Review of Analysis and Modeling Techniques for Incompressible, Turbulent Bluff-Body Wakes

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abstract here *LH&FZ*

Nomenclature

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ρ = density, kg/m^3

Subscripts

$()_\infty$ = freestream quantity

Acronyms

CFD = Computational Fluid Dynamics

I. Introduction

INTRO sentence to paper should have this fancy capitalization.

- Driving Physical Phenomena *FZ*
  - differences from potential flow
  - blunt/bluff body definition, differences from streamlined body flow
  - massively separated flow
  - base pressure
  - wake
- Real World Applications *LH*
  - parachute
  - reentry capsule
  - vehicles
  - buildings
  - show similarity between cylinder/sphere wake and more complex bluff body

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Big whorls have little whorls, which feed on their velocity, and little whorls have lesser whorls, and so on to viscosity (in the molecular sense). Richardson (1922) [1]

II. Experimental Methods And Results

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- Historical Study
- Experimental techniques
  - ballistic range?
- Applications
  - Simple cases: cylinder/sphere
    - Drag vs Re?
    - Wake velocity profiles?
    - Wake structure?
  - Sharp vs bluff: sphere vs cube
  - Complex cases: capsule/building

III. Computational Methods and Results

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- Historical Study
- Computational techniques
- Applications
  - Simple cases: cylinder/sphere
  - Sharp vs bluff: sphere vs cube
  - Complex cases: capsule/building

A. Turbulence Modeling Aspects

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- Compare turbulence model performance for sphere/cylinder
  - SA
  - SST
  - SAS
  - URANS
  - LES

– DES

– DNS?

LIST ALL FIGURES HEAR, REORDER AND DESCRIBE LATER

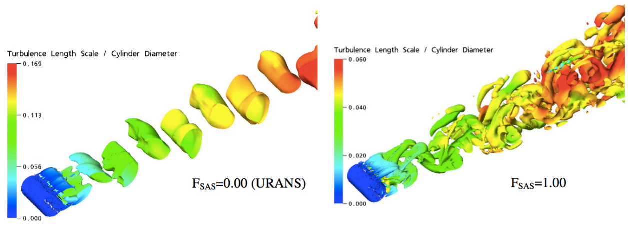

Fig. 1 SAS vs URANS cylinder [2]

Figure 5: Resolved structures for cylinder in crossflow using different constants FSAS

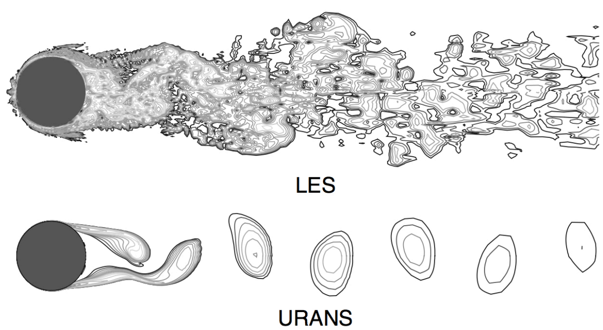

Fig. 2 cylinder les vs urans instantaneous [3]

Instantaneous vorticity magnitude at a given spanwise cut for flow over a circular cylinder at ReD 1⁄4 1 106. 25 contour levels from xD=U1 1⁄4 1 to xD=U1 1⁄4 575 (exponential distribution) are plotted.

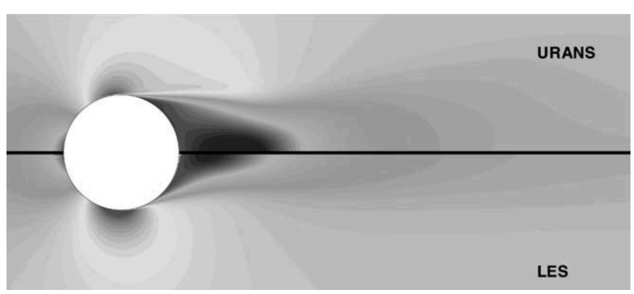

Fig. 3 cylinder les vs urans averaged [3]

Fig. 5. Mean streamwise velocity distribution predicted by LES and URANS. 45 contour levels from U=U1 1⁄4 0:2 to U=U1 1⁄4 1:7 are plotted.

