Body-flight Theory

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Drawings, illustrations, and images by Niklas Daniel unless otherwise stated.
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Humans have built bridges longer than recorded history without complex engineering knowledge. But with a greater theoretical understanding of the activity, humans have been able to create engineering marvels the world over. Similarly, one does not have to be an expert at the theoretical to excel at body-flight, but a deeper understanding may help elevate the sport to a new level.

To fully exploit your body's maneuvering potential in the air, we have to understand what is aerodynamically and physically possible and which underlying principles apply. The following will present aerodynamic fundamentals and principles of a person in freefall – be it skydiving, base jumping, or flying in a vertical wind tunnel. This paper will eventually cover theory and application for all human flight disciplines, whether for training purposes or general inquiries. The goal of part 1 of this paper is to establish a more elegant and convenient way to visualize body-flight movement with the purpose of creating order by introducing AXIS systems. Future installments will cover topics such as physics, aerodynamics, applications, etc.

I explicitly invite comments, contributions and critique in order to advance the theoretical knowledge of the sport of body-flight (please send to articles@AXISflightschool.com).

Part 1: A Skydiving Coordinate System

The system presented here is a type of bookkeeping that will outline the different ways a skydiver or tunnel flyer can move in the air. The language developed here and its use is meant to best represent the activity, and lay a theoretical concept or knowledge foundation.

An AXIS coordinate system is an arbitrary reference frame imposed upon physical phenomena to simplify our observations and analysis. Thus I am going use the one that is most appropriate for skydiving and tunnel flying, called the *Wind-AXIS* (relative wind). In future installments, we will use this system/language to examine the physics of body flight, as well as other noteworthy discoveries that pertain to body-flight performance.

Terminology

There are three words frequently used by skydivers interchangeably with respect to body-flight, which can cause some confusion: (body)-position, (body)-posture, and (body)-orientation.

Position will be used to define a flyer's location in space, i.e. relative to another person, a particular location in a wind tunnel, or within a formation.

Posture will specifically refer to a jumper's body-shape or anatomical-position. Different body-postures offer various functions depending on a flyers needs. Some qualities can include: "being neutral", "aerodynamically stable/unstable", "drive-inducing", "symmetrical", "asymmetrical", etc. A change in a person's geometric shape or posture can be referred to as morphing (think of the F-14 Tomcat with its unique feature called a variable-sweep wing), which is done to increase aerodynamic performance. This allows a proficient body-pilot to take part in various freefall disciplines, and even alter flying orientation – something unachievable by aircraft. Even when the engines stop, an aircraft has an inherent built-in stability and ability to glide. Humans on the other hand have no built in stability, and must find control in the relative wind by properly shaping their body to facilitate stability and mobility.

Orientation is a *mechanical alignment* between a flyer's torso and the oncoming relative wind. A body-pilot is able to fly in two modes using six fundamental body-flight orientations:

Horizontal Modes

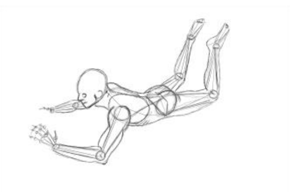


Fig. 1a: Belly

Fig. 1b: Back

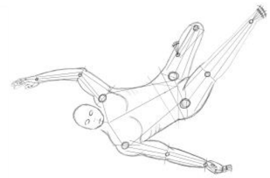


Fig. 1c: Right Edge

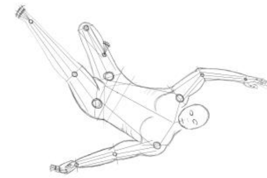


Fig. 1d: Left Edge

Vertical Modes

Fig. 2a: Head-Up

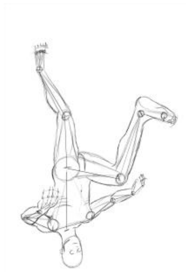


Fig. 2b: Head-Down

Alignment of the body's spine in relation to the Wind-AXIS (relative wind) determines whether a person is horizontal or vertical. A perpendicular alignment equals a horizontal flying orientation, whereas a parallel alignment equals a vertical one. Since a jumper's spine is rarely perfectly straight, an imaginary line connecting the Coccyx (tailbone) with the Thoracic (T1) vertebrae is compared to the relative wind to determine Orientation. This imaginary line will be referred to as the *Mean Spine Position or MSP.* Leaving the head out of the equation allows for movement of the skull and cervical spine to not affect the MSP. Each body-flight orientation has to be maintained by the jumper with a specific range of postures. The spine's alignment to the relative wind is nothing like a chord line on a fixed wing, and therefore angle of attack does not come in to play here. But the principle will be discussed at length at a later time.

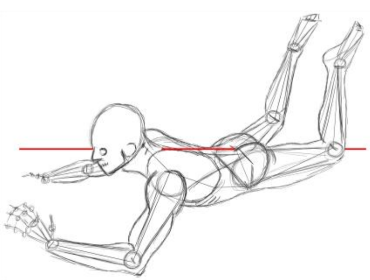


Fig. 3: Mean Spine Position (MSP)

Certain disciplines such as MFS (mixed formation skydiving) and VFS (vertical formation skydiving), have formations in their dive pools that dictate specific orientations the performers must present in order to score a point. Though these disciplines have been around for years, the word 'orientation' has still not yet been properly defined. This causes an issue within the judging community, as orientation is currently subjective and open to interpretation. In an objective discipline like formation skydiving, there is no room for subjectivity. A possible solution to this problem will be explored later through the implementation of an *orientation wheel (Fig.8)*.

AXIS System

Unlike a rigid airfoil, body-pilots are shape shifters that morph their cross-sectional geometry to utilize their entire body as a reconfigurable structure to fly in multiple orientations and speeds. To illustrate the six functional flying orientations, we need to implement a coordinate system that can highlight the different ways and directions the body can travel through the relative wind. To describe a body's movement in three-dimensional space, we use three imaginary lines of reference. Each imaginary line that passes through the body is called an AXIS, and it represents the directions around which the body can either rotate or move along. We the reader/observer are located next to the jumper, like a freefall camera-flyer, remaining in an upright orientation relative to the Wind-AXIS.

It is important to note that the classical coordinate system of an aircraft cannot be successfully applied to a body-pilot. The ability to completely alter our body shape and flight surfaces can result in some unusual and unexpected conclusions. Therefore any letter, number, or symbols used throughout this paper may be considered arbitrary.

