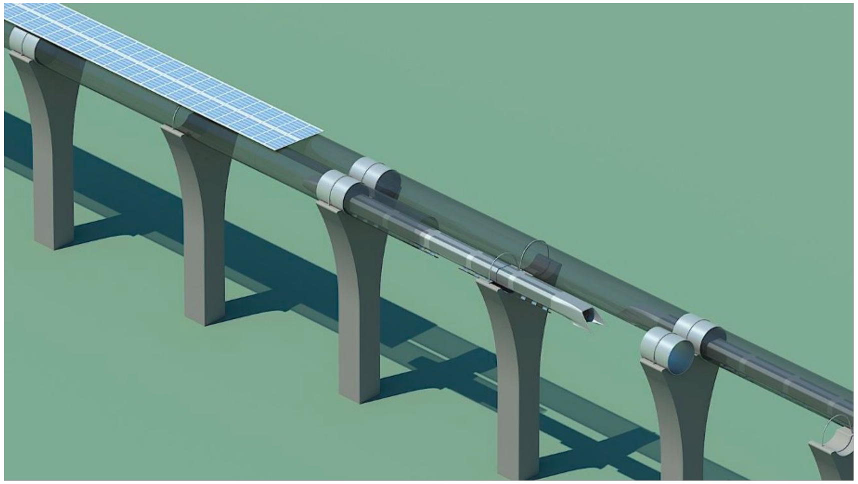
LIÈGE université
Wind Tunnel

Investigation of the flow around twin cylinders in the post-critical regime



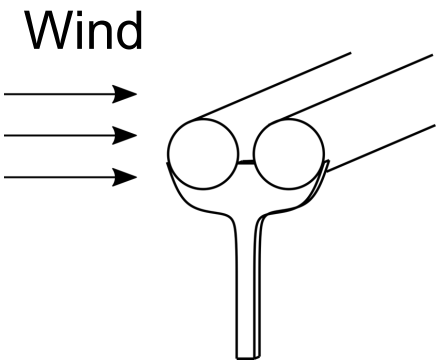
Raphaël Dubois & Thomas Andrianne

12th October 2023

Context

Twin chimneys
(Cornwall, 2015)

Hyperloop

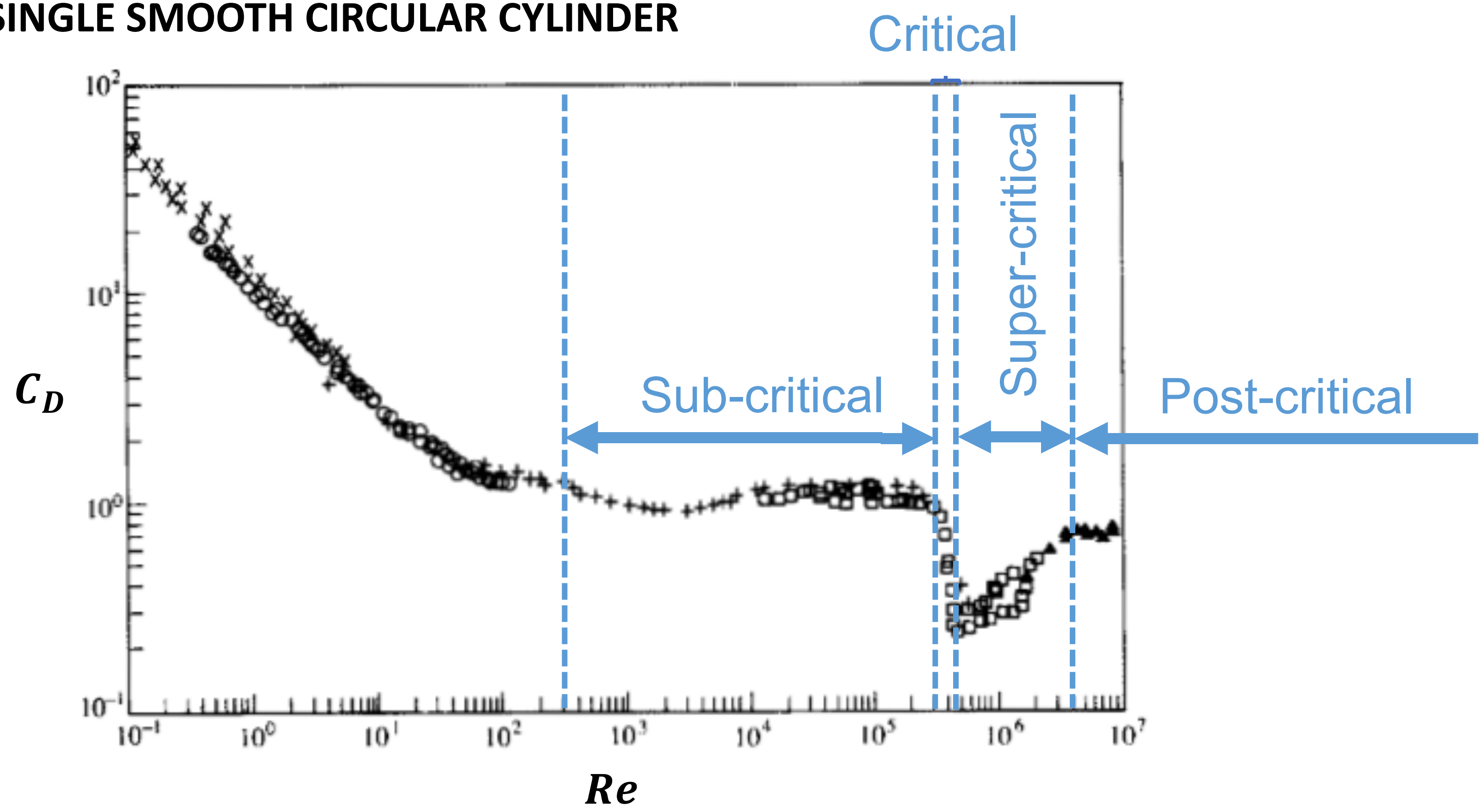


$D = 4$ m
$U_\infty \sim 30$ m/s

$\Rightarrow Re \sim 8 \times 10^6$

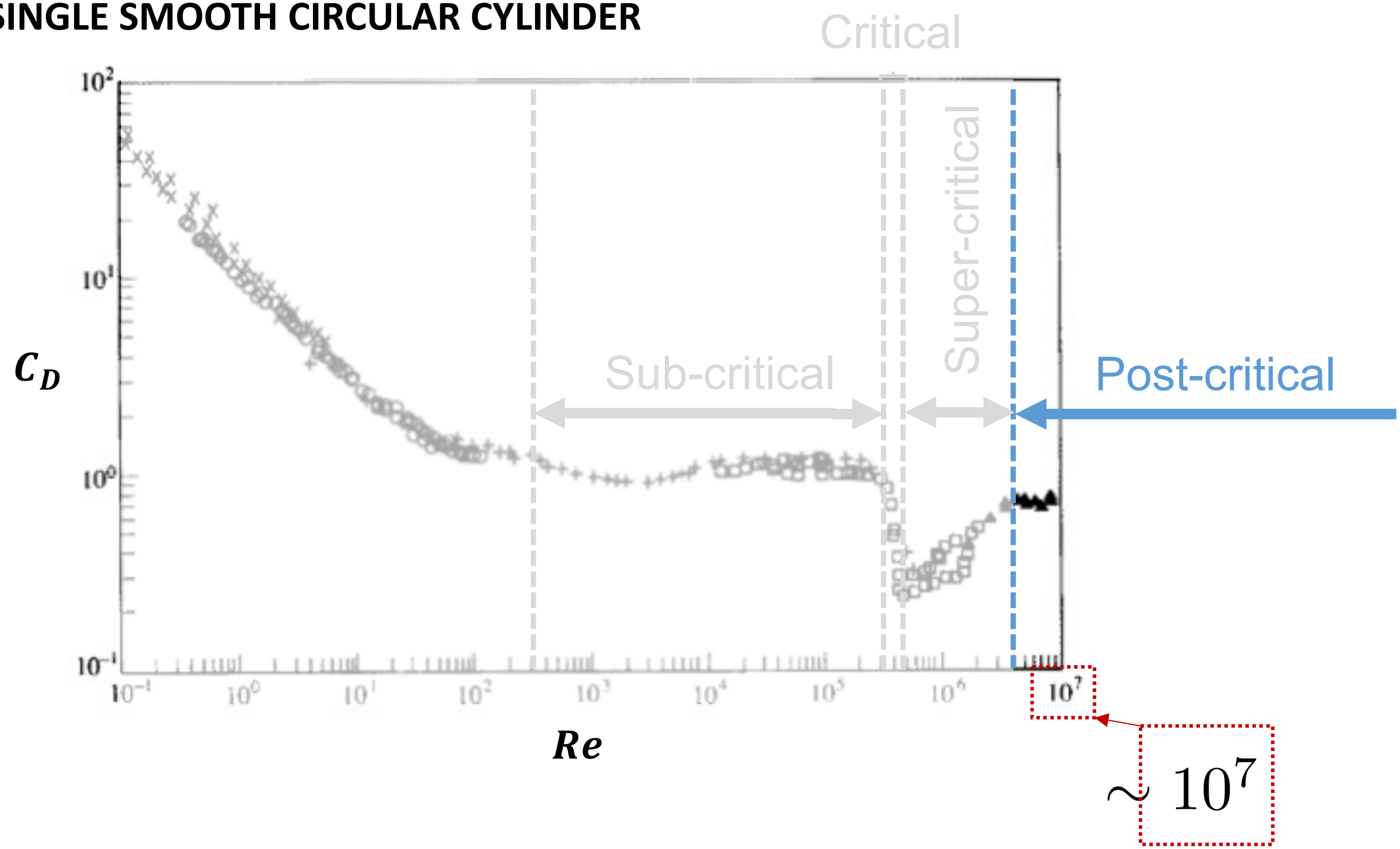
Context (2)

SINGLE SMOOTH CIRCULAR CYLINDER



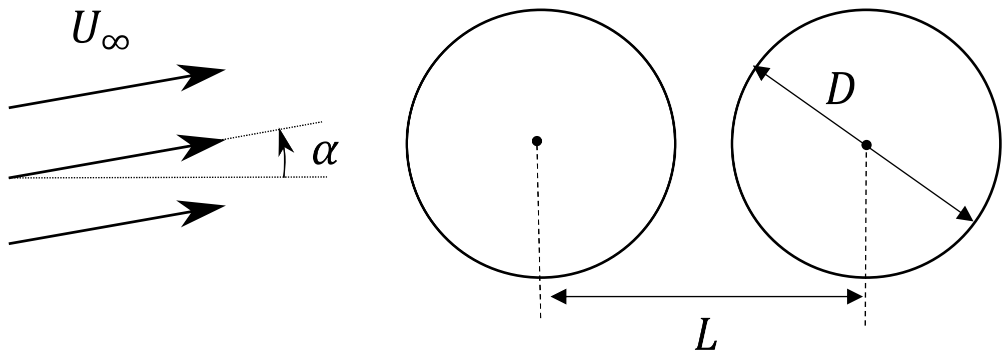
Context (2)

SINGLE SMOOTH CIRCULAR CYLINDER



Post-critical flow regime

Research project



Experimental investigation in low-subsonic wind tunnel

Static | **POST-CRITICAL** | **Dynamic**

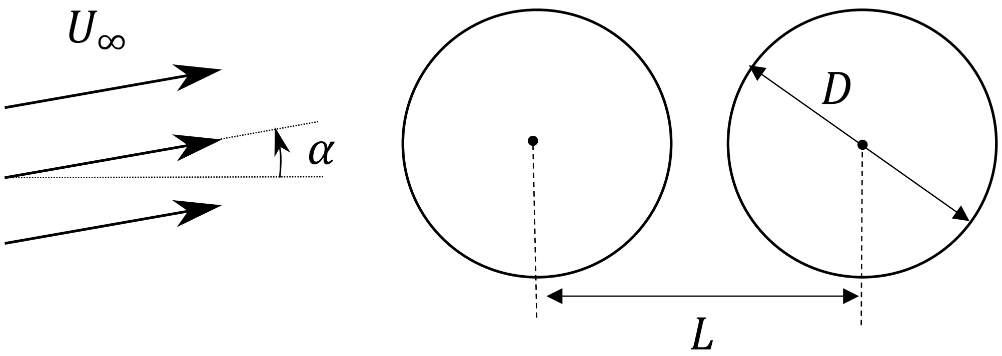
Static:

- $L/D = 1.2 - 1.8$
- $\alpha = 0° - 10°$
- Variation of free-stream turbulence

Dynamic:

- $L/D = 1.2 - 1.8$
- $\alpha = 0° - 10°$
- Different structural damping ratios

Research project



Experimental investigation in low-subsonic wind tunnel

Static | **POST-CRITICAL** | **Dynamic**

- $L/D = 1.2$
- $\alpha = 0° - 10°$
- Low-turbulent free-stream

Today

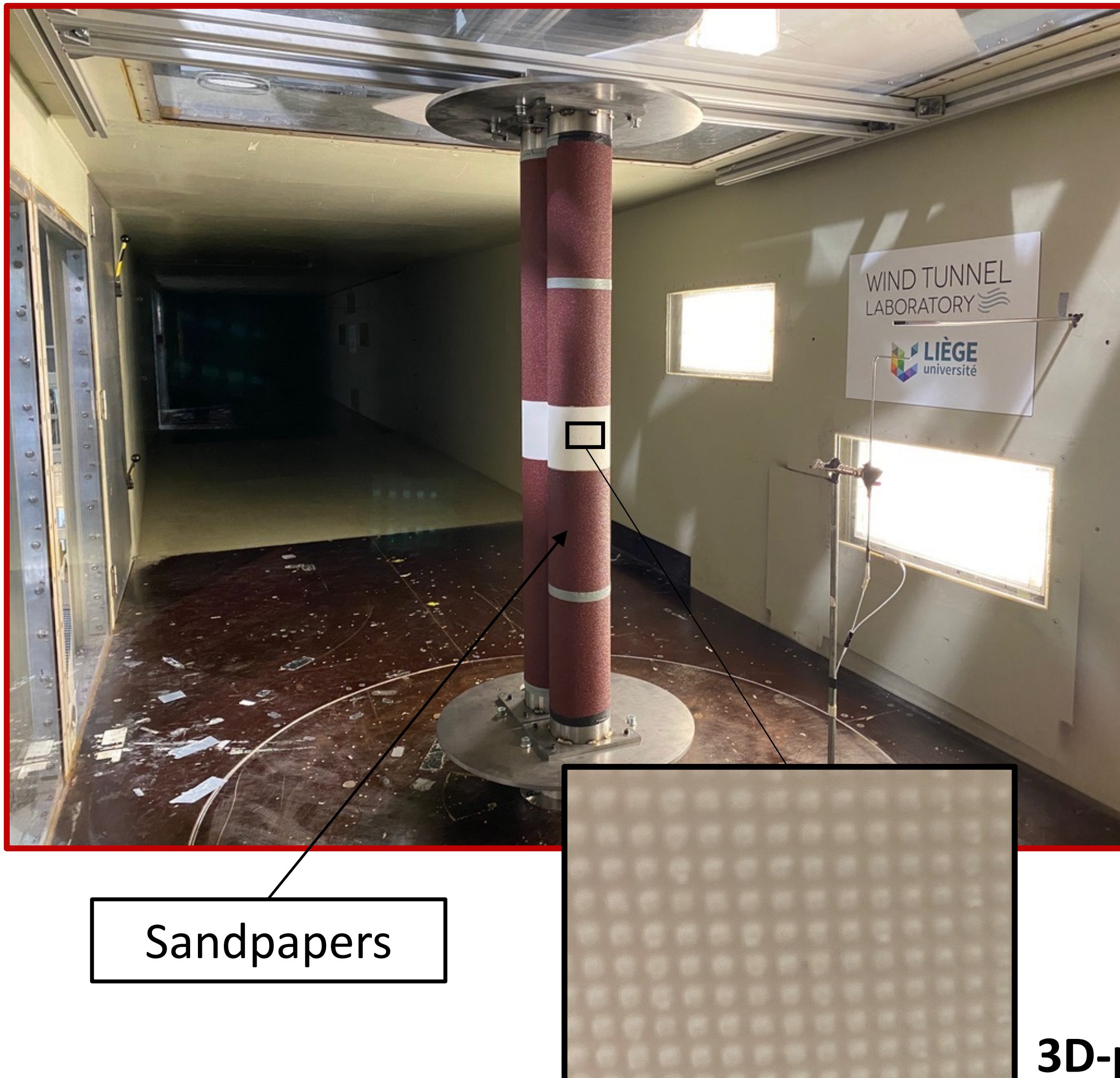
- $L/D = 1.2 - 1.8$
- $\alpha = 0° - 10°$
- Different structural damping ratios