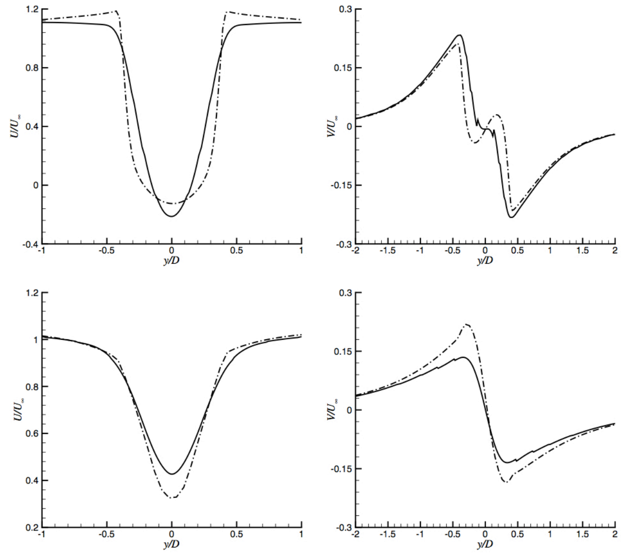

Fig. 4 cylinder les vs urans velocity profiles [3]

Fig. 6. Mean streamwise and vertical velocities at x=D 1⁄4 0:75 (upper figures) and x=D 1⁄4 1:50 (lower figures): (—) LES; (– –) URANS

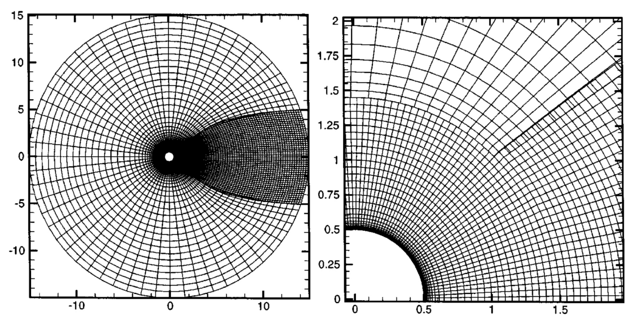

Fig. 5 cylinder les vs rans grid [4]

Figure1. Medium computational grid, CaseTS2.Innerblock150×36,wakeblock74×36, outer block 59 × 30. The three blocks meet near x = 1.06, y = 1.03. Grid for spalart cylinders.

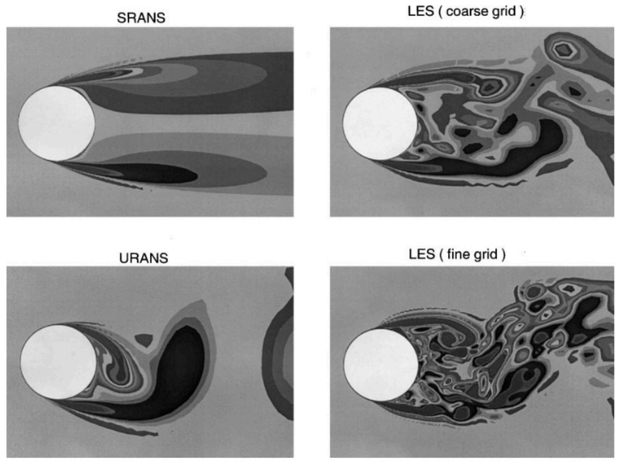

Fig. 6 cylinder les vs rans [5]

grid for LES shown above (actual simulations were DES)

