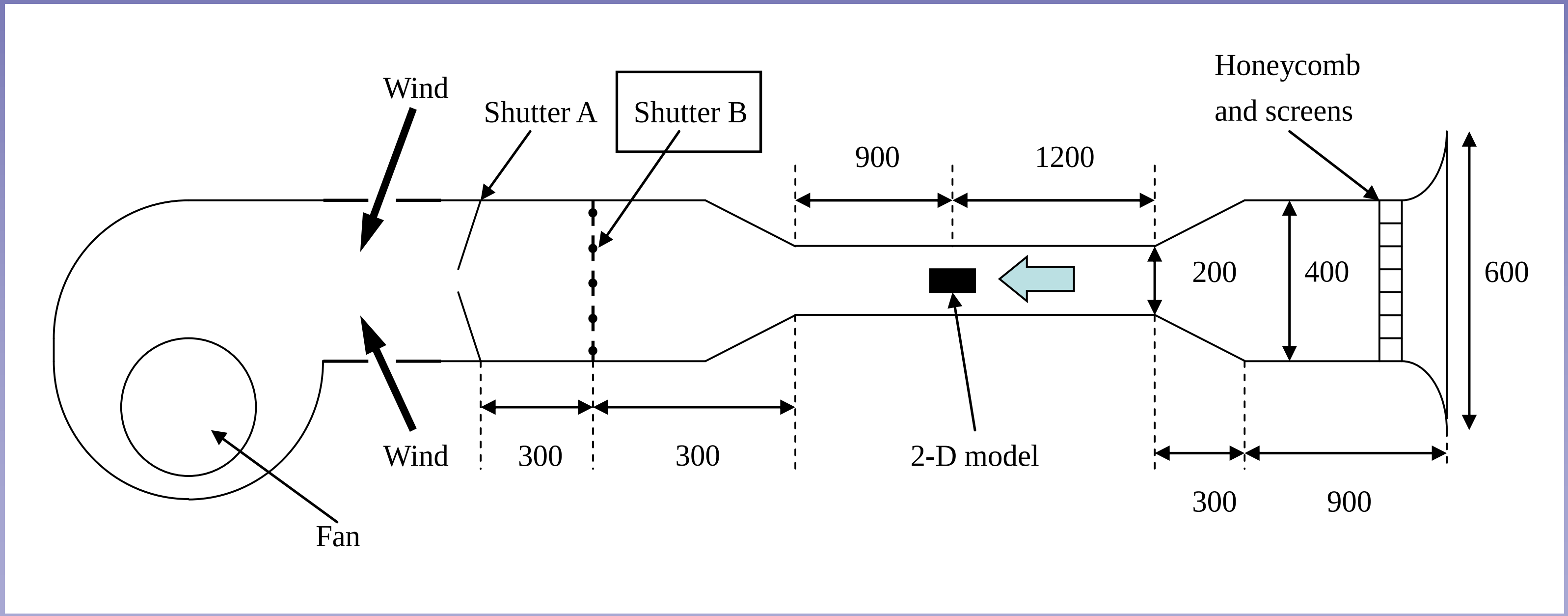


Drag/Lift forces overshoot

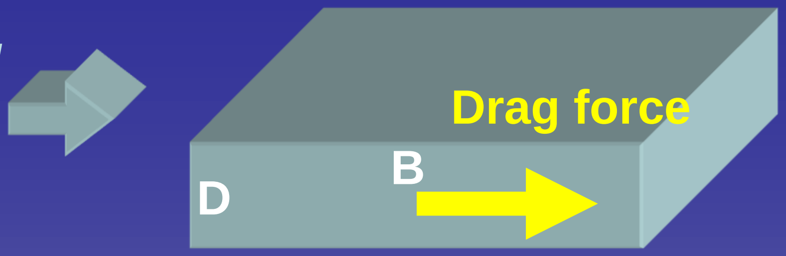
- Sarpkaya (1966)   drag, circular, vortex pair
- Taneda (1972)   lift, elliptic, vortex
- Shiraishi, Matsumoto (1982)   lift, rectangular, train overturn
- Nomura (2000)   drag, square, inertia force
- Matsumoto, et al. (2007)   drag, vortex
- Takeuchi, Maeda (2008)   drag, railway wagon, overshoot coefficient