Experimental static model

Experimental static model

$Re = 20\text{k} - 395\text{k}$

Experimental static model



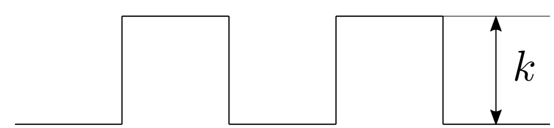
Sandpapers

3D-printed

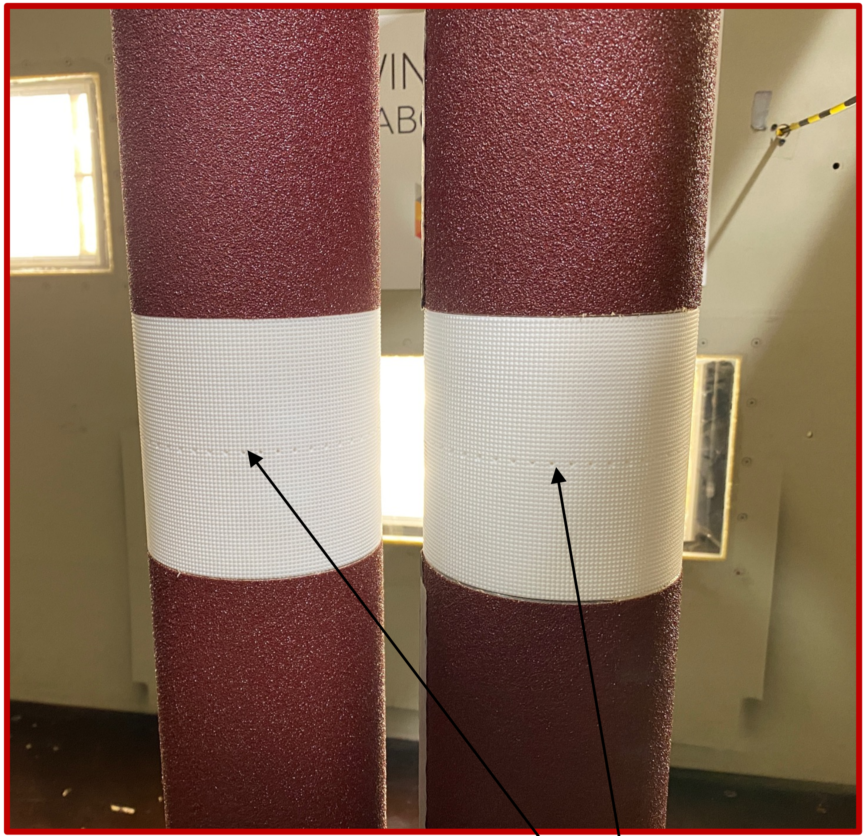
$Re = 20\text{k} - 395\text{k}$

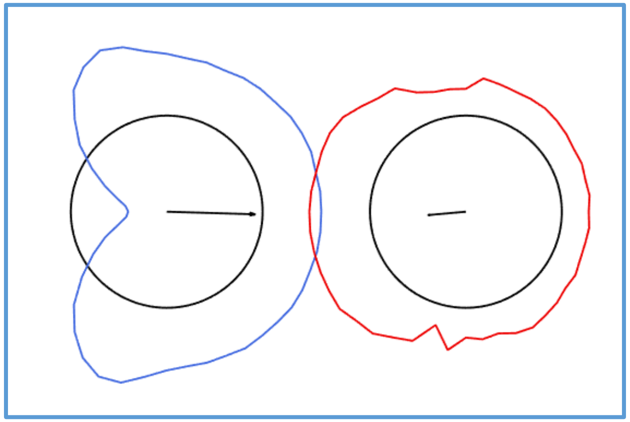
Rough cylinders

$(k/D = 7.2 \times 10^{-3})$



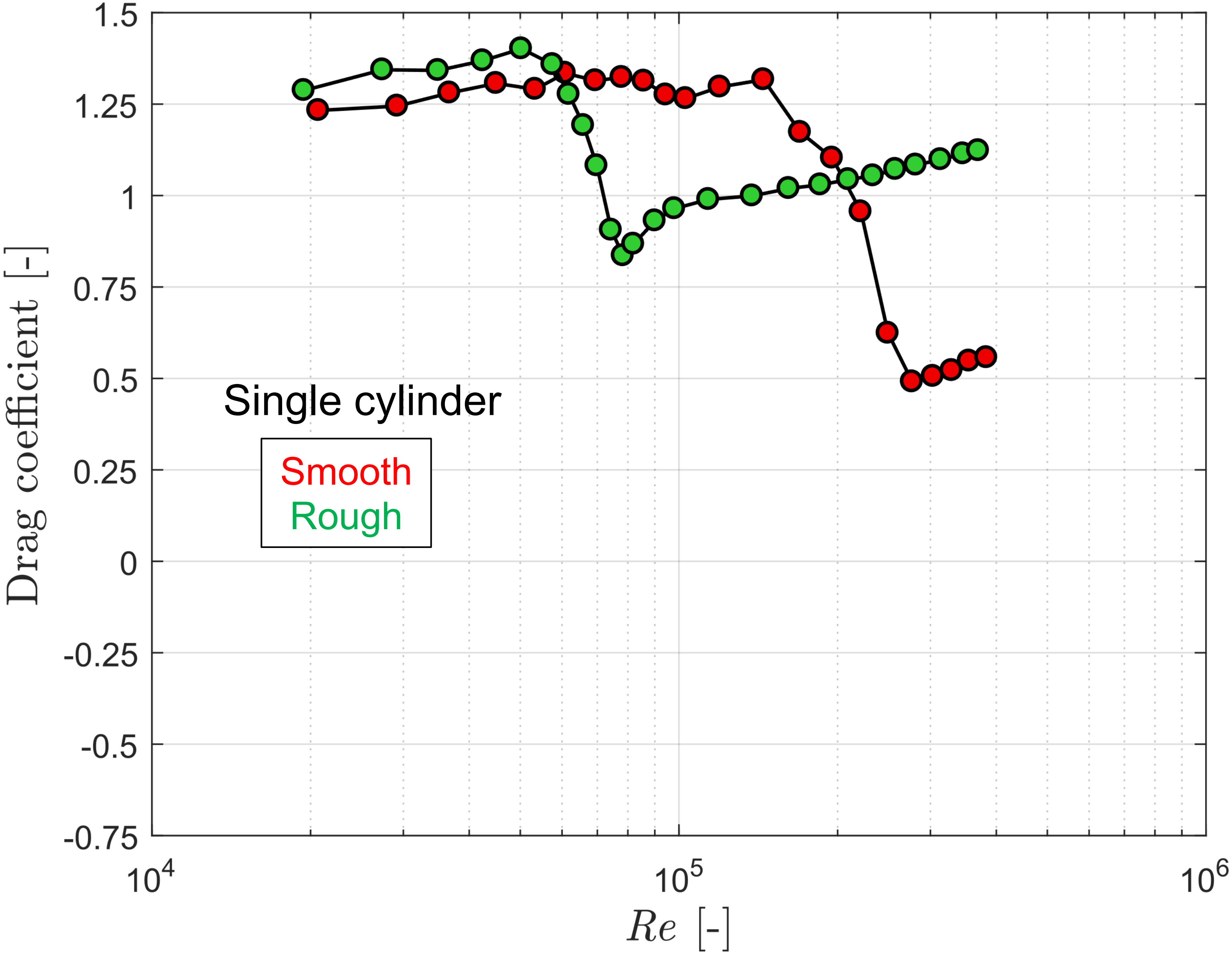
Instrumentation



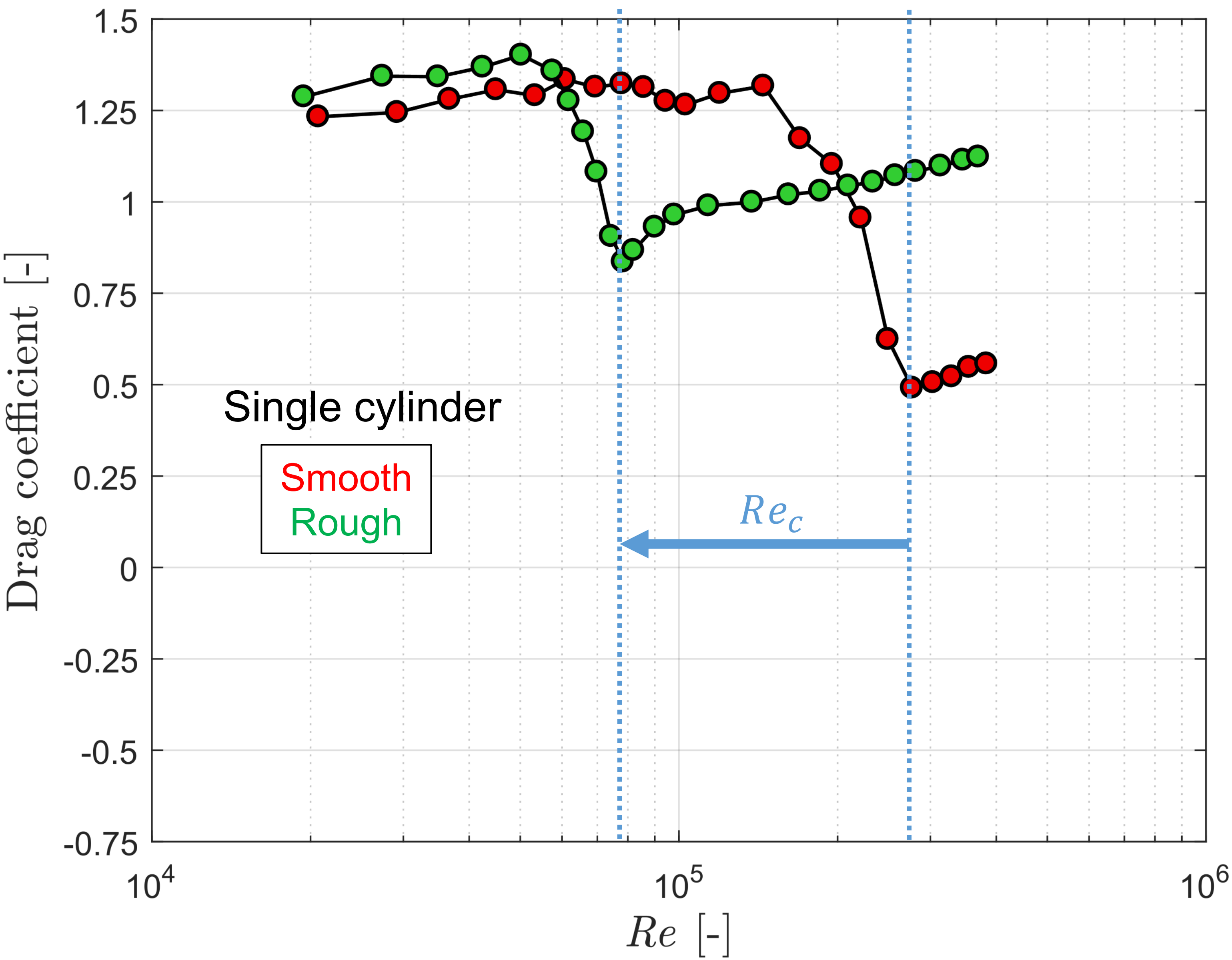


Unsteady pressure measurements (48 taps/cylinder)

