Hovercraft Skirt Design Notes

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1998

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Light Hovercraft Design

In this series we will cover the basics of light hovercraft design and construction. It will be written as simply as possible in terms easily understood by everyone. While it will be kept to a minimum, the series will include some basic algebra but if you get stuck you can just do as I do - swallow your pride and ask your children to help you out!

Let's begin by defining what a hovercraft is: a vehicle which supports itself on a dynamically generated cushion of air. This air cushion is normally generated by a fan driven by a gasoline fueled internal combustion engine often augmented but the dynamic air pressure generated by the hovercrafts forward motion. (The cushion can also be generated *entirely* by the forward motion of the vehicle but that type of vehicle, known as Wing In Ground effect, will not be covered in this series).

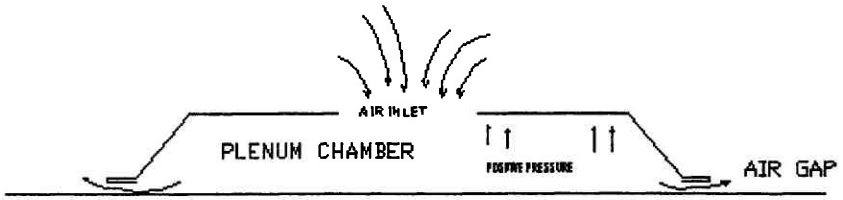


Figure 1

The simplest of all hovercraft can be viewed as an inverted pie plate as shown in figure 1. When air is blown into the hole at the top of the inverted plate, it causes an increased pressure within the *plenum chamber*. When this pressure equals the weight of the plate - the plate rises. As the flow of air increases the pressure remains constant but the ground clearance increases. Of course, this ground clearance only allows for limited obstacle clearance and so we add a flexible structure to the bottom of our pie plate known as a skirt. The same rules apply for a skirted vehicle except that the skirt will inflate prior to leaving the ground thus extending our hard structure clearance.

So exactly how much air and power do we need to lift a hovercraft? Let's get into it with an actual real life example:

Many years ago when I first moved into my new house we had nothing but seeded topsoil in our back yard. It was early spring and my wife coaxed me into planting a vegetable garden in the rear of the yard and so I need a "wheel-less" wheelbarrow to bring manure and other garden implements across the new grass seedlings and so I designed a simple hovering platform and this is how I went about it.

I decided to build a platform 4' x 6' with a lawn mower engine on one end driving an axial fan for lift. The load area would be 4' x 4' and it would be pushed and controlled from a standard lawn mower type handle bar and throttle control. This vehicle can be seen in figure 2.

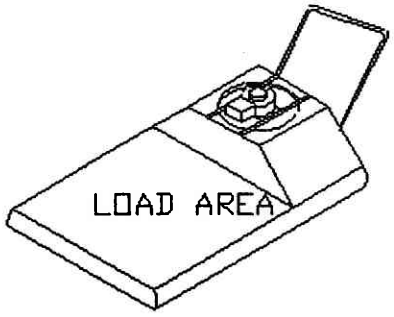


Figure 2

Step 1. Determine the *total weight (Wt)* of the vehicle by adding up the weight of its components.

structure	70 lbs
motor	80 lbs
load	200 lbs
Total	**350lbs**

Step 2. Determine the *cushion pressure (Pc)*
In order to determine the cushion pressure we must know the *cushion area (Ac)*. Since this vehicle is a rectangle it is easily determined by multiplying the length by the width. In this case:

$$Ac = 6' \times 4' = 24 \text{ square feet}$$

Equation 1

Knowing the cushion area we can now determine the cushion pressure by dividing the total weight by the cushion area.

$$Pc = Wt \div Ac = 350 \div 24 = 14.58 \text{ pounds per square foot}$$

Equation 2

As you can see, we are not dealing with enormous pressures here, but that is one of the great virtues of the hovercraft.

Step 3. Determine the *volume flow* (*Q*) of air required to lift the vehicle clear of the ground.
The volume of air is the quantity of air that must be contantly replaced as air "leaks" out from underneath the hovercraft. Of course, the higher the skirt is off the ground the bigger the "leak" is and so the more air will be required. As you have no doubt already guessed we must now decide how much ground clearance we want at the bottom of the skirt since this directly affects the *area of air escaping* (*Ae*). This area is calculated by multiplying the *peripheral length* (*pl*) of the cushion (the distance around the outer contact edge of the air cushion) by the air gap itself. In our case the peripheral length is length + length + width + width or 6' + 6' + 4' + 4' = 20 feet. How high do we want the skirt off of the ground? Well, I want it high enough not to damage the grass seedlings so an *air gap* (*hg*) ¼" to ½" will do. Since we are working in feet I must convert the ½" to feet so 0.5" ÷ 12" = 0.04167′ and since *pl* = 20 then our area of air escaping is:

$$Ae = 20 \times 0.04167 = 0.833 \text{ square feet.}$$

Equation 3

We now know how big the hole is that the air is escaping from but how do we know *how much* air is getting out? For this we must determine the *velocity of the escaping* air (***ve***). Air velocities are directly related to pressures and we have already found out the pressure of our air - the cushion pressure. We use this to determine the air velocity with the following equation:

$$ve = \sqrt{\frac{Pc}{½\rho}} = \sqrt{\frac{Pc}{0.00119}} \text{ feet per second}$$

Equation 4

(ρ is the symbol for the air density measured in slugs/cubic foot. At sea level this value is 0.00238 sl/ft^3).

This may look a little frightening but using a basic calculator you have only to divide the cushion pressure by 0.00119 and take the square root of the result and you have your answer. In our the case of our example, *ve = 110.7 ft/sec.* The volume flow of air is this velocity times the escape area or

$$\boldsymbol{Q = Ae \times ve} = 0.833 \times 110.7 = 92.2 \text{ cubic feet / second}$$

Equation 5

Step 4. Now that we know the pressure and volume flow we can determine the *horsepower* (***Hp***) required to do this work by using the following:

$$Hp = \frac{Q \times Pc}{550 \times yf}$$

Equation 6

yf is a value representing the fan efficiency and should be set to about *yf=0.55* to remain on the safe side so the equation becomes:

$$Hp = \frac{Q \times Pc}{550 \times yf} = \frac{92.2 \times 14.58}{550 \times 0.55} = \frac{1344.276}{302.5} = 4.44 \text{ horsepower}$$

This is more than my available Briggs & Stratton 3½ hp lawnmower engine will provide so I have to lower the air gap to ¼". Re-doing the above equations gives Hp= 2.2 horsepower which means that I will be able to play with the throttle to provide an air gap of ¼" to just under our original design specification of ½". This same series of equations can be used to determine the lift air requirements of almost any air cushion vehicle.

The next step is to locate a fan that will be compatible with the B&S 3½ hp engine. I had a 19½", 5-bladed Multi-wing fan with blades set at 30° available and in checking its data sheet discovered that it absorbed about 3.7 horsepower at 3600 rpm – very close to the horsepower of the engine at that speed (3.5hp @ 3600rpm). Interestingly, the data sheet also shows the fan delivering 106 cubic feet of air per second at 14 lbs/ft^2 which we can use to determine the *actual* fan efficiency by changing equation 6 into:

$yf = \frac{Q \times Pc}{Hp \times 550}$ or substituting our numbers $yf = \frac{106 \times 14}{550 \times 3.7} = 0.729$ or a fan efficienty of 72.9%.

Once the quantity and pressure of air requirements are known the fan supplier should be able to supply you with a chart of the fan's performance. This holds true for both centrifugal and axial flow fans.

In actual practice these numbers vary but in taking measurements on the "manure carrier" I found that they were quite close.

As my children grew older they discovered that they could ride around on this little platform. Thus the push handle was removed and an air-splitter added whereby ½ of the air was used to lift the machine and ½ was used to push it forward. Rudders, a seat and a control column were added and presto, my kids had a new toy. While it was limited to smooth surfaces it would travel at a running pace down the street. This end result can be seen in figure 3.

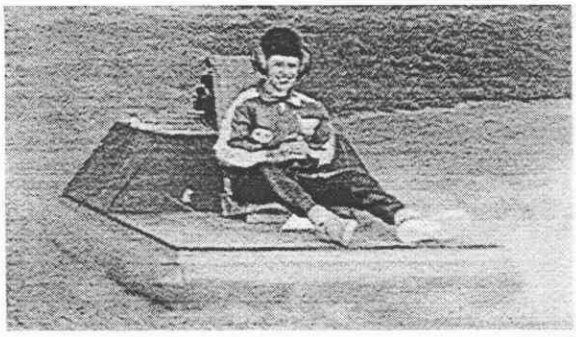
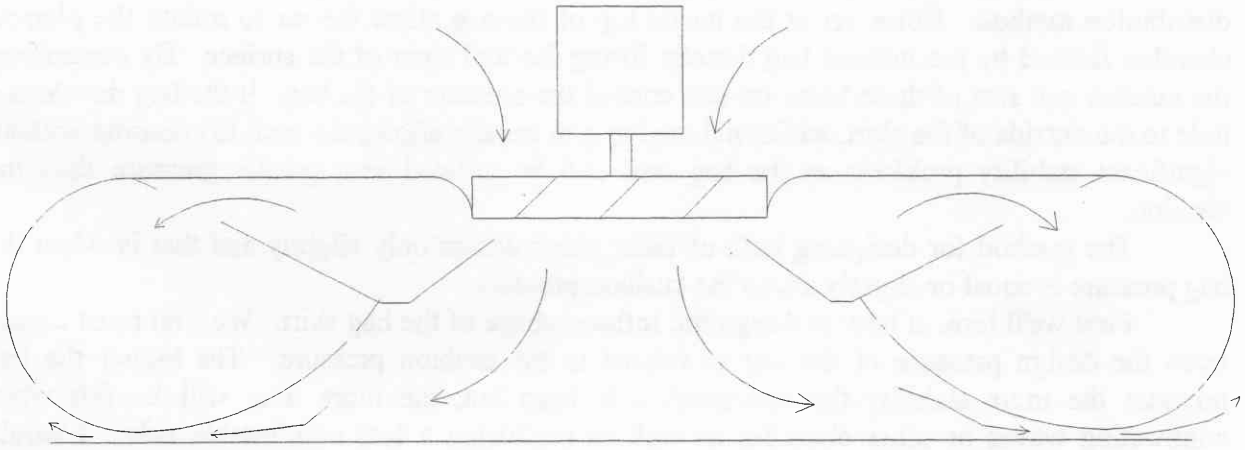


Figure 3

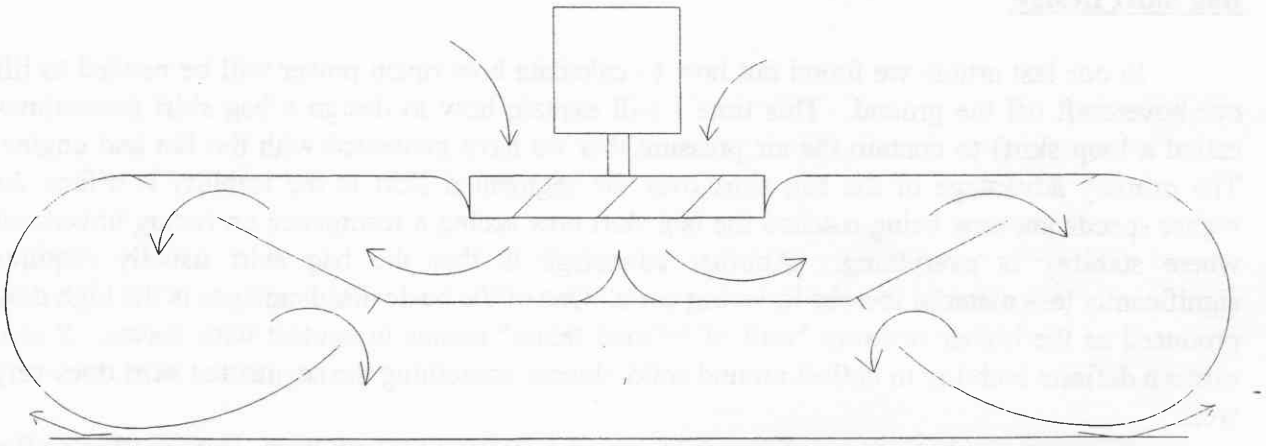
Bag Skirt Design

In our last article we found out how to calculate how much power will be needed to lift our hovercraft off the ground. This time I will explain how to design a bag skirt (sometimes called a loop skirt) to contain the air pressure that we have generated with the fan and engine. The primary advantage of the bag skirt over the segmented skirt is the stability it offers. As higher speeds are now being reached the bag skirt now seeing a resurgence on racing hovercraft where stability is everything. Another advantage is that the bag skirt usually requires significantly less material thereby lowering costs. One of the basic disadvantages is the high drag produced as the higher pressure "wall of inflated fabric" comes in contact with waves. It also offers a definite inability to deflect around solid objects, something the segmented skirt does very-well.

There are two basic types of bag skirt – the full flow and the no flow. Both methods offer different advantages over the other and you must decide what is best for your particular application.



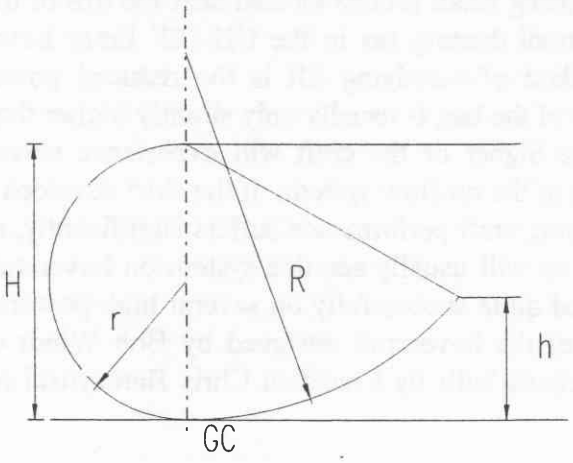
This cross-sectional view illustrates the "no-flow" system where only a small part of the supplied air is sent into the skirt. This is normally done by using small scoops located near the tips of the lift fan but this can also be accomplished by internal ducting (as in the UH-10F Entry Level hovercraft). The primary advantage to this method of supplying lift is the reduced power requirement to inflate the skirt itself. The pressure of the bag is usually only slightly higher than that of the cushion pressure. (It must always be higher or the craft will experience severe instability.) This leads to the primary disadvantage of the no-flow system: if the skirt develops a hole or even small tears to the exterior of the cushion, craft performance suffers significantly, to the point where the craft will not hover at all! You will usually see this system on hovercraft where lift power is at a premium but it is still used quite successfully on several high-powered racing machines. Most notably are virtually all of the hovercraft designed by Bob Windt of Universal Hovercraft. The very fast racing hovercraft built by Canadian Chris Barczynski all utilize the no-flow bag skirt system.



