

A E 303 - Lab 1

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A E 303, Section 3, with Dr. Xiaofeng Liu

This lab measured atmospheric pressure and room temperature, applied corrections, and analyzed uncertainties. Statistical methods were used to compute mean, standard deviation, and uncertainty. Results were presented in tables and a convergence test.

I. Nomenclature

T	=	Temperature (°F or K)
P	=	Atmospheric Pressure (inHg, mmHg, or Pa)
ρ	=	Air Density (kg/m ³)
g_0	=	Standard Gravitational Acceleration (9.80665 m/s ²)
R_{air}	=	Specific Gas Constant for Air (287.058 J/kg/K)
S_x	=	Sample Standard Deviation
$S_{\bar{x}}$	=	Standard Deviation of the Mean

II. Introduction

This lab involved measuring atmospheric pressure and room temperature using a barometer and thermometer. Corrections for latitude and temperature were applied, and statistical analysis was performed to calculate mean, standard deviation, and uncertainties.

III. Objectives

This lab aims to achieve the following objectives:

- 1) Learn how to correctly measure the room ambient pressure (i.e., the atmospheric pressure) and the room temperature using a barometer and a thermometer, respectively.
- 2) Learn how to apply the latitude and temperature corrections to the atmospheric pressure measurement, respectively.
- 3) Learn how to calculate the sample mean ($\bar{x}$), the sample standard deviation (S_x), and sample standard deviation of the means ($S_{\bar{x}}$), respectively, using the atmospheric pressure and room temperature as examples.
- 4) Learn how to characterize the one-time sample uncertainty and the mean value uncertainty for the measured atmospheric pressure and the room temperature, respectively.
- 5) Learn how to characterize the one-time sample uncertainty and the mean value uncertainty for derived variables, using the room air density as an example.
- 6) Learn how to determine the significant digit of the measured quantities by estimating the measurement resolution of the derived variables, using the room air density as an example.
- 7) Learn how to conduct the “convergence test” for the measured statistical quantities, e.g., the mean value and the standard deviation, etc.

IV. Theory

This experiment involved measuring atmospheric pressure and room temperature using a barometer and a thermometer. Since barometers are typically calibrated under standard conditions, we had to adjust for gravitational acceleration and temperature to get more accurate pressure readings.

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A. Gravity and Temperature Corrections

Barometric pressure readings vary based on location due to differences in gravity. The standard gravitational acceleration is $g_0 = 9.80665 \text{ m/s}^2$, but it changes with latitude. A correction factor from a reference table was used to account for this. Temperature also affects the barometer since mercury expands and contracts with heat. We applied a temperature correction factor to adjust for this.

B. Statistical Analysis

After applying the corrections, we analyzed the pressure and temperature data using basic statistical methods. The sample mean $\bar{x}$ represents the average of our measurements:

$$\bar{x} = \frac{1}{N} \sum_{i=1}^N x_i \quad (1)$$

where N is the number of measurements and x_i represents each individual reading.

The sample standard deviation S_x tells us how much the data varies:

$$S_x = \sqrt{\frac{1}{N-1} \sum_{i=1}^N (x_i - \bar{x})^2} \quad (2)$$

A useful metric is the standard deviation of the mean, $S_{\bar{x}}$, which shows how much uncertainty is in our average value:

$$S_{\bar{x}} = \frac{S_x}{\sqrt{N}} \quad (3)$$

C. Uncertainty Analysis

Measurement uncertainty comes from instrument limitations and environmental factors. We estimated uncertainty for a single measurement using a confidence interval:

$$x \pm t_{v,p} S_x \quad (4)$$

where $t_{v,p}$ is a statistical factor from the t-distribution.

For derived values like air density, uncertainty carries over from pressure and temperature uncertainties. The uncertainty in air density ρ was estimated using error propagation:

$$\delta\rho = \sqrt{\left(\frac{\partial\rho}{\partial P}\delta P\right)^2 + \left(\frac{\partial\rho}{\partial T}\delta T\right)^2} \quad (5)$$

where δP and δT are the uncertainties in pressure and temperature.

D. Convergence Test

To check if our data was reliable, we performed a convergence test. This meant plotting the sample mean, standard deviation, and standard deviation of the mean as more data was added. If these values stabilized as N increased, it confirmed that our dataset was statistically sound.

By applying these corrections and analyses, we improved measurement accuracy and learned more about how to quantify uncertainty in atmospheric pressure readings.