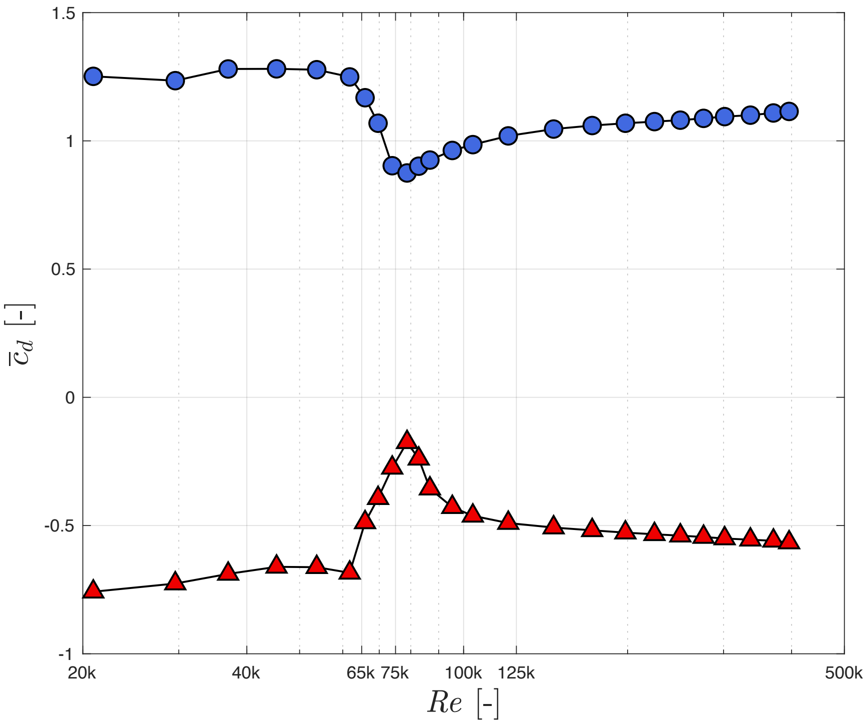
Triggering the post-critical regime

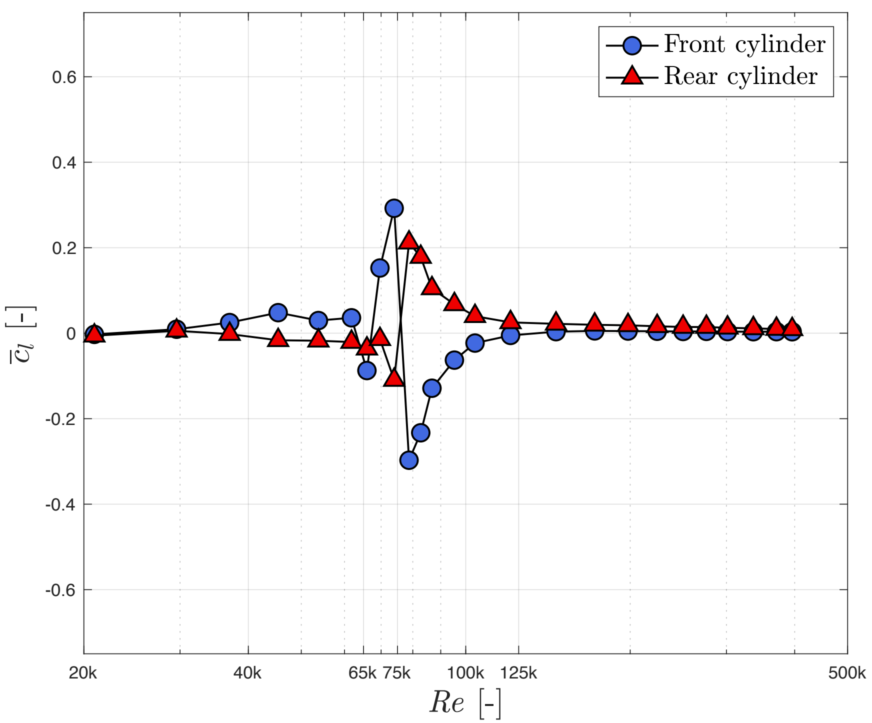


Triggering the post-critical regime

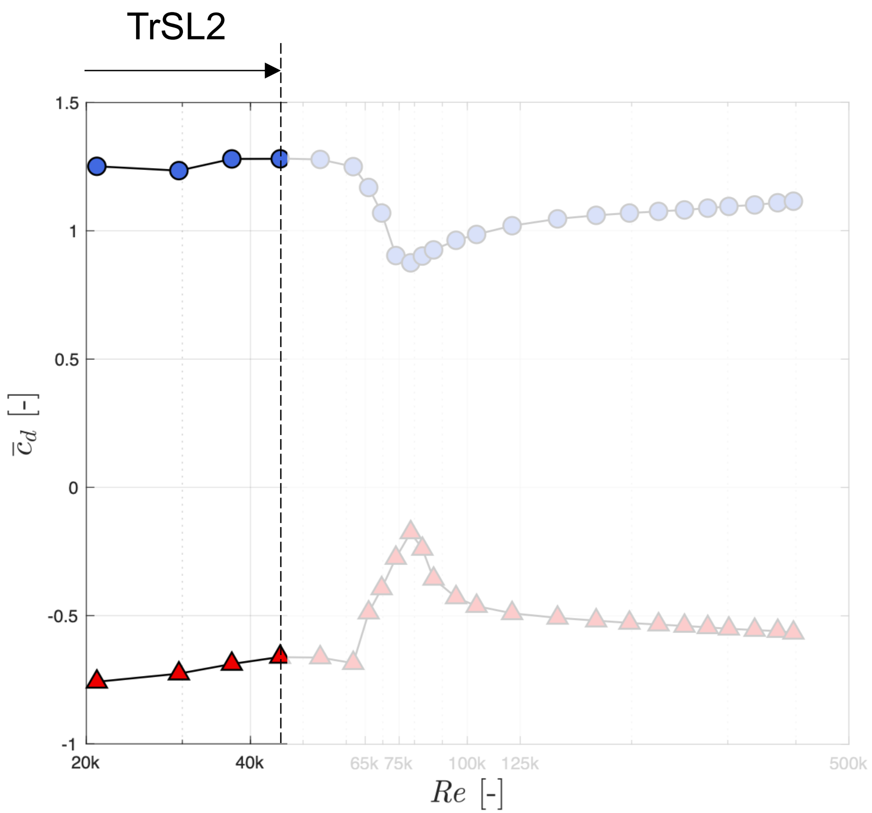


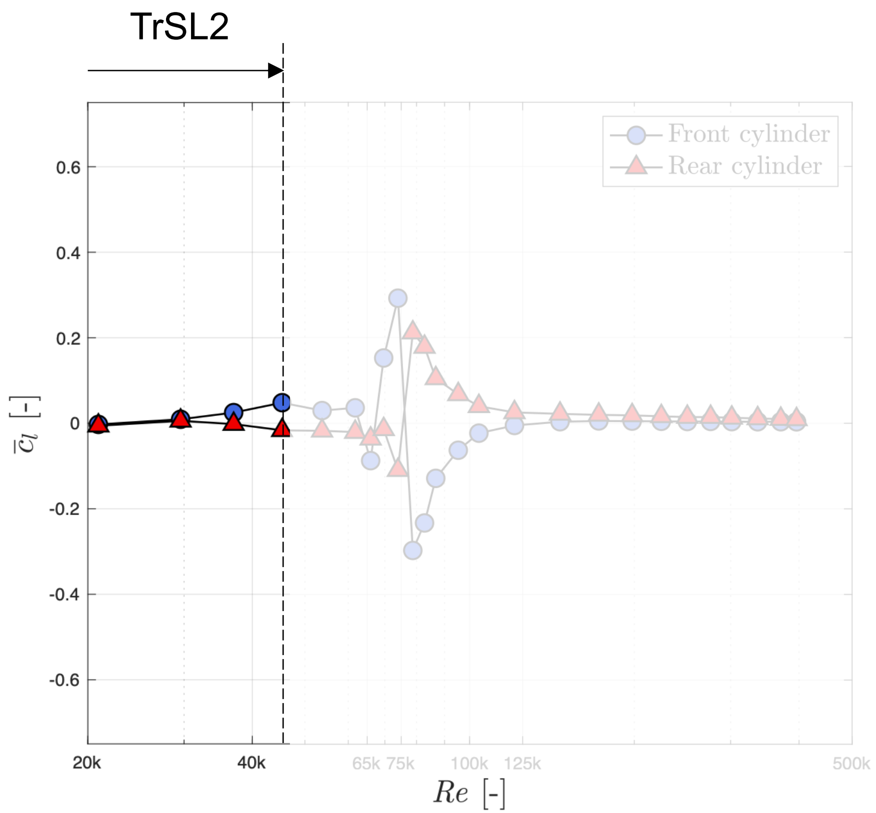
Flow regimes – Tandem arrangement



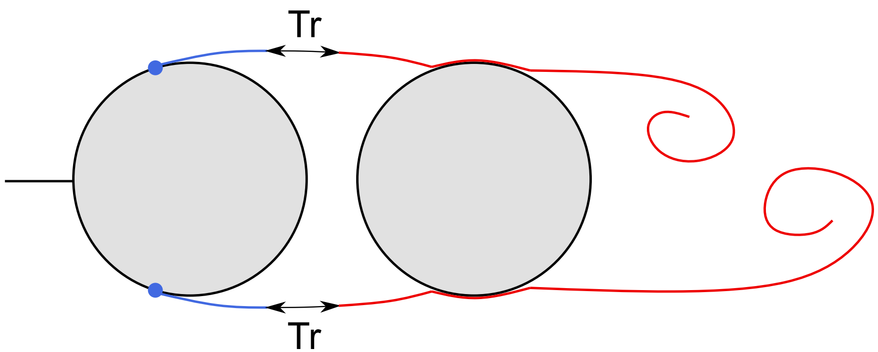


Flow regimes – Tandem arrangement

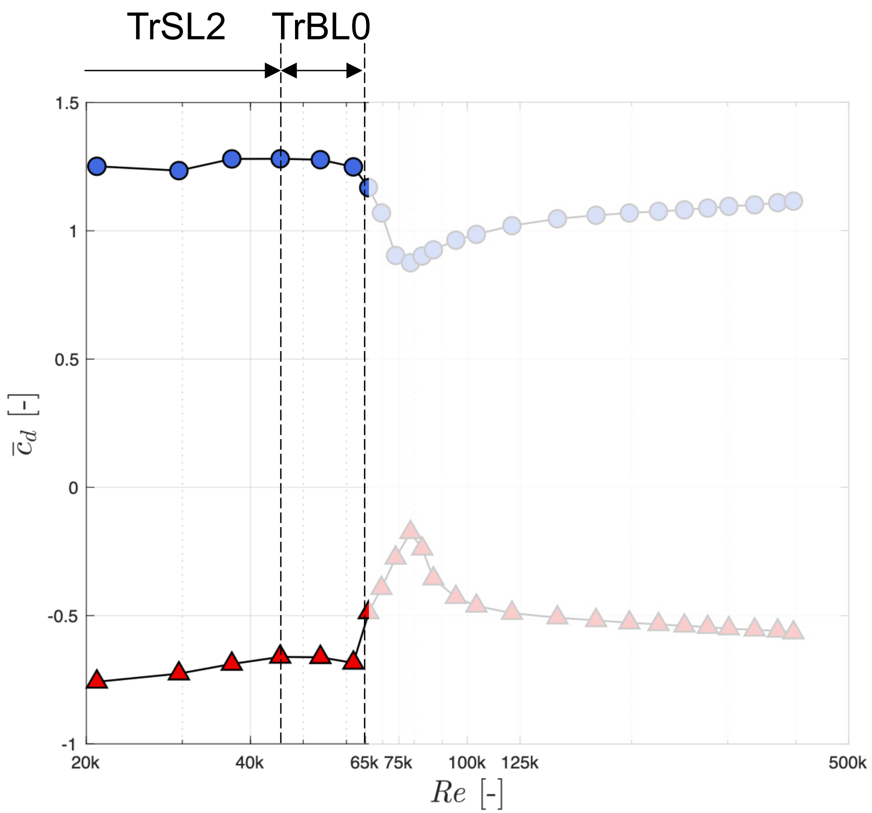


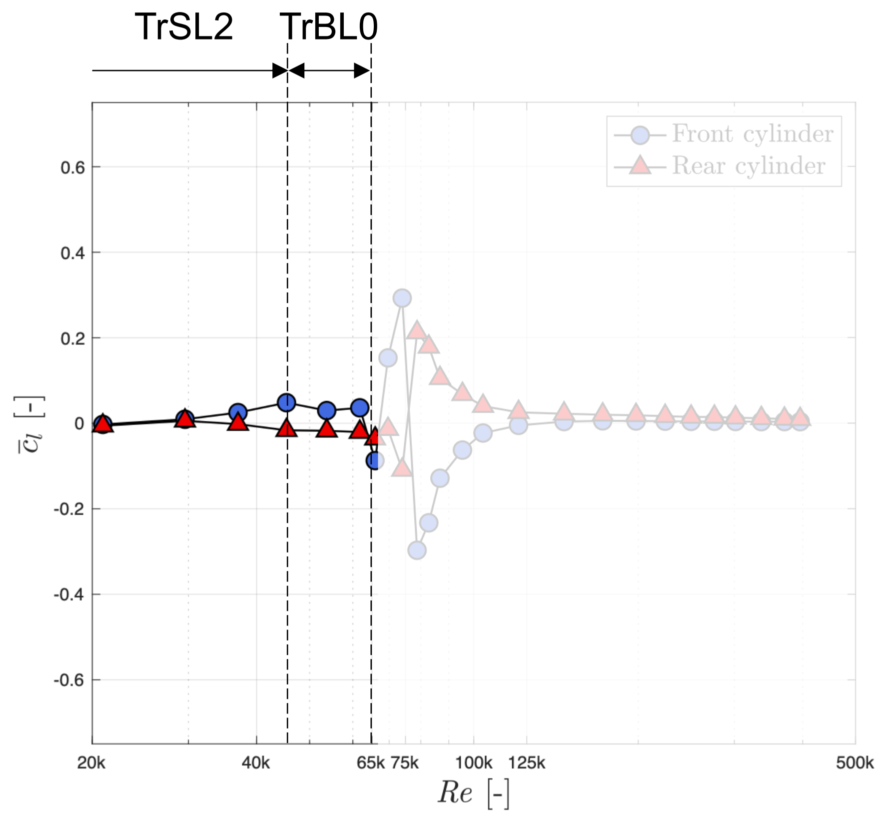


sub-critical

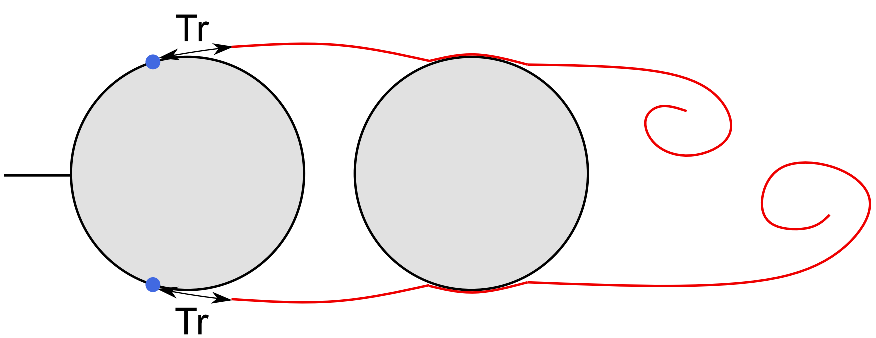


Flow regimes – Tandem arrangement

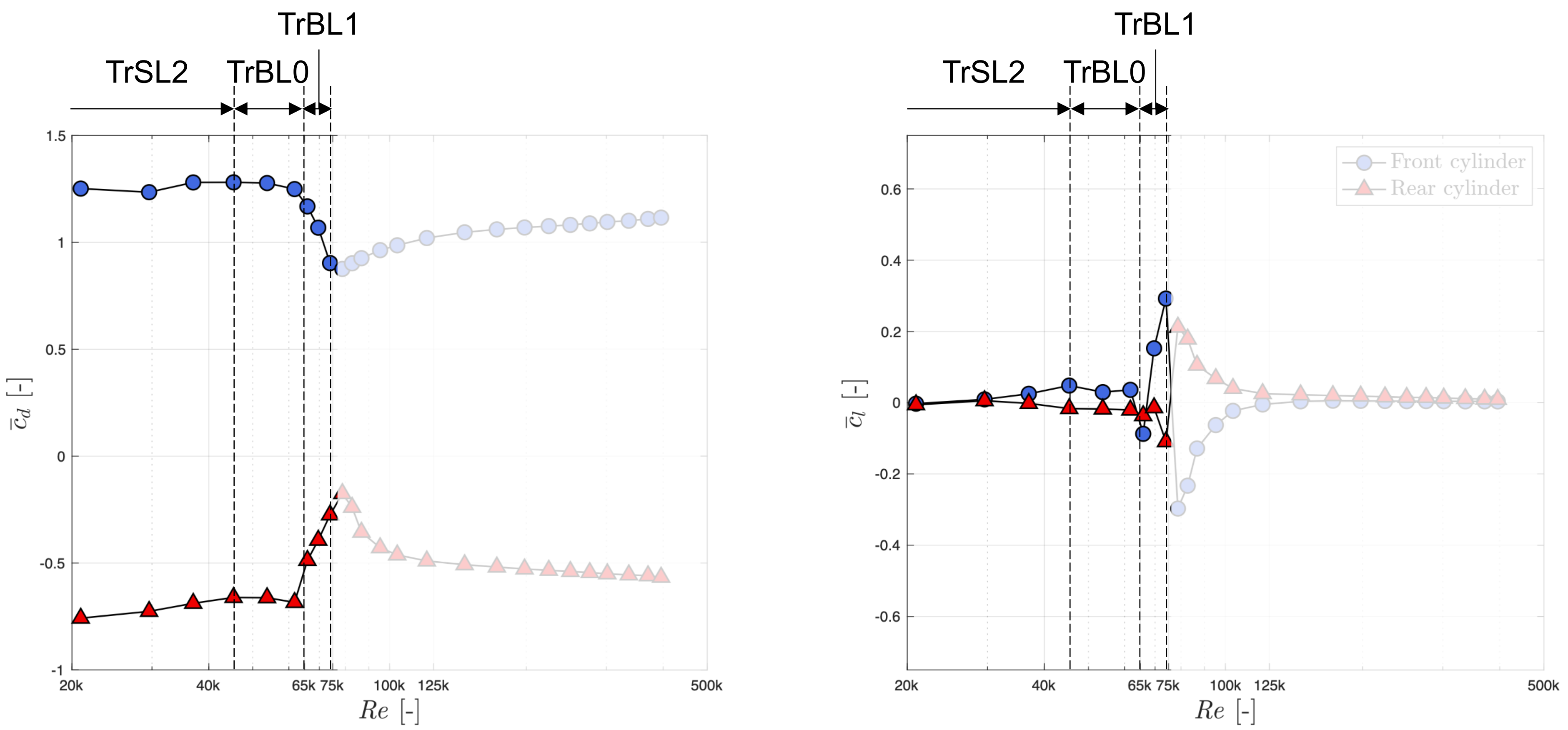


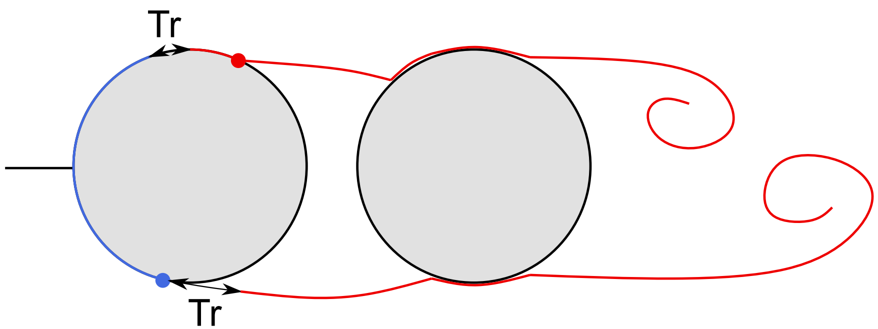


