MAE 253 - Experimental Aerodynamics I
Lab 2 – Wind Tunnel Turbulence Study
Final report due date: 02/11/2018

Objective: Using the turbulence sphere and pressure transducer:

- Determine the turbulence factor and per cent turbulence of NCSU's subsonic wind tunnel.

Theory: In the area of wind tunnel testing, there exists disagreement between tests conducted in different wind tunnels at the same Reynolds number and between tests conducted in wind tunnels and in flight. This disagreement can be attributed in large part to the turbulence of the wind tunnel, i.e., the level of unsteady velocity fluctuations about the flow's average velocity. The turbulence is mainly produced by the propeller, the guide vanes, and the vibration of the wind tunnel walls. Research has shown that this turbulence causes the flow pattern in the tunnel to be similar to the flow pattern in free air at a higher Reynolds number. In short, the effective Reynolds number in the test section is generally higher than the freestream Reynolds number (*Re*), given by the equation,

$$Re = \frac{\rho V_\infty l}{\mu}$$

where ρ is the fluid density, V_∞ is the freestream velocity, l is the reference length of the model being tested, and μ is the dynamic viscosity of the fluid.

For a sphere, it has been experimentally verified that the Reynolds number at which the drag coefficient decreases rapidly depends strongly on the degree of turbulence in the wind tunnel. The Reynolds number at which the reduction occurs (henceforth called the critical Reynolds number) decreases with increasing tunnel turbulence as, in general, a higher turbulence leads to faster transition (when the point of separation shifts aft on the sphere leading to a smaller wake and lesser drag). Flight measurements have shown that the critical Reynolds number of a sphere in free atmosphere is 385,000 and is independent of the turbulence structure.

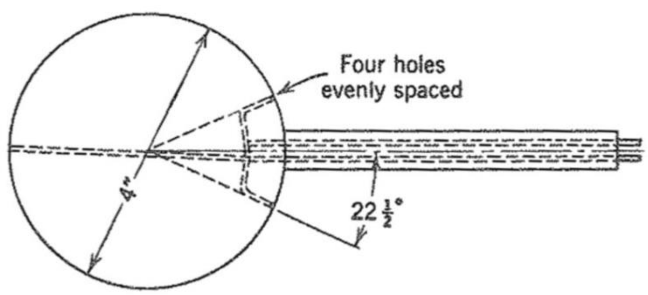

Figure 1: Turbulence sphere [1].

Before the use of hot-wire anemometry as a method to measure wind tunnel turbulence, a turbulence sphere, shown in Fig. 1, was used to measure relative turbulence of a wind tunnel. The critical Reynolds number of the sphere can be measured in two ways: (i) plot the measured C_D based on cross-sectional area vs. Reynolds number and determine the Reynolds number at which C_D = 0.30 (Fig. 2); (ii) take the average of the four pressures of the aft surface of the sphere, subtract this value from the stagnation value at the leading edge of the sphere to get a pressure differential ΔP, and plot the pressure coefficient ($\Delta P/q$), where q is the freestream dynamic pressure, with the Reynolds number for the sphere to obtain the critical Reynolds number at $\Delta P/q$ = 1.22 (Fig. 2). The absence of force balances and associated calibrations to obtain drag makes the pressure method a more advantageous method than the drag option.

The critical Reynolds number of the sphere is then used to define a turbulence factor (*TF*) for the tunnel by comparing the tunnel's critical Reynolds number to that of the freestream conditions by the relation:

$$TF = \frac{3.85 \times 10^5}{Re_{tunnel}}$$

Finally, the per cent turbulence can be obtained by interpolating the resulting *TF* using data from Fig.3.

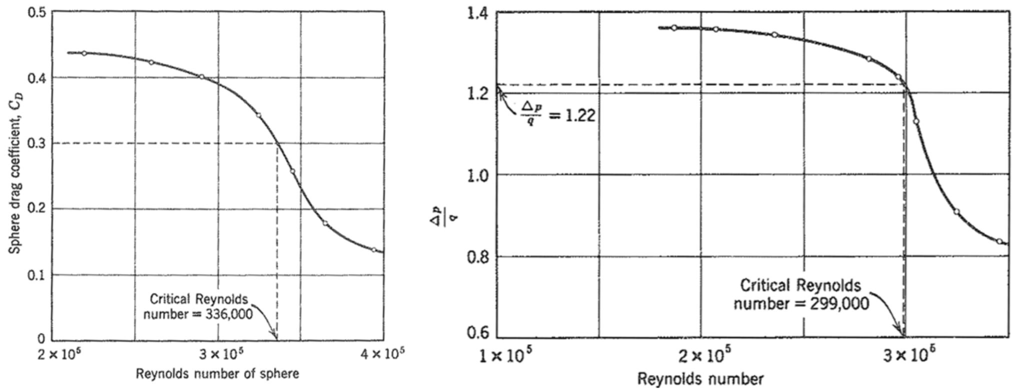

Figure 2: Variation of drag coefficient (left) and pressure coefficient (right) with Reynolds number for a sphere [1].

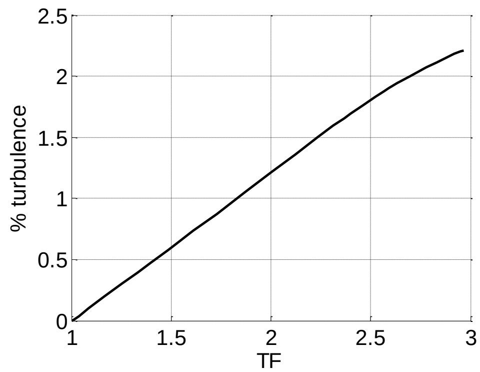

Figure 3: Variation of turbulence factor with per cent turbulence [1].

Experiment: Using the wind-tunnel (WT) pressure transducers, Ashcroft® differential pressure sensor, and multimeter system record the following data for different flow velocities:

Table 1: Data collected to determine wind tunnel turbulence

$P_{transducer}$ (psf)	$T_{transducer}$ (°F)	$P_{atmospheric}$ (Pa)	I_{sensor} (mA)
from WT transducer	from WT transducer	from barometer	from multimeter

The pressure difference (*ΔP*) for the sphere can be determined from the current readings by using the calibration equation for the Ashcroft® pressure sensor calculated in Lab 1.

The following constants can be used to help with your analysis:

1. Dynamic viscosity of air, μ_{air} = 1.825 x 10^{-5} Ns
2. Diameter of turbulence sphere, *d*: 0.2032 m

In the final report,

- Plot the variation of the pressure coefficient with Reynolds number for the turbulence sphere.
- Determine the turbulence factor of the wind tunnel.
- Using the digitized data from Fig. 3, interpolate the turbulence factor to determine the per cent turbulence in NCSU's subsonic wind tunnel.
- Present your code in the Appendix.

References: [1] Barlow, J. B., Rae, W.H., and Pope, A., "Low Speed Wind Tunnel Testing, 3rd Edition," Texts Wiley and Sons, New York, NY.