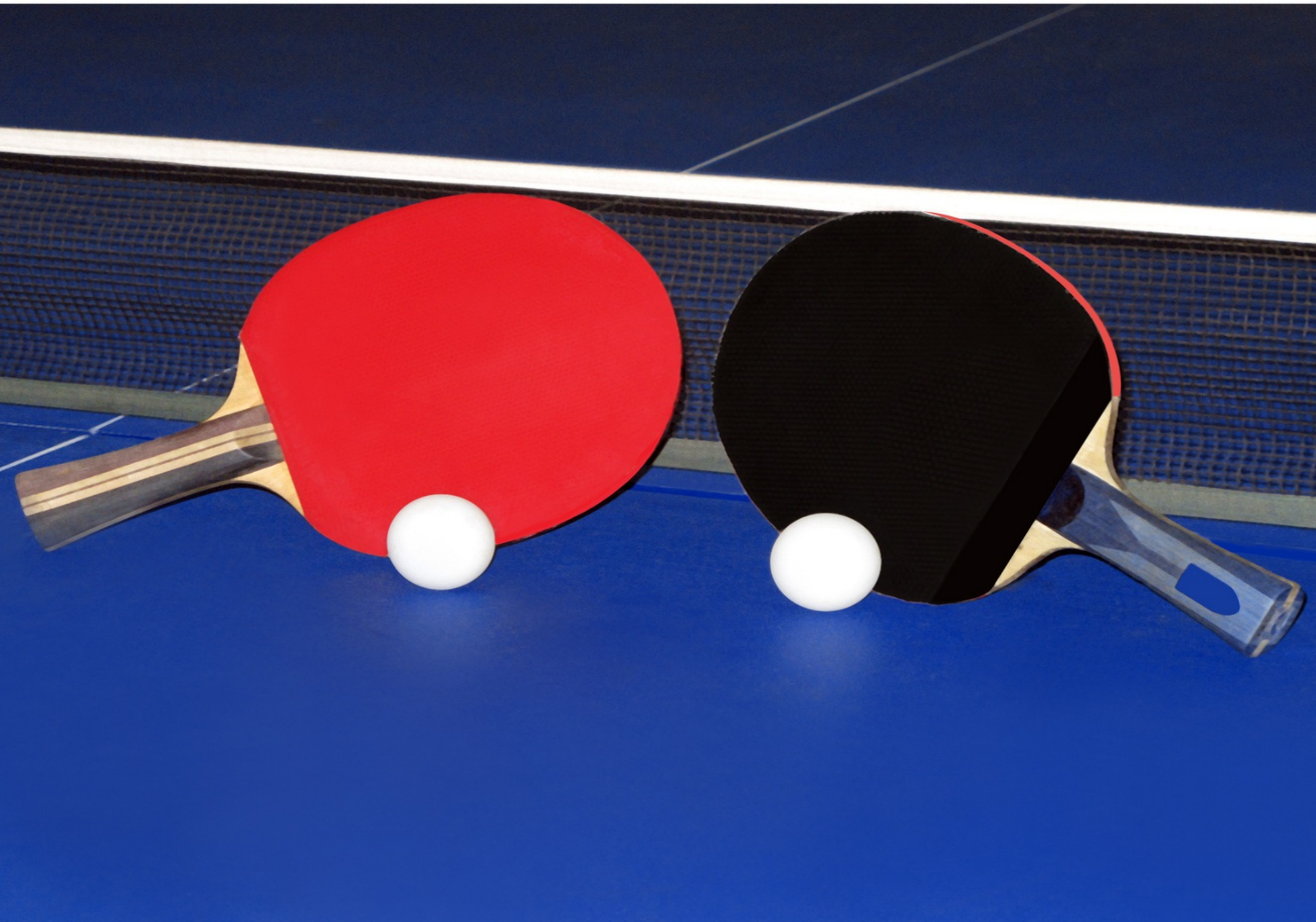
Khanh Tuan Phung

# TABLE TENNIS

## HOW TO CLASSIFY, READ, PREDICT SPINS AND RETURN A SPINNING BALL

Referring to The Principles of Physics



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## HOW TO
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Referring to the Principles of Physics

By Khanh Tuan Phung

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# About the Author

Khanh Tuan Phung
Studied physics in university.
Having played table tennis since childhood
as a hobby and for physical exercises.

## Acknowledgments

Special thanks to Prof. Dr. Miran Kondrič, ITTF Sport Science and Medical Committee Chairman for the supports and advices, especially for the arrangement for the review of the book by the experts in the fields and writing the foreword. Thanks to all the reviewers for the helpful comments on the book.

CONTENTS

## Foreword

The book content is well described with the title. It is addressed to the people involved or want to be involved in table tennis. It is written in popular, descriptive language with avoidance of too many technical terms and equations, maybe in some places for the price of technical clearness but thus closer to general public audience. It describes an overview of the Motions of the Table Tennis Ball and the Racket, Spins of Table Tennis Ball, Reading and Predicting of Spin and other Features of the Ball and Ways of Striking the Ball. The theoretical background and illustrated drawings and photographs in this book are interesting and thought-provoking on various accounts.

The author tries to classify the features of the table tennis game regarding the laws of physics. His intention is to technically explain every possible ball movement, how to read and predict it, and how to strike the ball back. The experienced players know these facts from experience, from trial-and-error learning, but the beginners are sometimes lost when predicting the ball movement. It is clear that a substantial amount of work was put in production of this book and that it was difficult to illustrate various spins and flight paths.

In my opinion the classification is adequate, technically correct and complete, covering all the possible strokes, rebounds, and materials used in table tennis.

*Who will benefit from reading this book?*

- Technically educated beginners (familiar with high-school physics) learning the table tennis game who would like to understand the behavior of the ball translation and rotation during the game.
- The table tennis coaches who would like to understand and who would like to be able to explain the effects of the various ball rotations to players but don't know how to.

- It might be useful as an introductory reading to someone who is interested in making the table tennis computer simulations.

I believe the book is worth reading and I recommend it to the table tennis community as a guide to understanding the ball behavior during the rallies. Many things that players know intuitively are here explained technically, and this can be helpful when figuring out how to pose the racquet when receiving "that annoying" serve the next time.

This book addresses coaches, players, pedagogues, students of physical education at higher education institutions, faculties of physical culture, as well as specialists working in sports science. The book is based on the author's long practical and theoretical experience.

ITTF Sports Science and Medical Committee Chairman
Prof. Miran Kondrič

## Introduction

The table tennis game is considered as the game of speed and spin. Spin - the hidden power of the ball - makes the ball bounce off a returner's racket surface following an unexpected path or trajectory, which is stunningly different from the one that the returner expected it would be.

This book is not dealing with the practical techniques involving the movements of arm and legs for striking the ball and the tactics for playing the game but instead introducing a way based on the principles of physics for classifying, reading and predicting of spins, and ways which could be deemed as a theoretical method for returning a spinning ball based on the motions of the racket and the flight path and spin direction of the ball.

This book consists of the following 4 chapters and 3 annexes:

Chapter 1. Overview of the Motions of the Table Tennis Ball and the Racket. Terminology and References.

Chapter 2. Spins of Table Tennis Ball.

Chapter 3. Reading and Predicting of Spin and other Features of the Ball.

Chapter 4. Ways of Striking the Ball.

Annex 1. Kinds, Features and the Effects of Spins of Table Tennis Ball.

Annex 2. Forces Analysis Method and Illustrations of Forces acting upon RIB (racket-incident-ball) and the resulting Flight Path and Spin of RRB (racket-rebounding-ball).

Annex 3. Illustrations of Racket Shots and the resulting Trajectories and Spins of Returning Ball.

The illustrated drawings and photographs with symbols (vectors, etc.) in this book are not to scale and do not precisely show the features of the ball.

CHAPTER 1

# Overview of the Motions of the Table Tennis Ball and the Racket. Terminology and References

## A. Overview of the Motions of the Table Tennis Ball and the Racket

### 1. Types of Motions of Table Tennis Ball

1.1. When a racket surface hits a table tennis ball, the ball flies and usually spins (rotates) on an imaginary axis passing through the center of gravity of the ball, similar to the Earth which moves around the sun and rotates (spins) on its axis. So, there are two types of motions associated with the table tennis ball:

(1) Flying motion (Translation), and
(2) Spinning motion.

1.2. The basic features of the table tennis ball that should be considered when playing the table tennis game:

(1) Features of Flying Motion:
   i. Shape of trajectory of the ball,
   ii. Angle of incidence (I) of the ball touching the table surface and the racket surface,
   iii. Angle of reflection (R) of the ball bouncing-off (rebounding) the table surface and racket surface,
   iv. Flight speed.

(2) Features of Spinning Motion:
   i. Kinds of spin (Top-Spin, Back-Spin, etc.),
   ii. Spinning speed.

1.3. The features of flying motion and spinning motion, especially the kinds of spin and spinning speed of the ball touching the table surface (table-incident-ball or TIB) and the ball bouncing-off (rebounding) the table surface (table-rebounding-ball or TRB) are different from each other. Axis of spin of the ball may also change during its flight and after the ball touching the table surface or the racket covering surface.

## 2. Types of Motions of Racket Surface

2.1. The motions of a racket covering surface when it is moving to strike the ball are classified into two main types of motion as follows:

(1) Through-The-Center of the Ball Motion (TTC or TTCB Shot), and
(2) Tangential-To-(The)-Surface of the Ball Motion (TTS or TTSB Shot).

# B. Terminology

Following are some terms and abbreviations used in this book and their meanings, which are elaborated for the convenient reference in the process of analyzing the factors that affect the motions of the ball. Other terms, their meanings and abbreviations, if any, are explained in the sections they appear.

## 1. Trajectory of Ball

Trajectory of ball is the flight path of a ball when the ball is bouncing off (rebounding) the racket covering of the player who strikes it until it touches the opponent's racket surface. Flight path of a ball is represented by a line passing through the center of gravity of the ball.[*]

There are two kinds of trajectory of the ball in the table tennis game:

(1) Trajectory of a serving ball (a service): The trajectory of the ball struck by the server to his or her opponent in the service.
(2) Trajectory of a returning ball (a return): The trajectory of the ball, having been served or returned, struck by a returner to his or her opponent.

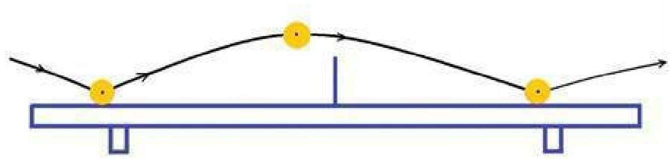

Fig. 1.1. Trajectory of a serving ball (a service).

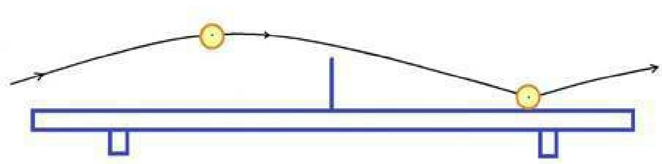

Fig. 1.2. Trajectory of a returning ball (a return).

[*] Explanation of the center of gravity of an object is in Annex 2.

## 2. Incident Ball Flight Path, Rebounding Ball Flight Path and the Normal

2.1. Incident ball flight path is the ball flight path before and until it hits a table surface or a racket covering surface. So, there are two kinds of incident ball flight path:

(1) Table-Incident-Ball Flight Path (TIB flight path),
(2) Racket-Incident-Ball Flight Path (RIB flight path).

2.2. Rebounding ball flight path is the flight path of the ball bouncing off a table surface or a racket covering surface. So, there are two kinds of rebounding ball path:

(1) Table-Rebounding-Ball Flight Path (TRB flight path),
(2) Racket-Rebounding-Ball Flight Path (RRB flight path).

Note:
There are two kinds of TIB (table-incident-ball) and TRB (table-rebounding-ball):

i. TIB and TRB on the table surface side of a server in the serving ball trajectory, and
ii. TIB and TRB on the table surface side of a returner (player who returns the ball to his/her opponent).

TRB (table-rebounding-ball) flight path from a returner’s table court and RIB (racket-incident-ball) path are the same.

2.3. The Normal is the line perpendicular to the table surface or the racket covering surface at the point the ball hits it (point of impact).

## 3. Incident Ball Plane and Rebounding Ball Plane

3.1. Incident ball plane is the plane formed by the incident-ball flight path to the table or the racket surface and the normal. Incident ball plane is perpendicular to the table surface or the racket covering surface. There are two kinds of incident ball plane:

(1) Table-Incident-Ball plane (TIB plane), and
(2) Racket-Incident-Ball plane (RIB plane).

3.2. Rebounding ball plane is the plane formed by the rebounding ball path and the normal. Rebounding ball plane is perpendicular to the table surface or the racket covering surface. There are two kinds of rebounding ball plane:

(1) Table-Rebounding-Ball plane (TRB plane), and
(2) Racket-Rebounding-Ball plane (RRB plane).

Note: Incident and rebounding ball planes of a no-spin or vertical-spin ball are flat planes (Fig.2.3). Those planes of a side-spin ball are curved planes (Fig. 3.13).

## 4. Angle of Incidence (I) and Angle of Reflection (R)

4.1. Angle of incidence (I) of a ball path is the angle forms by the table- or racket – incident-ball path (TIB or RIB path) and the normal at the point of impact. There are two kinds of angle of incidence:

(1) Table angle of incidence, and
(2) Racket angle of incidence.

4.2. Angle of reflection (R) or angle of rebounding ball path is the angle forms by the table or racket covering rebounding ball (TRB or RRB path) and the normal at the point of impact. There are two kinds of angle of reflection:

(1) Table angle of reflection, and
(2) Racket angle of reflection

Note: In case the ball flight path is a curved line, the line tangential to the ball flight path at the ball center of gravity (the velocity vector) at the impact point is used to determine the angle of incidence and reflection.

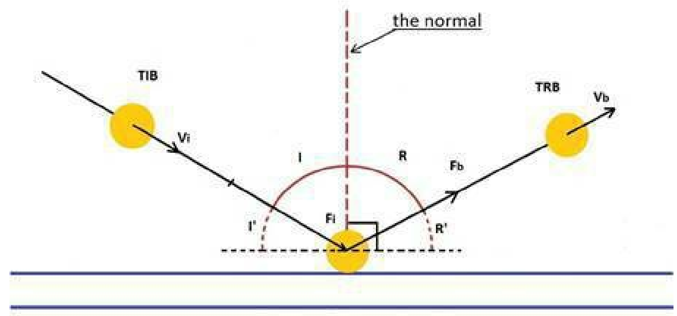


Fig. 1.3. TIB flight path (represented by Vi, Fi) and TRB flight path (by Vb, Fb).The normal. Angle of incidence (I) and reflection (R).

## 5. Axis of Spin of Ball

Axis of spin (or rotation) of a table tennis ball is an imaginary line passing through the center of gravity and two poles of the ball (like the Earth's axis of rotation, the north pole and the south pole) on which the ball is spinning.

Fig. 1.4. The Earth model and a standard table tennis ball, two table tennis balls with painted black dot and circular lines with arrows to represent and show spin-poles, axis of spin (rotation), equatorial spin line, latitudinal spin lines, and direction of spin of the balls.

## 6. Equatorial Spin Line and Latitudinal Spin Line, Equatorial Spin Plane and Latitudinal Spin Plane, Spin-Poles

Following terms are used referring to the names of geographic coordinates applied for the Earth to conveniently specify the features of ball and the techniques of striking the ball.

6.1. Equatorial spin line of ball is a line around the ball similar to the Earth's equator, which is at an equal distance to the two poles.

6.2. Equatorial spin plane of ball is a plane holding the equatorial spin line, perpendicular to the ball’s axis of rotation (spin) and passing through the ball’s center point (center of gravity).

6.3. Latitudinal spin lines are circular lines on the ball surface located on two sides of the equatorial spin line, parallel to each other and to the equatorial spin line, like the Earth’s lines of latitude.

Circumference or the length of latitudinal spin line is shorter than that of the equatorial spin line. The farther apart from the equatorial spin line or the nearer to the poles, the shorter the circumference of a latitudinal spin line is.

6.4. Latitudinal spin plane is a plane holding the latitudinal spin line, perpendicular to the ball’s axis of spin but not passing through the center of the ball as the Equatorial spin plane.

6.5. Spin-Poles are two poles on the ball surface where axis of spin meets the ball surface, like the North Pole and the South Pole of the Earth.

## 7. Vertical-Spin, Inclined-Spin and Horizontal-Spin

The ball when hitting the table surface is said having:

7.1. Vertical-Spin when the ball spin plane (equatorial spin plane) is perpendicular to the table surface or the axis of spin is parallel to the table surface.

7.2. Inclined-Spin when the ball spin plane is not perpendicular to the table surface but forming an acute angle with the table surface.

7.3. Horizontal-Spin when the ball spin plane is almost parallel to the table surface.

Inclined-Spin and Horizontal-Spin are sorted in a type of spin called Side-Spin.

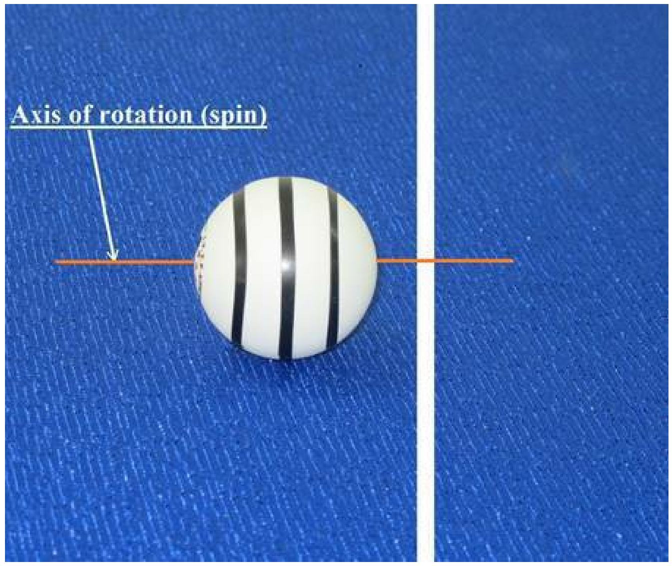


Fig. 1.5. A Vertical-Spin ball having equatorial spin plane perpendicular to table surface, axis of spin parallel to it.

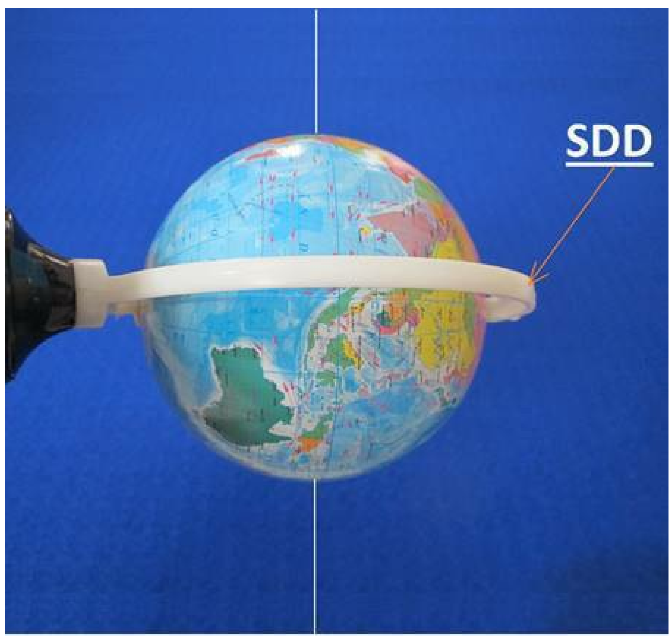


Fig. 1.6. The Earth model is used to help visualize the axis of spin, spin lines, spin and flight direction, and spin-directions-dividing plane (SDD plane) of the ball.

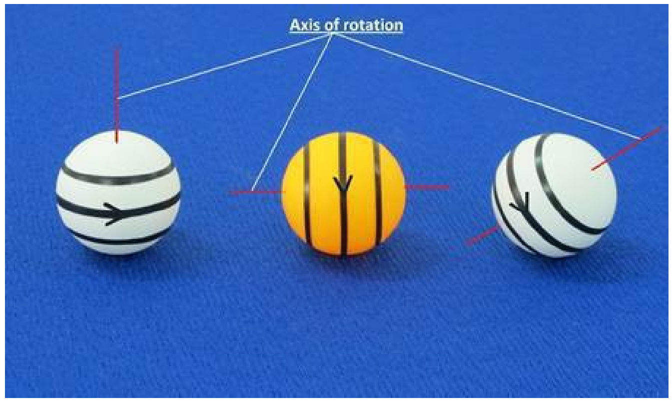


Fig. 1.7. A Horizontal-Spin ball (left), Vertical-Spin ball and an Inclined- Spin ball.

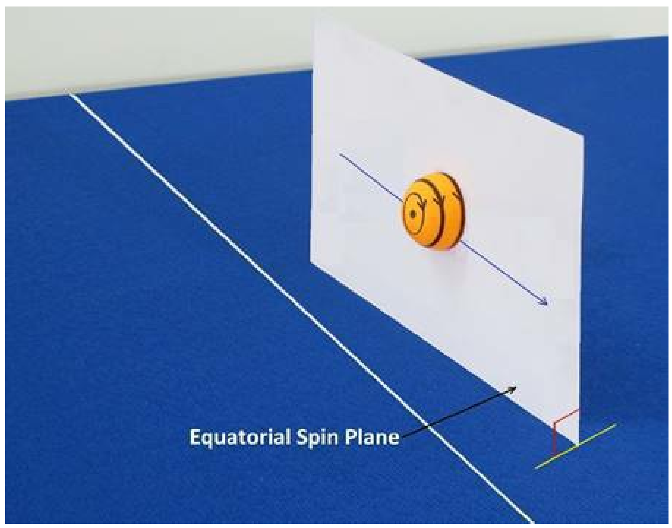


Fig.1.8. Equatorial spin plane holding the equatorial spin line and passing through the ball center.

## 8. Spin-Directions-Dividing Plane of the Ball (SDD Plane)

8.1. SDD (spin-directions-dividing) plane is a plane dividing the spinning ball into two equal halves (half-sphere) in a way that spin direction in one half-sphere is opposite to that of the other half sphere when compared with the ball flying direction.

8.2. SDD (spin-directions-dividing) plane has two basic features:
(1) It holds the axis of spin (rotation) (i.e., the ball axis of rotation lies in this plane) and the through-the-center flying velocity vector of the ball.
(2) It is perpendicular to the Equatorial spin plane.

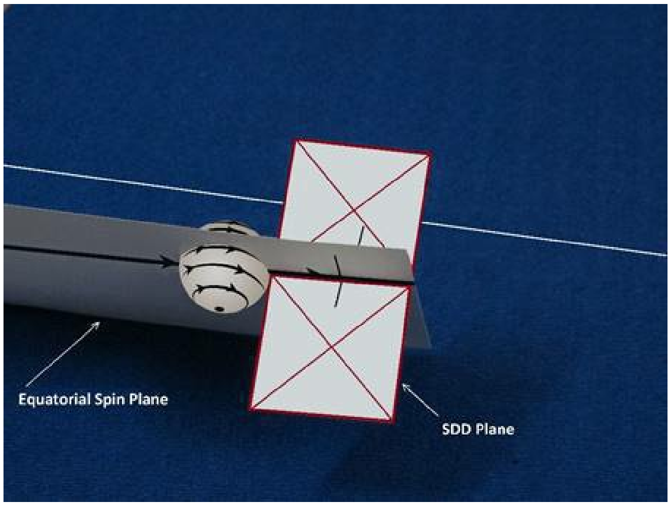


Fig.1.9. SDD (spin-directions-dividing) plane and Equatorial Spin plane.

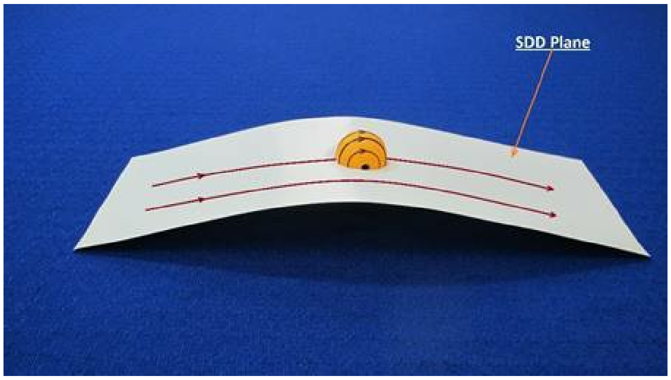


Fig. 1.10. SDD plane is a curved plane when the ball flight path is a curved line.