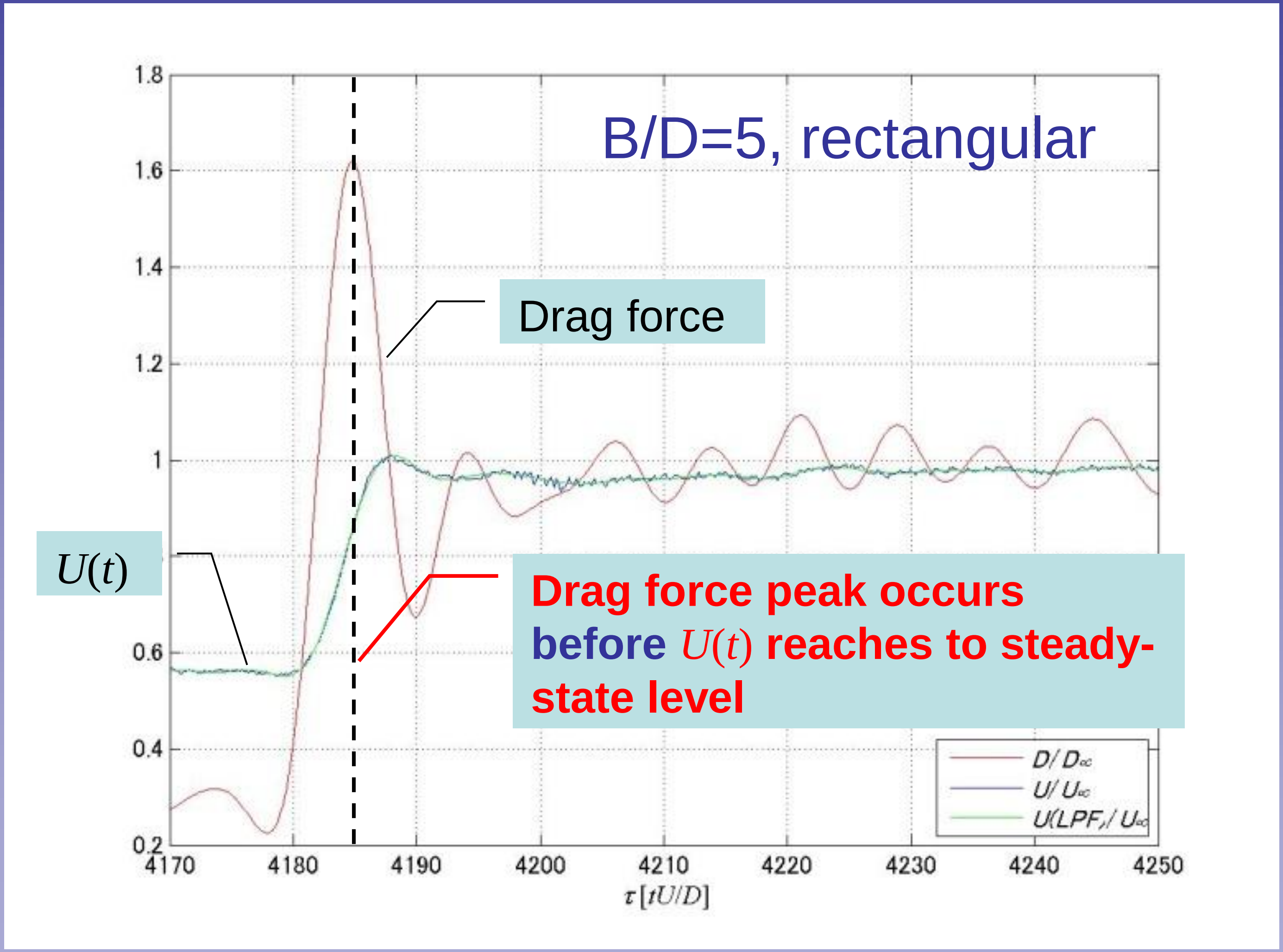
The wind tunnel

for generating gusty winds

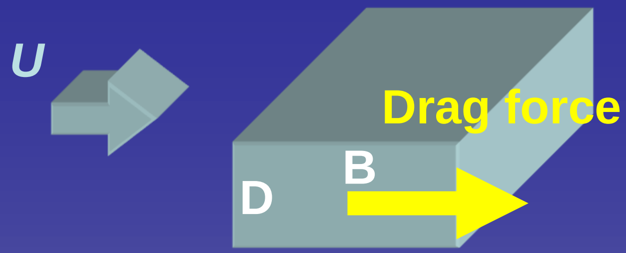


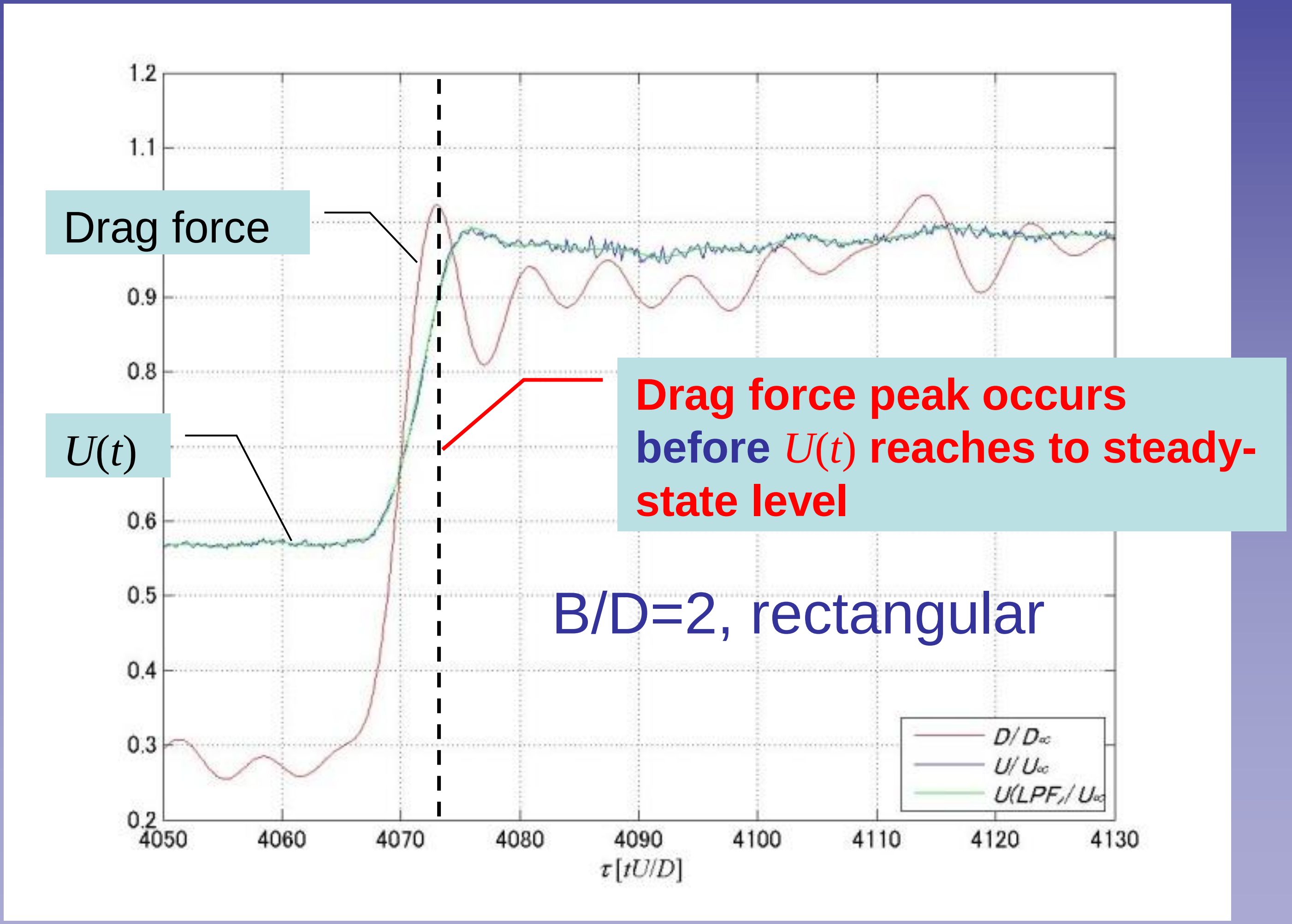
Drag force by load cells





Drag force by load cells





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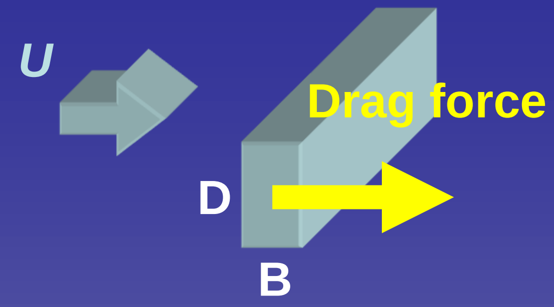
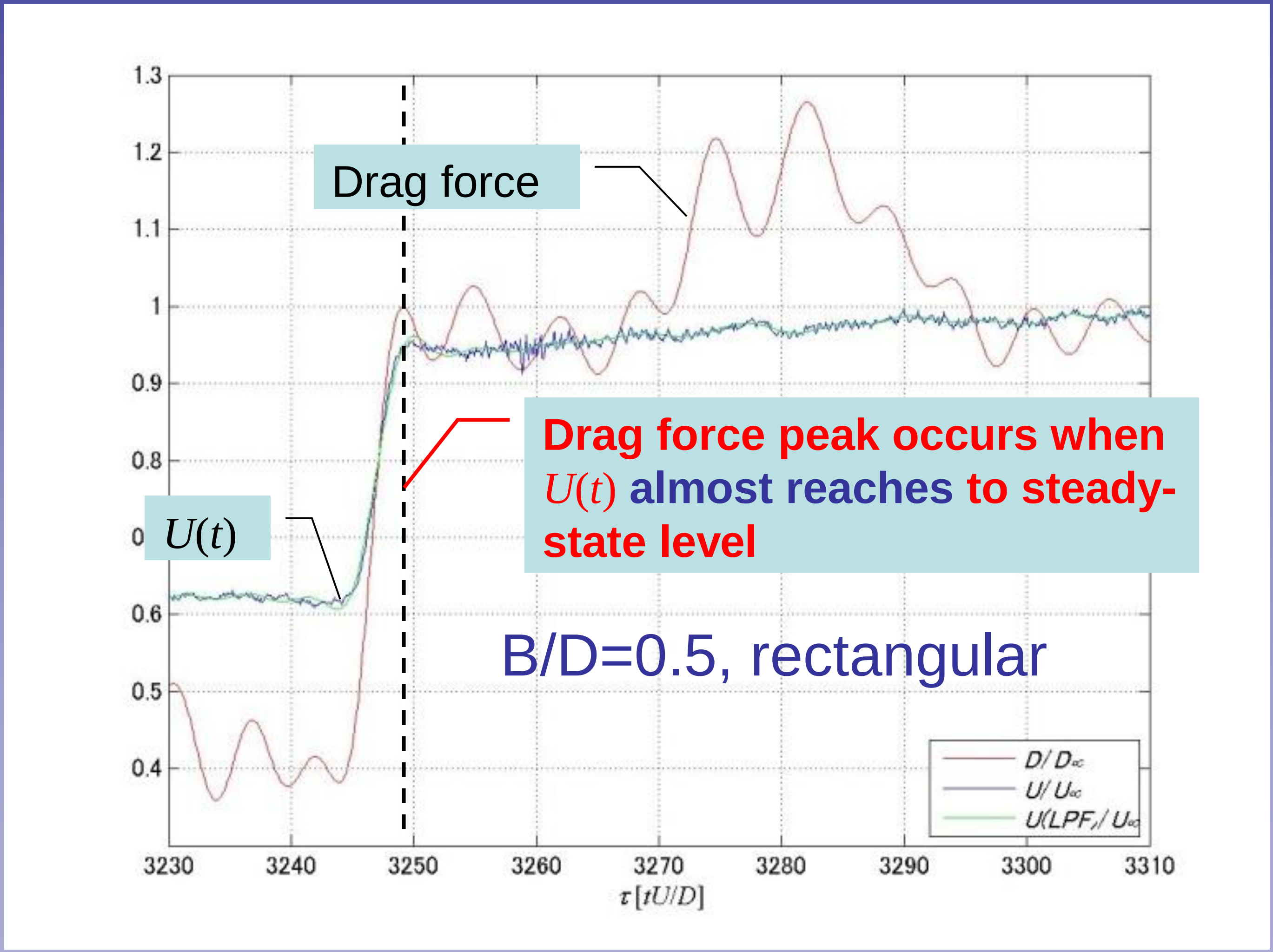
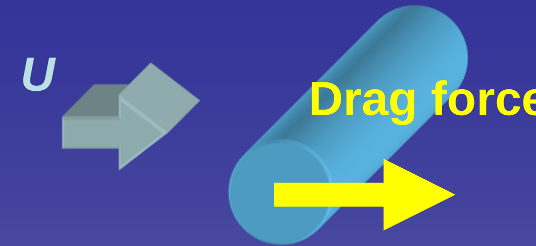
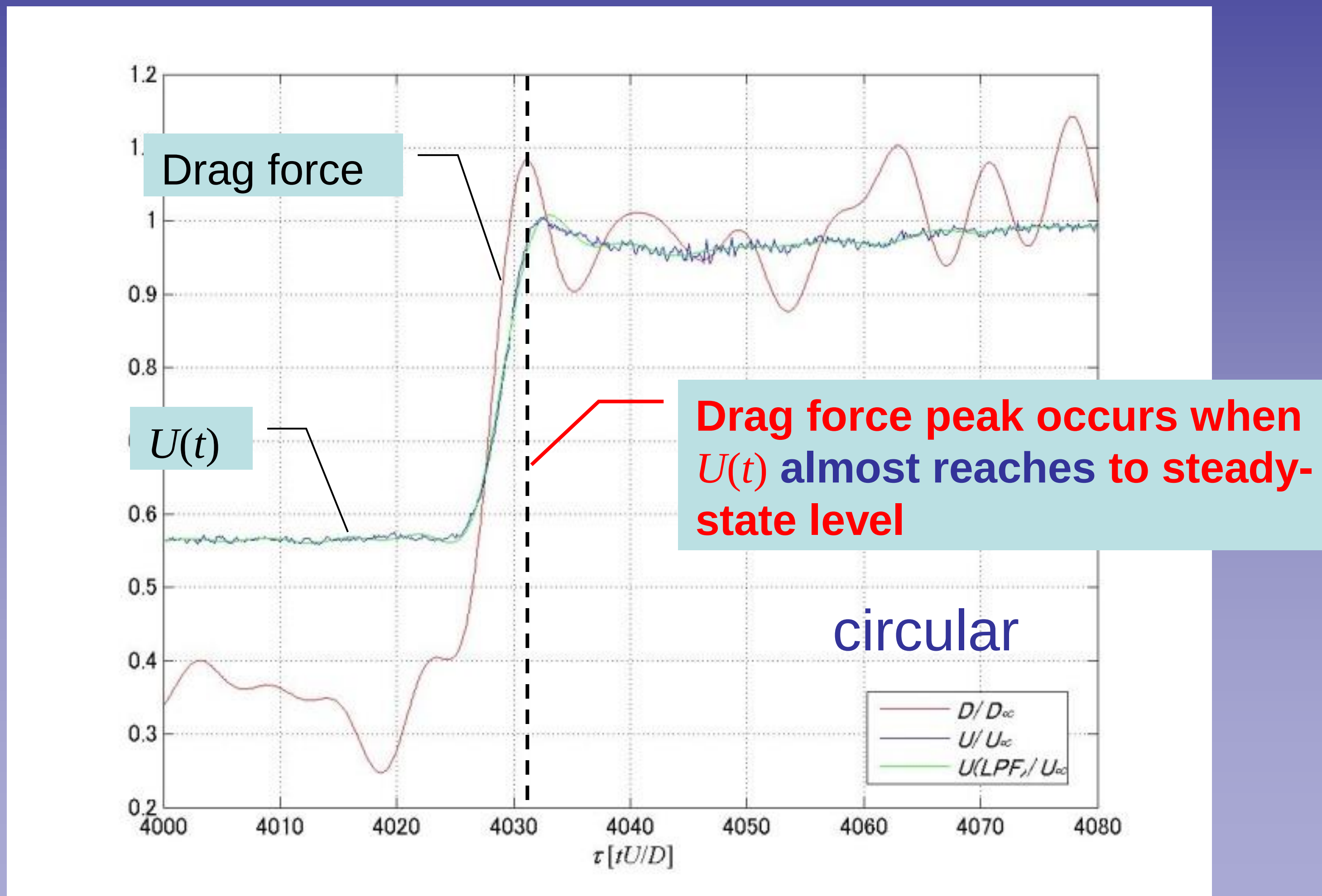