V. Materials and Equipment

A. Barometer

A mercury barometer was used to measure atmospheric pressure. This instrument provides readings in inches of mercury (inHg) and millimeters of mercury (mmHg). The recorded values required corrections to account for local gravitational acceleration and temperature variations.

B. Thermometer

A standard room thermometer was used to measure ambient temperature in degrees Fahrenheit ($^{\circ}\text{F}$). This measurement was essential for applying temperature corrections to the barometric pressure reading.



Fig. 1 Barometer used for measuring atmospheric pressure.



Fig. 2 Thermometer used for measuring room temperature.

C. Experimental Setup

The barometer and thermometer were placed in a controlled indoor environment to minimize environmental fluctuations. Data was recorded manually by each student in the class, forming a dataset for statistical analysis.

VI. Procedure

The experiment involved measuring atmospheric pressure and room temperature, applying necessary corrections, and performing statistical analysis. The steps followed are outlined below.

A. Data Collection

- 1) A mercury barometer and a standard room thermometer were placed in a controlled environment to minimize fluctuations in pressure and temperature.
- 2) Each student in the class recorded three values:
 - Barometer reading in inches of mercury (*inHg*).
 - Barometer reading in millimeters of mercury (*mmHg*).
 - Thermometer reading in degrees Fahrenheit ($^{\circ}\text{F}$).
- 3) The recorded data were compiled into a shared dataset for further analysis.

B. Applying Corrections

- 1) The raw atmospheric pressure readings were adjusted for local gravitational acceleration using a gravity correction table.
- 2) A temperature correction table was used to account for thermal expansion effects on the barometer.
- 3) The corrected pressure values were converted to Pascals (*Pa*) for consistency in calculations.

C. Statistical Analysis

- 1) The sample mean ($\bar{x}$), sample standard deviation (S_x), and standard deviation of the mean ($S_{\bar{x}}$) were calculated for both atmospheric pressure and room temperature.
- 2) The uncertainty of a single measurement and the uncertainty of the ensemble average were determined using statistical confidence intervals.
- 3) The uncertainty in air density, a derived variable, was computed using error propagation principles.

D. Convergence Test

- 1) The convergence of the sample mean, standard deviation, and standard deviation of the mean was analyzed by progressively increasing the sample size.
 - 2) A plot was generated to visualize whether these statistical values stabilized with additional data points.
- By following these steps, the experiment ensured accurate measurements and provided a foundation for uncertainty analysis and statistical evaluation.

VII. Data Reduction

The barometric pressure readings were corrected for latitude and temperature. The corrections were applied as follows:

- **Latitude Correction:** Corrections were interpolated from the Gravity Correction Table for San Diego's latitude (32.7°N).
- **Temperature Correction:** Corrections were interpolated from the Temperature Correction Table based on the recorded temperature for each sample.

Statistical analysis was performed to calculate the sample mean ($\bar{x}$), standard deviation (S_x), and standard deviation of the mean ($S_{\bar{x}}$) for temperature, pressure, and air density.

VIII. Results

A. Uncertainty for One-Time Sample

Table 1 Measurement results and uncertainty for one-time sample

T [°F]	P [inHg] Before Correction	P [Pa] After Correction	ρ [kg/m ³]
73.44	29.83	101030	1.19

B. Uncertainty for Ensemble Average

Table 2 Measurement results and uncertainty for ensemble average

T [°F]	P [inHg] Before Correction	P [Pa] After Correction	ρ [g/m ³]
73.44	29.83	101029	1190