Note:

SDD plane at a point of time on the ball flight path is a flat plane.

The entire SDD plane is a curved plane when the flight path is a curved line as illustrated in Fig. 1.10.

## 9. Top-Half and Under-Half, Right-Half and Left-Half of a Spinning Ball

9.1. SDD (spin-directions-dividing) plane divides the ball into two equal halves (two halves of ball) called Top-Half (or Upper-Half) and Under-Half (or Lower-Half) or Right-Half and Left-Half referring to the SDD plane, which holds the flight path, passes through the center of gravity of the ball and is perpendicular to the ball spin-plane.

9.2. Top-Half and Under-Half of ball exist when a flying ball has vertical-spin or inclined- spin, i.e., SDD plane is parallel or inclined to the table surface. Top-Half is the half above SDD plane, and Under-Half is the half below SDD plane.

9.3. Right-Half and Left-Half of the ball exist when a ball is flying with inclined-spin or horizontal-spin, i.e., SDD plane is inclined or perpendicular to the table surface. Right- Half is the half to the right side of SDD plane, and Left-Half is the half to the left side of SDD plane.

9.4. Spin direction of one half of the ball is opposite to that of the other half.

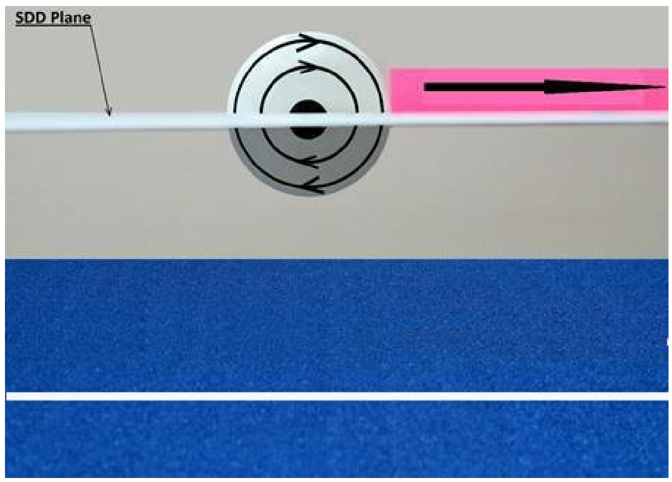


Fig. 1.11. Top-Half and Under-Half of a spinning ball on two sides of the SDD plane.

Note: In Fig. 1.11. spin of top-half is following the ball flight direction while spin of under-half is opposite to it.

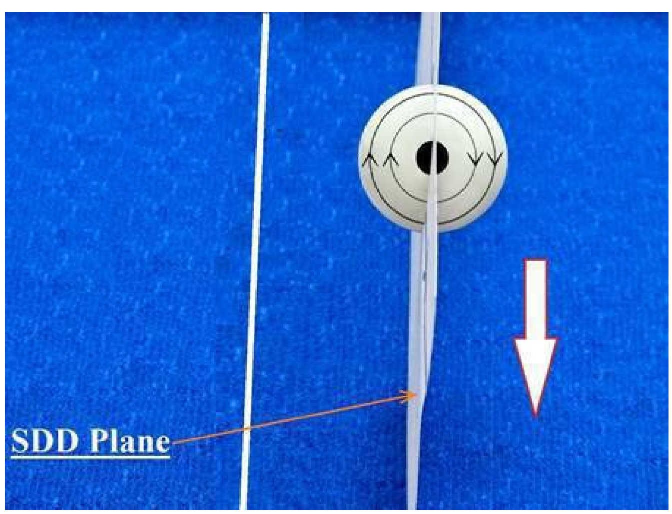


Fig. 1.12. Right-Half and Left-Half of a Horizontal-Spin Ball.

Note: In Fig. 1.12. spin of right-half of ball is following the ball flight direction, while spin of left-half is opposite to it.

*Remark: In case the ball has no spin, there is no SDD (spin-directions-dividing) plane. In this case the plane holding the ball flight velocity vector, passing through the ball center and parallel to the table surface is used as a reference plane to determine Top-Half (or Upper-Half) and Under-Half (or Lower-Half) of the ball.*

## 10. Spin speed

Spin speed or rotational speed of ball is the number of revolutions a ball spinning (rotating) on its axis of spin during a unit of time. For example: Spin speed of ball is 100 rps (revolutions or rotations per second) or 6,000 rpm (revolutions or rotations per minute).

## 11. Linear speed of spin

Linear speed of spin (or linear speed of rotation) (Vr) of ball is the expression spin speed of a point on a spinning ball in terms of the length or distance traveled by this point during a unit of time. Linear speed of spin of a ball could be expressed as (xxx) meters per second or (xxx) kilometers per hour.

Linear speed of spin of a point on a table tennis ball having perpendicular distance R to the axis of spin is calculated by the equation:

Linear speed of spin (Vr) = $2 \pi R$ * spin speed (s)
$2 \pi R$ is the circumference of a circle having radius R.

Spin speed of all points on the ball surface around its axis of spin is the same, but linear speed of spin of these points are different depending of the perpendicular distance (R) of these points to the axis of spin. The bigger the radius, the higher the linear speed is.

Linear speed of spin of a point on the equatorial spin line is biggest. Linear speed of spin of two spin-poles of the ball is zero.

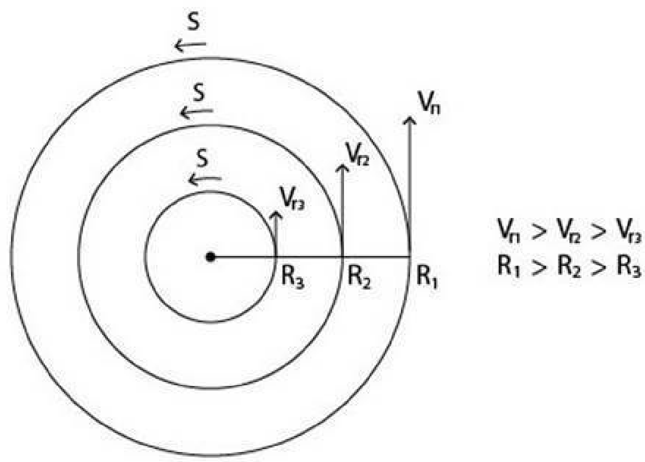


Fig. 1.13. Top-down view of a horizontal-spinning ball.

### 12. Through-The-Center (TTC) of the Ball Shot

Please see definitions in Chapter 4.

### 13. Tangential-To-(The)-Surface (TTS) of the Ball Shot

Please see definitions in Chapter 4.

## C. References


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2. http://**www.physics.usyd.edu.au/~cross** - Sydney University, Physics Dept./Rod Cross for Physics of Bounce and Magnus Force
3. http://**www.youtube.com/watch?v=23f1jvGUWJs** Magnus force
4. http://**www.physicsclassroom.com** for Forces (Vertical and Horizontal), Addition of Forces, Vector Addition Methods, Law of Reflection, Circular motion, Projectile motion, Momentum, etc.
5. http://**www.farside.ph.utexas.edu** for Law of Reflection
6. **http://ittf.com** The International Table Tennis Federation regarding the Laws of Table Tennis.

CHAPTER 2
# Spins of Table Tennis Ball

## 1. Overview

There are many different kinds of spin of the flying ball players of the table tennis game can generate. In order to identify the direction of spin of a ball flying through the air -- a three dimensional space -- and the effect of spin on the flight path, three references or categories of which the characteristics are explained in the following sections are used for classifying spins.

Spins are first classified into two groups:

1. Flight-Path-Following (FPF) Spin Group (Spin Group 1), and
2. Flight-Path-Crossing (FPC) Spin Group (Spin Group 2).

In each group spins are sorted into two types:

(1) Vertical-Spin Type, and
(2) Side-Spin Type (consisting of Inclined-Spin and Horizontal-Spin).

In each type, spin could have one of following four styles:

i. Top-Spin Style,
ii. Back-Spin Style,
iii. Clockwise-Spin Style,
iv. Counterclockwise-Spin Style.

The combination of the style, type of spins in each group of spin as classified above probably provides almost all kinds of spin which can be generated by players on the table tennis ball.

Classifying and naming of the group, type and style of spin of the table tennis ball in this book helps player in reading spins of TIB (table-incident-ball) and so predicting sooner the angle of reflection, spin and other features of TRB (table-rebounding-ball) or RIB (racket-incident-ball), so that player can make quick decision as to the kind of stroke he or she will use to properly strike back the spinning ball to the opponent.

# 2. Groups of Spins

Spins of ball are sorted into two groups based on the direction of the ball's spin plane and the direction of the ball flight path as follows:

## 2.1. Flight-Path-Following (FPF) Spin (Spin Group 1)

Spins belong to FPF (Flight-Path-Following) Spin Group when the spin direction of either half of the ball (top-half or under-half, right-half or left-half) follows the flight direction and the ball flight path and lies in the ball's equatorial spin plane.

FPF (flight-path-following) spin ball has general features as follows:

i. TRB (table-rebounding-ball) will have the same FPF spin as TIB (table-incident-ball). This feature is applicable to Vertical-Spin, Inclined-Spin and Horizontal-Spin.

ii. TRB plane and TIB plane are the same plane, or in other words, TIB flight path, TRB flight path and the normal are in the same plane, which is either a flat plane or a curved plane.

iii. The ball (TIB and TRB) flight path is deflected by the effect of Magnus force (aerodynamic lift of a spinning ball) which is generated when a spinning ball is flying through the air. (Further information in Chapter 3)

Followings are photos and drawings illustrating the features of FPF spin:

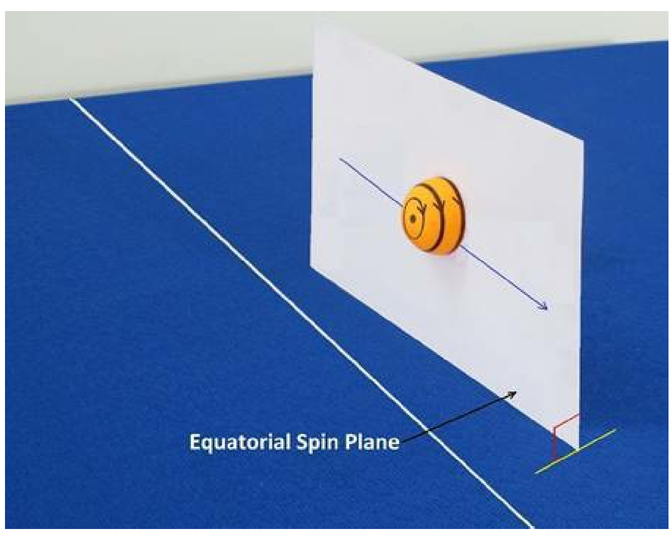


Fig. 2.1. The Equatorial spin plane of FPF-Vertical-Top-Spin ball is perpendicular to the table surface.

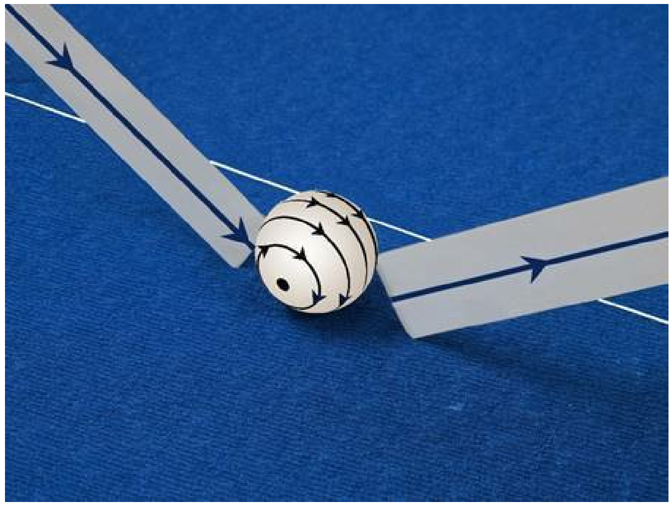

Fig. 2.2. FPF-Vertical-Top-Spin Ball, TIB flight path and TRB flight path.

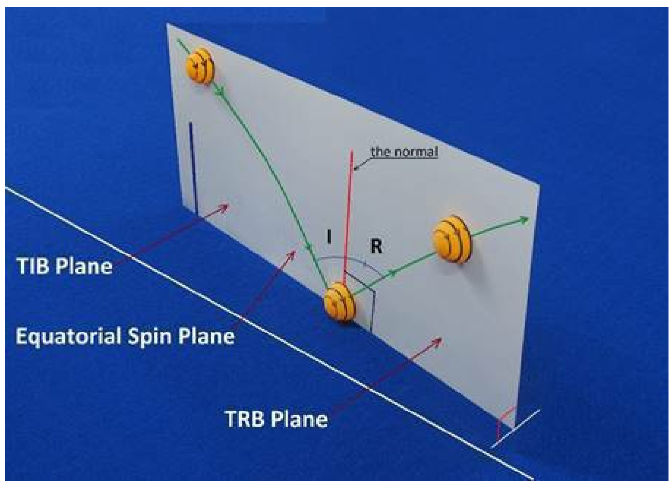


Fig. 2.3. FPF Vertical-Spin TIB flight path, TRB flight path and the normal all lie on the same flat plane perpendicular to the table surface.

Note: TRB has the same FPF Vertical-Top-Spin as TIB.

## 2.2. Flight-Path-Crossing (FPC) Spin (Spin Group 2)

Spins belong to Flight-Path-Crossing (FPC) when the equatorial spin plane of the ball cross the ball flight path or the ball flight path goes through the equatorial spin plane of the ball, in other words.

FPC spins have some common features as follows:

i. Equatorial spin plane of TIB is closely perpendicular to the table surface,
ii. TRB flight path does not lie on TIB plane but on a plane that cross

TIB plane at the normal,

iii. TRB flies to the opposite direction of the spin direction of the ball at the impact point with the table surface -- spin direction of the bottom side of the ball, or from other point of view, TRB flies following the spin direction of the top side of the ball. (further explanation in Chapter 3),

iv. TIB flight path is not deflected or it is similar to the flight path of a no-spin ball as Magnus force (or aerodynamic lift of a spinning ball) is not generated when equatorial spin plane is perpendicular to the ball flight path. (further explanation in Chapter 3).

Followings are photos and drawing illustrating the features of FPC-Spin Ball.

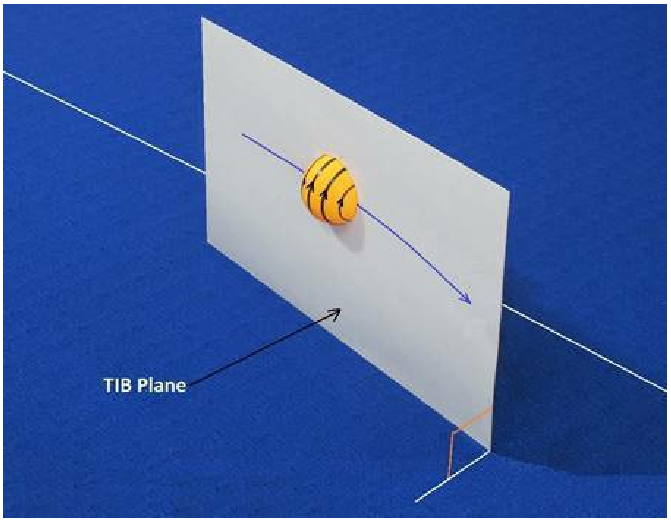


Fig. 2.4. Equatorial and Latitudinal spin lines of FPC-Vertical-Spin ball pass through TIB plane, which is holding the ball flight path and perpendicular to the table surface.

Fig. 2.5. FPC-Vertical-Clockwise-Spin TIB flight path and TRB flight path

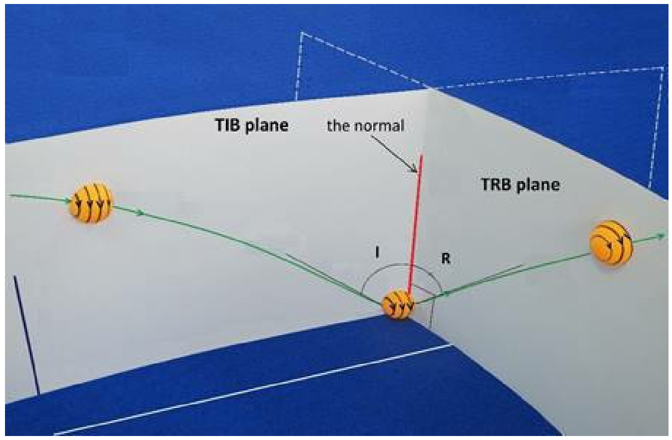


Fig. 2.6. FPC TIB flight path and TRB flight path do not lie on one plane.

Note:
TIB plane could be a slightly curved plane or a flat plane,
TRB plane is crossing TIB plane at the normal,
TIB has FPC-Vertical-Spin while TRB has FPF-Vertical-Top-Spin.
*Remark: FPC-spin ball is usually a high ball above the net and slow in flying speed.*

# 3. Types of Spins

There are two types of spins sorted based on the direction of the equatorial spin plane and the table surface as follows:

## 3.1. Vertical-Spin Type

A ball is having Vertical-Spin when the equatorial spin plane of the flying ball is perpendicular to the table surface.

Vertical-Spin has following features:

i. Equatorial spin plane is perpendicular to the table surface,
ii. A point on the equatorial spin line touches the table surface when the ball touches it,
iii. Axis of rotation of the ball is parallel to the table surface.

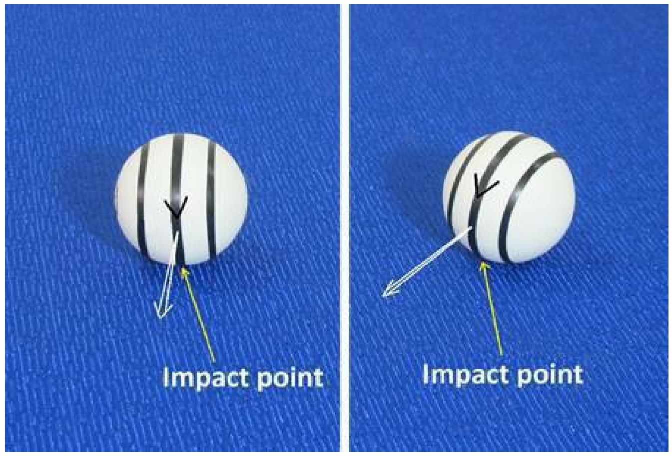


Fig. 2.7. Two Vertical-Spin balls, flying from two different directions, hit the table surface at a point on its equatorial spin line.

## 3.2. Side-Spin Type

A ball is having side-spin when the equatorial spin plane of the flying ball is not perpendicular to the table surface.

There are two kinds of side-spin distinguished based on the gradient degree of the equatorial spin plane and the table surface, namely: Inclined-Spin and Horizontal-Spin.

### *(1) Inclined-Spin Type*

Basic features of inclined-spin are as follows:

i. Equatorial spin plane is inclined to the left or right to the table surface as seen by the returner,
ii. A point on the latitudinal spin line of the ball touches the table surface when the ball touches it,
iii. Axis of rotation of the ball is inclined to the table surface.

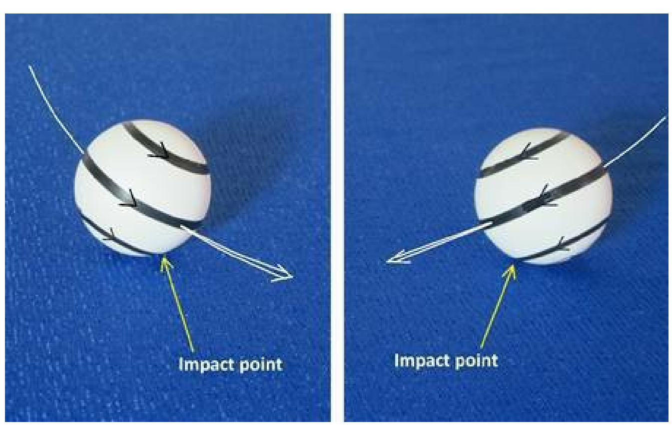

Fig. 2.8. Two inclined side-spin balls, one with equatorial spin plane inclined to the left side and one to right side of returner, both hit table surface at a point on its latitudinal spin line.

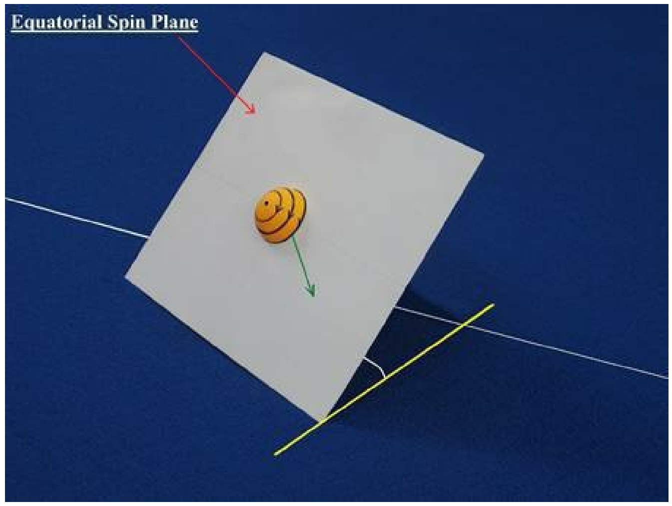


Fig. 2.9. Equatorial spin plane of an inclined-spin ball is inclined to the table surface.

### *(2) Horizontal-Spin Type*

Basic features of horizontal-spin are as follows:

i. Equatorial spin plane is almost parallel to the table surface,

ii. The ball hits table surface at a point very close to either of its spin-poles,

iii. Axis of rotation of the ball is almost perpendicular to the table surface.

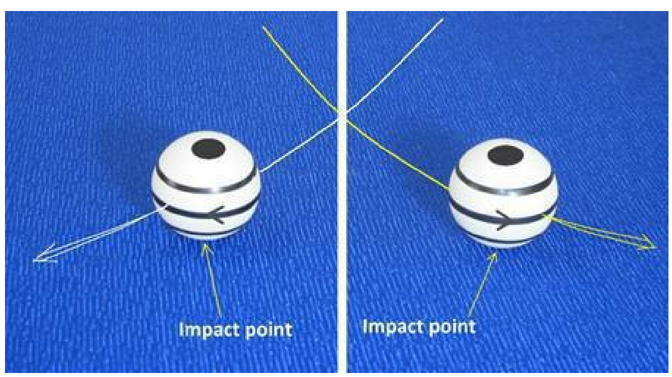


Fig.2.10. Two Horizontal-spin balls (clockwise and counterclockwise spin) hit the table surface at a point close to its spin-pole.

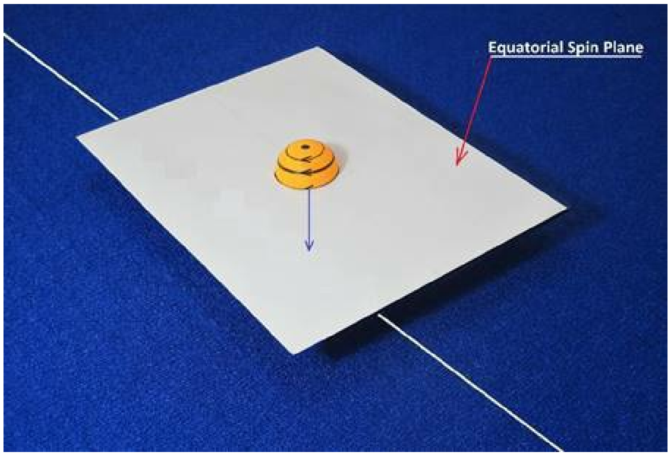


Fig. 2.11. Equatorial spin plane of a horizontal-spin ball is almost parallel to table surface.

# 4. Styles of Spins

Styles of spin are sorted and named based on the direction of rotation of the ball. There are four styles of spins distinguished:

- Top-Spin and Back-Spin,
- Clockwise-Spin and Counterclockwise-Spin.

## 4.1. Top-Spin and Back-Spin Styles

A ball is having Top-Spin when the direction of rotation of the top-half of the ball (the half above the SDD plane) is following the ball flying direction. The direction of rotation of the under-half of a top-spin ball is therefore opposite to the ball flying direction.

