WINGSUIT DESIGN AND BASIC AERODYNAMICS 2

In this article I would like to expand on the basic aerodynamics principles I covered in my first article (Wingsuit Flying and Basic Aerodynamics 1) and to explain the challenges encountered when designing and flying wingsuits.

Wingsuits, like any airfoil, creates **lift** and **drag**. Lift and drag are aerodynamic forces that depend on the shape and size of the flying body, air conditions, and the flight velocity (airspeed). Lift is directed perpendicular to the flight path and drag is directed along the flight path.

Every flying body requires **airspeed** to generate lift on its lifting surfaces (wings, fuselage, tail, canard wings, etc.). Also, it has its minimum airspeed at which it will still generate enough lift to fly. This speed is called the **stall speed**. Below that speed it will loose lift and stall, or as some people say, will fall from the sky. The same goes for a wingsuit. It requires speed to fly.

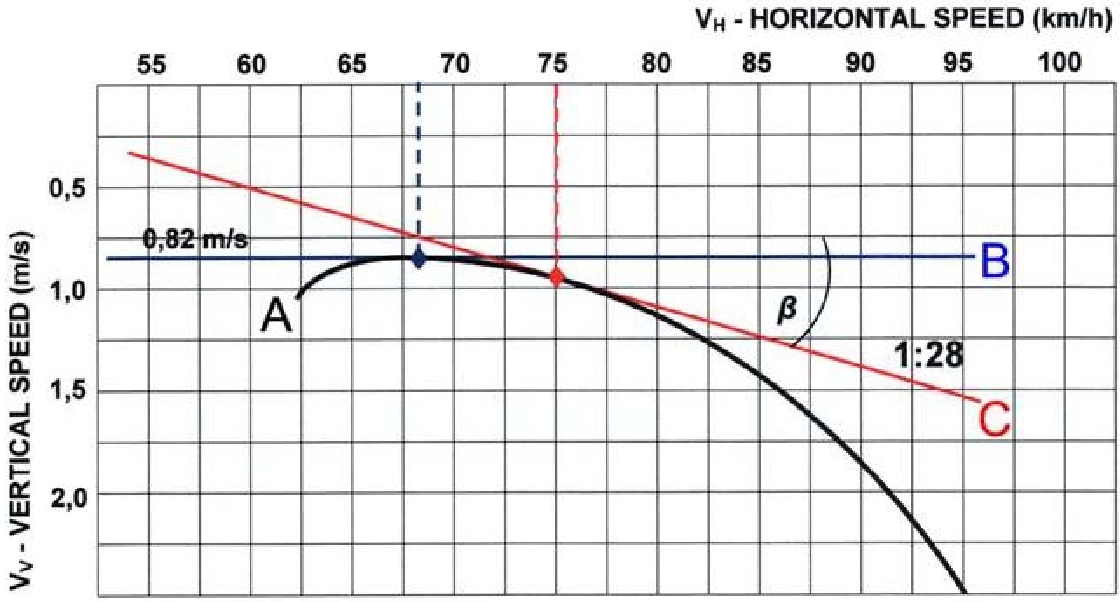
One easy way to describe the characteristics of a flying body in short is through **glide ratio**. Glide ratio is the ratio between lift and drag coefficients (C_L/C_R). Because lift and drag are both aerodynamic forces, lift to drag ratio is an indication of the **aerodynamic efficiency** of the flying body. Or to put it simply, it says how well the body flies.

Glide ratio varies with airspeed. There is a speed at which this ratio is the best, and this speed is usually 30 – 40 % higher than the stall speed (ask any glider pilot about minimum and best gliding speed, 90% of times the answer will be 60-70 km/h minimum speed and 80-90 km/h best gliding speed). Flying at the **optimum speed** (best gliding speed), flying body will cover the longest distance for available height. Flying below or above that speed, flying object will cover less distance for available height.

There is also a speed at which a flying body has **minimum vertical speed (sink rate)**, and this speed is lower then the best gliding speed. But, at this speed flying body has significantly **lower** glide ratio, so flying at this speed will result in more flying time (free fall in case we are jumping wingsuit), but it will cover much less ground distance.

Also, if we maintain speed above the optimum, both flying (free fall) time and covered distance will be reduced.

Above mentioned characteristics can be described by a chart which shows relationship between horizontal and vertical speed (it is mostly used for gliders and hang gliders). Here is one example:



(This chart shows real polar graph for L-13 Blanik glider)

In the above chart, **black curve A** (proper term is **polar curve**) is showing what will be vertical speed (in meters per second) for any given horizontal speed (in kilometres per hour) during the flight.

If we draw a **horizontal line B (blue)** to the top of the curve, we can see that its touches the curve at the point marked with a blue diamond with coordinates x=68 km/h, and y= 0.82 m/s. That line represents minimum vertical speed of 0.82 m/s, which is achieved at 68 km/h. Notice here that if we move along the curve to the left or to the right from that point, vertical speed will increase with the change of speed.

But if we draw a **tangent line C (red)** from the start of coordinate system (x=0, y=0), it will touch the curve at the point marked with red diamond with coordinates x=75 km/h and y=0.95 m/sec. This is the point of maximum aerodynamic efficiency and if flying body maintains this speed it will cover the largest distance for given altitude. At this horizontal speed flying body has the maximum glide ratio of 1:28 in this example. That means that flying body will cover 28 meters of horizontal distance for the loss of 1 meter of altitude.