pre-critical



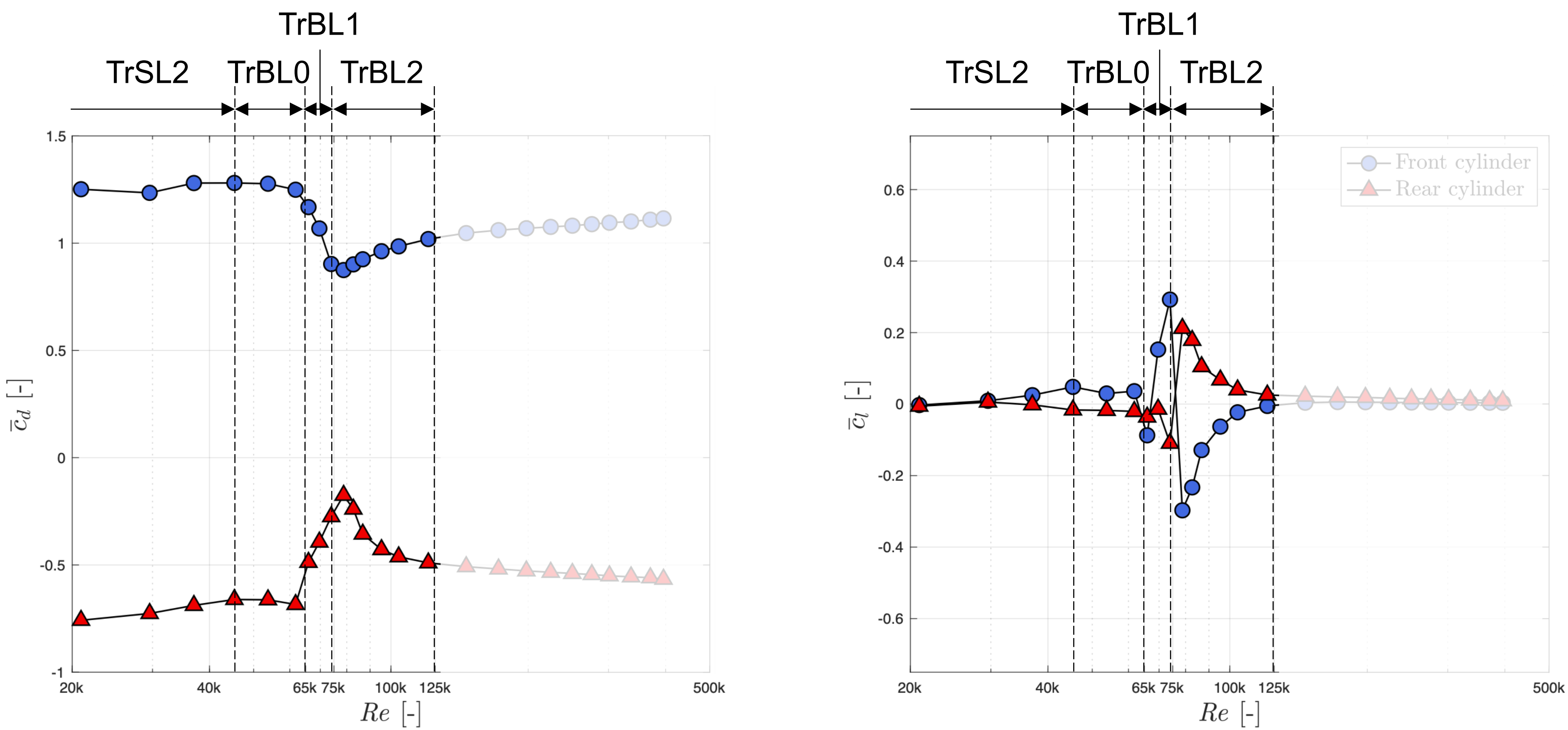
Flow regimes – Tandem arrangement

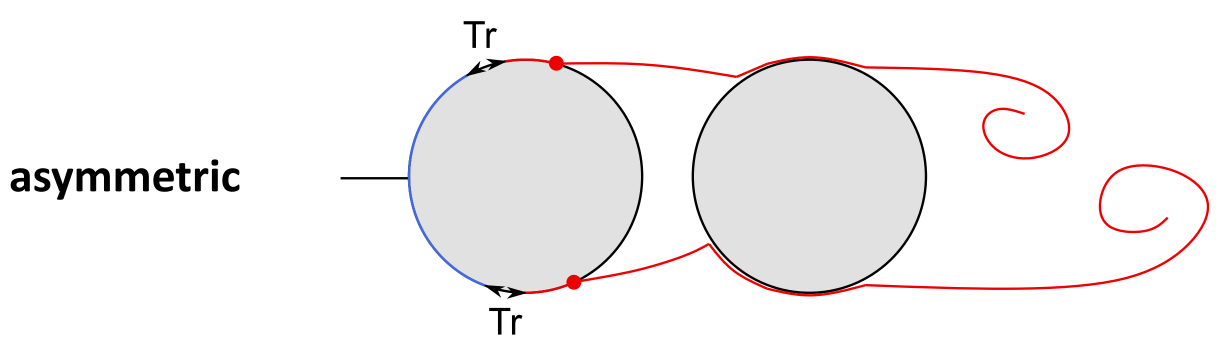




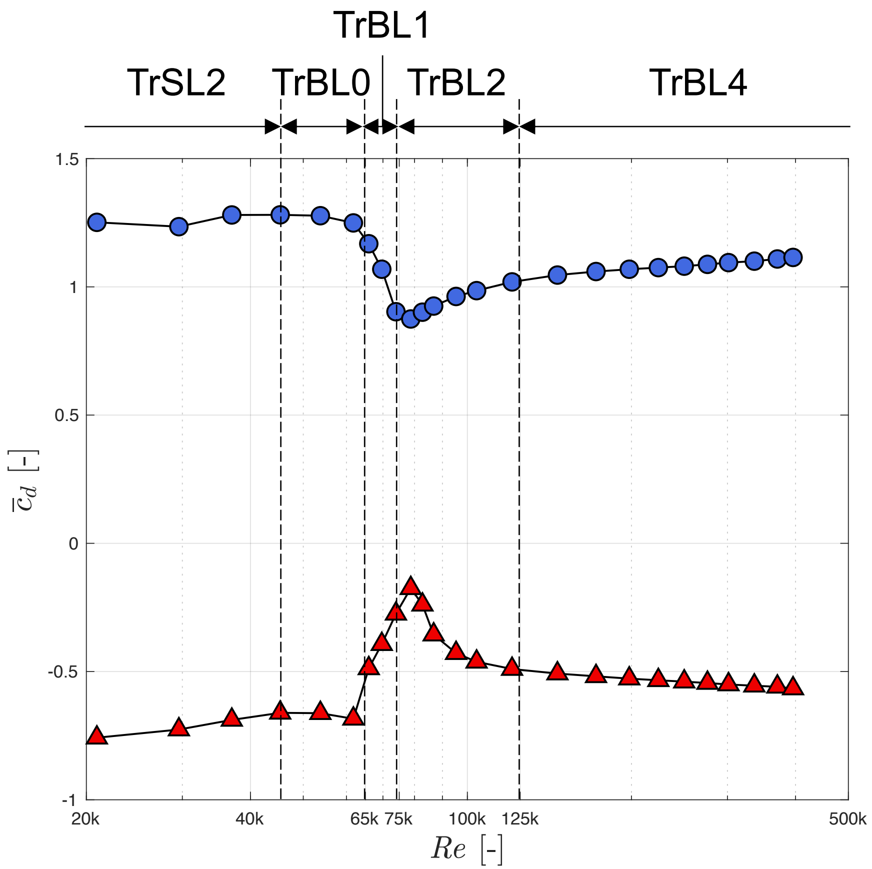
critical

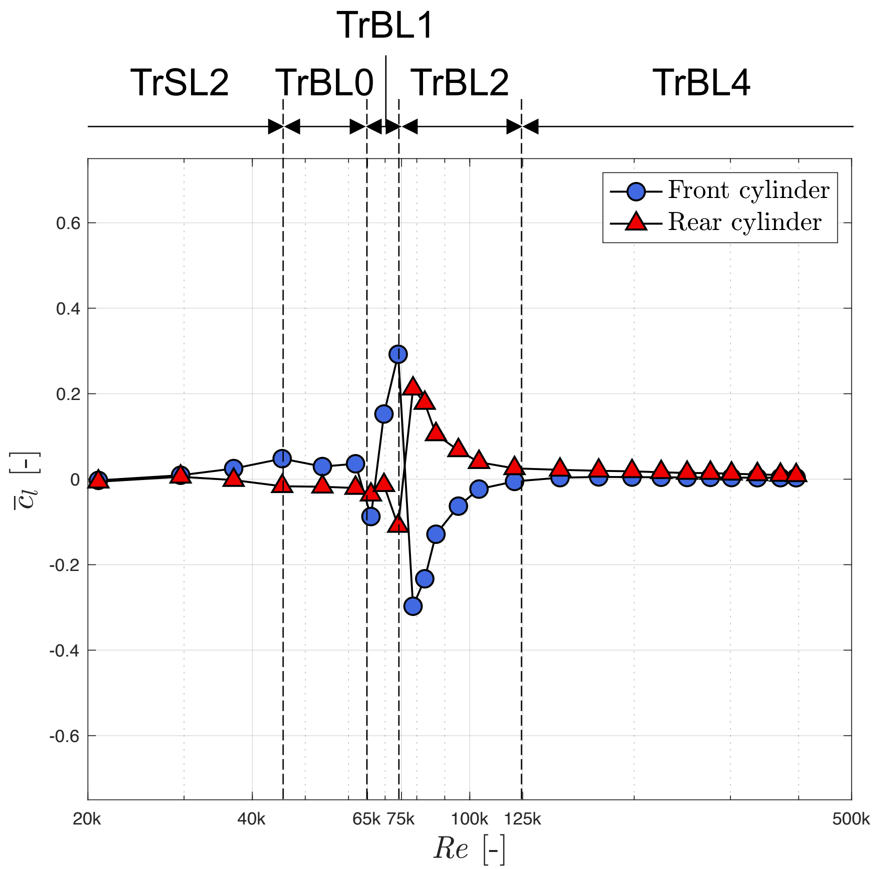
Flow regimes – Tandem arrangement



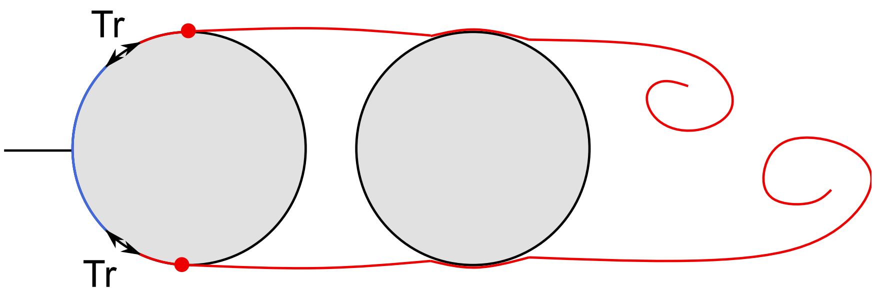


Flow regimes – Tandem arrangement

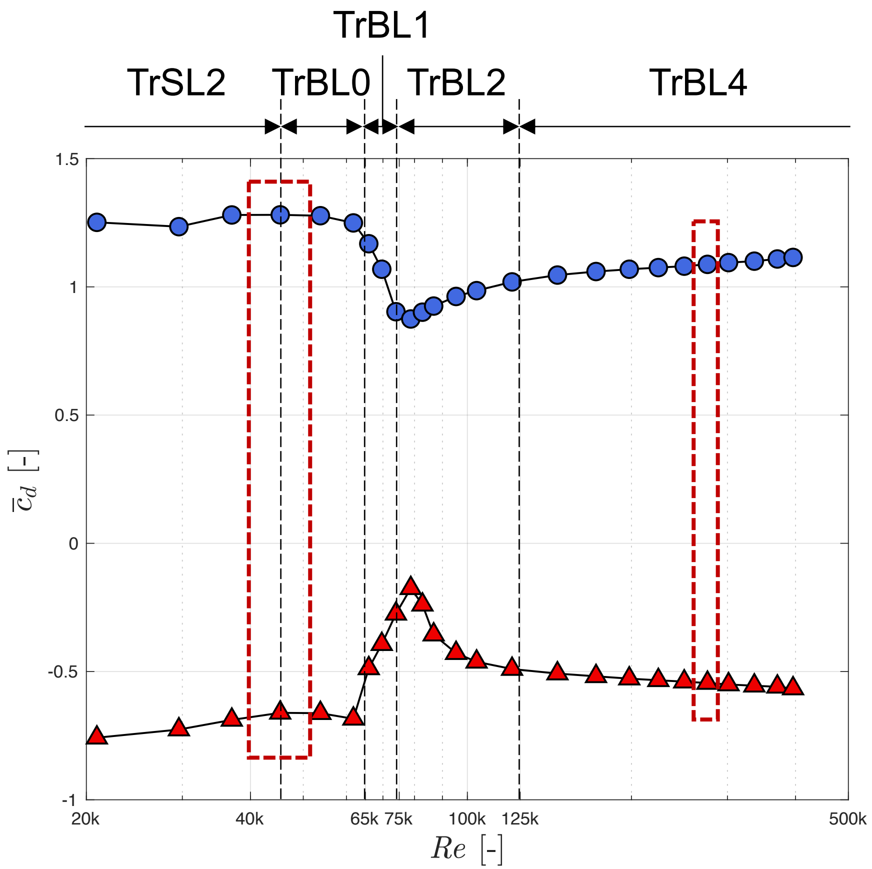


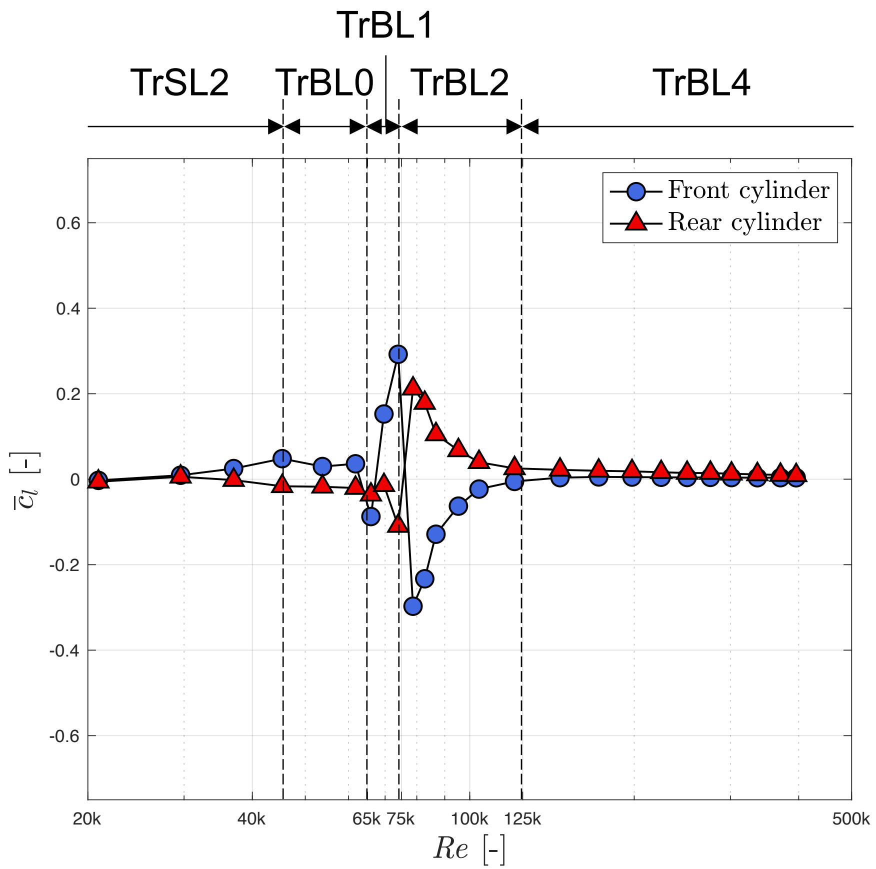


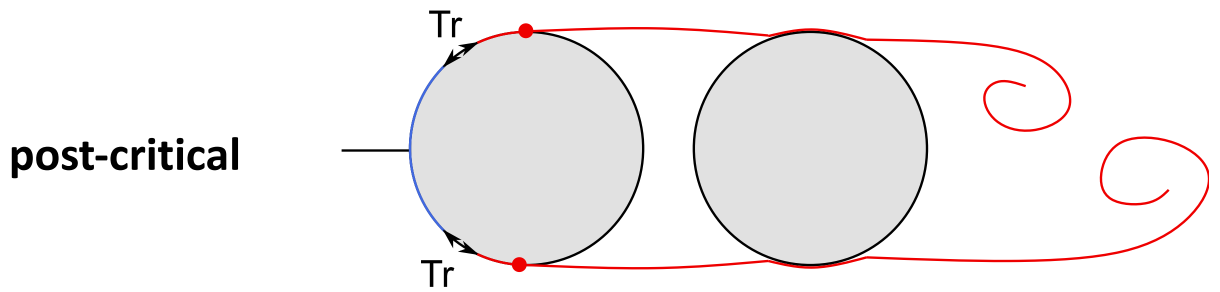
post-critical



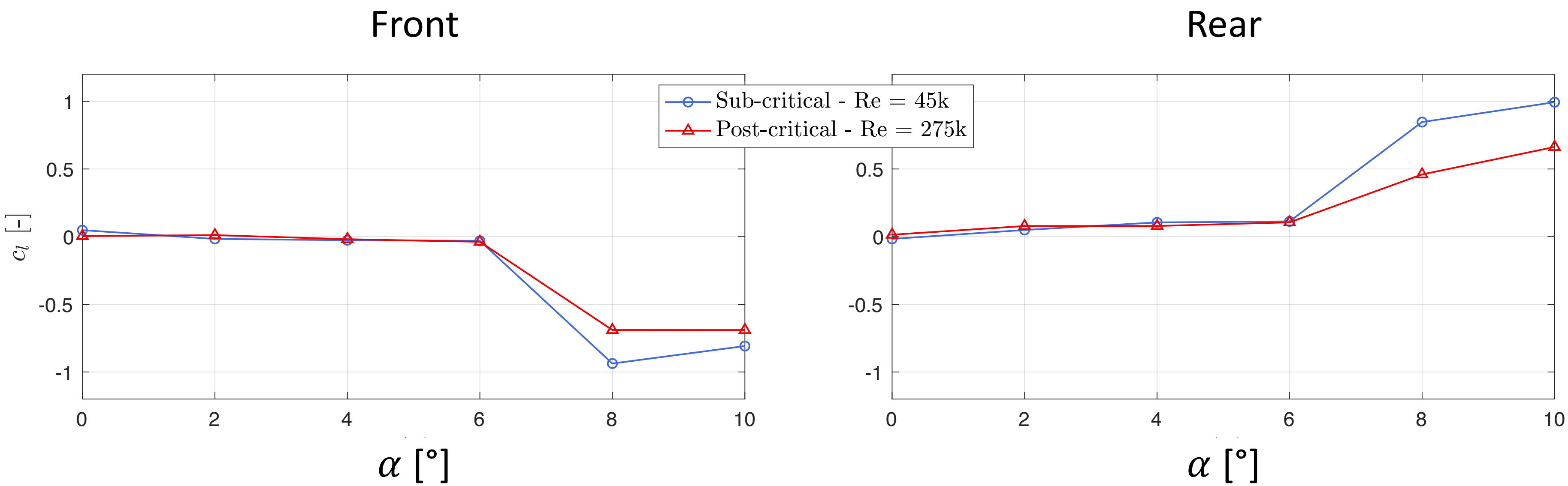
Flow regimes – Tandem arrangement

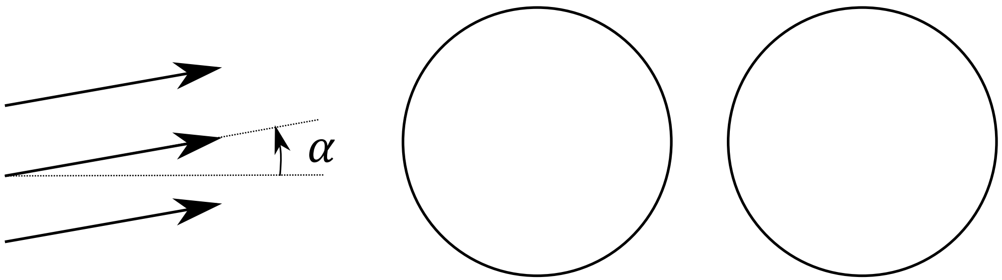