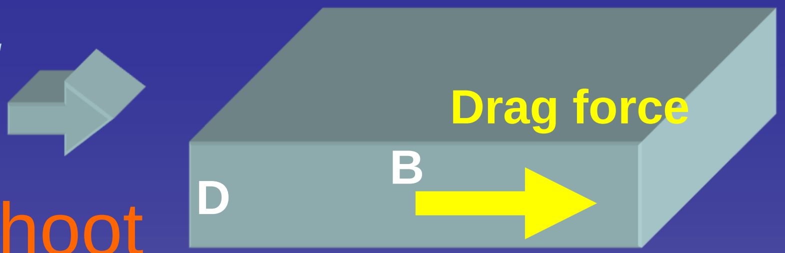


Drag force by load cells

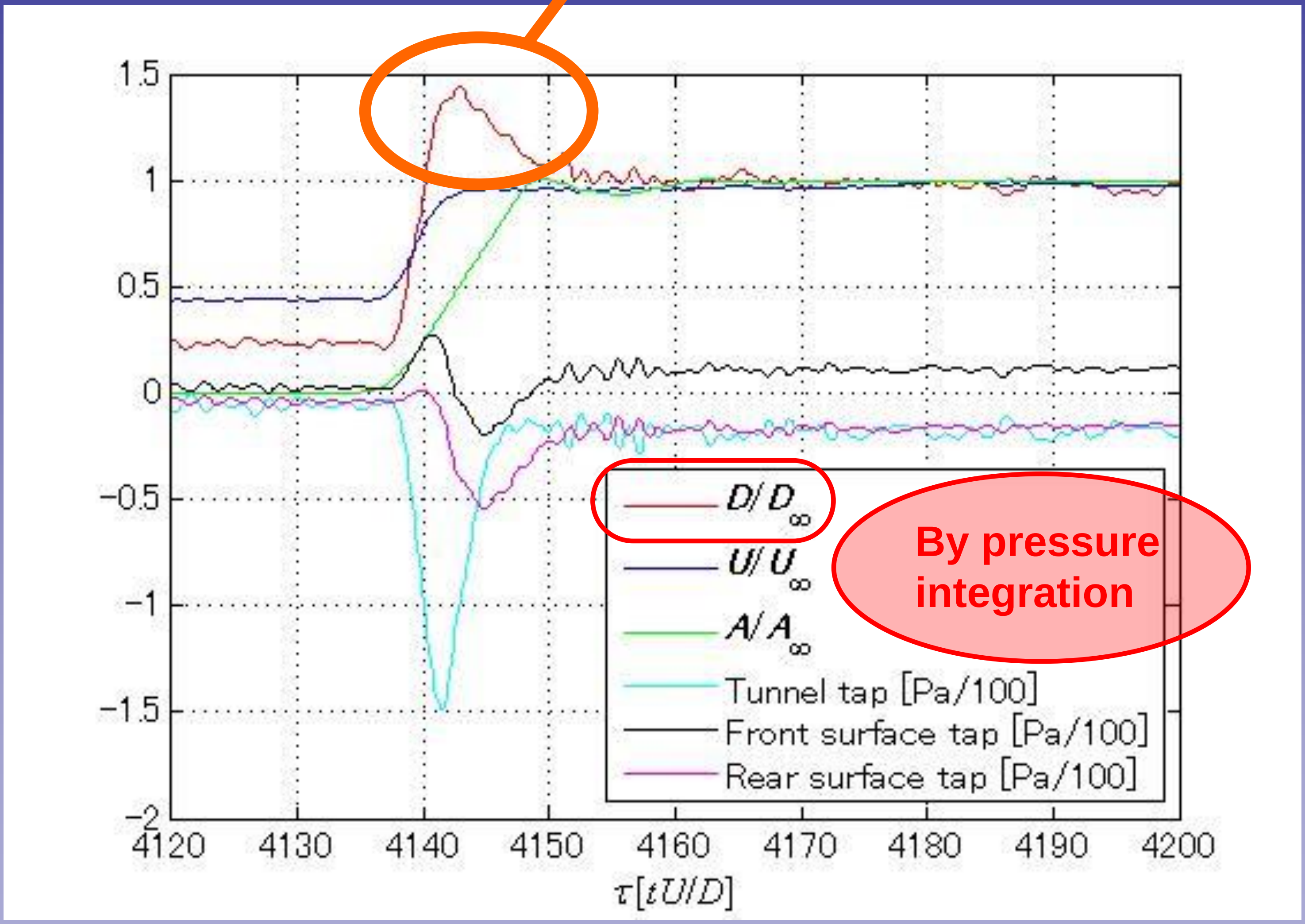




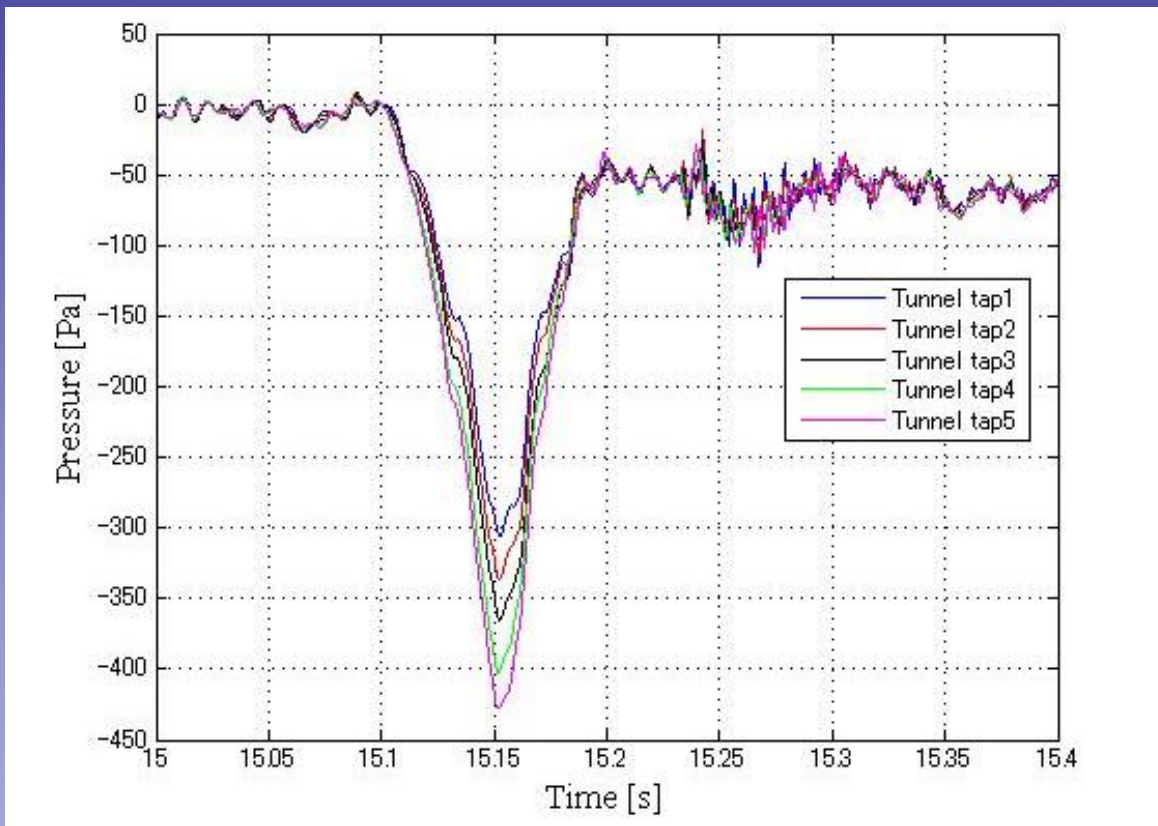
B/D=5, rectangular

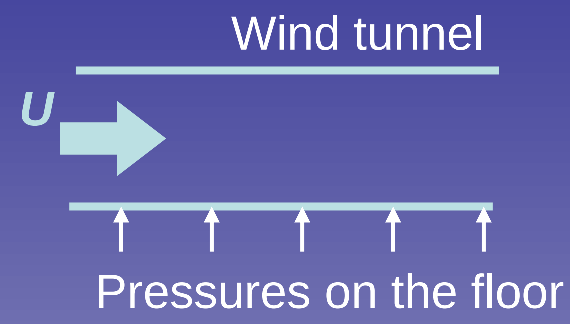


overshoot



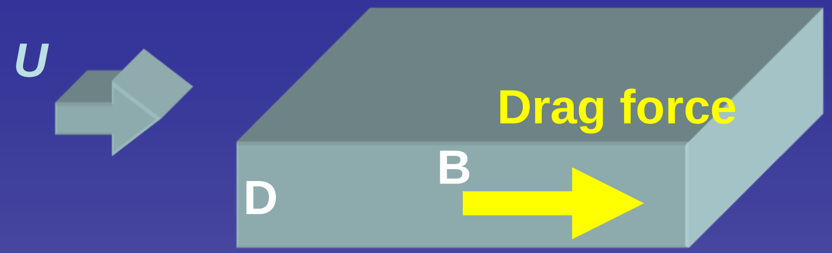
Static pressures in wind tunnel



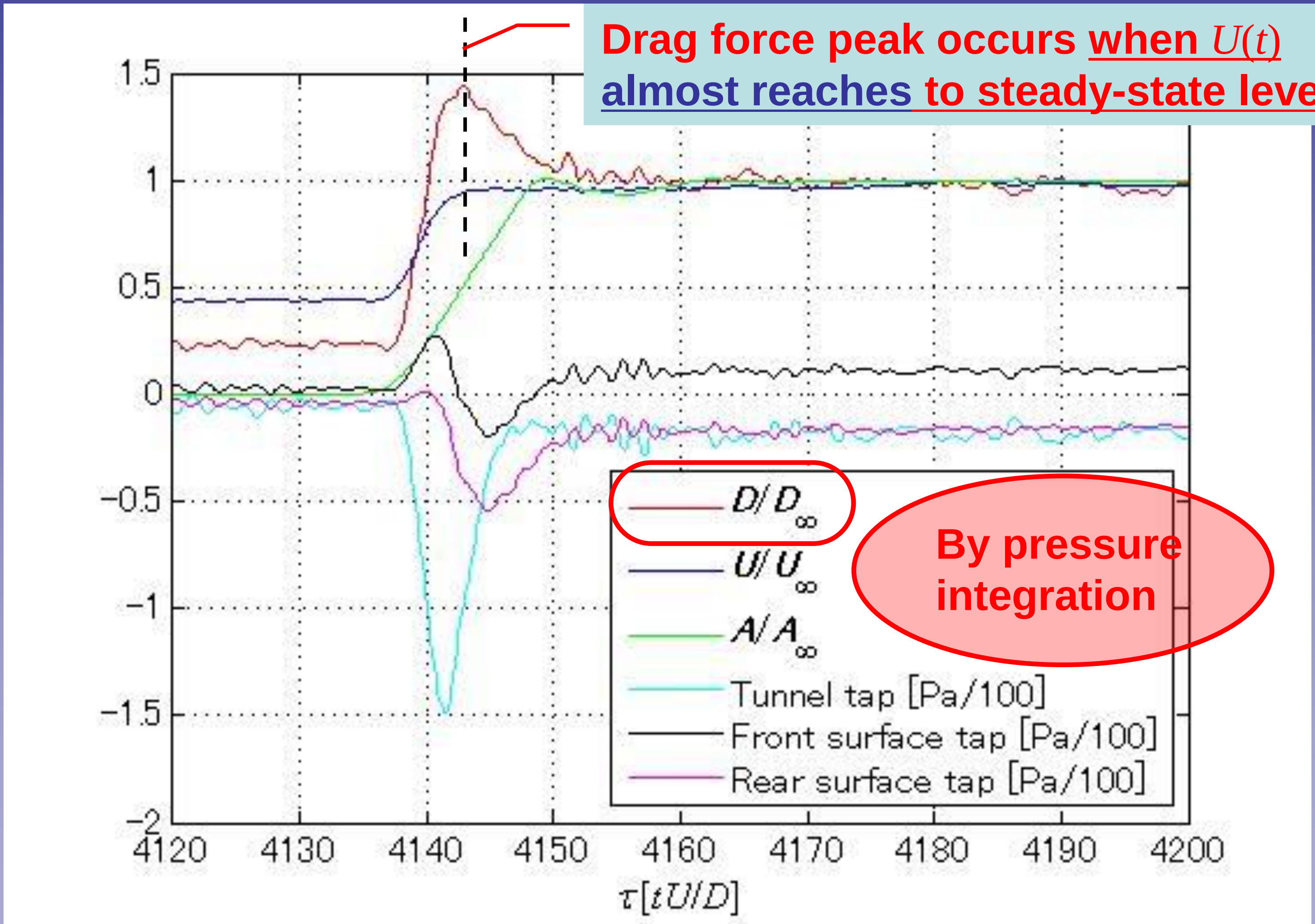


- No pressure convection in wind tunnel
- Reference pressure

B/D=5, rectangular



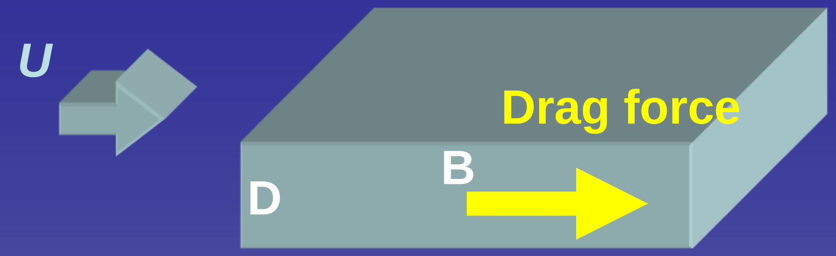
Drag force peak occurs when $U(t)$ almost reaches to steady-state level

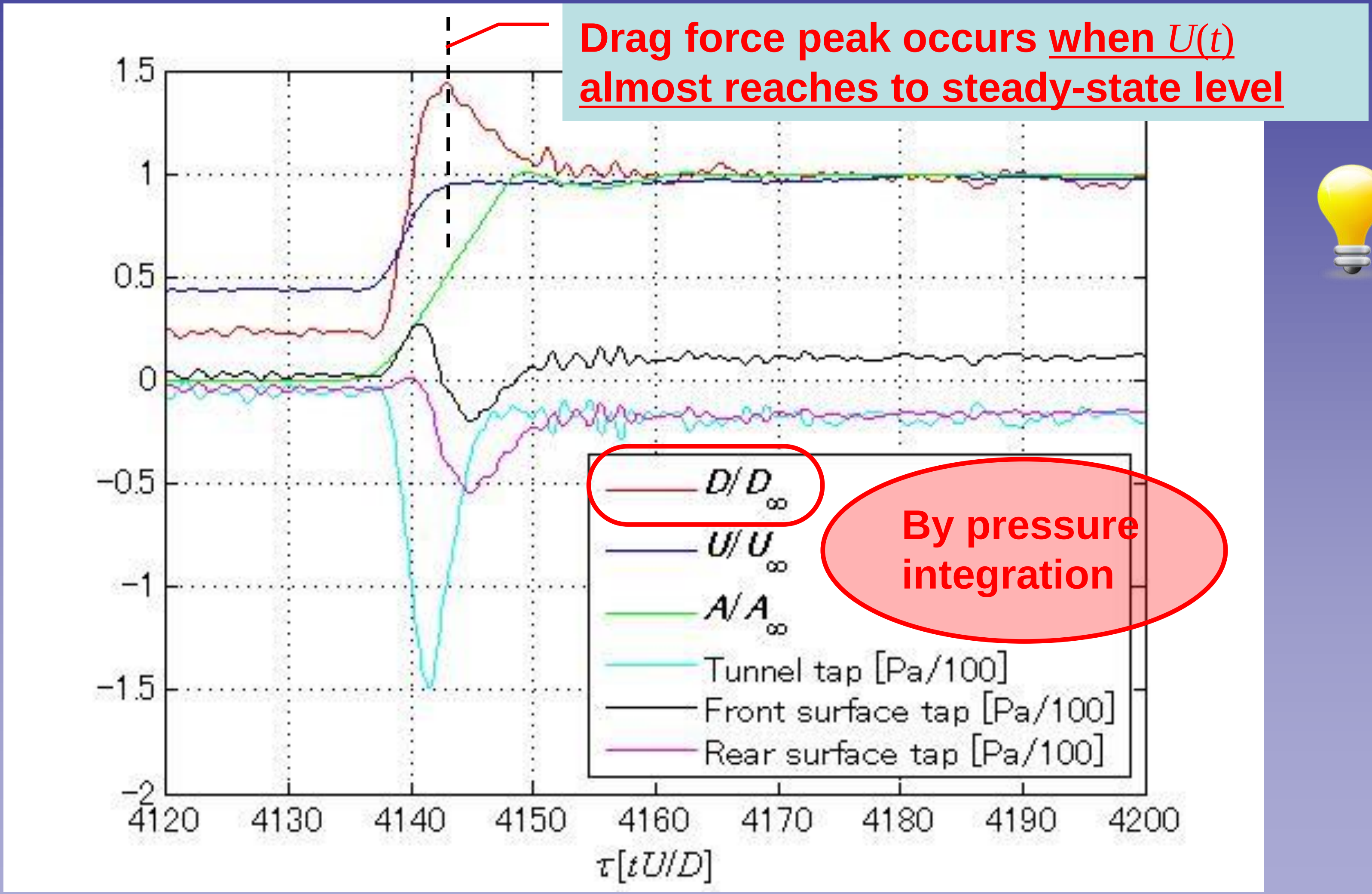


By pressure integration

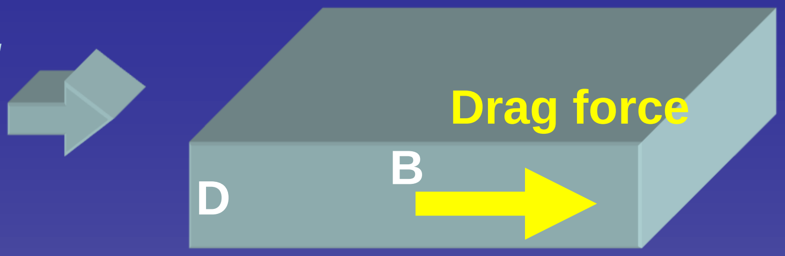
?