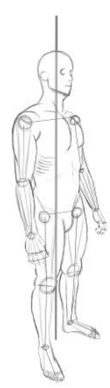
Frames of Reference

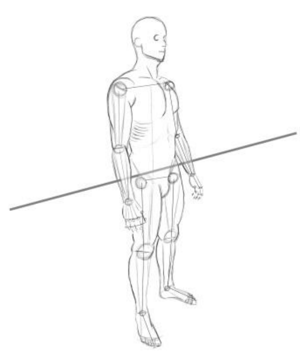
An individual AXIS-system can be applied to multiple frames of reference, such as the body in relation to itself, the body in relation to earth (gravity), and finally the body in relation to the relative wind. Since our goal is to make observations about skydivers/tunnel flyers falling through the air, a jumper's relationship with the relative-wind will become our main point of interest. But first, let us isolate these three separate systems and then see later how they interact with one another:

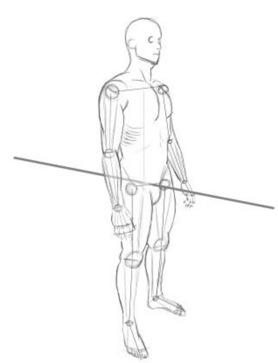
1) Body-fixed system (local coordinate system)

A person's body has height, width, and depth. An outside reference frame like the floor is not required to know how to measure a person's height. Regardless if a person is standing up or lying down, you would know to measure your subject from head to toe. Likewise, if you were to measure a person's width, you would know to measure them from side to side (ex. arm-span). You could also measure a person from front to back, belly button straight through the body to the spine.

Thusly, a jumper's body will be divided into these three properties by individual reference-lines, abbreviated by dual letters. Each one of these imaginary lines is called an AXIS. The body-AXES will be referred to by their medical names.







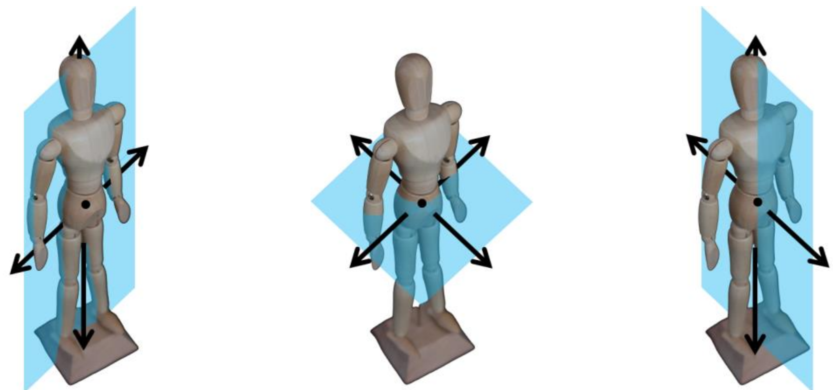
Body-AXES: *Fig. 4a: Longitudinal (LO)* *Fig. 4b: Lateral (LA)* *Fig. 4c: Anteroposterior (AP)*

Body-AXIS	Longitudinal (LO)	Lateral (LA)	Anteroposterior (AP)
Dimension	Height	Width	Depth
Location	Top to bottom	Side to side	Front to back

Table 1: Body-AXES with their dimensions and locations.

Center of gravity is an important concept to consider when discussing flight because of its impact on balance and stability. This hypothetical point is where the force of gravity acts upon. Indicated in the images below by a black sphere near the waist, the CG is located where all three AXES intersect and is essentially the average location of the person's weight. Since jumpers rarely stay perfectly still the CG is not fixed, but the precise location changes with every new body posture, and with the addition of equipment.

Body-planes are a combination of any two body-AXES used to create a two-dimensional surface (like a sheet of paper) representing a collection of body parts exposed to the relative wind. These parts of the body become the 'flying surfaces'. There are three such planes, which are fixed to the person. It is possible to fly on either of the two surfaces defined by each plane, which gives us a total of six surfaces to fly on (think of a 6-sided die). These six surfaces make up the body-flight-orientations mentioned earlier. The body-planes will be referred to by their medical names.



Body-planes: *Fig. 5a: Coronal* *Fig. 5b: Transverse* *Fig. 5c: Sagittal*

Body-plane	Coronal	Transverse	Sagittal
Combination of AXES	LO x LA	LA x AP	LO x AP
Location of Body	Parallel to the spine, it divides the body into front and back sections	Perpendicular to the spine, it divides the body into top and bottom sections	Parallel to the spine, it divides the body into left and right sections
Application	Belly / Back	Head-up / Head-down	Edge-Left / Edge-Right

Table 2: Body-planes with the AXES combination that define them, their locations, and their applications.

The cross-sectional geometry around the flyer's center of gravity on the plane that is aligned perpendicularly to the relative wind will greatly affect the jumper's fall rate, stability, and direction.

2) Earth-fixed system

Gravity, or our body's relentless acceleration towards earth, is a skydiver's power source. This drives our bodies through the air, and as a byproduct produces the relative wind we feel on our bodies. The gravitational force is represented by a straight line, which starts at the jumper's CG, at the center of the body-fixed coordinate system, and then connects to the center of the planet. Inexperienced skydivers will use the horizon/ground as their primary frame of reference (visually) for their flight performance, because they instinctively know that the gravitational force acts on their body in a constant downward direction. But aerodynamic forces, not gravity, dominate our movements in freefall. A good example is the body-flight orientation "head-down". Though gravity tells us which direction down is, this is a bit misleading, as one should think of it as head in to the wind, not necessarily head towards earth. Since airflow is not always aligned with gravity, particularly when exiting an aircraft, we cannot use the ground or horizon as a reliable reference for body-flight movement analysis.

3) Wind-fixed system

The definitions for maneuvers performed in skydiving/tunnel-flying are determined by the relative wind. What differentiates a roll from a turn is which orientation we are flying in (our presentation to the relative wind). In the introduction, we established that *orientation* is the jumper's body-alignment compared to the relative wind. The relative wind emanates from the oncoming airflow opposite to our trajectory. Therefore, a wind-fixed system is the most relevant AXIS-system to skydiving, and is most easily visualized in a vertical wind tunnel where the wind and earth-fixed frames overlap. In the figures below, the Wind-AXIS is represented by a blue line called 'Z', which is always in-line or parallel with the relative wind.

Note: In the event a skydiver jumps from an aircraft with an initial forward velocity, the Wind-AXIS shifts relative to the earth-AXIS system. Every jumper needs to adjust for the shift in origin of the relative wind on exit, and must continue to adjust for it as the jumper's path begins to move in the earthward direction. The jumper's trajectory-change from horizontal to vertical is a phenomenon skydivers call "the hill".