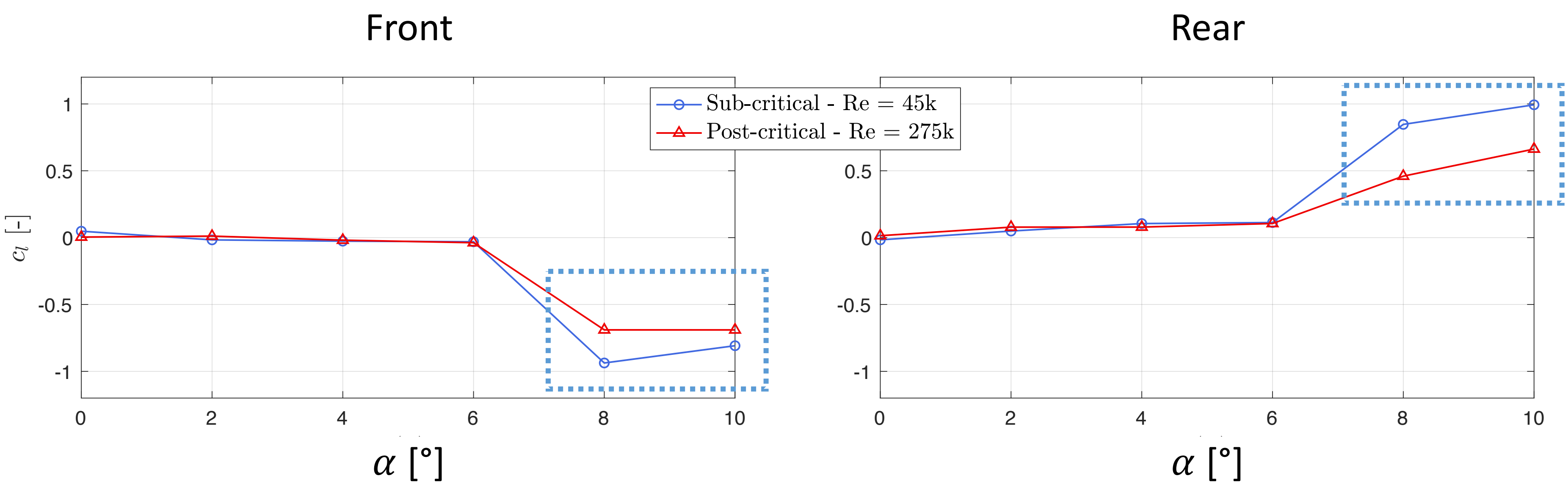


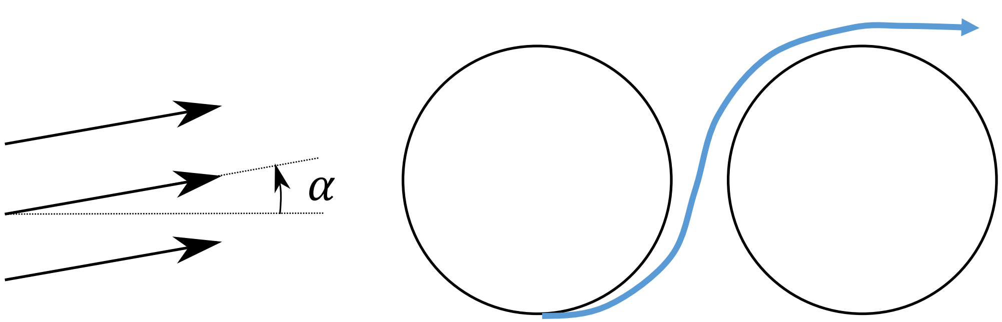
Wind incidence – Time-averaged lift



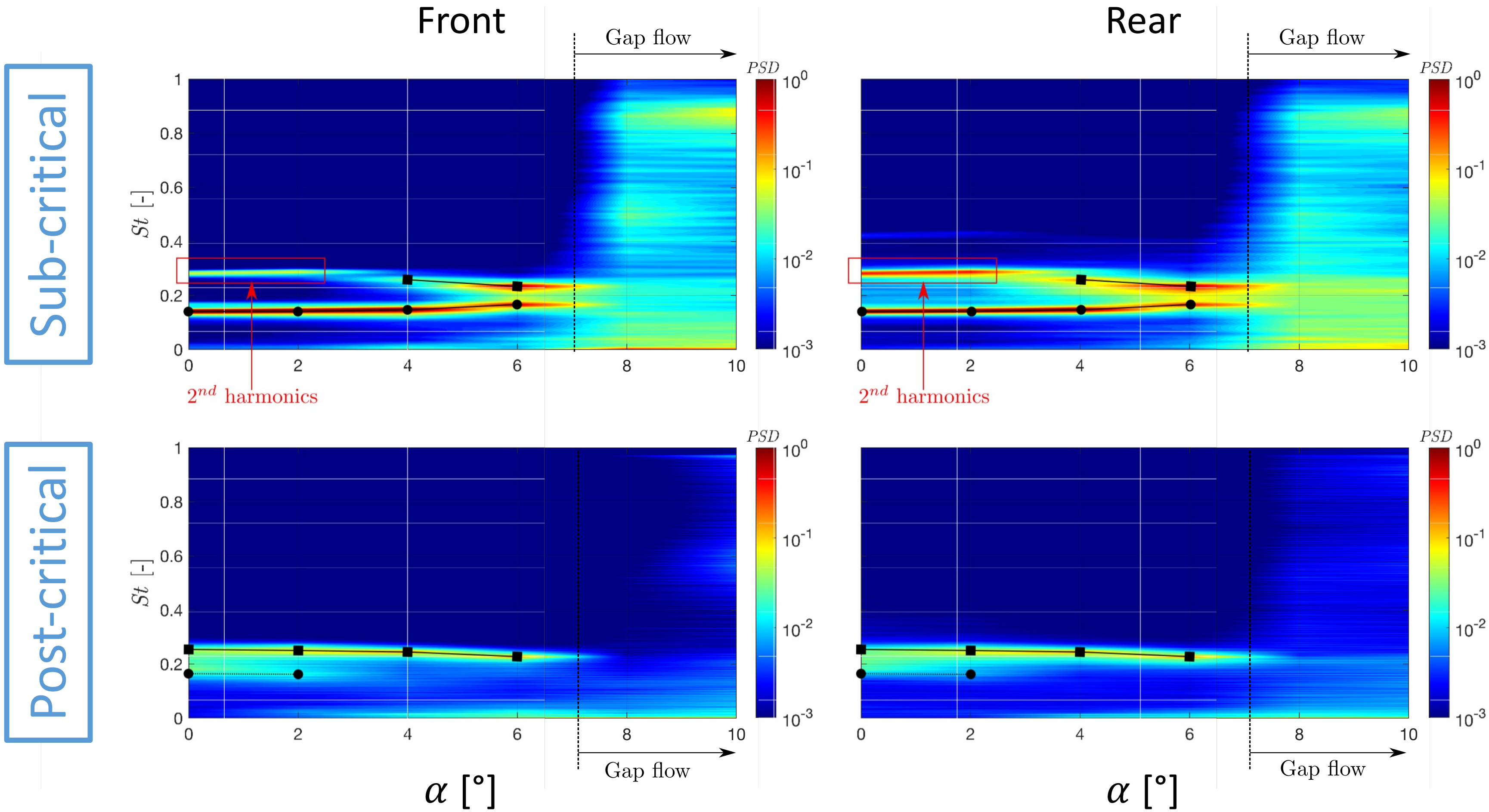


Wind incidence – Time-averaged lift



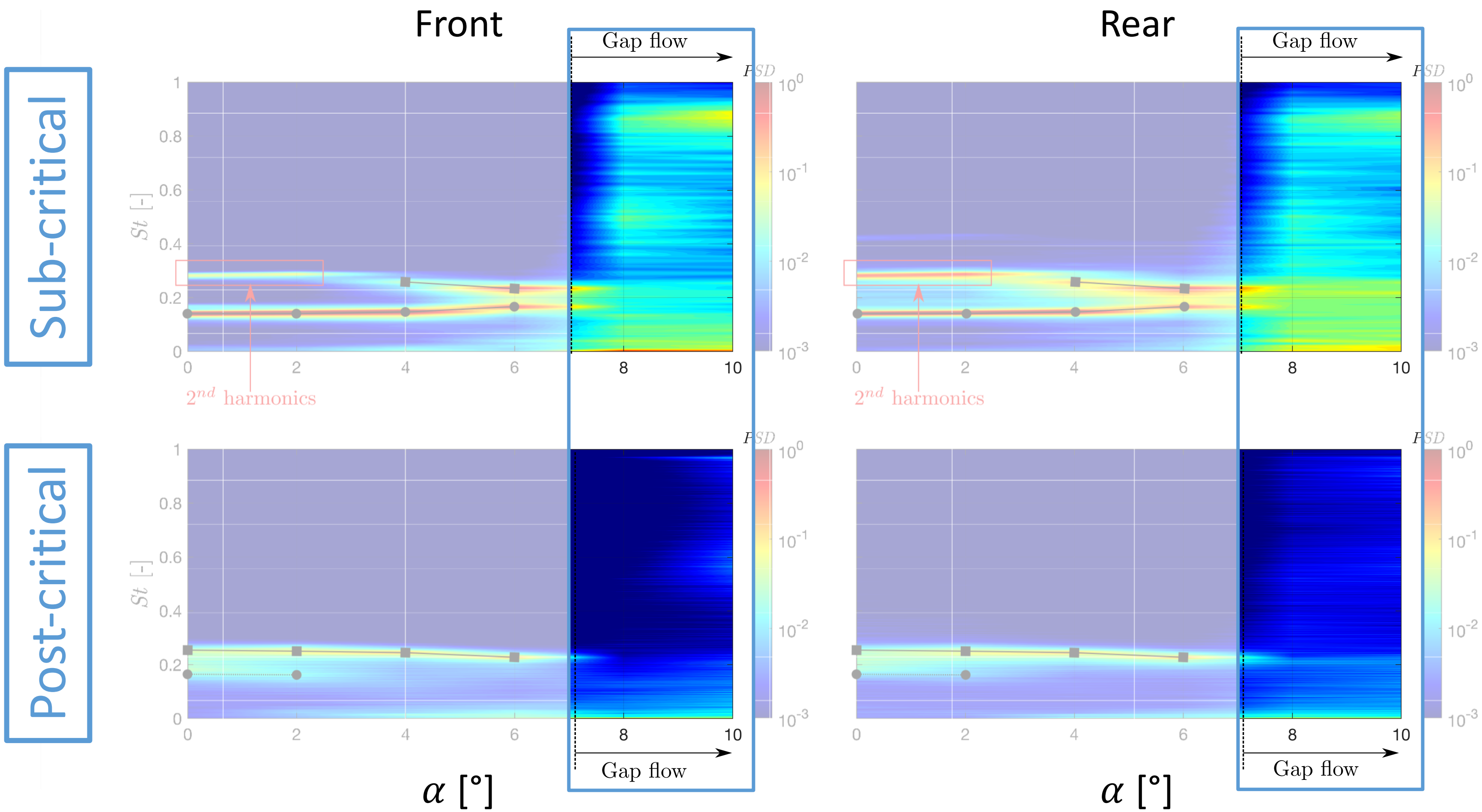


Wind incidence – Frequency content of lift



$$St = \frac{fD}{U_\infty}$$

Wind incidence – Frequency content of lift



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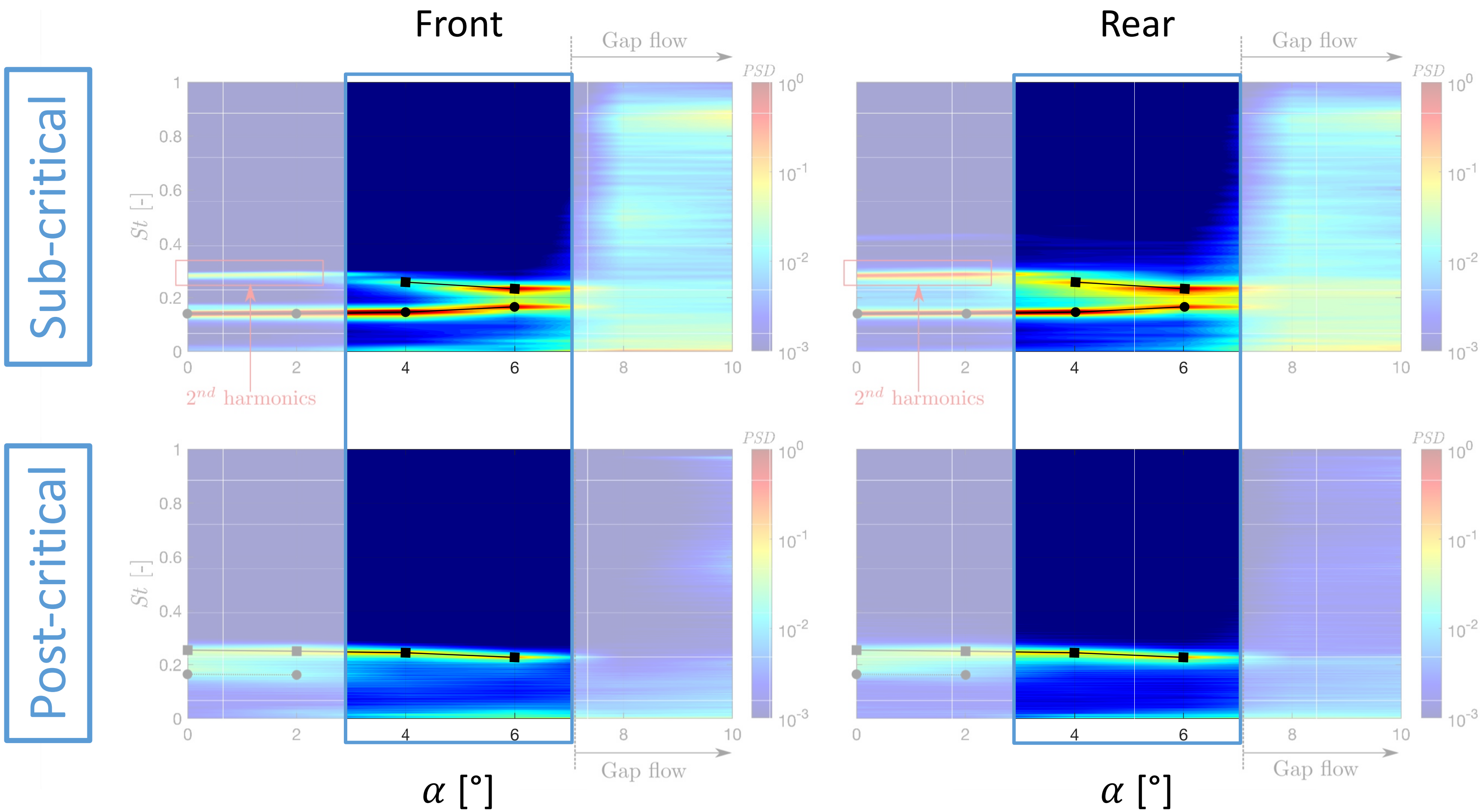

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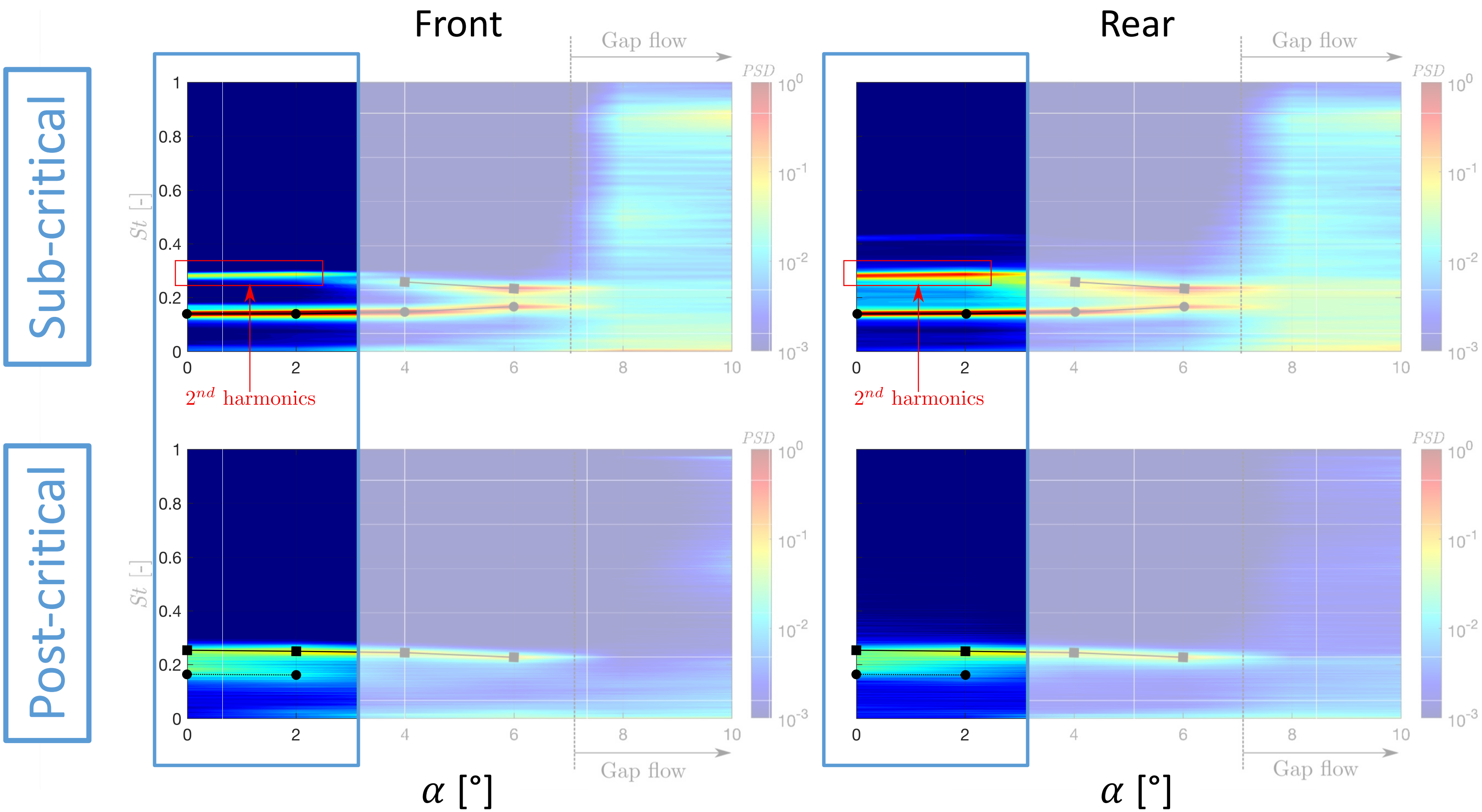
Wind incidence – Frequency content of lift