A ball is having Back-Spin when the direction of rotation of the top-half of a spinning ball is opposite to the ball flying direction. The direction of rotation of the under-half of the top-spin ball is therefore following the ball flying direction.

Top-Spin and Back-Spin are associated with Vertical-Spin type ball and also Inclined-Spin type ball.

Top-Spin and Back-Spin are commonly not associated with Horizontal-Spin type as it is difficult to distinguish the top-half and under-half of the spinning ball in this case.

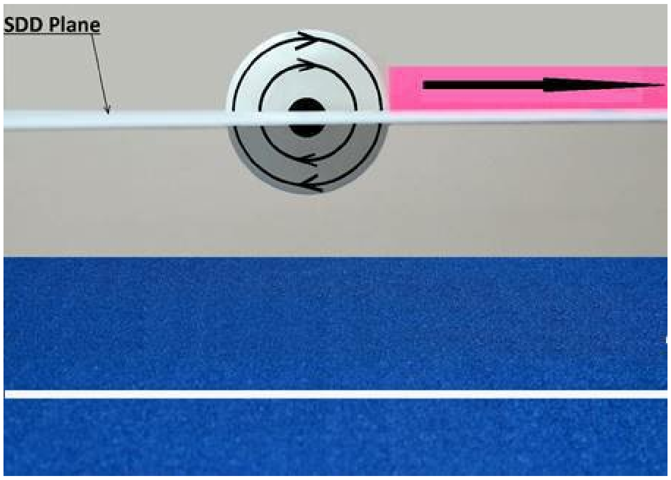


Fig. 2.12. FPF-Vertical-Top-Spin Ball.

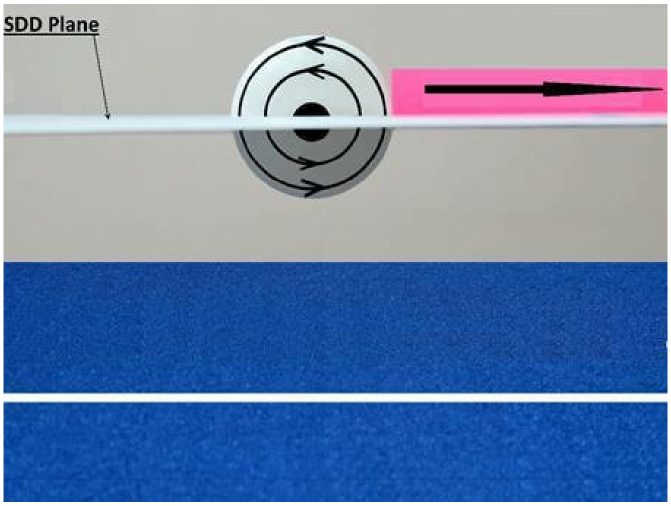


Fig. 2.13. FPF-Vertical-Back-Spin Ball.

## 4.2. Clockwise and Counterclockwise-Spin Styles

The Clockwise-Spin and Counterclockwise-Spin denote the direction of rotation of a spinning ball seen from above the ball.

Clockwise and Counterclockwise-Spins could be apparently distinguished when the ball has horizontal-spin type.

A ball having inclined-spin type could be seen as having top-spin associated with clockwise or counterclockwise spin, or back-spin associated with clockwise or counterclockwise spin.

*Remarks:*

*When a clockwise-spin ball touches the racket covering surface, RRB (racket-rebounding-ball) tends to fly to the right side of the returner.*
*When a counterclockwise-spin ball touches the racket covering surface, RRB tends to fly to the left side of the returner*.

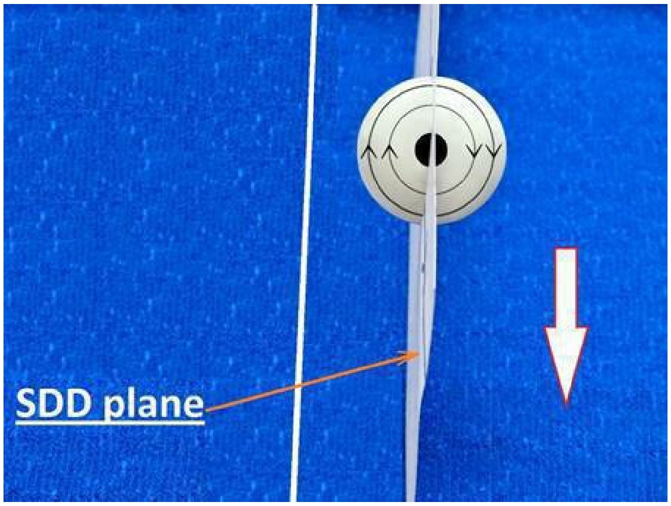


Fig. 2.14. FPF-Horizontal-Clockwise-Spin Ball.

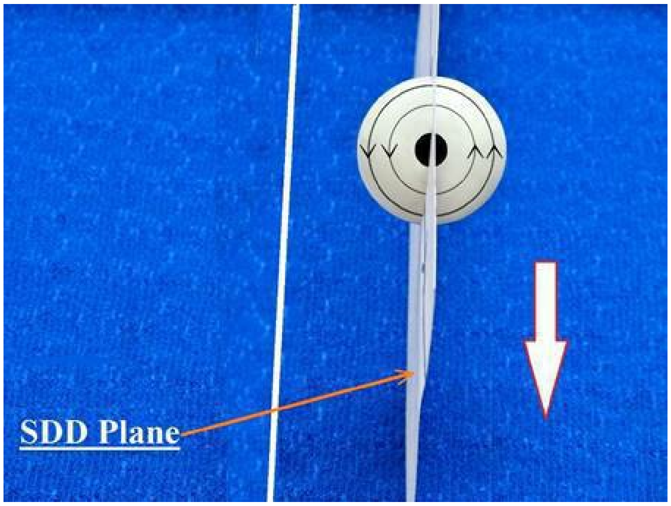


Fig. 2.15. FPF-Horizontal-Counterclockwise-Spin Ball.

# 5. Full Names and Features of Spins of Table Tennis Ball

Combinations of Styles and Types of spin in each of two Spin Groups provide a total number of 8 different kinds of spin which a ball can have in a table tennis game as shown in the following table 1.

….

| Table 1. Name of all Kinds of Spins of Table Tennis Ball | | | | |
|---|---|---|---|---|
| Spin Group | Spin Type | Spin Style | **Full Name of all Kinds of Spins of TT Ball** [4] | Feat-ures [1] |
| 1. FPF-Spin<br><br>FPF: Flight-Path-Following (Spin Group 1) | 1.Vertical-Spin<br><br>2. Side-Spin<br><br>2.1. Inclined-Spin<br><br>2.2.Horizontal-Spin | 1.Top-Spin<br><br>2.Back-Spin<br><br>3. Clockwise-Spin<br><br>4. Counter-clockwise-Spin | 1. FPF-Vertical-Top-Spin<br><br>2. FPF-Vertical-Back-Spin<br><br>3. FPF-Inclined-Clockwise-Top-Spin [2]<br><br>4. FPF-Inclined-Counterclockwise-Top-Spin [3]<br><br>5. FPF-Horizontal-Clockwise-Spin<br><br>6. FPF-Horizontal-Counterclockwise-Spin | |
| 2. FPC-Spin<br><br>FPC: Flight-Path-Crossing (Spin Group 2) | 1.Vertical-Spin [3] | 1. Clockwise-Spin<br><br>2. Counter-clockwise-Spin | 1. FPC-Vertical-Clockwise-Spin<br><br>2. FPC-Vertical-Counterclockwise-Spin | |

*Remarks:*
*[1] Table 2 Summary of features of the effects of spins of table tennis ball in Annex 1.*
*[2] FPF-Inclined-Back-Spin does not exist.*
*[3] FPC-spin plane could be either vertical or inclined at a small angle to the normal whose effects are almost the same or slightly deviated from those of vertical-spin. Therefore, only Vertical-Spin is designated for FPC-Spin Group.*
*[4] Full name with FPC as abbreviation is always used to indicate a kind of*

*ball spin belonging to FPC-Spin group. However, shortened name of which the words FPF and vertical are omitted is often used to indicate a ball spin belonging to FPF-Spin group, when there is no confusion. So, when a ball is written as having 'Top-Spin', this means that it has 'FPF-Vertical-Top-Spin'.*

CHAPTER 3

# Reading and Predicting of Spins and other Features of Ball

## 1. Overview

Spins of table-incident-ball (TIB) which is imparted by a player’s racket stroke is usually the main concern of a returner. However, spin of table-rebounding-ball (TRB) or racket-incident-ball (RIB) is actually the one which is handled by the returner.

Spin of TRB is affected by the reactions (forces) of the table surface acting upon TIB and likely different in its type, style and speed from that of TIB, especially in the case of back-spin TIB and FPC-spin TIB.

In addition to spin, there are other features as specified below that player has to know in order to properly strike back the ball to the opponent.

### 1.1. Features of TIB (table-incident-ball) and TRB (table-rebounding-ball)

Kind of spin of a ball is a crucial feature to be considered for returning an oncoming ball. However, it is only one of the four key features of TIB and TRB or RIB which player has to consider:

(1) Kind of Spin (FPF- or FPC-, Top-Spin or Back-Spin or No-Spin),
(2) Spin Speed (fast or slow),
(3) Flight Path (including angle of incidence and reflection, direction and shape),
(4) Flight Speed (fast or slow).

### 1.2. Methods for Reading and Predicting Spin and other Features of Ball

There are two methods used for reading and predicting the kinds of spin and other features of a flying ball:

***(1) Direct method.***

Player just directly looks at the ball surface to see the ball’s spin direction and guess its spin speed, look at the ball flight path to see the angles of incidence and reflection, and guess the flight speed based on experiences.

Direct method is not so effective for reading spin as the ball is small, flying very fast, having logo confined in a small area and stamped on one place on the ball surface; all of that make it difficult to see the trace of ball spin. Therefore, player needs to use indirect method for reading spin and other features of ball, especially TRB.

***(2) Indirect method.***

Player has to confirm the type of the opponent's racket covering surface, which is a sticky or non-sticky rubber, before play and then process the information perceived to predict the kind of spin and other features of ball after performing below actions i. and ii. in combination with iii.:

i. Looking at and confirming the motion of the racket when hitting the ball.
ii. Looking at and confirming the shape of the ball flight path and compared it with the shape of a no-spin ball flight path.
iii. Analyzing forces acting upon the ball and their effects.

### 1.3. Serving Ball and Returning Ball

There are two types of oncoming ball of which the four features (spin, etc.) a player has to read or predict in order to properly return the ball to his/her opponent.

(1) Oncoming ball from a service which hits the table surface twice,
(2) Oncoming ball from a returned ball after a serve which hits the table surface once.

Note: The methods used for determining the features of ball as mentioned in above 1.2 could be used for determining the features of the second time TRB of a serving ball as TRB of the first time becomes the second time TIB on the returner's table court.

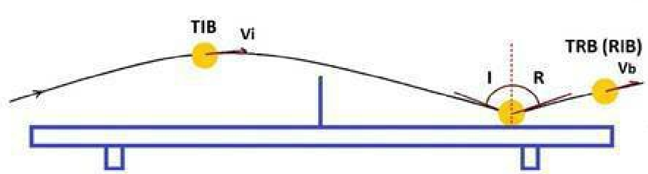


Fig. 3.1. TIB and RIB of a Returning Ball Trajectory.

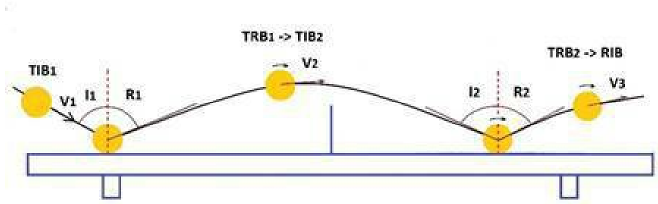


Fig. 3.2. TIBs and RIB of a Serving Ball Trajectory.

## 1.4. Forces acting upon the ball

Spin and other features of ball are affected by the following forces acting upon the ball under the ideal playing conditions.

(1) Force acted by racket covering surface upon the ball.[1]
This Force is acting instantaneously when the racket hits the ball and makes the ball (table-incident-ball or TIB) fly and spin following a certain flight path. This force is further described Chapter 4.

(2) Reaction (Force) of the table surface acting upon the ball (TIB) when the ball hits the table surface.[1]
This force which makes the ball bounce-off (rebound) the table surface also affects the ball spin.

(3) Magnus force or Lift of a Spinning Ball.[2]
This force (symbol as **F**m or **L**), which is generated when a spinning ball flying (translating) through the air, deflects or curves the ball flight path downwards, upwards or sideways depending the direction of rotation (spin) of the ball and the ball flight direction (exactly the free air stream flow which is opposite to the ball flight direction). “The direction of the force is perpendicular (at a right angle) to the flow direction and perpendicular to the axis of rotation of the ball”.[3]

(4) Weight [4]
Weight (symbol as p) is a force that always applies on the ball and is directed towards the center of the Earth.

(5) Drag of the Air [5]
Drag (symbol as **D** or **F**d) is an aerodynamic force created by the resistance of the air to the motion of the ball through the air. Drag is

directed along and opposed to the flight direction of the ball.[5] Drag decreases the ball flying speed and spinning speed and affects the ball flight path.

*Remarks:*

*[1] For further information on force and reaction, please refer to:*

- *Newton's Laws of Motion, Glenn Research Center, NASA, http://**www.grc.nasa.gov**.*
- *Physics of Bounce, Rod Cross, Physics Dept., Sydney University, http://**www.physics.usyd.edu.au/~cross/BOUNCE.htm**.*
- *Center of Gravity, Glenn Research Center, NASA, http://www.grc.nasa.gov.*

*[2] For further information on Magnus force, please refer to the followings:*

- *Lift of Rotating Cylinder and Ideal Lift of a Spinning Ball, Glenn Research Center, NASA, http://www.grc.nasa.gov.*
- *What is Magnus Force? Rod Cross, Univ. of Sydney, **http://www.youtube.com/watch?v=23f1jvGUWJs**,.*
- *Center of Pressure, Glenn Research Center, NASA, http://www.grc.nasa.gov*

*[3] Excerpt from "Approximate Force on Spinning Ball", GRC, NASA, http://www.grc.nasa.gov.*

*[4], [5] For more information on Weight and Drag and their effects on the flight of a ball please refer to:*

- *"Ballistic Flight Equations", "Flight Equations with Drag", "Forces on a Baseball", Glenn Research Center, NASA, http://**www.grc.nasa.gov**.*
- *"Projectile Motion", **http://www.physicsclassroom.com**.*

### 1.5. Law of Reflection and Flight Direction of Rebounding Ball

The law of reflection governing the reflection of light-rays from a smooth surface is referred for approximating the flight direction of ball bouncing-off (rebounding) the table surface (TRB or table-rebounding-ball) although the physical principle governing the ball (having mass) rebound is different from that of light (having no mass). The statements which are borrowed from the law of reflection of light-ray and deemed as postulates to determine the ball rebound from a no-spin table tennis ball hitting a hard and smooth table surface under ideal conditions are as follows:

i. The angle of reflection (R) of rebounding ball (TRB) is equal to the angle of incidence of incident ball (TIB),
ii. The rebounding-ball flight path (TRB) and incident-ball flight path (TIB) are on the opposite sides of the normal,
iii. The rebounding ball flight path (TRB), the incident-ball flight path (TIB), and the normal lie on the same plane.

In reality, the angle of reflection is not equal to the angle of incident as the flight path of table-rebounding-ball is deflected due to various factors like abrasiveness of the table surface, loss of energy at impact, weight, etc. (Fig. 3.1 and 3.2).

Note: The flight direction of ball rebound from racket surface (racket-rebounding-ball or RRB) is explained in Chapter 4 and Annex 2.

## 2. Reading of Spin of TIB (table-incident-ball) of Returning Ball

Spin is a feature of TIB (table-incident-ball) which needs to be derived by using means of the indirect method [above point 1.2.(2)]. Other features of TIB could be derived by looking at the ball (direct method).

### 2.1. Spin and the Shape of TIB (table-incident-ball) Flight Path

Spin of a flying ball will generate a force, Magnus force or Lift of a spinning ball, which will deflect the flight path of the ball. So, by looking at the shape of the flight path and compared it with that of a no-spin ball we can derive that the ball has no-spin or spin and its spin kind (direction, etc.).

***(1) Spin Direction and the Direction of Magnus Force***

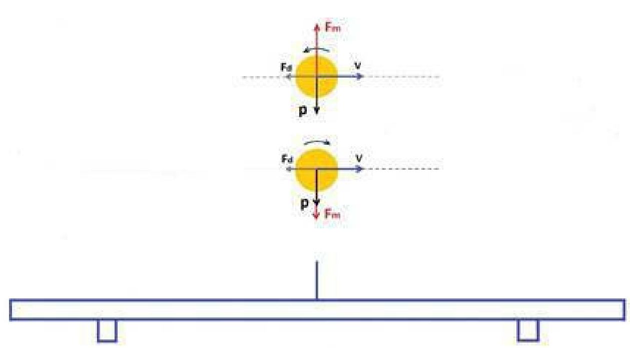

Fig. 3.3. Magnus force (Fm) of a FPF, back-spin ball is directed upwards, and top-spin ball is downwards.

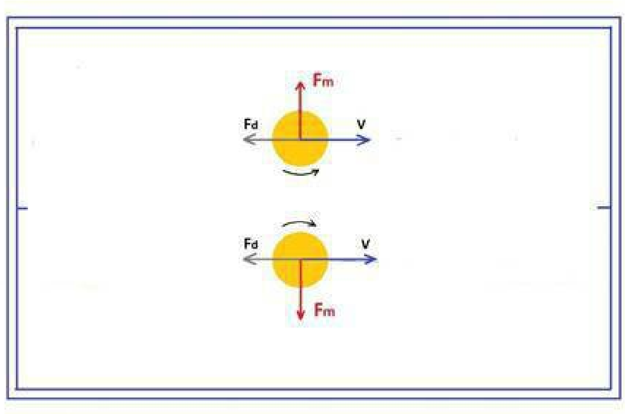


Fig. 3.4. Top-down view of a FPF-Horizontal-Spin ball with its Magnus force (**F**m) directed towards the left side in case of counterclockwise spin, and to the right side in case of clockwise-spin as viewed by returner.

*Remarks:*
*The direction of Magnus Force (**F**m) is from the half of the ball having spin following the flight path (velocity vector) toward the half having spin against it.*

*Magnus force (Lift of a spinning ball) is very small or does not exist when the ball has FPC (flight-path-crossing)-Vertical spin.*

### *(2) Illustrations of FPF Spin and Shape of TIB Flight Path*

Followings are illustrations for comparing flight path of no-spin ball and those of FPF-vertical-top and back spins, horizontal-clockwise and counterclockwise spins.

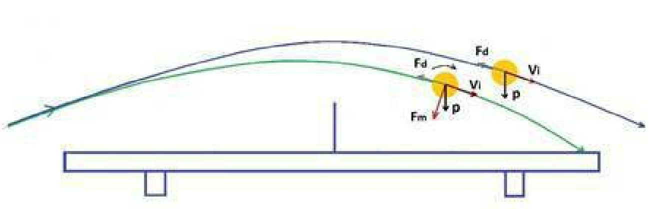


Fig. 3.5. Flight path of FPF-Vertical-Top-Spin ball (lower) curved (deflected) downwards due to downward Magnus force compared with that of no-spin ball (upper line).

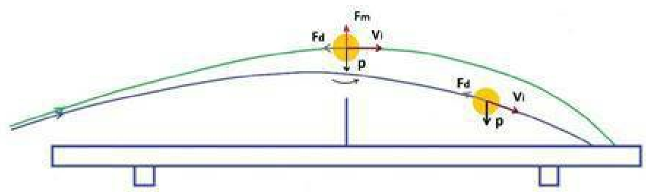


Fig. 3.6. Flight path of FPF-Vertical-Back-Spin ball (upper line) deflected upwards due to upward Magnus force (of Lift) compared with that of a no-spin ball (lower line).

Note: The ball flight paths with no spin, FPF-Vertical-Top and Back spins in the above Fig. 3.5 and 3.6 lie on a flat plane (TIB plane) perpendicular to the table surface.

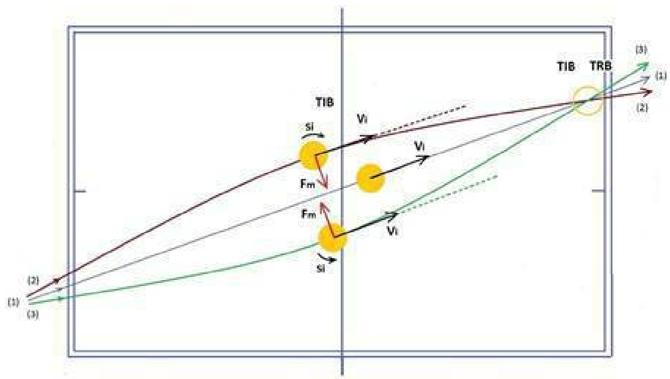


Fig. 3.7. Shapes of TIB flight paths having FPF-Horizontal and:
-Clockwise Spin (2), -Counterclockwise Spin (3),
-No or Vertical Spin (1).
(Top down view).

## *(3) Illustration of FPC Spins and TIB Flight Path*

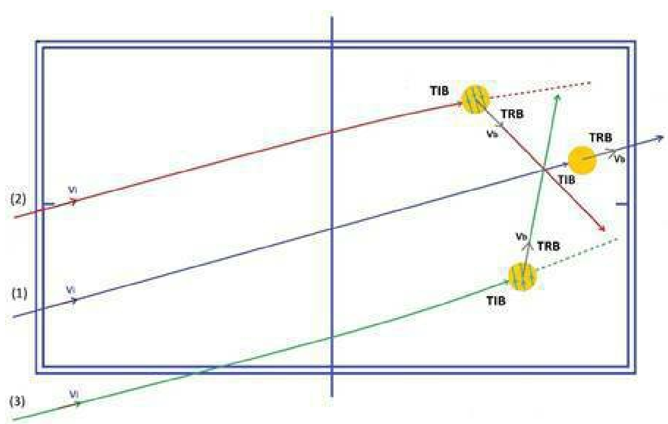


Fig. 3.8. Flight paths of TIB having FPC (flight-path-crossing)-spin [lines (2) & (3)] are similar to that of no spin or FPF-Vertical-Spin ball [line (1)] (Top-down view)

Note: Dashed line is flight path of ball if it has no spin.

### 2.2. Spin and the Motions of Racket

The resulting spin of the ball struck by racket or RRB (racket-rebounding-ball) is depending on three factors: (1) the motion of the racket or the force acted by the racket on the ball, (2) spin of the oncoming ball and (3) the features of racket covering surface, i.e., sticky (spin-) rubber surface or non-sticky (no-spin) rubber surface. Further information is described in Chapter 4 and the illustrations of the shape of RRB are in Annex 2.

## 3. Reading and Predicting of Spins and other Features of TRB (Table-Rebounding-Ball) of Returning Ball

A returner of the table tennis game when staying close to the table will not have enough time to read spin and other features of TRB by looking at the ball (TRB) and its flight path as applied to the case of TIB. Through experiences and/or by viewing slow-motion film of ball, player could predict or guess in advance possible kinds of spin of TRB from TIB flight path before (without) looking at the flight path of TRB. However, player can save time and expenses required for learning in practices and obtaining slow-motion film by using the forces analysis method as described below to predict the probable spins, angle of reflection, flight direction, etc. of TRB based on the spin kind and other features of TIB.

### 3.1. Forces Analysis Method for Predicting of Features of TRB (Table-Rebounding-Ball)

The method of addition of vectors, which represent forces and motion (flight direction and speed, spin direction and speed), is the main tool used to find out the resultant force acting upon TRB. In addition, various principles of physics such as Newton's three laws of motion, law of reflection, law of conservation of energy, and the notion of center of gravity, etc. are referred for finding out the possible cases concerning the kind of spin, direction of flight, angle of reflection and speed which can happen to a TRB. The effect of spin - the hidden power of the ball - on the motions of the rebounding ball is explained in the analysis of acting forces. Further explanation and information on the Forces Analysis Method, the laws of motions, law of reflection and the notion of center of gravity is in Annex 2.