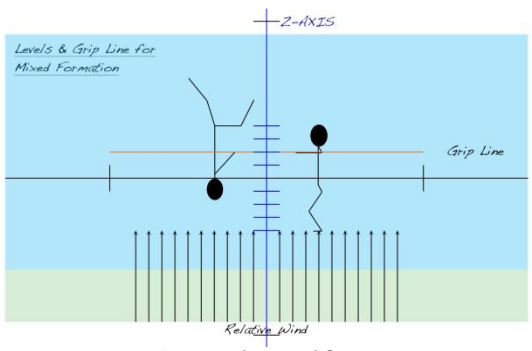


Fig 6a: Mixed vertical formation

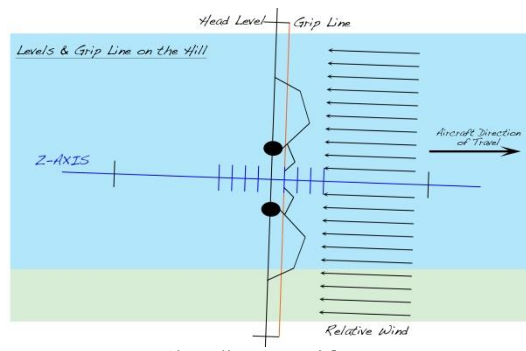


Fig 6b: Belly oriented formation

In both images one jumper appears to be head-up and the other head-down when taking the horizon into account. But the relative wind determines orientation, not the ground; therefore in fig. 6a (left) the performers are in a mixed vertical formation, where indeed one jumper is head-down and the other head-up. In fig. 6b (right) however, which depicts an exit situation, the performers are both in a belly-oriented formation where neither of them is vertical with respect to the Wind-AXIS.

The Iron Man example: A popular comic book character can help us better understand how the relative wind influences our body's flight characteristics, and determines orientation. If Iron man were to hover using only his rocket boots, then he is relying on only thrust and therefore is not actually flying. Flight requires airflow to pass over a flying surface. If Tony now powers up his rocket boots and flies straight up into the sky, he is actually flying head down because of how the relative wind is interacting with his body. His flight performance and body's handling characteristics are that of a head down flyer. If he now shuts off the engines and falls back to earth, he is in the head-up orientation, as the wind is making contact with his body from feet to head.

Six degrees of freedom (6DOF)

Jumpers can move in six distinct directions while in any of the six body-flight orientations. Half of these are called translation, while the other half are called rotation. Three X, Y and Z-AXES (which are fixed to the relative wind) are highlighted in the three primary colors, and pass through the body perpendicular from one another (aka orthogonal coordinate system).

Translation

Translation in its purest form involves any movement of the jumper in a straight line along a specific AXIS that maintains heading. Jumpers who move to a new location through space in this manner, are said to have translated into that particular direction. Translational movements are highlighted in the three primary colors: blue, red, and yellow.

Rotation

Rotation in its purest form involves a revolving movement around an AXIS. The terms Yaw, Pitch, and Roll clarify the type of rotation being executed. The body-plane about which a body moves is always perpendicular to its AXIS of rotation. Rotational movements are highlighted in secondary colors, i.e. a turn/yaw involves a rotation around the blue vertical AXIS. Therefore, the body is passing through the red Y-AXIS and yellow X-AXIS, creating the color orange – blue's complimentary color.

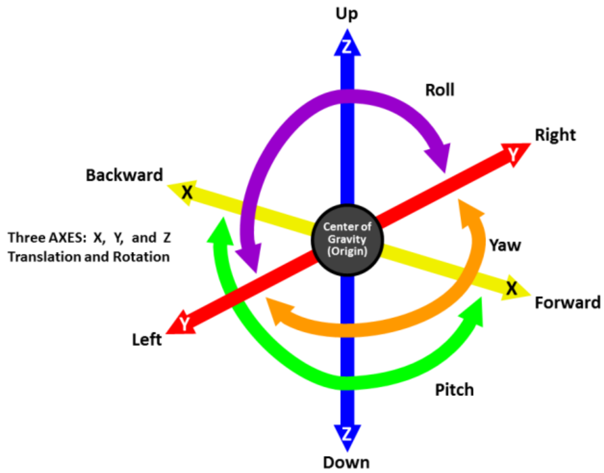


Fig. 7: Six degrees of freedom

Wind-AXES	Rotation	Translation
Z-AXIS	Yaw or heading – Left & right turns	Up & down 'Floating & sinking'
X-AXIS	Roll or bank – Left & right tilt (barrel roll, cartwheel)	Forward & Backward 'Drives'
Y-AXIS	Pitch or elevation – Up & down tilt (flip)	Side ways 'Side-slides'

Table 3: Wind-AXIS with their role in rotations or translations

If neither rotation nor translation is present within a flyers performance, the jumper is said to be 'neutral' in his or her current orientation. To be neutral, one does not have to hold a specific body posture; rather being neutral is the act of neutralizing any rotational and or translational movements all at once. Therefore various body postures can be considered neutral. A jumper can choose to be "passive" after an initial input, such as a high lift track. Letting your momentum come to rest naturally over time without any additional input is called "coasting"

Wind-AXES defined

The Z-AXIS

The Z-AXIS, shown in blue, is the "line of force" as it is always aligned with the relative wind. Yaw is the rotation to the left and right around the Z-AXIS and is solely responsible for heading and directional stability. Based on how the person's torso (MSL) lines up with the Z-AXIS, the jumper can be either horizontally or vertically aligned, giving you his or her orientation. In the wind-tunnel scenario this Z-AXIS is always parallel to the walls of the flight chamber.

In order to define the other two AXES, let us first digress a little and talk about "heading". The subject of heading presents a challenge in skydiving. Unlike an airplane that has a primary flight orientation, a skydiver can fall through the air in multiple orientations. A jumper's orientation influences the concept of heading. Skydivers typically use the word "heading" like a sailor uses the term "relative bearing", a direction that is always straight ahead. There is a difference between heading and flight path. A great example is a belly flyer who is engaged in a side slide. The heading and direction of travel are perpendicular from one another. In skydiving, heading is determined by examining a person's MSP and then referencing the X-AXIS, of the Wind-AXIS system. With the 'clock method', the heading of the jumper is measured as if on a clock face perpendicular to the Z-AXIS (relative wind). An object, such as another jumper, the center of a formation, a tunnel wall or a fixed object on the horizon is said to be at 'twelve o'clock' when it is straight ahead. This means that heading is not line-of-sight. Turning your head to look around does not constitute a heading change, as you have not rotated your body on the Z-AXIS. The body plane of flight is always comprised of the X and Y-AXES. Heading is located on the body plane of the applied orientation in the forward/backward direction of the flyer. A jumper's heading always lies in the forward direction of travel on the X-AXIS. When applied to an external reference point, a jumper is said to be in-facing when the target is in front of the flyer at the 12 o'clock position. If the target is behind the jumper, in the 6 o'clock position, s/he is now out-facing.