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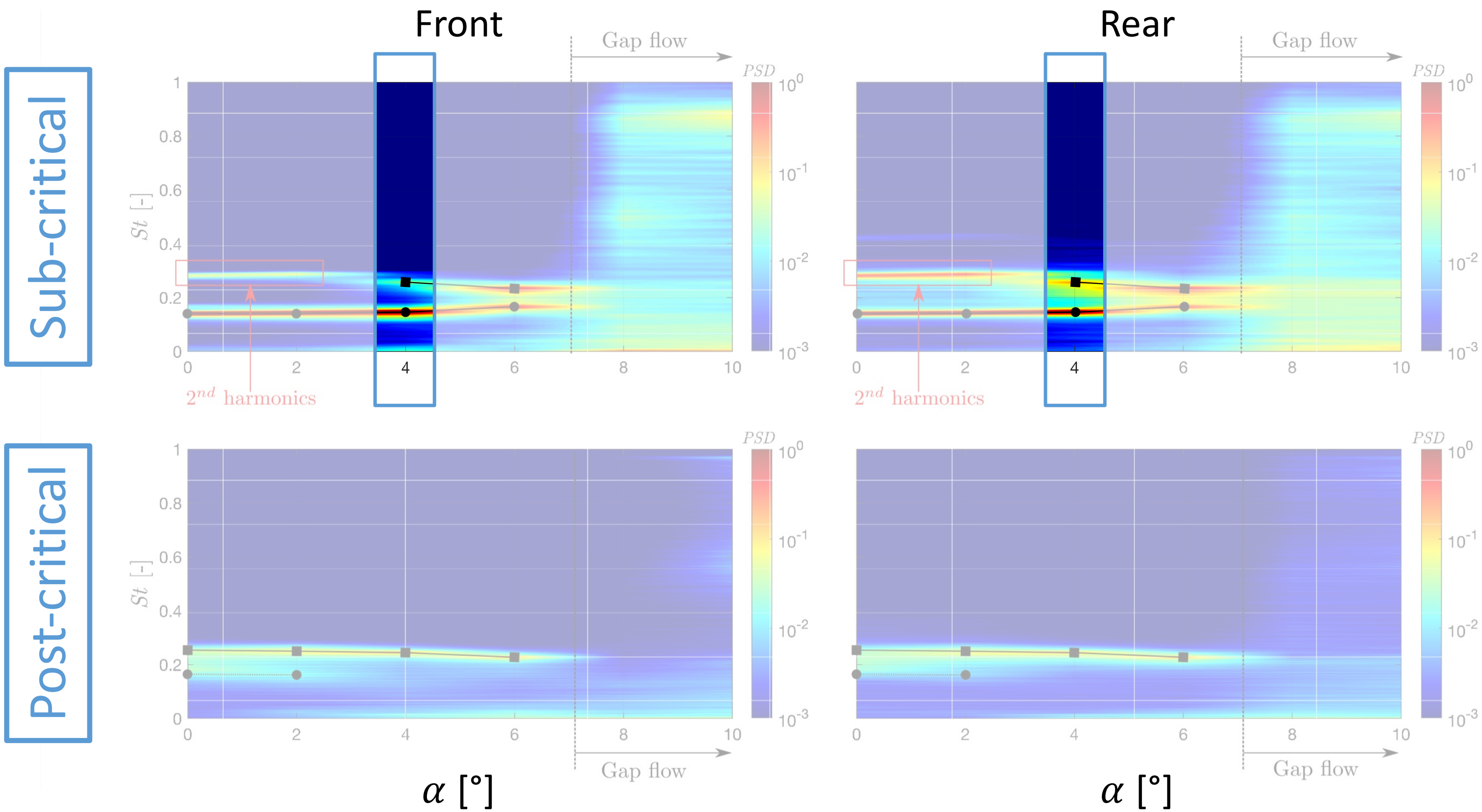
Wind incidence – Frequency content of lift

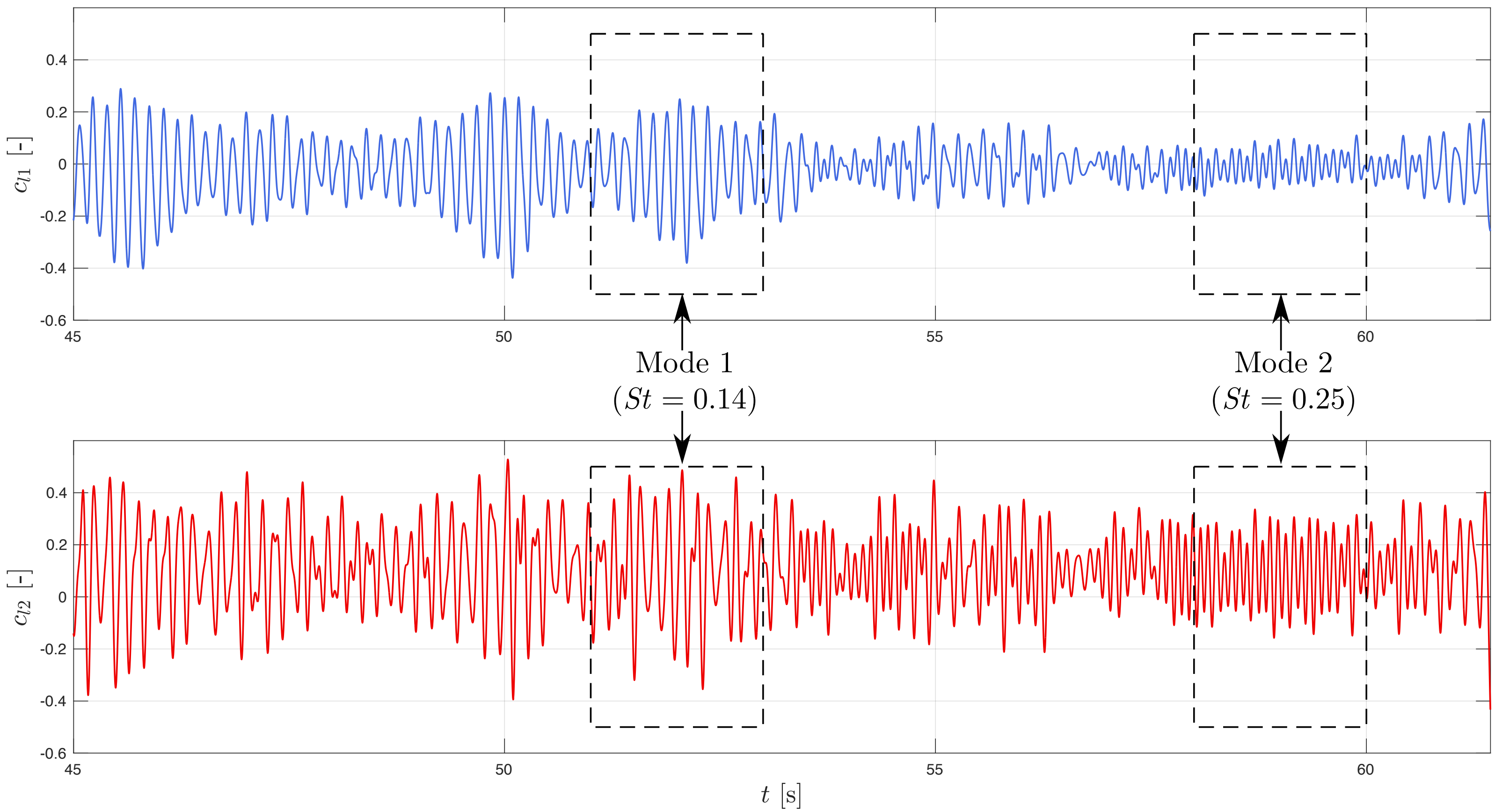


$$St = \frac{fD}{U_\infty}$$

Bi-stability – Temporal lift

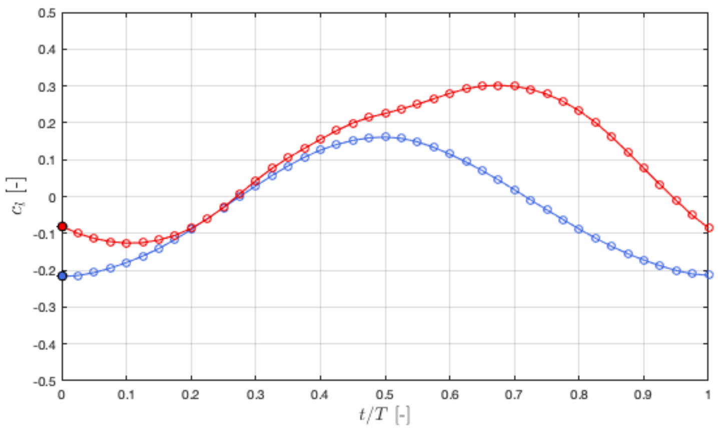
Sub-critical flow regime: Re = 45k

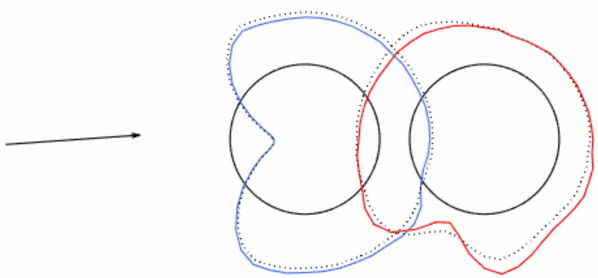
$\alpha = 4°$



Bi-stability – Phase-averaged

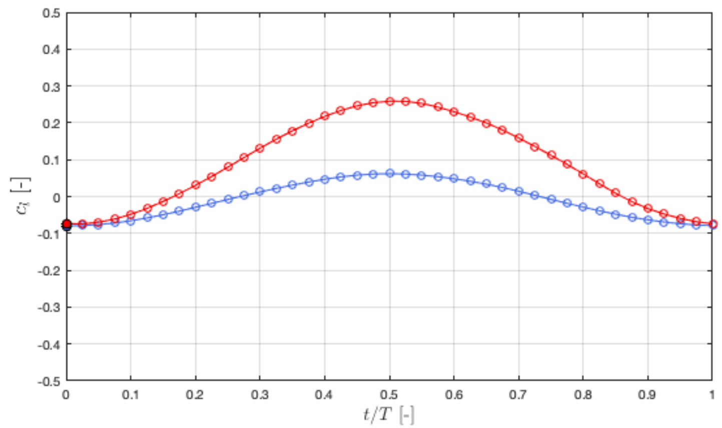
Mode 1 ($St = 0.14$)

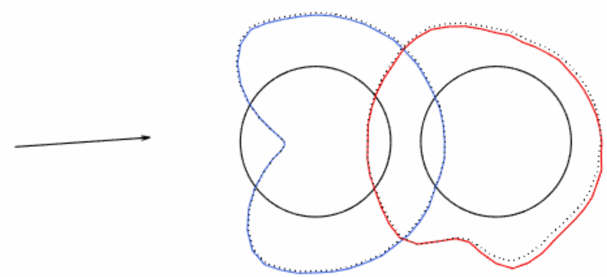




Alternate re-attachment

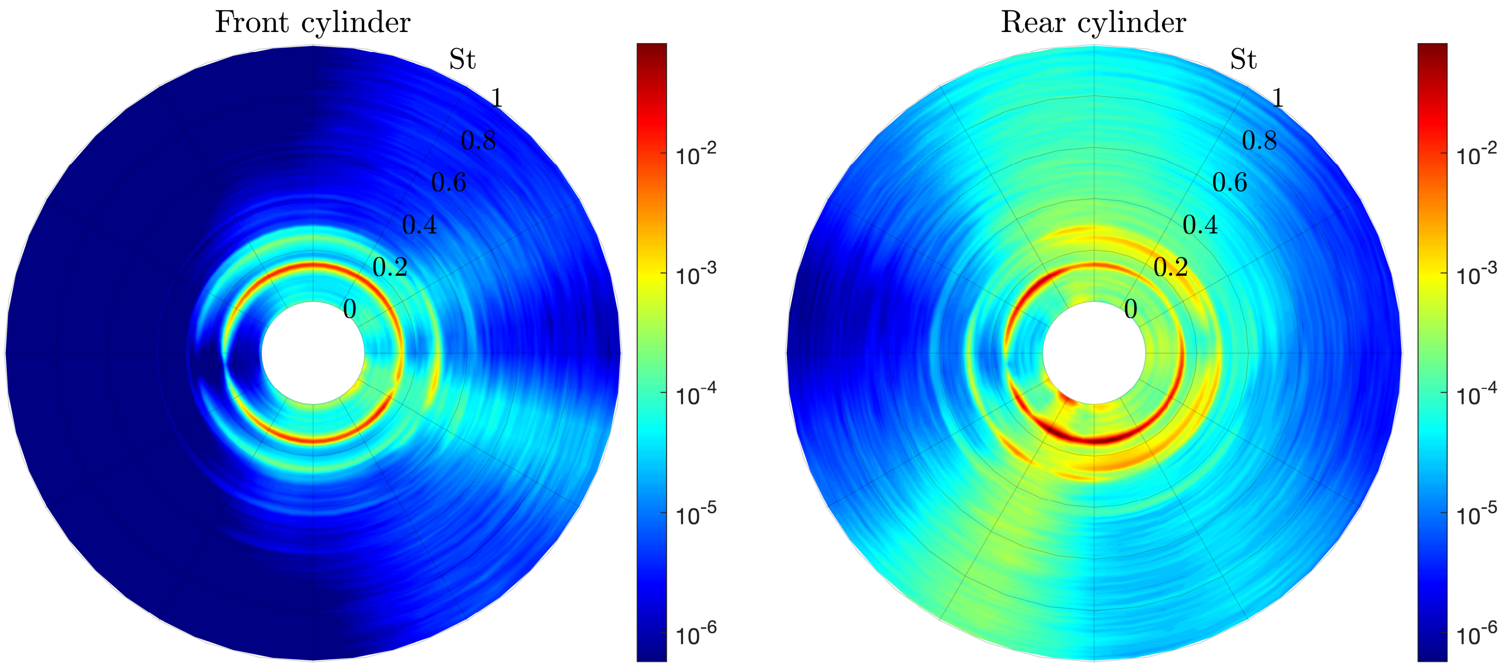
Mode 2 ($St = 0.25$)



