Numerical prediction of the integral length scale of isotropic turbulence

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- Numerical method
- Model test
  - Experimental introduction
  - CFD calculation
- Case study: SUBOFF
- Conclusion

Part 0—INTRODUCTION

an important parameter of turbulence spectrum [1]

turbulence integral length scale

an important parameter in low-frequency broadband noise [2-6] prediction

[1] LIEPMANN H W. On the application of statistical concepts to the buffeting problem [J]. Journal of the Aeronautical sciences, Dec.1952, Vol (19):793-800.

[2] BLAKE W K. Mechanics of flow-induced sound and vibration [M].New York: Academic Press, 1986:735-756.

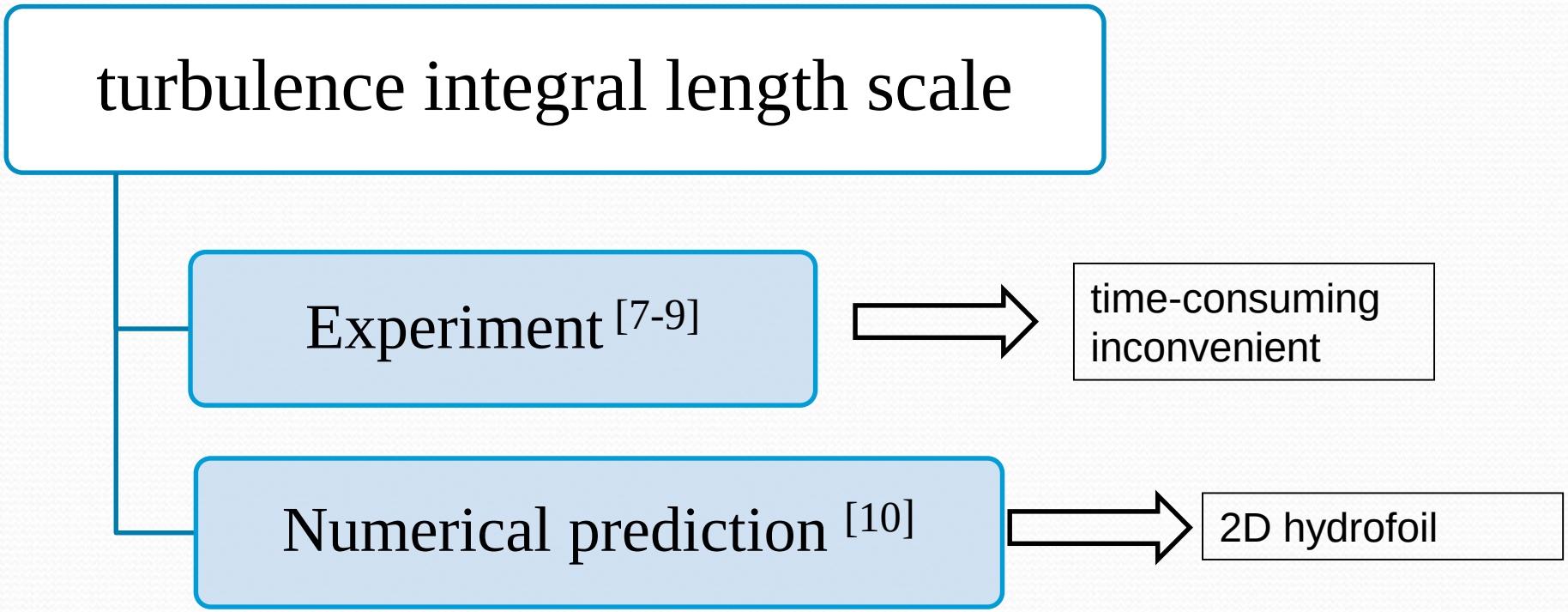
[3] KIRSCHNER I N, CORRICEAU P J, MUENCH J D, UHLMAN J S, KROL W P. Validation of propeller turbulence ingestion acoustic radiation model using wind tunnel measurements[C]. Louisiana: FLOW NOISE MODELING, MEASUREMENT and CONTROL, ASME, 1993:175-186.

[4] ZHU Xi-qing, LI Ya, SUN Hong-xing. Prediction of noise induced by interaction between turbulence flow and propeller blades [J]. Technical Acoustics, 2006，25（4）：361-364.

[5]ZHU Xi-qing, Tang Deng-hai, SUN Hong-xing. Study of Low-frequecny Noise Induced by Marine Propeller [J]. Journal of hydrodynamics. 2000,15（1）： 74-81.

[6] Prediction of Low-Frequency Broadband Noise Induced by the Interaction between Injected Turbulence and Propeller [J]. Shipbuilding of China, 2014,Vol.55 NO.3：3-11.

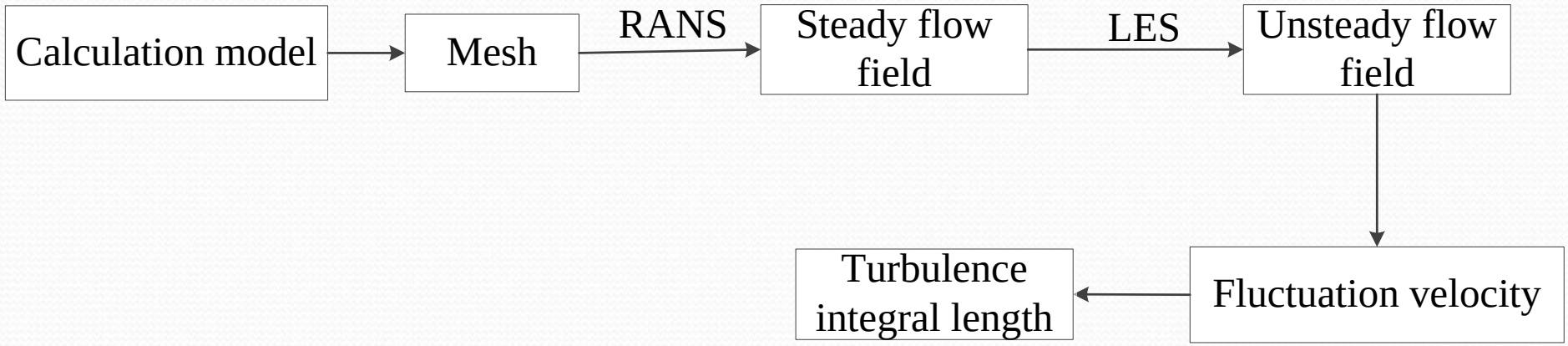
Part 0—INTRODUCTION



[7] Zhang Guoping. Comparison on Turbulence Measurement and Analysis Methods in Cavitation Tunnel by Particle Image Velocimeter [R]. Wuxi: China Ship Scientific Research Center，2010.
[8] Liu Jianhua, Xie Hua, Tian Yukui. Validation of a new method for turbulence integral length measurement based on a HWA and LDA combined system [C]. Proceedings of 23st Symposium on National Hydrodynamics, 2011:283-289.
[9] Xie Hua, Liu Jianhua, Tian Yekui. Research and analysis on HWA and LDA joint test of turbulence integral length [C]. Proceedings of 13st Symposium on Underwater Noise, 2011:345-350.
[10]WANG Xiao, HUANG Zhen-yu. Turbulence analysis in the wake flow of asymmetric airfoil based on large eddy simulation，2014,29（3）：288-293.