**Parameters, Symbols and Reasoning used in Forces Analysis Method**

**Fic** TTC (through-the-center) force exerted by the ball (TIB) flying at Vi speed upon the table surface at the time of impact,

**Fis** TTS (tangential-to-the-surface) force exerted by the ball (TIB) spinning speed Si upon the table surface at the time of impact,

**Vi** Flying speed of TIB at impact point,

**Si** Spinning speed of TIB at impact point,

**Fbic** TTC reaction force of the table acting upon the ball against **Fic**,
(Table bouncing-off force acting upon the ball as a reaction to the incident ball TTC force Fic, in other words.)

**Fbis** TTS reaction force of the table acting upon the ball against **Fis**,
(Table bouncing-off force acting upon the ball as a reaction to incident ball TTS force **Fis**, in other words.)

**Fb** The resultant force exerted by the table surface on TIB at impact point.

**Fb** = **Fbic** + **Fbis** (vector quantity)
TRB (table-rebounding-ball) flies following the direction of the instantaneous reaction force Fb and its flight path is deflected by the external forces acting on the ball (weight, drag, Magnus force)

St Top-Spin component that is always generated on TRB when a flying ball (TIB) of any kinds of spin (topspin, backspin, no-spin) hits a table surface.
(One of the explanations for the generation of St is that when a flying ball hits the table surface, the flying speed of the point hitting the table surface is reduced due to friction, while the opposite point through the ball center continues to fly at the speed before impact. The ball therefore spins forwards or has top-spin.)

Sr Spin component (Sr) generated by the TTS table reaction force Fbis on TRB when a spinning ball (TIB) hits table surface. Spin direction of Sr is always opposite to that of Si, Sb Spin speed of TRB

Sb = Si + (or -) St - Sr

[ + St when TIB has top-spin, - St when TIB has back-spin]

Vr Flight speed component to TRB generated by TTS table reaction force Fbis.

Vr is an addition to Vb in case TIB has top-spin or a deduction to Vb in case TIB has back-spin.

Vloss A value that is always deducted to Vi when TIB hits the table surface due to loss of energy at impact.[*]

Vb Resultant flight speed of TRB

Vb = Vi – Vloss +/- Vr

[ + Vr in case TIB has top-spin, - Vr in case TIB has back-spin]

[*] Similar to Vloss, Sloss exists due to loss of energy at impact. For simplification sake, Sloss is excluded in the above analysis on finding spin speed.

Notes:

Vb > 0 (positive value) means TRB flies forwards following flight direction of TIB having FPF spin.

Vb = 0 means TRB does not fly forwards and towards returner but instead jumps (bounces-off) upright from the table surface.

Vb < 0 (negative value) means TRB does not fly forwards and towards returner side but instead flies backwards or to the opposite direction of TIB having FPF spin .

Sb > 0 (positive value) means TRB has the same spin direction as TIB or spin direction of ball remains unchanged after the ball hits table surface or racket surface, in other words.

Sb = 0 means TRB has no-spin.

Sb < 0 (negative value) means TRB has opposite spin direction to that of TIB, or in other words, spin direction of ball is reversed after impact.

[Symbols: >: bigger, >>: much bigger, <: smaller, <<: much smaller, =: equal, ≥: equal or bigger, ≤: equal or smaller]

### 3.2. Illustrations and Summary of Features of TIB and TRB

Followings are drawings showing the instantaneous forces acted by the ball (TIB) on the table and reactions by the table on the ball (TRB) at impact point, the flight direction and spin of TIB and TRB for the several common cases of TIB having no-spin, FPF (Flight-Path-Following) spins and FPC (Flight-Path-Crossing) spin.

***(1) No-Spin TIB***

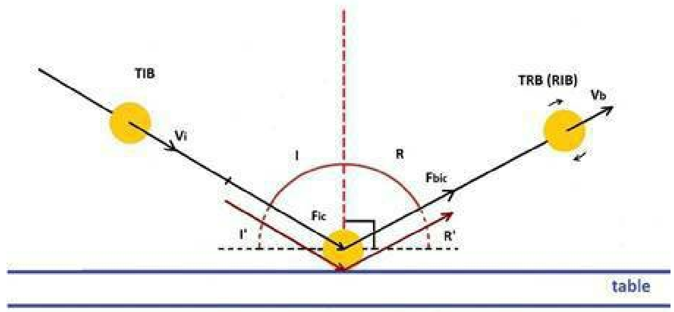


Fig. 3.9. Forces on No-spin TIB and TRB.

| Table 3. Features of TRB from No-Spin TIB | | |
|---|---|---|
| **Features** | **TIB** | **TRB** |
| 1. Flight Path: | | |
| -Angle of incidence (I) and reflection (R) | I | R > I due to loss of energy at impact.<br>TRB flight path is closer to table surface than TIB. |
| -Direction | TIB flies forwards in a flat plane perpendicular to the table surface. | TRB flies forward in the same fl plane as TIB’s. |
| -Shape | Straight or parabolic line [*] | Parabolic line [*] or deflected a little due to small top spin |

| | | |
|---|---|---|
| | | generated at impact. |
| 2. Flight Speed | Vi | Vb < Vi (due to loss of energy<br>impact)<br>(Vb = Vi - Vloss) |
| 3. Spin Kind | No-Spin | FPF-Vertical-Top-Spin (due to S |
| 4. Spin Speed | No spin | Top-spin speed is not big and depending on TIB speed (Vi) an (angle of incidence). |

[*] Ball flight path acted by a smash is considered a straight line in a short length. A no-spin ball flight path is assumed a parabolic line as drag is assumed negligible for convenience of citing the effect of spin on flight path.

## *(2) FPF-Vertical-Top-Spin TIB*

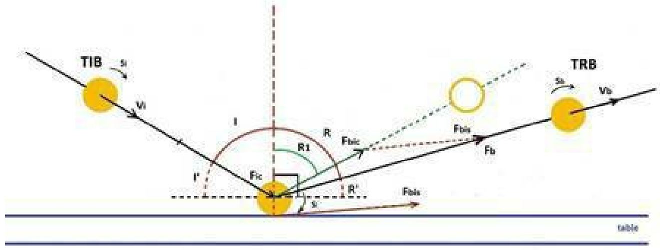


Fig. 3.10. Forces on FPF-Vertical-Top-Spin TIB and TRB.

| Table 4. Features of TRB from a FPF-Vertical-Top-Spin TIB | | |
|---|---|---|
| **Features** | **TIB** | **TRB** |
| 1. Flight Path: | | |
| -Angle of incidence (I) and reflection (R) | I | R >> I as R > R1 of no-spin ball > I.<br>TRB flight path is much closer to the table surface than TIB and closer than TRB of no-spin TIB. |
| -Direction | TIB flies forwards in a flat plane perpendicular to the table surface (TIB plane). | TRB flies forwards in the same flat plane as TIB's. |
| -Shape | Deflected parabolic line curved downwards due to top-spin. | Deflected parabolic line curved downwards due to top-spin. |
| 2. Flight Speed | Vi | Vb = Vi - Vloss + Vr<br>Three possible cases:<br>1. Vb > Vi when Vr > Vloss.<br>TRB's flying speed is faster than TIB's.<br>2. Vb = Vi when Vr = Vloss.<br>TRB's speed is same as TIB's.<br>3. Vb < Vi (rare case) when Vr < Vloss.<br>TRB's speed is smaller than TIB's. |
| 3. Spin Kind | FPF-Vertical-Top-Spin | Two possible cases:<br>1. FPF-Vertical-Top Spin,<br>2. No-Spin (very rare). |
| 4. Spin Speed | Si | Sb = Si + St – Sr<br>Three possible cases:<br>1. Sb = Si when Sr = St.<br>TRB has the same top spin kind and spin speed as TIB.<br>2. Sb < Si when Sr > St.<br>TRB has the same top spin kind as TIB but its spin speed is smaller (usual case). |

| | | |
|---|---|---|
| | | 3. Sb = 0 when (Si + St) = Sr.<br>TRB has no spin.<br>[4. The last case: Sb is a negative value when (Si + St) < Sr; Consequently, TRB has back spin or opposite spin direction to TIB. This case most likely does not exist in practice.] |

### *(3) FPF-Vertical-Back-Spin TIB*

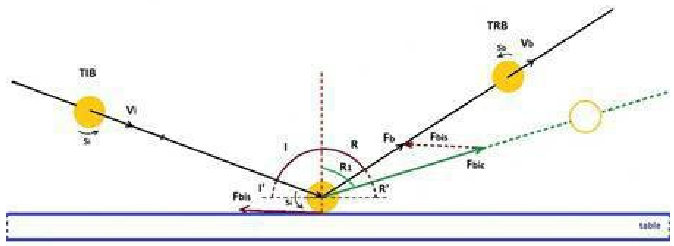


Fig. 3.11. Forces on Back-Spin TIB and TRB, and TRB flight path.

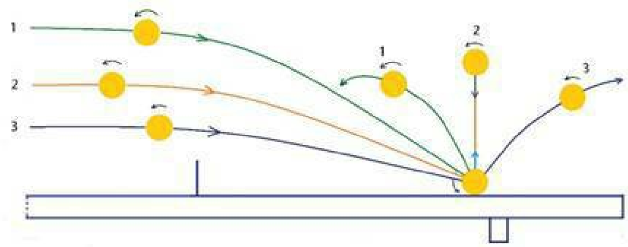


Fig. 3.12. Three possible cases of TRB flight path from FPF-Back-Spin TIB.

*Remark:*
*In Fig. 3.12 spin direction of ball is unchanged after the ball hits the table surface. However, in theory and probably also in practice, spin of ball, under certain conditions, might be reversed after impact.*
*TRB of flight path (1) has top-spin instead of back-spin as the other two paths.*

. . .

| Table 5. Features of TRB from a Back-Spin TIB | | |
|---|---|---|
| **Features** | **TIB** | **TRB** |
| 1. Flight Path: | | |
| -Angle of incidence (I) and reflection (R) | I | R ≤ I<br>TRB flight path is equal or higher above the table surface than TIB. |
| -Direction | TIB flies forward in a flat plane perpendicular to the table surface (TIB plane). | TRB flies in the same flat plane as TIB plane. |
| -Shape | Deflected parabolic line curved upwards. | Possible cases:<br>1. A parabolic line when Sb is zero,<br>2. A deflected parabolic line curved upwards or downwards depending on type of spin of TRB (ref. to below point 3). |
| 2. Flight Speed | Vi | Vb = Vi -Vloss - Vr = Vi - (Vloss + Vr)<br>Three possible cases:<br>1. Vb < Vi (usual)<br>TRB flies forwards and slower than TIB.<br>2. Vb= 0 when Vloss + Vr = Vi.<br>TRB just jumps upright.<br>3. Vb is a negative value when:<br>Vloss + Vr > Vi.<br>TRB flies or jumps backwards. |
| 1. Spin Kind and<br>2. Spin Speed | FPF-Vertical-Back-Spin | Sb = Si – St – Sr or Sb = Si – (St + Sr)<br>Three possible cases:<br>1. Sb < Si when Si > St + Sr.<br>FPF-Vertical-Back-Spin (same as TIB).<br>2. Sb = 0 when Si = St + Sr.<br>No spin.<br>3. Sb < 0 (negative value)<br>when Si < St + Sr.<br>FPF-Vertical-Top-Spin (opposite to TIB). |

### *(4) FPF-Side-Spin TIB*

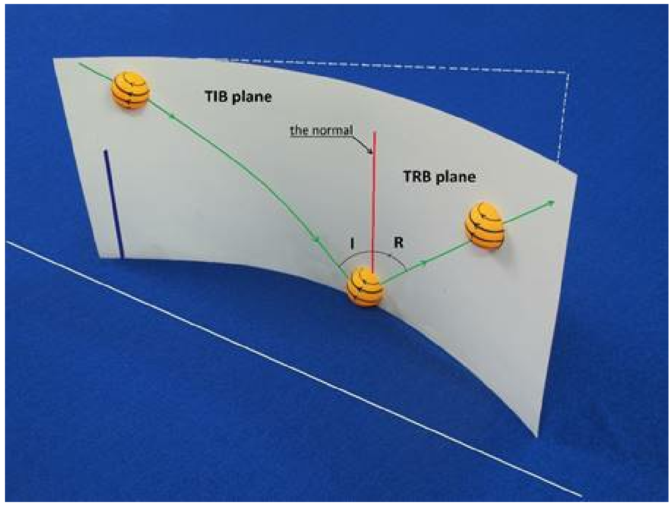


Fig. 3.13. Side view of flight paths of FPF-Horizontal-Clockwise-Spin TIB and TRB.

Note: TIB and TRB flight paths lie on the same curved plane holding the normal.

*Remark: Features of TRB corresponding to the different kinds of FPF-Side-Spin TIB could be derived by using the same method and process as described above.*

### *(5) FPC-Vertical-Clockwise and Counterclockwise-Spin TIB*

Fig. 3.14. FPC-Clockwise-Spin ball when touching the table surface.

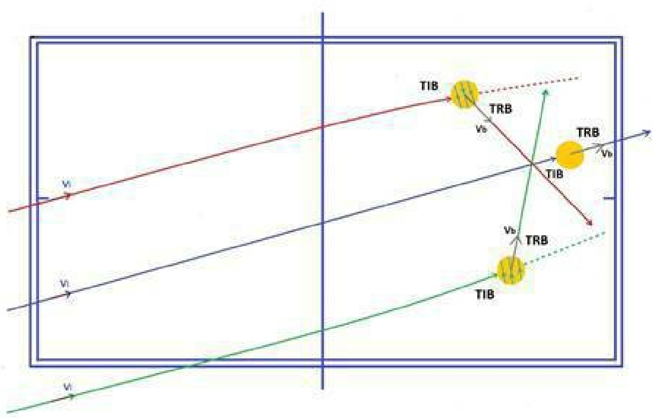


Fig. 3.15. Trajectory of ball (consisting of flight path of TIB and TRB) when:- TIB has FPC-Vertical-Counterclockwise Spin (2),
- FPC-Vertical-Clockwise Spin (3) and.
- No-spin or FPF-Vertical Spin (1).
(Top down view and spin direction viewed by returner.)
Dashed line is the ball flight path if it has no spin.

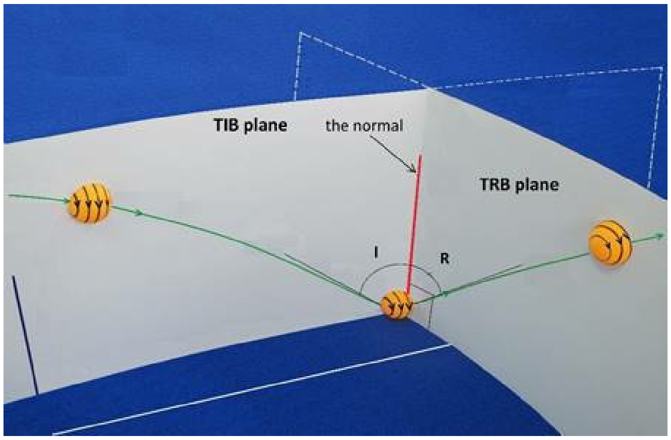


Fig.3.16. Flight path of TIB having FPC-Vertical-Counterclockwise Spin and its TRB flight path having FPF-Vertical-Top Spin.

Note: TRB plane cross TIB plane at a closely right angle at the normal.

Following is the summary of features of two kinds of FPC spin: FPC-Vertical-Clockwise Spin and FPC-Vertical-Counterclockwise Spin.

| **Table 6. Features of TRB from FPC-Vertical-Clockwise and Counterclockwise-Spin TIB** | | |
|---|---|---|
| **Features** | **TIB** | **TRB** |
| 1. Flight Path: | | |
| -Angle of incidence (I) and reflection (R) | I | R > I<br>TRB flies closer to the table surface than TIB. |
| -Direction | TIB flies forwards in TIB flat plane which may be occasionally curved near impact point. | TRB flies following a deviated direction that is closely perpendicular to the normal direction that TRB would follow if TIB has no-spin or FPF-vertical spin. |
| | Counterclockwise-Spin. | TRB flies leftwards |
| | Clockwise Spin | TRB flies rightwards |
| -Shape | Please see fig. 3.15 and 3.16. | Deflected parabolic line due to top-spin. |
| 2. Flight speed | Vi | Vb >> Vi as<br>Vb = Vi - Vloss + Vr<br>Vi is small, so Vloss is much smaller.<br>Vr is usually very big as Fbis is big due to high spin speed of TIB. |
| | | |

| | | |
|---|---|---|
| 3. Spin kind | FPC-Clockwise or Counterclockwise-Spin. | FPF-Vertical-Top-Spin (both cases) |
| 4. Spin speed | Si (fast) | Sb < Si as<br>Sb = Si + St – Sr<br>St is very small due to small flight speed and high ball.<br>Sr is usually bigger than St but smaller than Si. |

## 4. Reading and Predicting of Features of TRB (Table-Rebounding-Ball) of Serving Ball

The same method and process of reasoning used for deriving the features of TIB and TRB from the trajectory of returning ball could be used for the trajectory of serving ball as TRB1 (table rebounding ball at the server's table side) will become TIB2 (table incident ball at the returner's table side. Therefore, only drawings showing several patterns of the trajectories of serving ball are provided below for references. Drawings are not to scale and used for highlighting the acting forces and the ball flight paths.

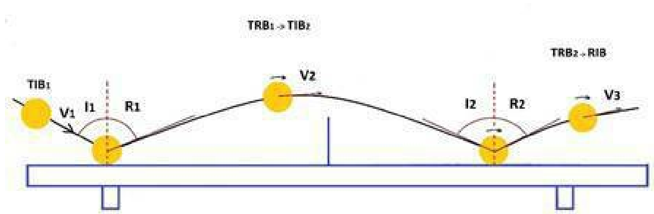


Fig. 3.17. Trajectory of No-Spin Serving Ball.

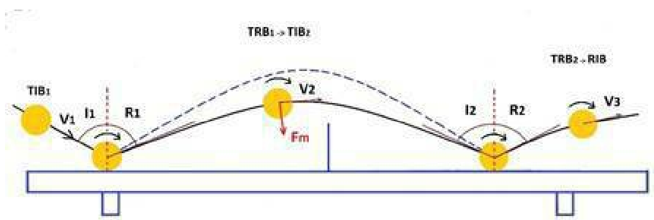


Fig. 3.18. Trajectory of Vertical-Top-Spin Serving Ball.

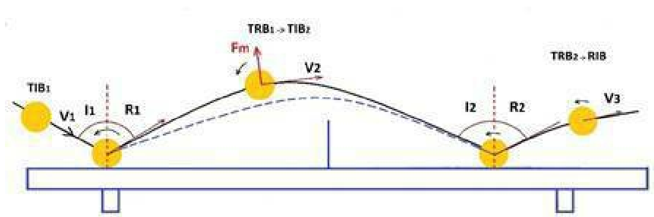


Fig. 3.19. Trajectory of Vertical-Back-Spin Serving Ball.
Note: Dashed line in Fig. 3.18 and Fig. 3.19 is trajectory of ball if it has no-spin.

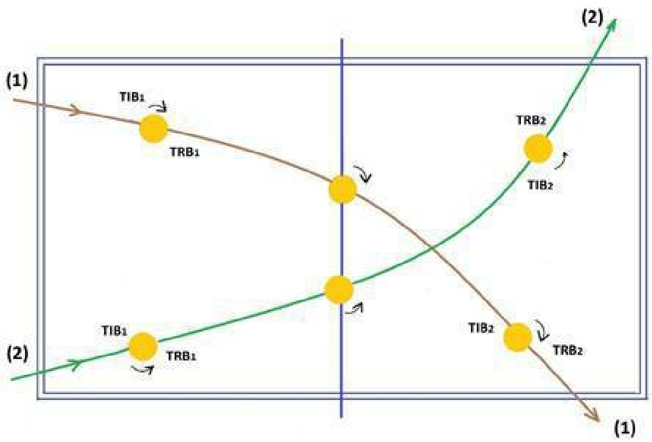


Fig. 3.20. Trajectory of Horizontal-Spin Serving Ball having clockwise spin (1) and counterclockwise spin (2).

CHAPTER 4
# Ways of Striking the Ball

This Chapter introduces methods or ways of striking back oncoming ball having spin and no-spin based on the motions of racket surface relative to the flight path and spin of the oncoming ball primarily applied to the case of two factors as follows:

- Oncoming ball is the returning ball having spin or no-spin,
- Racket rubber surface used is a spin-rubber.

However, the methods described below may in several aspects be used for striking the ball in a service and returning the ball when using a no-spin rubber surface racket.

Flight path and spin of RRB (racket-rebounding-ball) could be derived referring to the law of reflection and forces analysis method (please see section 1.5 of Chapter 3 and Annex 2), which could be verified by player in practice.

This Chapter also provides a detailed description of 2 methods or (theoretical) techniques for striking ball which are named as TTC (Through-The-Center) of the ball Stroke and TTS (Tangential-To-(The)-Surface) of the ball Stroke, which are helpful for returning a spinning ball and generating spin.

## 1. Factors Affecting the Ways of Striking the Ball

In order to find out the proper ways of striking back the ball having desired flight path and spin to the opponent, we have to determine first the factors which affect the features of the ball bouncing off the racket surface (RRB or racket-rebounding-ball). Following are four key factors to be considered:

### 1.1. Features of Racket Rubber Surface

Ways of striking the ball depend so much of the features of racket rubber surface. There are many different kinds of racket rubber, but they are sorted into two groups for analysis of reactions exerted by the rubber surface on the ball, based on which the basic ways or techniques of striking on the ball are derived:

(1) Spin rubber,
(2) No-spin rubber.

Further information on the effects of spin rubber and no-spin rubber on the ball is described in the below section 2.

### 1.2. Flight Path of the Ball

There are three different kinds of flight path of the ball when it is struck by the racket:

(1) The ball flight path which will be struck by the server is almost a vertical straight line path going downwards after the ball has been tossed near vertically upwards.
(2) Table-Rebounding-Ball (TRB) flight path of serving ball trajectory which could be a rising line or a descending line when the ball is struck.
(3) Table-Rebounding-Ball (TRB) flight path of returning ball trajectory which could also be a rising line or a descending line when the ball is struck.

### 1.3. Ball Spin and Spin Speed

(1) The ball which will be struck by the server has no-spin.
(2) The TRB (table-rebounding-ball) which will be returned or struck back by a player to his or her opponent may have spin or no-spin.

### 1.4. Ball Flying Speed

The ball flying speed is affecting the angle of reflection of RRB and also affecting player’s choice of strokes to be used such as a block, a drive shot or a drop shot, etc.

## 2. Effect of Spin and No-Spin Rubber Surface on RRB (Racket-Rebounding-Ball)

### 2.1. Reactions of Racket Rubber Surface

When a flying ball with spin hits the racket rubber surface, the ball will bounce off (rebound) the racket surface by the effect of two reactions (forces) from the rubber surface:

(1) TTC (through-the-center) of the ball reaction against a force acting upon the racket surface due to the ball flight speed,
(2) TTS (tangential-to-the-surface) of the ball reaction against a force acting upon the racket surface due to the ball spin speed.[*]

[*] In case of no-spin rubber surface, TTS reaction is very small or considered as zero (**F**bis ≈ 0) (please see below Section 2.2)

The RRB flight direction follows the direction of the vector sum of these two forces, of which illustrations are given in Annex 2.

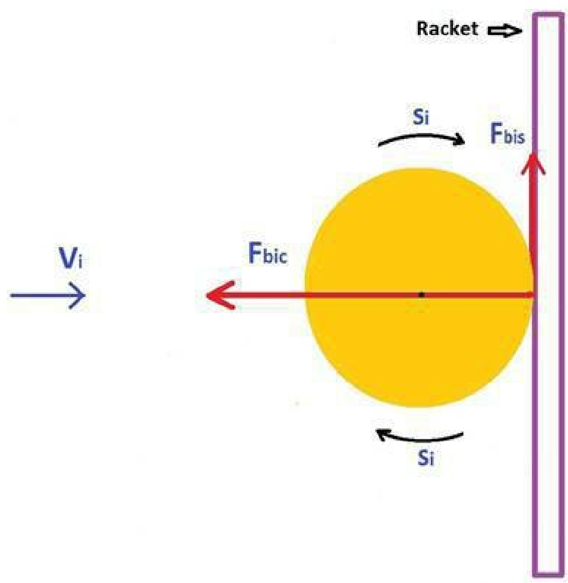


Fig. 4.1. Two components of Reaction from Racket Rubber Surface:
**F**bic (TTC) and **F**bis (TTS).

