Table of Contents

JB Fueston - 2627845 | AE314 FFT Boundary Layer Project | 17 April 2026

References: Stack Overflow, MATLAB docs, SignalAnalysisFourier script, AI No AI code used except where flagged Sutherland's Law Reference Values: https://doc.comsol.com/6.3/doc/com.comsol.help.cfd/cfd_ug_fluid-flow_high_mach.08.43.html

```
clear, clc, close all
tic
```

Import

```
calib  = load('C:\Users\jbfue\Downloads\Data\Data\Calibration.mat');
zero = load('C:\Users\jbfue\Downloads\Data\Data\zero1.mat');

% Calibration coefficients     UNITS OF ... - REMEMBER TO CONVERT SI
coeffs_HW = calib.HW_cal;      % m/s
coeffs_Pdyn = calib.Pdyn_cal;  % inWc
coeffs_Patm = calib.Patm_cal;  % inHg
coeffs_Tatm = calib.Tatm_cal;  % K

% Z pos
zMeas = calib.zMeas_SI; % m

% Tare HW & PS
Z = zero.zero1;
zero_HW = mean(polyval(coeffs_HW,   Z(:,1)));  % m/s
zero_Pdyn = mean(polyval(coeffs_Pdyn, Z(:,2)));  % inWc

% Load and sort files - This segment was AI-assisted, could not figure out
% how or why the files were coming out of order.
files = dir('C:\Users\jbfue\Downloads\Data\Data\zPos_*.mat');
nums = regexp({files.name}, '\d+', 'match');
nums = cellfun(@(x) str2double(x{1}), nums);
[~, sortIdx] = sort(nums);
files = files(sortIdx);
```

Process

```
%All metrics @ each Z in SI
nFiles = length(files);
```

```
% Preallocate so MATLAB doesn't complain
z_all = zeros(1, nFiles);
V_mean = zeros(1, nFiles);
U_std = zeros(1, nFiles);
Pdyn = zeros(1, nFiles);
Patm = zeros(1, nFiles);
Tatm = zeros(1, nFiles);
V_rms = zeros(1,nFiles);
TI = zeros(1,nFiles);
V_std = zeros(1,nFiles);
V_CI = zeros(1,nFiles);

for i = 1:40
    raw = load(fullfile(files(i).folder, files(i).name));
    V = raw.data;

    % Velocity from HW
    HW_cal = polyval(coeffs_HW,   V(:,1)) - zero_HW;
    V_mean(i) = mean(HW_cal);
    V_std(i) = std(HW_cal);

        % TI
        TI(i) = V_std(i)/V_mean(i);

        % 95% CI (Vel uncertainty)
        N = 2.4e6;
        V_CI(i) = 1.96 * std(HW_cal) / sqrt(N);

    % Dynamic Pressure
    Pdyn_cal = polyval(coeffs_Pdyn, V(:,2)) - zero_Pdyn;
    Pdyn(i) = mean(Pdyn_cal) * 249.089;   % Pa

    % Z position
    z_all(i) = zMeas(i);

    % Ambient conditions
    Patm(i) = mean(polyval(coeffs_Patm, V(:,3))) * 3386.39;  % Pa
    Tatm(i) = mean(polyval(coeffs_Tatm, V(:,4)));            % K

end
```

Compute

```
% V_inf from free stream
R = 287.05;
P_mean = mean(Patm);
T_mean = mean(Tatm);
rho = P_mean/(R*T_mean);
q_mean = mean (Pdyn);
V_inf = sqrt((2*q_mean)/rho);

% Boundary layer thickness (99% criteria)
```

```
delta99 = interp1(V_mean, zMeas, 0.99*V_inf, 'linear');

% Non-dimensionalized boundary layer
V_nd = V_mean / V_inf;
z_nd = zMeas / delta99;


% Shear stress
    % Sutherland's Law
    mu_0 = 1.716*10^(-5);
    T_0 = 279;
    S = 111;
    mu = mu_0 * (T_mean/T_0)^(3/2)*((T_0 + S)/(T_mean+S));

tau = (V_mean(1)/zMeas(1))*mu;
C_f = tau / q_mean;

% FFT Method
frq_fun = 1/120;
Fs = 20000;
frq_Nyq = 10000;
freqs = [0,frq_fun:frq_fun:frq_Nyq];

raw_fft = load(fullfile(files(10).folder, files(10).name));
V_tran = raw_fft.data;
V_tran = polyval(coeffs_HW, V_tran(:,1)) - zero_HW;
V_AC = V_tran - mean(V_tran);
V = fft(V_AC);
ampV = abs(V);
ampV = ampV(1:N/2+1);
ampV = ampV./N;
ampV = ampV(2:N/2).*2;

% Slice freqs to match ampV
freqs_sliced = freqs(2:N/2);

% PSD
PSD_fft = ampV.^2 * (N/Fs);

% Calculate k using the sliced frequencies
k = (2*pi*freqs_sliced) ./ mean(V_tran);

% Welch's Method
segment_length = 2^15;
window = hamming(segment_length);
noverlap = round(segment_length/2);
nfft = segment_length;

[PSD_Welch, f_Welch] = pwelch(V_AC, window, noverlap, nfft, Fs);

k_Welch = (2*pi*f_Welch) ./ mean(V_tran);

% Largest turbulent eddy frequency
```

