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Lunar Golf Ball Flight Simulation

Link to code repository

The purpose of this project is to model the flight of a golf ball on the Moon, accounting for spherical lunar geometry but neglecting aerodynamic drag. To this end, a six degree-of-freedom (6-DOF) Monte Carlo model was created to accept normally distributed initial conditions and determine the trajectory and orientation of the golf ball.

Table 1 lists the nominal value and uncertainty associated with each input.

Input	Nominal Value	Tolerance (±)
Initial Velocity	85 m/s	5 m/s
Launch Angle	45°	2°
Aiming Misalignment	0°	3°
Initial Spin Rate	2000 rpm	500 rpm
Spin Axis Misalignment	0°	3°

Table 1: Input parameter dispersions

Several assumptions are made in order to simplify the computation.

1. The Moon is a perfect sphere with radius 1737.4 km.
2. Only gravitational acceleration (1.625 m/s^2) acts on the ball after it is launched.
3. The ball does not roll or bounce upon impact with the lunar surface.
4. Spinning has no effect on the trajectory of the ball in the absence of air resistance.

Note that the ball is launched from the equator (0° latitude and longitude) towards the lunar North Pole while spinning about its local z-axis.

The 6-DOF model yields the following results. 500 test cases were analyzed in an effort to ensure a representative spread of data while avoiding excessively expensive computations.

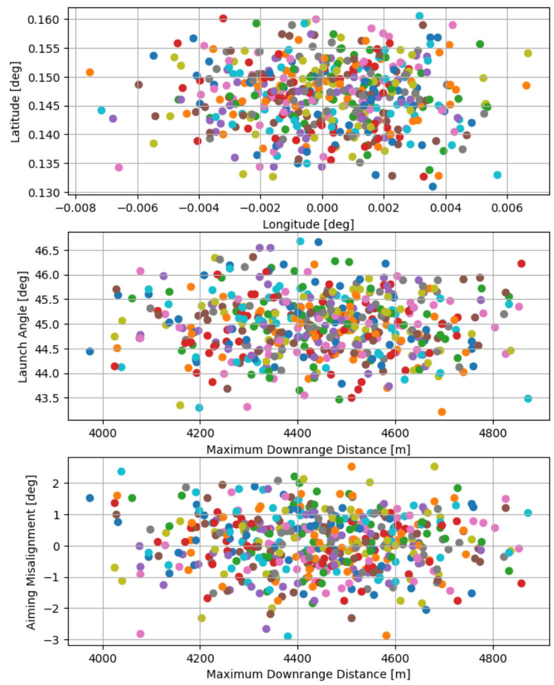

Figure 1: Scatterplots of landing latitude vs. longitude, launch angle vs. downrange distance, and aiming misalignment vs. downrange distance

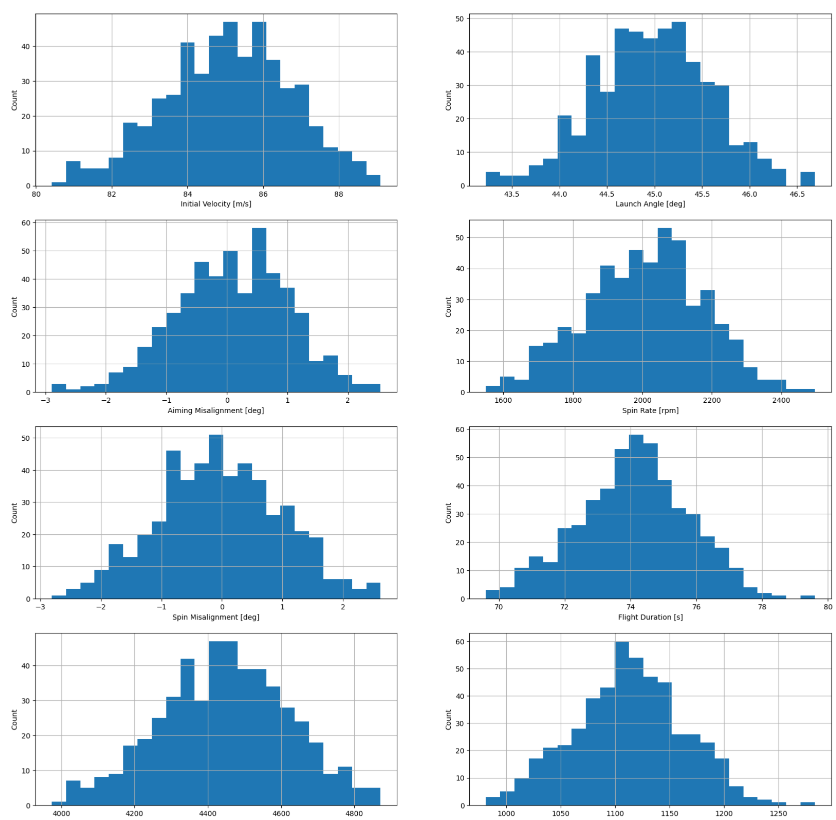

Figure 2: Histograms of input parameters, flight duration, maximum downrange distance, and maximum altitude