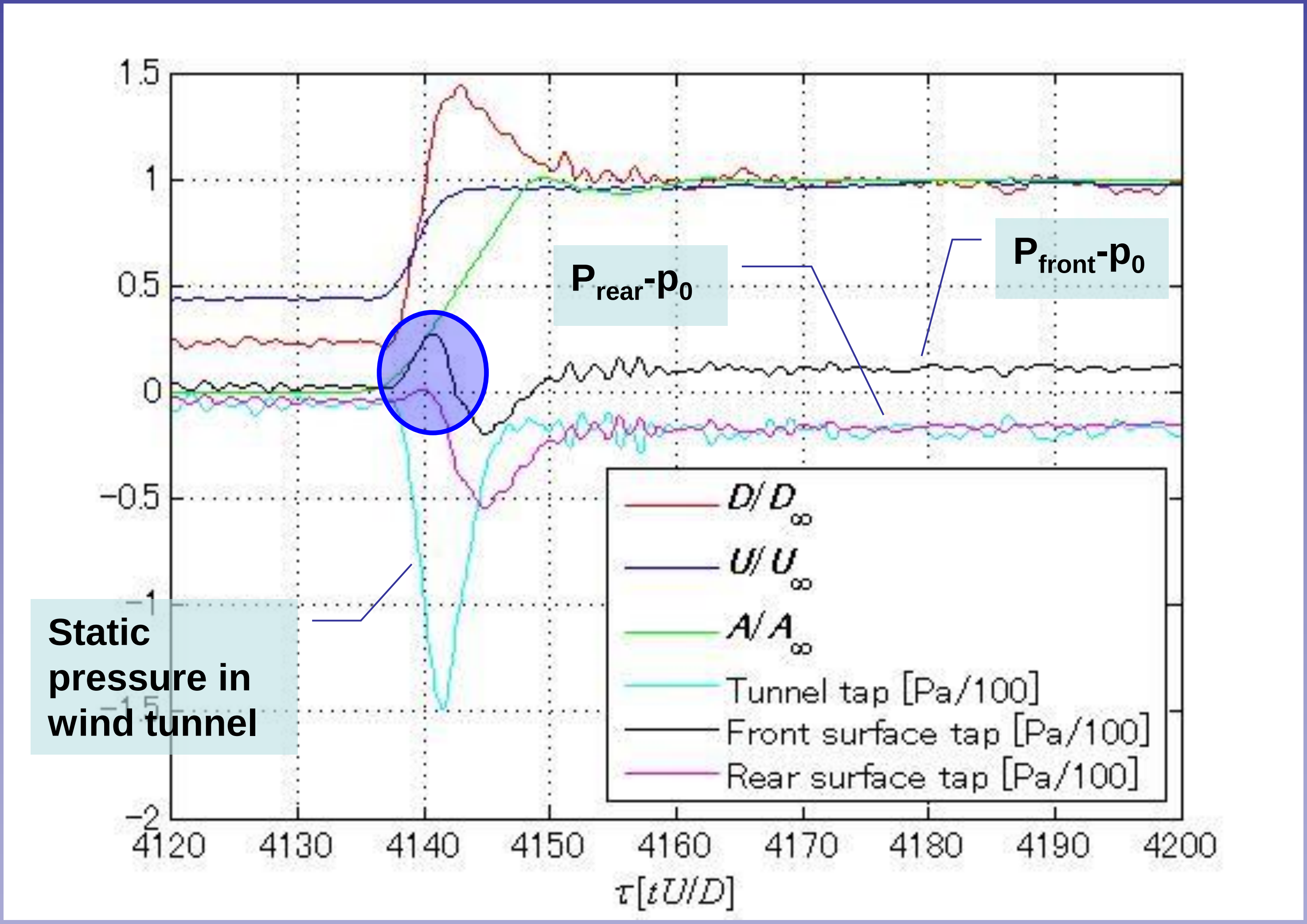
B/D=5, rectangular



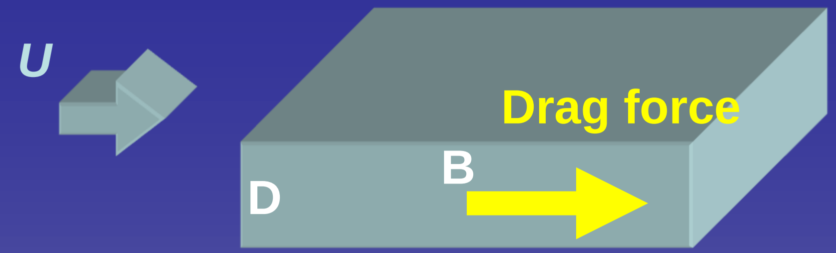


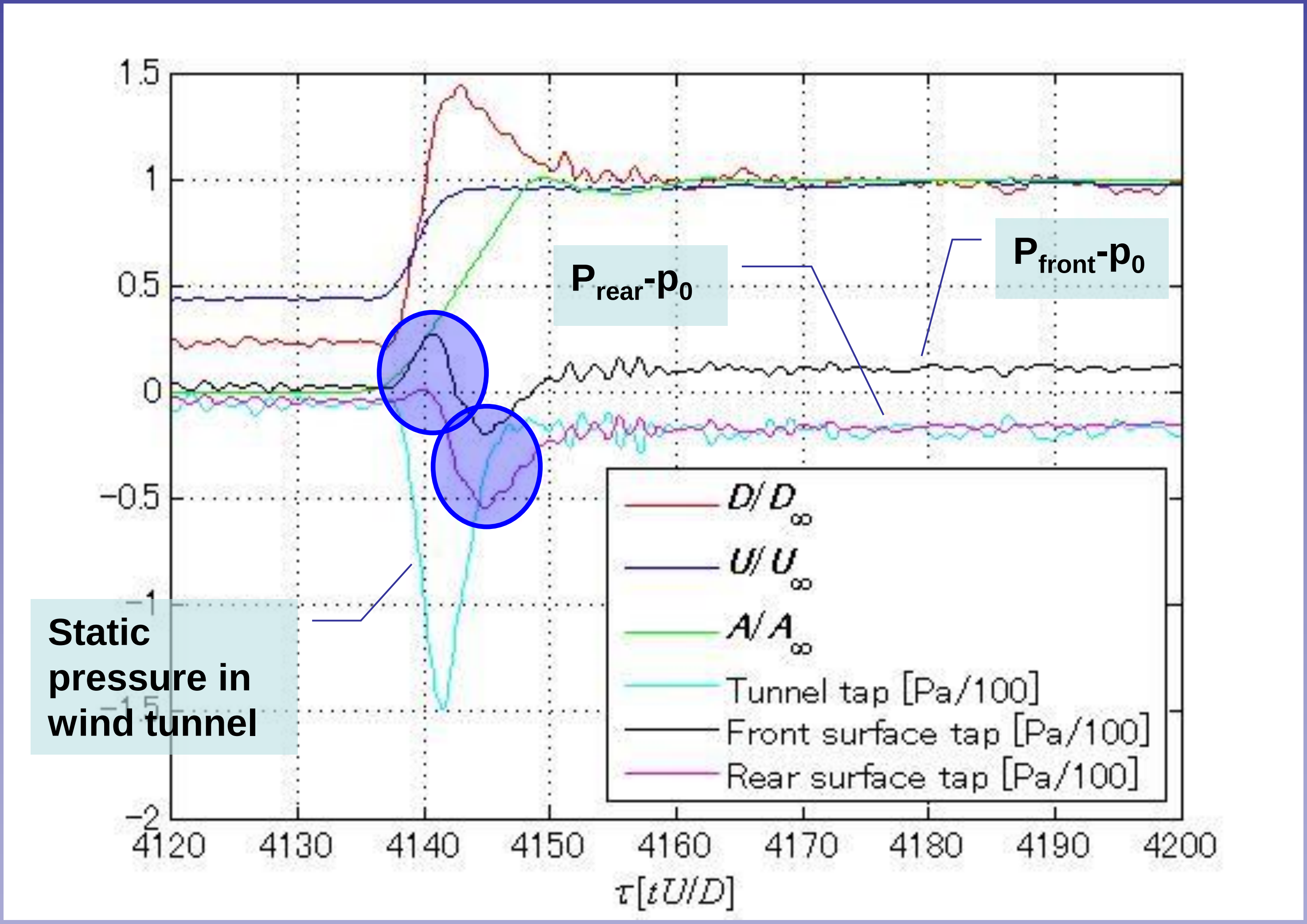
B/D=5, rectangular



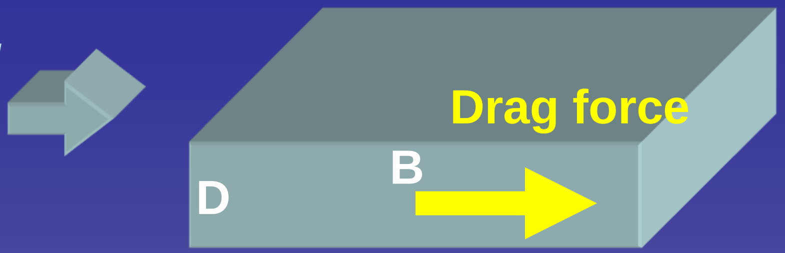


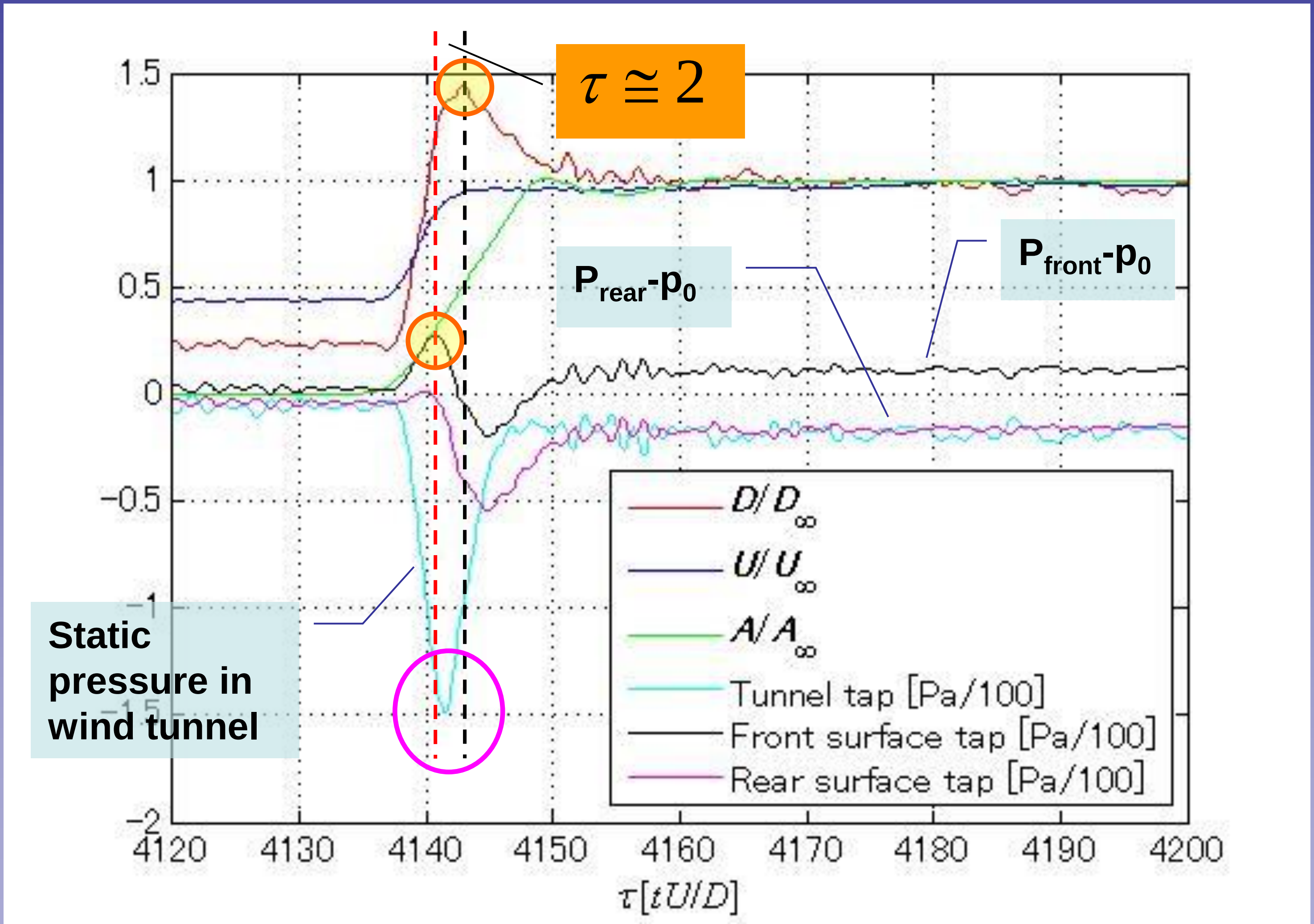
B/D=5, rectangular





