Sports Biomechanics Lab

Frisbee Flight Simulation and Throw Biomechanics

Research of Sarah Hummel High Flying Frisbee Science

Television story about frisbee research at UC Davis, filmed by Discovery Channel of Canada

Aired November 15, 2002

Wham-O claims that more frisbees are sold each year than baseballs, basketballs and footballs combined. Frisbee sports such as Ultimate Frisbee, Disc-Golf, and Guts have gained world wide popularity. Ultimate and Disc Golf made their first appearance as medal sports at the 2001 World Games in Akita, Japan.

Two brief, somewhat anecdotal, descriptions of the flight dynamics and aerodynamics for the informed layman have been provided by Bloomfield (1999) and Schuurmans (1990). The book by Johnson (1975) is a practitioners' guide including information on the history of the Frisbee, Frisbee games and throwing techniques.

Until recently scientific, quantitative research on frisbee flight mechanics was relatively scarce. Stilley (1972) and Mitchell (1999) used wind tunnel studies to measure the aerodynamic lift and drag forces on the Frisbee as a function of angle of attack, the angle between the velocity vector and the Frisbee plane. More recently Potts and Crowther (2000) have also measured pitching and rolling moments. Our recent investigations derived a dynamic model for Frisbee flight (2000, 2002) and studied the biomechanics of the Frisbee throwing motion (2001).

The end goal of our research is to model the flight of the frisbee and simulate the resulting trajectory for any set of initial release conditions. How a person might produce these release conditions (with the goal of someday being able to throw further) is the aim of the Frisbee biomechanics study.

UC Davis Publications

FRISBEE FLIGHT SIMULATION and THROW BIOMECHANICS

Master's Thesis, 1.95 MB PDF File

FRISBEE FLIGHT SIMULATION

5th MACS Frisbee Simulation PDF File

ADDENDUM to 5thMACS PDF File

This work focuses on developing a three dimensional mathematical model of frisbee flight including the translational and rotational dynamics of the disc driven by the aerodynamic forces and moments. Thus, the flight equations of motion for the Frisbee are derived. These equations are written in terms of 10 aerodynamic coefficients whose magnitudes are unknown. These coefficients can be estimated using experimental flight data. The experimental flight data was collected by placing markers on a frisbee and using a 3-D motion analysis system to track the trajectory of an 18 meter flight. With known aerodynamic coefficients, the flight trajectory can then be simulated for any given set of initial conditions.

A MUSCULOSKELETAL MODEL FOR BACKHAND FRISBEE THROWS

8th ISCSB Frisbee throws PDF File

A kinematic and inverse dynamic analysis has been performed for backhand Frisbee throws. High-speed video cameras were used to acquire joint angle data of the thrower in actual maximum range throws. A dynamic model consisting of 7 rigid bodies and 6 degrees of freedom was created with AUTOLEV. Inverse dynamics techniques were used to determine the joint torques associated with each degree of freedom. The initial flight conditions of the Frisbee were determined from the kinematics of the throw model at the point of release. The model can be used in the optimization of muscular dynamics to obtain release conditions that result in maximum range.

IDENTIFICATION OF FRISBEE AERODYNAMIC COEFFICIENTS USING FLIGHT DATA

ISEA 2002 Frisbee Aerodynamics PDF File

Simulation of a complete flight motion requires knowledge not only of initial conditions, but also the dependence of all forces and moments experienced by the Frisbee due to its dynamic motion through the air. The constants relating the linear approximations of these forces and moments to angles, velocities and angular velocities are called *aerodynamic coefficients*. An approximate flight model requires a minimum of ten coefficients denoted below by the symbol C;

Lift force: $F = (C_{lo} + C_{la}\ a)\ Arv^2/2$

Drag force: $D = [C_{do} + C_{da}\ (a - a_o)^2]\ Arv^2/2$

Rolling moment: $L = [C_{Lr}r + C_{Lp}p]\ Adrv^2/2$

Pitching moment: $M = [C_{Mo} + C_{Mq}q + C_{Ma}a]\ Adrv^2/2$

Spindown moment: $N = C_{Nr}r\ Adrv^2/2$

where F and D are the lift and drag forces; L, M, and N and p, q, and r the roll, pitch and yaw moments and angular velocities , respectively; a_o the angle of attack at zero lift; A and d the Frisbee planform area and diameter, respectively; v the speed and r the atmospheric density.