By far the most common method of supplying air to the bag skirt system is the full flow method. All of the cushion air first passes through the bag. Often, the bag itself is used as the air distribution method. Holes cut at the inside top of the bag allow the air to inflate the plenum chamber formed by the inflated bag thereby lifting the hull clear of the surface. By controlling the number and size of these holes we can control the pressure of the bag. If the bag develops a hole to the outside of the skirt, additional engine rpm usually allows the craft to continue without significant stability problems as the bag will still be inflated at a greater pressure than the cushion.

The method for designing both of these skirts differs only slightly and that is when the bag pressure is equal or slightly above the cushion pressure.

First we'll look at how to design the inflated shape of the bag skirt. We first must decide upon the design pressure of the bag as related to the cushion pressure. The higher the bag pressure the more stability the hovercraft will have but, the more drag will be felt when confronting waves or other obstacles as well as producing a less comfortable ride. I would suggest that a cruising craft would not want to exceed a bag pressure 1.5 times the cushion pressure but a racing craft might well have a bag pressure 2 to 2.5 times the cushion pressure.



The first step in determining the skirt cross section is to draw out a cross sectional view of the hull. Next we determine the cushion height (**h**). This is typically 1/8 of the width of the craft. If you make the cushion height too high you will again get into the problems of instability. Too low and you won't have adequate ground clearance and the hull bottom will constantly be in contact with surface objects. Next we determine where the ground contact line will be for the skirt. This is usually directly below the outer skirt fixing point. It can be positioned 1" - 2" inside of this point but it should ***never*** be outside of this point or you'll be back into that problem of instability. Once the ground line is drawn in the height of the skirt (**H**) can be determined. The radius (**r**) is ½ of this height. The inner radius (**R**) is dependent upon the pressure differential between the bag and the cushion pressure. The value for R can be determined by looking up the multiplying factor in table 1. For example, if your design pressure

PL/Pc	R/r
1.2 : 1	6.00
1.3 : 1	4.53
1.4 : 1	3.50
1.5 : 1	3.00
1.6 : 1	2.66
1.7 : 1	2.43
1.8 : 1	2.25
1.9 : 1	2.09
2.0 : 1	2.00

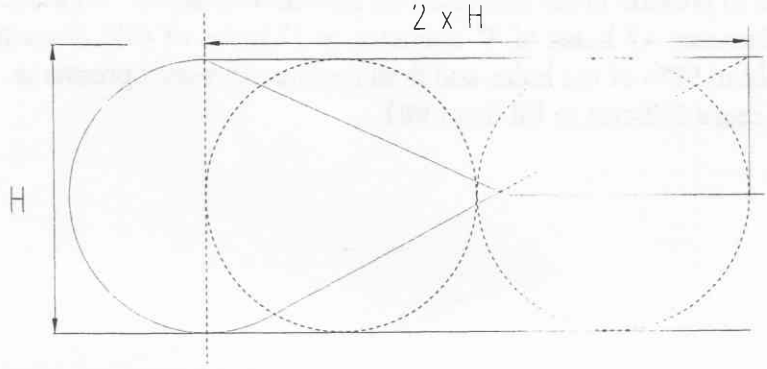
differential is 1.5 : 1, the multiplying factor is 3. We then multiply our value for **r** times 3 which is the value we use for **R**. We can now draw in this inner radius.
If you'd prefer to use an equation:

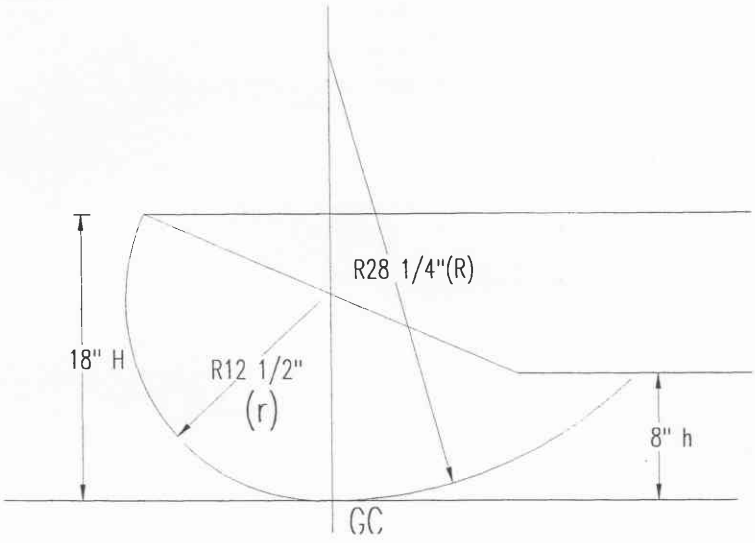
$$R = \left(\frac{PL}{PL - Pc}\right) \times r$$

The cross section for the no-flow skirt is different when the pressure differential is non-existent or close to 1 : 1. In this case the inner loop is actually not a loop at all but rather a straight line drawn tangentially from the circle formed by the outer loop to an imaginary-attachment point that is located two diameters inboard of the outer attachment point.

Bag skirt cross sections designed in this manner will have a balanced geometry and will automatically take up this designed shape, provided the pressure differentials are as predicted.

The bow section on a bag skirted machine must be handled in a different manner. If the skirt attached to the bow is the same as that on the craft sides, it will tend to tuck under the craft and increase the drag significantly. This tendancy to tuck under is lessened by increasing the pressure differential. The racing hovercraft produced by Keith Smallwood in England have a symmetrical skirt with an identical cross section around the entire periphery of the machine but they also use a pressure differential of close to 2.5 to 1. If you watch a UH-10F Entry Level craft at speed over water you will see that the bow skirt tucks under the bow and can even cause wrinkling of the side skirts. This is because the bow is the same as the sides on this type. Even over grass the bow skirt tends to tuck under on this model.





To avoid this problem we design the bow section to appear as in the following diagram, with the outer radius drawn in to take up a shape similar to the drawing. The inner radius **(R)** is then calculated in the same fashion as for our side skirt section, by multiplying **(r)** by our multiplying factor from table 1. This type of bow section will minimize drag over both water and land and avoid the commond "tuck under" problems so often associated with homebuilt

hovercraft that have a symmetrical section around the entire periphery of their craft.

So how do we achieve the design pressure differential between the skirt and the plenum? If you are using the no-flow method then you will have to experiment by using a pressure gauge or an instrument known as a pressure manometer. (A future issue will explain how to build a simple pressure manometer that you can use in many ways to learn more about your hovercraft.) If your lift system employs the full flow method we use the following equation:

$$A = \frac{Q}{20\sqrt{PL - Pc}}$$

where **A** = total area of the holes that we must cut on the inner side of the skirt (in square feet).

Q = the lift air flow required to lift our hovercraft (from equation 5 in the last article)

PL = pressure of the air within the skirt itself (in pounds per square foot)

Pc = is the pressure of the air in the plenum, or our cushion pressure (in pounds per sq. ft.)

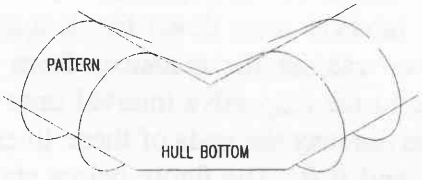
Now we know the area of the holes to be cut but how many and what diameter? Well the area (in square feet) of a 3" diameter hole is 0.049 sq. ft.; a 3½" hole is 0.0668 sq. ft.; a 4" hole is 0.087 sq. ft. and a 4½" hole is 0.110 sq. ft. So if our design says we have **Q**=200 ft^3/sec with **PL**=18 lb/ft^2 and **Pc**=12 lb/ft^2 we will need to provide holes that equal an area of 4.08 sq. ft. To achieve this we can use 61 holes of 3½" diameter, 47 holes of 4" diameter or 37 holes of 4½" diameter. (When cutting the holes, cut only about 90% of the holes and then measure to verify pressures. It is easy to cut more holes but much more difficult to fill them in!)

Bag Skirt Tailoring

In our last article we discussed how to determine the correct shape that our bag skirt will take once the power is applied and we are floating on our magic cushion of air. In order to ensure that the skirt will take up this designed form we must cut out the panels of material to a specific shape that will then be sewn and/or glued together. There are two methods for achieving these required shapes: either by a mathematical method using contours or by using templates laid up over the hull. Either method works well and the choice is up to you.

Template Method

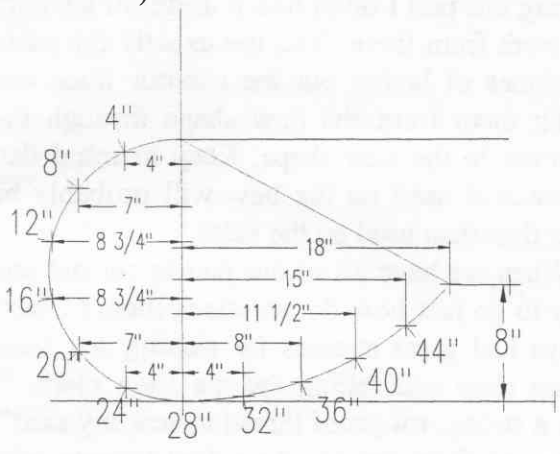
I'll start with the simplest first. You can use any workable sheet material for this purpose. - I've known constructors to use anything from 1" thick styrofoam to ¼" plywood for this purpose. What is involved is to draw the skirt cross-sectional shape onto the sheet and cut it to the *exact* shape. Cut out enough copies of these shapes to install on the upside down hovercraft hull as shown in the diagram below.



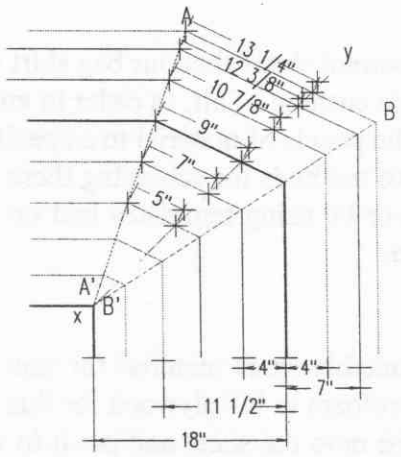
Then place the skirt material over the forms so that it takes up the designed shape of the inflated skirt. You can use staples, tacks, etc. to hold the skirt in place. Where the seams join together, use a stapler or pins to bring the material together. Using a suitable marker (I often use white coloured pencils) draw where the seams are to take place. When cutting the material, allow for a 1" seam. This must be repeated for each corner or shape change of the skirt.

Mathematical Method

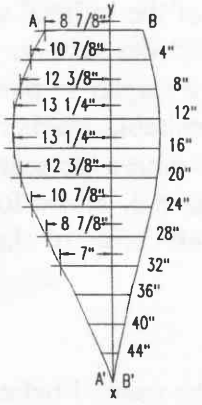
This is my preferred method that I have used many times over the years. I believe it can give you almost perfect results and with the common usage of computer aided drawing programs it is now much simpler and more accurate than before. (The photograph on the top right of page 4 shows the results of using this method to redesign the skirt for the UH-10F Entry Level hovercraft.)



In the last article we designed the shape we wish our skirt to take. We then lay this shape in scale or full scale onto a piece of paper (or on a virtual sheet using a CAD system) and start by putting marks at intervals around the circumference of the skirt. If doing this by hand I recommend 2" intervals; if using a CAD system use 1". (For illustrative purposes, the figure shows 4" intervals.) Next we draw a vertical line from the outside skirt attachment edge of the hovercraft hull straight down to the ground. From this line, measure horizontally the distance from each interval marking to the vertical line and record this measure on the drawing as shown in the figure below. These measurements are essentially contour lines – just as you would see on a terrain map.



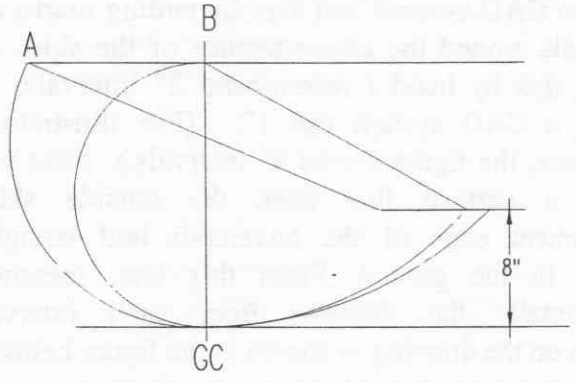
Our next step is to create a new drawing of the hovercraft hull as seen from directly above. For simplicities sake we usually examine each corner individually. We then transfer these contour measurements to the new drawing effectively showing where the skirt extends with respect to the outer attachment point. Onto this drawing we add a line *X Y* which runs at a right angle to the contour lines. We then get out our ruler and measure the distance from this line to the line - *A A'* and from *B B'*, recording them as we go. (The illustration only shows the distances from *A A'* to *X Y*). This provides us with the required information to lay out a piece of material which will join our side panels together.



We now lay out a third piece of paper which will become out template for the corner section. First we draw a vertical line to represent *x y*. Then we measure our interval lines down the length of this line. Now we transfer the distances from the previous drawing to the respective interval onto the drawing. We then connect the ends of these lines to create lines *A A'* and *B B'*. The figure below shows the centre line *x y* and the lines *A A'* and *B B'* and the 4" interval lines.

This is the final shape of the template for our corner. We can then cut out this pattern (I usually transfer it to a piece of hardboard or scrap plywood) and then trace around it directly onto the skirt material. When cutting out the shape I always over cut by about 1" to allow for sewing.

When we deal with the bow to side shape we repeat the process beginning with the 2" interval lines around the bow cross section. When doing this part I often find it useful to lay both the bow and side onto the same sheet of paper and work from there. You use exactly the same techniques of laying out the contour lines and tracing them from the bow shape through the transition to the side shape. Keep in mind that the material used on the bow will probably be wider than than used on the sides.