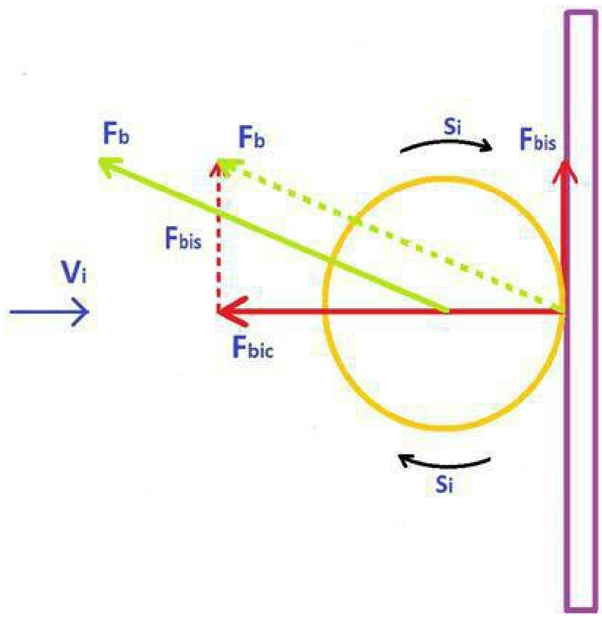


Fig. 4.2. RRB (racket-rebounding-ball) flight is following the direction of
**F**b = **F**bic+ **F**bis.

## 2.2. Features of RRB from No-Spin Rubber Surface

No-Spin Rubber surface is so slippery that when a flying ball with spin hits the rubber surface, the spinning motion of the ball just slips on the surface and thus imparting no force or very small force on the rubber surface. The TTS reaction (**F**bis) of no-spin rubber surface on the ball is therefore zero or very small. So, there is only one effective reaction, i.e., TTC reaction, of the racket surface acting upon the ball at impact whether the ball has spin or no spin. (**F**b ≈ **F**bic as **F**bis ≈0)

The resulting features of RRB from a spinning RIB hitting a no-spin surface are as follows:

(1) RRB continues to have the same spin direction as RIB (racket-incident-ball). RRB spin speed is almost the same as or smaller than that of RIB depending on the slipperiness degree of the rubber surface.

(2) RRB flight path and RIB flight path are on the opposite sides of the normal (except when RIB is perpendicular to the racket surface).

Illustrations of several cases of RIB and the approximate RRB flight path from a no-spin rubber surface when the racket is not moving:

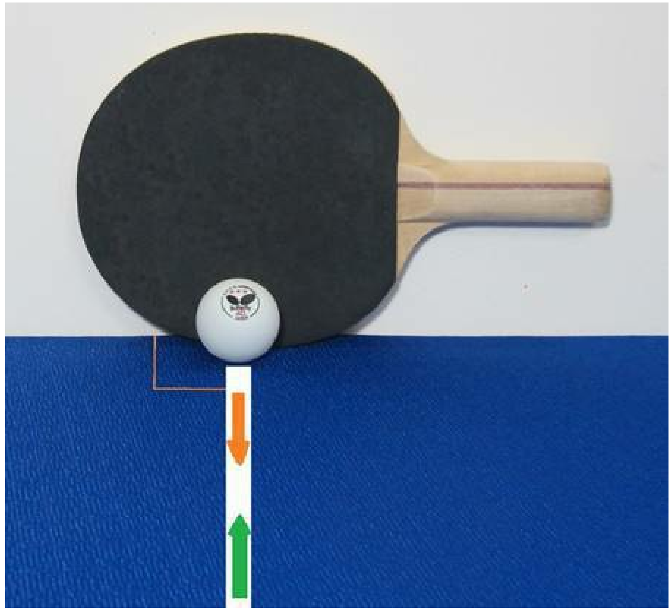

Fig. 4.3. No-Spin RIB and RRB.

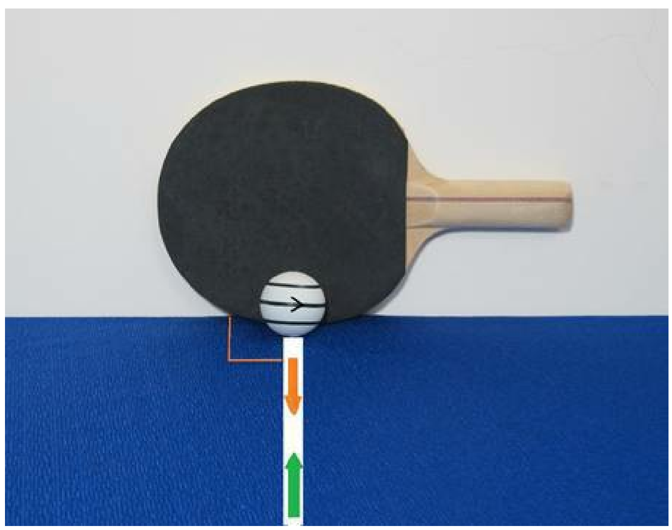

Fig. 4.4. Spinning RIB and RRB.

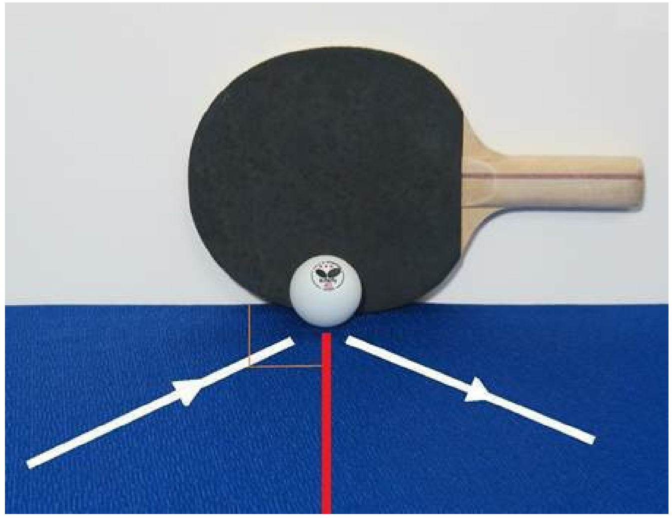

Fig. 4.5. No-spin RIB act acute angle and RIB.

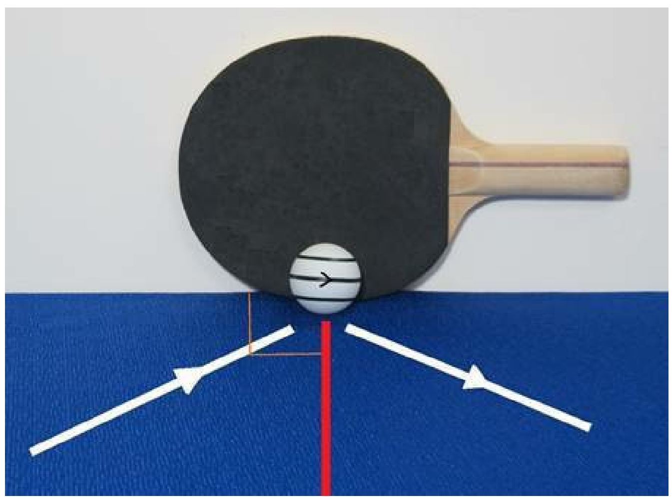

Fig. 4.6. Counterclockwise-spin RIB at acute angle and RRB.

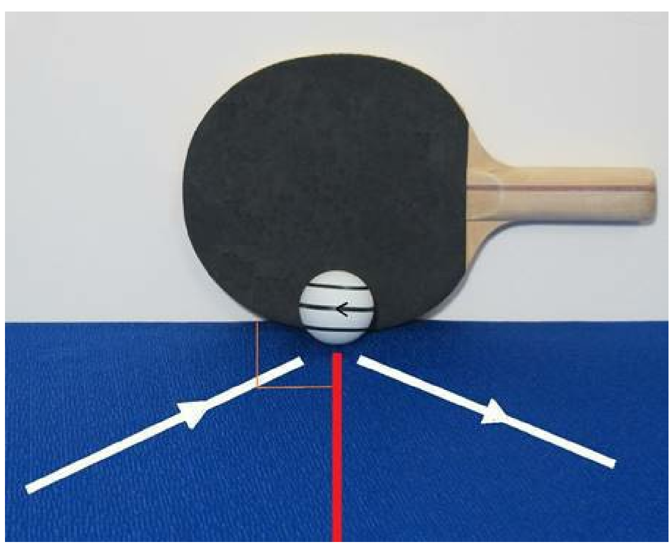

Fig. 4.7. Clockwise-spin RIB at acute angle and RRB.

*Remark: No-spin RIB (Fig. 4.5), Counterclockwise spinning RIB (Fig. 4.6) and Clockwise Spinning RIB (Fig. 4.7) hitting no-spin rubber surface at an acute angle, flight paths of the corresponding RRBs are almost alike and in the opposite side of the normal.*

## 2.3. Features of RRB from Spin-Rubber Surface

Spin-rubber surface is a sticky or tacky rubber surface which has high friction so that when a flying ball with spin hits it, the sticky rubber surface can catch the spinning or rotating motion of the ball surface and thus exerting a TTS reaction on the ball surface against the force exerted by the ball spin on the racket surface. Consequently, there are two reactions (forces), TTC reaction and TTS reaction, exerted by the rubber surface upon the ball when a flying ball with spin hits the spin rubber surface.

General features of RRB from a spin-rubber surface racket which is standing still (not moving) when a flying ball hits it and bounces-off towards the opposite direction of RIB are as follows:

(1) Spin direction of RRB is usually opposite to that of RIB or in other words, spin direction of RIB is reversed after it hits the racket rubber surface, [*]

(2) Flight path and direction of RRB which is following the direction of the vector sum of TTC reaction and TTS reaction could be on the opposite side or the same side of the normal with RIB depending on spin direction of RIB.

[*] RRB could have no-spin or the same spin as RIB depending on various factors like RIB’s flight speed and angle of incident, kinds of shot (racket is moving) of the racket, etc., which are further described in the following sections.

Illustrations of several cases of RIB and RRB flight path from spin-rubber surface when the racket is not moving:

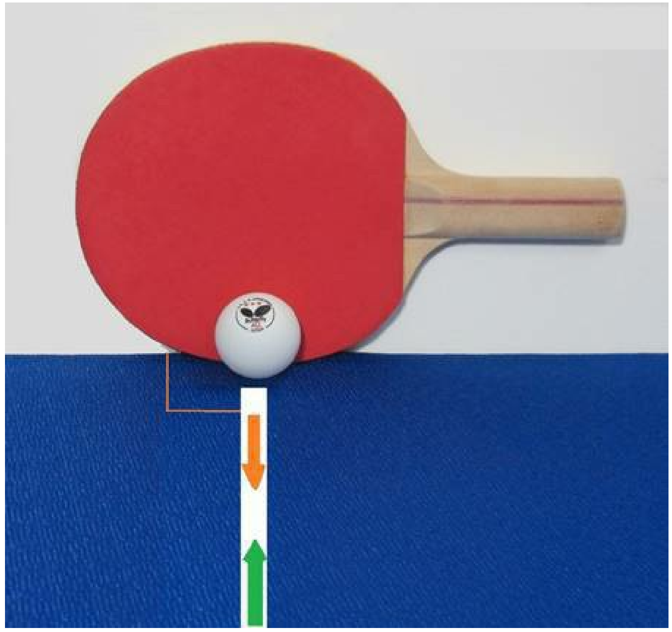

Fig. 4.8. No-spin RIB hitting at right angle to spin-rubber surface.

Note: RRB is flying in almost the same path as RIB but in opposite direction.

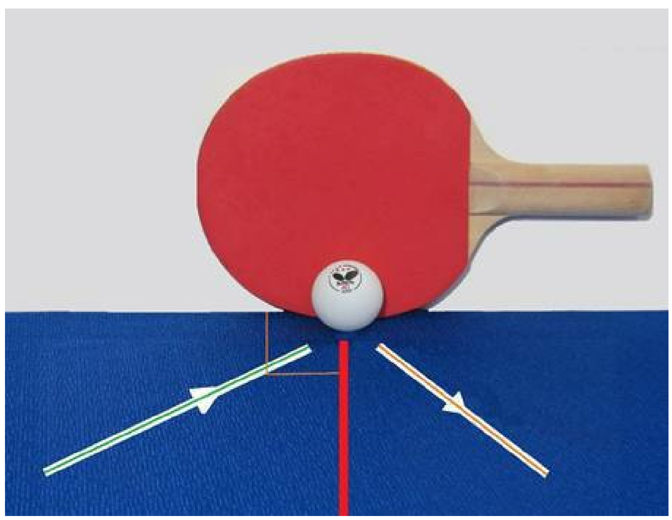

Fig. 4.9. No-spin RIB hitting a spin-rubber surface.

Note: In Fig. 4.9. RRB and RIB paths are in the opposite sides of the normal.

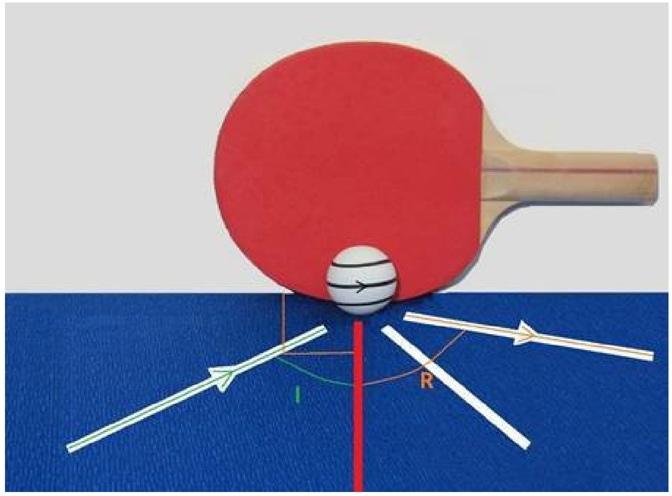

Fig. 4.10. Counterclockwise-spin RIB hitting spin-rubber surface.

Note: In Fig. 4.10 RRB and RIB flight paths are on the opposite sides of the normal. Angle of reflection (R) of RRB is bigger than the angle of incidence (I) or RRB flight path is closer to the racket surface than RRB of a no-spin RIB due to TTS reaction against spin.

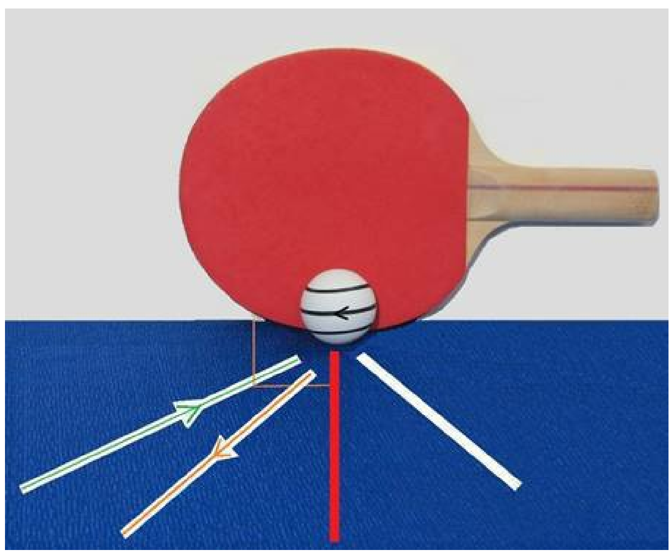
Fig. 4.11. Clockwise spinning RIB at acute angle to spin-rubber surface.

Note: RRB from a horizontal-clockwise RIB could be on the same side of the normal with RIB path, and the angle of reflection (R) could be equal to, smaller or bigger than the angle of incidence depending on spin speed, flight speed and angle of incidence of RIB.

White strip lines in Figs. 4.10 and 4.11 represent RRB path in case RIB has no spin.

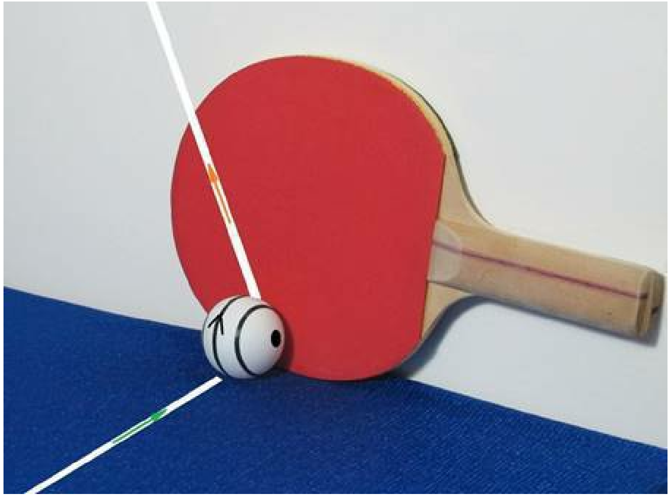

Fig. 4.12. Vertical-Top-Spin RIB at right angle to spin-rubber surface.
RRB flies upwards and closely to rubber surface.

# 3. Ways of Striking the Ball

## 3.1. Overview

The types and styles of using the racket to strike on the ball are classified following three steps similar to the three steps used for classification of ball spins.

First, the different ways of striking or strokes are sorted into two categories or groups:

1. Racket is moving when hitting the ball is called a Shot.
2. Racket is standing still when the ball hits its surface is called a Block.

As for shot (racket is moving), following two types of shot are classified:

(1) TTC (Through-The-Center) of the ball shot (TTC or TTCB shot),
(2) TTS (Tangential-To-(The)-Surface) of the ball shot (TTS or TTSB shot).

TTC and TTS shots could then be performed in the following styles:

i. Face-upright, Face-close, Face-open Racket shot. (Reference is on the racket).
ii. Downward and forward, Upward and forward, Upright, Sideway,

Horizontal shot. (reference is on the movement direction of racket compared with the table surface).

iii. Following-Spin, Counter-Spin or Spin-Pole shot. (reference is on the racket-incident-ball or RIB).

iv. Equatorial spin line and Latitudinal spin line shot.

v. Vertical-Spin and Side-Spin (imparting) shot.

So, the name of a shot based on the combination of various features of the stroke as sorted above could be expressed as:

- TTS, Face-close, Upward and Forward, Counter-Spin, Equatorial spin line Shot.

For block, mainly face-upright, face-close or face-open is considered, so a name of a block could be as a Face-close block.

Illustrations of forces acting upon the ball by a shot and a block for approximating the flight path of the returned ball (RRB) are in Annex 2.

## 3.2. TTC (Through-The-Center) and TTS (Tangential-To-(The)-Surface) Shots

A shot in this book is generally defined as a stroke when the racket is moving to hit the ball back to the opponent. Shot is more often used in table tennis than Block.

TTC and TTS shots can be performed when using spin-rubber racket. However, for no-spin rubber racket , in general only TTC shots can be used to properly strike the ball to the opponent's table court as there is no friction on the rubber surface to generate the tangential to the ball surface force (Fbis ≈ 0) to lift the ball as explained in above Subsection 2.2.

Following are the detailed descriptions of the types and styles of shot.

### *(1) TTC (Through-The-Center) of the Ball Shot*

Two kinds of TTC shot are distinguished: Perfect TTC shot and Imperfect TTC shot:

**a. Perfect TTC Shot**

A shot is a perfect TTC shot when it meets two conditions:

i. The line of motion of racket surface is perpendicular to its surface or following the same line as the normal,[*] in other words,
ii. The RIB (racket-incident-ball) hits the rubber surface at right angle.

[*] the normal is the line perpendicular to the rubber surface at the point of impact with the ball.

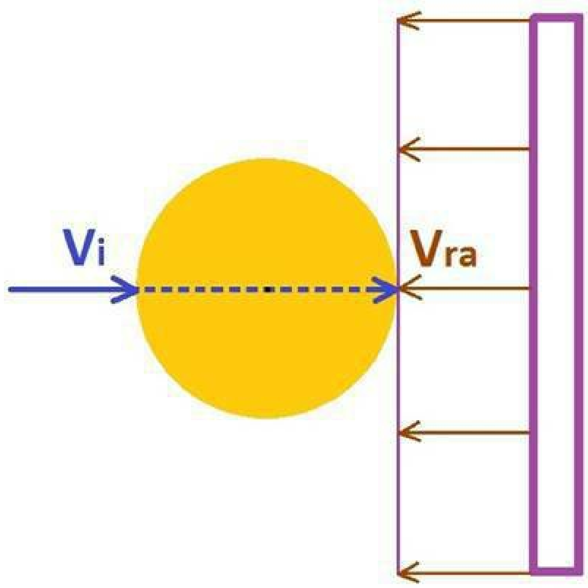


Fig. 4.13. A Style of Perfect TTC Shot.

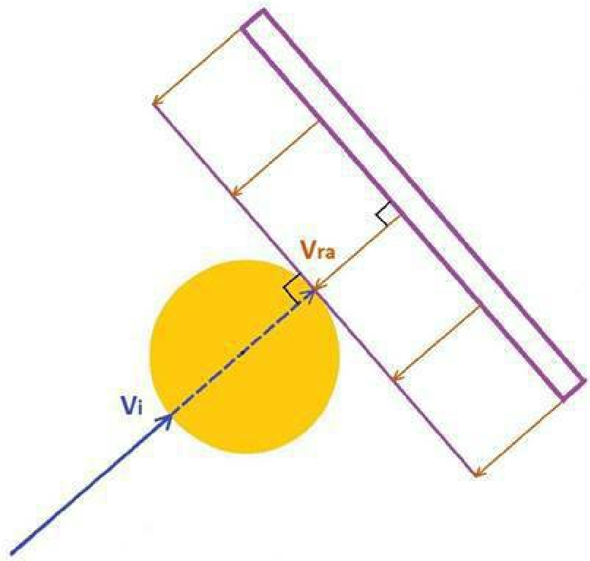


Fig. 4.14. A Style of Perfect TTC Shot.

*Remarks:*

- *Perfect TTC shot can be performed with both no-spin rubber and spin-rubber rackets.*
- *For spin rubber racket, Perfect TTC shot is generally used to strike spin and no-spin RIB, smash high ball RIB with small spin.*

**b. Imperfect TTC shot**

A shot is an Imperfect TTC shot when it meets either one of the following two conditions:

i. The line of motion of the racket surface is perpendicular to its surface, and the RIB flight path is not perpendicular to the rubber surface at impact point, or

ii. The line of motion of the racket surface is not perpendicular to its surface but forms a small angle (say: less than 45 degree) with the normal.

Note: In case the angle is equal or bigger than 45 degree Imperfect TTC shot could be considered as Imperfect TTS shot.

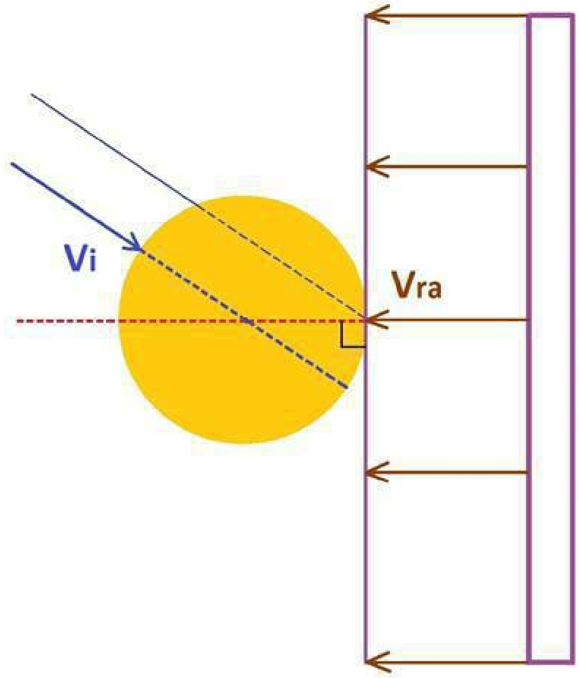


Fig. 4.15. A Style of Imperfect TTC Shot (type i.)