The Frisbee was marked with three reflective tape markers or emitting LEDs in a triangular configuration on its upper surface. High speed (180 Hz) video kinematic data acquisition cameras and standard DLT techniques were used to record the xyz locations of the three markers on the Frisbee during multiple flights between 2 and 20 meters in length. This position data, with the dynamic flight model (Hubbard and Hummel, 2000), allows the estimation of the aerodynamic force and moment coefficients for a Frisbee in flight using the following iterative algorithm;

1. Guess 12 initial conditions (IC's for 6 rigid body degrees of freedom and 6 associated velocities) for each of n experimental flights and values for the 10 coefficients. This results in a total of 10 + 12n unknown parameters to be estimated. The symbol **p** denotes the vector of parameters.
2. Simulate (integrate the ODE's for) each flight given the parameter vector **p**.
3. Use the simulated state variables to predict the xyz motion of the markers.
4. Calculate the residual (defined as the sum of squared differences between the predicted and measured xyz marker motions for all times over all flights.
5. Using 82 other simulations calculate both the gradient and Hessian of the residual with respect to **p**.
6. Determine a correction to the parameters **p** (both initial conditions and coefficients) that reduces the residual using the method of Hubbard and Alaways (1989).
7. Return to step 2 until the residual is below a desired value.

We found it necessary to use data from several flights containing trajectory information over a wide range of a to yield accurate coefficient estimates. Our results using short flights agree well with linearizations of the measurements of Potts and Crowther (2001) verifying that the method is indeed valid. In fact, this technique is the only way we know to obtain estimates of the coefficients CLr, CLp and CMq, since wind tunnel tests for these are impractical.

REFERENCES:

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Hubbard, M. and L. W. Alaways, Rapid and accurate estimation of release conditions in the javelin throw, J. Biomechanics, 22,(6/7), 583-595, 1989.

Hubbard, M. and S. A. Hummel, Simulation of Frisbee flight, 5th Conference on Mathematics and Computers in Sports, G. Cohen (Ed.), University of Technology, Sidney, Australia, 14-16 June, 2000.

Hummel, S. A. and M. Hubbard, A musculoskeletal model for backhand Frisbee throws, 8th International Symposium on Computer Simulation in Biomechanics, Politecnico di Milano, Milan, Italy, July 5-6, 2001.

Hummel, S. A. and M. Hubbard, Identification of Frisbee aerodynamic coefficients using flight data, 4th International Sports Engineering Conference, Kyoto, Japan, Sept 3-6, 2002.

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Mitchell, T.L., The aerodynamic response of airborne discs, MS Thesis, University of Nevada. Las Vegas, 1999.

Potts, J.R. and W.J. Crowther, The flow over a rotating disc-wing, , RAeS Aerodynamic Research Conf. Proceedings, London, UK April 2000.

Schuurmans, M., "Flight of the Frisbee", New Scientist, July 28, 127 (1727) (1990), 37-40.

Stilley G.D. Aerodynamic Analysis of the Self-Suspended Flare, RDTR No. 199, NAD, Crane, IN, USA, 1972.

OTHER STUDIES:

Curious to know what other types of frisbee related research is going on??

Below is a list of past and current projects I am aware of, if you are doing a project, let me know

and I can add you to the list.

Graduate Research:

Jon Potts (2003)	University of Manchester, England	http://www.disc-wing.com
T.L.Mitchell (1999)	University of Nevada, Las Vegas	The aerodynamics response of airborne discs
Philip W. Cotroneo (1980)	California State University, Hayward	Biomechanical and aerodynamical aspects of the backhand and sidearm frisbee-disc throws for distance

Undergraduate Research:

Brian	Iowa State	Analysis of a flying disc

Danowsky, Babak Cohanim - Senior Project (2002)	University	
Sebastian Olsson, Carina Sjöström, Martin Solli, Christoffer Windahl - Modeling Project (2002)	University of Linköping, Sweden	Frisbee Simulator
Design Class (2002)	Tennessee Tech, Dept of Mech. Eng.	Design of a frisbee thrower
Design Class (2002)	Rensselaer Polytechnic Institute	Design of a frisbee thrower
M.J. Goupell, J.R. Schmidt (2001)	Hope College, Dept of Mathematics	Modeling the flight of a flying disc
Miscellaneous:		
Theo Pozzy		http://home.attbi.com/~tpozzy/prodrives.htm
Peter Lissaman	University of Southern California	
Alan Adler	Superflight INC.	http://www.aerobie.com/aerobie.htm
Greg Utrecht		http://www.geocities.com/gregu10/diskphysics.html
	Newton's Apple	http://mansfieldct.org/schools/MMS/staff/hand/Flightfrisbee.htm#flightangmom.
	Exploratorium	http://www.exploratorium.edu/sports/ask_us_sports_october.html
Louis Bloomfield		http://howthingswork.virginia.edu/balls_birdies_frisbees.html
Dr. Ralph D Lorenz	University of Arizona	http://www.lpl.arizona.edu/~rlorenz/frisbee.html