Comparing NACA0012 Characteristics Using Pressure Taps in a Wind Tunnel

Borg, Auston J. Lam, Brandon H. Latzko, Alexander J.
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***Abstract*—**

***Index Terms*—**

I. Introduction

INTRO

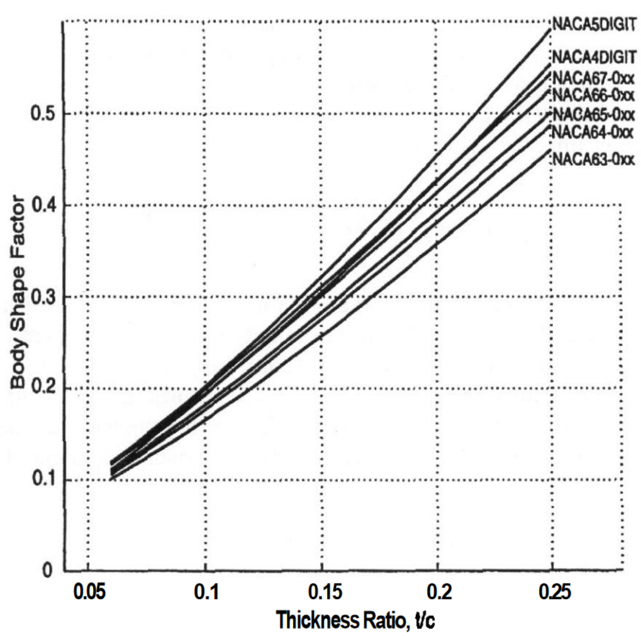

Fig. 1. Body shape factor for common airfoil shapes [?].

II. Procedure

A. s1

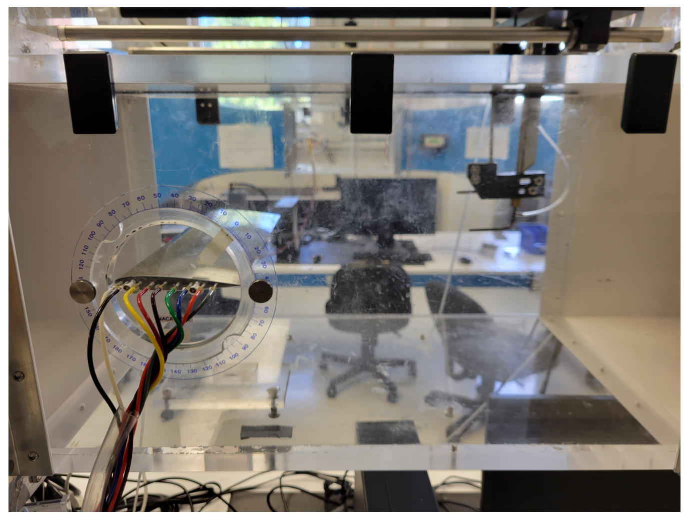

Fig. 2. Wind tunnel test section with NACA0012 airfoil installed. The airfoil is oriented at an angle of attack of zero degrees.

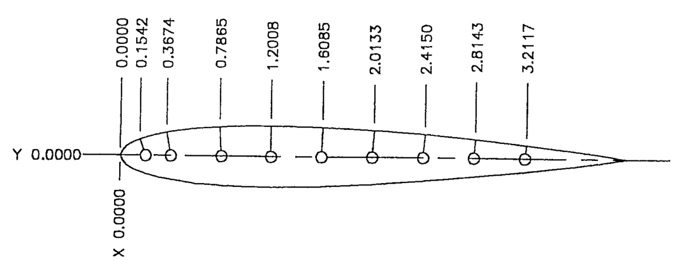

Fig. 3. Pressure tap locations for the NACA 0012 airfoil used in this experiment. The chord of the airfoil is 4 inches [?].

III. Results

The ambient pressure, P_{amb}, of the room was measured using a wall-mounted barometer. The temperature, T, and the relative humidity, φ, of the room was measured using a digital thermometer and hygrometer placed next to the test section. The measured atmospheric conditions are summarized in Table I.

TABLE I
ATMOSPHERIC CONDITIONS

Parameter	Value	Uncertainty ($\pm$)
P_{amb}	767.70 mmHg	0.02 mmHg
T	21.1 °C	0.1 °C
φ	49%	1%

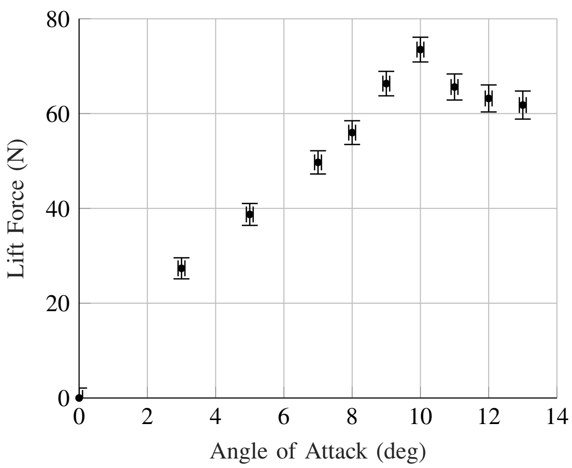

Fig. 4. Lift force.