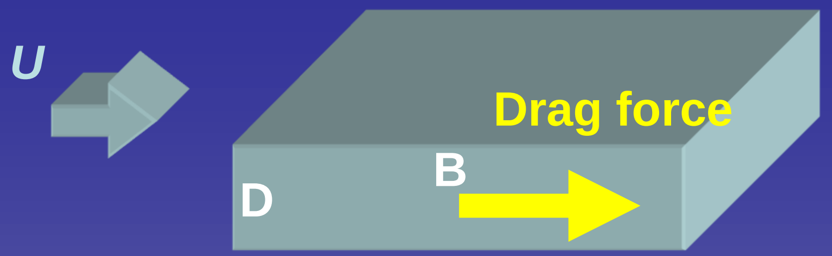
B/D=5, rectangular

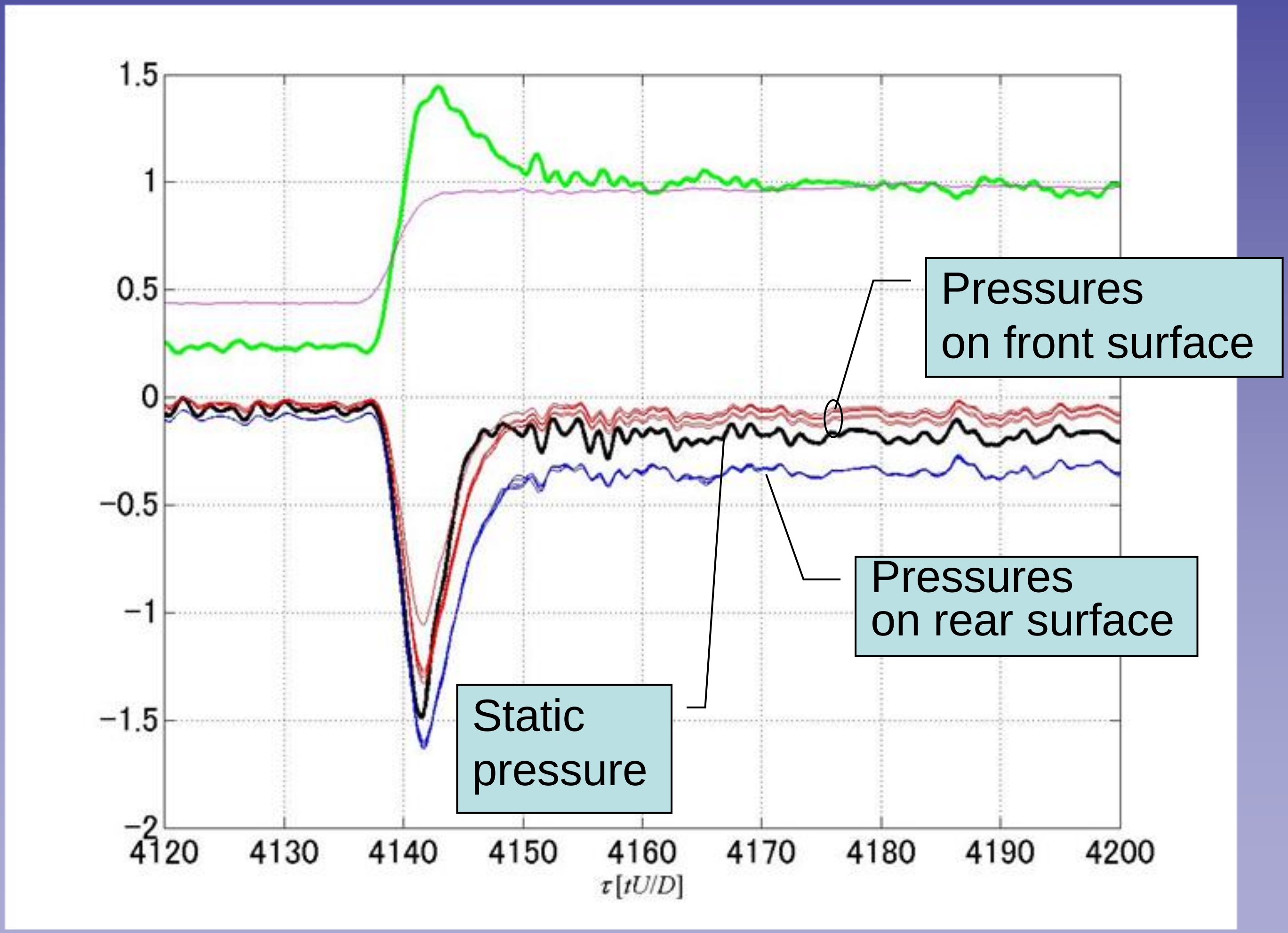


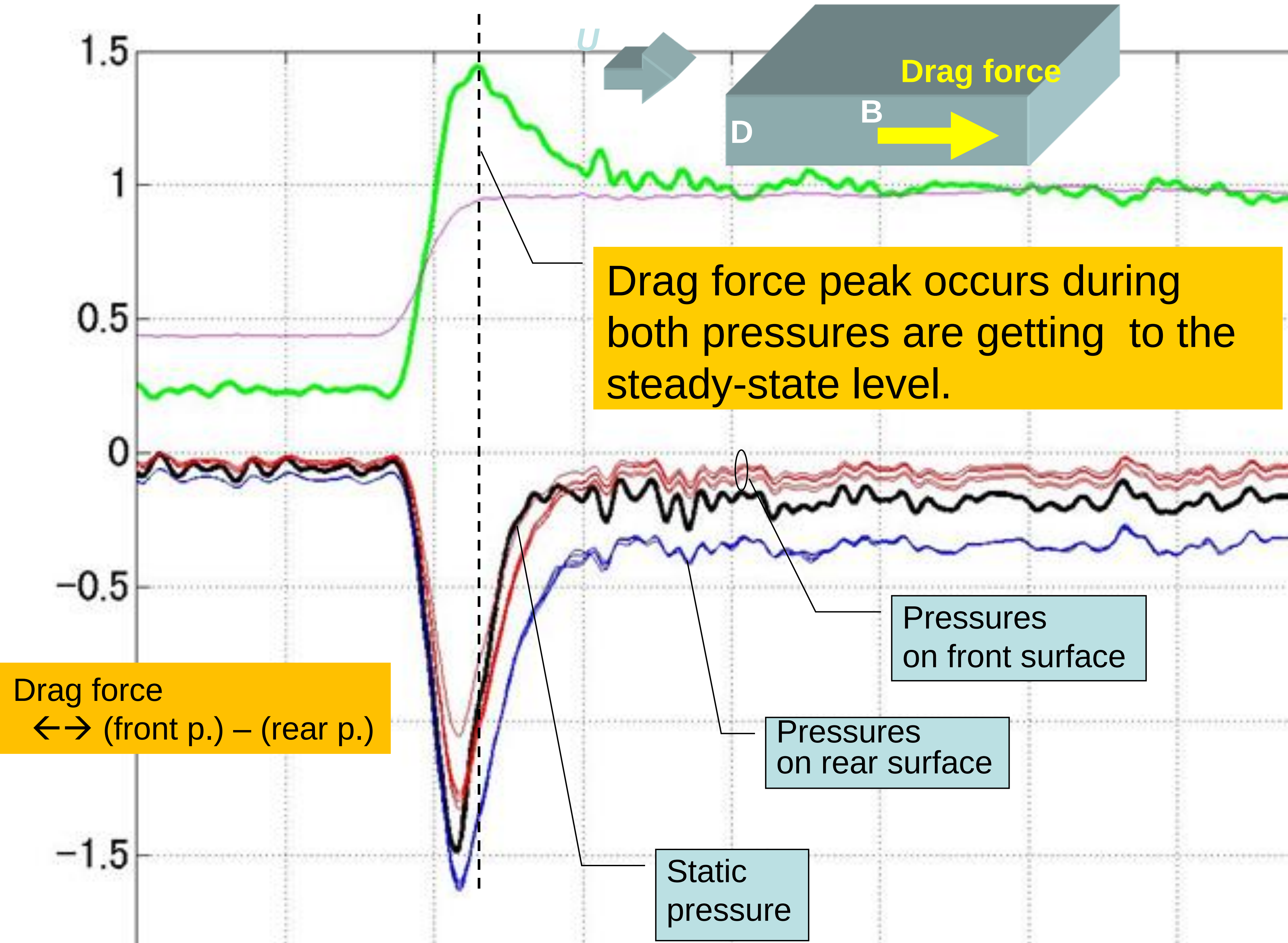


- The drag force peak looks to be *uncorrelated* to both peaks of the surface pressure and the static pressure.