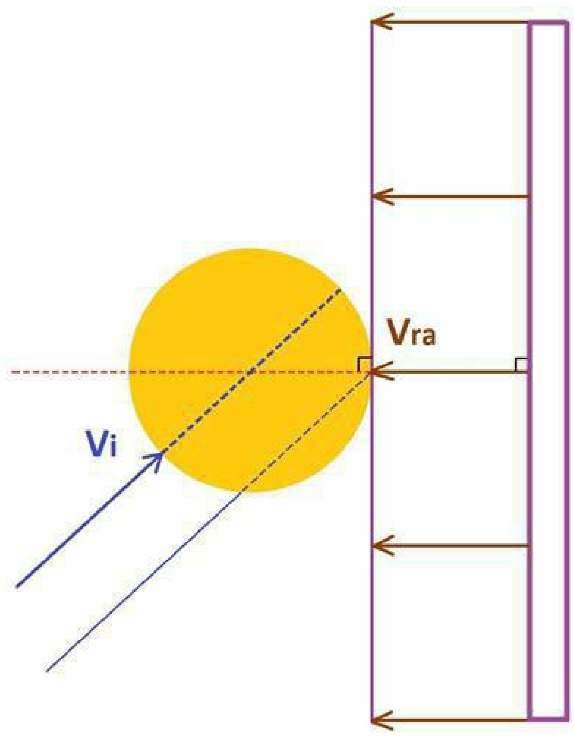


Fig. 4.16. A Style of Imperfect TTC Shot (type i.)

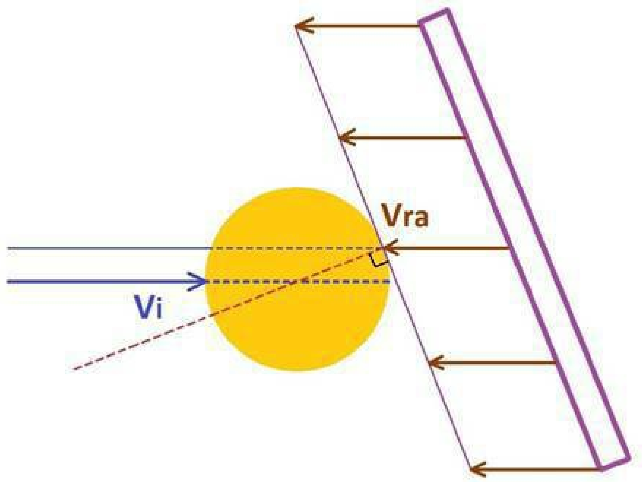


Fig. 4.17. A Style of Imperfect TTC Shot (type ii.)

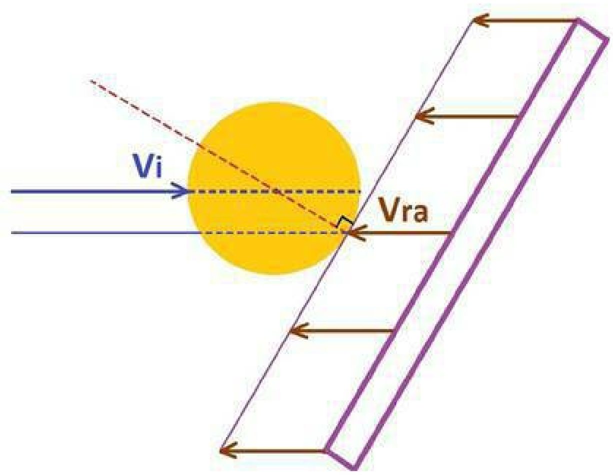


Fig. 4.18. A Style of Imperfect TTC Shot (type ii.)

*Remark: Imperfect TTC shot can be performed when using no-spin rubber racket.*

### *(2) TTS (Tangential-To-(The)-Surface) Shot*

TTS shot is generally used with spin-rubber surface racket to hit RIB having spin to the opponent. There are two kinds of TTS shot are distinguished: Perfect TTS shot and Imperfect TTS shot.

#### a. Perfect TTS Shot

A shot is a Perfect TTS shot when the line of motion of the racket forms a right angle with the line perpendicular to the racket surface (the normal). Or the line of motion of racket lies on the racket surface plane, in other words.

Perfect TTS shot can be an upward and forward shot, a downward and forward shot, a horizontal and forward shot or an upright or downright (racket surface motion is perpendicular to the table surface) shot.

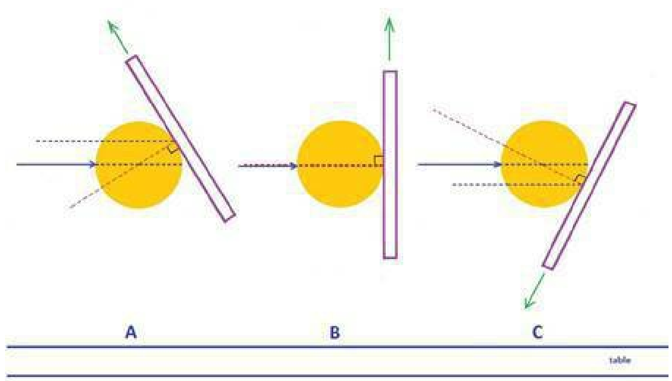


Fig. 4.19. Three Styles of Perfect TTS Shot.

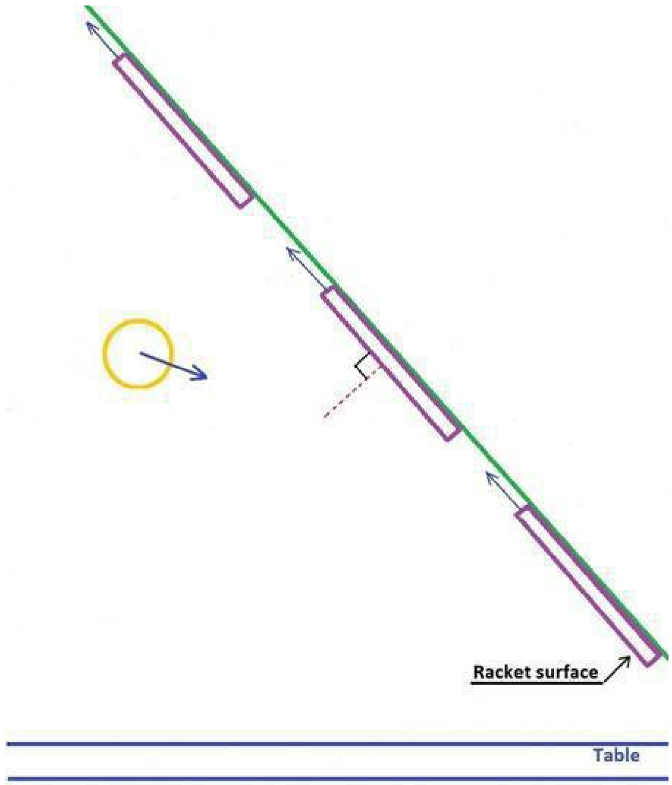


Fig. 4.20. Sequence of racket surface of Perfect TTS Shot in upward

and forward motion.

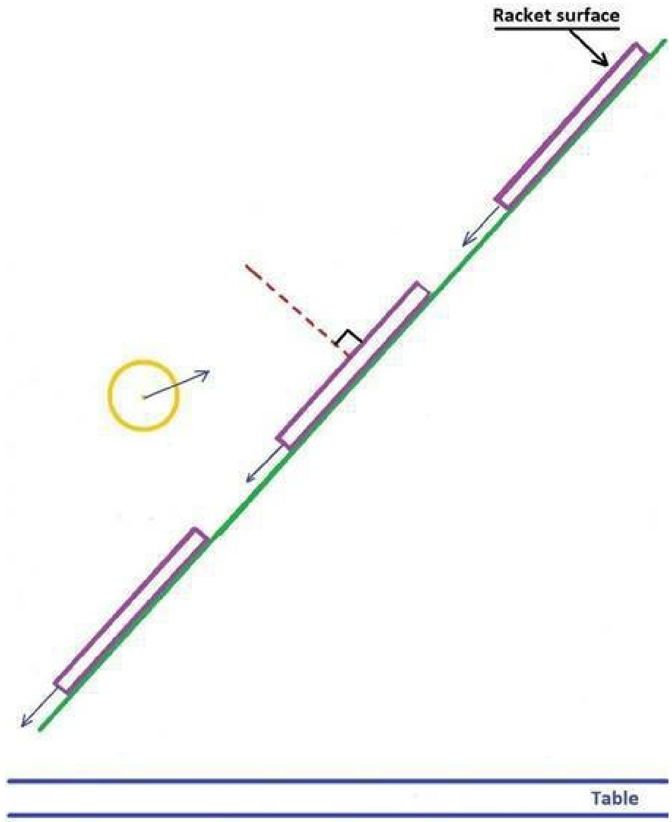


Fig. 4.21. Sequence of racket surface of Perfect TTS Shot in downward and forward motion.

*Remarks:*

- *Perfect TTS shot is effective only with spin-rubber racket.*
- *Perfect TTS shot is generally used to strike back ball with fast spin. Perfect TTS shot can generate higher spin speed on the ball when the friction degree of the rubber surface is higher.*
- *Perfect TTS can't be used to strike the ball when no-spin rubber racket is used.*

**b. Imperfect TTS Shot**

The racket surface of Imperfect TTS shot does not move on a flat plane as in the case of Perfect TTS, but instead the edge of its surface does as shown in the below drawings.

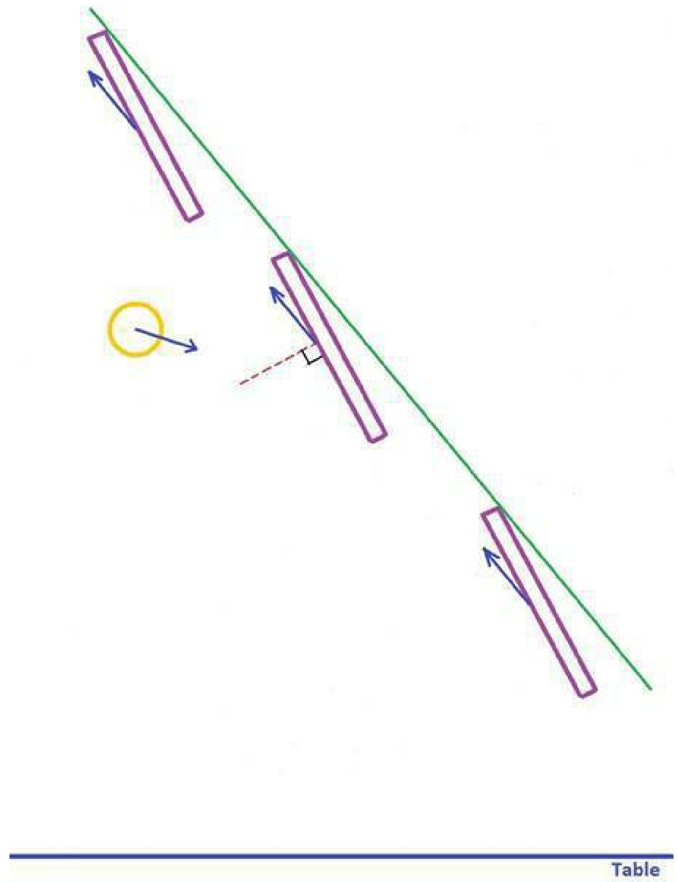


Fig. 4.22. Sequence of racket surface of Imperfect TTS Shot in upward and forward motion.

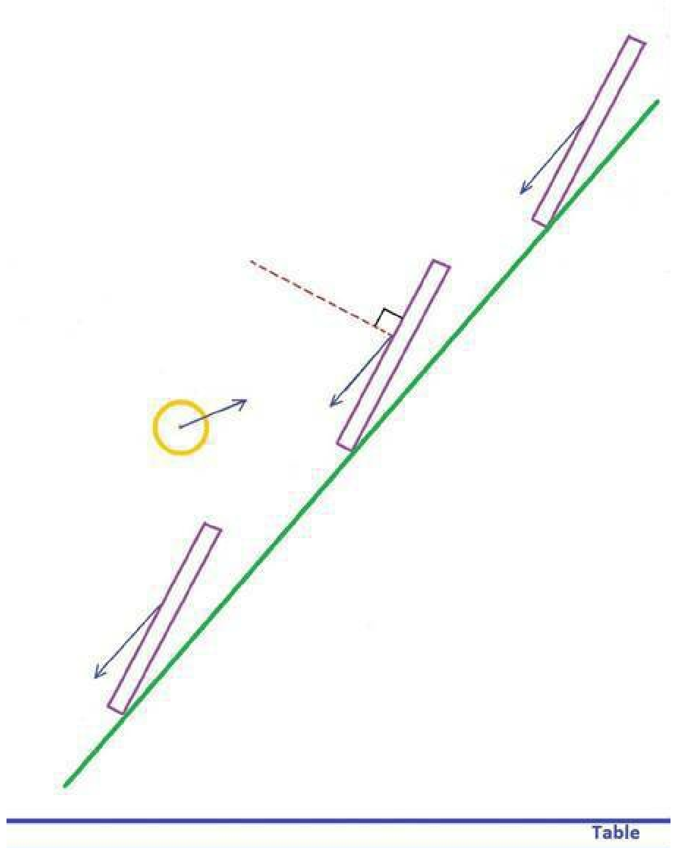


Fig. 4.23. Sequence of racket surface of Imperfect TTS Shot in downward and forward motion.

*Remarks:*

· *Imperfect TTS is used with spin-rubber surface racket.*

· *Imperfect TTS shot can lift the ball to a higher flight path above the net than that generated by the Perfect TTS shot when other factors are similar.*

### 3.3. Face-upright, Face-close, Face-open Racket Shot

These three styles of shot can be used in combination with both TTC shot and TTS shot.

(1) Face-upright shot is a shot when the racket surface is almost perpendicular to the table surface when it hits the ball.

(2) Face-close shot is a shot when the racket is inclined forward from the upright position so that the surface when hitting the ball can see the table surface.

(3) Face-open shot is a shot when the racket surface is inclined backward from the upright position so that the surface when hitting the ball looks away from the table surface.

Highlights:

- Face-open racket shot always hits the ball at a point below the SDD (Spin-Directions-Dividing) plane, or on the Lower-Half of the ball with reference to the SDD plane.
- Face-close or face-upright racket can hit the ball at a point on the Top-Half (Upper-Half) or Under-Half (Lower-Half) of the ball demarcated by SDD plane or right on the SDD line, depending on the features of RIB (racket-incident-ball) such as angle of incident, RIB is on rising path or descending path when it is hit by the racket, etc.

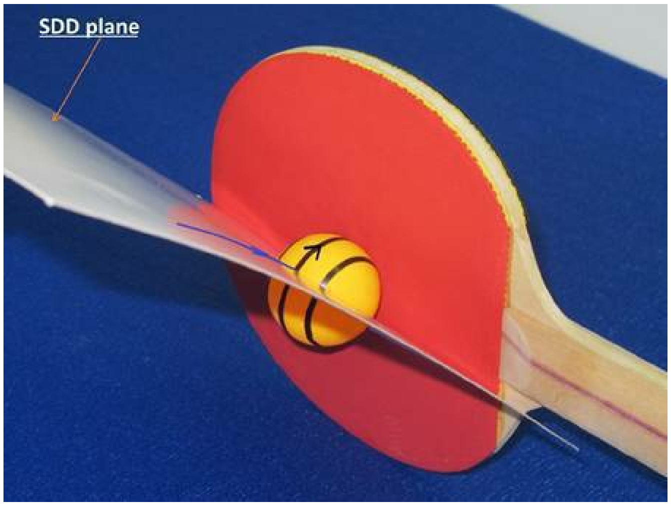


Fig. 4.24. Face-upright, Counter-spin Shot.
(racket moves forwards and upwards)

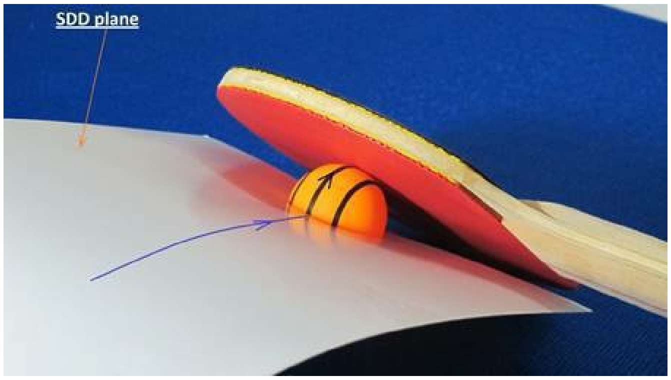


Fig. 4.25. TTS, Face-close, Counter-spin Shot.

(racket moves forwards and upwards).

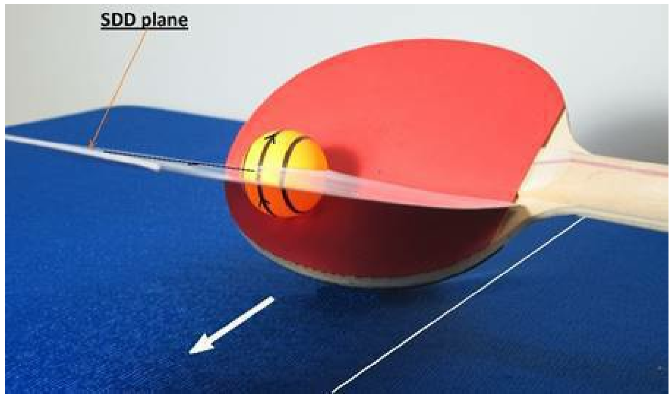


Fig. 4.26. TTS, Face-open, Following-Spin Shot.
(racket moves forwards and downwards)

### 3.4. Following-Spin Shot and Counter-Spin Shot

These shots are generally used with combination with TTS shot to strike back ball with very fast spinning speed.

(1) Following-Spin shot is a shot when the motion of the racket is following the spin direction of the incident ball (RIB or TRB) when the racket hits the ball. (Fig. 4.26).

(2) Counter-Spin shot is a shot when the motion of the racket is against the spin direction of the incident ball (RIB or TRB) when the racket hits the ball. (Fig. 4.25).

Highlights of Following-Spin Shot:

- RRB's spin direction is the same as RIB's.
- The motion of Following-Spin shot has to be done at high speed, at least as high as the linear spin speed of the ball, otherwise the surface of a spinning ball can catch the spin-rubber surface and thus activating a reaction of the rubber surface, which drives the ball to the undesired direction. Following-Spin shot is therefore considered more difficult to execute than Counter-Spin shot.
- Following-Spin shot is usually used to strike back a side-spin TRB of which flight path is a curved line to the right side or the left side of a returner.

Highlights of Counter-Spin Shot:

- RRB's spin direction is opposite to that of the RIB.

· RRB's spin speed is faster than that of RIB. (Following-Spin shot usually makes RRB spin slower than RIB).

· It is easier to control the flight path of RRB by using Counter-Spin shot than Following-Spin. Counter-spin shot is therefore used to strike back all oncoming ball having all kinds of spin.

### 3.5. Equatorial Spin Line Shot and Latitudinal Spin Line Shot

(1) Equatorial spin line shot is a shot that hits the ball at a point on the equatorial spin line.

(2) Latitudinal spin line shot is a shot that hits the ball at a point on latitudinal spin line.

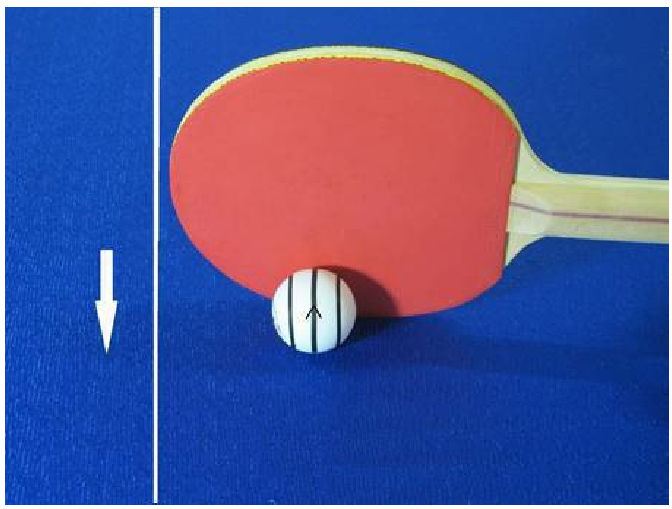

Fig. 4.27. TTS Shot hitting the equatorial spin line of a vertical spin ball.

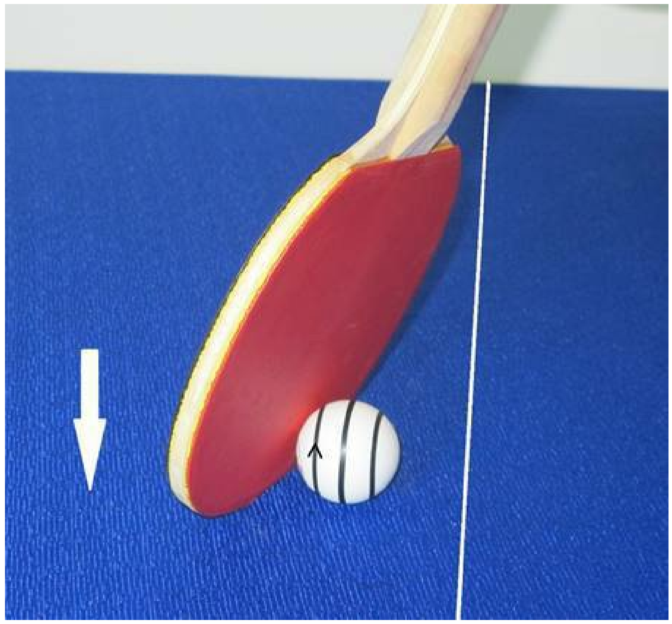

Fig. 4.28. TTS Shot hitting a latitudinal spin line.

Highlights:

- Equatorial spin line TTS shot makes RRB spin speed higher than that generated by Latitudinal spin line shot as equator linear spin speed of RIB is higher than Latitude's.
- Latitudinal spin line TTS shot on vertical spin RIB hits RIB at its side and generates side-spin on RRB.

## 3.6. Vertical-Spin-Generating Shot and Side-Spin-Generating Shot

TTS shots are used to generate vertical-spin ball and side-spin ball.

To generate vertical-top and bottom spin on the ball: the racket surface when moving and hitting the ball would in a majority of cases should be either perpendicular to the incident ball plane (Fig. 4.27) or a plane perpendicular to the table surface depending on the ball spin and spinning plane. Racket moving upwards will generate top-spin, downwards will generate back-spin.

To generate inclined-spin and horizontal-spin (side-spin): the racket surface when moving forwards and hitting the ball should be inclined (not perpendicular) to the incident-ball plane. (Fig. 4.28).

## 3.7. Spin-Pole Shot

This type of shot hits the ball at a point right at either spin-pole or very close to it where (linear) spin speed is close to zero. One of the applications of this shot is perhaps to bring a horizontal-spin RIB of a serving ball trajectory back to the opponent's table court.

## 4. Block

A block is defined in this book as a stroke of which the racket is standing when the ball hits its surface. The racket-incident-ball (RIB) is therefore struck back towards the opponent by the reactions of the racket rubber surface as explained in 2.1. A Block can be performed at a position above and close to the table surface or outside the table surface.

Three types of block are often used:

1. Face-upright racket block which is used when RIB has no spin or small spin speed.
2. Face-close racket block which is used when RIB has top-spin.
3. Face-open racket block which is used when RIB has back-spin.

A Block with no-spin rubber surface is usually executed with face-upright or face-open (a little) racket surface.

## 5. Predicting of Trajectory and other Features of RRB by Force Analysis Method

By practicing and experiences a good player could foresee or predict the resulting trajectory, kind of spin, etc. of the returning ball from a racket shot that he or she imparts on the ball. However, in addition to practices and experiences, player could use the Force Analysis Method as described and illustrated in Annex 2 to foresee the approximate effect of forces imparted by the racket on the flight path, spin, etc. of RRB, based on which he or she could adjust the strokes.

## 6. Reference for Tracking of Trajectory of Ball

Tracking the entire trajectory of the opponent's oncoming ball as well as one's own returning ball right from the moment the ball bounces off the racket surface is essential to improve the quality of the returning ball to the opponent.

Usually the net is used as a reference, and the ball trajectory is seen as close to the net or high above the net, etc. based on which player adjusts his/her shot.

In order to track the entire trajectory of ball from the start, the second point or line of reference, which is the racket surface or the normal line to the racket surface at the impact point with the ball, should be used.

The ball is, therefore, seen also as close to the racket surface or close to the normal, based on which player could adjust the angle of attack (angle formed by the motion of racket surface and the ball flight path) to make the RRB flight path closer or higher to the net according to his/her wish. (Illustrations in Annex 2)

## 7. Ways of increasing speeds of ball

The ball flying speed and spinning speed depend on two factors:

(1) Features of racket consisting of blade and rubber surface (including pimple rubber top sheet and sponge.)
(2) Striking techniques.