The X-AXIS

The X-AXIS, shown in yellow, lies on the body-plane in the forward/backward direction. Tilting the body side to side around the X-AXIS is called banking for small amounts and roll for larger ones. A jumper's heading is determined by observing the positive (front of body) end of the X-AXIS as it rotates on Z. Heading is always perpendicular to the Z-AXIS. While rotating on the X-AXIS, the jumper maintains heading while either side-sliding or altering orientation (barrel roll or cartwheel), depending on the magnitude of the rolling action. In the wind-tunnel scenario this AXIS runs parallel to the net of the tunnel, in the direction of the jumper's heading.

The Y-AXIS

The Y-AXIS, shown in red, also lies on the body-plane and is perpendicular to the X and Z-AXES. Tilting the body front to back (or nose up and down) around the Y-AXIS is called Pitch. Small changes in pitch cause the body to translate forwards or backwards, while larger changes in pitch can alter orientation (flipping). In the wind-tunnel scenario, the Y-AXIS is always parallel to the net of the tunnel, and perpendicular to the X-AXIS (flyer's heading).

Wind-AXES applied to orientations

Start by locating the Z-AXIS as it is always fixed to the relative wind on the vertical plane. Next, locate the X-AXIS, which is perpendicular to the Z-AXIS, and is in line with a jumper's heading. Lastly the Y-AXIS is always perpendicular to the X and Z-AXES but on the same plane as the X-AXIS.

Orientation (Flight-mode)	Primary flight surface(s)	Terminal speed	Base support	Visual perspective	Z-AXIS location on body	X-AXIS location on body	Y-AXIS location on body
1) Belly (Horizontal)	Front	Slow	Large	Right-side-up	Belly to Back	Crown of head to Tailbone	Right hip to left hip
2) Back-fly (Horizontal)	Back	Slow	Large	Upside-down	Back to Belly	Crown of head to Tailbone	Right hip to left hip
3) Head-up (Vertical)	Bottom, front, and back	Medium	Medium	Right-side-up	Tailbone to crown of head	Belly to Back	Right hip to left hip
4) Head-down (Vertical)	Top, front, and back	Fast	Small	Upside-down	Crown of head to tailbone	Belly to Back	Right hip to left hip
5) Right Edge (Horizontal)	Right side, front, and back	Medium	Small	Side-ways	Right hip to left hip	Belly to Back	Crown of head to Tailbone
6) Left Edge (Horizontal)	Left side, front, and back	Medium	Small	Side-ways	Left hip to right hip	Belly to Back	Crown of head to Tailbone

Table 4: Wind-AXES applied to orientations

Table 4 (above) highlights the various flight characteristics the different flying orientations have. As one progresses though the chart, greater flying skill is required in order to maintain control over one's body in freefall. Therefore the chart also highlights the most logical learning approach.

Orientation Borders

Using an *orientation wheel (Fig. 8)*, we can establish imaginary boundary lines called *'Orientation Borders'* (OB) that divide the space around a jumper into six sections.

This wheel can be implemented looking at a jumper either from the front or side. The Z-AXIS, indicated in blue, and the center of gravity ball in the middle of the wheel (black), help orient the wheel's position to the jumper. The grey horizontal line can represent either the X or Y-AXIS depending on whether a front or side view is being implemented.

There are four of these lines in all, passing through the jumper at 45degree angles relative to the Wind-AXIS system. In order to identify which orientation a jumper is in, we compare the person's MSP (mean spine position) with the OB (orientation borders).

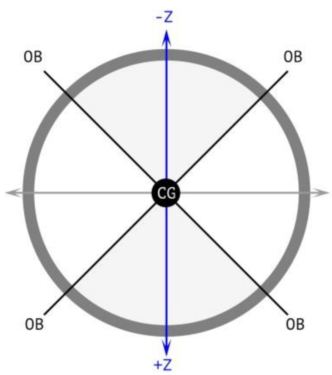


Fig. 8: Orientation Wheel

Below are various examples of comparing the MSP to the OB in order to determine the resultant orientation. In the images below, we examine each body orientation by looking at the person first from the front, and then the side. There is only one example of Edge-flying (right), as the other side would be a mirror image of the first. The frontal view looks straight down the X-AXIS (roll), the edge-on view is looking at the flyer straight down the Y-AXIS (pitch) - to be elaborated on shortly.

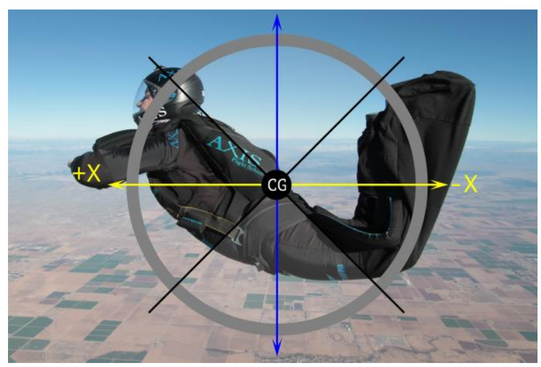
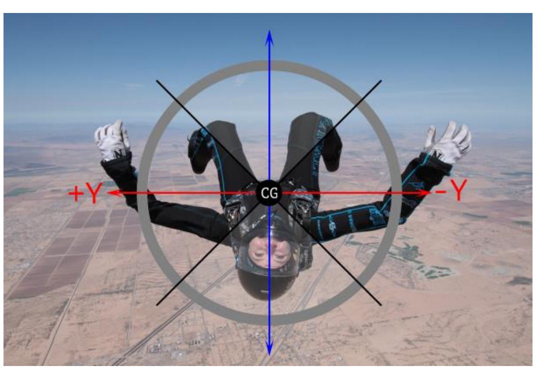