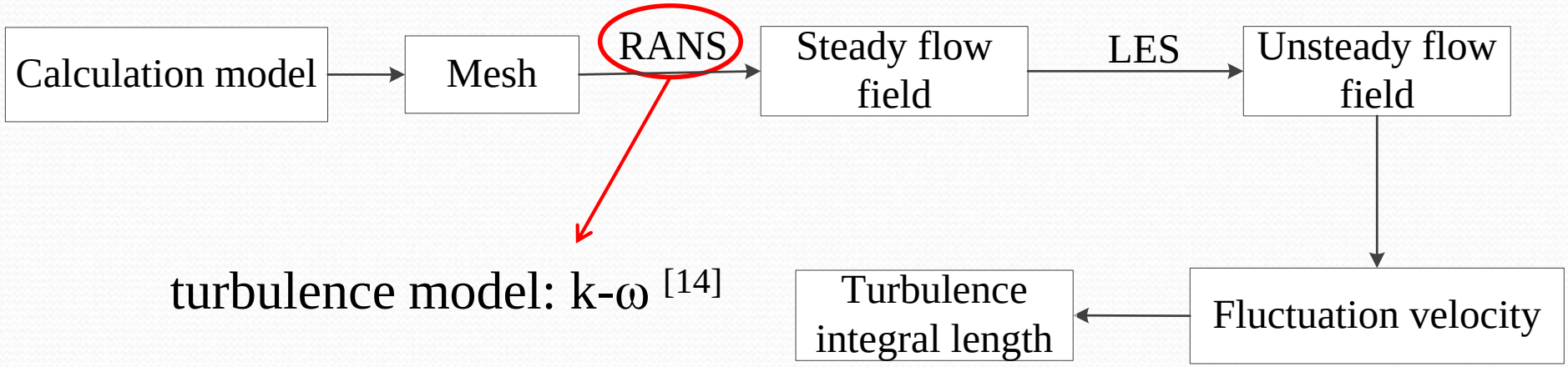
Part 1— NUMERICAL METHOD

Flow chart of the numerical method



Part 1— NUMERICAL METHOD

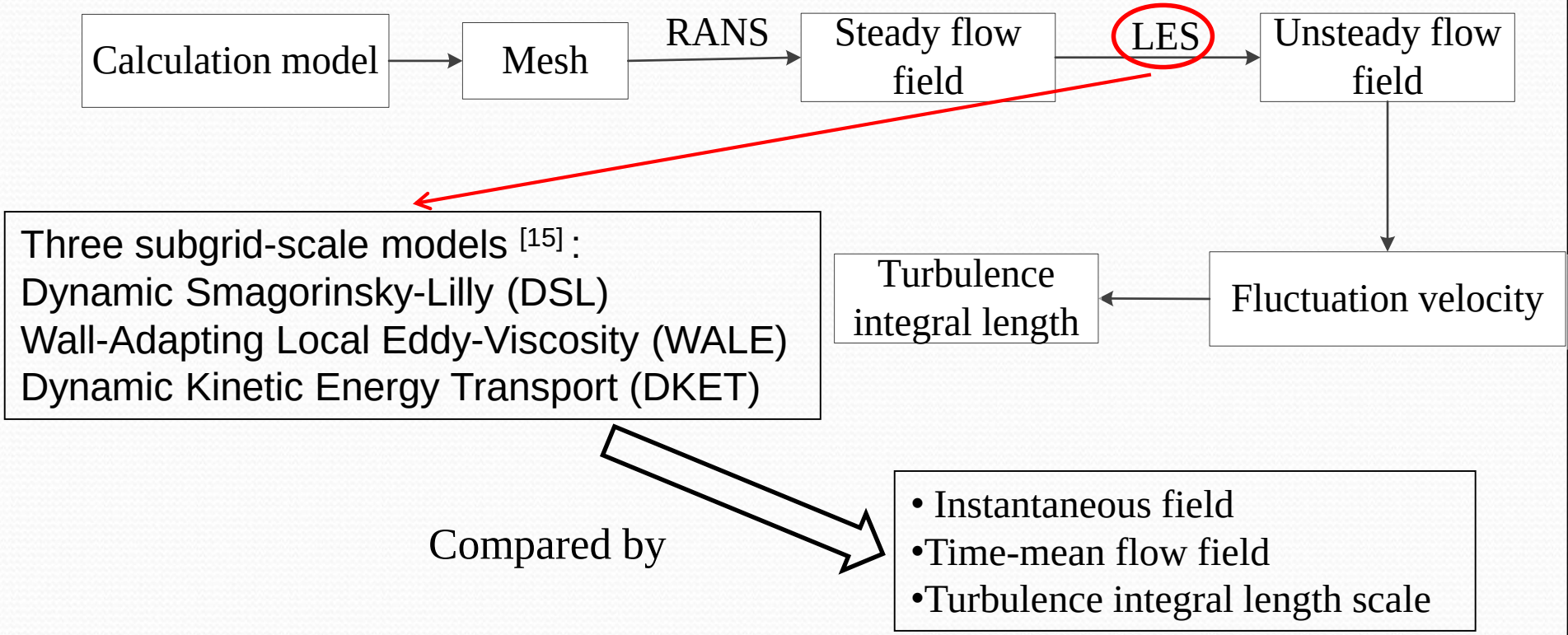
Flow chart of the numerical method



[14] DAVID C, WILCOX. Formulation of the k-ω Turbulence Model Revisited[C]. Reno: 45th AIAA Aerospace Sciences Meeting and Exhibit, 2007.

Part 1— NUMERICAL METHOD

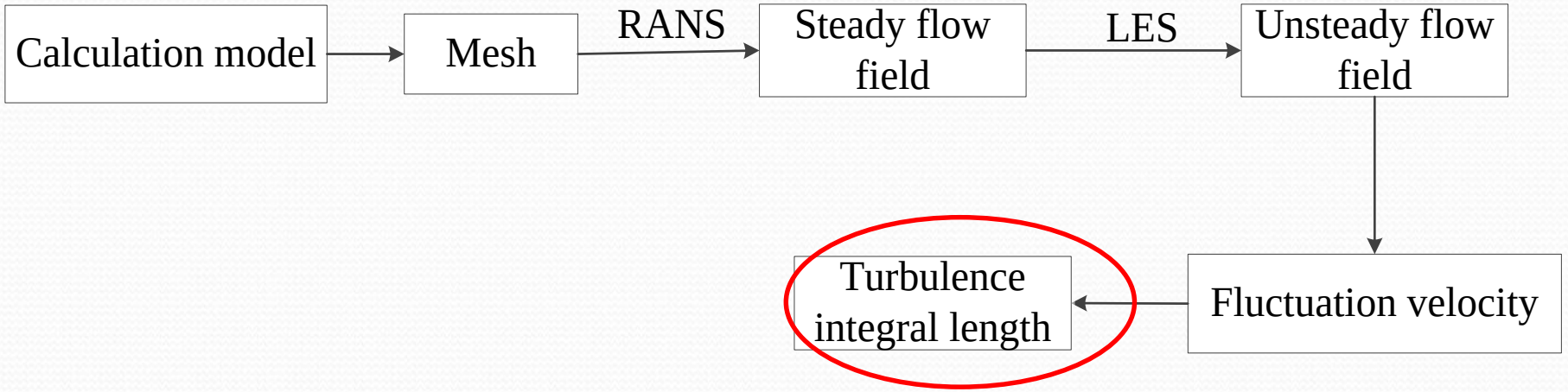
Flow chart of the numerical method



[15] Zhang Zhao-shun, Cui Gui-xiang, Xu Chun-xiao. Theory and modeling of turbulence. Beijing: Tsinghua University Press.

Part 1— NUMERICAL METHOD

Flow chart of the numerical method



Part 1— NUMERICAL METHOD

The fluctuation speed of the unsteady flow field:

$$u'\left(\vec{x},t\right)=u\left(\vec{x},t\right)-\left\langle u\left(\vec{x},t\right)\right\rangle=u\left(\vec{x},t\right)-\overline{u\left(\vec{x},t\right)}$$

where $\left\langle u\left(\vec{x},t\right)\right\rangle$ is ensemble average.

The cross-correlation function of fluctuation speed at two different spots is defined as:

$$R\left(r\right)=\frac{\overline{u'\left(\vec{x},t\right)u'\left(\vec{x}+r,t\right)}}{\sqrt{\overline{u'\left(\vec{x},t\right)^2}}\sqrt{\overline{u'\left(\vec{x}+r,t\right)^2}}}$$

where r is distance between the two spot.

Then the turbulence integral length scale can be calculated as:

$$L=\int_0^{r_{\max}}R\left(r\right)dr$$

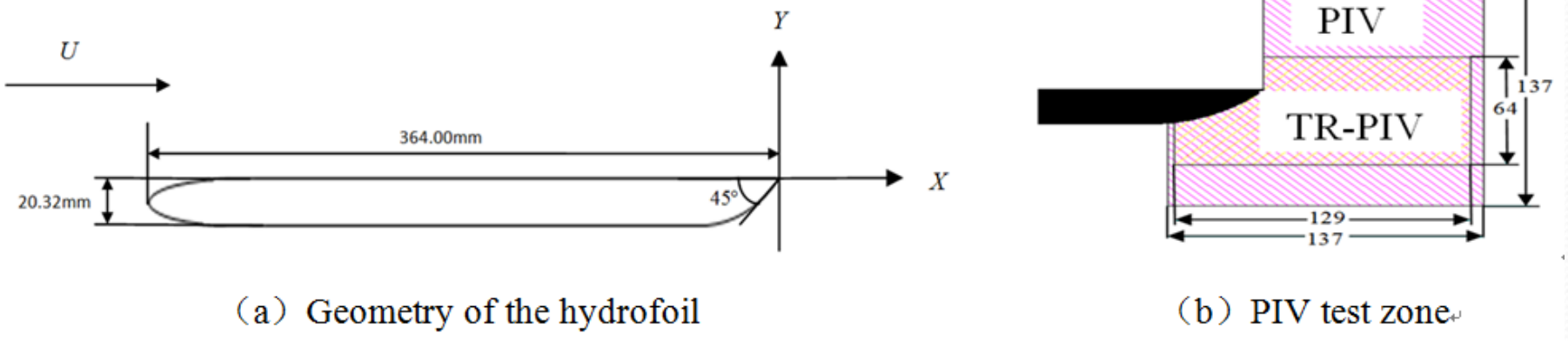
where $r_{\max}$ is the distance when $R(r)=0$ for the first time.

[15] Zhang Zhao-shun, Cui Gui-xiang, Xu Chun-xiao. Theory and modeling of turbulence. Beijing: Tsinghua University Press.

Part 2— MODEL TEST

- Experimental introduction

China Ship Scientific Research Center (CSSRC)



（a）Geometry of the hydrofoil （b）PIV test zone

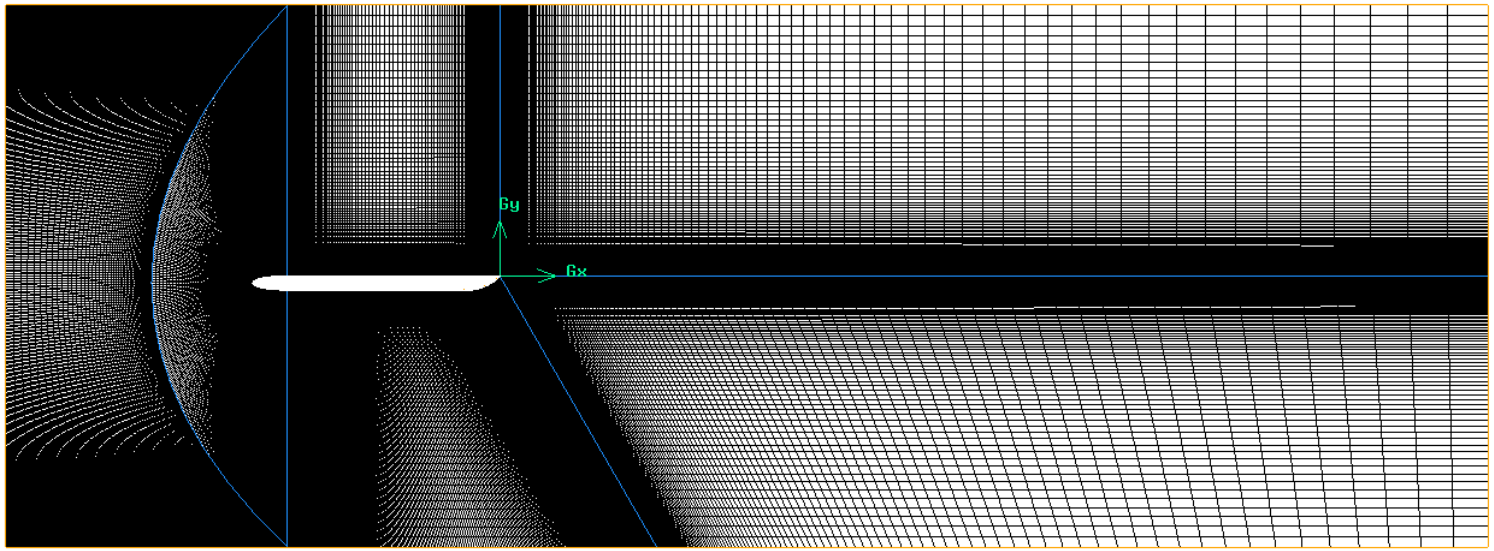
Fig.2 Geometry and PIV test zone

U_0=4.1m/s and the Re=1.3×10^6

[7] Zhang Guoping. Comparison on Turbulence Measurement and Analysis Methods in Cavitation Tunnel by Particle Image Velocimeter [R]. Wuxi: China Ship Scientific Research Center，2010.