Player could get in the market racket blade and rubber surface suitable to his/her techniques to increase speed of ball.

As regards technique, following are several ways as to increasing flying speed and spinning speed of ball from a player's stroke:

- Increasing speed of a stroke.
- Striking close or on the equator spin line of ball.
- More TTC shot will increase flying speed.
- More TTS shot will increase spinning speed.

Note: Top-pin increases the ball downward velocity as Magnus force or Lift (**L**) generated by top-spin is directed downward although it is not always perpendicular to the table surface as weight (**p**). On the contrary, back-spin ball decreases the downward velocity as Lift (L) in this case is directed upwards, i.e., opposed to the direction of weight (**p**).

# 8. Summary of main features of several types of shots

**Table 7. Summary of main features of several types of shots**

| S/N | Types of shot | Point of attention | Flight path of RRB (racket-rebounding-ball |
|---|---|---|---|
| 1. | TTS shot | Used when RIB has more spin. | Close to racket surface (s Annex 2) |
| 2. | TTC shot | Used when RIB has small spin or no-spin. | Close to the normal (of racket)<br>(see Annex 2) |
| 3. | Counter-Spin shot | Spin direction of ball is reversed after bouncing-off racket surface. | Close to racket surface |
| 4. | Following-Spin shot | Spin direction of ball is unchanged after bouncing-off racket surface (usually). | Close to the normal |
| 5. | Vertical-Spin-Generating shot | Racket surface is perpendicular to incident-ball plane when it is moving and hitting the ball. | Please see Annex 2 |
| 6. | Side-Spin - Generating shot (inclined-spin and horizontal-spin) | Racket surface is inclined (not perpendicular) to incident-ball plane when it is moving and hitting the ball. | Close to racket surface |

Illustrations of trajectories and spins of the ball hit by player A to player B and the corresponding returned ball by player B to player A are in Annex 3.

ANNEXES

Annex 1. Kinds, Features and the Effects of Spins of Table Tennis Ball.

Annex 2. Forces Analysis Method and Illustrations of Forces acting upon RIB (racket-incident-ball) and the resulting Flight Path and Spin of RRB (racket-rebounding-ball).

Annex 3. Illustrations of Basic Shots and the resulting Trajectories and Spins of Returning Ball.

# ANNEXES

ANNEX 1

# Kinds, Features and the Effects of Spins of Table Tennis Ball

**Table 1. Name of all Kinds of Spins of Table Tennis Ball**

| Spin Group | Spin Type | Spin Style | **Full Name of all Kinds of Spins of TT Ball** [4] | Feat-ures [1] |
|---|---|---|---|---|
| 1. FPF-Spin<br><br>FPF: Flight-Path-Following (Spin Group 1) | 1.Vertical-Spin<br><br>2. Side-Spin<br><br>2.1. Inclined-Spin<br><br>2.2.Horizontal-Spin | 1.Top-Spin<br><br>2.Back-Spin<br><br>3. Clockwise-Spin<br><br>4. Counter-clockwise-Spin | 1. FPF-Vertical-Top-Spin<br><br>2. FPF-Vertical-Back-Spin<br><br>3. FPF-Inclined-Clockwise-Top-Spin [2]<br><br>4. FPF-Inclined-Counterclockwise-Top-Spin [3]<br><br>5. FPF-Horizontal-Clockwise-Spin<br><br>6. FPF-Horizontal-Counterclockwise-Spin | |
| 2. FPC-Spin<br><br>FPC: Flight-Path-Crossing (Spin Group 2) | 1.Vertical-Spin [3] | 1. Clockwise-Spin<br><br>2. Counter-clockwise-Spin | 1. FPC-Vertical-Clockwise-Spin<br><br>2. FPC-Vertical-Counterclockwise-Spin | |

*Remarks:*

*[1] Table 2 Summary of features of the effects of spins of table tennis ball in Annex 1.*

*[2] FPF-Inclined-Back-Spin does not exist.*

*[3] FPC-spin plane could be either vertical or inclined at a small angle to the normal whose effects are almost the same or slightly deviated from those of vertical-spin. Therefore, only Vertical-Spin is designated for FPC-Spin Group.*

*[4] Full name with FPC as abbreviation is always used to indicate a kind of ball spin belonging to FPC-Spin group. However, shortened name of which the words FPF and vertical are omitted is often used to indicate a ball spin belonging to FPF-Spin group, when there is no confusion. So, when a ball is written as having 'Top-Spin', this means that it has 'FPF-Vertical-Top-Spin'.*

. . .

| **Table 2. Summary of Basic Features and the Effects of Spins of Table Tennis Ball** | | | |
|---|---|---|---|
| **1. FPF (Flight-Path-Following) Spin Group** | | | |
| **Full Name of Spin of TIB** (Table-Incident-Ball) | **Features** | **Features** | **Full Na of Spin TIB** (Table- Incident Ball) |
| 1.1. FPF- Vertical- Top Spin | Common feature of FPF spin: Flight path of ball lies on Equatorial spin Plane. | | 1.2. FPF Vertical- Back-Sp |
| | 1. Spin of top-half of ball (above SDD plane) is following ball flight direction. | 1. Spin of top-half of ball (above SDD plane) is opposite to ball flight direction. | |
| | 2. Spin of under-half of ball (below SDD plane) is opposite to ball flight direction. | 2. Spin of under-half of ball (below SDD plane) is following ball flight direction. | |
| | 3. Spin-plane is perpendicular to table surface. | 3. << (the same as left 1.1.3) [similar to 1.1. (5)] | |
| | 4. TIB touches table surface at a point on ball equatorial spin line. | 4. << (the same as left 1.1.4) | |
| | 5. TRB spin kind is the same as TIB. | 5. TRB spin kind is usually the same as TIB. But under special circumstances TRB might have no-spin or reversed spin. | |
| | 6. TRB spin speed $\leq$ TIB (usual) | 6. TRB spin speed could be:<br>(1) < TIB spin speed (usual), or<br>(2) = 0 or no-spin (probable), or<br>(3) small and negative figure, that is, spin direction is reversed or opposite to that of TIB (rare) | |
| | | | |

| | | | |
|---|---|---|---|
| | 7. TRB flight speed > TIB (usual) | 7. TRB flight speed < TIB (usual) | |
| | 8. TRB is closer to table surface than TIB | 8. TRB is higher above table surface than TIB. | |
| | 9. TIB and TRB flight paths are curved lines deflected downwards compared with that of no-spin ball. | 9. TIB and TRB flight paths are curved line deflected upwards before falling down compared with that of no-spin ball. | |
| | 10. TIB, TRB and the normal lie in a flat plane perpendicular to table surface. | 10. << | |
| 1.3. FPF- Inclined- Clockwise- Top-Spin | 1 to 8 are similar to those of 1.1 | 1 to 8 << | 1.4. FPF Inclined Counter clockwi Top-Spi |
| | 9. Ball (TIB and TRB) flight path is a curved line similar to a parabola with its vertex oriented toward the right side of returner. | 9. Ball (TIB and TRB) flight path is a curved line similar to a parabola with its vertex oriented toward the left side of returner. | |
| | 10. TIB, TRB and the normal lie in a curved plane. | 10. << | |
| 1.5. FPF- Horizontal- Clockwise- Spin | 1. Spin of right-half of ball (right side of SDD plane) seen by returner is following ball flight direction. | 1. Spin of right-half of ball (right side of SDD plane) seen by returner is opposite to ball flight direction. | 1.6. FPF Horizon Counter clockwi Spin |
| | 2. Spin of left-half of ball (left side of SDD plane) is opposite to ball flight direction. | 2. Spin of left-half of ball (left side of SDD plane) is following ball flight direction. | |
| | 3. Spin plane is parallel to table surface. | 3. << | |
| | 4. TIB touches table surface at a point very close to its spin-pole. | 4. << | |
| | 5. TRB spin kind is the same as TIB. | 5. << | |

| | | |
|---|---|---|
| | 6. TRB spin speed ≈ TIB | 6. << |
| | 7. TRB flight speed ≥ TIB | 7. << |
| | 8. TRB is closer to table surface than TIB. | 8. << |
| | 9. Ball (TIB and TRB) flight path is a curved line similar to a parabola with its vertex oriented toward the right side of returner. | 9. Ball (TIB and TRB) flight path is a curved line similar to a parabola with its vertex oriented toward the left side of returner. |
| | 10. TIB, TRB and the normal lie in a curved plane. | 10. << |

. . .

| Table 2. Summary of Basic Features and the Effects of Spins of Table Tennis Ball | | | |
|---|---|---|---|
| 2. FPC (Flight-Path-Crossing) Spin Group | | | |
| **Full Name of Spin** | **Features** | **Features** | **Full Name o Spin** |
| 2.1. FPC- Vertical-Clockwise Spin | Common feature of FPC spin: Flight path of ball does not lie on Equatorial spin plane but passes through it, or in other words, Equatorial spin plane crosses the ball flight path. | | 2.2. FP Vertica Counte clockwi Spin |
| | 1. Spin direction of ball is <u>following</u> the rotation of watch needle seen by returner. | 1. Spin direction of ball is <u>opposite</u> to the rotation of watch needle seen by returner. | |
| | 2. Spin plane is perpendicular to table surface or inclined at a small angle to the normal. | 2. << (the same as left 2.1.2) | |
| | 3. TIB touches table surface at a point on or very close to the equatorial spin line. | 3. << | |
| | 4. TRB flies faster and closer to the table surface than TIB | (4) << | |
| | 5. TRB has FPF-Vertical-Top-Spin while TIB has FPC-Vertical-Clockwise-Spin. | 5. TRB has FPF-Vertical-Top-Spin while TIB has FPC-Vertical-Counterclockwise-Spin. | |
| | 6. TRB spin speed ≤ TIB | 6. << | |
| | 7. TRB flight speed >> TIB | 7. << | |
| | 8. TRB is closer to table surface than TIB. | 8. << | |
| | 9. TRB flies to the <u>right</u> side of returner and its flight direction is closely at right angle to the TIB flight path. | 9. TRB flies to the <u>left</u> side of returner and its flight direction is closely at right angle to TIB flight path. | |
| | 10. TRB plane is a flat plane crossing TIB plane at the normal. (TRB and TIB do not | 10. << | |

| | | | |
|---|---|---|---|
| | lie in the same plane). | | |

ANNEX 2

# Forces Analysis Method and Illustrations of Forces

# acting upon RIB (racket-incident-ball) and the resulting Flight Path and Spin of RRB (racket-rebounding-ball)

## I. Forces Analysis Method

The process or method, which is named as Forces Analysis Method and explained below, is used to determine all the forces acting on the ball in the table tennis game, identify the effect of each force on the motion of the ball in order to find out the resultant motion consisting of flying and spinning motion of the ball bouncing off the table surface and the racket surface caused by the resultant force. The effect of spin on the motion is clarified in the analysis process.

The bases, references and reasoning used in the process of analysis of forces are as follows:

Notes: Only racket covering surface consisting of smooth spin-rubber top sheet (pimple-in top sheet) with sponge and FPF (flight-path-following) spin ball is examined in this Annex.

**1. The tip-to-tail method of addition of vectors**, which represent force and motion, is the main tool used to find out a resultant vector (force) acting upon RIB at the time of impact with the racket surface.

**2. Newton's three Laws of Motion** are the base for finding out the acting forces and the resulting flight path of the ball.
Summary of the statements of Newton's three laws of motion:

(1) "Every object will remain at rest or in uniform motion in a straight line unless compelled to change its state by the action of an external force." [1] (Newton's first law)

(2) "Force is equal to the change in momentum (mV) per change in time. For a constant mass, force equals mass times acceleration." F = m*a. [1]
Or in other words:

"For an external applied force, the change in velocity depends on the mass of the object. A force will cause a change in velocity; and likewise, a change in velocity will generate a force. The equation works both ways." [1] (Newton's second law)

(3) "For every action (force) in nature, there is an equal and opposite reaction".["In other words, if object A exerts a force on object B, then object B also exerts an equal force on object A." [1] (Newton's third law)

[1] Excerpt from Newton's Laws of Motion, Glenn Research Center, NASA, **http://www.grc.nasa.gov**.

### 3. The law of reflection

The statements of the law of reflection of light-ray reflected from a smooth surface are referred for approximating the direction and angle of reflection of RRB (racket-rebounding-ball) from the racket rubber surface, similar to the case of table surface (please refer to Chapter 3, Subsection 1.5)

However, as the racket covering surface of pimple-in spin rubber top sheet and sponge underneath is smooth but not as hard as the table surface, the three statements of the law of reflection used as postulates for approximating the ball rebound from a no-spin ball are modified a little bit to read as follows:

i. Angle of reflection or angle of RRB varies depending on the features of racket covering surface and other factors as described below. [2]
ii. RIB flight path and RRB flight path might be on the opposite sides or on the same side of the normal depending features of racket covering surface and other factors. [2]
iii. RIB flight path, RRB flight path and the normal all lie on the same plane.

[2] If the stickiness degree of rubber sheet, the elasticity of sponge of the racket covering surface, flying speed of a no-spin RIB are higher, RIB is sinking deeper into the rubber surface or in other words the racket covering surface is sagged more when the ball hits the racket covering surface. As a result, RRB flight path will be shifted downward and in certain case lying on

the same side of the normal with RIB, not to mention the action of weight which always pulls the ball downward and other factors like loss of energy at impact, etc.

Note: Player should carry out simple tests to know the effect of his/her racket covering surface used, which is a sticky smooth (pimple-in) or pimple-out rubber top sheet with or without sponge, and even a non-sticky covering surface, on the direction of the rebound (RRB) by shooting a no-spin ball with a variety of angles of incidence and speeds to the racket surface in standing still position. Similar tests of ball with spins should also be conducted (please refer to Chapter 4, Sub-section 2.2 and 2.3.)

## 4. Center of Gravity

The center of gravity of an object – the table tennis ball in this case – is used to describe the ball flight path or trajectory and its spinning motion.

"The center of gravity is a geometric property of any object. The center of gravity is the average location of the weight of an object. We can completely describe the motion of any object through space in terms of the translation of the center of gravity of the object from one place to another, and the rotation of the object about its center of gravity if it is free to rotate." (Excerpt from Center of Gravity – cg, Glenn Research Center, NASA, **http://www.grc.nasa.gov**.)

A standard table tennis ball is assumed a completely round ball and having uniform mass, its center of gravity is the center of the ball.

## 5. Five forces acting on a ball

The ball in a table tennis game when played under ideal conditions, i.e., there is no strange air current, is subjected to the following five forces (not to mention the case the ball hits the net assembly):

(1) *Instantaneous force acted by racket covering surface on the ball,*
*(2) Instantaneous reaction force acted by the racket surface on the ball when it hits the surface.*
*(3) Weight (p) which is a force that is always acting on the ball and directed towards the center of the Earth.*

$$p = m*g$$

where:

m is the mass of the ball, which is 2.7g (0.0027kg) for a standard table tennis ball.

g is the gravitational acceleration of the Earth. The nominal average value of g at the Earth surface is approx. 9.8 $m/s^2$.

Weight of a standard table tennis ball is

$p = 0.0027kg \times 9.8m/s^2 = 0.026kg.m/s2$ or 0.026N (N for Newton)

Weight makes a flying ball fall down to the ground following a parabolic line or a ballistic flight path in a vertical flat plane if weight is the only external force acting on the ball.

(4) *Magnus force (Fm) or Lift (L) of a spinning ball*

Lift is an aerodynamic force that is perpendicular to the flight direction and always generated when the ball is spinning and flying through the air. The direction of Lift is explained in Chapter 3, Section 2.

The magnitude of ideal lift force generated on a smooth spinning ball is calculated by the following equation which is derived from Kutta-Joukowski Lift theorem for a cylinder:

$$L = \text{Lift} = 4/3\,(4\,\pi^2\, b^3\, s\, \rho\, V)$$ [3]

Where:

b is radius of ball,

s is spin speed of the ball measured in revolutions per second (rps),

V is velocity of air or velocity of the ball,

$\rho$ (rho) is density of the air which is mass per unit volume, [5]

$\pi$ is pi number = 3.14159…

In reality, lift is affected by many other factors such air resistance characteristics of the ball surface, air viscosity and compressibility, etc. The effect of these other factors is accounted for in a lift coefficient (Cl). “The lift coefficient is an experimentally determined factor that is multiplied times the ideal lift value to produce a real lift value.” [3]

**Real Lift (Lr) = Lift Coefficient (Cl) [4] x Ideal Lift**

[3] Excerpt from Ideal Lift of a Spinning Ball, Glenn Research Center, NASA, **http://www.grc.nasa.gov**.

[4] Lift coefficient of a table tennis ball is taken as 0.29 with reference to the information from a source.

[5] Density of air varies depending on various factors like air pressure, temperature, altitude, etc. "At sea level and at 15°C, air has a density of approximately 1.225 $kg/m^3$ according to ISA (International Standard Atmosphere)." (Density of Air, http://www.en.wikipedia.com.)

***Calculation example of a magnitude of lift***:
The magnitude of ideal lift of a spinning table tennis ball having standard radius (b) of 0.02m (20mm), flying at a velocity (V) of 15m/s (108km/hr), spinning speed (s) of 85rps (5,100 revolutions per minute), in the air having density of $1.225kg/m^3$, calculated by the above equation is:

$$L \text{ (Ideal lift)} = 0.657kg.m/s^2 \text{ or } 0.657N \text{ (N for Newton)}.$$

The real lift is:

$$Lr = Cl \times L = 0.29 \times 0.657N = 0.19N$$
(about 7.3 times the weight of a ball which is 0.026N.)

For reference, top players can strike the ball to reach the velocity of almost 35 meters per second (126km/h) and spinning speed of 151 revolutions per second (9,060rpm).

Lift of a spinning table tennis ball is therefore big and affecting considerably the shape of the ball flight path.

Lift also increases the downward speed of the ball when Lift is directed downward by top spin, i.e., to the direction of weight p, and decreases downward speed when Lift is directed upward by back spin, i.e., opposed to the direction of weight.

(5) *Drag of the air*

Drag (symbol as D or Fd) is an aerodynamic force generated by the resistance of the air to the motion of the ball. Drag is directed along and opposed to the ball flight direction. The effect of drag is negligible in table tennis game as the ball is small and flying fast in a short distance between two players. A no-spin ball flight path is therefore regarded as a parabolic line or a ballistic flight path lying in a vertical plane (the case weight p is the only external force). So, when the flight path is seen deflected, i.e., curved upward, downward or sideways compared with a reference parabolic line, player can attribute the cause of the deflection to the other force -- Magnus force or Lift.

For further information on drag, drag equation for calculation of its magnitude, please refer to "Forces on a Baseball" and "Flight Equations with Drag (no thrust – constant mass", Glenn Research Center, NASA, **http://www.grc.nasa.gov**.

Note: The calculation and determination of the precise flying and spinning velocity and the flight path of the incident ball and rebounding ball, based on the actions of force from the racket surface, lift (L), weight (p), drag (D) and the velocity of incident ball, which are all vector quantity having a magnitude and a direction, is a complicated process using complicated mathematical equations and not a subject of this book. The purpose of the explanation and information provided herein is to help players recognize the strong effect of spin on the ball flight path, read the spin direction of ball by looking at the curved shape of the ball flight path as explained in Chapter 3, and visualize the ways of returning a spinning ball as described in Chapter 4.

## 6. The Reasoning

The reasoning from which the force analysis method is derived, based on which the motions (flight path, spin, speed) of RRB are approximated and the effects of spin are highlighted, is summarized as follows:

(1) When a ball hits a table or a standing still racket surface, a force is generated in association with a change in the velocity of the ball at the time of impact. A reaction force from the table or racket surface is instantaneously generated and acting on the ball and causing a change in velocity (speed and direction of flight) of the rebounding ball, referring

to Newton's 2nd law of motion--the law of reflection is also referred for approximating the direction of flight of rebounding ball. The instantaneous force from the ball and reaction force from the table or racket surface which are generated at the time of impact are represented by vectors passing through the center of gravity of the ball referring to the notion of center of gravity mentioned in the above point 4.

(2) From the observations of the behavior of rebounding ball from the tests of pushing a ball on a horizontal, smooth and flat surface to make it translate (move) but don't spin, translate at slow speed and have horizontal-clockwise spin, and translate at slow speed and have horizontal-counterclockwise spin to hit the spin-rubber surface of a standing still racket in upright position as illustrated in Chapter 4, Section 2.3, we can conclude that spin causes change to the flight path direction (one of two characteristics of velocity vector) of the rebound. Likewise, the change in direction of the ball caused by spin generates a force (symbol as Fbis) acting instantaneously at the time of impact and through the center of gravity of the ball, referring to Newton's second law of motion and the notion of center of gravity. This force Fbis generated by spin causes change to the direction of the rebound, in other words.

**Calculation example of linear speed** of a point on the equatorial spin line of a spinning ball when it hits the table or racket surface:

Linear speed (Vr) = 2 π R * spin speed, where:
2 π R is the circumference of the ball's equator (3.1416 x 4 cm = 12.56 cm. or 0.0001256 km)
So, if spin speed (S) is 5100rpm (revolutions per minute), Vr is 38.43 km/hr. And if S is 8000rpm, Vr is 60.28 km/hr.

(3) When a forced is applied by the imperfect TTC shot or TTS shot from the racket surface to a no-spin ball, which is an unconfined object, the ball translates (flies) and spins about its center of gravity.

Note: Please refer to "Torque (Moment)", Glenn Research Center, NASA, **http://www.grc.nasa.gov** for the explanation regarding the translation and spinning motions of an unconfined ball.

## 7. Parameters

The parameters, symbols and abbreviations, and the equations used for predicting and determining RRB flight path, spin and other features:

**Vi** Flying speed of TIB at impact point;

**S**i Spinning speed of TIB at impact point;

**Fic** TTC (through-the-center) force exerted by RIB (racket-incident-ball) flying at Vi upon the racket covering surface at the time of impact;

**Fis** TTS (tangential-to-the-surface) force exerted by the spinning speed Si of RIB (racket-incident-ball) upon the racket covering surface at the time of impact;

**Fbic** TTC reaction force of the racket covering surface acting upon the ball against **F**ic (racket bouncing-off force acting on the ball as a reaction to the incident ball TTC force Fic, in other words;)

**Fbis** TTS reaction force of the racket covering surface acting upon the ball against **F**is (racket bouncing-off force acting upon the ball as a reaction to the incident ball TTS force **F**is, in other words;)

**Vra** Flying speed of the racket when it hits the ball;

**Fra** Forces exerted on the ball when the racket in motion hits the ball;

**Frac** TTC (through-the-center) force component of Fra;

**Fras** TTS (tangential-to-the-surface) force component of Fra,

**Fra** = **Frac** + **Fras** (vector quantity);

**Fb** The resultant force acting on the ball at the impact point of the racket and the ball,

**Fb** is the sum of 4 main forces: **Frac, Fras, Fbic** and **Fbis** as mentioned above.

**Fb** = **Fbic + Fbis** (in case of Block where Fra = 0)

**Fb = Frac + Fras + Fbic + Fbis** (in case of Shot)

The ball (RRB) flies following the direction of **F**b which is a force going through the center of gravity of the ball;

**Sb** Spin speed (or resultant spin speed) of RRB;

**Vb** Flying speed of RRB,
Flying speed Vb of the ball (TRB) is in proportion with the strength of the resultant TTC force **F**b acting on the ball. Vb is higher when **F**b is bigger and vice versa;

TRB Table-Rebounding-Ball;

RIB Racket-Incident-Ball (TRB is the same as RIB);

RRB Racket-Rebounding-Ball;

I Angle of Incidence of the ball, which is the angle formed by RIB and the normal of the racket surface or TIB and that of the table surface;

R Angle of Reflection of the ball, which is the angle formed by RRB and the normal of the racket surface or TRB and that of the table surface.

*Remark:*
*Spin component, which is always generated when a ball (no-spin or with spin) hitting the racket, similar to St as in the case of ball hitting a table surface (Chapter 3, Subsection 3.1.(1)), is not taken into consideration because the effect of racket shot on RRB spin is too big compared with this spin component*

## II. Illustrations

The following illustrations of several common cases of racket blocks and shots having different angles of attack -- the angle I of -RIB (racket-incident-ball) relative to the normal or angle I' relative to the racket surface -- striking the oncoming ball (RIB) having no-spin or spin are to help players visualize the effects of racket stroke and ball spin on the rebound (RRB) The vectors drawn in the drawings show the direction and strength (or speed) of the ball (the longer the vector, the higher the speed of the ball). The detailed features of RIB (racket-incident-ball) and the corresponding RRB (racket-rebounding-ball) are described below each drawing.