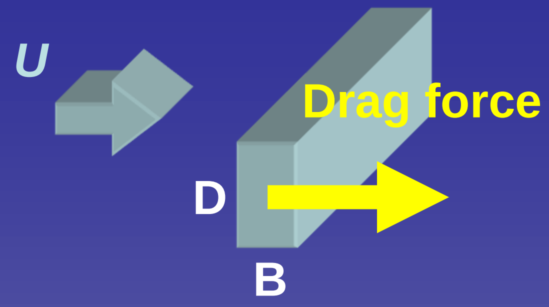
Net surface pressures

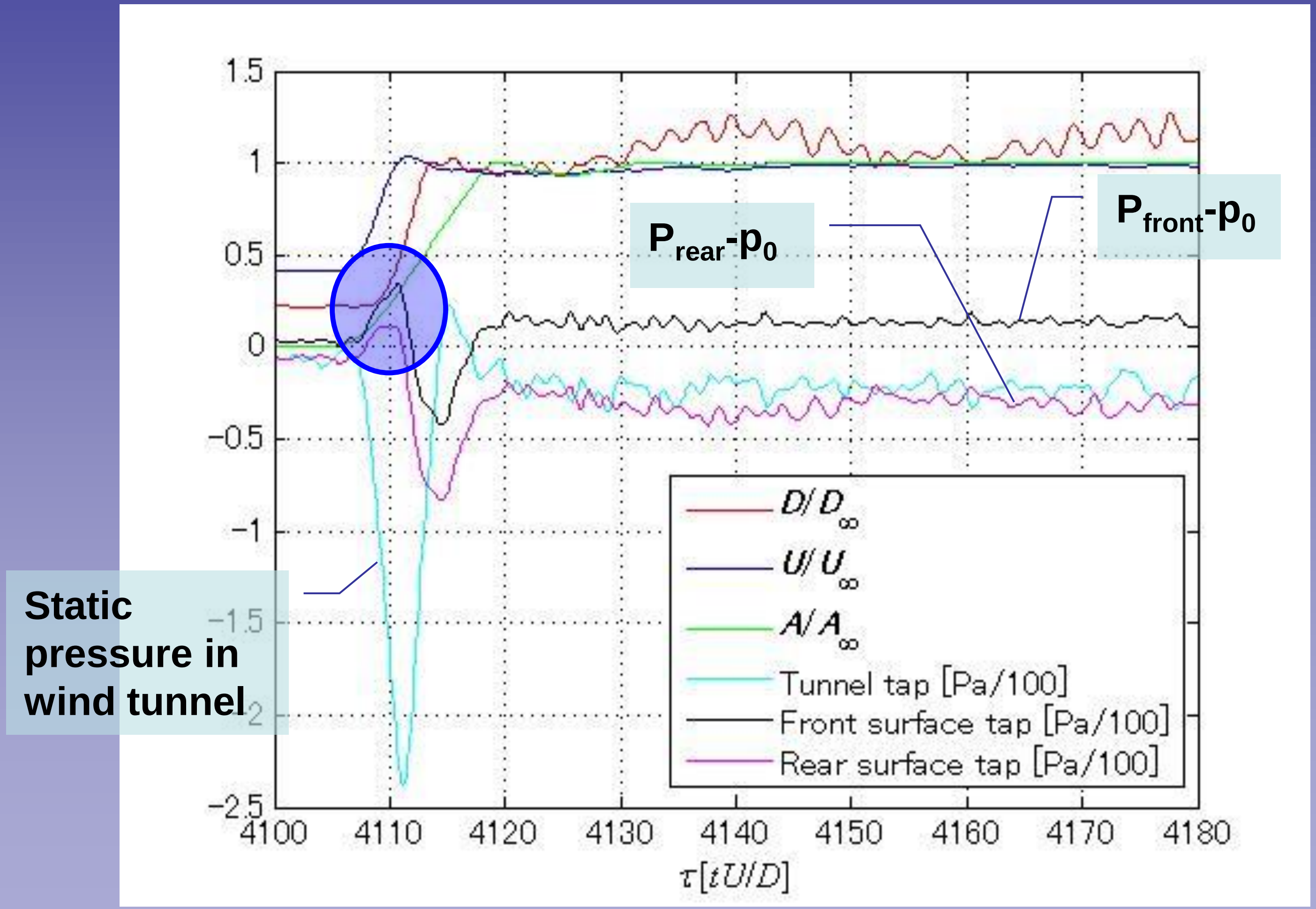


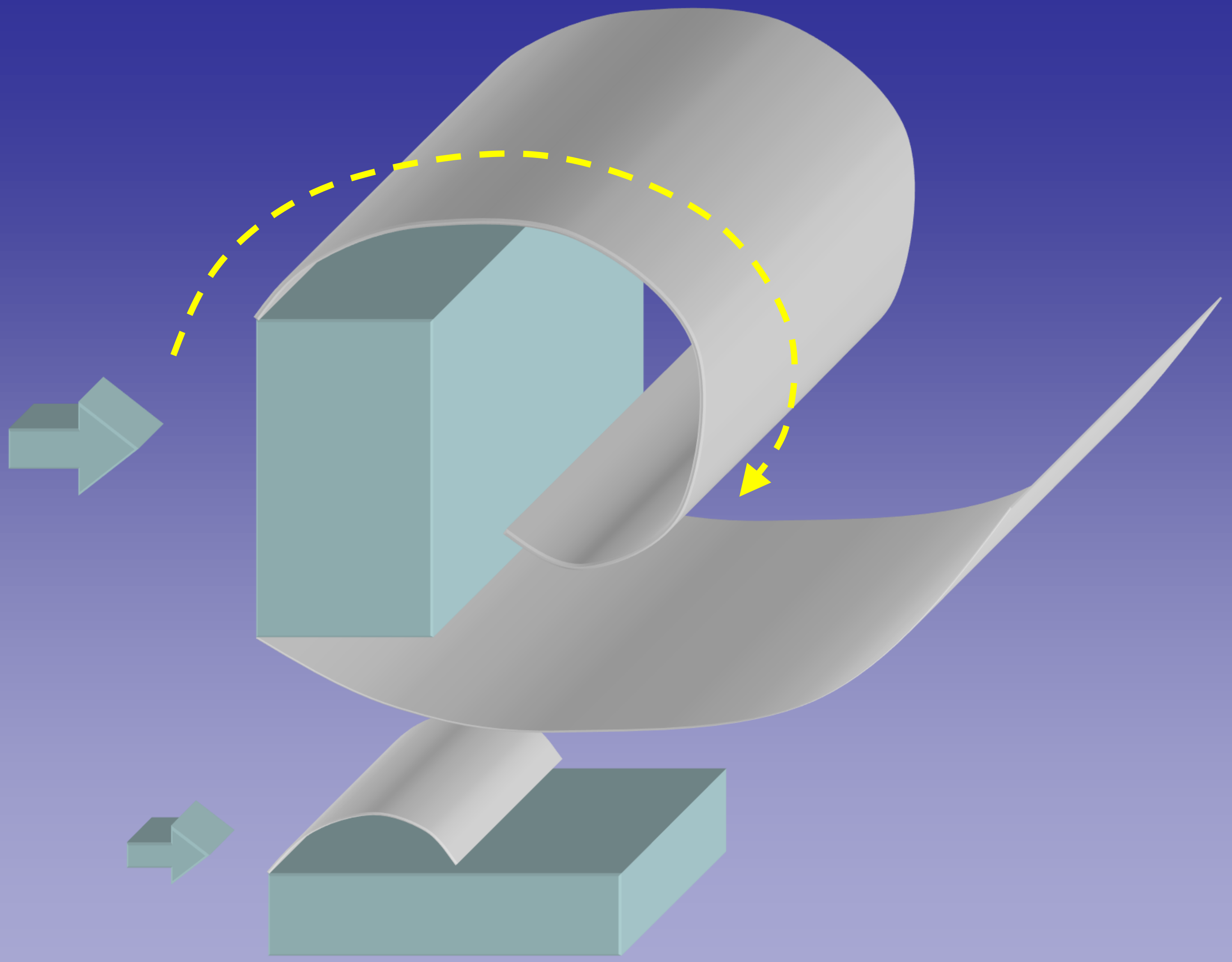



1.5
1
0.5
0
−0.5
−1.5
U
Drag force
B
D
Drag force peak occurs during both pressures are getting to the steady-state level.
Pressures on front surface
Pressures on rear surface
Static pressure
Drag force ←→ (front p.) – (rear p.)

