Characterizing Surface Roughness in Numerical Simulations

Karen A. Flack* and Michael P. Schultz†

* Department of Mechanical Engineering
United States Naval Academy
Annapolis, MD USA 21402
e-mail: flack@usna.edu

† Department of Ocean Engineering and Naval Architecture
United States Naval Academy
Annapolis, MD USA 21402
e-mail: mschultz@usna.edu

ABSTRACT

While Direct Numerical Simulations (DNS) have recently made significant advancements in the ability to compute the flow over rough surfaces, these simulations are still not able to capture realistic roughness at ship scale Reynolds numbers. Engineering predictions of rough wall boundary layers on marine vehicles still rely on wall functions for Large Eddy Simulations (LES) and Reynolds Averaged Navier-Stokes (RANS) simulations. The use of wall functions is dependent on similarity between rough and smooth wall boundary layers, often referred to as Townsend's similarity hypothesis[1]. Numerous studies[2] have shown that this hypothesis is valid for roughness height (k) to boundary layer thickness (δ) ratios indicative of large marine vehicles. This allow for the creation of the Hama[3] roughness function (ΔU^+), the difference between the velocity profiles for smooth and rough walls in the log-law regime, or the momentum deficit resulting from surface roughness. Roughness function maps for a range of roughness Reynolds numbers (k^+) indicate when a surface is hydraulically smooth (no roughness effect), transitionally rough (viscous and pressure drag are important) and fully rough (pressure drag dominates).

The roughness function is the key piece of information needed for modelling surface roughness using a wall function. A roughness function map based on a measure of the roughness height (e.g. *rms*, peak-to-trough, average) for a specific surface is only valid for that roughness. If the roughness function map is based on the equivalent sandgrain roughness height (k_s), then the roughness function is valid for all surfaces in the fully rough regime[4]. While k_s, a hydraulic scale, is a convenient way to represent a surface roughness, most marine vehicles do not operate with the boundary layer condition of fully rough over most of the hull. Therefore it is important to provide predictive correlations for ΔU^+ in the transitionally rough regime for surface roughness typically found on ship hulls[5]. These include slimes, grasses and calcareous biofouling, all with a range of density and morphology. The challenges to represent this wide range of surface conditions and potential scales to characterize biofouling in predictive correlations will be discussed.

REFERENCES

[1] A.A. Townsend, *The Structure of Turbulent Shear Flow*, 2nd ed., Cambridge University Press, 1976.

[2] K.A. Flack and M.P. Schultz, "Roughness Effects on Wall Bounded Turbulent Flows", *Physics of Fluids*, Vol. **26**, 101305 (2014).

[3] F.R. Hama, "Boundary-layer characteristics for rough and smooth surfaces," *Trans. SNAME*, Vol. 62, pp. 333–351 (1954).

[4] K.A. Flack and M.P. Schultz, "Review of hydraulic roughness scales in the fully Rough regime," J. Fluid Eng. 132(4), 041203 (2010).

[5] M.P. Schultz, J.M. Walker, C.N. Steppe, and K.A. Flack, Impact of diatomaceous biofilms on the frictional drag of fouling-release coatings, *Biofouling* Vol. 31, pp. 759-773 (2015).