Part 2— MODEL TEST

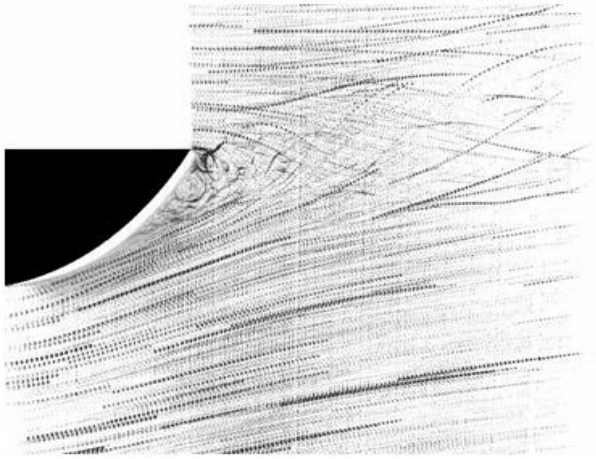
- CFD



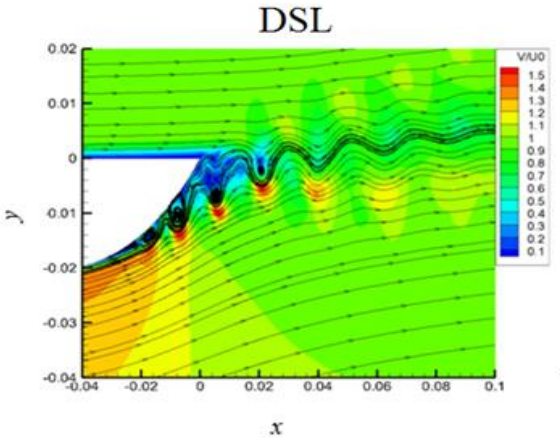
the mesh, about 260,000, and the $y^+ \approx 10$

Part 2— MODEL TEST

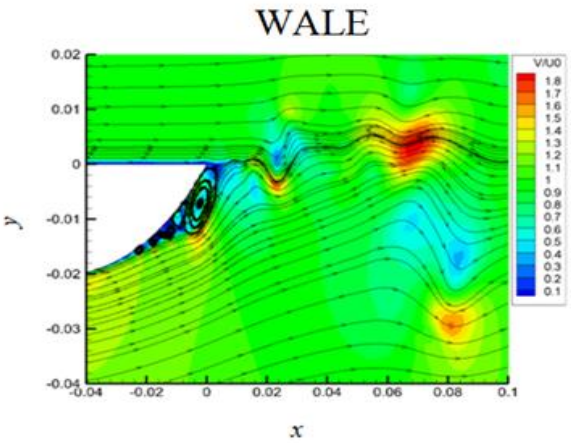
➢Instantaneous field



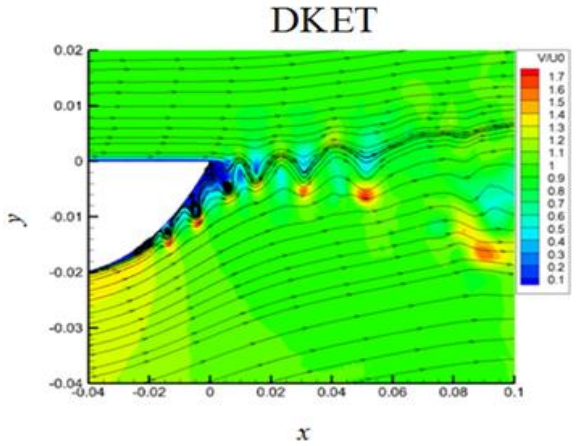
(a) the instantaneous flow field measured by PIV



(b) the instantaneous flow field calculated by DSL



(c) the instantaneous flow field calculated by WALE

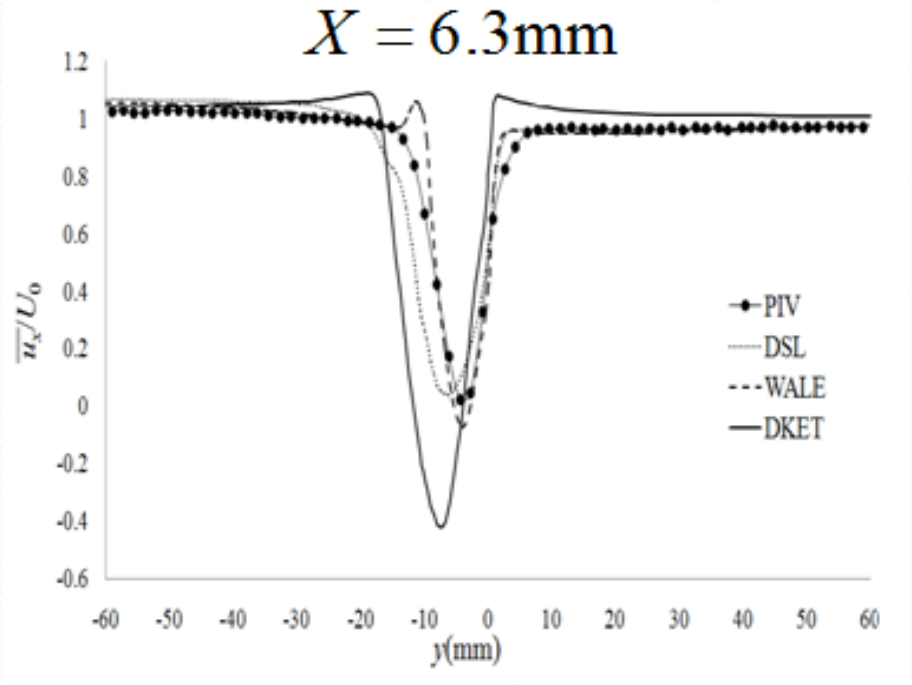


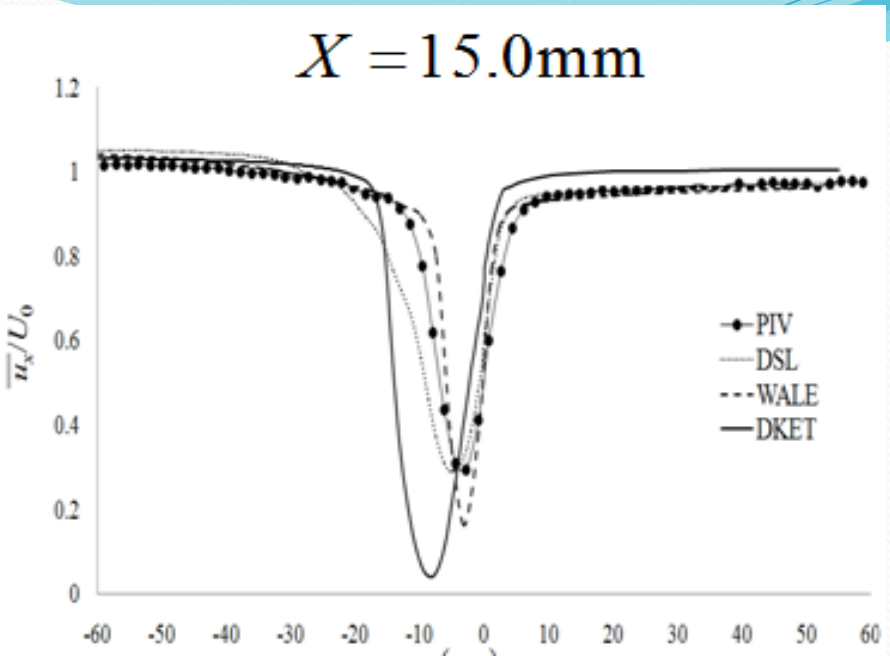
(d) the instantaneous flow field calculated by DKET

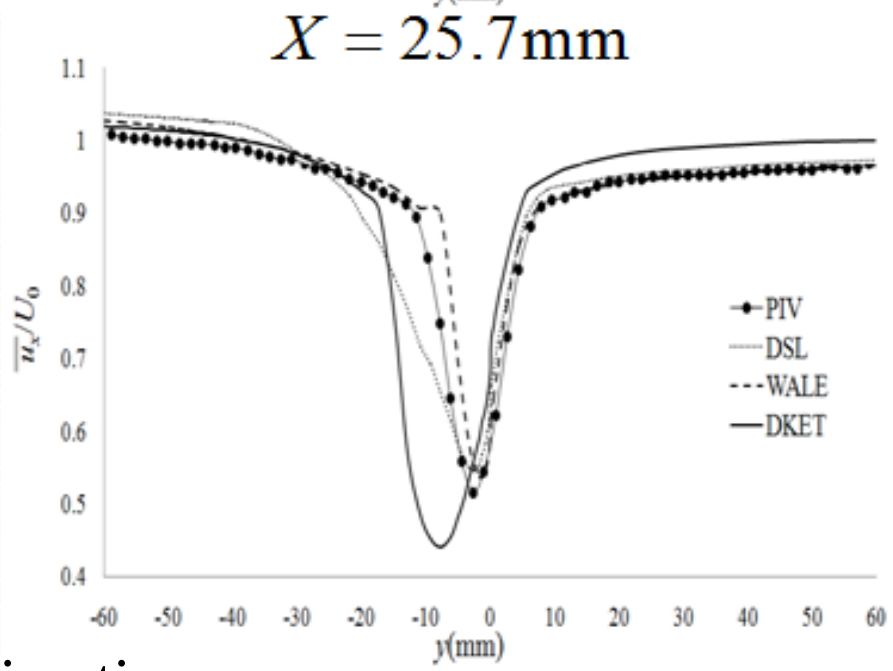
Fig.4 the instantaneous flow field by PIV and LES