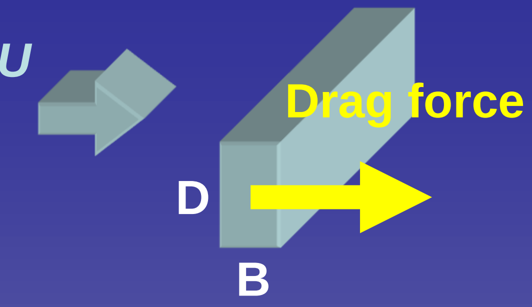
B/D=0.5, rectangular

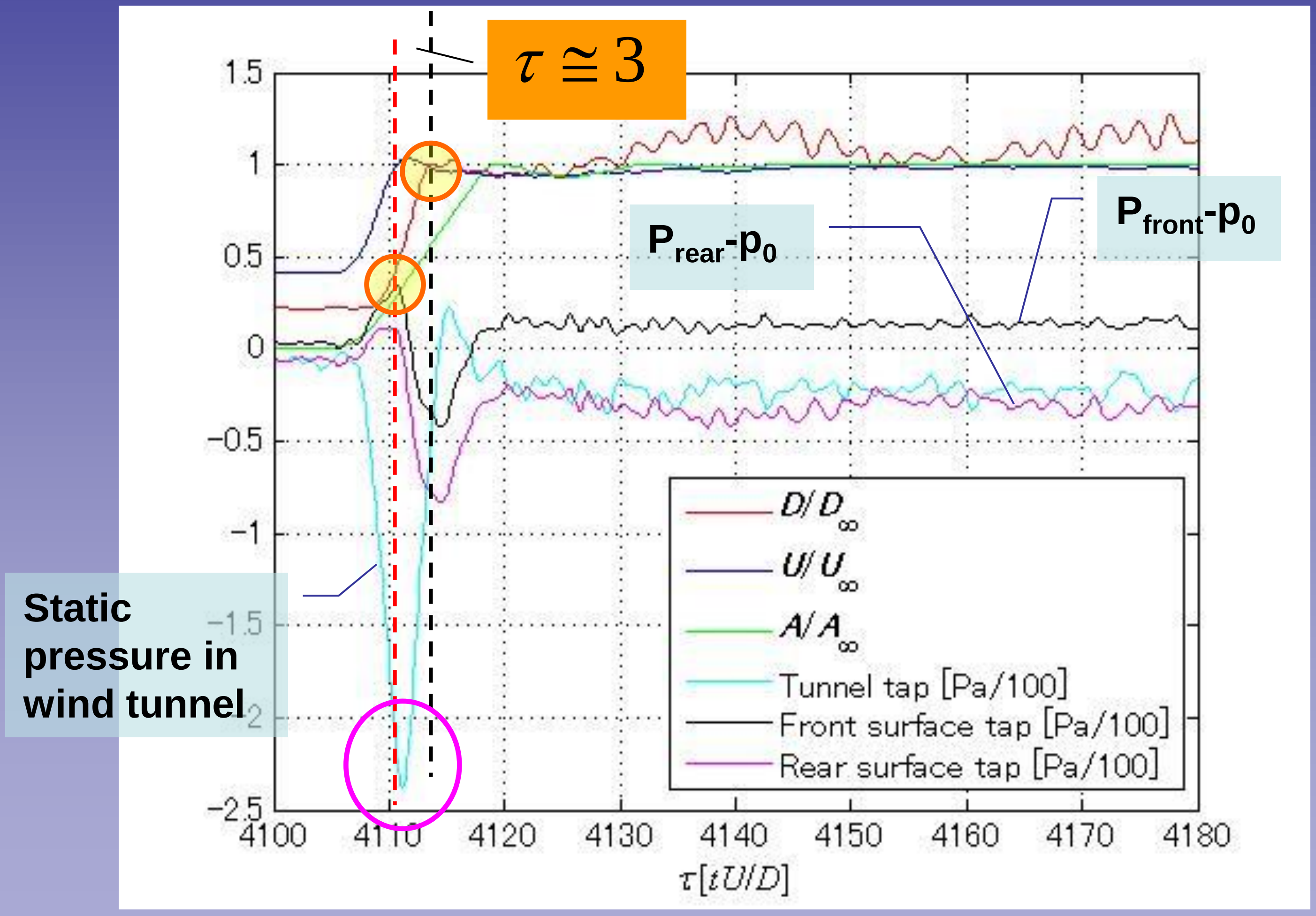


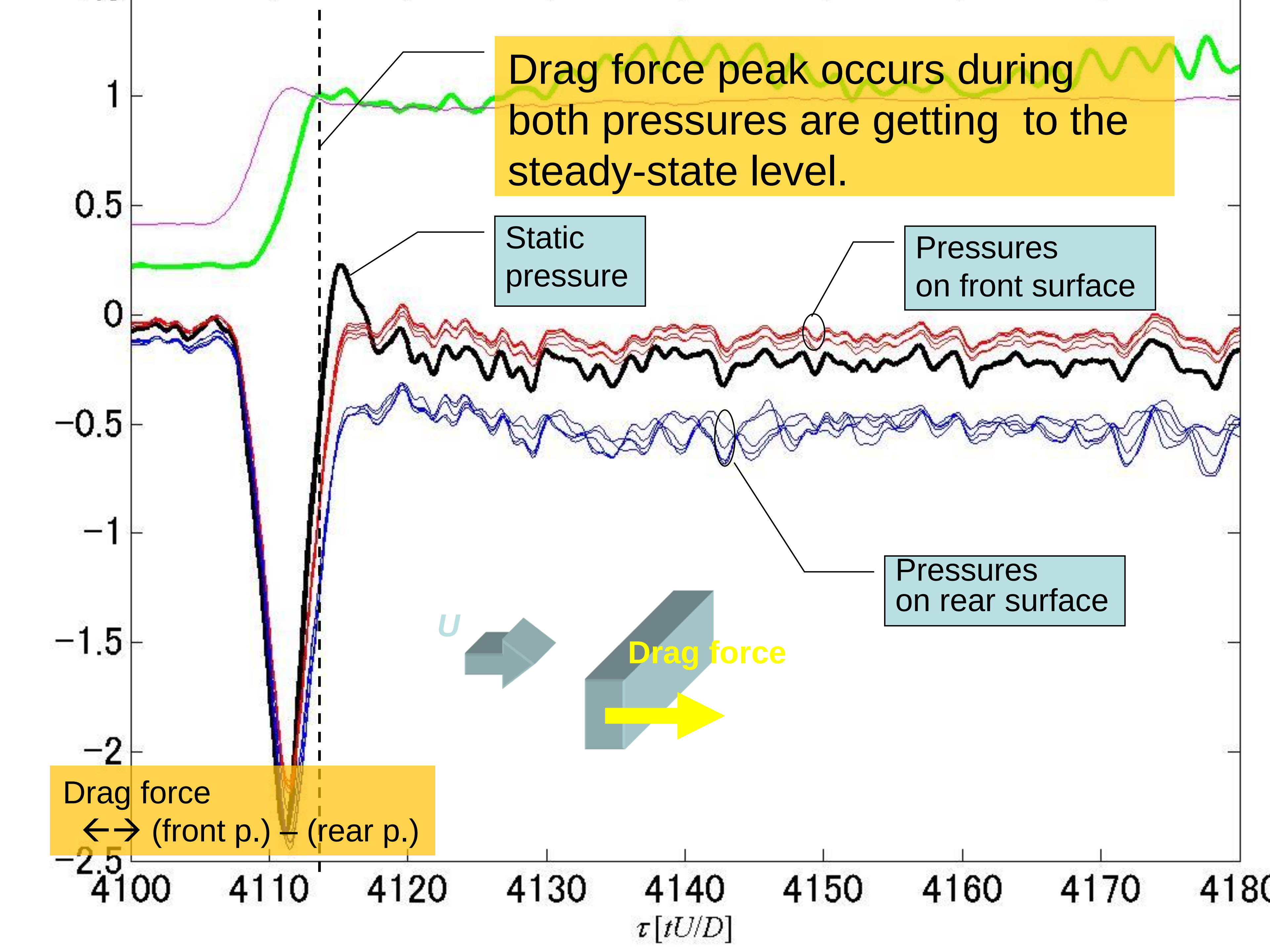




B/D=0.5, rectangular






Drag force peak occurs during both pressures are getting to the steady-state level.
Static pressure
Pressures on front surface
Pressures on rear surface
U
Drag force
Drag force
←→ (front p.) – (rear p.)
1
0.5
0
−0.5
−1
−1.5
−2
−2.5
4100
4110
4120
4130
4140
4150
4160
4170
4180
τ [tU/D]

Where does the peak come from?

- Independent of each pressure transient properties
- Not caused by static pressure
- Simply due to the time difference between both pressure reaching to the steady level.

The rear surface pressure tends to remain more negative value because of :

- Caused by the formation of the circulation pair in wake, partly.

Inertia force

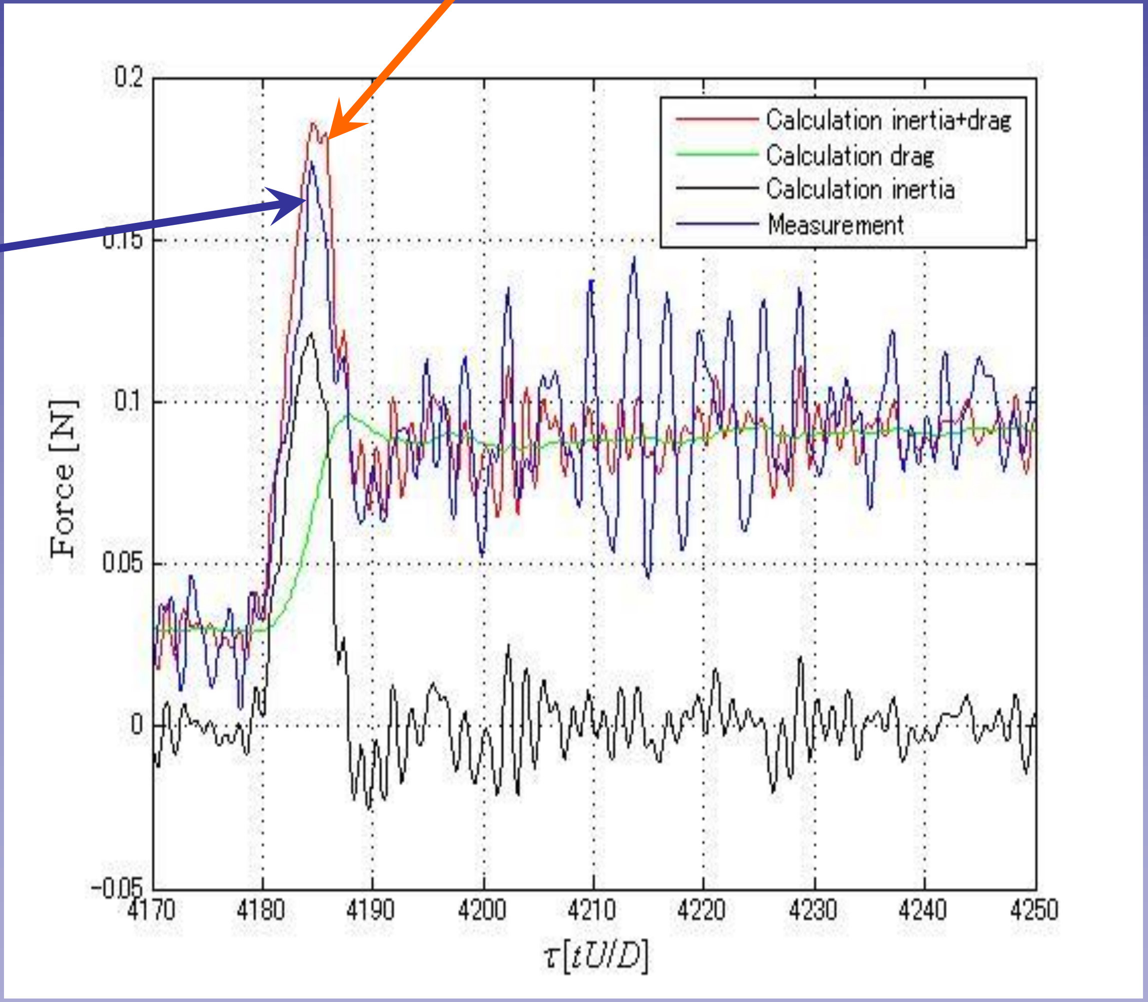
$$F_D = \boxed{\rho V_o C_m \frac{dU}{dt}} + \frac{1}{2}\rho U^2 C_D A$$

- Perfect fluid
- Static pressure difference along streamwise direction
- Body configuration

B/D=5, rectangular

Drag force (calculated)

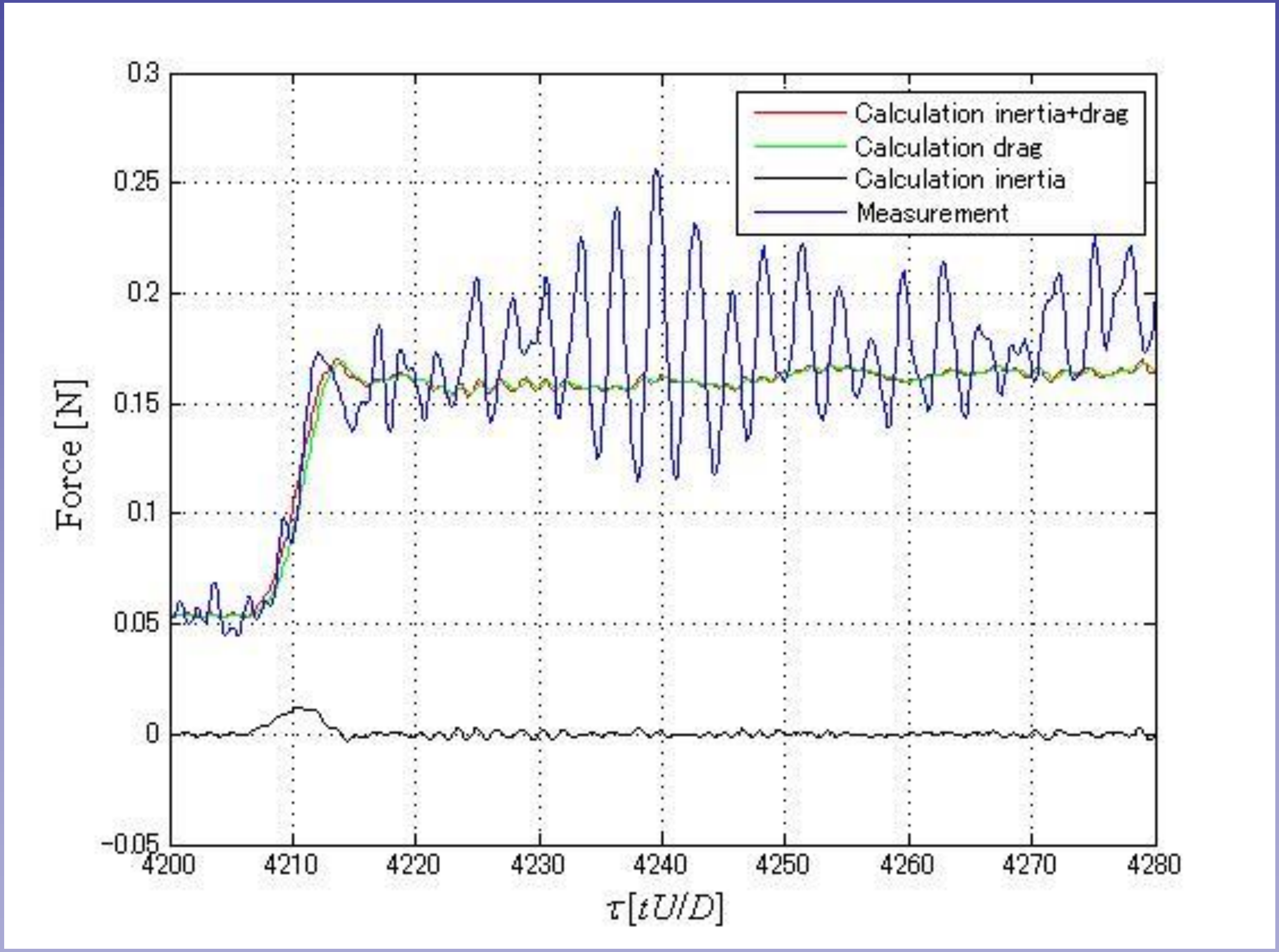
Drag force (observed)



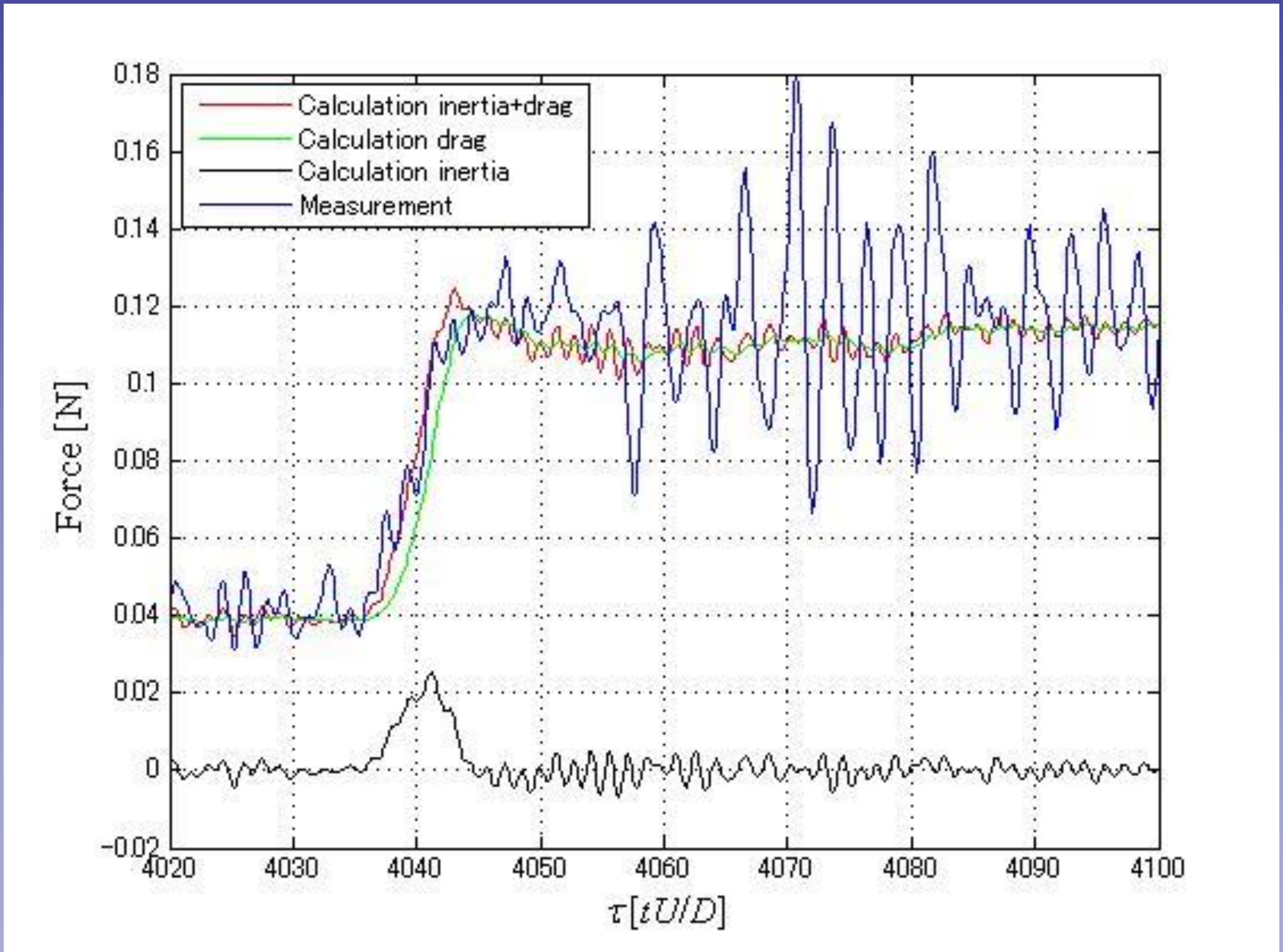
- Drag force taking the inertia force into account may explain the observed phenomenon in some cases.