Fig. 9a: Frontal view *Belly* *Fig. 9b: Edge-on view*



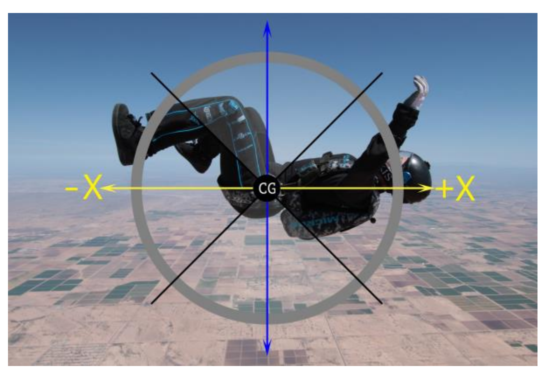


Fig. 10a: Frontal view *Back* *Fig. 10b: Edge-on view*

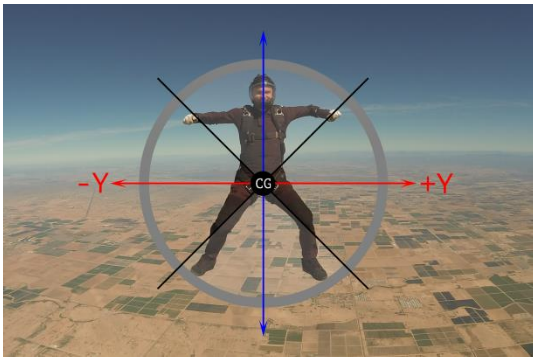


Fig. 11a: Frontal view

Head-up

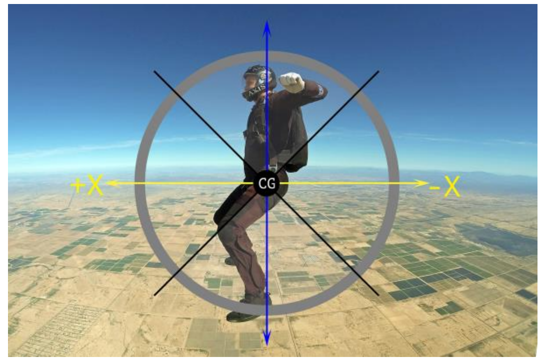


Fig. 11b: Edge-on view

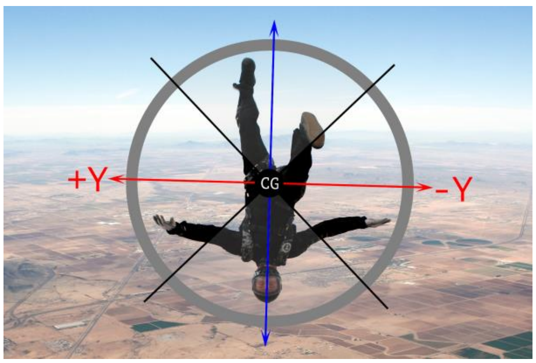


Fig. 12a: Frontal view

Head-down

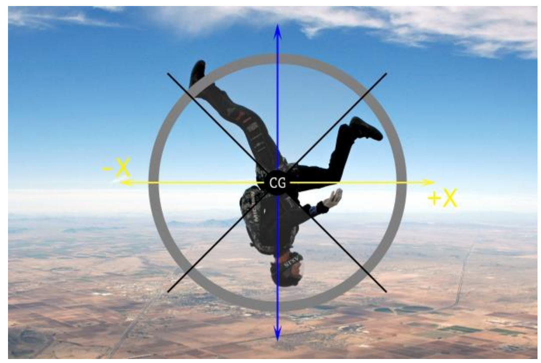


Fig. 12b: Edge-on view

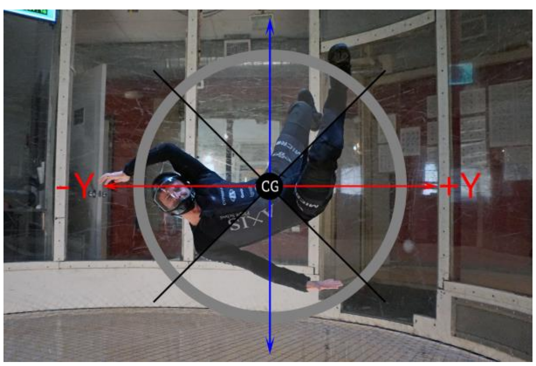


Fig. 13a: Frontal view

Edge Flying

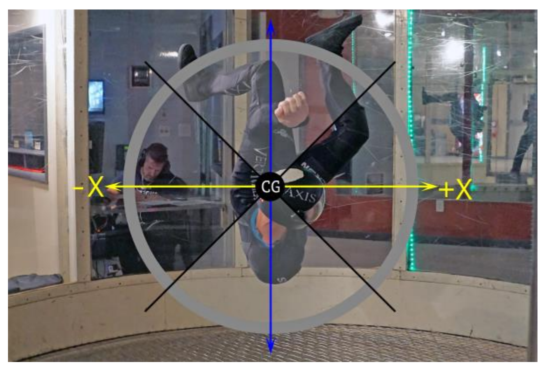


Fig. 13b: Edge-on view

Range of Motion

There are a few body postures and flight modes that appear to break the MSP/OB rules at first glance. Body-flight is not a ridged undertaking and requires for some range-of-motion in order for a person to stay balanced and mobile. This means a jumper can alter their body posture considerably while remaining in his or her original orientation.

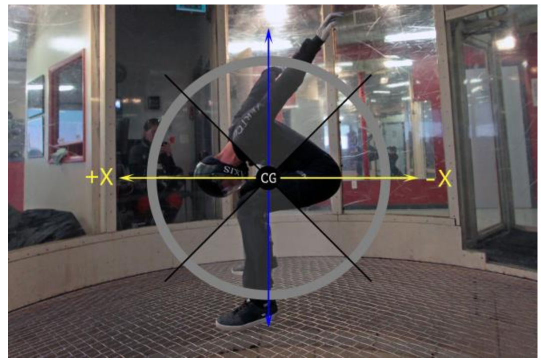


Fig. 14a *Range of Motion* *Fig. 14b*

Fig. 14a (left): Niklas Daniel maintains his balance while back-flying, although the body posture resembles that of a belly arch. Fig. 14b (right): Niklas Daniel transitions from Head-up to Head-down via a front flip. During the transition, Nik pauses and flies the position in the image in a neutral fashion before continuing (link to video).
Photos by Brianne Thompson.

Fig. 14b presents some issues that need to be addressed. I am in a head-up orientation, and even though I am looking behind me through my legs, in my opinion, this posture should be considered head-up. The MSP however closely resembles that of a belly flyer, with the front of the torso leaning onto the relative wind, and the top of the head is presented to the relative wind with the visual field being upside down.

As determined earlier, line of sight does not affect heading or orientation. So we must pay close attention to the MSP and OBs with respect to the relative wind. In addition, it is worth noting that vertical flying orientations can implement belly and back flying surfaces simultaneously. Looking at the image above, one can see that there is a balanced amount of belly and back flying surfaces being implemented to maintain this posture. To a certain extent and depending on your flying skills, you can “stretch” a maneuver a little across the OB line before losing stability.

(Side note: Curling the body in the manner demonstrated in Fig. 14b does not bring orientation into question while flying in an Edge orientation.)

Flight modes that incorporate a horizontal component such as angle/dynamic flying, which can also blur the defined lines of the OBs are covered in more depth further down in this article.

Move Combinations

Any maneuver that simultaneously combines translational and or rotational movements, results in a "super-positioning-move". These will generally change a flyer's location, orientation, and/or heading simultaneously. Examples include flying a circular path or an arc.

Fig. 15: High lift track

Fig. 16: Carving

Some of these moves have their own names such as "high lift track" *(Fig. 15)*, where the goal is to translate forward on the X-AXIS while simultaneously floating 'up' on the Z-AXIS. Another super-positioning example is "carving" *(Fig. 16, image by Steve Curtis)*, which refers to a flyer translating around a target in a circular path (like an orbit) on the horizontal plane. This is accomplished by translating on the X-AXIS just off to the side of the target, while simultaneously adding some rotation on the Z-AXIS to adjust heading.