Part 2— MODEL TEST

- Time-mean flow field



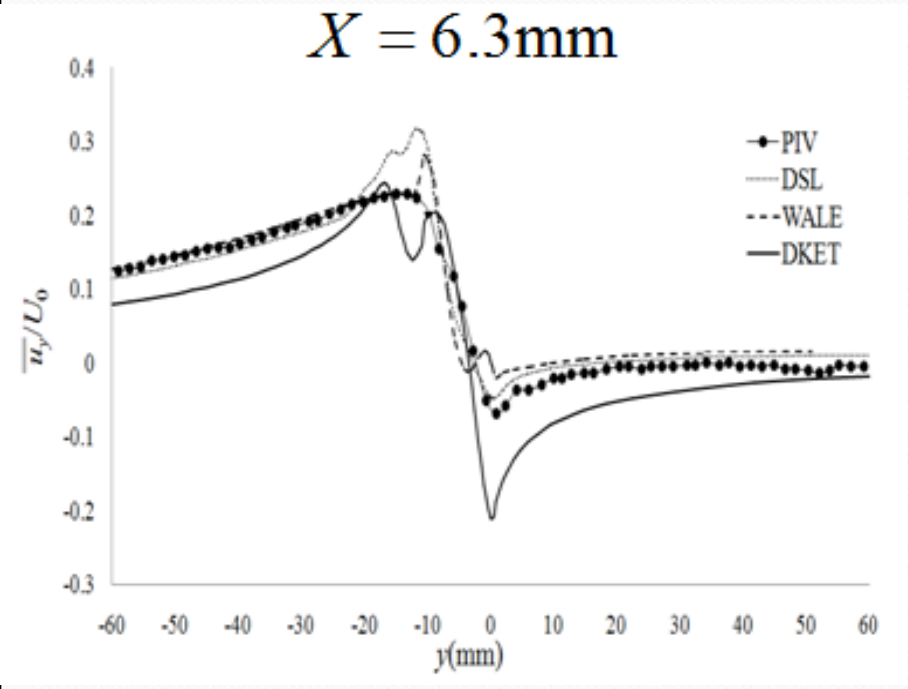


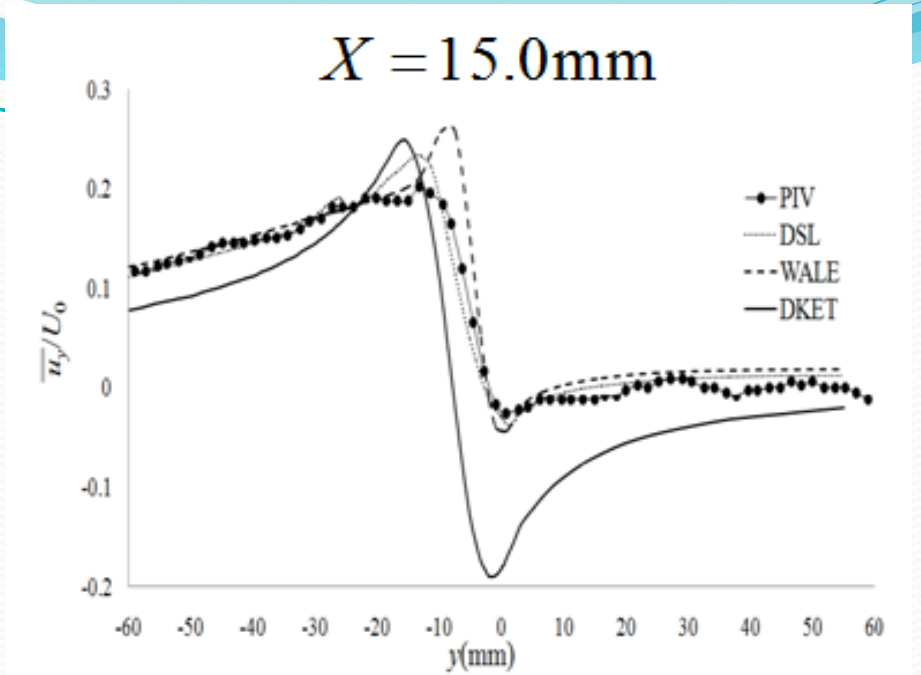


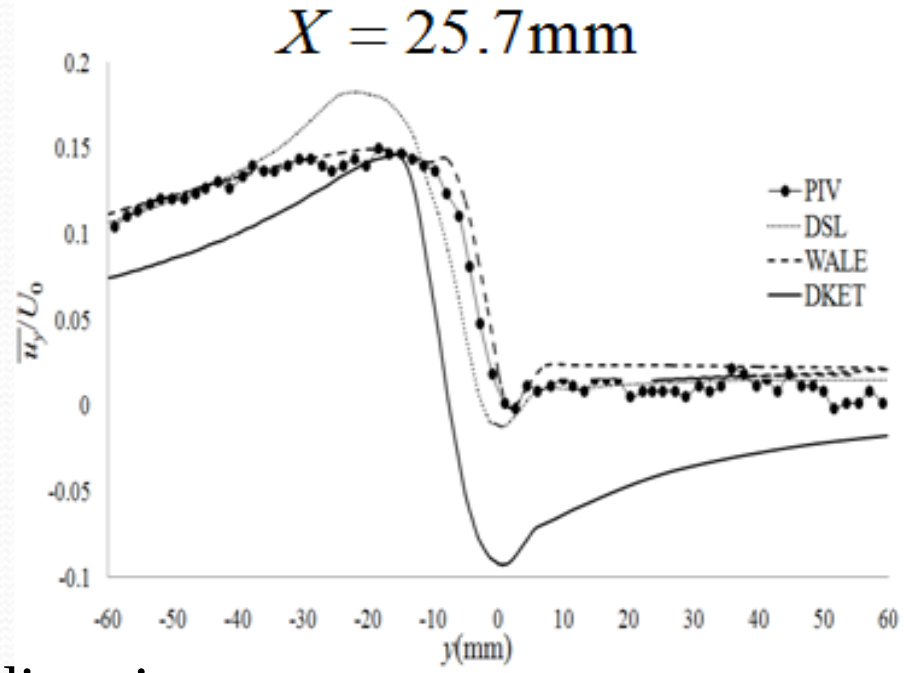
（a）time-mean velocity in flow direction

Part 2— MODEL TEST

- Time-mean flow field



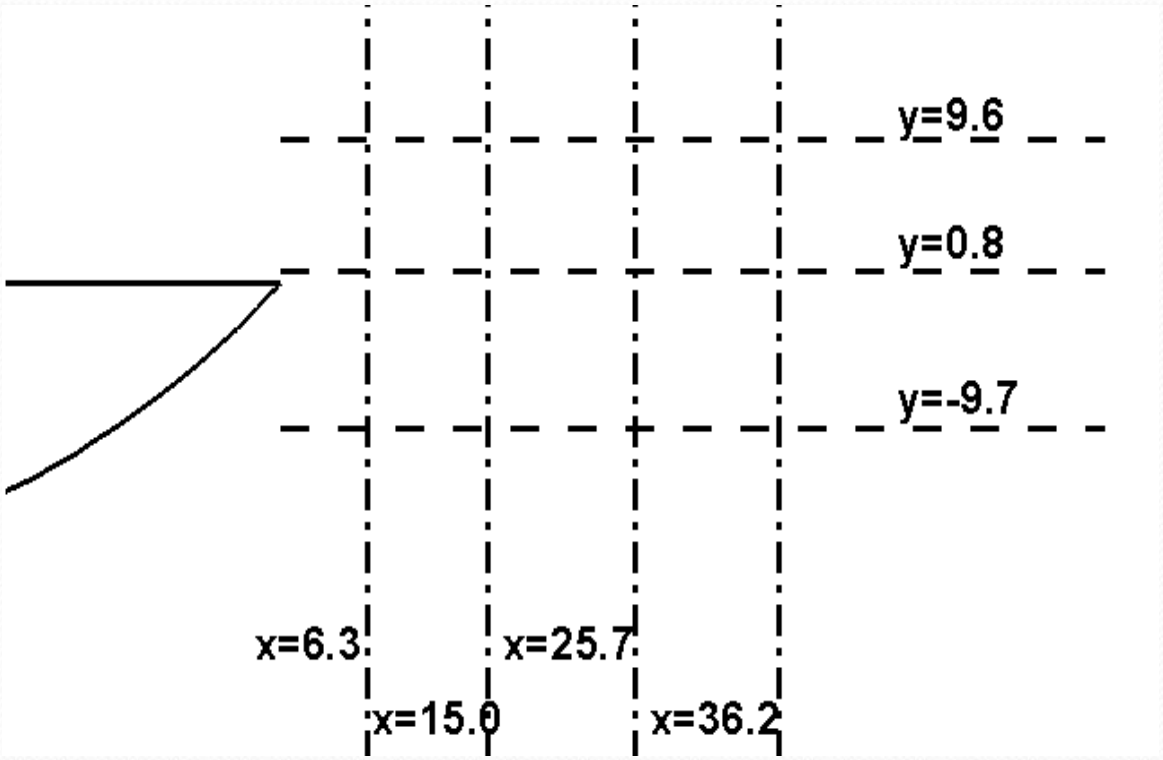




（b）time-mean velocity in vertical direction

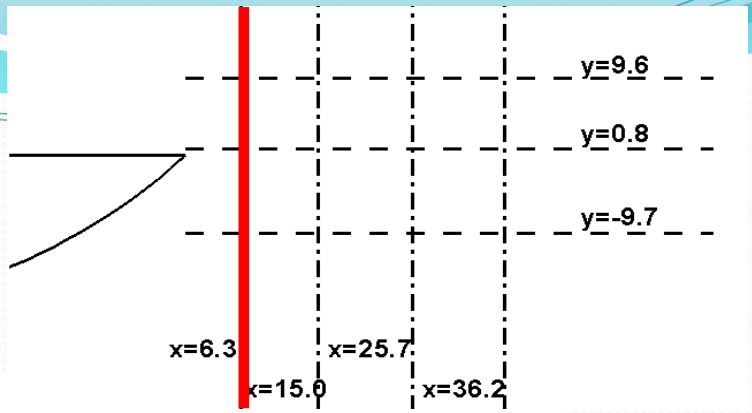
Part 2— MODEL TEST

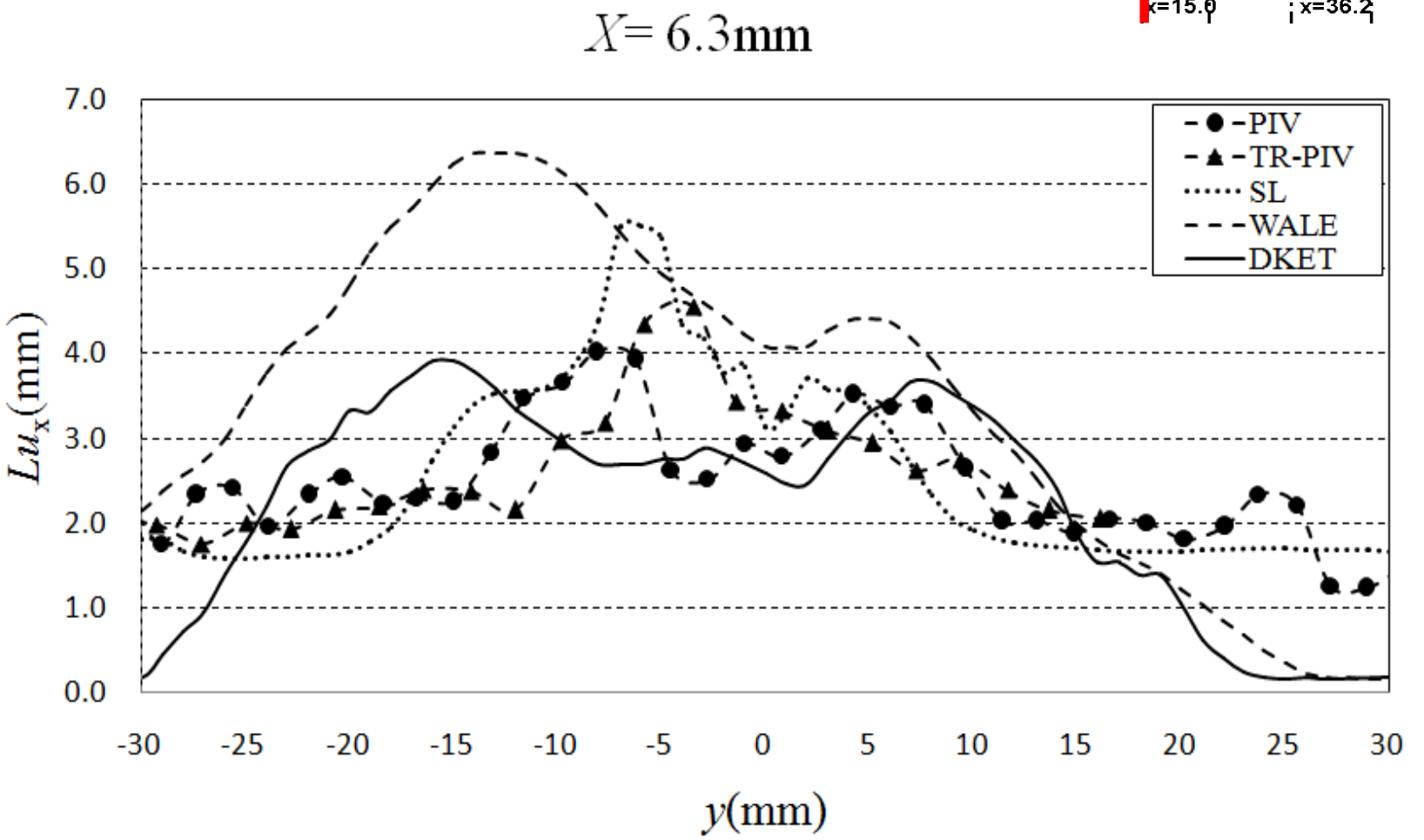