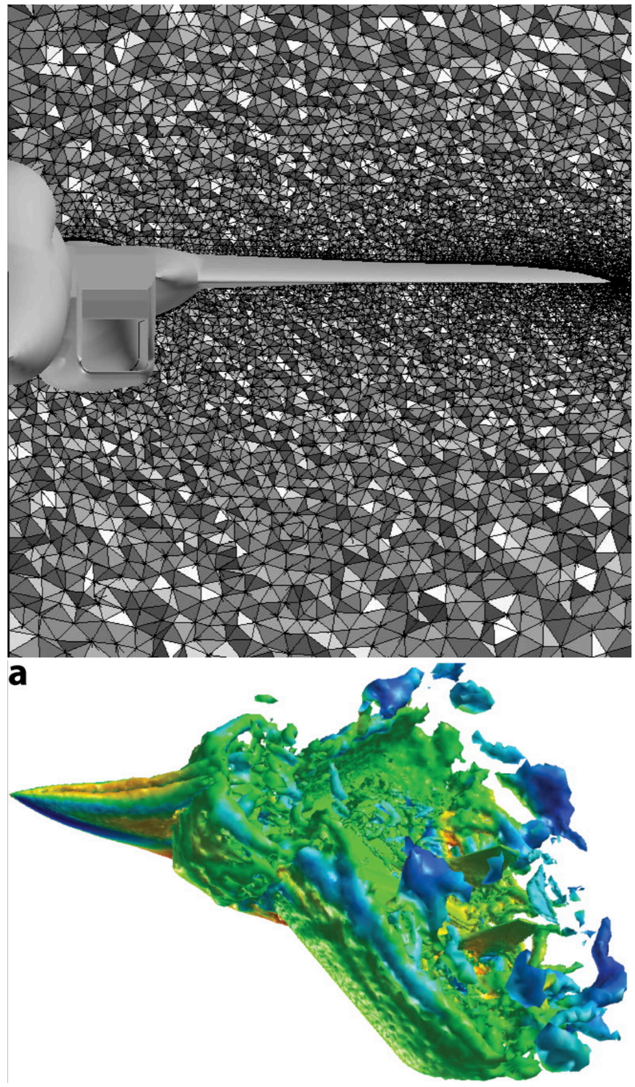

Fig. 7 F-15 DES grid (left) [6] vorticity isocontours (right) [7]

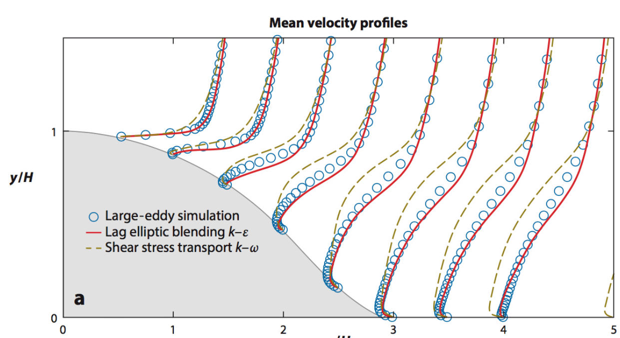

Fig. 8 curve backstep velocity profile les vs rans [8]

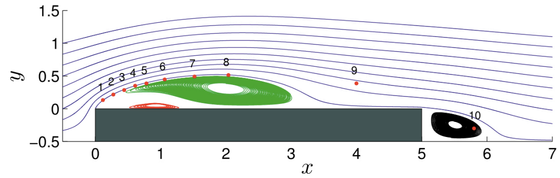

Fig. 9   DNS square cylinder vortex locations Re=3000 [9]

Fig. 4. Streamlines of the mean velocity field (U,V) (x,y) The green lines show the primary vortex, the red lines mark the secondary vortex and the black lines denote the wake vortex. The red dots denote the locations of the probes used for the computation of time spectra in section x5. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

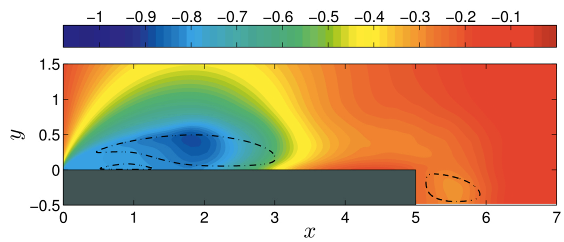

Fig. 10   DNS square cylinder mean pressure distribution Re=3000 [9]

Fig. 5. Isocontours of the mean pressure field P(x,y). The dashed lines report the location of the primary vortex, secondary vortex and wake vortex.