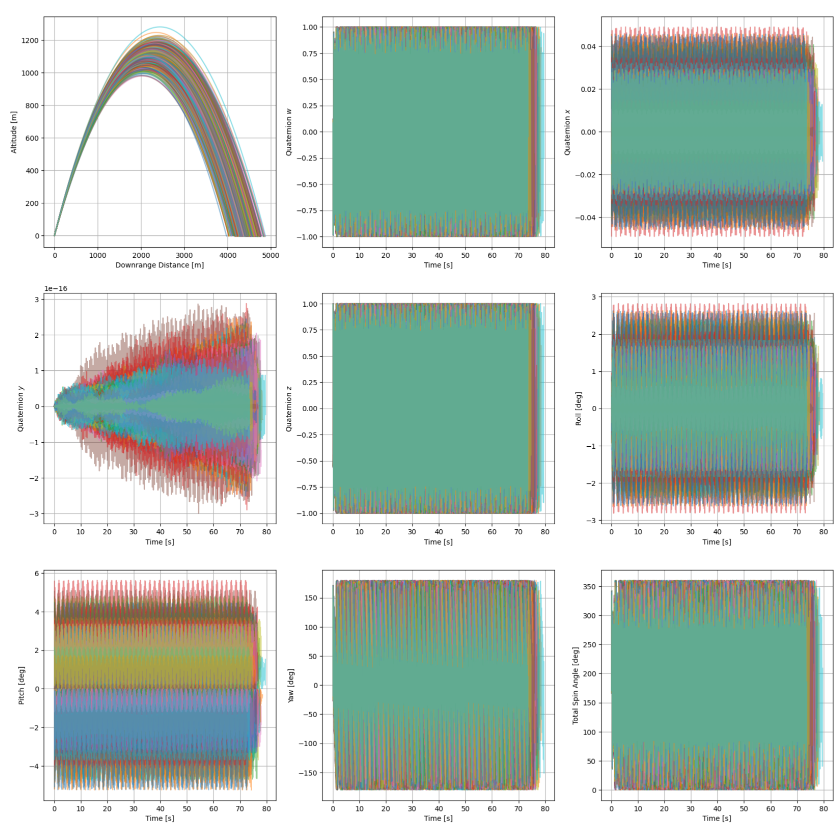

Figure 3: Yarnball plots of altitude vs. downrange distance, quaternion components vs. time, and Euler angles vs. time

There are several results of special interest, which are discussed below. A ‘downsized’ depiction of the yarnball plots is included in the Appendix for better readability of parameter trends.

1. In order to achieve maximum downrange distance, the optimal launch angle is 45°. This ensures that the downrange (x and y) components of the ball’s trajectory are optimized so as to achieve a balance between range and height.

2. The landing position of the golf ball is lower relative to its launch position due to the curvature of the Moon. This manifests in the yarnball plot as a negative final altitude.

3. Since the ball’s spin axis only has nonzero x and z components (assuming a nonzero spin misalignment), the y quaternion is approximately zero. The imaginary $[x, y, z]$ components of a quaternion describe the axis of rotation, while the scalar quantity w represents the extent of rotation.

4. Although the ball primarily spins about its yaw axis, the effects of spin misalignment also propagate to the roll and pitch axes. In the absence of misalignment, the roll and pitch components of the ball would be zero.

This model can be expanded to an atmospheric environment by incorporating aerodynamic effects such as turbulent gusts and the Magnus Effect (i.e., drag).