- Turbulence integral length scale



Part 2— MODEL TEST

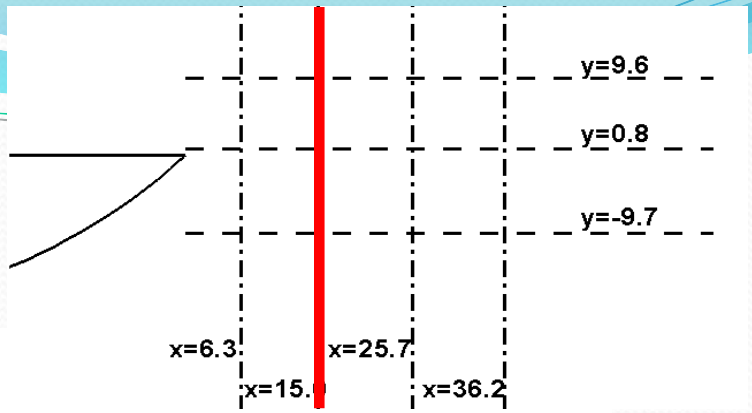
- Turbulence integral length scale

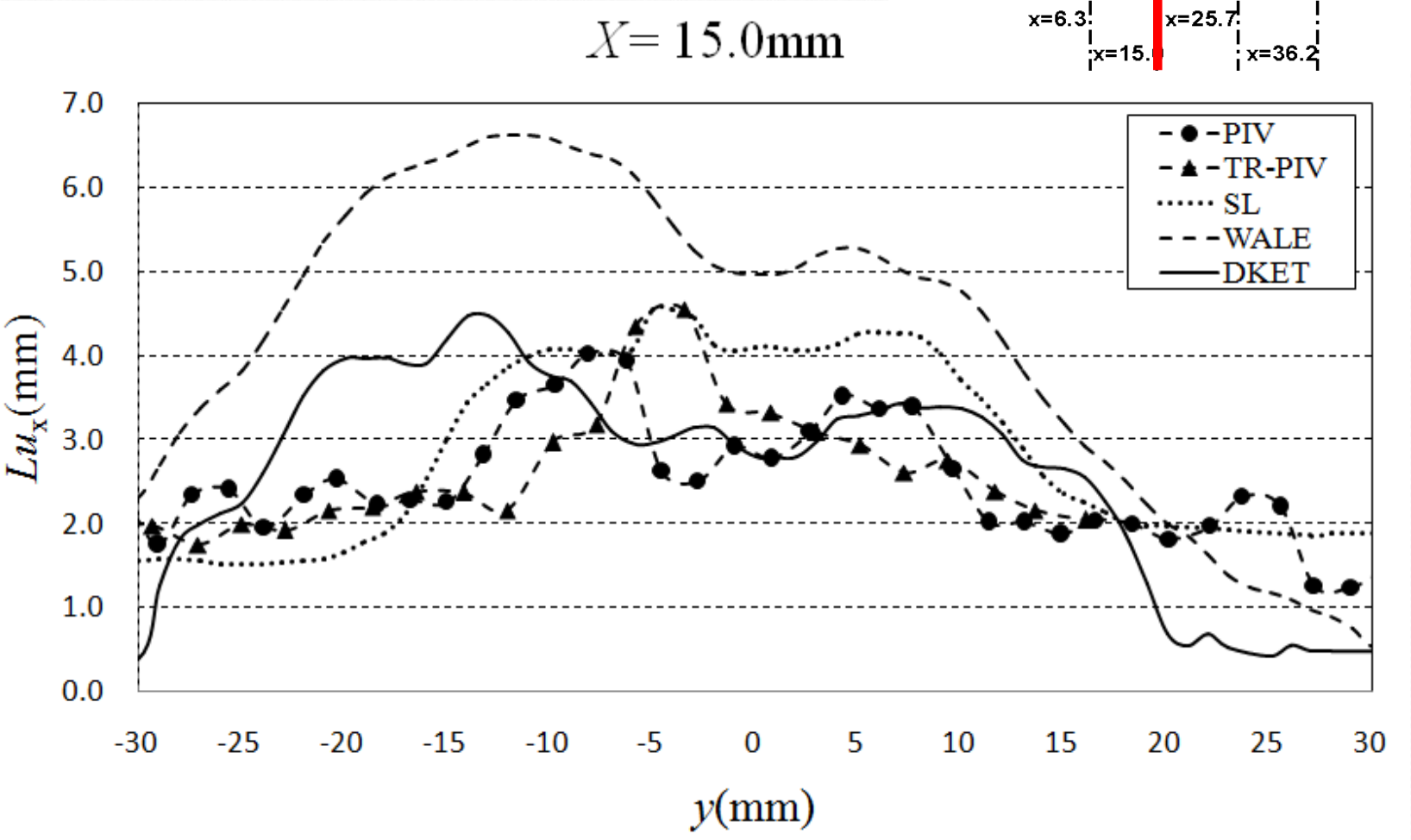




Part 2— MODEL TEST

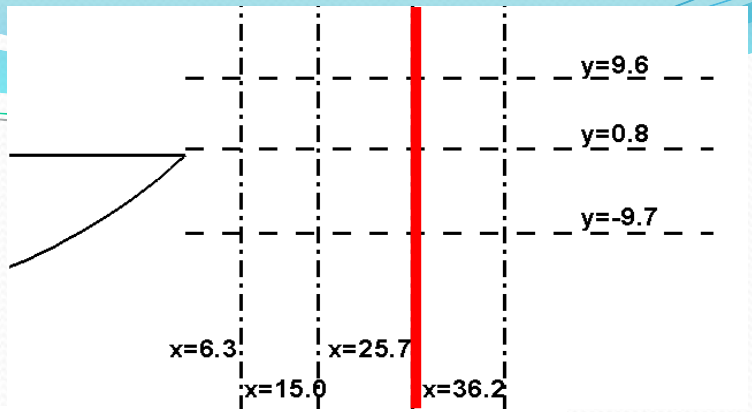
- Turbulence integral length scale

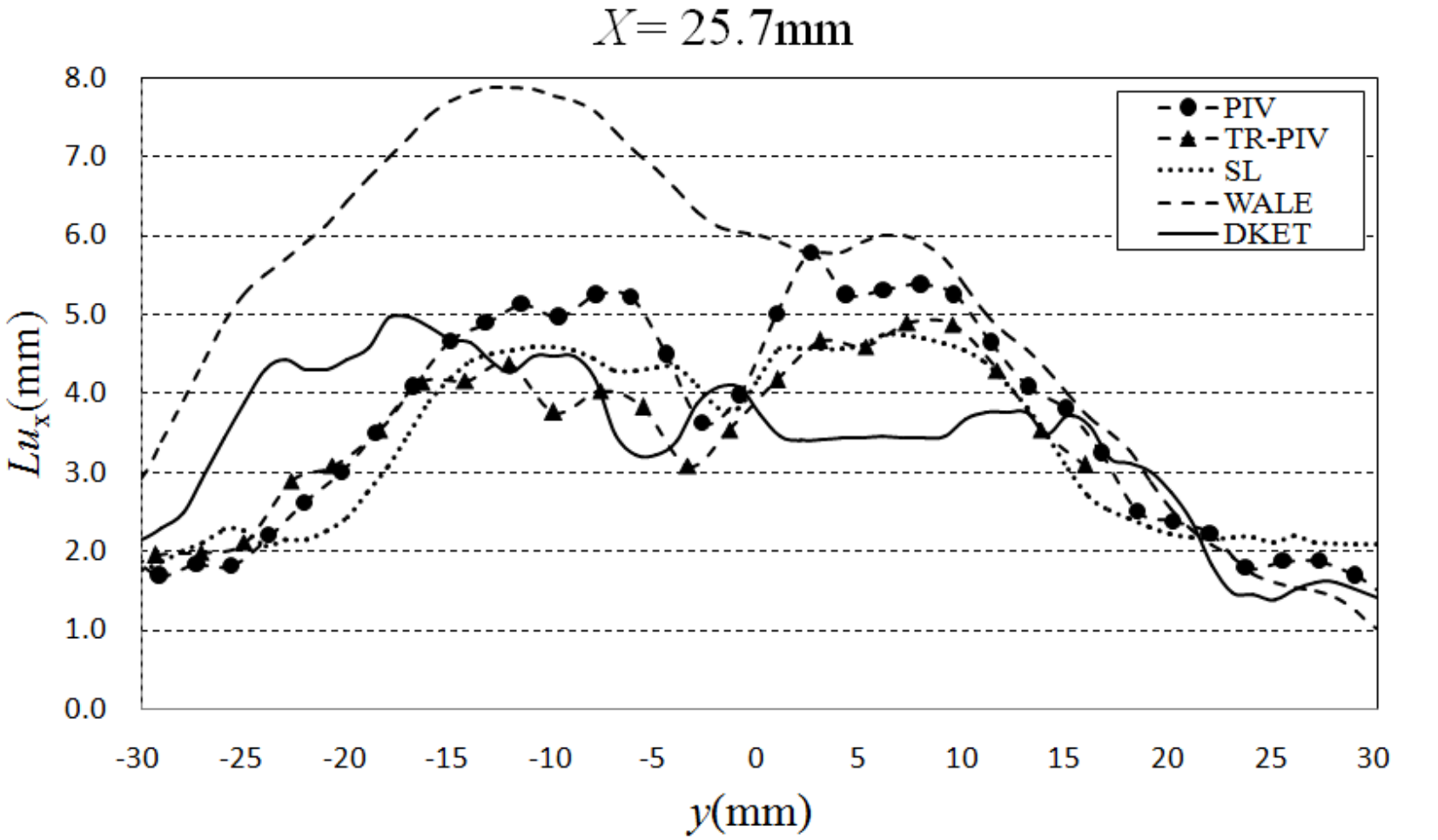




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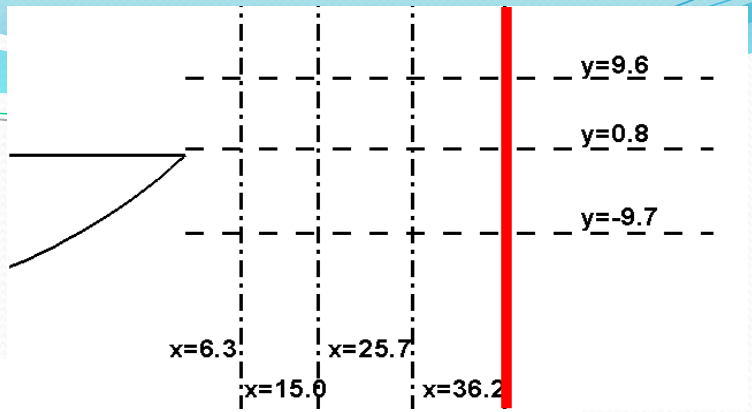
- Turbulence integral length scale