C. Resolution of Measurement

Table 3 Resolution of Measurement

T [°F]	P [inHg]	P [mmHg]	ρ [g/m ³]
1.31	0.29	1.06	11.9

D. Convergence Test

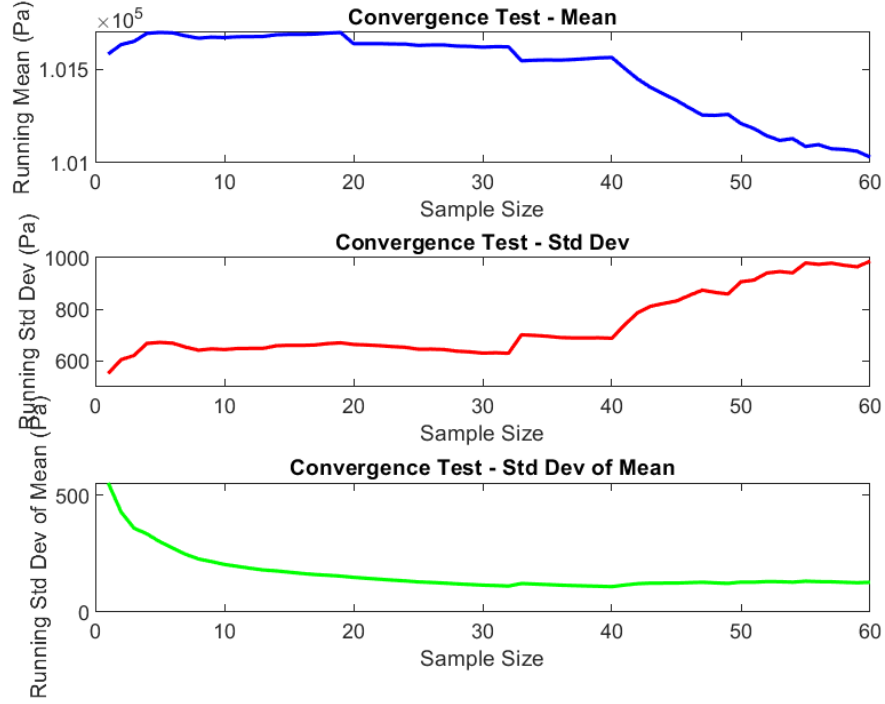


Fig. 3 Convergence test results for mean, standard deviation, and standard deviation of the mean.

IX. Discussion

The equipment used in this experiment, specifically the barometer and thermometer, showed signs of instability, which may have impacted the accuracy of the measurements. Both instruments are relatively old and prone to wear and calibration drift. For instance, the barometer relies on mercury, which can expand and contract unevenly due to temperature variations, especially in aging devices. Similarly, the thermometer's responsiveness may have degraded over time, leading to inconsistencies in recorded values.

These limitations underscore the importance of proper calibration and maintenance. Regular recalibration against more modern, precise instruments would reduce systematic errors and improve reliability. Despite these challenges, the statistical analysis methods applied, including uncertainty quantification and convergence testing, helped mitigate some of the inherent measurement variability.

The convergence test results demonstrated that the mean and standard deviation stabilized with an increasing number of samples, indicating that the dataset is statistically robust despite equipment limitations. This suggests that while individual measurements may be less reliable, ensemble averages provide a reasonable approximation of true values.

X. Conclusion

This experiment gave us a hands-on look at measuring atmospheric pressure and temperature, adjusting for environmental factors, and analyzing uncertainties. Some key takeaways include:

- Applying corrections for latitude and temperature is essential to improve measurement accuracy.
- Statistical methods like mean, standard deviation, and uncertainty analysis help make sense of the data.
- Older equipment introduces inconsistencies, reinforcing the need for regular calibration or updated tools.
- Convergence tests showed that taking more samples leads to more reliable results.

In the end, while our instruments had their flaws, the data analysis techniques helped us extract meaningful and reliable results. Using more modern equipment in the future could further reduce uncertainties and improve accuracy.

XI. Appendix

A. Raw Data

AE 303, Tuesday Class, Lab 1

Date: February 21, 2025

Group 1 Name List

Name	Barometer Reading (inch)	Barometer Reading (mm)	Thermometer Reading (°F)	Your signature
Aldulimi, Talal	29.92	760.1	73	Talal
Alfar Diaz, Majied Majdi	29.95	761	73	Majied
Andersen, Jaxon Bryden	29.95	761.0	73	Jaxon
Anjum, Muhammad	29.95 29.97	760.8 761	73 81°	MA
Arzillo, Joseph Paul	29.96	760.8	73	Joseph Arzillo
Barichievich, Ethan Sloan	29.95	761.0	73	Ethan Sloan
Beardsley, Jordyn Kayla	29.92	760.9	73°	Jordyn
Bento, Lorenzo Joaquin	29.92	760.0	73°	Lorenzo
Carmon, Samuel Joseph	29.96	760.0	73°	Samuel
Chiavetta, Amelia Marie	29.94	761.0	73°	Amelia
Crook, Mason Charles	29.96	760.0	73°	Mason
Eckenburg, Sam Austin	29.95	761.0	73°	Sam
Ellison, Cole Anthony	29.95	761.0	73.0°	Cole
Estrella Jr, Rogelio S	29.97	760.9	79.0°	Rogelio
Figone, Jake Ryan	29.96	760.6	73°	Jake
Fisher, Mitchell	29.95	760.6	73°	Mitchell
Foxhoven, Alexander Leo	29.96	760.8	73°	Alexander
Gangavarapu, Laasya	29.98	761.0	73°	Laasya
Gentner, Harold	29.97	761.0	73°	Harold
Goulart, Sofia	29.60	760.0	73°	Sofia