Remarks:

- Spins on the ball examined all are of FPC spin group.
- **Fb** in case of a no-spin oncoming ball and the corresponding **Fi** or the component **Fbic** of a spinning ball and the corresponding **Fic** are assumed lying on the opposite sides of the normal for easy notice of them on the drawings. In reality, **Fb** and **Fbic** could be on the same side of the normal with Fi and Fic respectively under certain conditions as explained in Part I, point 3.(3).
- Weight (**p**) is ignored for the simplicity of analysis of forces at the impact point.

## 1. Block (Still-Racket Stroke)

Racket is standing still, only ball is moving when hitting the racket covering surface.

### *(1) Case 1.1.*

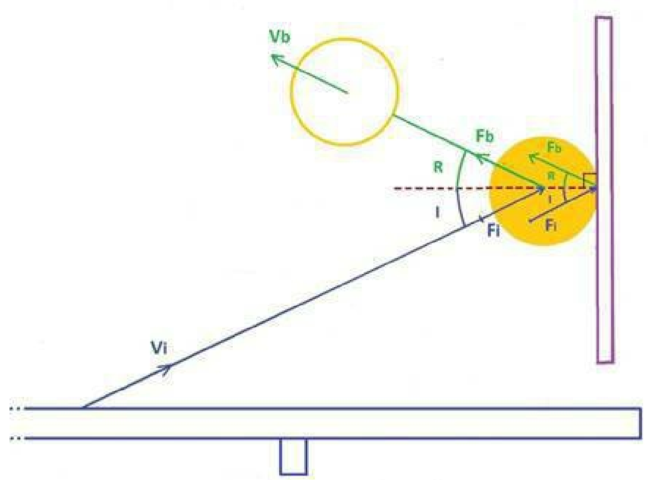


Fig. A2.1-1. No-spin ball (TRB) in rising path hitting the racket in Block and Face-upright position (at a right angle with the table surface).

Features:

- RRB flight path and RIB flight path are in some cases on the opposite sides of the normal and in the same plane holding the normal.
- Angle of reflection (R) of RRB is smaller than angle of incidence (I) of RIB due to friction of racket rubber surface, elasticity of sponge and loss of energy at impact.
- RRB likely has back-spin and its spinning speed is depending on the flight speed and angle of incidence of RIB, friction degree of racket rubber surface.

### *(2) Case 1.2.*

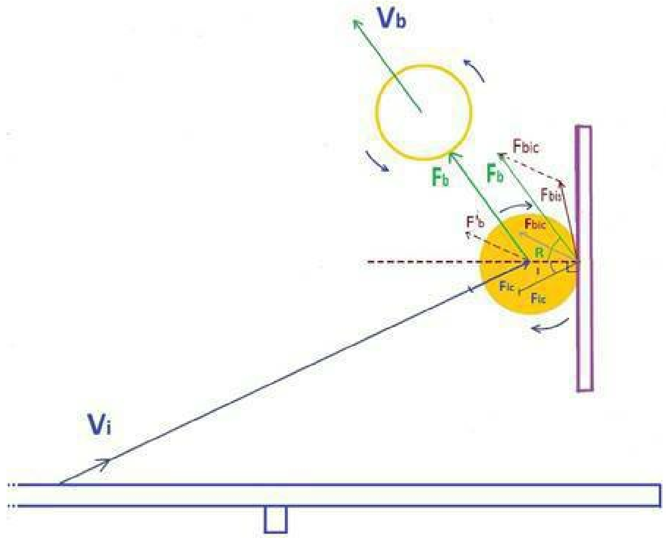


Fig. A2.1-2. Vertical-Top-Spin ball (TRB or RIB) in rising path hits the racket in Block and Face-upright position.

Remark on **Fbis**:
**Fbis** is assumed not lying on the racket covering surface but instead raised at a small angle above it for easy noticing of this force, and also considering the factor that the racket covering surface is sagged a little bit due to the elasticity of sponge and rubber sheet when the ball hits it.

Features:

- RRB flight path and RIB flight path are on the opposite sides of the normal and in the same plane with the normal.
- R is bigger than I.
- **Fbis** and **Fbic** are on <u>the same side</u> of and above the normal.
- RRB flies more upwards higher above the horizontal line (the normal in this case) and the net, closer to the racket surface when compared with that of no-spin RIB.
- RRB flies much more upwards or closer to the racket surface when **Fbis** is bigger due to faster spin speed.
- Spin direction of the ball is usually reversed after the ball hits the racket surface; that means RRB will have the same top-spin type as RIB.

[**Fb’** shows the flying direction of RRB in case RIB has no spin (**Fbis** = 0).]

## *(3) Case 1.3.*

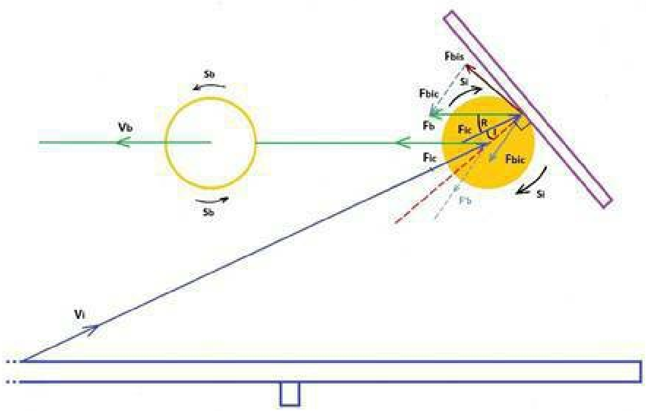


Fig. A2.1-3. Vertical-Top-Spin ball (TRB) in rising path hits the racket in Block and Face-close position.

Features:

- RRB flight path and RIB flight path are on the same side of and above the normal and in the same plane holding the normal.
- R is bigger than I.
- **Fbis** and **Fbic** are on <u>the opposite sides</u> of the normal. **Fbic** is now directed downwards compared with the upward direction as in the case of upright-racket in Fig. A1.2.
- RRB flight path following the direction of **Fb** (**Fb** = **Fbis** + **Fbic**) is shifted downwards closer to the horizontal line or the net compared with that of upright-racket position.
- RRB flies much closer to the racket surface when **Fbis** is bigger by faster spin speed.
- Spin direction of the ball is usually reversed after the ball hits the racket surface, i.e., RRB will usually have the same top-spin style as RIB when RIB.

[**Fb**' shows the flying direction of RRB in case the TRB has no spin (**Fbis** = 0).]

## *(4) Case 1.4.*

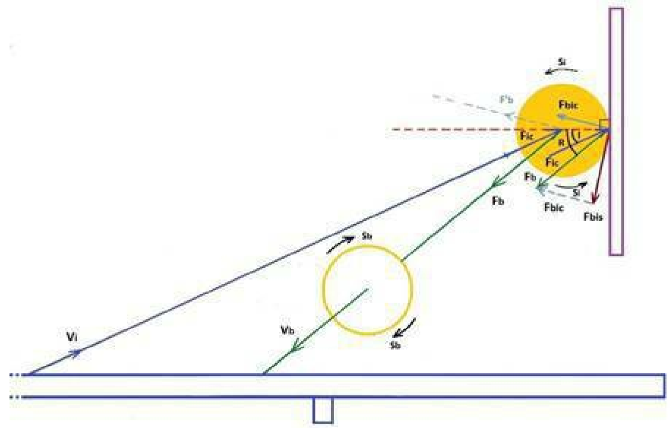


Fig. A2.1-4. Vertical-Back-Spin Ball (RIB) in rising path hits the racket in Block and Face-upright position.

Features:

- RRB flight path and RIB flight path are on the same side of and below the normal and in the same plane holding the normal.
- R is bigger than I.
- **Fbis** and **Fbic** are on <u>the opposite sides</u> of the normal. **Fbis** is directed downwards and almost perpendicular to the table surface. **Fbic** is directed upwards but still close to the horizontal line (the normal in this case). In the Fig. A1.4 the magnitudes of Fbis and Fbic are assumed not much different, **Fb** (**Fb**= **Fbis** + **Fbic**) is directed downwards and towards the returner's table court.
- RRB flies downwards following Fb will hit the returner's table court but not his or her opponent's. RRB flight path is lifted higher when **Fbis** is smaller, and it is above the normal (the horizontal line in this case) when **Fbis** = 0 (no-spin ball case).
- Spin direction of the ball is usually reversed after the ball hits the racket rubber surface, i.e., RRB will usually have the same back-spin style as RIB.

## *(5) Case 1.5.*

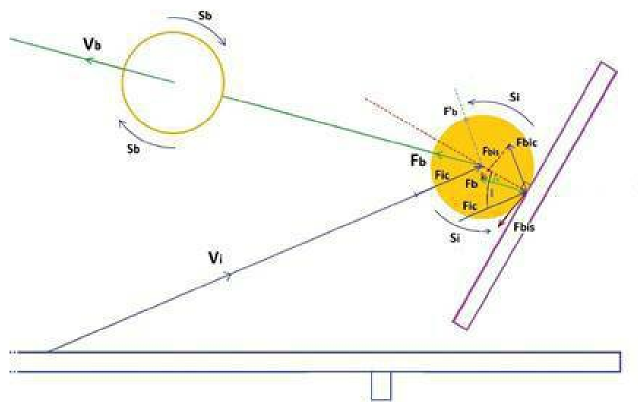


Fig. A2.1-5. Vertical-Back-Spin ball (TRB) in rising path hits the racket in Block and Face-open position.

Features:

- RRB flight path and RIB flight path are on <u>the same side</u> of the normal and in the same plane holding the normal.
- R is smaller than I.
- **Fbis** and **Fbic** are on the opposite sides of the normal. **Fbis** is directed downwards far from the perpendicular line to the table surface but still pointing at the returner's table court, and **Fbic** is turned more upwards compared with that of upright-racket in Fig. A1.4. **Fb** (**Fb** = **Fbis** + **Fbic**) is directed higher above the table surface but its magnitude is smaller
- RRB flight path is lifted higher above the table surface compared with that of upright-racket.
- Spin direction of the ball is usually reversed after the ball hits the racket surface, i.e., RRB will have the same back-spin type as RIB.

Remarks:

If the racket is turned more backwards to make the racket surface more open, RRB flight path is expected to be raised higher above the table surface and the net to make the rebound surely fly over the net, in theory.

However, when the racket is more open, the driving force **F**b becomes much smaller, and it could become too small to drive to ball to the opponent's table court. Eventually the ball drops on the returner's table court. Also, the ball could likely slide (skid) on the table surface when the racket surface is open closer to the parallel line with the RIB flight path. In this case, the rebound will drop on the returner's table court.

## 2. Shot (Moving-Racket Stroke)

Shot is a stroke when the racket is moving to hit the ball. Several cases of shot on the spinning RIB are examined but not No-Spin RIB as it is similar to the case of Block. No descriptions of features are provided in the following drawings as they are similar to those described in Block.

### *(1) Case 2.1. Top-Spin RIB -- Imperfect TTC, Face-upright, Horizontal Shot*

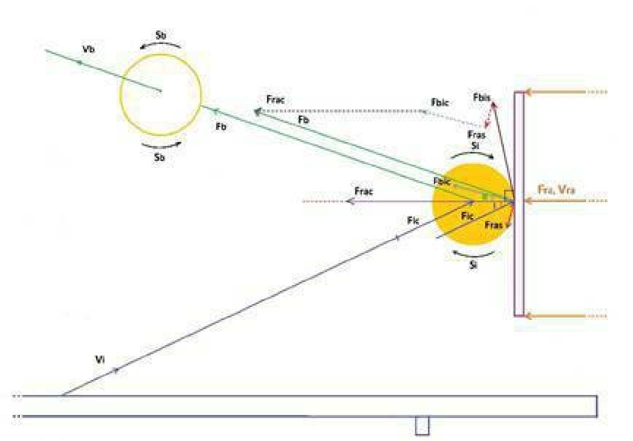


Fig. A2.2-1. Top-Spin RIB -- Imperfect TTC, Face-upright, Horizontal Shot.

### *(2) Case 2.2. Top-Spin RIB -- Perfect TTS, Counter-Spin, Face-close, Upward and Forward Shot*

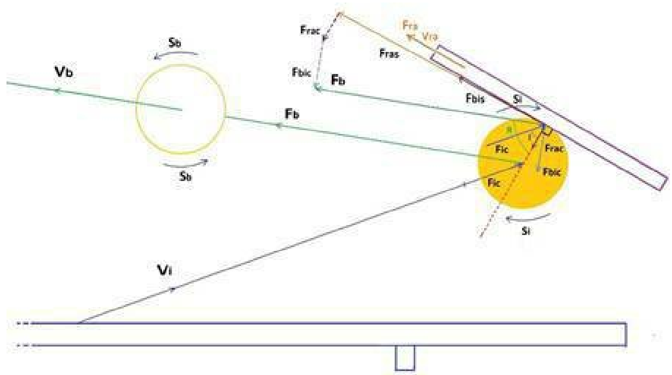


Fig. A2.2-2. Top-Spin RIB -- Perfect TTS, Counter-Spin, Face-close, Upward and Forward Shot.

### *(3)  Case 2.3. Back-Spin RIB -- Imperfect TTC, Face-upright, Horizontal Shot*

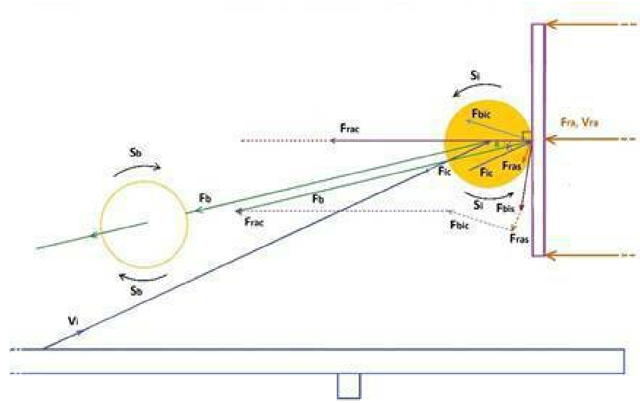


Fig. A2.2-3. Back-Spin RIB -- Imperfect TTC, Face-upright, Horizontal Shot.

### *(4) Case 2.4. Back-Spin RIB -- Imperfect TTC, Face-open, Horizontal Shot*

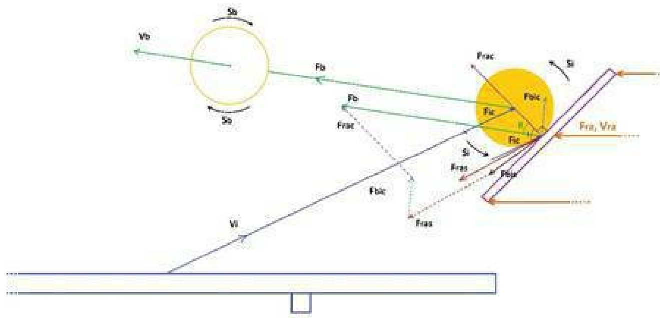

Fig. A2.2-4. Back-Spin RIB -- Imperfect TTC, Face-open, Horizontal Shot.

ANNEX 3

# Illustrations of Racket Shots and the resulting Trajectories and Spins of Returning Ball

The following figures are used as references for seeing the relationship between:

- the spin kinds and the shape of trajectory of the oncoming ball or RIB (racket-incident-ball),
- the kinds of returning shot and the resulting spin and shape of trajectory of the returning ball or RRB (racket-rebounding-ball);

based on the assumption that:

- oncoming ball has FPF vertical or side-spin, and
- spin direction of the ball remains unchanged after the ball hits the table surface.

Only several cases of the frequently used FPF (flight-path-following), Vertical and Horizontal-Spins of the oncoming balls are illustrated.

All dimensions in the drawing are not to scale and shapes of trajectory do not reflect the ones in reality. Dashed line in the drawings is the ball flight path if it has no spin.

# 1. Case 1: TTS Counter-Spin Shot

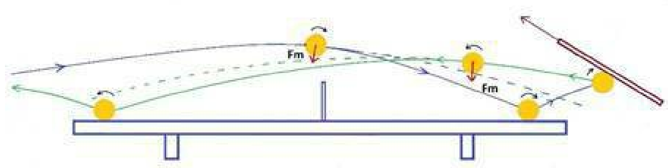


Fig. A3.1. Side view of top-spin oncoming ball, TTS counter-spin shot and top-spin returning ball.

Features:

1. Oncoming ball: Vertical-Top-Spin ball.

   TIB flight path (blue line) is a curved line deflected downwards compared with that of no-spin ball due to the effect (Magnus effect) of top-spin.

2. Racket stroke: TTS (perfect), Face-close, Upward and Forward, Counter-Spin Shot.

3. Returning ball: Vertical-Top-Spin ball.

   The ball spin direction is reversed after the ball hits the racket surface.

   RRB flight path is a curved line deflected downwards due to the effect of top-spin.

Remarks: TRB flies closer to the table surface than TIB as TIB has top-spin.

## 2. Case 2: TTS Following-Spin Shot

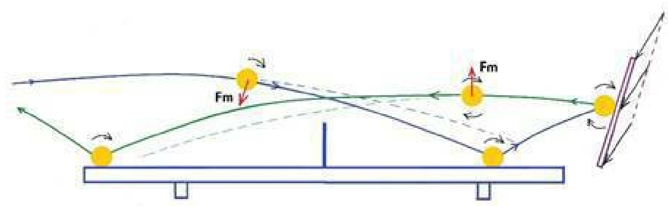


Fig. A3.2. Side view of top-spin oncoming ball, imperfect TTS following-spin shot and back-spin returning ball.

Features:

1. Oncoming ball: Vertical-Top-Spin ball. TIB flight path (blue line) is a curved line deflected downwards due to the effect (Magnus effect) of top-spin.

2. Racket stroke: TTS (imperfect), Face-open, Downward and Forward, Following-Spin Shot.

3. Returning ball: Vertical-Back-Spin ball.
The ball spin direction remains unchanged after the ball hits the racket surface.
Returning ball (or RRB) flight path (green line) is a curved line deflected upwards compared with that of no-spin ball due to the effect of back-spin.

Remarks: TRB of oncoming ball flies closer to the table surface as its TIB has back-spin. Meanwhile, TRB of returning ball flies higher above the table surface as its TIB has back-spin.

# 3. Case 3: TTC Counter-Spin Shot

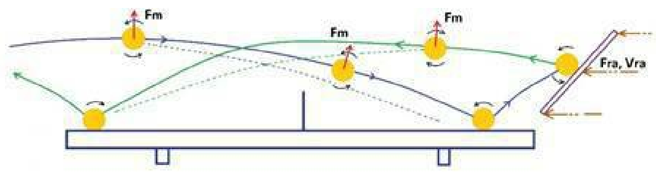


Fig. A3.3. Side view of back-spin oncoming ball, imperfect TTC counter-spin shot and back-spin returning ball.

Features:

1. Oncoming ball: Vertical-Back-Spin ball.
   TIB flight path (blue line) is a curved line deflected upwards due the effect of back-spin.

2. Racket stroke: TTC (imperfect), Face-open, Horizontal, Counter-Spin Shot.

3. Returning ball: Vertical-Back-Spin ball.
   The ball spin direction is reversed after the ball hits the racket surface.
   Returning ball (RRB) flight path (green line) is a curved line deflected upwards due to the effect by back-spin.

Remarks: TRB of oncoming and returning balls both fly higher above the table surface as TIB of each has back-spin.

## 4. Case 4: TTS Following-Spin Shot

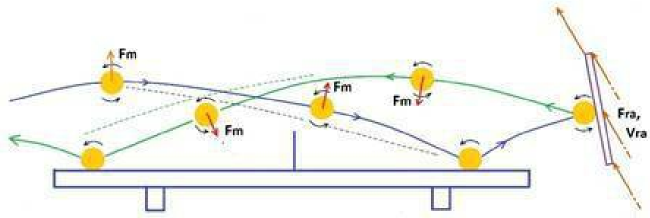


Fig. A3.4. Side view of back-spin oncoming ball, imperfect TTS following-spin shot and top-spin returning ball.

Features:

1. Oncoming ball: Vertical-Back-Spin ball.
   TIB flight path (blue line) is curved line deflected upwards due to the effect (Magnus effect) of back-spin.

2. Racket stroke: TTS (imperfect), Face-upright (nearly), Upward and Forward, Following-Spin Shot.

3. Returning ball: Vertical-Top-Spin ball.
   The ball spin direction remains unchanged after the ball hits the racket surface.
   Returning ball (RRB) flight path is a curved line deflected downwards due to the effect of top-spin.

Remarks: TRB of oncoming ball flies higher above the table surface as its TIB has back-spin. Meanwhile, TRB of returning ball flies closer to the table surface as its TIB has top-spin.

## 5. Case 5: TTS Following-Spin Shot

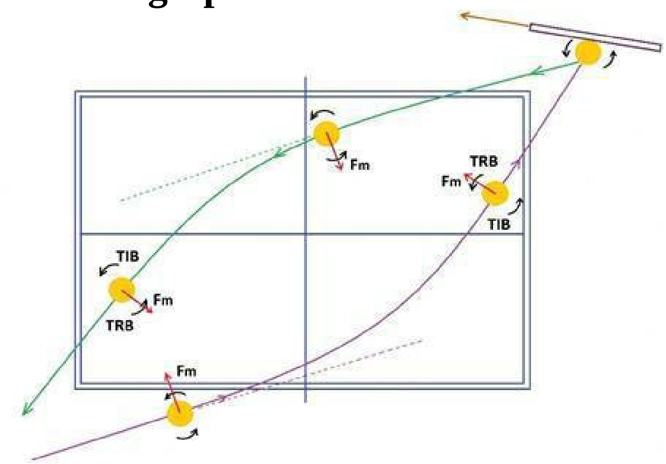


Fig. A3.5. Top-down view of horizontal-spin oncoming ball,
TTS following-spin shot and the returning ball.

Features:

1. Oncoming ball: Horizontal-Counterclockwise-Spin ball.

   Trajectory (TRB flight path) curves to the left side of the returner by Magnus force acting sideway upon the ball.

2. Racket stroke: TTS, Face-Upright (nearly) and Close (a little), Forward and Toward (the side of the ball), Following-Spin Shot.

3. Returning ball: Horizontal-Counterclockwise-Spin.

   The ball spin direction remains unchanged after the ball hits the racket surface.

   Returning ball curves to the left side of the opponent or the right side of the returner. In other view, the returning ball curves to the opposite side of the oncoming ball curved trajectory.

# 6. Case 6: TTS Counter-Spin Shot

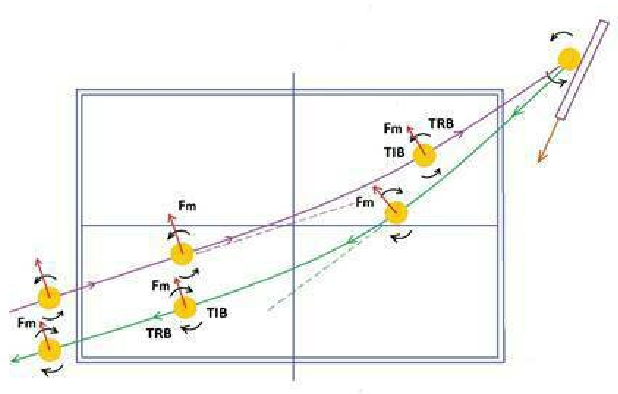


Fig. A3.6. Top-down view of horizontal-spin oncoming Ball,
TTS counter-spin shot and returning ball.

Features:

1. Oncoming ball: Horizontal-Counterclockwise-Spin ball.

   Trajectory (TRB flight path) curves to the left side of the returner by the Magnus force acting sideway upon the ball which is generated by side-spin.

2. Racket stroke: TTS, Face-Upright (nearly) and Close (a little), Forward and Toward (the side of the ball), Counter-Spin Shot.

3. Returning ball: Horizontal-Clockwise-Spin.

   The ball spin direction is reversed after the ball hits the racket surface.

   Returning ball curves to the right side of the opponent or the left side of the returner. Or in other view, the returning ball curves to the same side of the oncoming ball curved trajectory.