

**Golf Simulator in Scilab:
Capturing a swing and estimating the carry
with a tiny low-cost Radar**

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ABSTRACT

By using the equations of golf ball flight dynamics, this article demonstrates how to code a swing simulator for a ball in Scilab.

The simulator uses an ODE (ordinary differential equation) solver from Scilab, the fluid dynamics equations on a ball (taking into account gravity, drag forces, and Magnus forces), the restitution of forces from a golf club applied to a ball for launches, its flight, bounce and roll.

In the second part, the article presents a method for capturing the speed of the ball in flight using 2 low-cost radars, coupled with an Arduino Mini and an adapted sound card.

The radar signal is recorded in WAV format and filtered to extract speed and spin information during flight, using spectral density.

Keywords: *Golf Ball, Simulator, Scilab, Radar, Spectral dentistry.*



Chapter 1

Introduction

After spending a few years playing golf, I wanted to learn more about the dynamics of the interactions between the club, the ball, and the elements.

Of course, the academic literature and publications were quite abundant. But I came accross articles [PWB76] written in 1976 and [SS94] in 1994. The description of the ball's physics pushed me to undertake modeling this system in Scilab. Subsequently, I did it in Java, C++, and then C# to use it under *Unity game engine®™*.

When the results were satisfactory, I thought about capturing the flight of a golf ball with instrumentation. After tests with sonar, which were largely insufficient, I took small presence detection radars for automatic doors.

I didn't know what I was getting into, but after a updating my knowledge on signal filtering and a few lines of programming in Scilab, I found a way to capture the essential data. Namely the speed and backspin of the flight of a golf ball.

This article describes all items I found, and how I set all them together. Equations, programs, filtering, estimators and electronics compounents to make a Virtual Golf Simulation.

All the equations presented in this article are derived from public publications or books, with references listed in the bibliography. I will not revisit the demonstrations and physical explanations, as they are not the focus of these pages. What matters to me is the relationship between this information and how I have used or adapted it.



Chapter 2

Golf Ball Flight

The main equation is the ball's flight. The equation accounts 3 forces : Magnus Force, Air Drag Force and gravity, such as :

$$\sum \vec{F} = \vec{F}_m + \vec{F}_d + \vec{F}_g \quad (2.1)$$

2.1 Drag Force

2.1.1 Air characteristics

Definition 1: The Air Drag Force

The Air Drag Force is the resistance exposed on the cross-sectional area of an object, orthogonal to the displacement, determined by the relation given by [BR] as 2.2

$$F_d(V) = -\frac{1}{2} \cdot \rho(T) \cdot C_d \cdot S \cdot V^2(t) \quad (2.2)$$

where:

$$\rho(T) = 1,292 * \frac{273,15}{273,15 + T}$$

$\rho(T)$ = Air density Rho depending on temperature T

T = Temperature

C_d = Drag Coefficient, depending on the object

V = Object's Velocity

$F_d(V)$ = Drag Force due to Air Resistance depending on velocity V

S = The cross-sectional area exposed, orthogonal to the displacement.

2.1.2 Ball's characteristics in the air

Considering those characteristics of a dimpled ball model,



$$\begin{aligned}
 \text{mass } m &= 0,04593 \text{ g} \\
 \text{Dynamic viscosity } \mu &= 1,5 \cdot 10^{-6} \text{ m}^2/\text{s} \\
 \text{Diameter } D &= 0,04267 \text{ m} \\
 \text{Radius } r &= \frac{D}{2} \\
 \text{Inertia } I &= \frac{2}{5} \cdot m \cdot R^2 \\
 \text{Cross-section } S &= \pi \cdot R^2 \\
 \text{Ball Velocity} &= V
 \end{aligned}$$

We have an estimated models,

$$Re = \frac{\rho(T) \cdot V \cdot D}{\mu} \quad (2.3)$$

$$C_d = 0,36 + \frac{24}{Re} + \frac{6}{1 + \sqrt{Re}} \quad (2.4)$$

$$\vec{F}_d = -\frac{1}{2} \cdot \rho(T) \cdot C_d \cdot S \cdot \sqrt{(V(x)^2 + V(y)^2 + V(z)^2)} \cdot \hat{V} \quad (2.5)$$

where,

$$\begin{aligned}
 \hat{V} &= \text{Unit vector of the velocity} \\
 Re &= \text{Reynolds Number estimator} \\
 C_d &= \text{Drag Coefficient White's relation} \\
 \vec{F}_d &= \text{Drag Force}
 \end{aligned}$$

Remark 1: Finally, the equation of the drag Force along the 3-axes becomes 2.6

$$\vec{F}_d = \begin{pmatrix} -\frac{1}{2} \cdot \rho(T) \cdot C_d \cdot S \cdot V_x^2 \\ -\frac{1}{2} \cdot \rho(T) \cdot C_d \cdot S \cdot V_y^2 \\ -\frac{1}{2} \cdot \rho(T) \cdot C_d \cdot S \cdot V_z^2 \end{pmatrix} \quad (2.6)$$

2.2 Magnus Effect

Definition 2: The Magnus Effect | The Magnus [Mag53] effect is due to the spin of a cylindrical object, moving in a fluid (air). It is called the Robin effect for a ball.