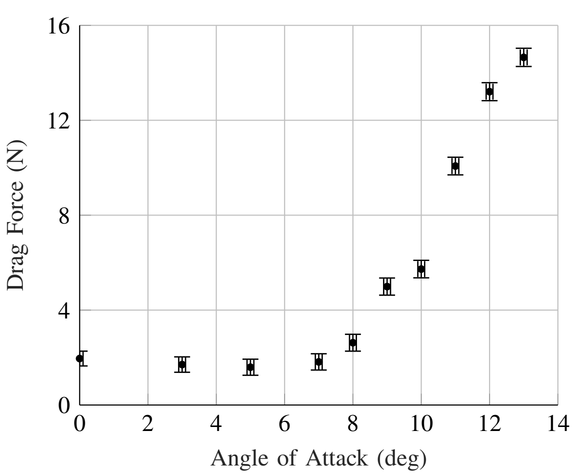

Fig. 5. Drag force.

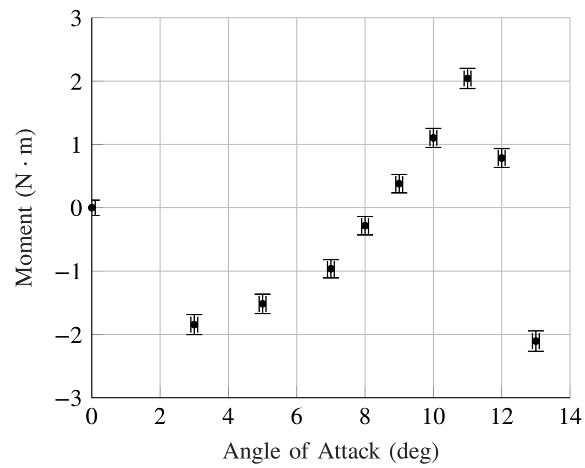

Fig. 6. Moment.

IV. Discussion

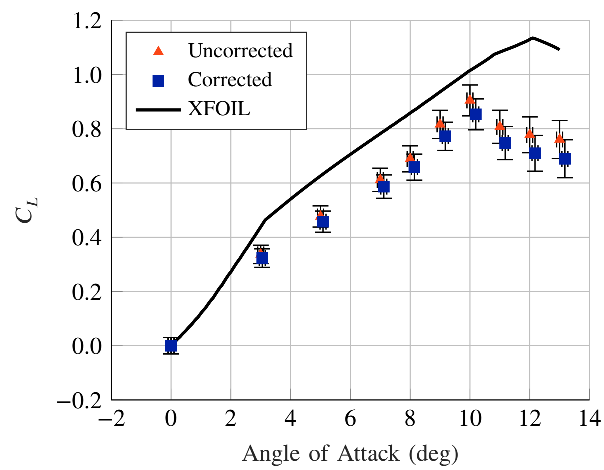

Fig. 7. Lift.

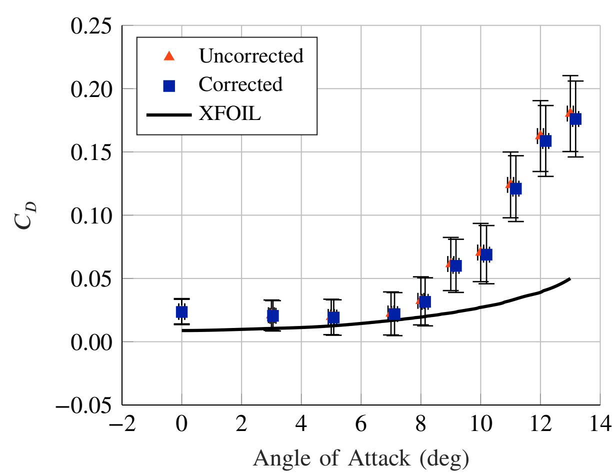

Fig. 8. Drag.