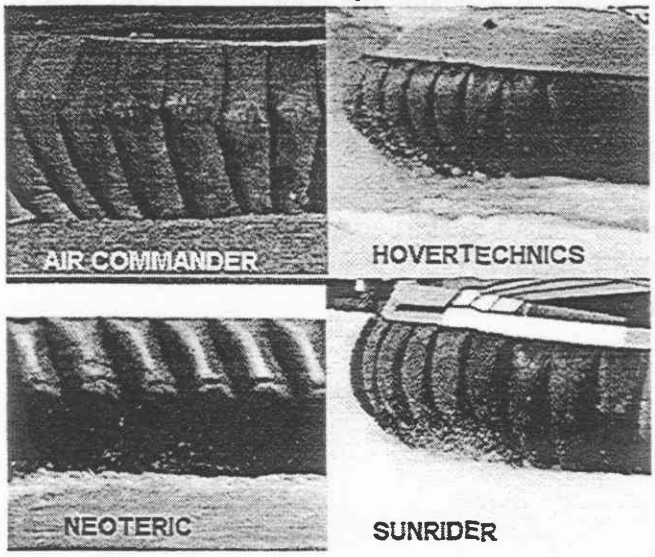
When we have all of our panels cut out and ready to go just how do we attach them? I have always had great success by visiting my local sewing shop and telling the the shop clerk, "I want a strong, rot-proof thread to sew my skirt". Of course there are always a few woman who chuckle behind me but this is exactly what you should ask for. Stay away from cotton or natural

fibre threads. I have always used Gutterman polyester upholstering thread and I know of several others who swear by nylon thread (although the nylon seems to jam up my sewing machine). I don't recommend hand sewing and I suggest at least three lines or passes with the machine. Based upon a suggestion by **Bob Windt** of Universal Hovercraft, I now glue a strip of material over each seam using contact cement in an effort to protect the seams. This strips will sometimes pull away and must be re-glued but this is easier than re-sewing! I've known a few who have had success using only glue! It all depends on the material you use.

What material should you use? I usually see two types of materials used on light, bag-skirted air cushion vehicles. These are either polyurethane or neoprene coated nylon fabrics. Both have their advantages and disadvantages. Usually, the choice comes down to what you can find from local suppliers. Whichever material you use there is a simple test you can perform to verify it's durability. I have named this the "*Fishlock Dime Test*" after the person who showed it to me: **Ron Fishlock**. Basically, you rub the edge of a dime as hard and as vigorously as you can in an attempt to remove the coating from the nylon. This rubbing effort should be an extreme workout lasting a good 60-seconds. If the coating does not rub off exposing the underlying nylon, then it will *probably* be a good skirt material. Aside from a durable material the next essential quality is weight. Material weights are generally given as ounces per square yard (even in these metric times). For a light acv bag skirt you should probably be looking for something around 8-10 oz. You may go to a 12-14 oz. but be aware of the added weight and less flexibility of this type of material. Many small craft builders with often use an even lighter 6-8 oz. but this will not last a long time in rough service. You must keep in mind that a bag skirt can take a significant beating and ask yourself, "Will this material survive what I intend to put it through?" The key ingredient in hovercraft design, construction and operation is *Common Sense*.

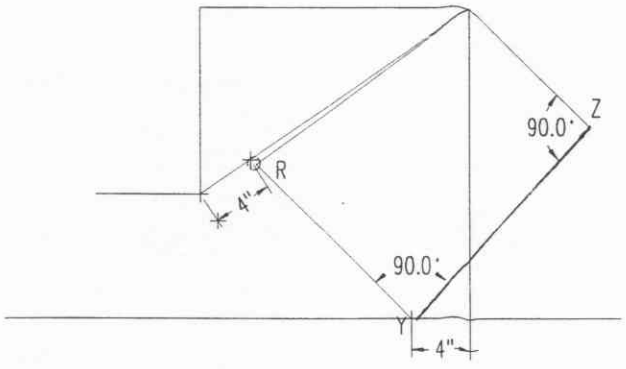
The Segmented Skirt

Segmented skirts have been with us ever since the late Denys Bliss working at Hovercraft Development Limited in England first took a knife and cut open the stitched seams on the HD4's internally webbed C-skirt. The segment skirt then evolved over the years into the loop/segment (to be covered in the next article), bag/segment, straight segment and the two primary versions of the extended segment that we have in extensive use today. These two versions are well illustrated in figure 1. The primary difference being the straight edged upper part of the segment as seen in the two examples on the left and the rounded uppers shown on the right of figure 1. Interestingly, both examples on the right are from British designers and the two on the left are American (although both types can be seen throughout the world). The two on the left can further be differentiated in that the jutting point of the segment is in the top 1/3 of the skirt on the Air Commander (as in the Scat) while the jut on the Neoteric is about at mid-height. So which is best? The answer, as always seems to be the case with hovercraft, is: "It depends".



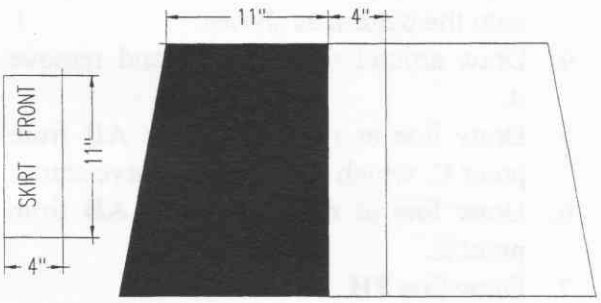
In all flavours, the extended segment skirt is simple to design, construct and repair. The segmented skirt offers a smoother ride than the bag skirt (although not as smooth as the loop/segment) and it is normally not bothered by obstacles a high as the cushion depth. It has a low drag due to the small contact area and unlike the bag skirt, it does not retain water when the hovercraft is left afloat. Recently, I've read literature that favour the flat sided extended segment skirt because of its better aerodynamics at the higher speeds currently being reached by the modern racing hovercraft. The rounded leading edge of the other type appears to create unfavourable airflow over the hovercraft hull – often leading to either the lifting of the hull or evacuation of the supporting air cushion and subsequent cushion collapse.

We'll first examine the design of the flat leading edge fully segmented skirt. The first step in the design process is to draw out a cross sectional drawing as in figure 2. We must mark in point **Y**, which is usually about 100mm or 4" inboard of the outer edge of the hovercraft hull. We then draw a line from point **Y** inboard to the inner skirt attachment point **R**, itself also usually 100mm or 4" up from the hull base. A line is then drawn from point **Y** to point **Z** at 90° from the line **RY**. The top edge of the segment is a line from **Z** to the outer attachment point on the hull.

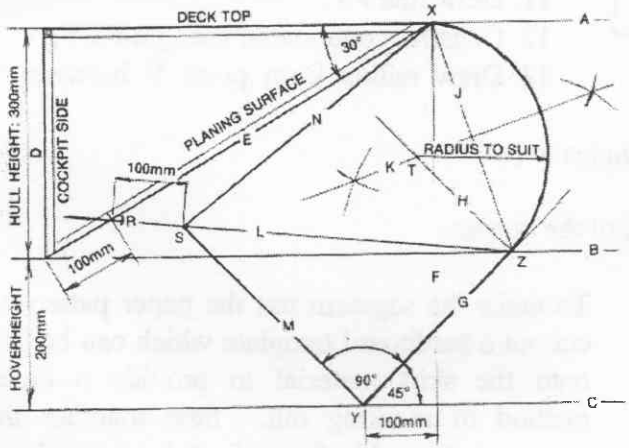


The next step is to transfer this profile shape to our template. The shaded portion of figure 3 is *exactly* the same as the side profile we designed in the previous figure. We then add the section for the skirt top face (in this

case 4") and then draw in the reverse of our side profile. This final layout should be transferred to a hardboard template and used as the pattern for our skirt segment. One other piece that will be needed is the top or skirt front of the segment. This is, of course, easily measured from the template and in our example is a 4" x 11" rectangle. (Be sure to cut this portion about 1" larger on each side to allow for sewing the seam!)



Designing the rounded extended segment skirt is a simple process that has been best described by **Jeremy Kemp** in his book ***Hovercraft: The Constructor's Guide***[1]. Jeremy has kindly provided his permission to reproduce the following section from his book. Note that the dimensions given in the example are from the *Challenger* hovercraft hull that is detailed throughout Jeremy's book.



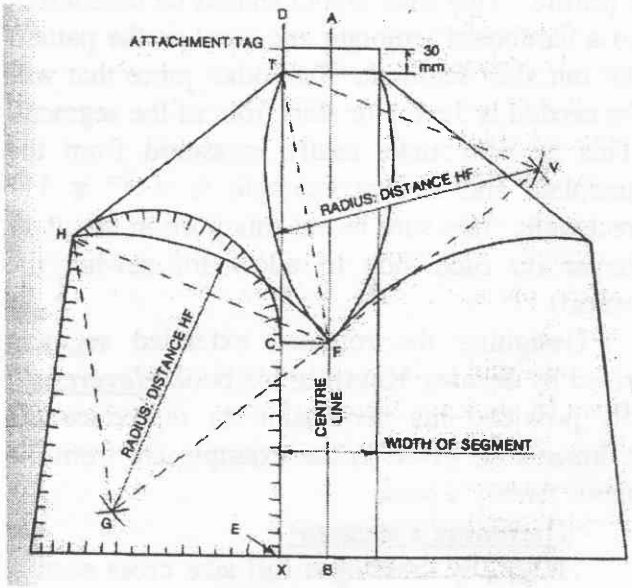
Designing a segment

Begin by drawing a full size cross section of the segment as show in figure 4. The important factors here are the planing surface angle and the hover height. The 45° angle is virtually standard and the point **Y** is usually 50mm – 100mm horizontally in from the outer edge of the craft. The following is a step by step method of achieving the cross section.

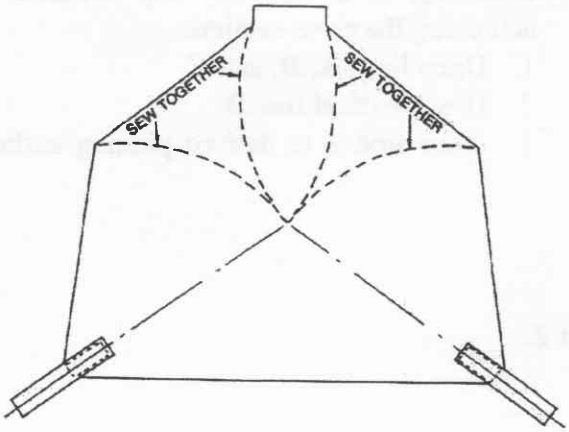
1. Draw lines **A**, **B**, and **C**.
2. Draw vertical line **D**.
3. Draw line **E** at desired planing surface angle (30°).
4. Draw vertical line **F** from point **X**.
5. Mark point **Y** (ground contact point).
6. Draw line **G** at 45° from point **Y** to point **Z**.
7. Draw line **H** at right angles to line **G** from point **Z**.
8. Draw line **J** from point **Z** to point **X**.
9. Bisect line **J** with line **K**.
10. Draw in radius to suit from point **T** (where line **K** crosses line **H**).
11. Draw line **L** from point **Z** to point **R** which is where the segment joins to the planing surface (usually 100mm from the hull base).
12. Mark point **S** on line **L**.
13. Draw in lines **M** and **N**.
14. Cut out paper template.

To design the pattern, figure 5, you will need a piece of paper approximately 90cm square.

1. Draw centre line **AB**.
2. Draw line **DX**, half width of segment from **AB** and parallel to it (usually the segment width is 2/3 of the hoverheight).

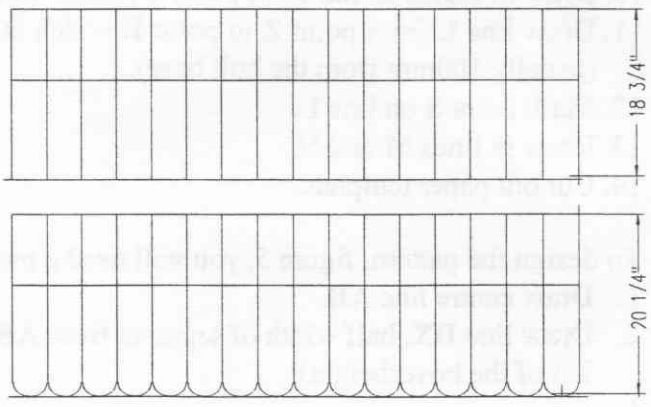


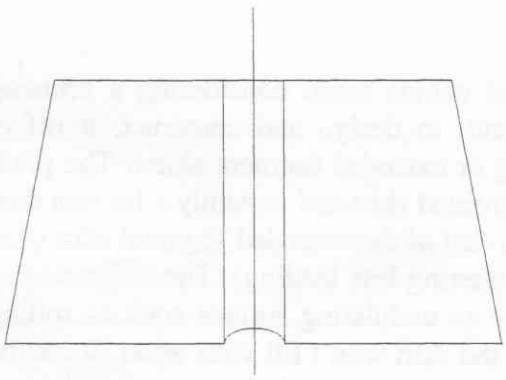
3. Lay the paper cross section template onto the pattern as shown.
4. Draw around the template and remove it.
5. Draw line at right angles to **AB** from point **C**, which is where the curve starts.
6. Draw line at right angles to **AB** from point **E**.
7. Draw line **FH**.
8. Construct the equilateral triangle **FHG**.
9. Draw radius from point **G** between **H** and **F**.
10. Mark point **T (FT = FH)**.
11. Draw line **FT**.
12. Construct equilateral triangle **FTV**.
13. Draw radius from point **V** between **T** and **F**.
14. Draw a line from point **T** to **AB** and right angles to it.
15. Draw line **HT**.
16. Repeat instructions 2 – 15 for the other half of the pattern.
17. Draw attachment tag.



To make the segment use the paper pattern to cut out a hardboard template which can be laid onto the skirt material to provide a quick method of marking out. Sew together the parts as indicated in figure 6. A loop should be stitched to each corner of the segment to enable it to be fixed to the lower attachment points on the planing surface of the hovercraft.

No matter which type of extended segment you use, when the hovercraft is fully up on it's cushion, the bottom of the skirt line will resemble the lower drawing in figure 7. At first glance, many will say that this is not a good skirt design as gaps are left allowing too much air to flow out from the skirt. While this is true, there are advantages. Primarily that of lower drag and increased strength of the segment due to it's triangular form. The principal disadvantages are increased lift airflow requirements, increased spray over water and, usually, uneven skirt wear. To create a better skirt seal, many operators trim the bottom of the segments to obtain the skirt line appearance





as seen in the upper part of figure 7. This results in a skirt template similar to that of figure 8, with that small oval cut out of the bottom of the segment. Since there will be more material at the bottom of the segment then skirt drag will increase.

Interestingly, I've also heard argument that by trimming the segment in this fashion, you also obtain a more consistant handling characteristic as the skirt wears and segments are replaced. This becomes more critical with hovercraft that are operated by several individuals.