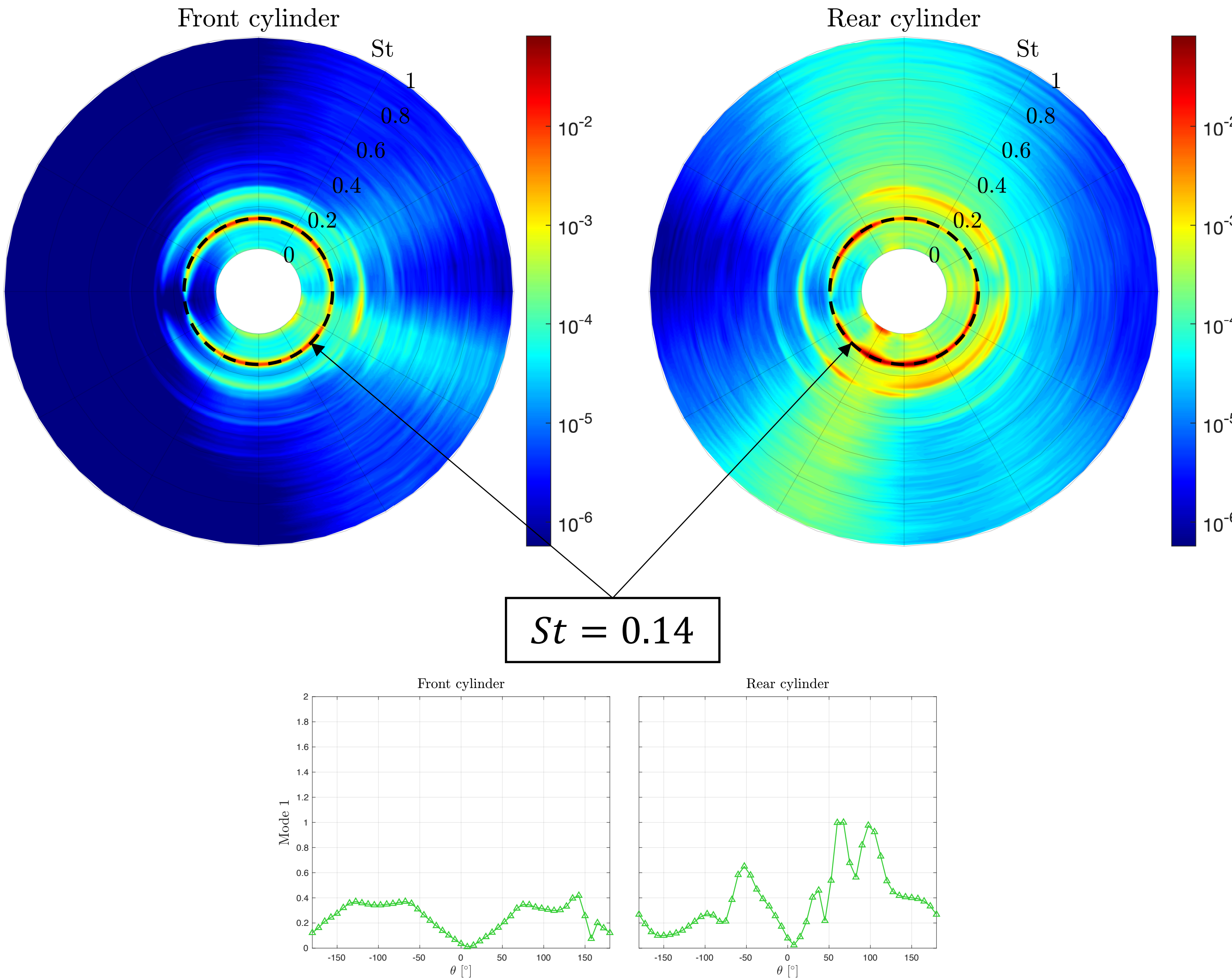


Steady re-attachment

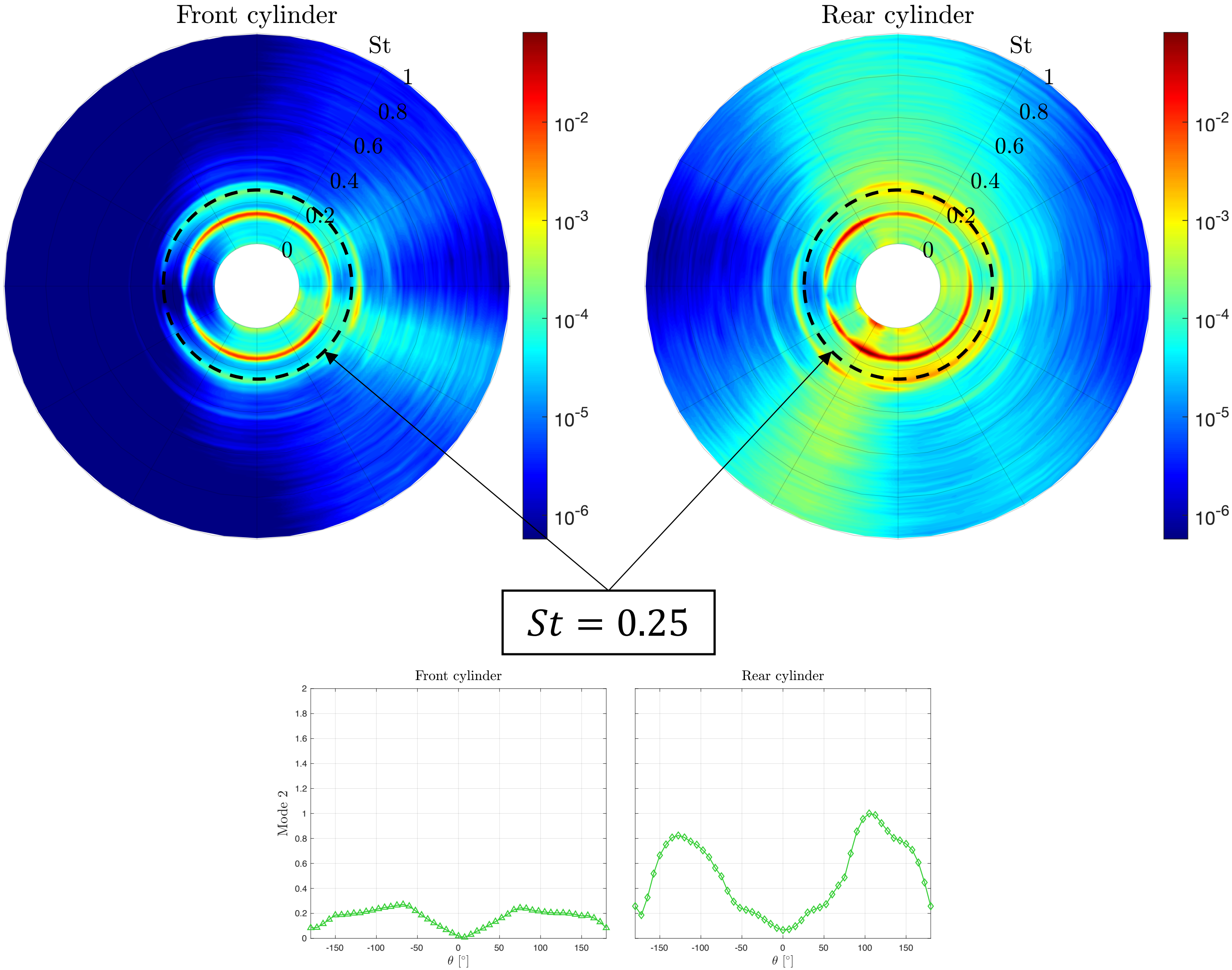
Bi-stability – Modal decomposition



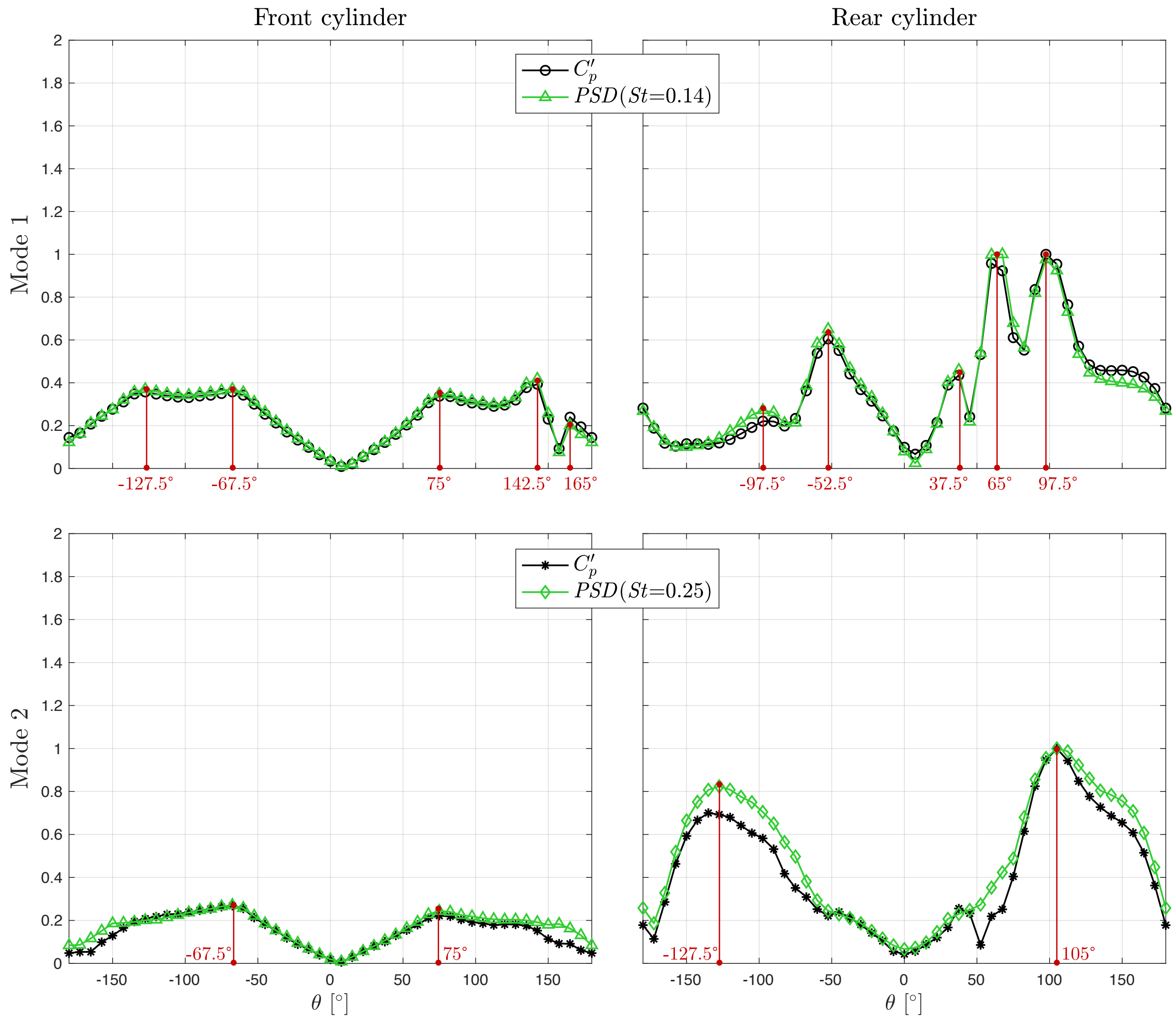
Bi-stability – Modal decomposition



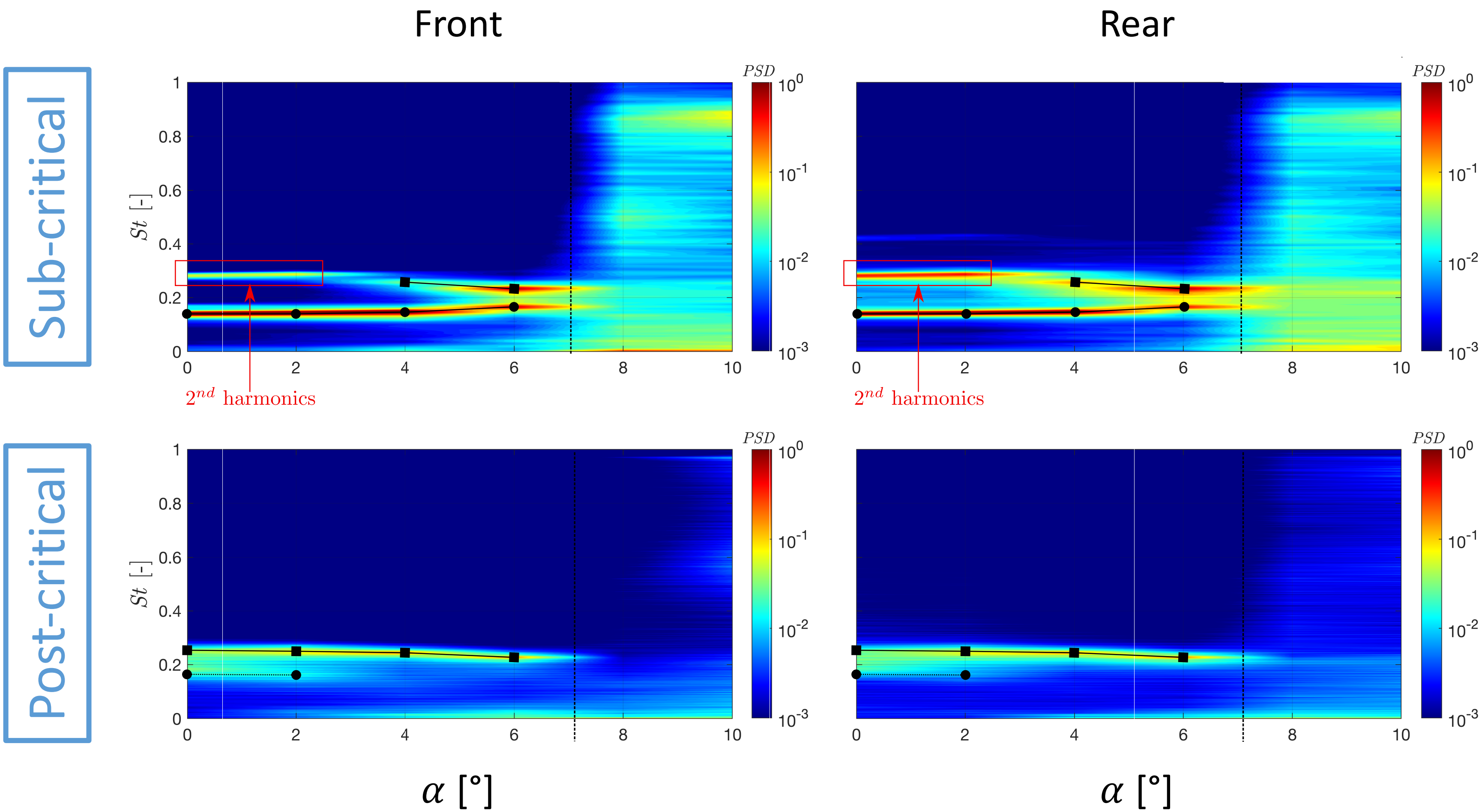
Bi-stability – Modal decomposition



Bi-stability – Time vs Frequency

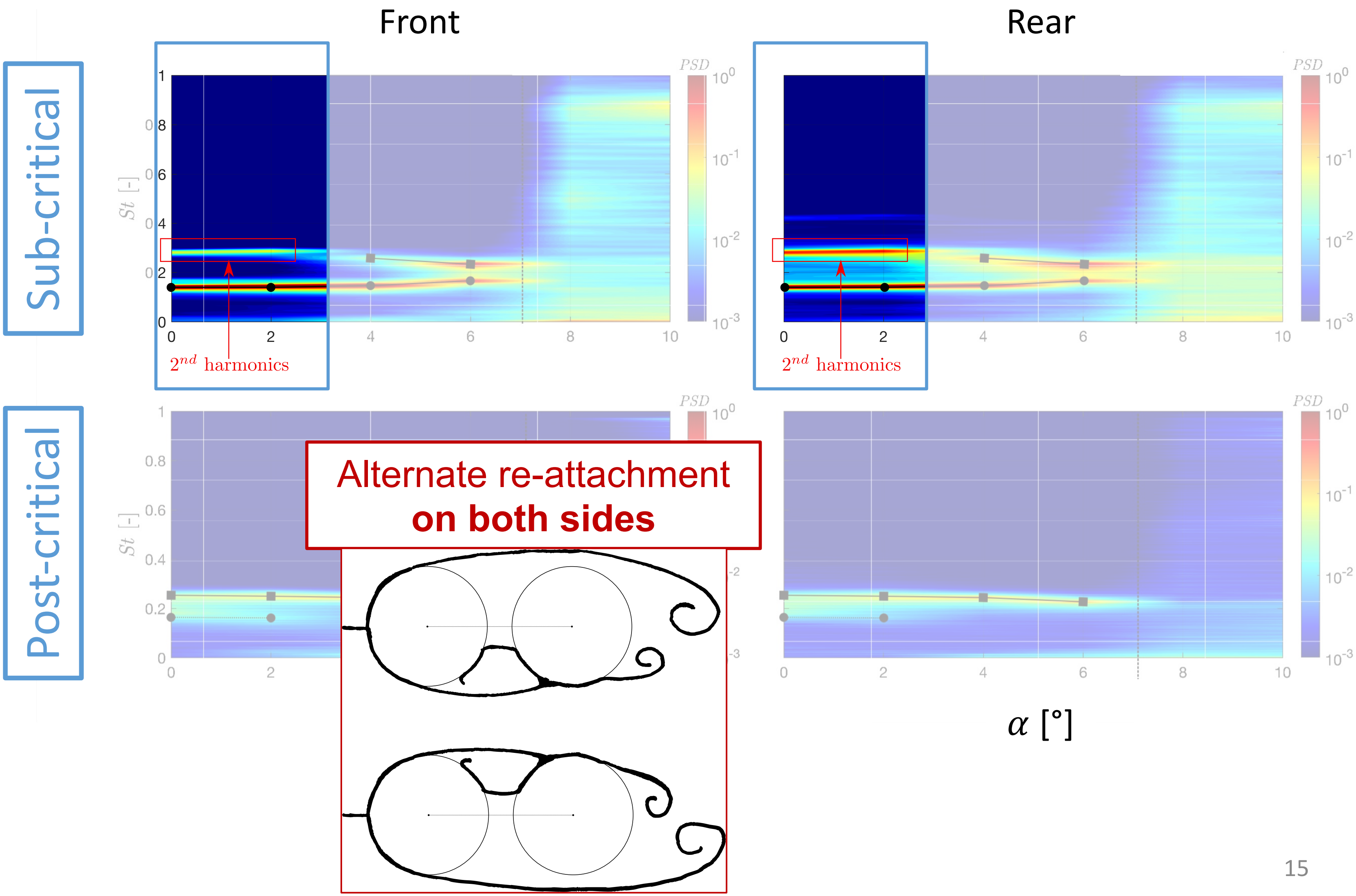


In summary…

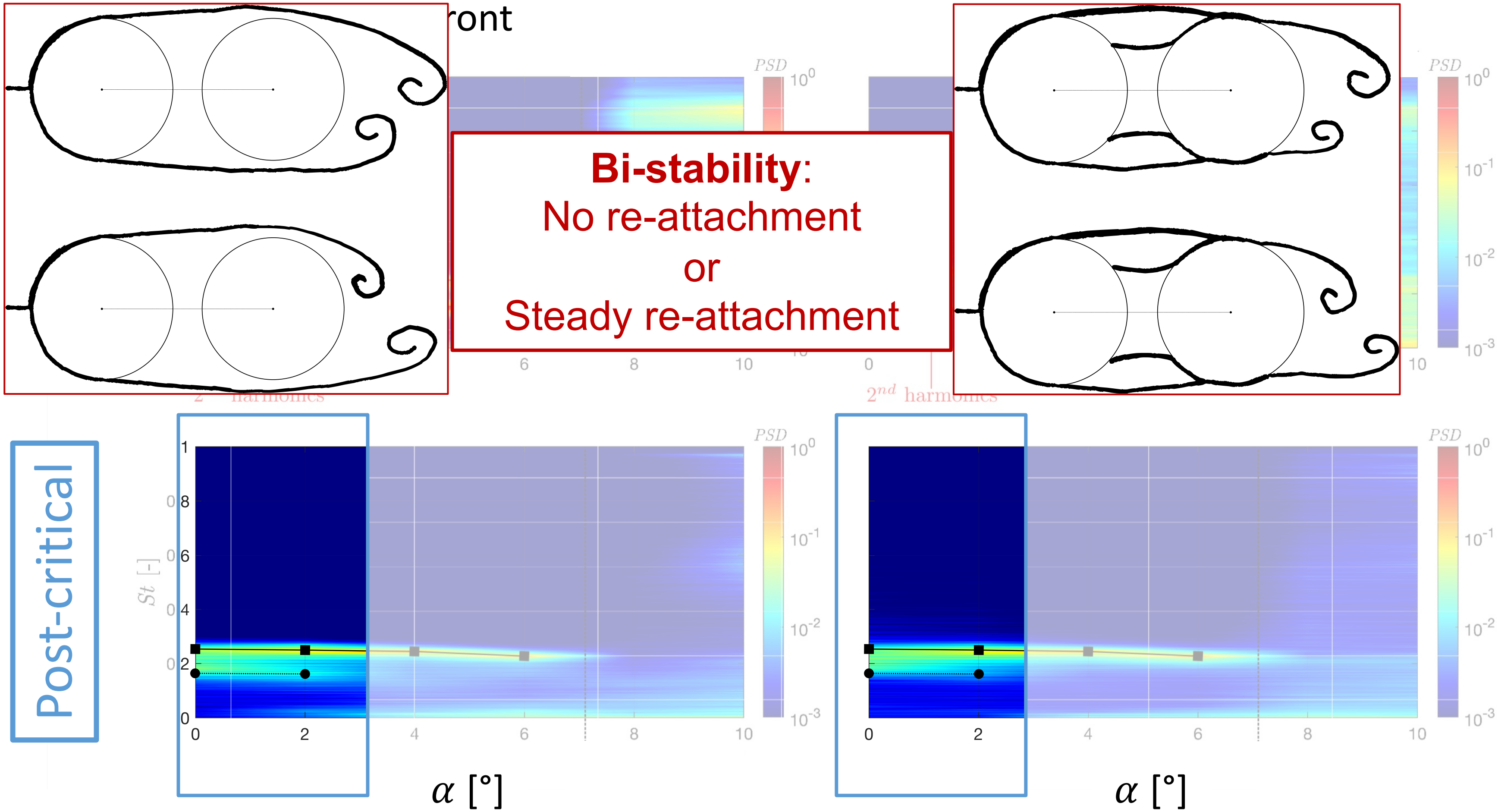


Front
Rear
Sub-critical
Post-critical
PSD
St [-]
2^{nd} harmonics
2^{nd} harmonics
α [°]
α [°]

In summary…

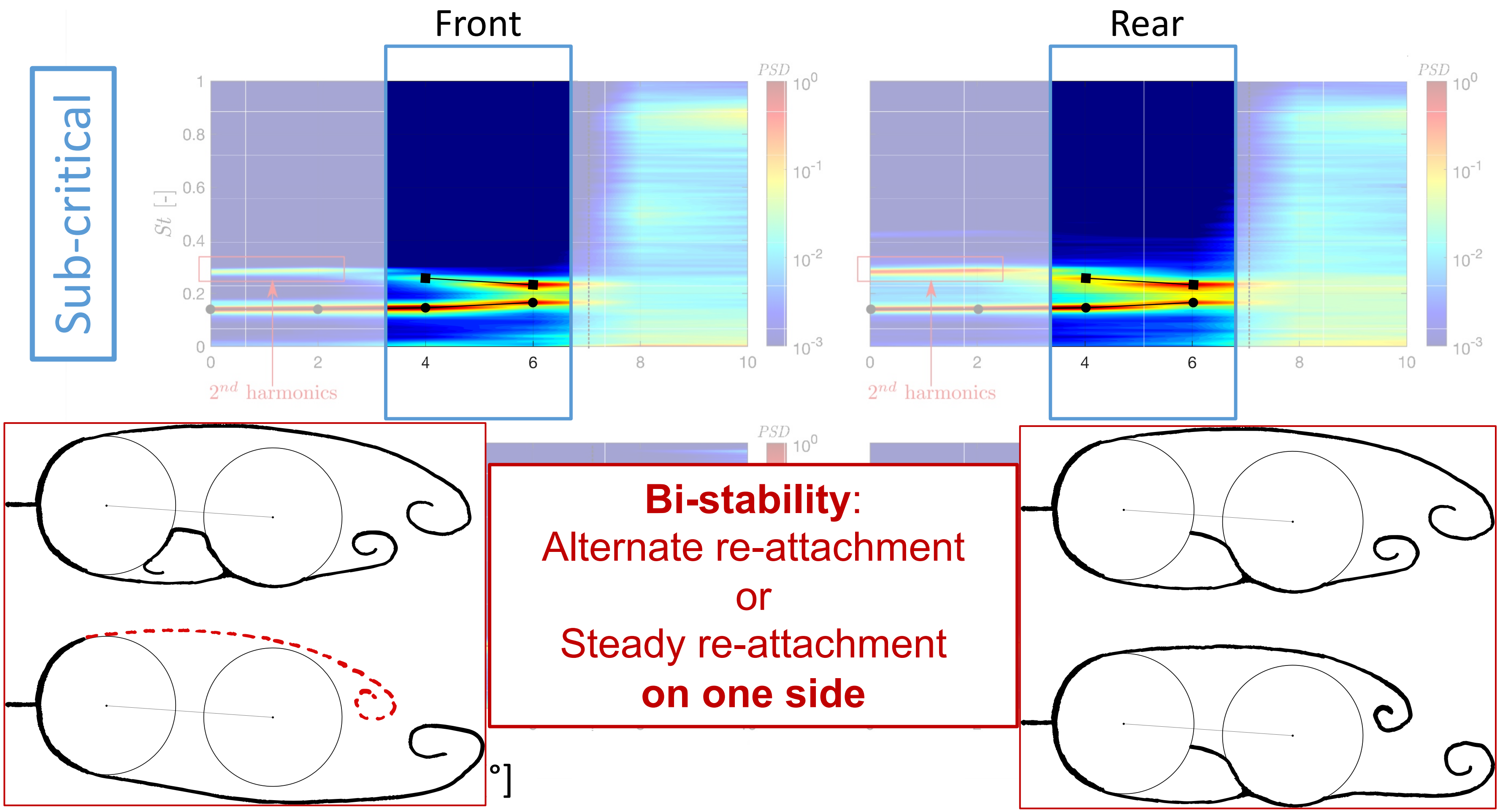

Front
Rear
Sub-critical
Post-critical
St [-]
PSD
2nd harmonics
Alternate re-attachment
on both sides
α [°]

In summary…



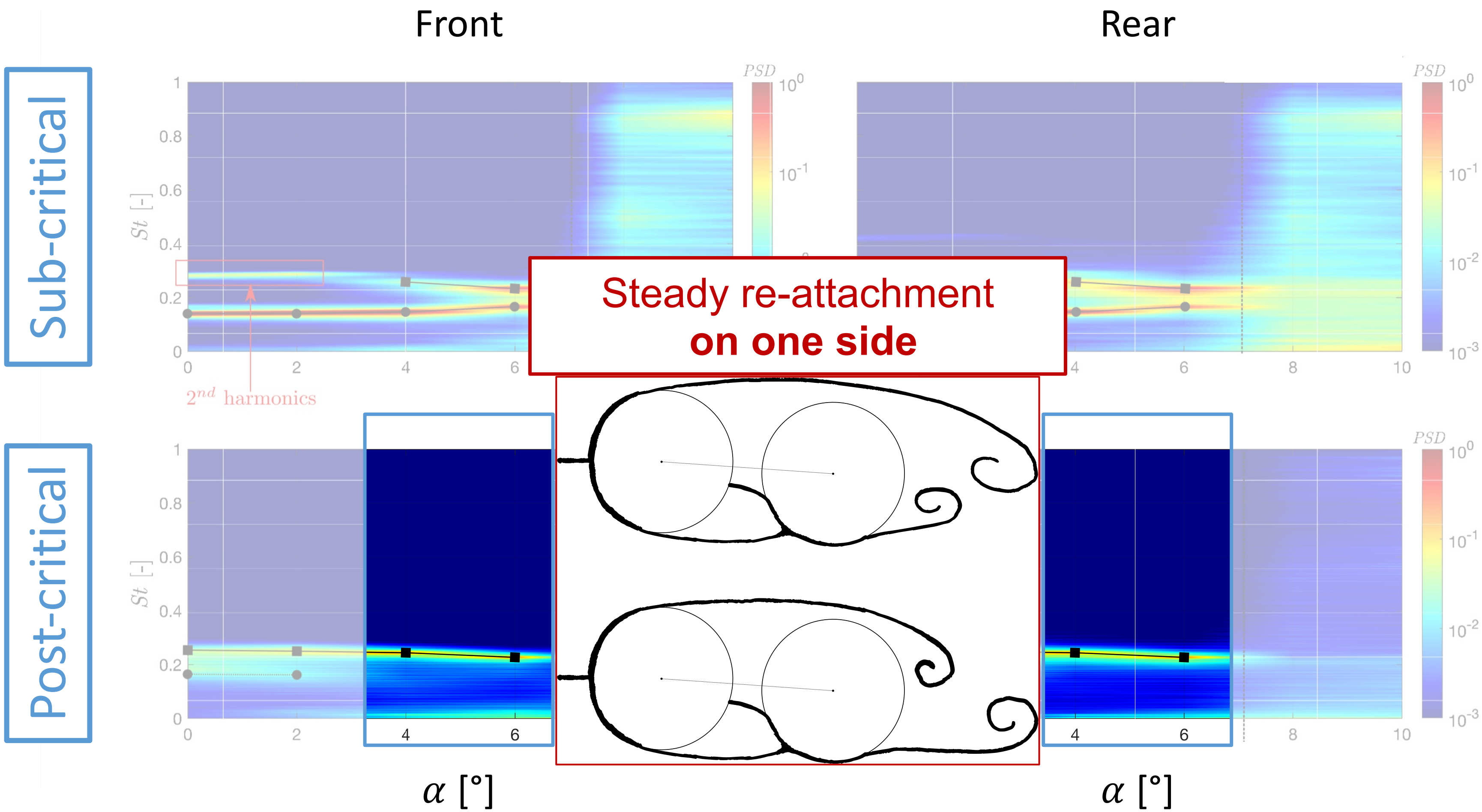
Bi-stability:
No re-attachment
or
