Dynamic Modelling of Fluid Interactions for Typical Sports Utilities

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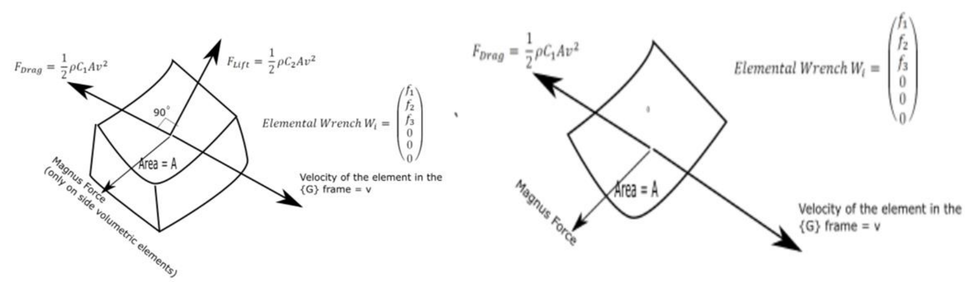
1. Introduction

This paper proposes a novel methodology to predict the motion of an arbitrary shaped body moving under non-vacuum conditions. A combination of the finite element method and screw theory is used to model the solid-fluid interaction to understand the behaviour of a rigid body. The method is specifically developed for two separate systems – one with surface quadrilateral elements and the other with four sided prismatic elements. The methodology allows generalising the forces on the elements rather than using different fluid force variations for different geometries. In the available literature, the force parameters were to be redefined to write the dynamics of a different shaped object. However, the developed method allows us to locally calculate the wrench on each element rather than the complete body. So, the parameters for a given environment needs to be determined only once and can be extended to any shape of rigid bodies following the given particular structure. The methodology was tested against experimental results for the sports utility objects like the Frisbee, football, tennis ball, and a rugby ball. The methodology developed does not require the determination of the secondary coefficients like the pitch moment coefficient and the roll moment coefficient [1].

2. Overview of the Methodology

The rigid body under analysis is either discretised into four sided prismatic element or a surface element. Each discretised element is under the effect of a wrench due to solid-fluid interaction forces. The wrench on each element is a combination of the drag and the lift force acting on each element. We use volumetric element for a Frisbee but surface elements for the balls of all sizes. The use of volumetric elements is preferred over surface elements in Frisbee because it is known that a Frisbee experiences additional lift force due to the pressure difference above and below its surface. Each volumetric element has its own local velocity written in the world fixed frame *{G}*. The volumetric elements experience lift force due to varied air velocities on the top and the bottom surface. The boundary volumetric elements experience Magnus force [2] for an additional side surface is exposed to air (Figure 1(a)). For surface elements, the lift generated by the Magnus force is the effective non-drag force, as only one surface is exposed to air (Figure 1(b)). The net wrench acting on the rigid body is the sum of all the wrenches acting on each element reduced to the centre of mass of the body.



(a) (b)

Figure 1: (a) Elemental forces on boundary (side) volume element of Frisbee (no side force for non-boundary elements); (b) Elemental forces on surface element of balls.

The wrench at each element is $W_i \equiv [f_i, 0]^T$. So, the net wrench acting on the centre with is given in equation 1, where r_i is the radius vector of the ith element with respect to the centre. Each volumetric element has interaction forces of the form shown in figure1.

$$W_{net} = [\sum_{i=1}^{n} f_i, \sum_{i=1}^{n} r_i \times f_i]^T \quad (1)$$

The parameters C_1 and C_2 are determined once for a particular known case and need not be reiterated, i.e., for a given environment the parameters shall not change no matter what is the shape of object as long as the volumetric elements are used. Same parameters are determined once for surface elements as well. Once the body parameters, i.e., the body-axes, mass, and the moment of inertia, and the net wrench at the centre of mass are known, the twist vectors can be determined using numerical techniques.

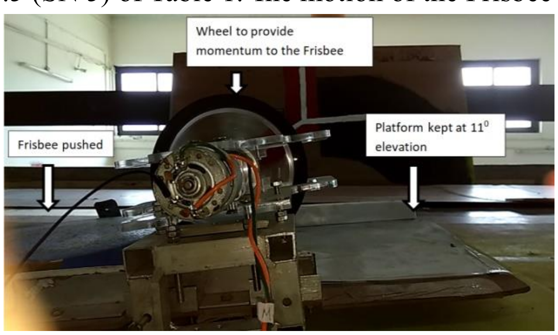
3. Overview of the Results

The trajectory of the Frisbee (mass = 38g) was experimentally determined. The initial velocity of the Frisbee was determined using vision techniques. The angular velocity was determined by assuming no slip condition at the point where the perpendicular wheel, as shown in Figure 2 (a), hits the Frisbee. For the other three cases, i.e., soccer ball, tennis ball, and the rugby ball, the experimental data were taken from [2], [3] and [4] respectively.

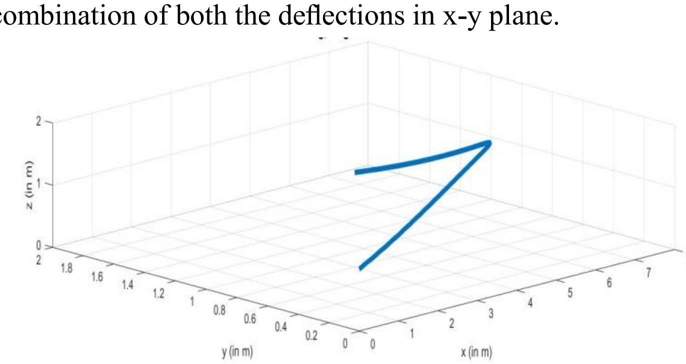
Table 1: Comparison of simulation results with the experiments for various cases (x-Longitudinal Deflection and y – lateral deflection at the end of the trajectory, NA – Not Available)

SN	Object	Details	Simulation (m)		Experimental (m)	
			x	y	x	y
1	Rugby Ball	Screw Kick (Special kick form [4])	43.27	7.037	35-47	-3.7-7.5
2	Tennis Ball	With top spin of 20 rev/s (Velocity = 30 m/s, Elevation = 5.5^0) [3]	11.43	0.001	10.85	NA
3	Tennis Ball	No spin (V=30 m/s, Elevation= 5.5^0)	13.03	0.0001	12.46	NA
4	Frisbee	Angle of attack = 0^0, Pitch = 11^0, V= 7m/s, Omega = 108 rad/s	6.3	0.2841	7.3-8	0.35-0.8
5	Frisbee	Angle of attack= 0^0, Pitch= 20^0, V= 7m/s, Omega=108 rad/s thrown at Height= 1 m	7.472	1.926	Average 9 m	Average 2 m
6	Football	Y deflection at 35 m X deflection for V = 38m/s and ground angle = 12^0 and Vertical Angle = 45^0	-	1.75	-	2.42

Figure 2(b) shows the motion of a Frisbee when thrown at a height of 1m and the initial states were as in serial no.5 (SN 5) of Table 1. The motion of the Frisbee is a combination of both the deflections in x-y plane.



(a)



(b)

Figure 2: (a) The experimental setup; (b) Simulated trajectory

References

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