1 Appendices

A Downsized Yarnball Plots

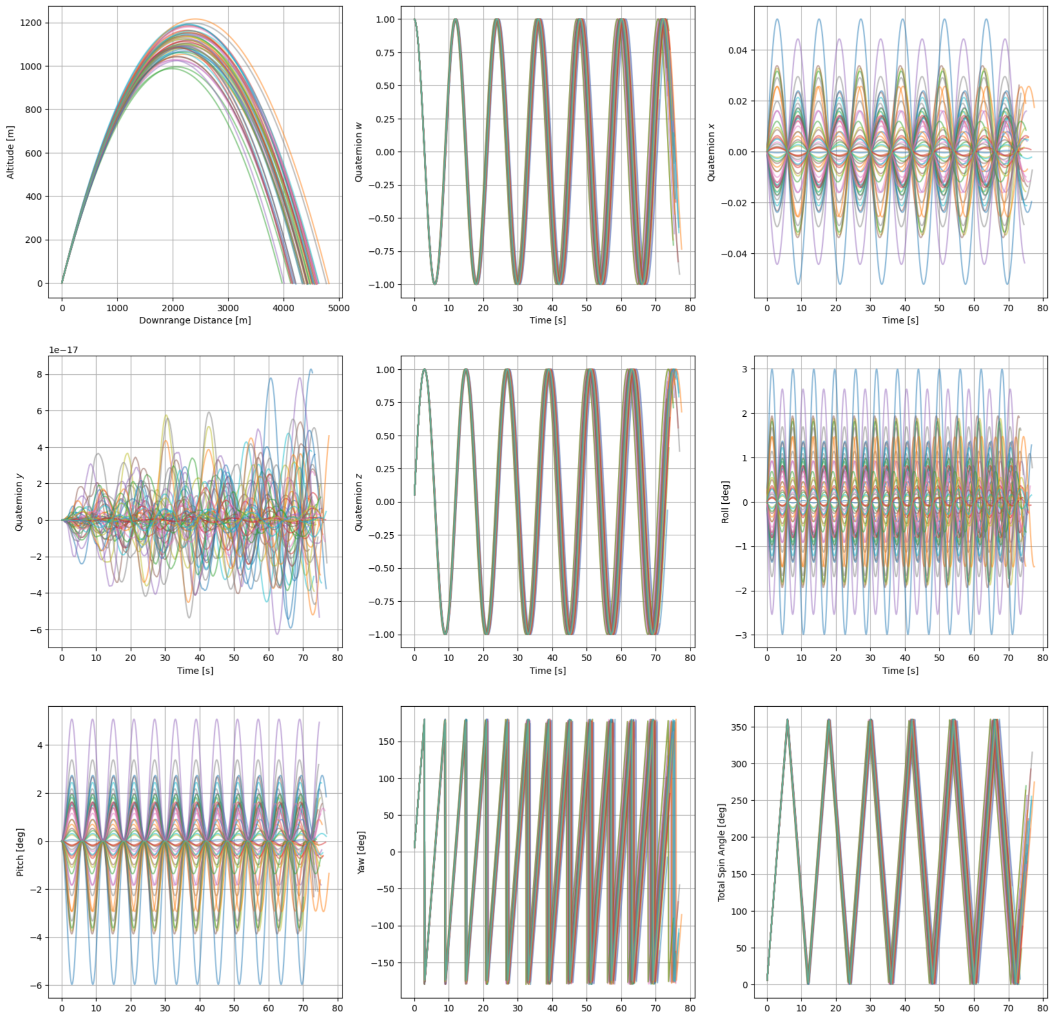

Figure 4: Yarnball plots with 20 test cases, spin rate of 10 rpm, and spin rate misalignment of 0.25 rpm

B 3D Trajectory Plot

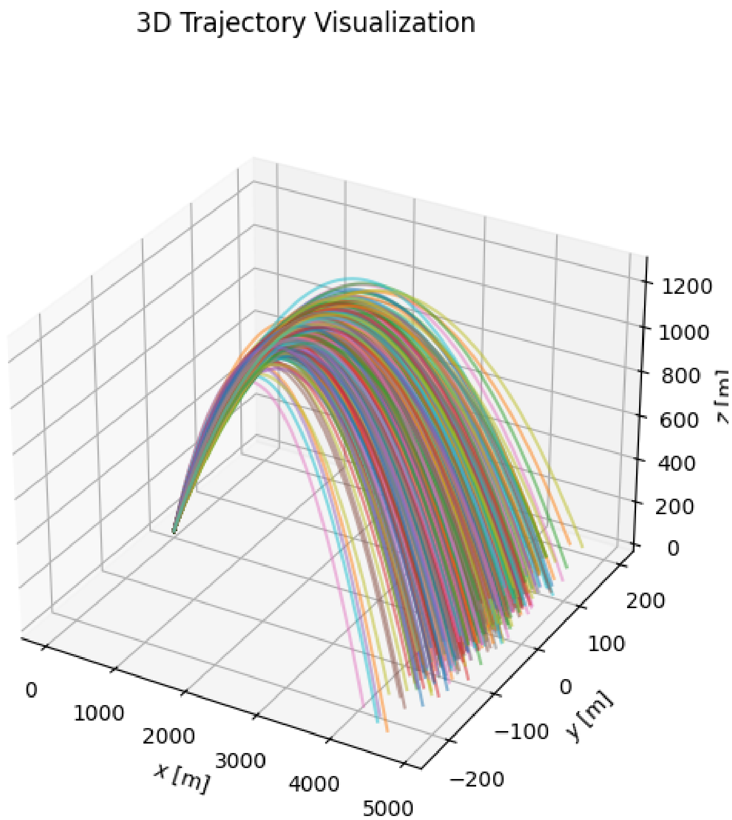

Figure 5: Three-dimensional trajectory of 500 test cases