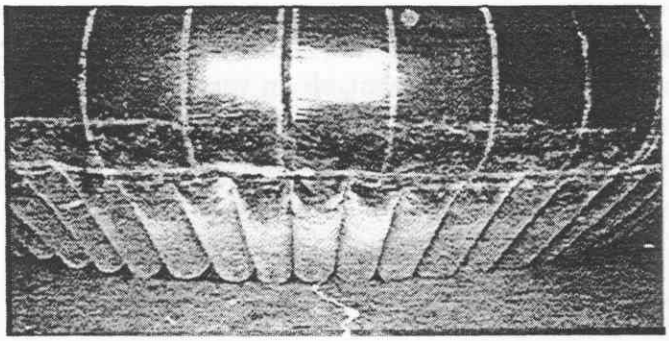
Skirt Material

The material most readily available and generally used by hovercraft builders is a Nylon fabric coated with either Polyurethane or Neoprene. This material is available in varying qualities and is usually measured by weight per square yard. The 4 - 6oz/sq.yd. Polyurethane coated Nylon is perfectly adequate for most small, light hovercraft. When sewing your segments be sure to use a rot proof thread.

1 *Hovercraft: The Constructor's Guide* by **Jeremy Kemp** is available for £12.50 from The Hoverclub of Great Britain, P.O. Box 354, Stafford, ST174SJ, ENGLAND.

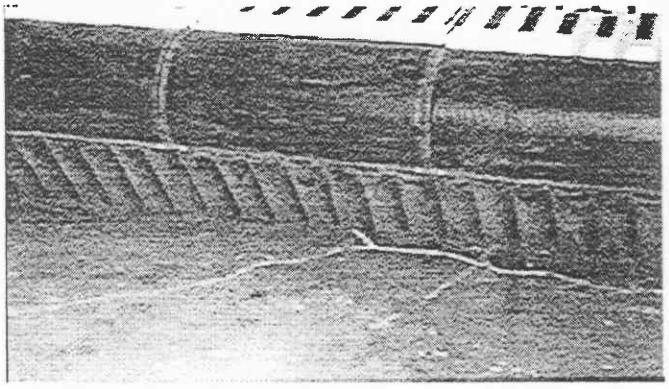
The Loop-Segment Skirt

In my opinion, the loop-segmented skirt is the best choice when considering a cruising hovercraft skirt design. While it is a little more difficult to design and construct, it offers passengers the most comfortable ride than either the bag or extended segment skirts. The pitch and roll stiffness is slightly less than that of the fully segmented skirt and certainly a lot less than the bag skirt, but the drag is the same or *slightly less* than that of the extended segment skirt (this is because of the lesser stiffness of the skirt system transferring less loading). The difference in ride smoothness is particularly felt when travelling over an undulating surface such as rolling waves. As with the fully segmented system, when afloat the skirt won't fill with water. It can be designed such that the segments are changed as, or more easily than extended segments and when well designed and constructed it is just a cool looking skirt!

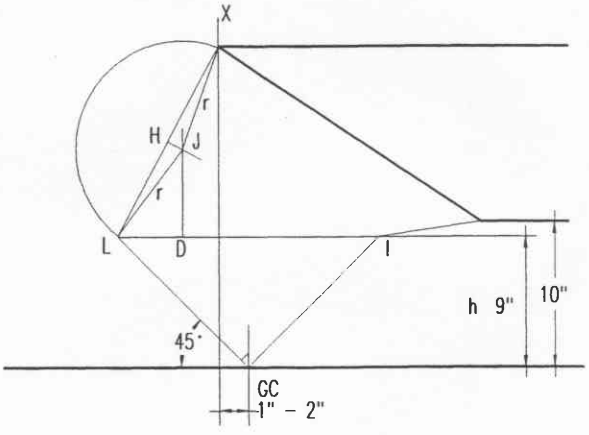


What is a loop-segment skirt? Take a look at the photo on the left. This is a head on photograph of the prototype Canair 504 during its first hovering trials. (The slight roll of the hovercraft to the right of the photograph was part of the testing procedure.) Although the prototype, you can still see the beautiful work that has gone into both the design and tailoring of this skirt system. The production vehicles are even better!

The photo below is a side view of the same prototype skirt system showing the same beautiful lines.

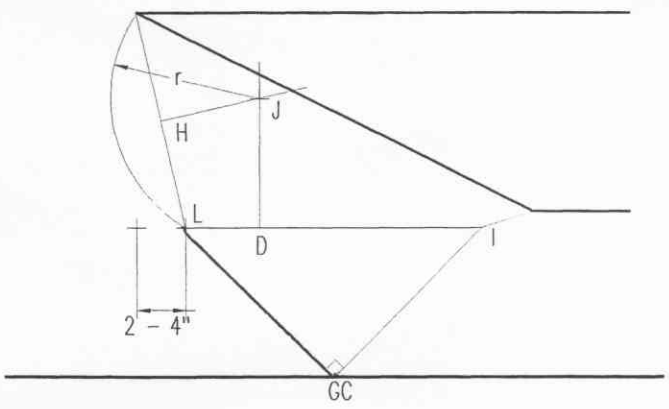


To design the loop-segment skirt we start with our now familiar side profile drawing of our hovercraft hull. The height of our segments is usually 75 – 100% of the cushion height (0.75 x h). The angle at the bottom of the segment at the Ground Contact point is *almost* always 90° and the finger should be at 45°. (I said *almost* always as I know of several individuals who have been experimenting successfully with variations on both the 90° and 45° figures.) The position of the Ground Contact point is, as with our other systems, 1 – 2" inboard or directly below the outer skirt fixing point and *never* outside of it.



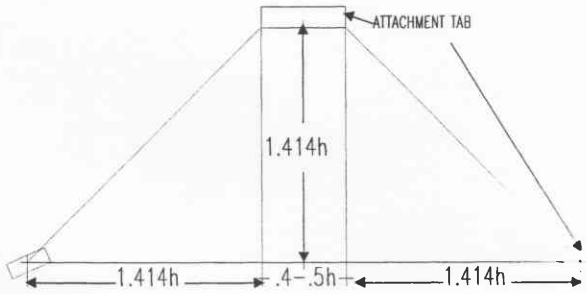
Once we've established the position of the segment we have to determine the shape of the loop itself. First we locate point **D** on line **LI** which will be ¼ of the length of **LI**. We then draw a line vertically from **D**. Draw in line **XL** and at

its middle mark point **H**. Now draw line **HJ** which bisects **XL** at a right angle. This determines point **J** which is the centre of the radius of the loop. The loop can now be drawn in using radius **r**.

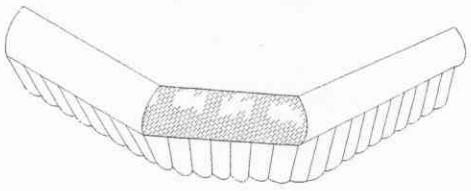


A slightly different procedure is applied to the bow of the hovercraft. We use the same size of segments but this time we set them back such that point **L** is 2 – 4" horizontally back from the outer skirt fixing point **X**.
Everything else is determined in the exact same fashion with **D** being ¼ of the length of **LI**.

Now that we know the shape of the skirt we must lay out the design of the skirt segments themselves. The magic number here is "1.414". I'm not sure who came up with this number but it has been repeated to me by people of several different nationalities and so if it works for others – it will work for us too!



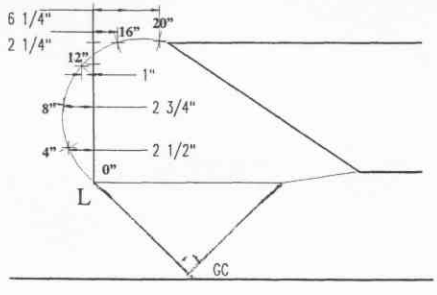
The centre height of the segment is taken from the design height of the segment **h**. In figure 1 this is shown as 9" so the value is 1.414 x 9" = 12.726". The chord or width of our segment is between 0.4 and 0.5 x h or 0.5 x 9" = 4.5". This is given as a rough figure as you may have to modify the chord to obtain an exact number of segments around the periphery of the hovercraft. Don't forget to draw in the attachment tab on the top of the segment and to add a loop on the ends of the segments to be able to attach the finger to the hull of the hovercraft.



Finally, we must tailor the loop shape. The best way to do this is the mathematical method as shown in the previous article on bag skirt tailoring. The only difference is that we determine the contour lines starting from point **L** as shown below, rather than the skirt fixing point as was done previously with the bag skirt.

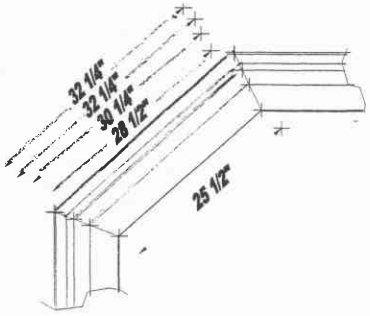
If we were to design the section of loop that is shaded in the drawing on the above right, we would use the following procedure:

We first determine the distances from **L** so that we can draw in our contour lines.



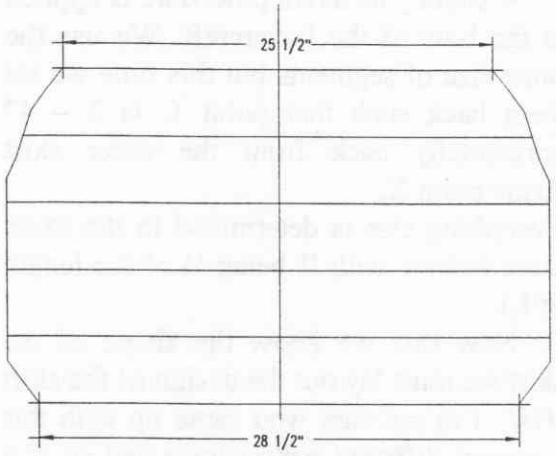
Next we transfer these contour lines to an overhead drawing of our hull corner. Once these contour lines are added, we measure the length of each contour from each seam.

These lengths are then used together with the original



distances to lay out the piece of loop material.

This final piece can be laid out on a piece of skirt material and cut directly. Make sure to allow and extra 1" around the border for stitching!



The Manometer

Referred to in an earlier article, the manometer can be used to measure air pressure through which we can calculate air velocities – it can even be used to determine the weight of your air cushion vehicle!

Basically, the manometer is comprised of a transparent tube filled with a liquid of known density (i.e. water). If a pressure is to be measured, one end of an open ended tube is placed at the point of measurement and the other end is connected to one end of the "U" tube while the other end of the "U" tube is left open to atmosphere. This general arrangement can be seen below in figure 1.

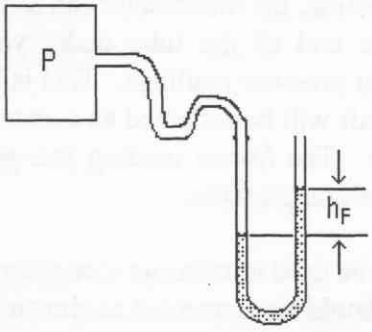


Figure 3 - A liquid filled manometer connected to a pressured container.

The pressure in the container, **P**, is directly related to the difference in height of the liquid in each side of the "U" tube by the following equation:

$$P = g \times \rho f \times hF$$

P – is the pressure in the container in lb/sq ft (which in this case is the pressure above atmospheric pressure)
g – is the acceleration due to gravity
ρf – is the density of the fluid in the manometer measured in slugs per cubic foot
hF – is the difference in height of the fluid in each side of the "U" tube measured in *feet*.

So, if we use water as the fluid in the container and measure the difference in inches this equation becomes simply:

$$P = 5.20 \times hf$$

where **P** is in lb/sq ft and **hf** is measured in inches.

A manometer can be thrown together quite simply by attaching a clear piece of tubing in a "U" shape onto a small piece of plywood. In a glass of water, add but a drop of your favourite food colouring and pour this into the tube to about mid level. At this point, the level of the two columns of water should be equal. Slide in the chart (from the end of this article) such that the zero level is even with the level of the two columns of water. When the pressure changes on one of the tubes, the level will rise (or fall) and can be read directly from the chart: ½" of motion equals 1" of water or you can read the pressure in lb/ft^2 directly from the left side of the chart.

So now we have a tool to measure pressure in pounds per square foot. How can we put it to use? By placing the end of the tube under the cushion of our hovercraft, we can read the cushion pressure directly. We can place it into the skirt bag to determine bag pressure. If we know the cushion area and then measure the cushion pressure we can determine the weight of our hovercraft using the following equation:

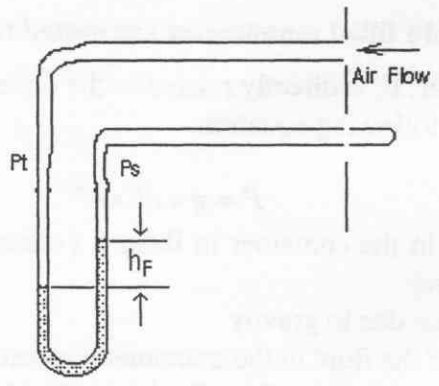
$$w = Ac \times Pc$$

where:

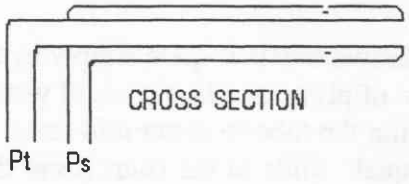
w = weight of the hovercraft in pounds
Ac = cushion area measured in square feet
Pc = cushion pressure as measured in lb/ft^2

As detailed in the next section, the manometer can also be used to deteremine air velocity. Therefore, when you shove the end of the tube under your hovercraft, point it in various directions and note the change in pressure readings. This is because the *velocity* of the air flow moving about under the hovercraft will be reflected as a change in *dynamic* pressure whereas we want to measure *static* pressure. The *lowest* reading you get from the manometer will be the reading you should use as the cushion pressure.