Fig. 4 Student Datasheet with recorded raw data. (Page 1 of 3)

~~San Diego~~ ~~144~~ ~~50 N~~
~~Level~~ ~~412°~~

San Diego: 32.7157° N, 117.1611° W

32.1740 ft/s²

GRAVITY CORRECTION TABLE — Table 2 — English System

To reduce the reading of the barometer to standard gravity = 9.80665 m/s² at 45°

Latitude	Observed Reading of the Barometer in Inches										
	20"	21"	22"	23"	24"	25"	26"	27"	28"	29"	30"
	LATITUDE 0° TO 45° THE CORRECTION IS TO BE SUBTRACTED										
	LATITUDE 46° TO 90° THE CORRECTION IS TO BE ADDED										
0°	-.054	-.056	-.059	-.062	-.064	-.067	-.070	-.072	-.075	-.078	-.080
5	.053	.055	.058	.061	.063	.066	.069	.071	.074	.077	.079
10	.050	.053	.055	.058	.060	.063	.066	.068	.071	.073	.076
15	.047	.049	.051	.053	.056	.058	.060	.063	.065	.067	.070
20	.041	.043	.045	.047	.050	.052	.054	.056	.058	.060	.062
25	.035	.037	.038	.040	.042	.043	.045	.047	.049	.050	.052
30	.027	.029	.030	.031	.033	.034	.035	.037	.038	.040	.041
32	.024	.025	.026	.028	.029	.030	.031	.032	.034	.035	.036
34	.021	.022	.023	.024	.025	.026	.027	.028	.029	.030	.031
36	.017	.018	.019	.020	.021	.022	.022	.023	.024	.025	.026
38	.014	.014	.015	.016	.016	.017	.018	.018	.019	.020	.020
40	.010	.011	.011	.012	.012	.013	.013	.014	.014	.015	.015
42	.006	.007	.007	.007	.008	.008	.008	.009	.009	.009	.010
44	-.003	-.003	-.003	-.003	-.003	-.003	-.004	-.004	-.004	-.004	-.004
46	+0.001	+0.001	+0.001	+0.001	+0.001	+0.001	+0.001	+0.001	+0.001	+0.001	+0.001
48	.005	.005	.005	.005	.006	.006	.006	.006	.006	.007	.007
50	.008	.009	.009	.010	.010	.010	.011	.011	.012	.012	.012
55	.017	.018	.019	.020	.021	.021	.022	.023	.024	.025	.026
60	.026	.027	.028	.029	.031	.032	.033	.034	.036	.037	.038
65	.033	.035	.036	.038	.040	.041	.043	.045	.046	.048	.050
70	.040	.042	.044	.046	.048	.050	.052	.053	.055	.057	.059
75	.045	.047	.049	.052	.054	.056	.058	.061	.063	.065	.067
80	.049	.051	.054	.056	.059	.061	.063	.066	.068	.071	.073
85	.051	.054	.056	.059	.061	.064	.067	.069	.072	.074	.077
90	+0.052	+0.055	+0.057	+0.060	+0.062	+0.065	+0.068	+0.070	+0.073	+0.075	+0.078

Fig. 5 Gravity Correction Table used for latitude adjustments.

