BME 450 Sports Engineering
Fall 2018

Lab 1: Golf Ball Trajectory Measurements and Simulation
Due: Friday, October 12, 2018

1 Overview

The purpose of this lab is to develop an analytical aerodynamic model to predict golf ball trajectories. Such a model allows golfers to practice indoors in virtual environments (e.g., a golf simulator), and may also be used to determine optimal launch conditions of the golf ball (i.e., the set of initial conditions for which the golf ball carries the furthest). Conversely, a measured trajectory can also be used to determine experimental launch conditions and aerodynamic lift and drag coefficients.

Using the aerodynamic forces acting on the golf ball and Newton's Second Law, the equations of motion of the golf ball may be written as ordinary differential equations (ODEs; see lecture notes). Knowing the initial conditions of the golf ball (its translational and angular velocity just after impact), the flight of the golf ball can be integrated through time using a standard ODE solver in MATLAB. Example code is provided on LEARN.

2 Data Collection

Shot data will be collected in the University of Waterloo Golf Teaching and Research Facility (Golf TeRF) golf simulator (MC 2037) on Friday, September 28 beginning at 2 pm. Attendance will be taken. Data to be recorded includes the golf ball launch conditions (ball speed, elevation, azimuth, and spin), the apex (maximum height during flight), and the landing position. At least 10 "good" shots will be collected. Following the lab experiment, the data will be uploaded to LEARN in a CSV file for subsequent analysis.

3 Modelling

Part I

Using the example code, measured launch conditions, and constant aerodynamic coefficients of $C_D = 0.28$, $C_L = 0.25$, and $C_M = 0.1$, plot the simulated golf ball trajectories in Matlab. Use a 3D plot (see *plot3*), and place all the trajectories on the same axes. Label all axes. Do the trajectories appear realistic? Compare with the data collected in the AboutGolf simulator. Do the shots align well? If not, what might be the reasons for the discrepancy between your simulations and the AboutGolf simulations?

Part II

Select one shot (measured launch conditions and your simulated trajectory) and plot its carry distance (i.e., distance in the X direction) as a function of air density, ρ. Use a normalized value of ρ ranging from 0.5 to 1.5 times the default value. Based on your results, explain how playing at different altitudes might affect golf and other sports (e.g. 1968 Summer Olympics in Mexico City).

Part III

Using an optimization algorithm (e.g., *fmincon*), determine the set of constant aerodynamic coefficients that minimizes the difference between your simulated shots and the data recorded in the golf simulator. What were the resulting aerodynamic coefficients? Plot the simulated flights, and label the apexes and landing positions. For comparison, label the apexes and landing positions of the recorded AboutGolf data. Do the simulated flights align well with the collected data? If not, why not?

Part IV

Calculate the mean ball speed from all the shots. Using this ball speed and the aerodynamic coefficients you found in *Part III*, determine the optimal amount of backspin and vertical launch angle to maximize carry distance (assume a straight shot, so no side spin or azimuth). Constrain the optimization to search within 1000-4000 rpm for backspin, and 0-45 deg for launch angle by setting the lower and upper bounds in the *fmincon* function. Comment on your findings (e.g. can these launch conditions be achieved? If so, how? If not, why not?).

4 Report

Include in the report:

- A brief introduction.
- Pertinent figures, properly labeled.
- Include responses to all questions.
- A brief summary of your results with conclusions.
- Include MATLAB code in the appendix.

All reports must be uploaded to the dropbox on LEARN **in pdf format** by 11:59 PM on Friday, Oct 12.