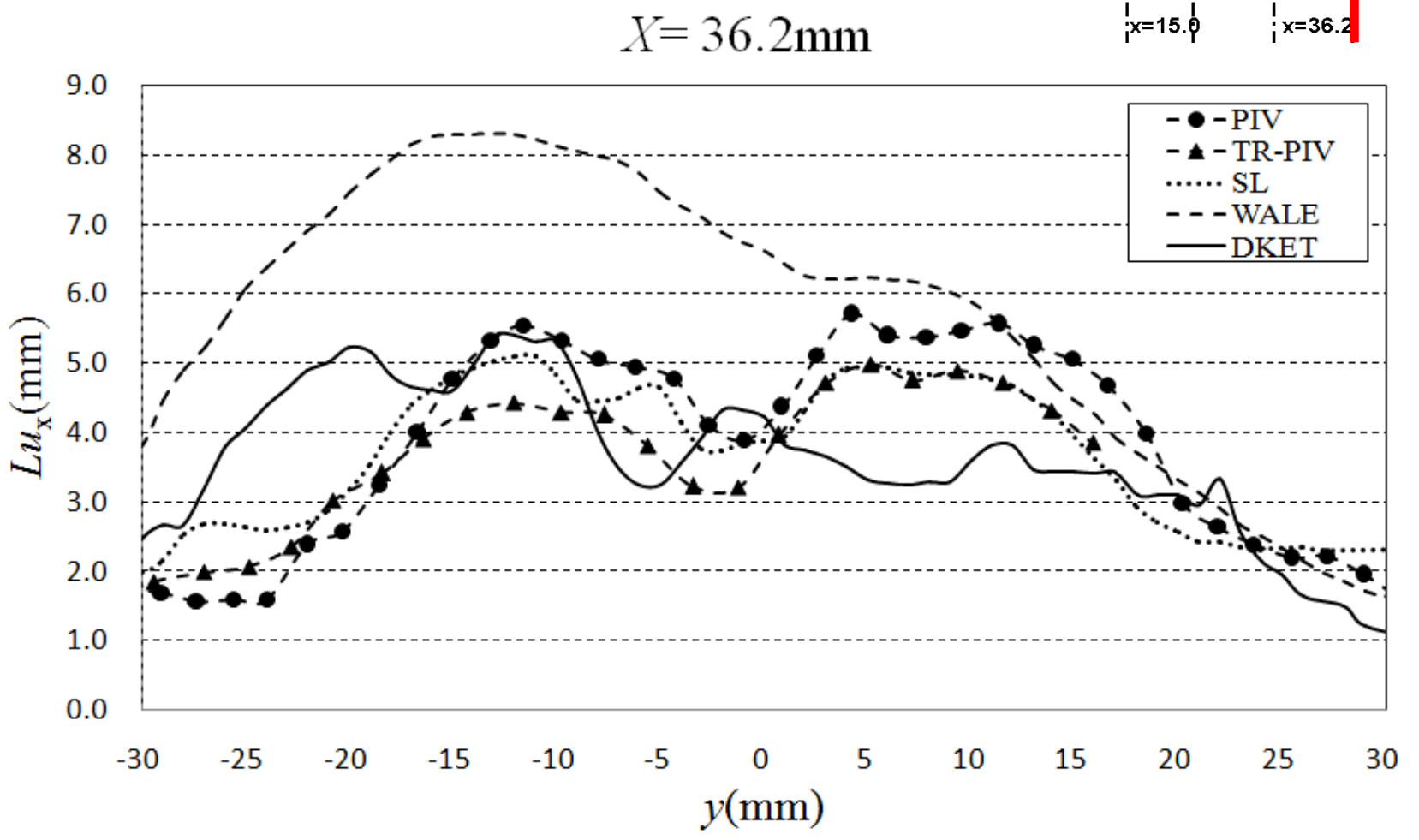




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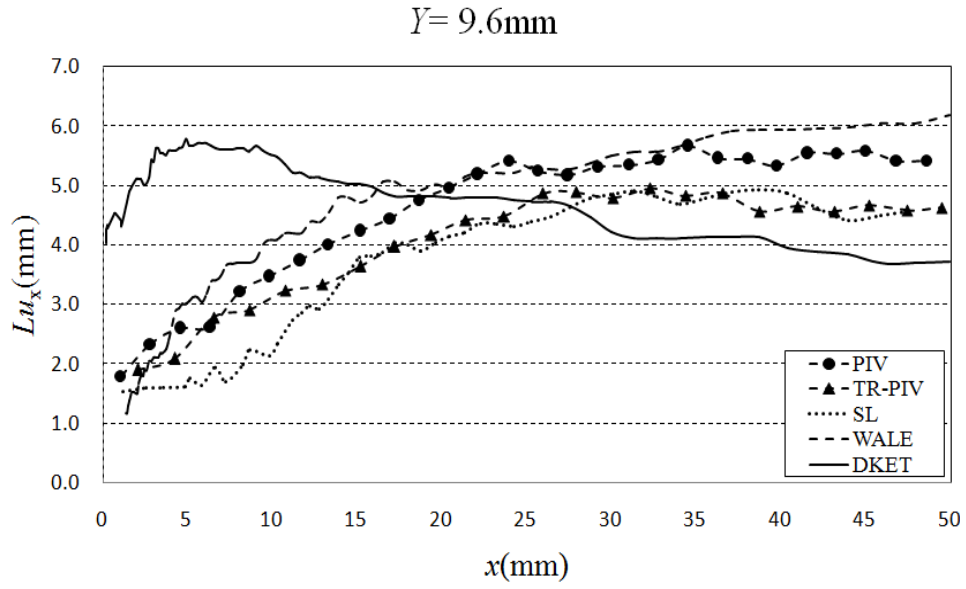
- Turbulence integral length scale