Transitions

A transition is an AXIS-shift between the six neutral orientations. Because the wind-AXIS system is defined by the relative wind, a transition involves a change in the body's primary flight surface (e.g. belly to another, such as head-up). In order for a body-pilot to transition from one orientation to another, rotation on either the pitch or roll AXIS are required. Therefore these two will be highlighted in the secondary colors green for pitch, and purple for roll.

A skilled body-pilot can rotate his or her body to various degrees of yaw, pitch, and roll. Rotations of more than 90 degrees around the X-AXIS or Y-AXIS result in an orientation change or "AXIS-shift". For example, a pitch alteration of 90 degrees or greater is called a flip, whereas roll of 90 degrees or greater is referred to either as a barrel roll when horizontal or a cartwheel when vertical. Rotations on the Z-AXIS, however, cannot provide a flyer with an orientation change, as it only changes the jumper's heading. Although the body can move in a countless number of ways through space, for practical purposes there are *only 48 possible transitions* using the six neutral orientations: 24 transitions involve pitch, rotating around the Y-AXIS (red) and 24 involve roll, rotating around the X-AXIS (yellow). There are no transitions involving the Z-AXIS (yaw) (because Z can only affect heading).

Each of the six body-flight orientations belongs to one of the three above listed planes. As such, each plane has an excluded maneuver - by name only. For example, a flyer is not able to perform a barrel roll while oriented vertically, because a vertical roll maneuver is called a cartwheel. The same principal applies for the other body-planes and their excluded maneuvers.

Orientation	Excluded transition
Belly & Back-fly	Cartwheel
Head-up & Head-down	Barrel roll
Left & Right Edges	Flip

Table 5: Orientations and excluded transitions

The three planes highlight the different orientations a person can fly in. However, what appears to be a single flying skill on one plane may require significant contributions from the other two planes. For example, head-up flying is a byproduct of belly and back-flying skills, and the pitch transition over the legs that connects the two. The lateral plane, and therefore edge-flying is often neglected in most training programs, and should be recognized as a true orientation of its own.

Edge-flying and "Wormhole" transitions

The X and Z-AXES of the Wind-AXIS system change location on the body when transitioning between horizontal and vertical flight modes through pitch. Similarly, transitions between the vertical and lateral flight mode causes the Y and Z-AXES to shift locations on the body during a roll maneuver. When transitioning between a horizontal and lateral flight mode however, an issue arises. Although one uses a ¼ barrel roll to transition between these two planes, they do not share the same final heading. The act of rolling, no matter the bank angle, is supposed to maintain heading. When an aircraft has its own propulsion system, it is typically in line with the longitudinal AXIS of the body. This creates very defined roll characteristics. When propulsion is absent, such as the case of a skydiver who only has gravity as a driving force, a rolling maneuver has the ability to change heading.

Fig. 17a: Slow flight mode *Edge-flying* *Fig. 17b: Fast flight mode*

Edge-flying can be performed in a wide spectrum of wind speeds. The slow and fast flight versions differ slightly in appearance. A slow fall rate (Fig. 17a) requires more surface area to be exposed to the relative wind. Therefore the legs are generally further apart (oriented horizontally), and the arm leading into the relative wind is stretched out past the head for added surface area. The fast flying version (Fig. 17b) involves the legs to be vertically oriented, while the leading arm rests under the torso. *Photos by Brianne Thompson*

Although flying on the side of the body is by definition a horizontal flight mode, edge-flying exhibits the flight characteristics of a vertically oriented one. This is because the vertical and lateral orientations are both aligned parallel to the relative wind. Since the names barrel roll and cartwheel are synonymous with roll, it would appear that edge-flying orientations have two possible roll AXES – a "roll duality". As heading is perpendicular to vertically aligned planes, the X-AXIS and therefore heading conforms to that of the vertical orientations. This allows for a cartwheel to take place on both parallel planes without heading being compromised throughout the maneuver. The pitch transition (flip) while flying on the side of the body is still referred to as a barrel roll. However, this creates a problem for maintaining heading when transitioning between the horizontal to the lateral planes. This is because a quarter barrel roll from the horizontal to the lateral falls into the roll category, but when performed in reverse should be considered a flip. A 90degree heading change is created when transitioning between the two planes. I have chosen to call this observation a *wormhole transition* (coined by my wife Brianne Thompson), since a roll maneuver is not supposed to transport your heading elsewhere. This counterintuitive characteristic does not go away by making the edge-flying roll-AXIS conform to that of the horizontal plane. This highlights the importance of recognizing a person's starting and ending orientation for proper motion tracking.

Transitions involving a rotation of 180 degrees start and end on the same plane, but always end on the opposing side: 24 possibilities. Transitions involving a rotation of 90 degrees start and end in planes that are perpendicular to one another: 24 possibilities. Transitions that rotate beyond 180 degrees (270 degrees, 360 degrees, etc.) are a combination of 90 degree and 180 degree transitions. Therefore, becoming proficient at these higher- degree transitions is merely a task of combining the foundational elements of 90's and 180's. The chart below is an inventory of all foundational maneuvers a jumper can perform in the air.

AXIS directions of travel defined (+/-)

In order to define the directions of angular rotation the right hand rule will be applied. This helps in understanding orientation conversions for vectors in three dimensions.

Fig. 18 (left): Right hand rule

Since falling towards earth is a jumper's direction of travel, we will establish "into the wind" as the positive direction, no matter the flying orientation. With the thumb of the right hand pointing in the positive direction of the Z-AXIS, the fingers of the hand represent the positive direction of the Z-AXIS torque as you curl them.

Z-AXIS: the path going into the relative wind is indicated to be positive, so we lose altitude in the positive direction of travel. In freefall a jumper can only travel in the negative direction relative to another jumper. When flying in the tunnel, the jumper can actually travel in the negative direction and fly away from the ground to go up.

X-AXIS: The positive direction of the X-AXIS always lies ahead of the jumper - the person's heading. Therefore a forward drive is positive, where as a backward drive is negative. A clockwise roll is positive, whereas a counterclockwise rotation is negative. To find X, turn the thumb of the right hand towards the direction of your heading. The positive X direction always lies ahead of the flyer, and the positive torque direction is clockwise as seen from the flyers perspective. Counter clockwise barrel rolls or cartwheels are rotations in the negative direction.

Y-AXIS: The positive direction is to the left of the flyer. This means a side slide to the left is positive, whereas a slide to the right is negative. This also means that a front flip is positive, whereas a back flip is negative. To find Y, look at the back of your hand (knuckles) with your fingers pointing towards your heading and your right thumb pointing to your left.