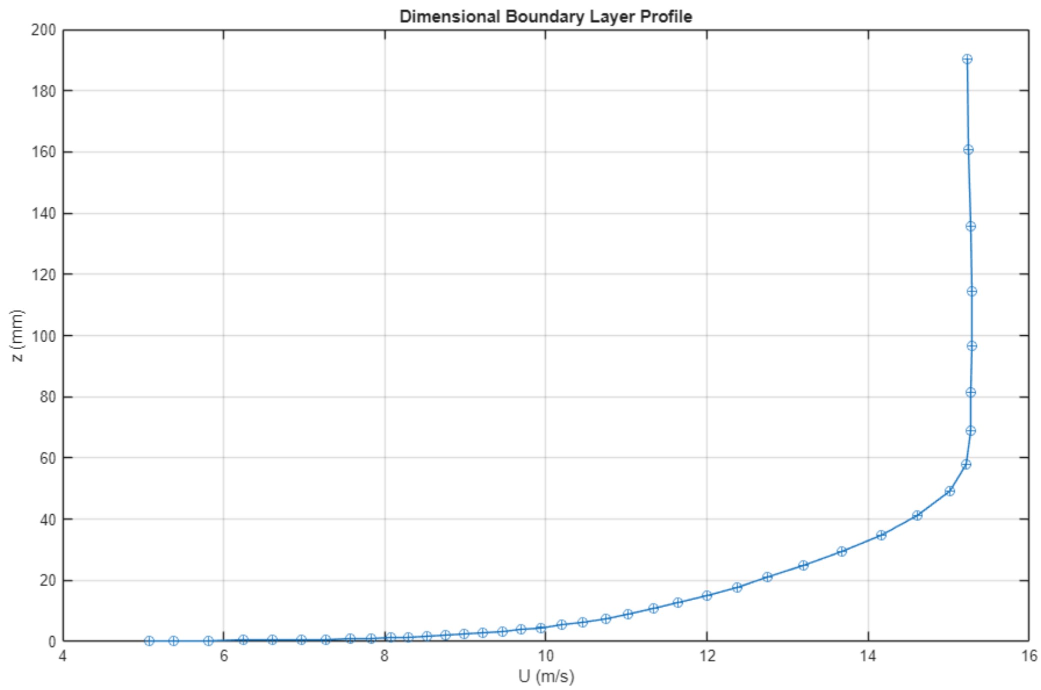
```
[~, max_idx] = max(PSD_Welch(2:end));
largest_eddy_freq = f_Welch(max_idx + 1);
```