But by generalization, the Magnus effect name is applied to any type of object subjected to this suction force. This lift force occurs, altering the ballistic trajectory of the golf ball. The Force depends on the Lift coefficient (C_l), that is associated with the object, according to its shape, nature and texture. So that the force is written as a componant of Object Velocity, SpinRate and a coefficient of Magnus effect C_m (2.7),

$$\vec{F}_m = C_m \cdot (\vec{\omega} \times \vec{V}) \quad (2.7)$$



where,

$$\begin{aligned}\omega &= \text{spin in rad/s} \\ V_p &= r\omega \text{ periferal velocity} \\ V &= \text{Ball Velocity} \\ C_m &= \text{Coefficient of Magnus effect}\end{aligned}$$

The main bibliography for golf ball I used, is [PAL05] and [SS94]. I have found several ways to calculate the C_m , given in expressions bellow. The first simple aproximation is given by 2.8, and the Coefficient of Magnus effect can be given by the first two estimators bellow 2.9, 2.10 ([PAL05]). But I kept this one 2.11 ([SS94], [Ala98]).

$$F_m = \frac{1}{2} \cdot C_m \cdot \rho \cdot \mu^2 \quad (2.8)$$

$$C_m = \frac{r\omega}{V} \quad (2.9)$$

$$C_m = -0,05 + \sqrt{0,0025 + 0,36 \left(\frac{r\omega}{V} \right)} \quad (2.10)$$

$$C_m = 0,5 \cdot \rho(T) \cdot S \cdot R^2 \cdot C_l \cdot \left| \frac{\omega}{V} \right|^{0,4} \cdot V \quad (2.11)$$

$$C_l = \frac{1}{2 + (V/R\omega) * \sin(\zeta)} \quad (2.12)$$

[GAS] gives a correction or adjustment coefficient C_l (2.12) to (2.11), where ζ in Lift Coefficient, is the angle between the axis of rotation and the direction of motion. If $R\omega \ll V$, then $C_l \approx R\omega \frac{\sin \zeta}{V}$. Certainly more appropriate than (2.9) to take into account an effect of side spin and backspin.

$$\sin \zeta = \frac{\|\vec{\omega} \times \vec{V}\|}{\omega \cdot V} = \frac{1}{\omega \cdot V} \cdot \sqrt{((\omega_j \cdot V_k - \omega_k \cdot V_j)^2 + (\omega_k \cdot V_i - \omega_i \cdot V_k)^2 + (\omega_i \cdot V_j - \omega_j \cdot V_i)^2)} \quad (2.13)$$

In order to meet my needs, I have choosen to provide my adapted C_l values to (2.11) instead of (2.12), from tests with my own balls (texture and number of dipples impact Reynolds number (2.3) as shown in [ASC⁺11]). These data are recorded in a Scilab table C_{l1} . C_m becomes (2.14).

$$C_m = 0,5 \cdot \rho(T) \cdot S \cdot R^2 \cdot C_{l1} \cdot \left| \frac{\omega}{V} \right|^{0,4} \cdot V \quad (2.14)$$

With my own Club Mizuno JPX and ball Decathlon :

$$C_{l1} = 'D';'W5';'H3';'I5';'I6';'I7';'I8';'I9';'PW';'AW';'SW';'LW' \quad (2.15)$$

$$0.64; 0.65; 0.54; 0.54; 0.83; 0.42; 0.53; 0.53; 0.52; 0.52; 0.51; 0.51 \quad (2.16)$$

Remark 2: Knowing 2.7 and 2.14 and 2.16, I chose the following Magnus force model

$$\vec{F}_m = \begin{pmatrix} C_m * (\omega_j * v_k - \omega_k * v_j) \\ C_m * (\omega_k * v_i - \omega_i * v_k) \\ C_m * (\omega_i * v_j - \omega_j * v_i) \end{pmatrix} \quad (2.17)$$



2.3 Gravity Force

Definition 3: The gravity force || The gravity force is determined by the acceleration g to the ground.

So that, the expression is simply,

Remark 3: The Gravity Force

$$\vec{F}_g = \begin{pmatrix} 0 \\ -mg \\ 0 \end{pmatrix} \quad (2.18)$$

2.4 Launch Velocity

Due to the impact of the golf club to the ball, it results a ball flight with a launch angle. The club head loft determines the launch angle, the club head speed and the texture of both determine the launch ball speed and ball spin [Pen01].

Due to the texture we have a loss in energy, that can be taken into account through the Coefficient Of Restitution e (COR [LJ94]).