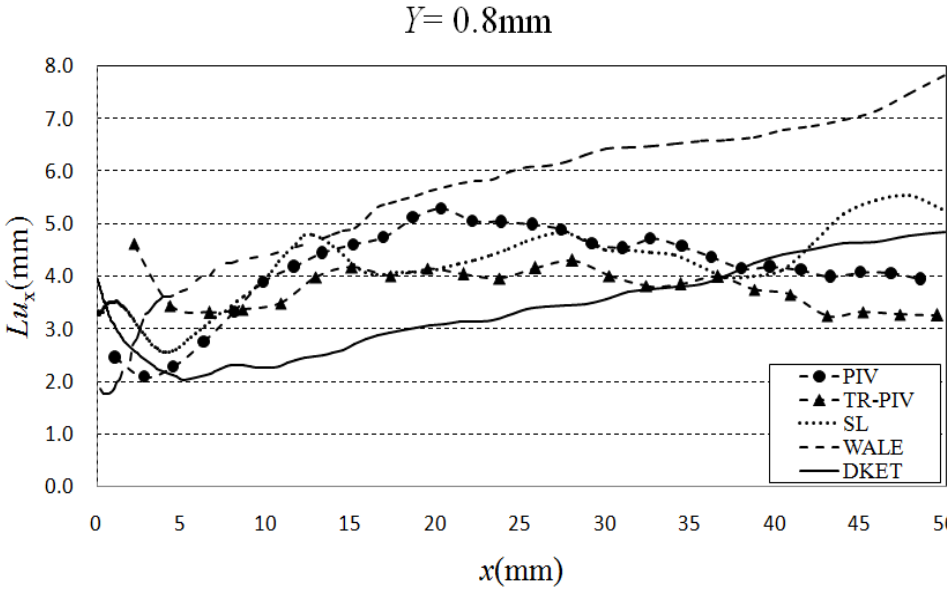


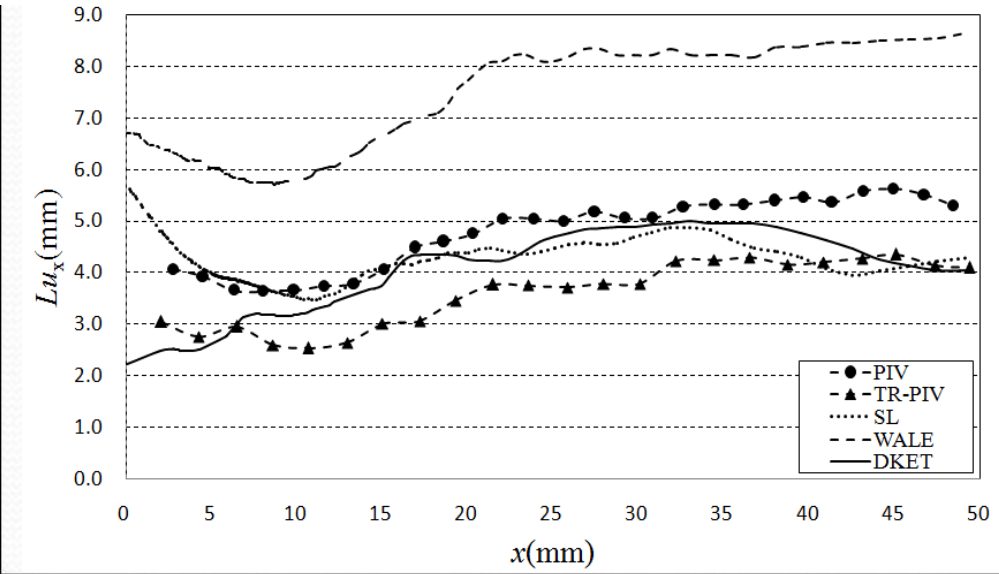


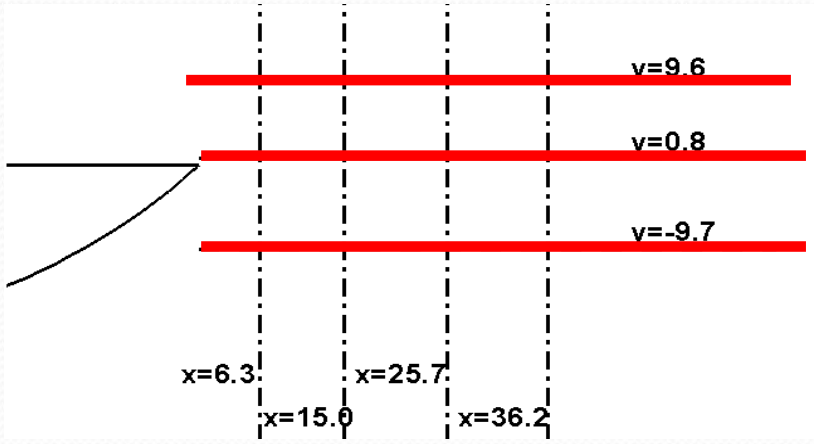
Part 2— MODEL TEST

➢Turbulence integral length scale









Part 2— MODEL TEST

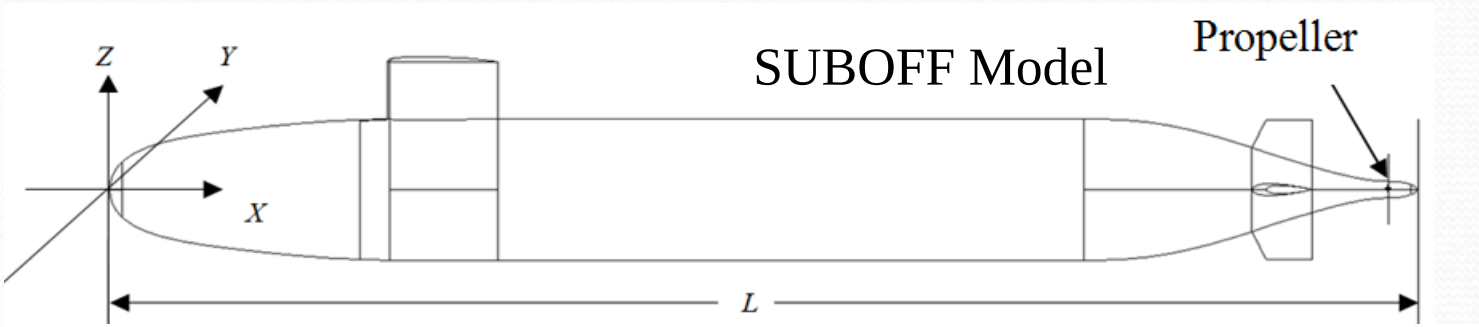
➢Turbulence integral length scale

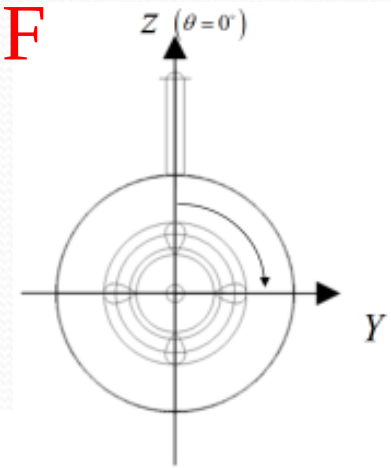
Tab.1 Comparison of different subgrid-scale models

Location	Experimental data			Numerical results					
				DSL		WALE		DKET	
	PIV	TR-PIV	Average	Cal	Error	Cal	Error	Cal	Error
X=6.3	2.307	2.540	2.424	2.534	4.56%	3.118	28.64%	2.341	3.39%
X=15.0	2.651	2.998	2.824	2.814	0.38%	3.755	32.93%	2.718	3.77%
X=25.7	2.980	3.317	3.149	3.177	0.91%	4.530	43.86%	3.178	0.94%
X=36.2	3.089	3.363	3.226	3.611	11.94%	5.151	59.67%	3.395	5.23%
Y=0.8	4.162	3.793	3.977	3.628	8.78%	3.770	5.21%	3.285	17.42%
Y=9.6	4.598	4.079	4.338	3.567	17.78%	3.769	13.13%	3.759	10.13%
Y=-9.7	4.769	3.595	4.182	4.181	0.03%	6.422	53.55%	2.341	3.39%
Mean error					6.34%		33.86%		6.81%

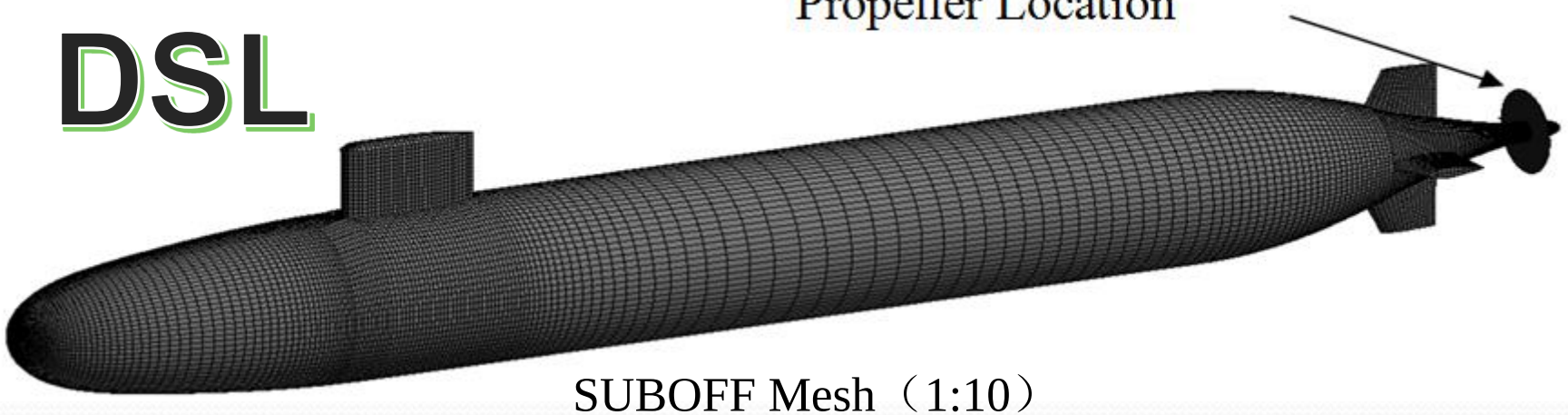
Part 3— CASE STUDY: SUBOFF

turbulence length at propeller disk of SUBOFF





DSL



SUBOFF Mesh（1:10）

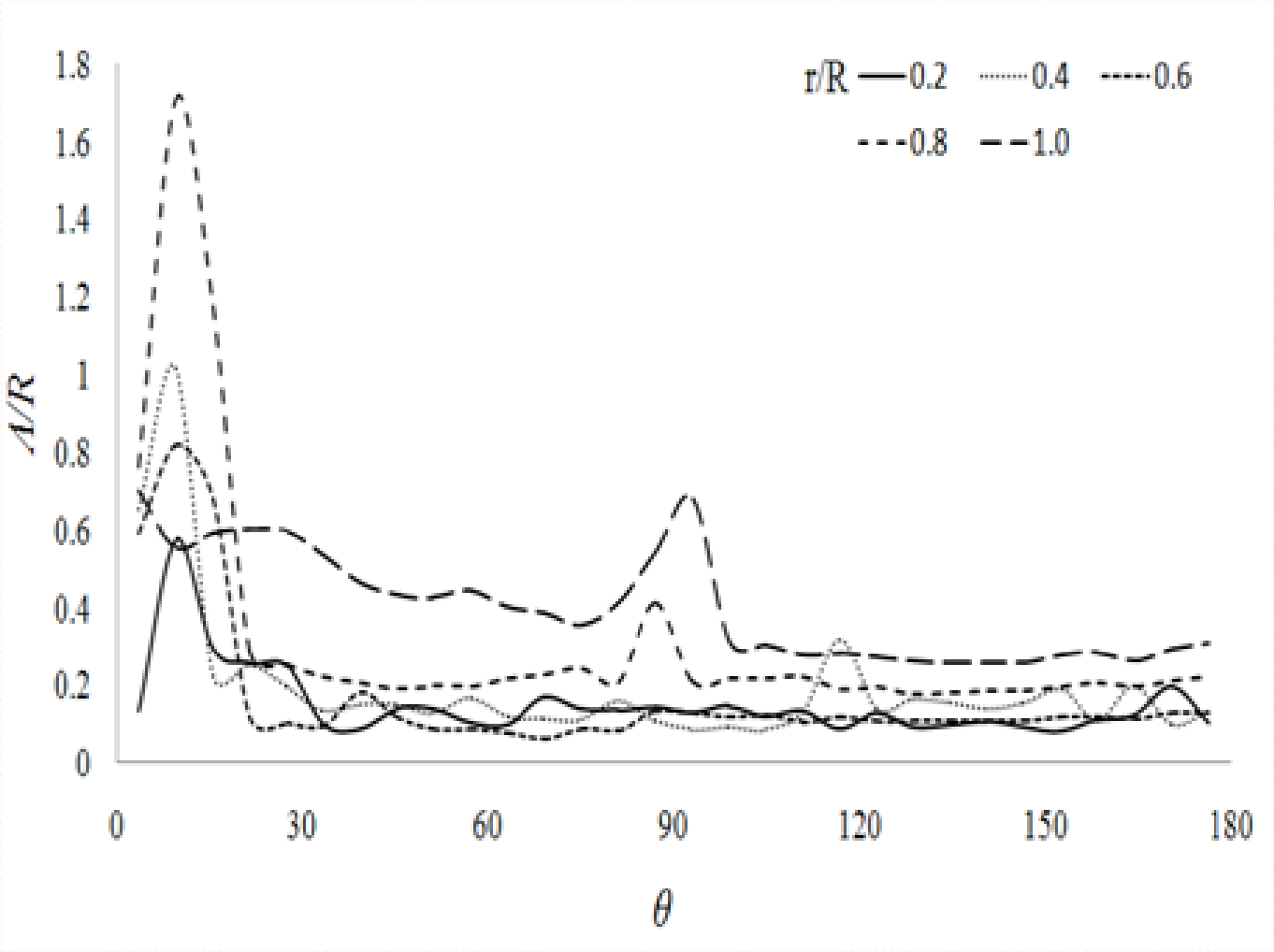
[8] NANCY C G, THOMAS T H. MING S C. GEOMETRIC CHARACTERISTICS OF DARPA SUBPFF MODEL. David Taylor Research Center[R]: 1989.

[9] Nancy C. Groves. GEOMETRIC CHARACTERISTICS OF DARPA SUBOFF MODELS[R]. David Taylor Research Center,1989.