The manometer can also be used to measure low-speed air velocity (or even air speed). In this case the tube arrangement should be connected as shown below:



This is, in essence, a common pitot tube as found on most aircraft. In fact, the cross section of the pitot tube looks like this:



It is basically a tube within a tube. The Outer tube has small holes around it's periphery in order to measure the static pressure. The end of the inner tube is in direct alignment with the airflow to

be measured. The measured difference between **Pt** and **Ps** will give you the *dynamic pressure* of the airflow. At sea level we can use the following formula to determine the air velocity:

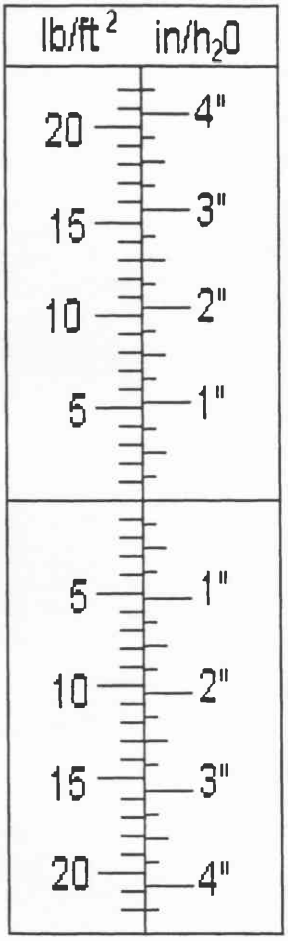
$$Pd = Pt - Pd \qquad V = 29\sqrt{Pd}$$

Where:

Pd – dynamic pressure in lb/ft^2
Pt – total pressure as measured from pitot tube in lb/ft^2
Ps – static pressure as measured from pitot tube in lb/ft^2
V – velocity of the air in feet per second

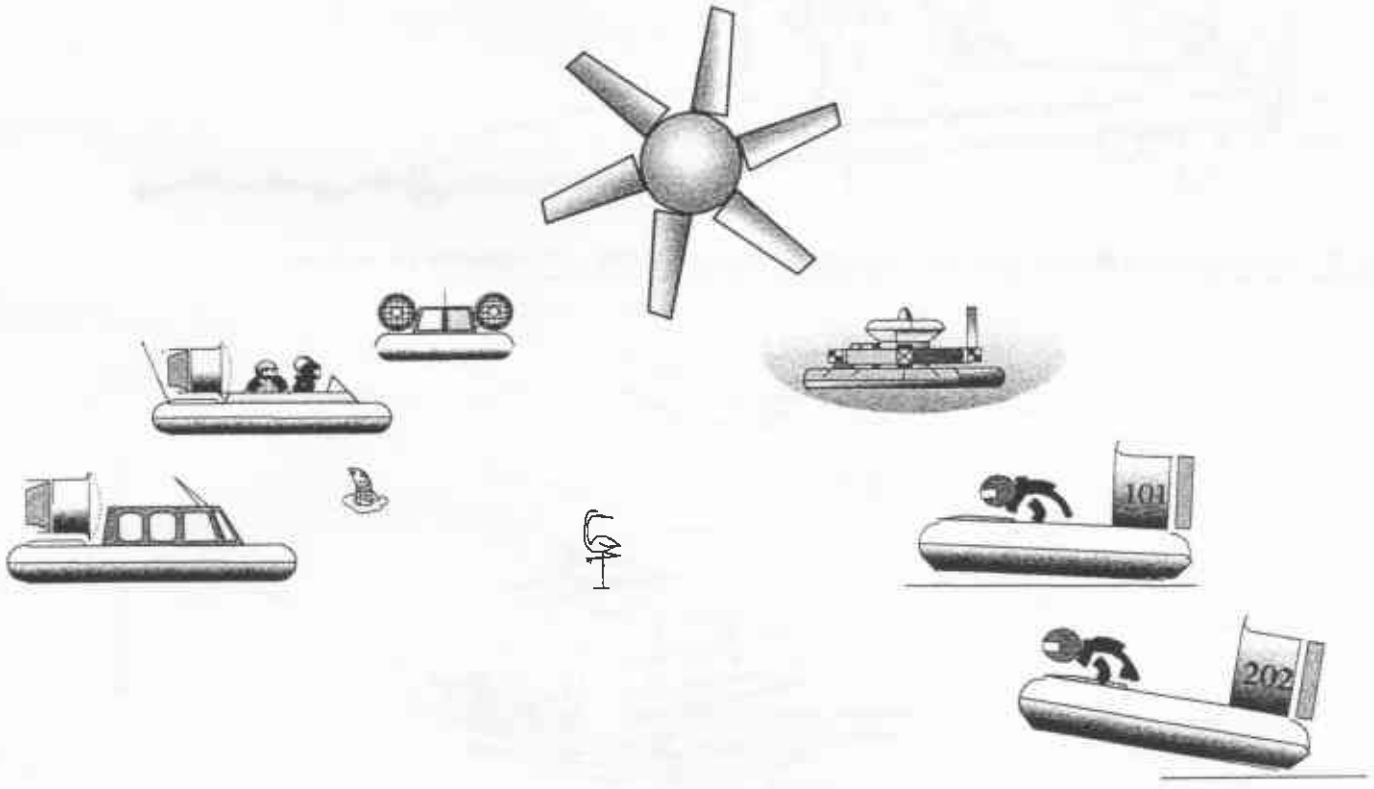
Of course, if this was used to measure our air speed we can convert **V** to *miles per hour* by using the following:

$$mph = V \times 0.6818$$



LES AÉROGLISSEURS LÉGERS
Amélioration de la poussée

par G.J.VERNIER



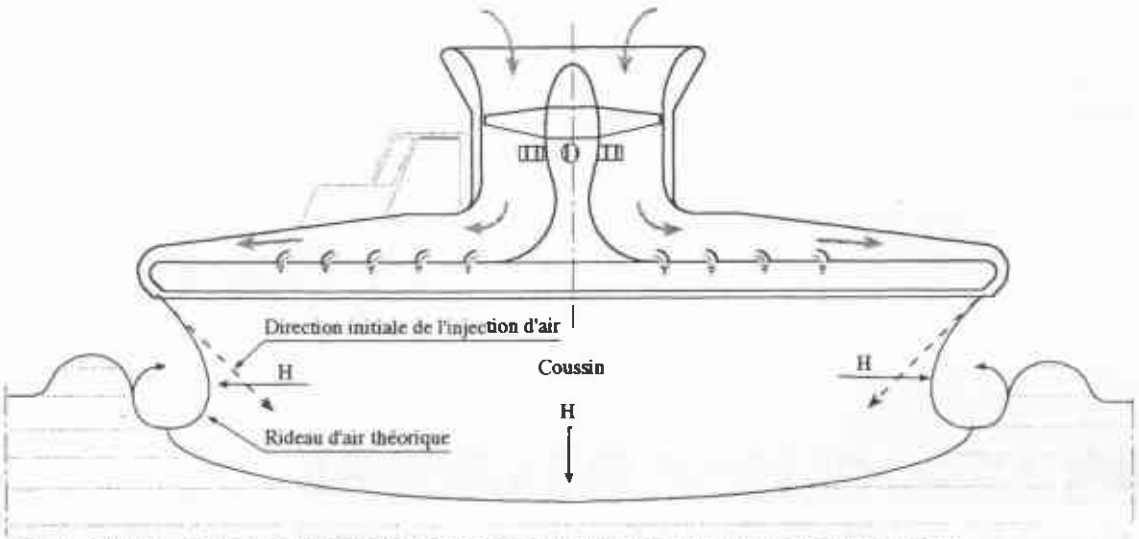
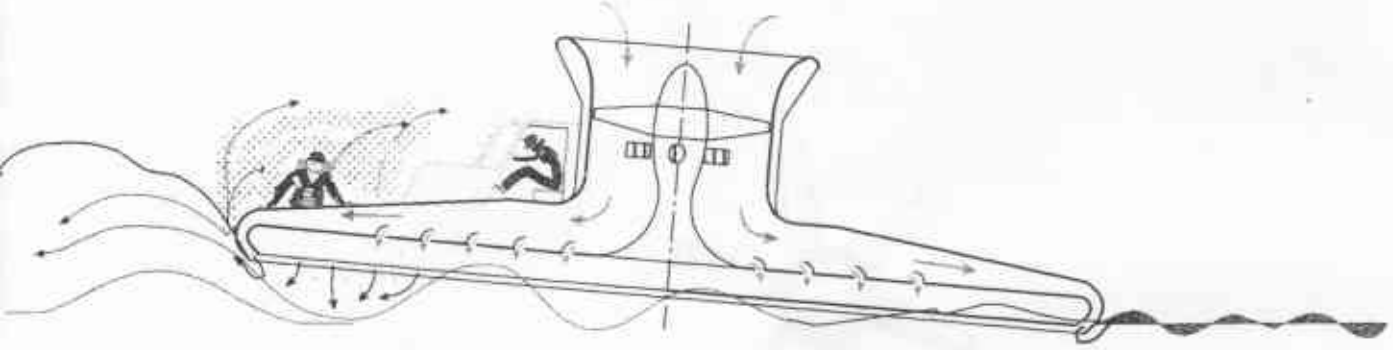


Fig. 1 - SR N1 . Tel que se l'imaginait Ch.Cockerell. Il le deviendra avec des jupes en tissu.



F ig. 2 - La traversée se la Manche, sans jupe. Ch.Cockerell se tient à l'avant, pour équilibrer l'Aéroglisseur .



G.J.VERNIER

Fig. 3 - Véhicule amphibie. Vous ne m'étonnez pas, je peux faire mieux et plus vite.

Je suis heureux de me trouver entre frères et cousins aéroglisseurs.

L'aéroglisseur léger, cet engin amphibie qui survole indifféremment la terre ou l'eau représente le véhicule le plus extraordinaire de notre siècle.

Sa découverte par Christopher Cockerell, ingénieur britannique, date de 1958. Il construisit d'abord une maquette puis un aéroglisseur léger : le SR N 1 (Fig.1). La motorisation de 500 hp (seulement) lui permettait tout juste le transport de deux personnes : le pilote et Ch.Cockerell, qui servait de ballast en se déplaçant, tout ruisselant d'eau, sur la plate-forme, dans un nuage de vapeur, car " ça crachait de partout". L'appareil fonctionnait très mal, oui ! Pourquoi ? (Fig.2)

Parce que Ch.C. n'avait pas pensé à la jupe (skirt) ou plutôt il s'imaginait que le jet d'air périphérique en tiendrait lieu. Dès qu'il a eu installé une toile imperméable autour de son bijou, le SR N1 est devenu tout joyeux. Sa vitesse, de 15km/h atteignit 60km/h. L'aéroglisseur léger bi-place était né. Beaucoup d'industriels, subjugués par les performances de cette petite chose, l'ont copiée, plus ou moins bien, pour réaliser des aéroglisseurs lourds (Heavy Crafts).

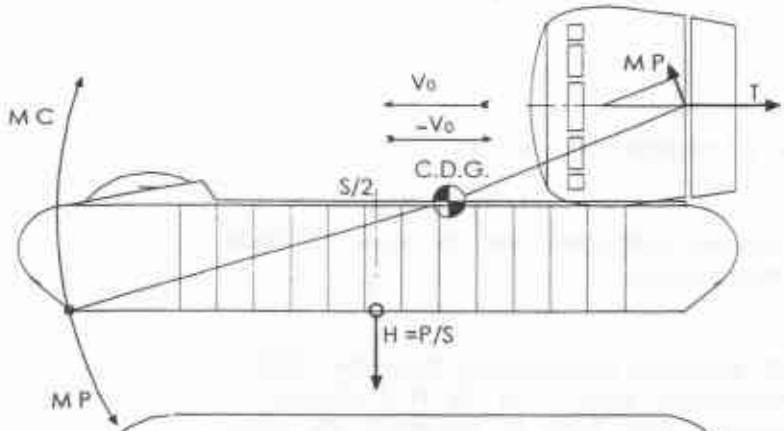
Nous, light Hovercrafts builders, drivers or fanatics, ne copions pas les gros aéroglisseurs. Nous continuons le travail de Ch.Cockerell sur des bi-places et monoplaces tout en diminuant la puissance de 500 hp à 50 hp pour transporter une ou deux personnes.

La compétition et la plaisance sont captivantes. Voir évoluer à quelques centimètres près, à 80-100/Km/h. des as du pilotage sur un circuit difficile (marécages, terre bosselée et eau, laisse les spectateurs pantois.

Pour chaque pilote, seul l'appareil devant lui est important sauf pour le premier qui se méfie du second qui le suit. Tout le monde plein gaz (throttle on). En général ça passe, parfois ça casse.

Un de nos clubs (Rhône Alpes Aéroglisseurs) se spécialise dans les raids de découverte, par exemple la remontée du Rhône, un de nos fleuves les plus turbulents. Cette année, le circuit utilise trois cours d'eau : Rhône, Saône et Loire. L'on peut y voir 25 Aéroglisseurs franchir des rapides, des bancs de sable, remonter des chutes d'eau (attention : pour pilotes confirmés seulement) et se décontracter à 80 km/h. lorsque l'eau est plate.

Souvent un conducteur fanatique de voiture tout terrain (4 wheels Drive,16V. Turbo-charged...) me dit: "vous ne m'étonnez pas avec vos machines. Je peux faire mieux et plus vite." (Fig.3) Je lui réponds: "d'accord, faisons un match, nous parcourons ce champ couvert d'herbe puis nous traversons le lac et le premier sur la berge en face a gagné". Il répond
" Je ne peux pas, vous trichez". Et moi " pour nous, cela ne présente aucune difficulté". Le malheureux, avec ses 200 hp à roulettes n'a rien compris et ne comprendra jamais.



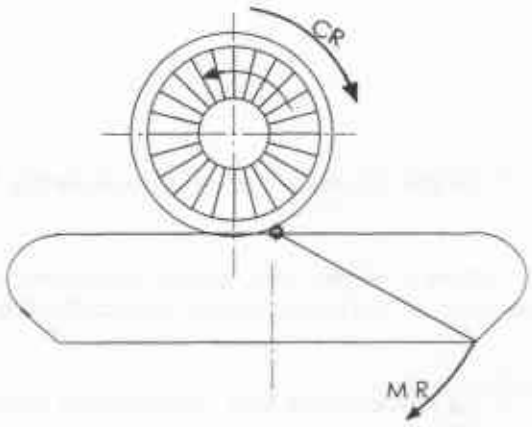
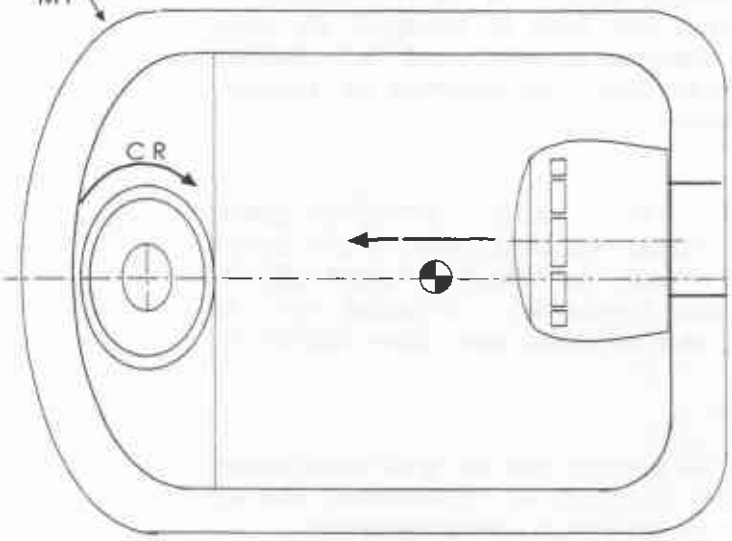


Fig.4 - Forces essentielles en présence.