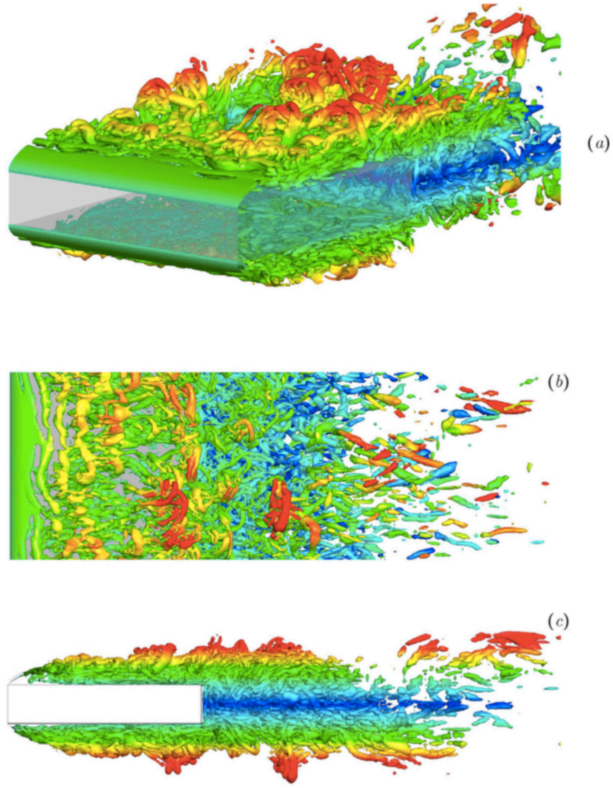

Fig. 11 DNS square cylinder vorticity contours Re=3000 [9]

Fig. 10. Instantaneous isosurfaces of $\lambda_2 = -2$ colored with y. Perspective, top and lateral views in (a), (b) and (c) plots, respectively.

IV. Current State of Bluff-Body Turbulence Analysis

- Current State of Knowledge
- Remaining Challenges

A. Experimental Methods

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B. Computational Methods

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V. Conclusions

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Acknowledgments

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Example citations

[10]

References

[1] Richardson, L. F., *Weather Prediction by Numerical Process*, Cambridge University Press, Cambridge, UK, 1922.

[2] Menter, F., and Egorov, Y., "A Scale Adaptive Simulation Model using Two-Equation Models," *43rd AIAA Aerospace Sciences Meeting and Exhibit, Aerospace Sciences Meetings*, Reno, NV, January 2005.

[3] Catalano, P., Wang, M., Iaccarino, G., and Moin, P., "Numerical simulation of the flow around a circular cylinder at high Reynolds numbers," *International Journal of Heat and Fluid Flow*, Vol. 24, No. 4, 2003, pp. 463 – 469. doi:https://doi.org/10.1016/S0142-727X(03)00061-4, URL `http://www.sciencedirect.com/science/article/pii/S0142727X03000614`, selected Papers from the Fifth International Conference on Engineering Turbulence Modelling and Measurements.

[4] Travin, A., Shur, M., Strelets, M., and Spalart, P., "Detached-Eddy Simulations Past a Circular Cylinder," *Flow, Turbulence and Combustion*, Vol. 63, No. 1, 2000, pp. 293–313. doi:10.1023/A:1009901401183, URL `https://doi.org/10.1023/A:1009901401183`.

[5] Spalart, P., "Strategies for turbulence modelling and simulations," *International Journal of Heat and Fluid Flow*, Vol. 21, No. 3, 2000, pp. 252 – 263. doi:https://doi.org/10.1016/S0142-727X(00)00007-2, URL `http://www.sciencedirect.com/science/article/pii/S0142727X00000072`.

[6] Forsythe, J. R., Squires, K. D., Wurtzler, K. E., and Spalart, P. R., "Detached-Eddy Simulation of the F-15E at High Alpha," *Journal of Aircraft*, Vol. 41, No. 9, 2004, pp. 193–200.

[7] Spalart, P. R., "Detached-Eddy Simulation," *Annual Review of Fluid Mechanics*, Vol. 41, No. 1, 2009, pp. 181–202. doi:10.1146/annurev.fluid.010908.165130, URL `https://doi.org/10.1146/annurev.fluid.010908.165130`.

[8] Durbin, P. A., "Some Recent Developments in Turbulence Closure Modeling," *Annual Review of Fluid Mechanics*, Vol. 50, No. 1, 2018, pp. 77–103. doi:10.1146/annurev-fluid-122316-045020.

[9] Cimarelli, A., Leonforte, A., and Angeli, D., "Direct numerical simulation of the flow around a rectangular cylinder at a moderately high Reynolds number," *Journal of Wind Engineering and Industrial Aerodynamics*, Vol. 174, 2018, pp. 39 – 49. doi:https://doi.org/10.1016/j.jweia.2017.12.020, URL `http://www.sciencedirect.com/science/article/pii/S0167610517304622`.

[10] Nakamura, Y., "Bluff-body aerodynamics and turbulence," *Journal of Wind Engineering and Industrial Aerodynamics*, Vol. 49, No. 1, 1993, pp. 65 – 78. doi:https://doi.org/10.1016/0167-6105(93)90006-A, URL `http://www.sciencedirect.com/science/article/pii/016761059390006A`.