Here it is important to note that any difference in weight (for the exactly the same flying body) **does not** influence glide ratio. Heavier body will have higher sink rate and will fly at higher airspeed, but the **glide ratio will stay the same** and both flying bodies will cover **the same distance from equal altitude**. This is the main reason why we think that the glide ratio is the only criteria to properly evaluate the quality and efficiency of wingsuit design.

So, the issue here is what do we want from the wingsuit.

If we want only to extend free fall time there are two ways to do that. One is to treat the wingsuit flyer as a regular skydiver and just increase the overall surface area of the suit and design it to look more like a parachute (or flying squirrel). This type of suit will mainly reduce vertical speed, but will have bad flying characteristics and will be a ''slow'' suit in general. This type of suit is good for those who are looking for longer freefall times.

But if we treat wingsuit flyer as a **flying** body, the only logical choice is to try to increase the glide ratio of a wingsuit. To do that, the designer has to choose between numbers of options, which have to be very well balanced, because in aerodynamics it is impossible to change one parameter without affecting the others.

In an attempt to increase glide ratio, the first option is to try to increase lift. Increasing the lift for the same wing area and weight will reduce the sink rate and therefore improve the glide ratio.

In general, the amount of lift depends on **area**, **span** and **shape** of the wings and other lifting surfaces. Also, the amount of lift depends of airspeed which, in turn, depends on before mentioned physical characteristics of the flying body. Since human body has a definite shape and varies very little in size and proportions, it is obviously not possible to do much in respect to that. Also, one has to bear in mind that the human body is not well suited to flying, regarding dimensions and proportions and available specific strength (power).

The shape of the arm wings is determined by a compromise between force needed to keep wings spread, and aerodynamic efficiency of the wings. To get the maximum wing area a straight wing might be the best, but it would be also very difficult to fly because it would require strength of Olympic Champion in gymnastics to keep your arms spread for 2 minutes. Finding optimum angle for the wing sweep was one of the most difficult tasks at the beginning of wingsuit design. Of course, we can try to increase span by adding some rigid parts to the wings and arms, but that would not be wingsuit any more. If you would like to strap some mechanical wings of that kind to yourself, we would strongly recommend hang gliding.

If we try to extend trailing edge of the wings down to the legs, the wing area would almost double, but in return, a very high force would be needed to keep your arms spread. Also, this wing shape would be prone to the effect known as flutter (flapping of trailing edge) that results in greatly reduced lift (in some circumstances lift can drop to zero due to flutter effect). A possible area for improvement lies in the use of different airfoils and angular positioning of the wing.

Almost the same principles apply to the leg wing. Not much room to increase wing area, because wider leg spread will lead to very small gain in wing area, but would make difficult to maintain proper flying position. Also, once again flutter problem is preventing the extension of leg wing trailing edge too far out.

The other area for improvement is to minimize drag which will also result in improved glide ratio. One can minimize drag by maintaining the proper flying position, but this is up to the individual pilot. From the manufacturing and design point of view, drag could be reduced by streamlining the wingsuit design (remove any bumps or flapping parts, using smooth low friction materials, etc), and by improving the production quality (overall finishing and fit of the wingsuit).

Research has been done in order to incorporate rigid or semi rigid leading edges on the arm wings to improve the airfoil shape. This would both increase the available lift and reduce drag, but this has to be precisely tailored for each individual wingsuit flyer. Also, rigid leading edges are much more sensitive to improper arm position and change in angle of attack.

In practice it is usually both, efforts to minimize drag and increase lift at the same time. When discussing all these options, one should never forget that wingsuits also have to be designed in order to allow parachutist for easy deployment of their canopy and use of emergency handles, as well as to be comfortable to wear and fly.

Testing the wingsuit is another area for discussion. It is still not an exact science, primarily because performance of a wingsuit depends largely on the pilot. One wingsuit type may be the best for one pilot, but would not work that well for another.

Phoenix – fly uses computer simulation technology for the design of wing airfoils and to perform basic calculations of two-dimensional airflow. But calculating three-dimensional airflow around a flying body is still a task that requires extreme computational strength that is well beyond the reach of anyone except large aerospace companies or institutions. Even then, those calculations have to be verified by wind tunnel testing or real test flights. Also, it needs to be noted that even minor position changes of any body parts (legs, arms, head, chest...) during the flight could significantly alter flying characteristics.

The obvious question here is did anyone ever try to put a wingsuit into an aerodynamic wind tunnel (do not confuse that with wind tunnel used to practice free fall!) to get data on wingsuit behaviour under different settings and conditions. Sure, that would be very nice indeed, but (surprisingly to some people) wind tunnel time and the preparation required (how and what to measure) is a very long, difficult and expensive process, usually requiring at least one years work to provide any useful information. The process is worthless without detailed planning and well determined goals, and if wind tunnel testing is not performed in this manner, the only result could be nice pictures of the wingsuit hanging inside the tunnel. At the moment, high costs associated with wind tunnels cannot economically justify this as a realistic testing option.

The field of aerodynamics is a fascinating blend between science and art. Knowledge of the theory alone is not enough, successful design requires imagination, experience and a 'feel' for what will work.

The Phoenix is rising…