C.P - Couple piqueur
C.C - Couple cabreur
C.R - Couple de renversement
C.D.G - Centre de Gravité
H. - Taux de Pression unitaire
M.P - Moment Piqueur
M.C- Moment Cabreur
M.R. - Moment de renversement
P/S - Poids total / Surface coussin
T. - Poussée de Propulsion
V0 - Vitesse de translation par rapport à l'air

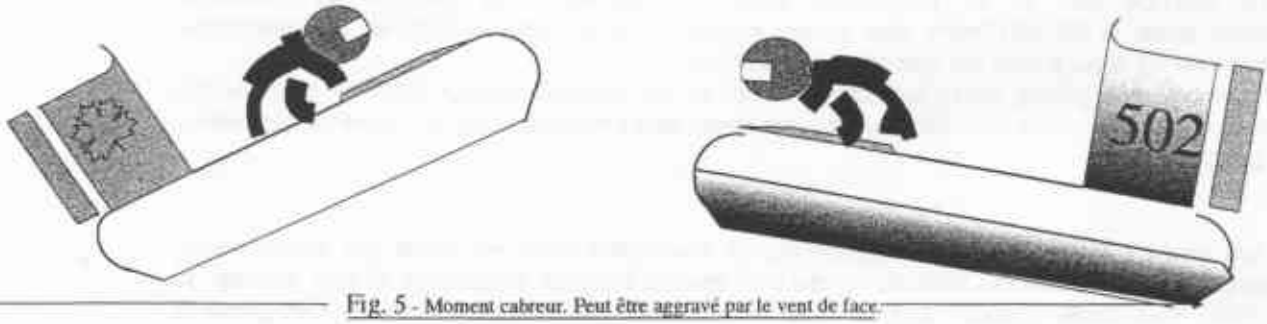


Fig. 5 - Moment cabreur. Peut être aggravé par le vent de face.



Fig. 6 - Moment piqueur. Aggravé par une jupe soufflée ou une rafale de vent arrière.
Bag skirt

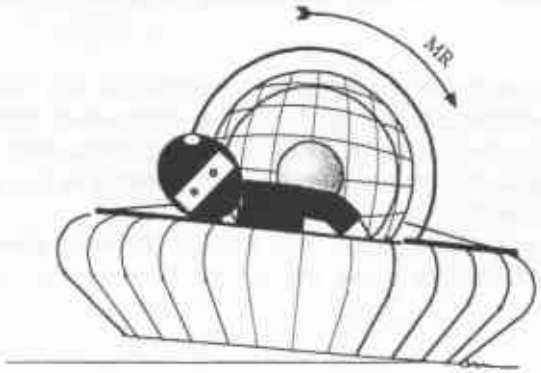


Fig. 8 - Moment de renversement. Risque d'arrachement de jupe & pertes de performances.

Système d'unités international (SI) & Symboles usuels

Unités de base: le **mètre** (m) unité de longueur
le **kilogramme** (kg) unité de masse du poids marqué 1 kg
la **seconde** (s) unité de temps
le **degré Kelvin** (°K) et le degré Celsius (°C) 0°K = -273°C,
288° K = 15°C

Unités secondaires: Le **Newton** (N) unité de force qui communique à une masse de 1kg une accélération de I m/ sec^2 (un mètre seconde par seconde)

L'**accélération** de la pesanteur (g = 9,81 m/s^2). Entre le poids (P) d'un corps de masse (m) et (g) nous avons la relation (P = m.g)

le **Joule** (J) unité de travail. Le Joule est le travail d'une force de un Newton sur un point qui se déplace de 1 mètre dans sa direction

le **Watt** (w) unité de puissance qui produit un travail de un joule en une seconde.

le **Pascal** (Pa) unité de pression de 1 Newton par m2
(hecto pascal : hPa - Kilo pascal : kPa).

Symboles usuels :-

v (m.sec)- vitesse (mètre seconde).
$\mathbf{v}_5$ (m/sec) - vitesse de l'air en sortie de tuyère
$\mathbf{V}_0$ (m.sec) - vitesse de déplacement de l'Aéroglisseur
$\mathbf{v}_{1...2...3}$ - vitesse au N° (1...2...3...)
N (t/m)- vitesse de rotation d'un axe ,d'une roue (tour par minute)
u (m/sec) - vitesse linéaire circulaire

T (kg) - Poussée en kg.f
T (N)- Poussée en Newton
g - Accélération pesanteur = 9,81 m/sec. sec (9,81 m.sec^2)
N (Newton) = 1kg/g Unité de Masse divisée par l'accélération de la pesanteur.
m (1kg = 9,81 N) Masse
S (m^2) = surface (S 1... S 5)
Q (m3/sec) Débit volumique d'air (mètre cube par seconde)
ρ = (1,225 kg /m 3 à 20° C) masse volumique d'air.
i (kg/sec) débit massique d'air = Q x ρ (kg par seconde)
m (kg ou N) masse d'air (= i)
η_p = rendement de propulsion
η_m = rendement de transmission
η_{mano} = rendement du ventilateur

π = 3,1416.. - Périmètre de la circonférence : $\pi . \Phi$ S cercle = πr^2

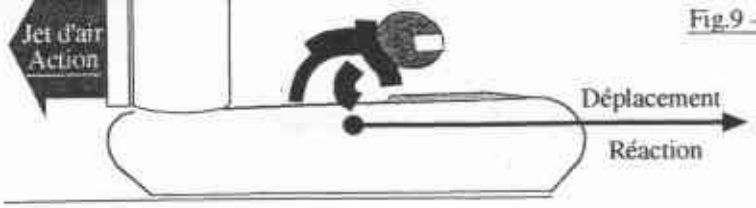


Fig.9 - L'Aéroglisseur projette un jet d'air vers l'arrière qui, par Réaction, le propulse vers l'avant.

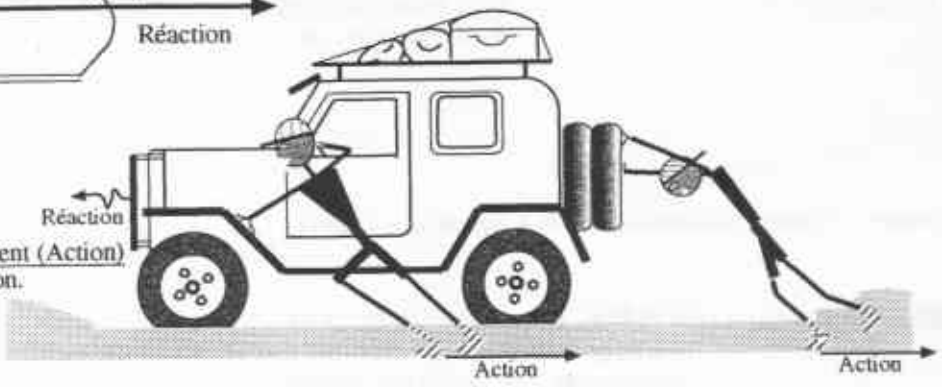


Fig.10 - Les pousseurs d'automobile poussent (Action) le véhicule qui avance par Réaction.

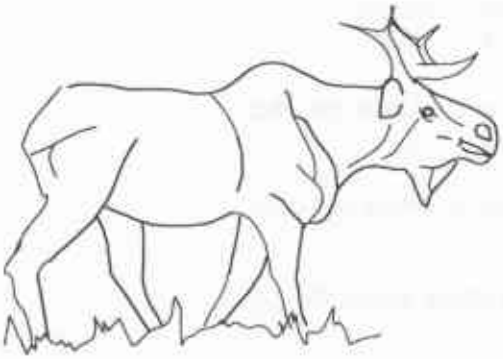




Fig.11 - La balle part (Action), n'importe où. Le chasseur reçoit une poussée (Réaction) de sens contraire (recul du fusil).

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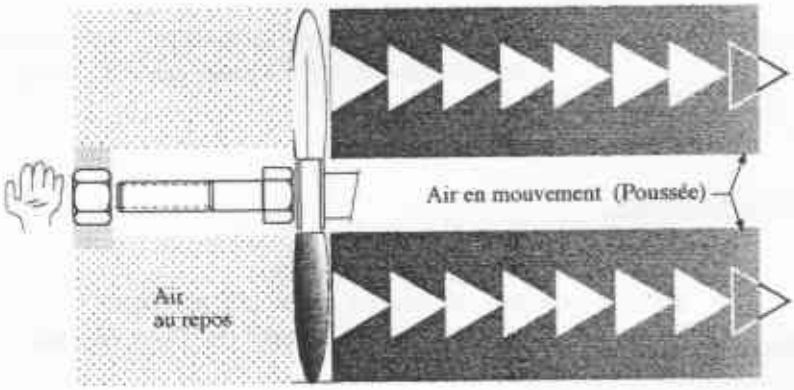


Fig.12 - l'Hélice ne se visse pas dans l'air.

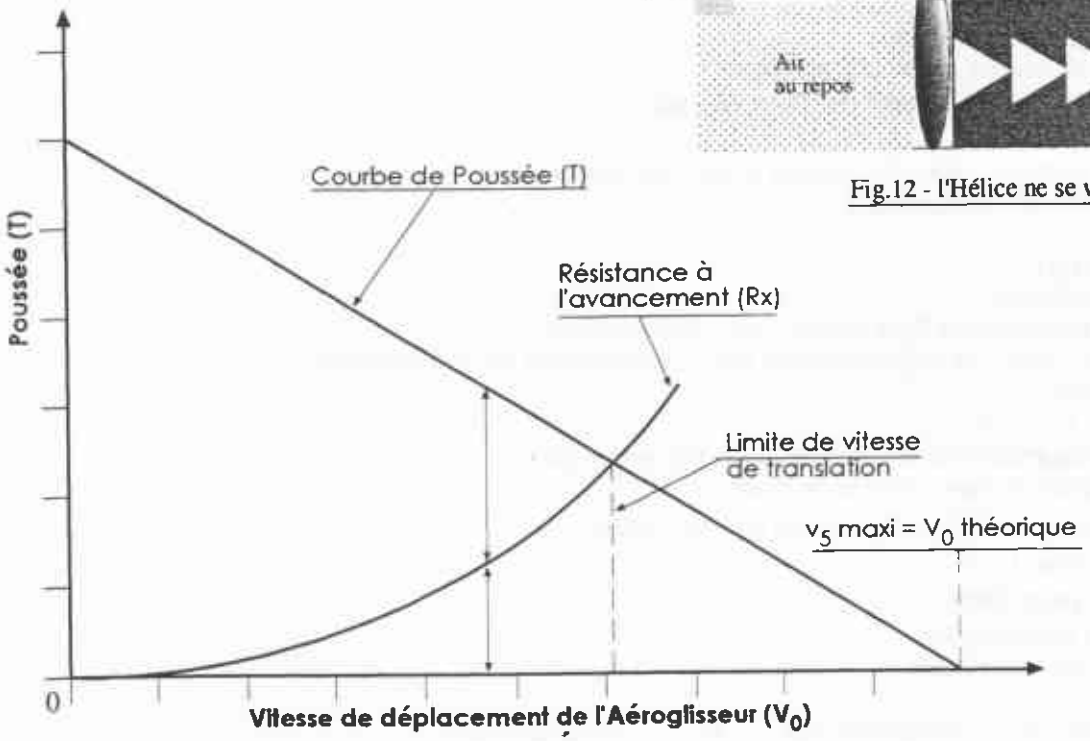


Fig.13 - Courbes de Poussée (T) & de Résistance à l'Avancement (Rx).

Dimensionnement de l'Aéroglisseur léger.

Le calcul n'est pas indispensable pour concevoir un aéroglisseur. On peut griffonner un croquis sur un coin de table ou copier un appareil aux bonnes performances. Parfois, c'est la réussite.
L'ennui arrive ensuite, on ne sait pas toujours pourquoi ça marche et l'on ne saura pas comment améliorer la chose. Mais la chance existe et l'on peut la rencontrer. Si elle n'est pas au rendez vous, beaucoup de temps et d'argent seront dépensés en vain.

Avant d'examiner les améliorations proposées, nous allons réviser quelques théories et calculer ensemble la propulsion d'un aéroglisseur léger.

Propulsion - Du latin *propulsus* = poussé en avant.
L'aéroglisseur projette un jet d'air vers l'arrière (action) qui, par réaction, propulse l'appareil vers l'avant. (Fig.9)

(Fig.10) Les pousseurs d'automobile (4 WD 32V. Zigomatics) poussent (action) le véhicule qui avance (réaction). *L'action est très fatigante.*

Un chasseur qui tire sur un moose (Fig.11) avec un fusil de 7 kgs, une balle de 300 grammes (action), reçoit sur son épaule une poussée (réaction) de 39 kg à la vitesse de 6 m/sec = 20 km/heure. Pendant que le chasseur vérifiait ses calculs, l'élan s'est sauvé.

Poussée (T) - C'est le produit $(\mathbf{m.v_5 = T_N.})$,
m = débit massique d'air par seconde ($\dot{m}$) à la sortie de tuyère c'est à dire au plan 5.
v_5 = vitesse du flux d'air à la sortie de la tuyère.

Exemple: débit massique = 20 kg/sec, v_5 = 44,44 m/sec T = 888,88 N = 91 kg.

ACTION ÉGALE RÉACTION
$$\mathbf{m.v = MV_0}$$

= Masse d'air projetée x par vitesse d'éjection = Masse du véhicule x vitesse du véhicule.

L'hélice ou le ventilateur ne se visse pas dans l'air. Le flux d'air éjecté par la tuyère ne s'appuie pas sur l'air extérieur. (Fig.12)

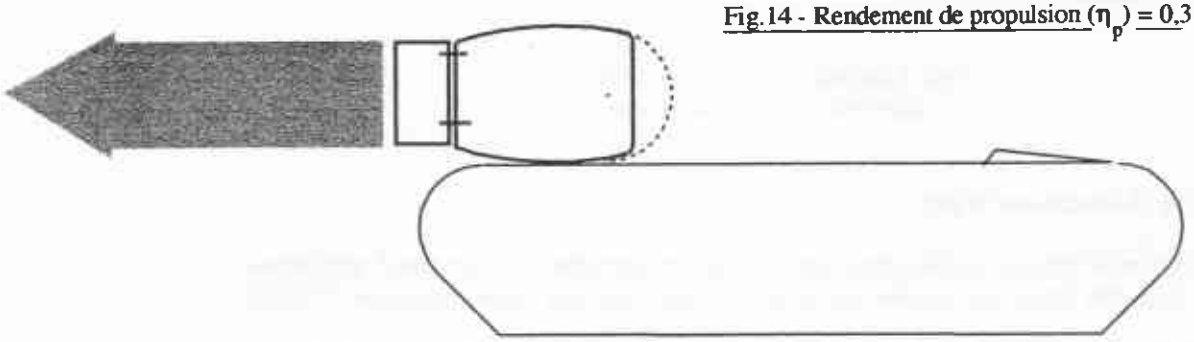
Le ventilateur met en mouvement une quantité d'air, précédemment au repos pour l'éjecter vers l'arrière. Cette action génère en retour, une réaction qui pousse l'appareil et le pilote vers l'avant (ou ailleurs si le pilote est distrait).