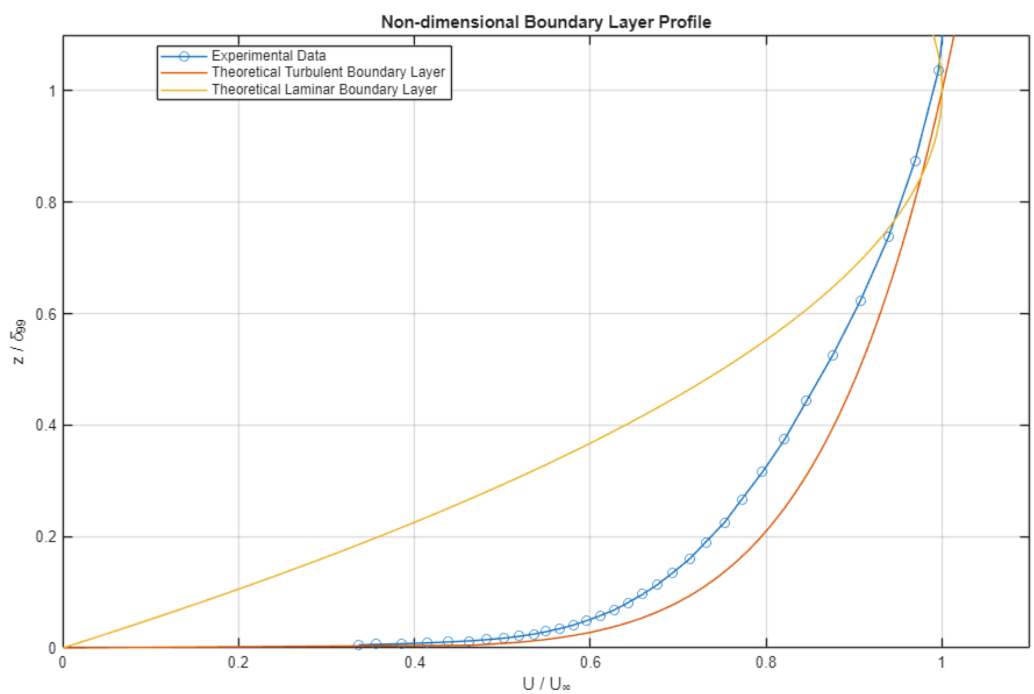
Output

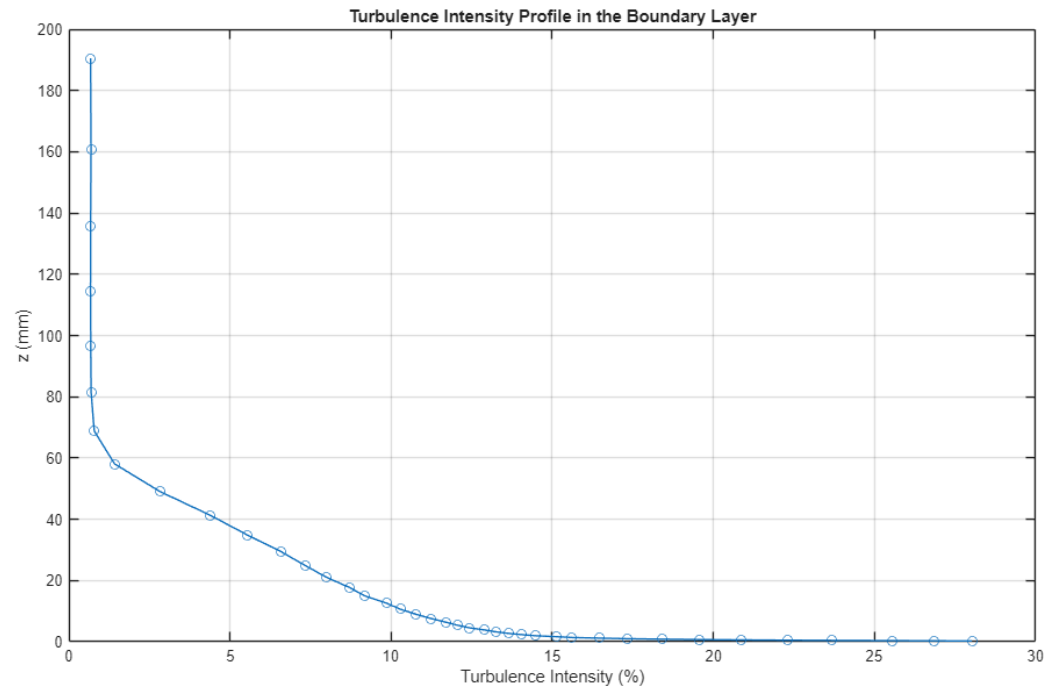
```
%Free-stream and boundary
fprintf('\na) Free stream velocity: %.2f %c %.4f [m/s]\n', V_inf, char(177),
mean(V_CI));
fprintf('b) Boundary layer thickness: %.4f [mm]\n', delta99*1000)

% Dimensional profile
errorbar(V_mean, zMeas*1000, V_CI, V_CI, zeros(size(zMeas)),
zeros(size(zMeas)), '-o')
xlabel('U (m/s)')
ylabel('z (mm)')
title('Dimensional Boundary Layer Profile')
grid on
% NOTE - Error bars are present here. 95% CI is miniscule b/c of sample
% size

% Non-dimensional profile
figure
plot(V_nd, z_nd, '-o')
xlabel('U / U_\infty')
ylabel('z / \delta_{99}')
title('Non-dimensional Boundary Layer Profile')
grid on
hold on
ratio = linspace(0,1.2,250);
turb_ther = ratio .^ (1/7);
lam_ther = 2*ratio - (ratio.^2);
plot(turb_ther, ratio)
plot(lam_ther, ratio)
xlim([0 1.1])
ylim([0 1.1])
legend('Experimental Data', 'Theoretical Turbulent Boundary Layer',
'Theoretical Laminar Boundary Layer', location='best')

% Shear, coefficient, classification
fprintf('c) Wall Shear: %.4f [Pa]\n   Coefficient of friction: %.4f\n', tau,
C_f)
fprintf(['d) This boundary layer is an example of a turbulent boundary
layer.\n' ...
    '   The velocity profile fits much closer to the 1/7 approximation than
the \n' ...
    '   laminar approximation. Additionally, the wall shear and coefficient
of skin\n' ...
    '   friction are consistent with the provided turbulent
approximations.\n'])
% TI
figure
plot(TI * 100, zMeas * 1000, '-o');
grid on;
```