- But not in all cases.

B/D=0.5, rectangular



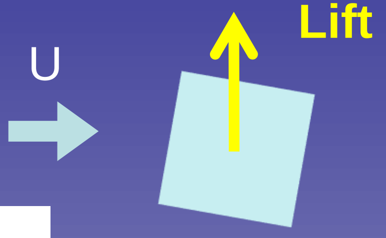
B/D=1, square



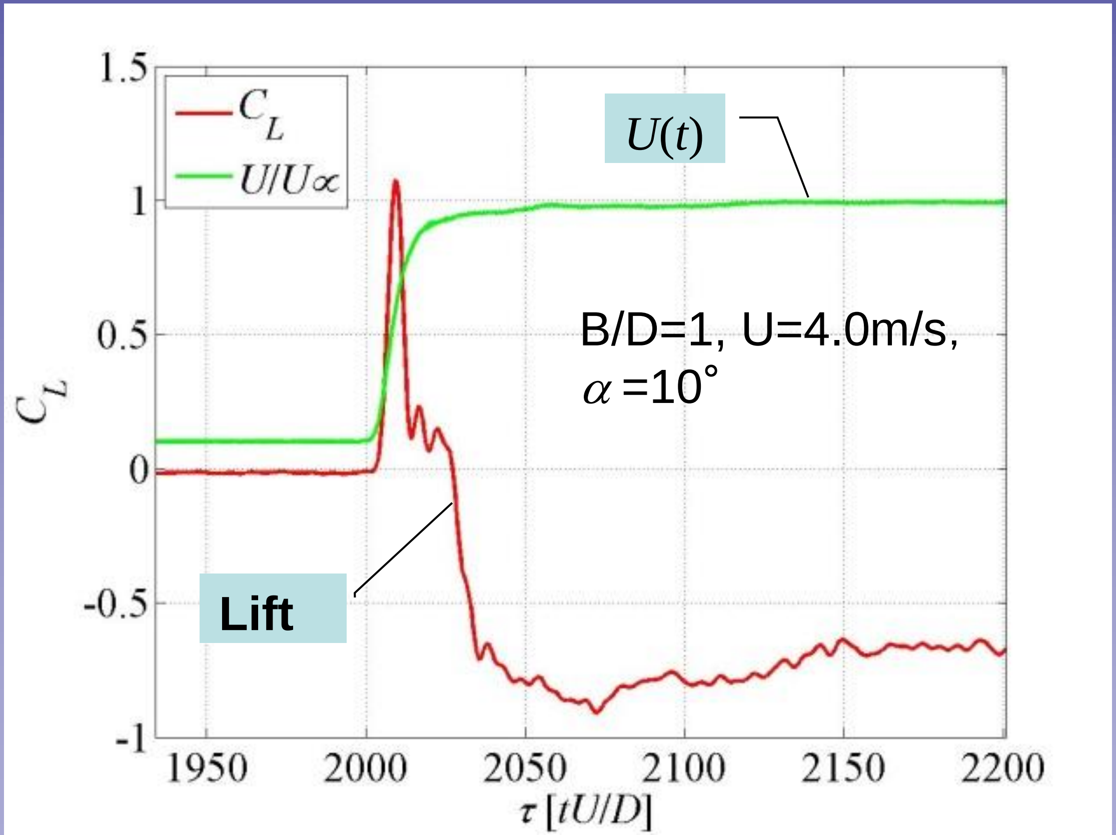
Calculation inertia+drag
Calculation drag
Calculation inertia
Measurement
Force [N]
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
-0.02
4020
4030
4040
4050
4060
4070
4080
4090
4100
$\tau[tU/D]$

Transient Lift force

Measured by load cell

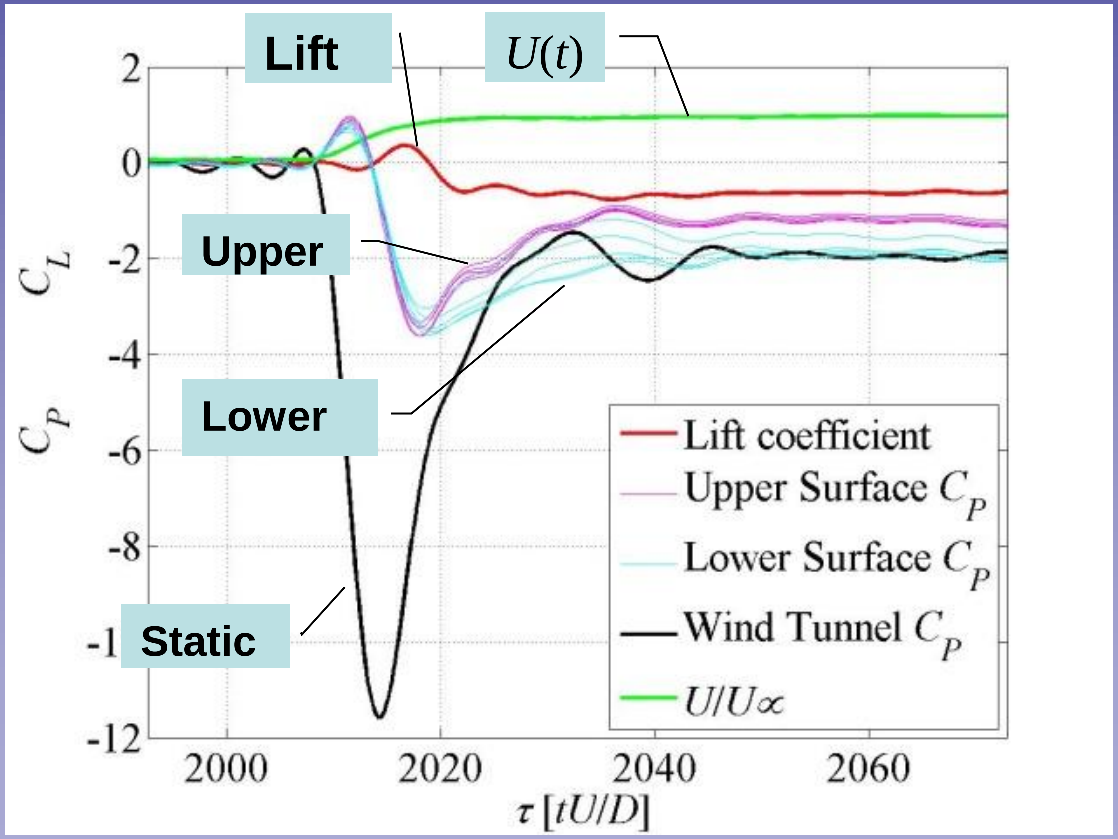


$\alpha = 10^{\circ}$

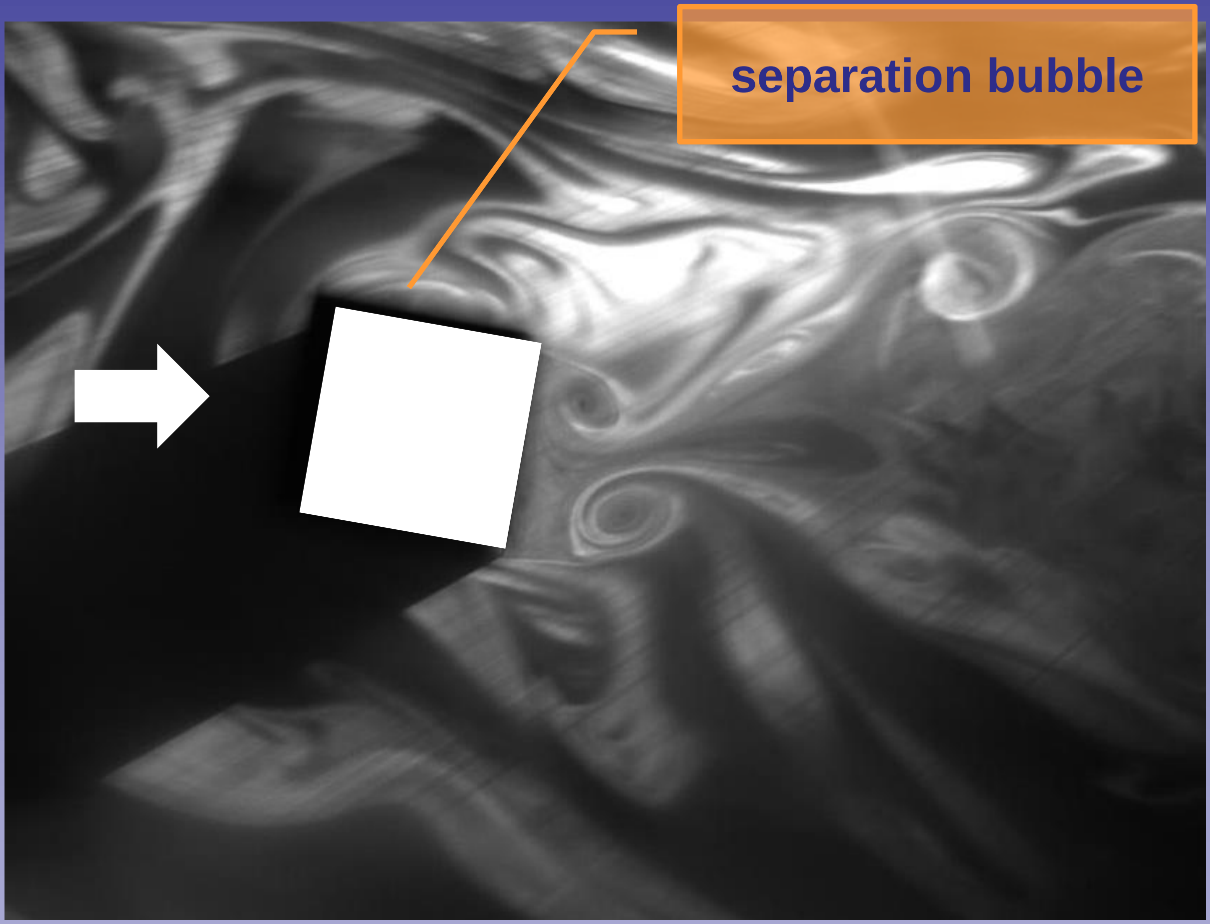


Pressures on upper and lower surfaces

B/D=1, U=4.0m/s, α =10°



Flow pattern at the lift peak



Conclusion

- The overshoot of drag force was observed typically for a rectangular cylinder with more slender cross section.
- The drag force overshoot is explained partially by the time difference between both pressure reaching to the steady level.
- The inertia force due to streamwise pressure gradient can contribute to the overshoot of drag force.

Conclusion (cont'd)

- The overshoot of lift force on a slightly inclined square cylinder is due to the temporal formation of the separation bubble on the upper surface.