La poussée max correspond au point fixe $V_0 = 0$ (Fig.13) Elle décroît lorsque la vitesse V_0 augmente. La vitesse V_0 maxi du véhicule est atteinte lorsque la résistance totale à l'avancement (Rx) coupe la courbe de poussée. La poussée est nulle lorsque $V_0 = v_5$.

Poussée lors du déplacement du véhicule -
L'aéroglisseur étant immobile, le ventilateur aspire l'air extérieur, au repos (débit au point fixe)
En translation, le ventilateur se déplaçant vers l'air au repos doit traiter une quantité de fluide plus importante en fonction de la vitesse du véhicule (débit à V_0 positive)

T point fixe = $m.v_5$ **T translation = $m.(v_5 - V_0)$**

Fig.14 - Rendement de propulsion (η_p) = 0,3



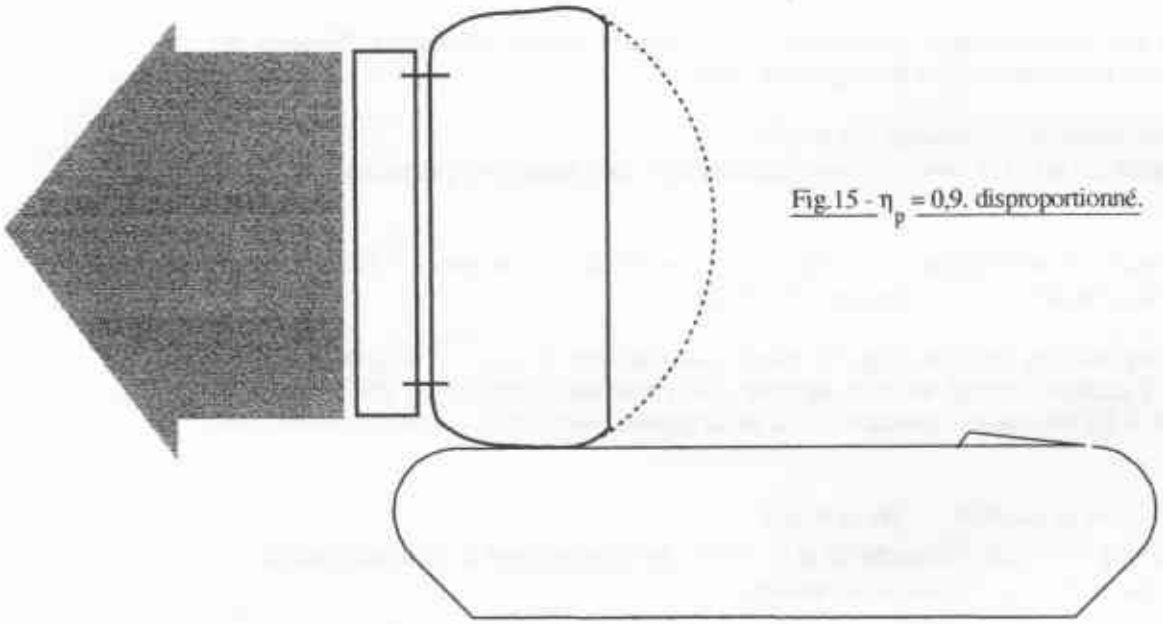


Fig.15 - η_p = 0,9. disproportionné.

à Puissance identique

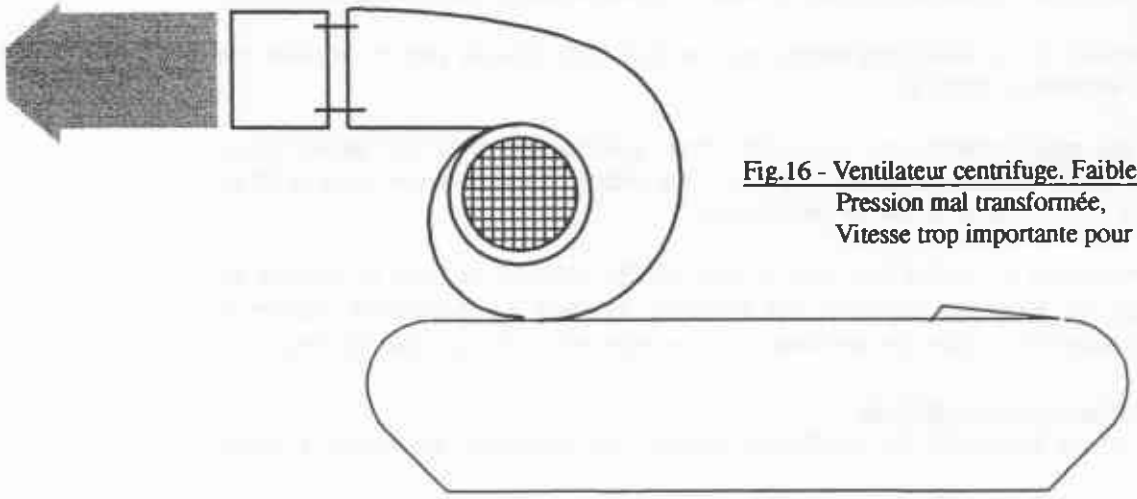


Fig.16 - Ventilateur centrifuge. Faible débit,
Pression mal transformée,
Vitesse trop importante pour nos applications.

Rendement de propulsion (η_p) -

C'est un élément très important car il conditionne la meilleure transformation de la puissance en poussée, pour une vitesse de translation donnée.

$$\eta_p = \frac{2V_0}{V_0 + v5}$$

V_0 = vitesse du véhicule
v_5 = vitesse de sortie de la veine d'air

Recherche de (η_p) pour un aéroglisseur donné -

Soit: V_0 = 16,66m/sec = 60km/h
v_5 = 50m/sec
η_p : 2 x 16,66 /16,66 + 50 = 0.4998 = 0,5

Si : $\dot{i}$ = 20 kg/sec
Q = 16,33 m^3/sec ($\dot{i}$ / ρ)
S_5 = 0,327 m^2 + Smoyeu = 0,39 m^2
Φ S_5 = 0,70 m

Puissance sur l'arbre ventilateur : $W = v_5^2 / 2 \times \dot{i}$ = 25000w

Poussée (T) = $m.v_5 = \dot{i}.v5$ = 1000N = 102 kg.f (Fig.14)

En reprenant les données de l'appareil ci dessus, cherchons ce que serait la poussée pour la même puissance (25 000 w) et pour un rendement propulsif (η_p = 0,9).

$v_5 = 2V_0 - \eta_p.V_0 / \eta_p$ = 2 x16,66 - (0,9 x 16.66 / 0.9 = 33,32 - 14,99 / 0,9 = 20,36 m/sec.

Recherche de $\dot{i} = W / v_5^2 / 2$ = 25000 / 207,26 = 120,61 Kg/sec.

Poussée (T) : $\dot{i} \times v_5$ = 2455,8 N = 250,25 kg.f
Débit volumique (Q) = $\dot{i} / \rho$ = 120,61 / 1,225 = 98,45 m^3/sec
Surface de passage (S_5) = Q / v_5 = 4, 83 m^2
Diamètre - - - - - Φ_5 = 1 x 2,48 m ou 2 x 1,75m. (Fig.15)

Ce calcul montre clairement qu'à puissance égale, plus le débit ($\dot{i}$) est important, plus (v_5) se rapproche de V_0, meilleur sera le rendement de propulsion., Selon toute logique, dans l'égalité : (m.v = x), si l'on diminue (v), (m) augmentera.

Dans le cas précédent, avec η_p = 0,9, nous arrivons à une incompatibilité de dimension. Nous ne pouvons pas prétendre à un η_p de 0,9 sur nos aéroglisseurs.
Cet exemple prouve aussi que beaucoup d'aéroglisseurs légers fonctionnent avec un rendement de propulsion inférieur à η_p= 0,50. ce qui est loin d'être déshonorant .

Diverses formes de η_p -

- Puissance utile: $\frac{V_0 (v_5 - V_0)}{1/2 (v_5^2 - V_0^2)} = \eta_p$ $\eta_p = \frac{2}{2 + T / \dot{i} \times V_0} = \frac{2V_0}{V_0 + v_5}$
  Puissance fournie:

Forme de **v5** fonction de η_p

$$v_5 = \frac{2V_0 - \eta_p V_0}{\eta_p}$$

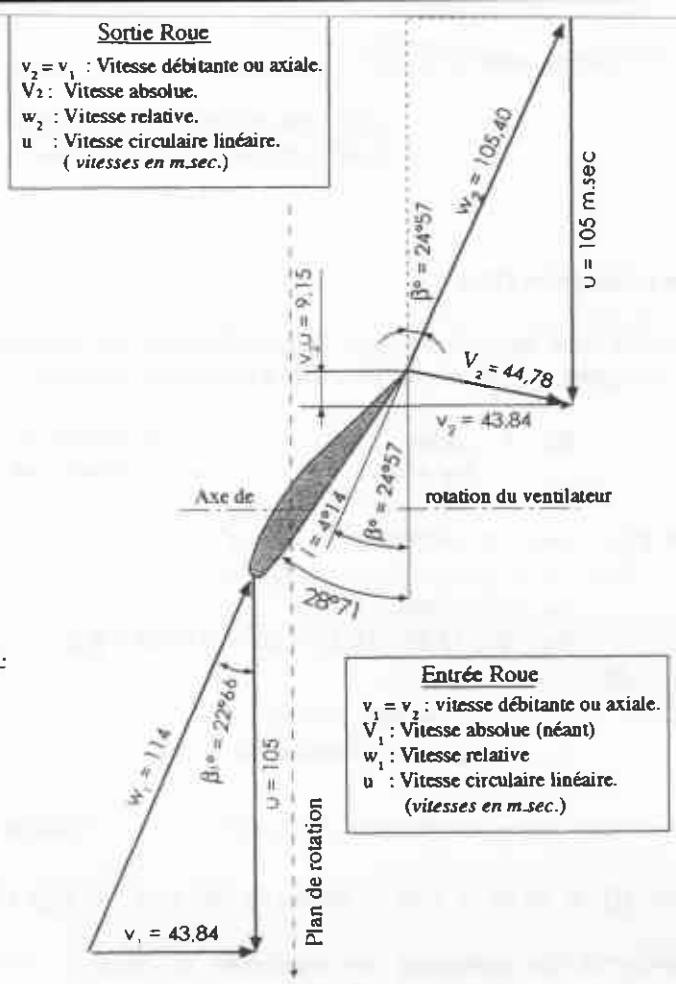
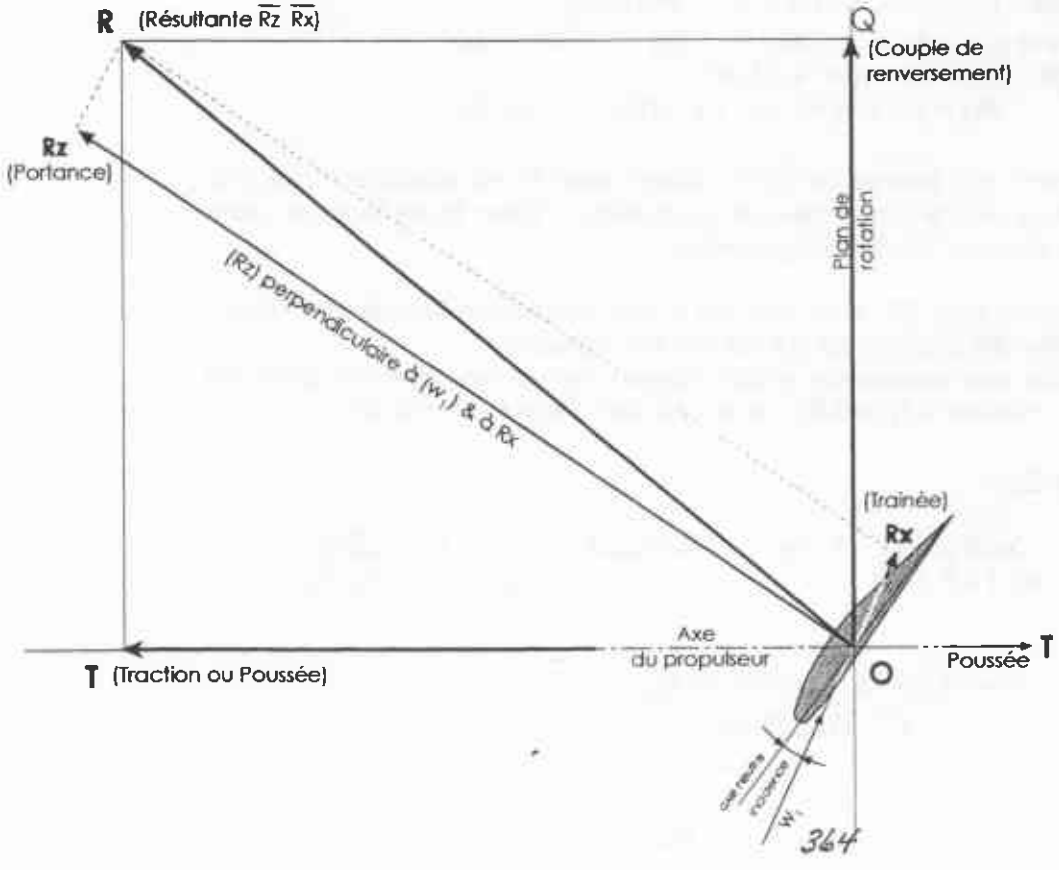


Fig.17 - Triangles des vitesses du fluide.
au Φ moyen - Point Fixe.

Fig. 18 - Projection de R (Rz + Rx) sur l'Axe du Propulseur (O-T)
& sur son plan de rotation (Q-o-u). i = 6°.