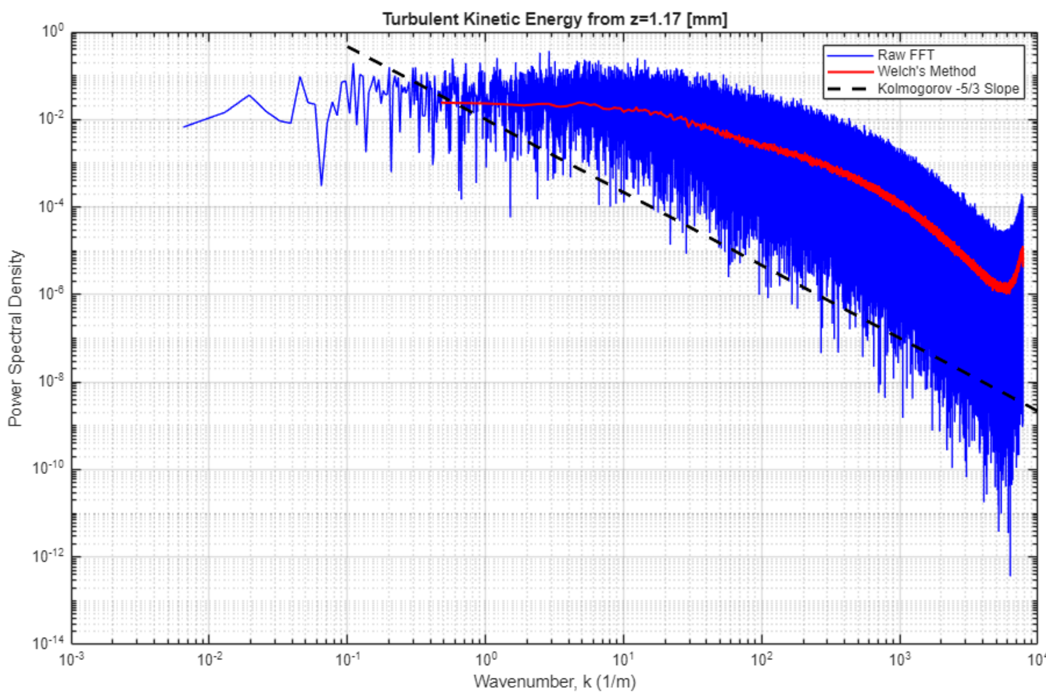
```
xlabel('Turbulence Intensity (%)');
ylabel('z (mm)');
title('Turbulence Intensity Profile in the Boundary Layer');

% PSD
figure;
loglog(k, PSD_fft, 'b'); hold on %FFT
loglog(k_Welch, PSD_Welch, 'r', 'LineWidth', 1.5); % Welch
k_range = [.1 10000];
plot(k_range, 1e-2 * k_range .^(-5/3), 'k--', 'LineWidth', 2) %Kolmogorov
grid on;
xlabel('Wavenumber, k (1/m)');
ylabel('Power Spectral Density');
title('Turbulent Kinetic Energy from z=1.17 [mm]')
legend('Raw FFT', 'Welch''s Method', 'Kolmogorov -5/3 Slope');
fprintf('e) The largest turbulent eddy frequency is: %.2f [Hz]\n\n',
largest_eddy_freq);
toc
```

```
a) Free stream velocity: 15.07 ± 0.0012 [m/s]
b) Boundary layer thickness: 47.2767 [mm]
c) Wall Shear: 0.3619 [Pa]
   Coefficient of friction: 0.0027
d) This boundary layer is an example of a turbulent boundary layer.
   The velocity profile fits much closer to the 1/7 approximation than the
   laminar approximation. Additionally, the wall shear and coefficient of
skin
   friction are consistent with the provided turbulent approximations.
e) The largest turbulent eddy frequency is: 6.10 [Hz]

Elapsed time is 5.868728 seconds.
```


Dimensional Boundary Layer Profile
z (mm)
U (m/s)
0
20
40
60
80
100
120
140
160
180
200
4
6
8
10
12
14
16


Non-dimensional Boundary Layer Profile
Experimental Data
Theoretical Turbulent Boundary Layer
Theoretical Laminar Boundary Layer
z / δ99
U / U∞
0
0.2
0.4
0.6
0.8
1





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