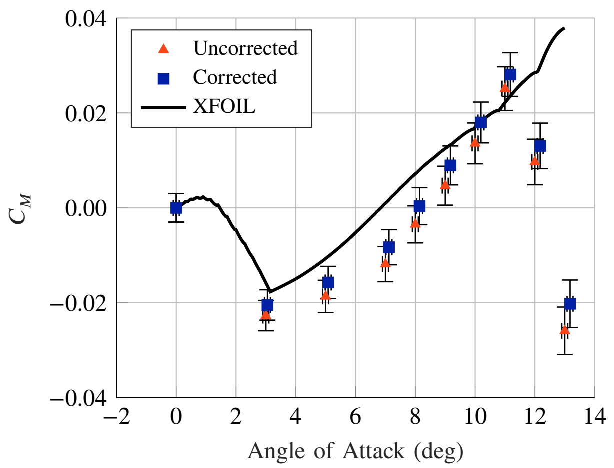

Fig. 9. Moment.

V. Conclusion

Appendix A: Uncertainty Calculations

TABLE II
Summary of Measurement Uncertainties

Parameter	Symbol	Justification	Uncertainty (±)
Temperature	μT	Digital	0.1 °C
Humidity	$\mu\varphi$	Digital	1%
Ambient Pressure	μP_{amb}	Barometer	0.02 mm
Static Pressure Difference	$\mu\Delta P$	95% Conf. Int.	Variable
Voltage	μV	95% Conf. Int.	Variable
Dynamic Pressure	μq	RSS	Variable
Saturation Pressure	μP_g	RSS	16 Pa
Density	$\mu\rho$	RSS	0.004 kg/m^3
Calibration Velocity	$\mu\upsilon_c$	RSS	~ 0.04 m/s
Interpolated Velocity	$\mu\upsilon$	Largest Percent Error	0.5%
Freestream Velocity	μU_∞	RSS	0.04 m/s
Characteristic Length	μL	Ruler	0.5 mm
Kinematic Viscosity	$\mu\nu$	[1]	2×10^{-9} m^2/s
Reynolds Number	μRe	RSS	938
Height	μh	Ruler	0.05 cm
Instantaneous Velocity	μU_2	95% Conf. Int.	Variable
Drag Force	μF_D	RSS	0.070 N
Coefficient of Drag	$\mu\upsilon$	RSS	0.065

The uncertainties for each measured value are summarized in Table II. First, the systemic bias in the reading of the transducer pressures and the voltage readings was accounted for by zeroing the respective values in the LabVIEW VI. The random uncertainty for each reading was then obtained by using a 95% confidence interval with a normal distribution. Because a sample size of 20000 was used for each reading, it was determined to be sufficiently large that the sample distribution approached the normal distribution according to the central limit theorem [2]. A z^* value of 1.96 was used for the calculation of the 95% confidence interval [2]. The margin of error then served as the uncertainty as seen in (1), where μX is the margin of error for an arbitrary measurement, S_x is the sample standard deviation, and n is the number of samples [2].

$$\mu X = z^* \frac{S_x}{\sqrt{n}} \tag{1}$$

The uncertainties in the calculated dynamic pressures, q, were then calculated using the root sum squared (RSS) method as seen in (2), where ΔP is the change in stagnation pressure and k is the tunnel calibration coefficient that was determined in the first lab experiment [2].

$$\mu q = \left[\left(\mu\Delta P\frac{\partial q}{\partial \Delta P}\right)^2 + \left(\mu k\frac{\partial q}{\partial k}\right)^2\right]^{1/2} \tag{2}$$

The uncertainty in the saturation pressure, P_g, was determined using error propagation theory as seen in (3), where T is the ambient temperature [3].

$$\mu P_g = \mu T\frac{\partial P_g}{\partial T} \tag{3}$$

The uncertainty in the fluid density, ρ, was calculated using the RSS method as seen in (4), where P is the ambient pressure, T is the ambient temperature, φ is the relative humidity, and P_g is the saturation pressure [2].

$$\mu\rho = \left[\left(\mu P\frac{\partial\rho}{\partial P}\right)^2 + \left(\mu T\frac{\partial\rho}{\partial T}\right)^2 + \left(\mu\varphi\frac{\partial\rho}{\partial\varphi}\right)^2 + \left(\mu P_g\frac{\partial\rho}{\partial P_g}\right)^2\right]^{1/2} \tag{4}$$

The uncertainty for the fluid velocity used in the calibration of the hot wire anemometer, υ_c, was then calculated using the RSS method as seen in (5), where q is the dynamic pressure, ρ is the fluid density, and V is voltage from the hot wire anemometer obtained from the fourth-order polynomial fit [2].

$$\mu\upsilon_c = \left[\left(\mu q\frac{\partial\upsilon_c}{\partial q}\right)^2 + \left(\mu\rho\frac{\partial\upsilon_c}{\partial\rho}\right)^2 + \left(\mu V\frac{\partial\upsilon_c}{\partial V}\right)^2\right]^{1/2} \tag{5}$$

Then, to obtain the uncertainty for the interpolated fluid velocities, υ, the greatest percent error from the calibration of the hot wire anemometer was used to simulate the worst-case deviation for all the interpolated velocities using the calibration curve.