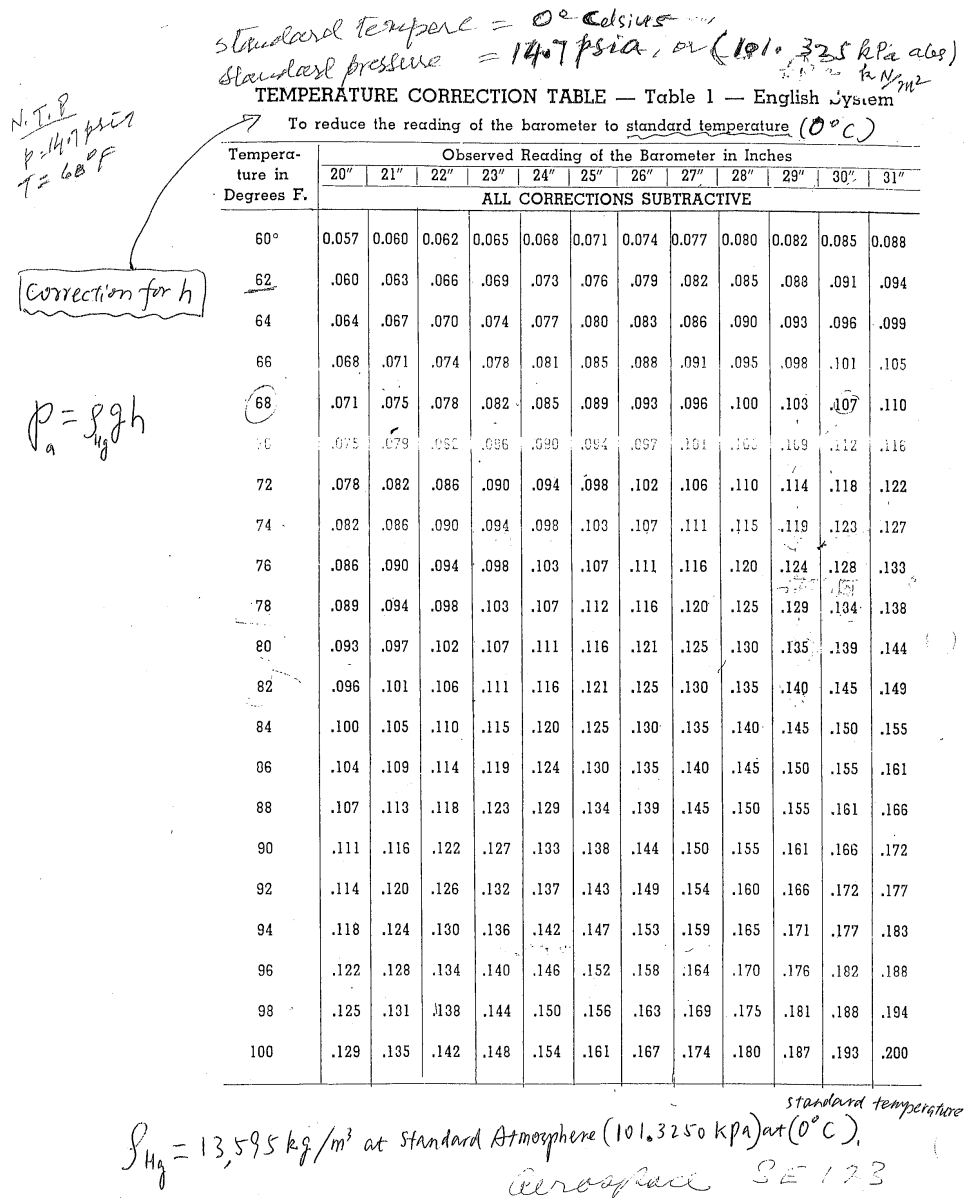


Fig. 6 Temperature Correction Table used for atmospheric pressure adjustments.