Part 3— CASE STUDY: SUBOFF

➢Results

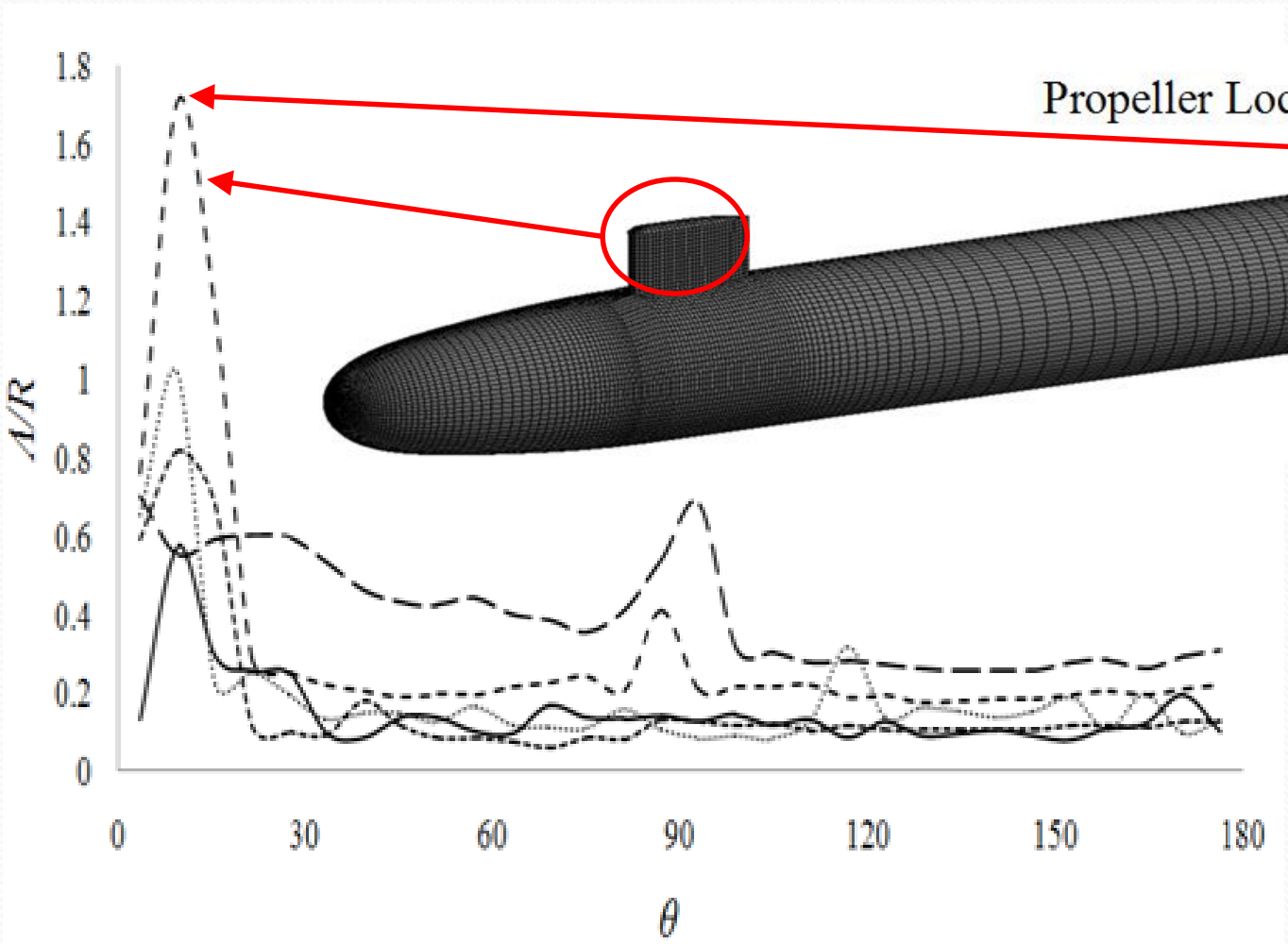
circumferential distribution of Λ at different radius



Part 3— CASE STUDY: SUBOFF

➢Results

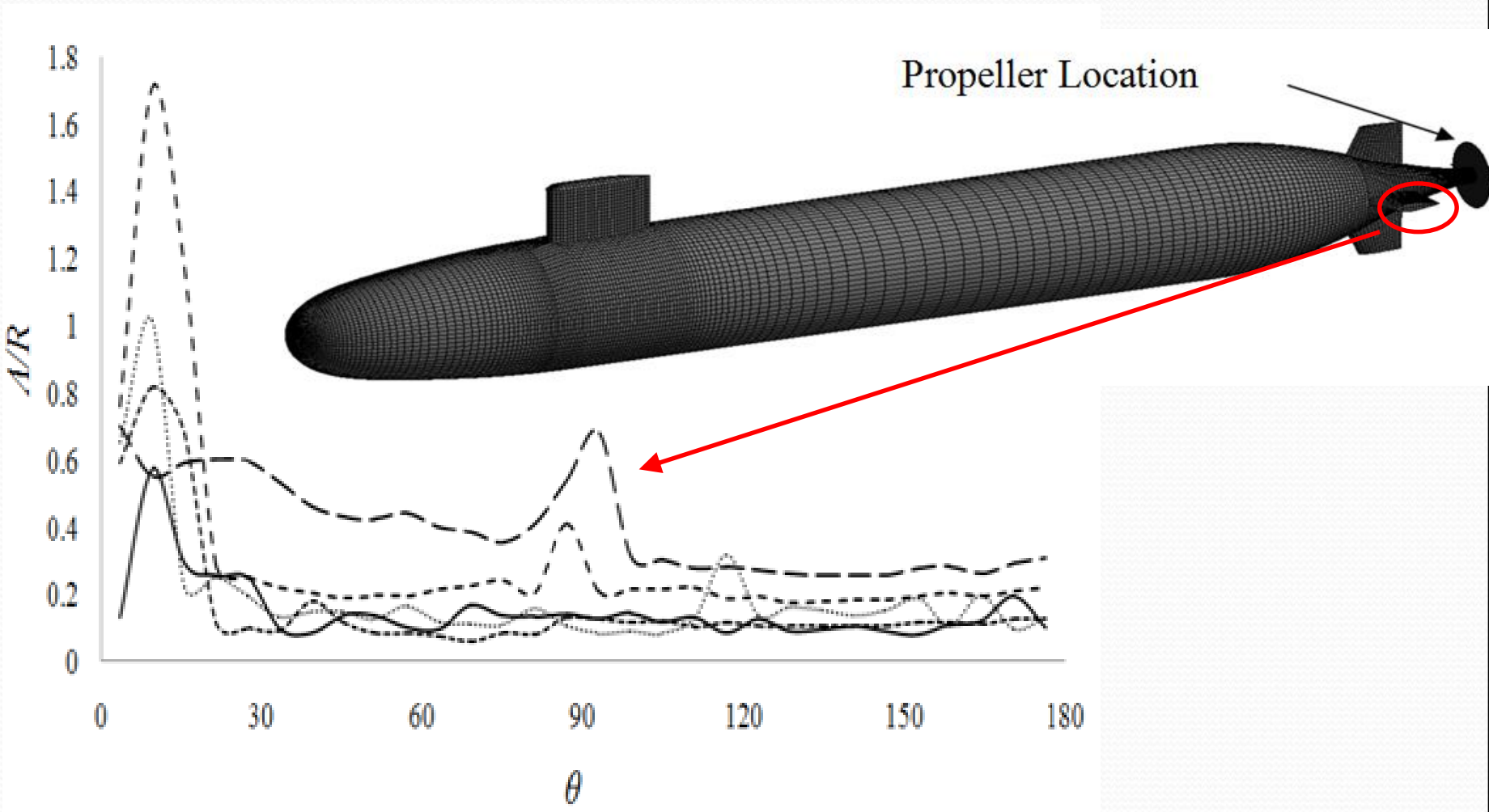
circumferential distribution of Λ at different radius



Part 3— CASE STUDY: SUBOFF

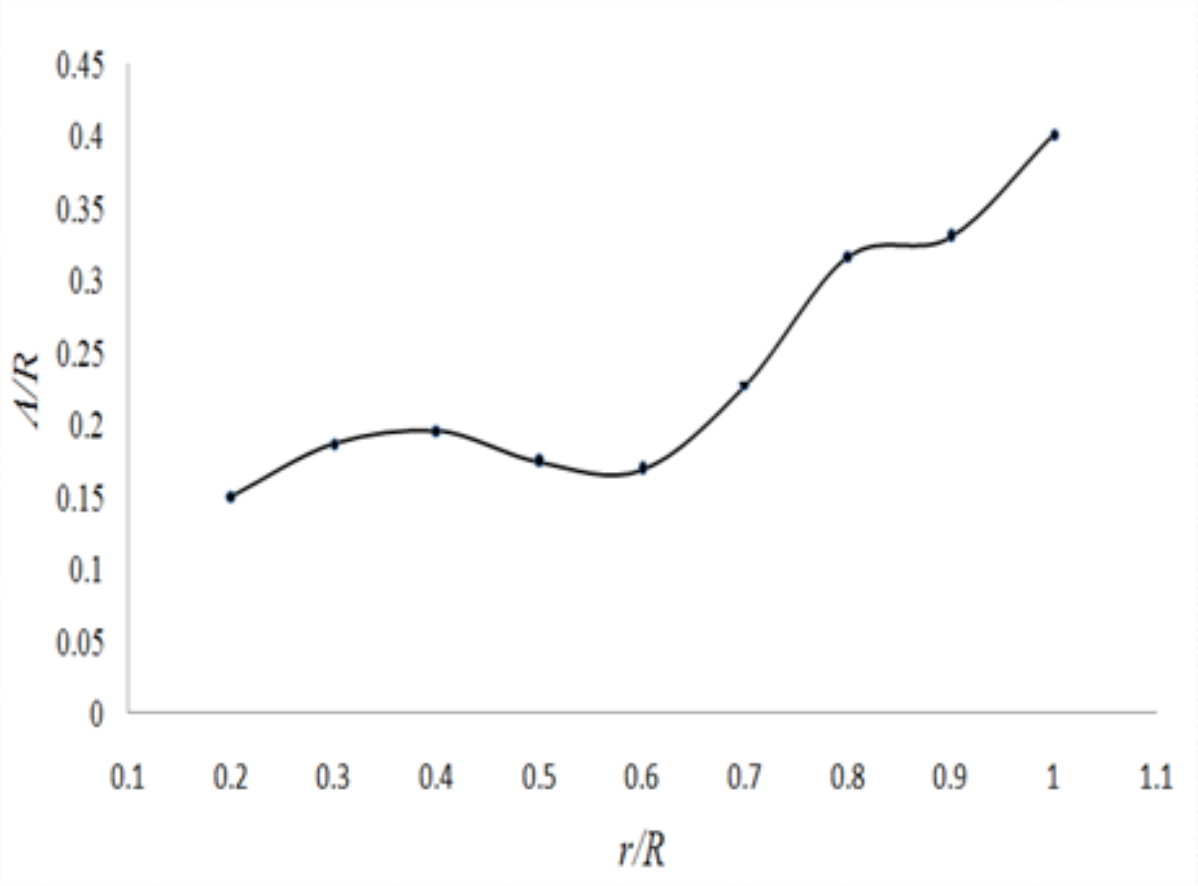
- Results

circumferential distribution of Λ at different radius



Part 3— CASE STUDY: SUBOFF

- Results



radial distribution of circumferential average of A

Part 4— CONCLUSION

- propose **a numerical method** to predict the turbulence integral length
- Analyze three subgrid-scale models (DSL, WALE, DKET) by comparing with the experimental data**: the DSL has the highest precision**
- SUBOFF:
  - The peak bars of Λ are near **20 and 90 degree** according to the existence of horse-shoe vortexes of conning tower and stabilizers
  - the integral lengths **at outside radius are lager than those at inside radius** because of the diffusion of vortexes

Thank you!

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