The uncertainty for the Reynolds number, Re, was calculated using the RSS method as seen in (6), where U_∞ is the freestream velocity, ν is the dynamic viscosity of the fluid, and L is the characteristic length [1].

$$\mu Re = \left[\left(\mu\nu\frac{\partial Re}{\partial\nu}\right)^2 + \left(\mu U_\infty\frac{\partial Re}{\partial U_\infty}\right)^2 + \left(\mu L\frac{\partial Re}{\partial L}\right)^2\right]^{1/2} \tag{6}$$

To obtain the uncertainties for the instantaneous velocity, a 95% confidence interval was used. The sample size of the data was larger than 1000, so a normal distribution was used. For a 95% confidence interval, the corresponding z^* value of 1.96 was used [2]. Using (1), the uncertainty in each velocity was found.

The uncertainty in the drag force, F_D, was calculated using the RSS method as seen in (7), where q is the dynamic pressure, h is the height of the velocity profile, $U_2(y)$ is the instantaneous velocity, and U_∞ is the freestream velocity.

$$\mu F_D = \left[\left(\mu U_\infty \frac{\partial F_D}{\partial U_\infty}\right)^2 + \left(\mu q \frac{\partial F_D}{\partial q}\right)^2 + \left(\mu h \frac{\partial F_D}{\partial h}\right)^2 + \left(\mu U_2(y) \frac{\partial F_D}{\partial U_2(y)}\right)^2\right]^{1/2} \quad (7)$$

The uncertainty in the drag coefficient, C_D, was calculated using the RSS method as seen in (8), where q is the dynamic pressure, F_D is the drag force, and L is the characteristic length.

$$\mu C_D = \left[\left(\mu F_D \frac{\partial C_D}{\partial F_D}\right)^2 + \left(\mu q \frac{\partial C_D}{\partial q}\right)^2 + \left(\mu L \frac{\partial C_D}{\partial L}\right)^2\right]^{1/2} \quad (8)$$

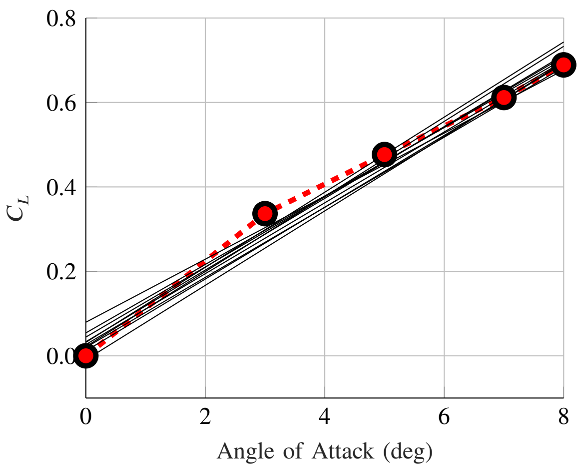

Fig. 10. Monte Carlo simulation of uncorrected coefficient of lift data.

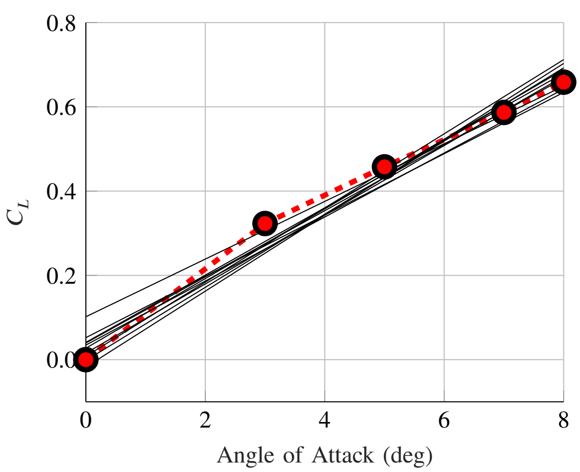

Fig. 11. Monte Carlo simulation of corrected coefficient of lift data.

This lab report was typeset using LaTeX.

References

[1] Bergman, T. L., and Lavine, A. S., “Appendix A: Thermophysical Properties of Matter,” *Fundamentals of Heat and Mass Transfer*, Wiley, Hoboken, NJ, 2017, p. 911.

[2] Ridgeway, S., “MOM_lab Uncertainty basics w tension,” *University of Florida* [PowerPoint slides], URL: https://ufl.instructure.com/courses/447927/files/65674680, 2022.

[3] Ku, H. H., “Notes on the Use of Propagation of Error Formulas”, *Journal of Research of the National Bureau of Standards*, Vol. 70C, No. 4, 27 May 1966, pp. 263–273.