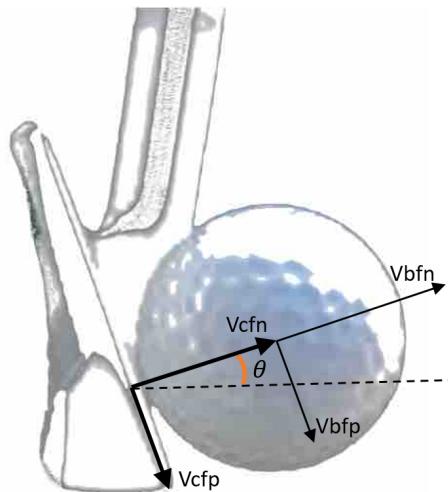


Figure 2.1: Velocity Components

[Pen01] gives an estimation of COR e :

$$e = 0,86 - 0,0029 \cdot V_{ci} \cdot \cos(\theta) \quad (2.19)$$

$$V_{bfn} = V_{ci} \cdot \cos(\theta) \cdot \frac{1+e}{1+\frac{m}{M}} \quad (2.20)$$

$$V_{bfp} = -V_{ci} \cdot \frac{\sin(\theta)}{1+\frac{m}{M}+\frac{5}{2}} \quad (2.21)$$

$$\psi_{bo} = \theta + \tan^{-1}\left(\frac{V_{bfp}}{V_{bfn}}\right) \quad (2.22)$$

$$\omega_{bo} = \omega_{bf} = -m \cdot V_{bfp} \cdot \frac{R}{I} \quad (2.23)$$



where,

- V_{ci} = Initial Club Velocity, parallel to the ground.
 V_{bf_n} = Final Ball Velocity Orthogonal to golf club face
 V_{bf_p} = Velocity of the golf ball, parallel of the club face
 θ = dynamic loft (club loft + Shaft Lean Impact < loft)
 e = COR, $e \approx 0.78$ for Irons, $e \approx 0.83$ for Drives and Woods
 ψ_{bo} = Launch Angle
 ω_{bo} = Spin of the golf ball
 I = Inertia (2.3)

2.5 Miss the sweet spot

It is difficult to perfectly center the ball and the club. The ball velocity model is modified to include a *Miss* parameter. It is the amount by which the sweet spot is missed. The initial ball velocity is (2.24),

$$V_{bi} = (1 - 35.56 * miss) \cdot \sqrt{V_{bf_n}^2 + V_{bf_p}^2} \text{ (miss measured in meter)} \quad (2.24)$$

2.6 Club Face Initial Velocity

Due to the Club Path (α_{cp}) and the Face to Path and Face Angle (γ_{fp}), the initial velocity of the club face restitution is modified.

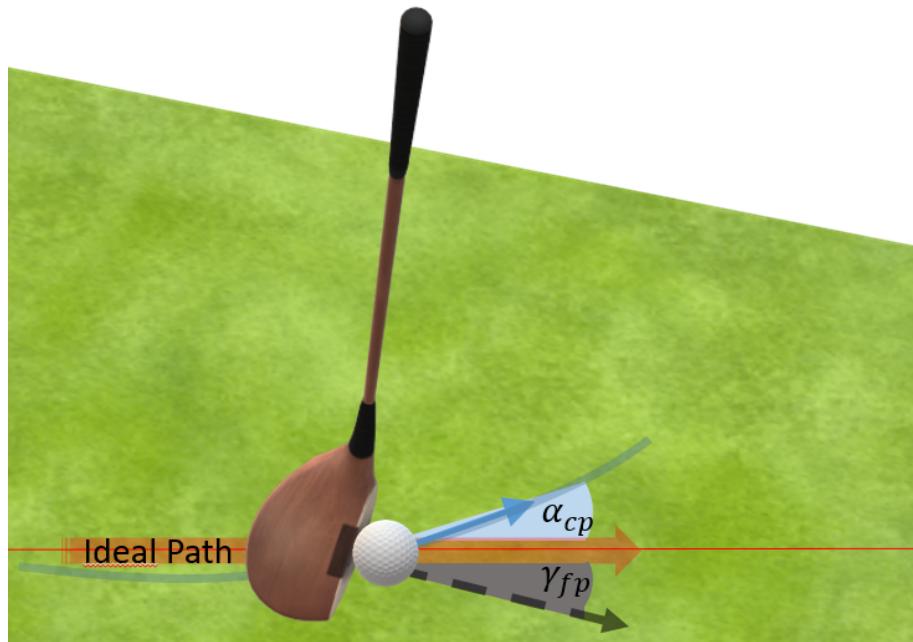


Figure 2.2: Club Path



2.7 Complete Model of flight

2.8 Ball's characteristics bouncing on the grass

[RL10]

2.9 Ball's characteristics rolling on the grass

[Pen02b] [Pen02a]



Chapter 3

Golf Ball Capturing

3.1 section

section

3.1.1 subsection

subsection



Chapter 4

Listings

4.1 Golfball.sci

```
1 // Copyright (C) 2016 - Corporation - Author
2 //
3 // About your license if you have any
4 //
5 // Date of creation: 16 juin 2016
6 //
7 //SCI2C: DEFAULT_PRECISION= DOUBLE
8 //
9 // ReadWave : FFT_Mat.sce
10 //
```

Listing 4.1: Listing of the golf ball fligth

//



Conflicts of Interest

The authors declare no conflict of interest.



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