B. MATLAB Code

```
%% AE 303 Lab 1
```

```
% Author: Parham Khodadi
```

```
clear; clc;
```

```
%% Step 1: Load Student Data
```

```
% Load the student data (Temperature and Barometric Pressure)
```

```
student_data = readmatrix('Student_Data.csv'); % Columns: Temp_F, P_inHg, P_mmHg
```

```

Temp_F = student_data(:,1); % Temperature in Fahrenheit
P_inHg = student_data(:,2); % Atmospheric Pressure in inches of Hg
P_mmHg = student_data(:,3); % Atmospheric Pressure in mmHg (for Table 3)

%% Step 2: Load Correction Tables
% Load the gravity correction table
gravity_corr = readmatrix('Gravity_Correction.csv'); % Columns: Latitude, 20in–30in
latitude = 32.7; % Latitude for San Diego
gravity_values = gravity_corr(:,2:end); % Correction values for barometer readings
barometer_readings = 20:30; % Barometric readings in inches of Hg

% Load the temperature correction table
temp_corr = readmatrix('Temperature_Correction.csv'); % Columns: Temp_F, 20in–31in
temp_corr_values = temp_corr(:,2:end); % Correction values for barometer readings
temp_corr_readings = 20:31; % Barometric readings in inches of Hg

%% Step 3: Apply Latitude and Temperature Corrections
% Latitude (Gravity) Correction
[~, closest_lat] = min(abs(gravity_corr(:,1) - latitude)); % Closest latitude row
gravity_factors = gravity_values(closest_lat, :); % Correction factors for given latitude
gravity_correction = interp1(barometer_readings, gravity_factors, P_inHg, 'linear', 'extrap');

% Apply Gravity Correction
P_corrected_inHg = P_inHg + gravity_correction;

% Temperature Correction
temp_correction = zeros(size(Temp_F));
for i = 1:length(Temp_F)
    % Find the closest temperature row
    [~, closest_temp] = min(abs(temp_corr(:,1) - Temp_F(i)));
    temp_correction(i) = interp1(temp_corr_readings, temp_corr_values(closest_temp, :), P_inHg);
end

% Apply Temperature Correction
P_corrected_inHg = P_corrected_inHg + temp_correction;

% Convert to Pascals (Pa)
P_corrected_Pa = P_corrected_inHg * 3386.39;

%% Step 4: Convert Temperature to Kelvin
Temp_C = (Temp_F - 32) * 5/9; % Convert Fahrenheit to Celsius
T_kelvin = Temp_C + 273.15; % Convert Celsius to Kelvin

%% Step 5: Compute Air Density using Ideal Gas Law:  $\rho = P / (R * T)$ 
R_air = 287.058; % Gas constant for air (J/kg/K)

% Compute air density (rho_air) using corrected pressure and temperature
rho_air = P_corrected_Pa ./ (R_air * T_kelvin);

%% Step 6: Compute Statistical Metrics
N = length(Temp_F); % Number of samples
mean_T = mean(Temp_F);
std_T = std(Temp_F);
std_T_mean = std_T / sqrt(N);

```

```

mean_P = mean(P_corrected_Pa);
std_P = std(P_corrected_Pa);
std_P_mean = std_P / sqrt(N);

mean_rho = mean(rho_air);
std_rho = std(rho_air);
std_rho_mean = std_rho / sqrt(N);

%% Step 7: Generate Tables for LaTeX
% Table 1: One-Time Sample Uncertainty
header1 = {'T_(F)', 'P_(inHg)', 'P_(Pa)', 'Density_(kg/m^3)'};
table1 = [mean_T, mean_P / 3386.39, mean_P, mean_rho];
writecell([header1; num2cell(table1)], 'Table1_OneTimeSample.csv');

% Table 2: Ensemble Average Uncertainty
header2 = {'T_(F)', 'P_(inHg)', 'P_(Pa)', 'Density_(kg/m^3)'};
table2 = [mean_T, mean_P / 3386.39, mean_P, mean_rho];
writecell([header2; num2cell(table2)], 'Table2_EnsembleAverage.csv');

% Table 3: Measurement Resolutions
header3 = {'T_Resolution_(F)', 'P_Resolution_(inHg)', 'P_Resolution_(mmHg)', 'Density_Resolution_(kg/m^3)'};
resolution_table = [std_T, std(P_inHg), std(P_mmHg), std(rho_air)];
writecell([header3; num2cell(resolution_table)], 'Table3_Resolution.csv');

%% Step 8: Plot Convergence Test
figure;
subplot(3,1,1);
plot(1:N, cumsum(P_corrected_Pa) ./ (1:N)', 'b', 'LineWidth', 1.5);
xlabel('Sample_Size');
ylabel('Running_Mean_(Pa)');
title('Convergence_Test_Mean');

subplot(3,1,2);
plot(1:N, sqrt(cumsum((P_corrected_Pa - mean_P).^2) ./ (1:N)'), 'r', 'LineWidth', 1.5);
xlabel('Sample_Size');
ylabel('Running_Std_Dev_(Pa)');
title('Convergence_Test_Std_Dev');

subplot(3,1,3);
plot(1:N, sqrt(cumsum((P_corrected_Pa - mean_P).^2) ./ (1:N)) ./ sqrt(1:N)', 'g', 'LineWidth', 1.5);
xlabel('Sample_Size');
ylabel('Running_Std_Dev_of_Mean_(Pa)');
title('Convergence_Test_Std_Dev_of_Mean');
saveas(gcf, 'convergence_plot_updated.png');

```