Note: To conserve space, the six flying orientations will be abbreviated thusly: BE = Belly, BA = Back-fly, HU = Head-up, HD = Head-down, EL = Edge-left, ER = Edge-right. Wormhole transitions will be indicated with **.

AXIS Shift Matrices

90- degree Transitions (12 Categories)

Category (orientations involved)	Transitions (AXIS-shift)	Action and direction (+ or -)	Heading Change
1) Belly and Head-Up	BE → HU HU → BE	Back Flip (-) Front Flip (+)	0° 0°
2) Back and Head-Up	BA → HU HU → BA	Front Flip (+) Back Flip (-)	180° 180°
3) Back and Head-Down	BA → HD HD → BA	Back Flip (-) Front Flip (+)	0° 0°
4) Belly and Head-Down	BE → HD HD → BE	Front Flip (+) Back Flip (-)	180° 180°
5) Left-Edge and Belly *(Wormhole)*	EL → BE ** BE → EL **	Barrel Roll right (+) Barrel Roll left (-)	90° 90°
6) Right-Edge and Belly *(Wormhole)*	ER → BE ** BE → ER **	Barrel Roll left (-) Barrel Roll right (+)	90° 90°
7) Left-Edge and Back *(Wormhole)*	EL → BA ** BA → EL **	Barrel Roll left (-) Barrel Roll right (+)	90° 90°
8) Right-Edge and Back *(Wormhole)*	ER → BA ** BA → ER **	Barrel Roll right (+) Barrel Roll left (-)	90° 90°
9) Left-Edge and Head-Up	EL → HU HU → EL	Cartwheel right (+) Cartwheel left (-)	0° 0°
10) Right-Edge and Head-Up	ER → HU HU →ER	Cartwheel left (-) Cartwheel right (+)	0° 0°
11) Left-Edge and Head-Down	EL → HD HD → EL	Cartwheel left (-) Cartwheel right (+)	0° 0°
12) Right-Edge and Head-Down	ER → HD HD → ER	Cartwheel right (+) Cartwheel left (-)	0° 0°

Table 6: 90- degree Transitions

180- degree Transitions (3 Categories)

Category (orientations involved)	Transitions (AXIS-shift)	Action and direction (+ or -)	Heading Change
1) Belly and Back	BE → BA BE → BA BA → BE BA → BE BE → BA BA → BE BE → BA BA → BE	Barrel Roll right (+) Barrel Roll left (-) Barrel Roll right (+) Barrel Roll left (-) Front Flip (+) Front Flip (+) Back Flip (-) Back Flip (-)	0° 0° 0° 0° 180° 180° 180° 180°
2) Head-Up and Head-Down	HU → HD HU → HD HD → HU HD → HU HU → HD HU → HD HD → HU HD → HU	Front Flip (+) Back Flip (-) Front Flip (+) Back Flip (-) Cartwheel right (+) Cartwheel left (-) Cartwheel right (+) Cartwheel left (-)	180° 180° 180° 180° 0° 0° 0° 0°
3) Right Edge and Left Edge	ER → EL ER → EL EL → ER EL → ER ER → EL ER → EL EL → ER EL → ER	Cartwheel right (+) Cartwheel left (-) Cartwheel right (+) Cartwheel left (-) Barrel Roll right (+) Barrel Roll left (-) Barrel Roll right (+) Barrel Roll left (-)	0° 0° 0° 0° 180° 180° 180° 180°

Table 7: 180- degree Transitions

Multi-AXIS combinations (twists)

There are two versions of twist maneuvers called horizontal-twist and vertical-twist. What determines which category is being executed depends on the performer's spinal alignment throughout the maneuver:

- A horizontal twist involves the performer starting the maneuver with his or her torso aligned perpendicular to the airflow (belly, back, or edges. S/he then has to turn (yaw), while simultaneously barrel rolling (roll) throughout the maneuver. This means that two AXES of rotations are being implemented simultaneously. An example of this is the half breaker in the dynamic dive pool, which in most cases will also have a translational movement coupled into it.

- A vertical twist involves the performer starting the maneuver with his or her torso aligned parallel to the relative wind (head-up or head-down). S/he then has to flip (pitch), while simultaneously inducing a rotation about the body's longitudinal body-AXIS. Depending on the spines alignment with the Wind-AXIS during the flip, the twisting motion will alternate between rolling and turning. This is because the flyer is effectively rotating on all three AXES simultaneously. This is why this maneuver is considered to be very difficult to perform.

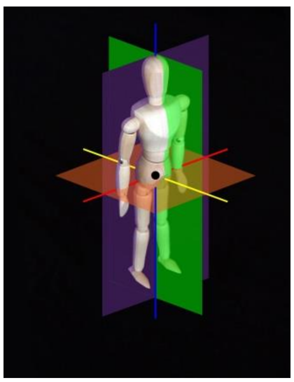


Fig. 19 (left): Three AXES of rotation and three planes of movement

As there are many degrees of twists (quarter, half, full, double, triple, etc. that can be incorporated into any transition) they were excluded from the transition matrix above. Just as an artist can create millions of colors by combining three primary colors, a skilled body pilot can combine fundamental flying techniques to create more complex ones. This strongly suggests that all forms of flight complement one another and that no single orientation is superior to another.

In the image to the left, the figurine moves independently and throughout. The planes are not body planes, but planes of movement! The orange plane is always perpendicular to the relative wind and therefore represents the body's cross sectional area pertinent to body flight.

Terminators

A terminator is a special OB that dictates when a heading change occurs through rotation. There are three terminator lines in all, which are colored red in the images below. They pass through the jumper at 45 degree angles relative to the Z-AXIS. In order to identify whether a body-pilot has transitioned through a terminator line, we need to compare the person's MSP with the appropriate orientation border, and then identify the resultant heading. A terminator transition will result in a 180 degree heading change. The exceptions are wormhole transitions, which by definition fly through a terminator, and have a heading change of 90 degrees.

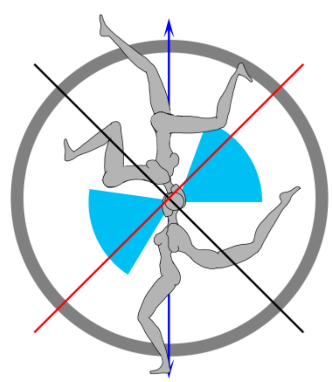


Fig. 20 (right): Side view of flyer shows the first terminator line in red. The blue cones represent a person's visual perspective.

The first can be seen edge-on (side view of the body) on the lateral (X+Z) plane. Here the belly and head-up orientations can be seen sharing the same heading. The back-fly and the head-down orientations also share a joint heading, but in the opposite direction of the first two.

In the images below, the two remaining terminator lines form an "X-shape" with respect to the relative wind, on the flyer's transverse plane, because he is engaged in horizontal flight. The left and right edge-flying orientations can be seen with opposite headings.