Steady re-attachment
Post-critical
PSD
10^0
10^{-1}
10^{-2}
10^{-3}
St [-]
2^{nd} harmonics
α [°]
α [°]

In summary…



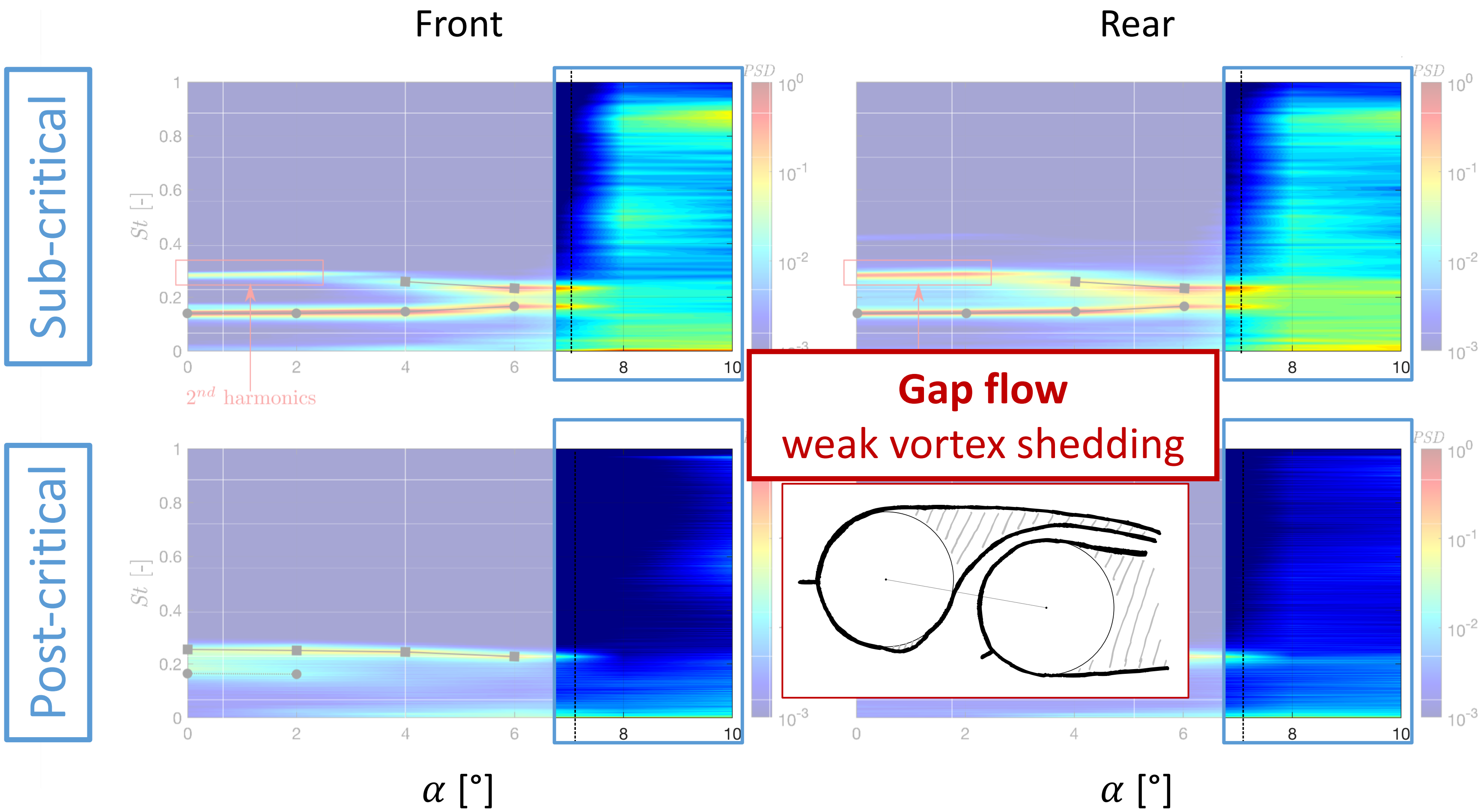
Bi-stability:
Alternate re-attachment
or
Steady re-attachment
on one side

In summary…



Front
Rear
Sub-critical
Post-critical
PSD
10^0
10^{-1}
10^{-2}
10^{-3}
St [-]
2^{nd} harmonics
Steady re-attachment
on one side
α [°]

In summary…


Front
Rear
Sub-critical
Post-critical
St [-]
PSD
2nd harmonics
Gap flow
weak vortex shedding
α [°]
α [°]

Conclusions

- Experimental investigation of the flow around **twin cylinders**
- Triggering **post-critical regime** using roughness
- **Complex** and **sensitive** flow behaviours
- Other parameters: L/D or free-stream turbulence

➡ **Challenging flow with many interesting phenomena**