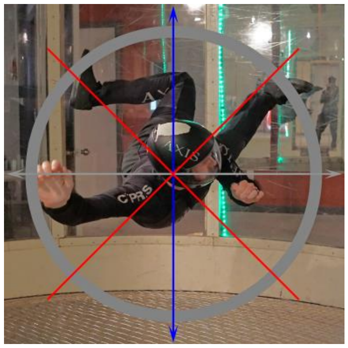


Fig. 21a *The two remaining terminator lines* *Fig. 21b*

A side view of the flyer shows the remaining (two) terminator lines in red (x-shape). These highlight the wormhole transition borders. If the flyer in either of the images were to transition to the belly or back-fly orientations, the resultant heading would be facing us; highlighting a 90degree heading change.

Terminators real world applications

Angle and dynamic flying appear to blur the defined borders between the six flying orientations. When incorporating horizontal movement, we need to take note of a flyers heading. If s/he is following a leader of an angle-jump by using the back-flying surfaces, then the heading remains in front of the flyer, no matter how shallow or steep the angle may be. The jumper is driving forward on his or her back when it is shallow (back-tracking), and continues to drive forward as s/he gets steeper (head-down). Even though the pitch of the flight has altered as much as 90 degrees, the heading remains the same, as do the applied flying surfaces.

However, if the jumper is leading an angle jump using his or her belly-flying surfaces, we need to be aware of the fact that when the flight is shallow (belly-tracking), that the jumper is driving forward in the belly orientation. As the angle of the flight gets steeper, at a critical angle the heading will have altered 180 degrees, because the jumper is now driving backwards while flying in the head-down orientation. This means the jumper is 'out-facing' with regards to his or her flight path. The leader never stops resting the front side of his or her body on the relative wind and continues to travel in the same compass direction. The challenging part about the steeper flight mode is that you are blind to the direction you are traveling in, and your heading control is counter-intuitive. Your 12 o'clock has become your 6 o'clock through the application of pitch, all the while maintaining your flight path. This heading change is indicated on the orientation wheel in Fig. 20 by the terminator (red line) that divides the image at a 45degree angle. Note a similar change as a belly-forward to head-down-backwards transition occurs when moving from back-fly-backwards drive to a head-up-forwards.

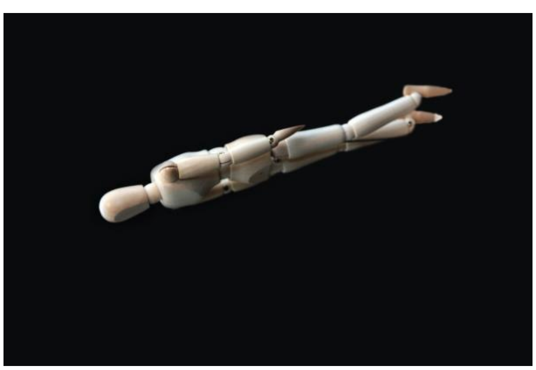


Fig. 22: Belly forward drive

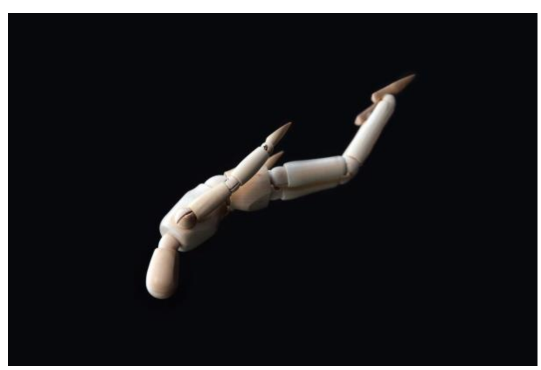


Fig. 23: Head-down backwards drive

In the images above, both jumpers have a flight-path towards the left but their individual headings vary by 180 degrees: given enough pitch (and thus crossing a terminator), a belly forward drive (fig. 22, left) quickly changes to a head-down backwards drive (fig. 23, right).

If a jumper is flying at a steep angle, such as carving in a wind tunnel, the jumper will have to rely not just on his or her vertical flying skills, but the horizontal ones as well. In order to add horizontal translation the belly, back, and even edge-flying surfaces need to be involved.

Heading in relation to the wind-tunnel's center while carving (dynamic)

Flight Surface	Angle	Orientation	Heading	Actions
Belly	Flat Steep Steep	Belly Head-up Head-down	In or out facing Out-facing Out-facing	For or back w/turn Backwards w/turn Backwards w/turn
Back	Flat Steep Steep	Back-fly Head-up Head-down	In or out facing In-facing In-facing	For or back w/turn Forwards w/turn Forwards w/turn
Right Edge	Flat Steep Steep	Right-edge Head-up Head-down	In or out facing Out-facing In-facing	For or back w/turn Backwards w/turn Forwards w/turn
Left Edge	Flat Steep Steep	Left-edge Head-up Head-down	In or out facing Out-facing In-facing	For or back w/turn Backwards w/turn Forwards w/turn

Table 8: Heading in relation to the wind-tunnel's center while carving (dynamic)

An interesting pattern emerges for steep angle flyers who use either their belly or back flying surfaces. While the front flying surfaces of the body are engaged, the jumper is always out-facing, regardless of orientation. And when a person's back flying surfaces are engaged, s/he is always in-facing regardless of orientation.

Fig. 24 (left): Niklas Daniel and Brianne Thompson flying dynamic utilizing their back flying surfaces in mixed orientations. Photo by David Cherry.

Conclusion

There is much we can learn about the sport of body-flight by implementing a coordinate system. Whether tunnel flying or skydiving, in order to continue testing our abilities and knowledge, we must question what we already know and try to see things in a new light. I hope that others can benefit from this system and perform follow-up experiments, even if just to confirm their current knowledge, or to start new conversations. It is my intent to get people to think about body-flight on a deeper level through thought experiment and practical application. The system presented is capable of modeling and tracking a wide range of flight modes and body configurations, which may help better understand the physics behind the sport and help develop more efficient ways of flying, learning, and teaching. With the introduction of a suitable coordinate system and language, the stage is set to discuss the physics and applications of our awesome sport. As always, the intent is to increase people's appreciation and joy in skydiving and tunnel flying.

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About the author

Niklas Daniel is a full time professional skydiver, writer, and photographer. A multi-rated USPA Instructor (AFF/IAD/Tandem), and IBA certified tunnel instructor, he remains an active competitor in several disciplines - mainly focusing on VFS and MFS. Nik was a member of the USA Skydiving Team from 2007-2010, and again from 2013-2014. He has brought back three world medals from the 2008, 2010, and 2014 world championships. Nik is co-owner of AXIS Flight School, with his wife Brianne Thompson, located at Skydive Arizona.

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