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Calcul d'un cycle

Nous disposons d'un moteur de 50 hp = 36,76 k w que nous voulons utiliser avec un rendement de propulsion (η_p = O,6) à 60 km/h (16, 66 m/sec)

Définition de la puissance : $W_w = \frac{v_5^2 \times i}{2}$

D'où l'on déduit $i = \frac{W}{v_5^2 / 2}$

Recherche de la vitesse (v_5) avec (η_p = O,6) et (V_0 = 60 km/h = 16,66 m/sec).

$v_5 = \frac{2V_O - \eta_p V_O}{\eta_p} = \frac{(2 \times 16,66) - (0,6 \times 16,66)}{0,6}$ = 38,87 m/sec

Puissance moteur : 36765 w
Rendement mécanique η_m :O,9
Rendement manométrique η_{mano} : O,7 x 0,9 (pales x Carénage)
Puissance utile : 36 765 x O,9 X 0,7 x 0,9 = 20 846 w

Débit massique : $i = \frac{W}{v_5^2 / 2} = \frac{20\,846}{38,87^2 / 2}$ = 27, 585 kg/sec

Débit volumique $Q = i / \rho$ = 27,58 / 1,225 = 22,53 m3/sec

Surface de passage S5 = $\frac{Q}{v_5} = \frac{22,53}{38,87}$ = 0,58 m^2

Diamètre moyeu: O,280 m
S moyeu = O, 0616 m^2
S_5 total = O,58 + 0,0616 = 0,6416 m^2

Diamètre extérieur = $\frac{\sqrt{0,6416}}{\pi} \times 2$ = 0,9035 m.

Poussée au point fixe $T = m.v_5 = i.v_5$ = 27,595 x 38,87 = 1 073 N = 109,33 kg.f
Poussée à 60km/H : T = m. ($v_5 - V_0$) = 585,29 N = 50,66 kg;f

Triangles des Vitesses (Fig.17)

Φ = 0,9035 m, d moyen = 0,5917 m, d = O,280 m, S = O,6411 m^2, l. pales O,3118 m.
Puissance sur arbre ventilateur : 36760 w x O,9 = 33084 w
Vitesse périph. (u) = 160 m/sec(max 170) - N = 3395 t/m - u pied de pales = 49,77 m/sec.

$v5 = v2 = v1 = \sqrt[3]{\frac{2W}{S\rho}} = \sqrt[3]{\frac{2 \times 33084}{0,6411 \times 1,225}}$ = 43,84 m/sec

$i = \frac{W}{v_5^2 / 2} = \frac{33084}{960,97}$ = 34,42 kg/sec

Entrée Roue : v_1 = 43,84 m/sec = vitesse débitante ou axiale au bord d'attaque des pales
W_1 au Φ moyen = $\sqrt{u^2 + v_1^2} = \sqrt{105^2 + 43,84^2}$ = 114 m/sec = vit. relative d'entrée.(v_1)
$B°_1$ = Arc tg. $B_1 = v_1 / u$ = 43,84 / 105 = 22°66 = angle d'attaque des pales.

Sortie roue : v2 = 43,84 m/sec = vitesse débitante au bord de fuite des pales.
$v_{2U} = \frac{W}{i \times u} = \frac{33084}{34,42 \times 105}$ = 9,15 - (v_{1U} = O) valeur et sens de la transformation.
$V_2 = \sqrt{v_{2U}^2 + v_2^2} = \sqrt{9,15^2 + 43,84^2}$ = 44,78 m/sec. - vitesse absolue.

$W_2 = \sqrt{v_2^2 + (u - v_{2U})^2} = \sqrt{43,84^2 + (105 - 9,15)^2}$ = 105,40 m/sec vitesse relative(2)

$B°_2$ = Arc sin $B_2 = v_2 / W_2$ = 43,84 / 105,40 = 24°57
$B°_1 - B°_2$ = 24°57 - 22,°66 = 1° 91 (taux de travail de la pale)

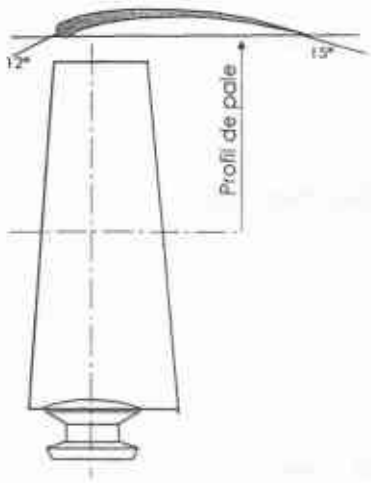


Fig.19 - Pale "Multiwing

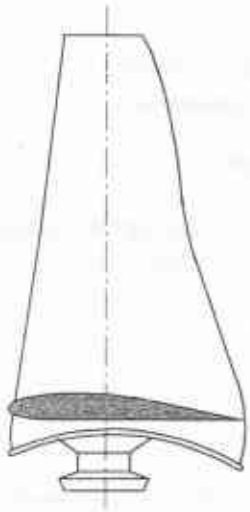


Fig.20 - Pale d'essai

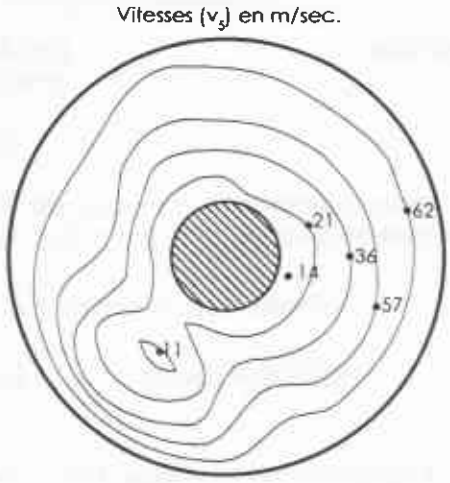


Fig.21 - Diagramme des vitesses sur S_5.

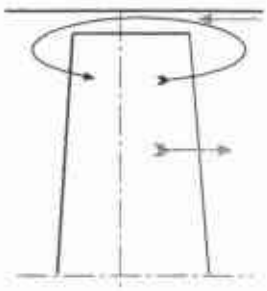


Fig.22 - Fuite marginale

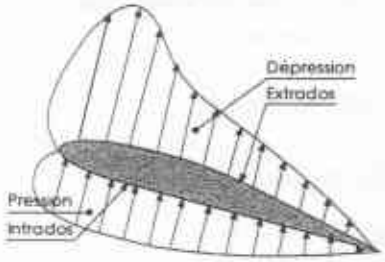


Fig.23 - La pression de l'intrados tend à combler la dépression de l'extrados

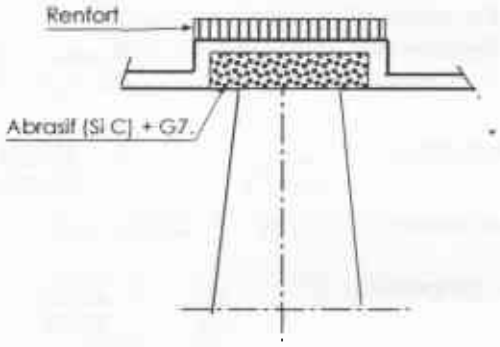


Fig.24 - Élimination du jeu périphérique par meule fixe.

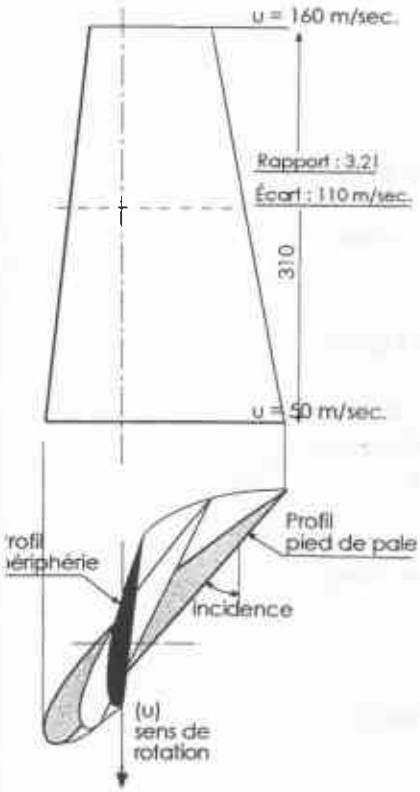


Fig.25 - Écart de vitesses circulaires & variation de l'incidence.



Fig.26 - Zone mal alimentée de pied de pale.

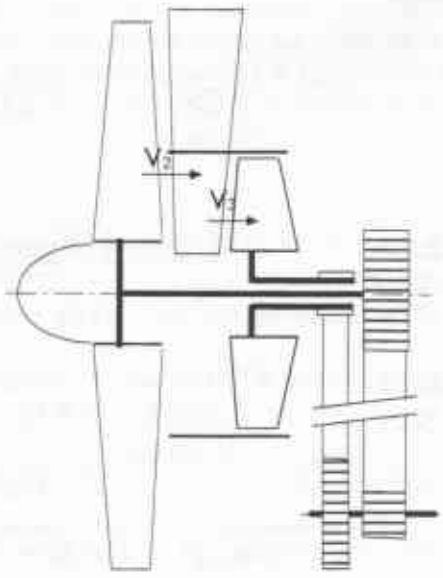


Fig.27 - Ventilateur auxiliaire pour alimentation de pied de pale.

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Défauts et propositions.

Les pales - Les pales que nous utilisons (multiwing) sont adaptées à des vitesses de rotation de l'ordre de 1500 tm. Leur profil concave-convexe l'indique. (Fig.19)
D'autre part, leur forme en plan n'est pas assez étoffée vers le pied de pale dont la vitesse linéaire circulaire est faible.
Exemple: pour une vitesse périphérique de 160 m/sec au Φ O,900, la vitesse en pied de pale sera au Φ 280 de 50 m/sec.

Nous avons essayé des pales de forme (Fig.20) qui procurent une meilleure alimentation en pied de pales sans que cela soit parfait.
Les pales que nous avons essayées étaient d'ailleurs en limite de sécurité. Un amateur, même éclairé, rencontre de grandes difficultés à réaliser une pale légère et résistante.
Lorsque l'on mesure les vitesses (v_5) sur le plan de sortie de tuyères et que l'on obtient une distribution de vitesse hétérogène comme sur (Fig.2) il est normal d'incriminer l'action des pales.

Jeu périphérique. Fuites marginales
Habituellement, les pales fonctionnent avec un jeu périphérique de 5 à 10 mm. Le ventilateur tourne à l'intérieur d'une paroi cylindrique (Fig.22) avec un jeu qui devrait être minimum pour limiter la création d'un anneau tourbillon entre la périphérie des pales et la paroi, engendré par la pression de l'intrados se vidant, par le jeu, dans la dépression de l'extrados. (Fig.23)

Une couche de grains d'abrasif (SiC) mélangés (1/2 gr 40, - 1/4 gr 60, - 1/4 gr400) liés et collés par le liquide (G7) de "Plastimo" sur la paroi de l'anneau joue le rôle de meule fixe avec pièce tournante (Fig.24). Les pales montées sur le moyeu d'un diamètre légèrement supérieur à la paroi circulaire (0,5mm) sont présentées sur leur axe et poussées en rotation au contact de l'abrasif. Arrêter l'opération lorsqu'elles tournent avec un léger frottement. Vous pouvez mettre en route.

Autre avantage : en cas de choc, avec déformation du carénage, les pales sont meulées au lieu de casser et de répandre les éclats dans les environs.

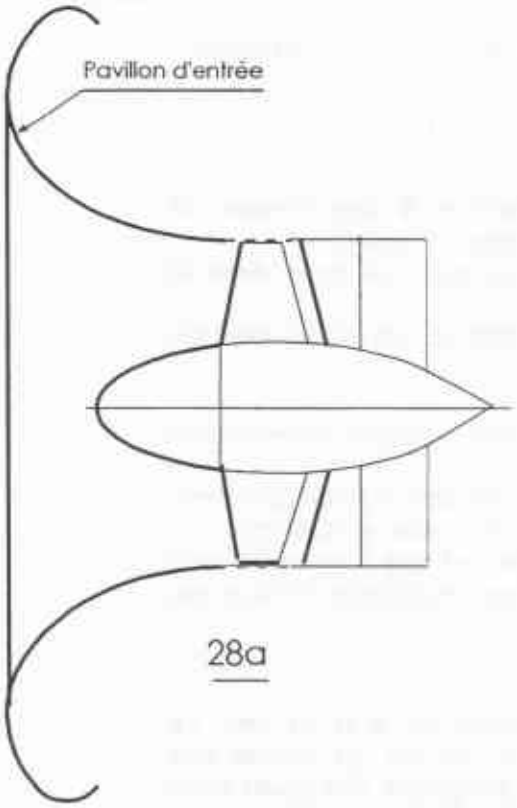
Pied de pales
Ecart de vitesse - La rotation d'une roue, physiquement idéale (mouvement continu, absence de vibration, faible résistance de palier) n'a qu'un défaut: les vitesses linéaires circulaires varient en fonction du rayon. Nous avons déjà vu qu'une roue de ventilateur de Φ 0,9/ Φ 0,28 tournant à 3400 t/m avait un rapport de vitesses de 1/3.

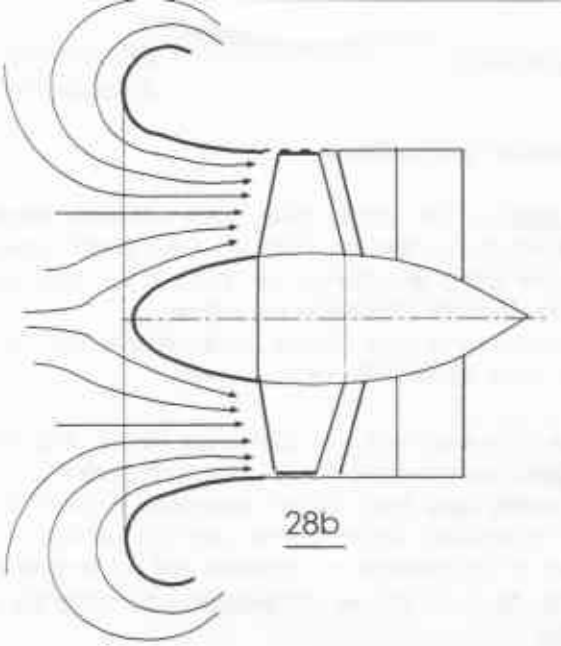
Dans ces conditions, malgré l'élargissement des pales et l'augmentation d'incidence de la périphérie vers le moyeu, l'homogénéisation de l'admission d'air reste aléatoire et le pied de pales demeure sous alimenté (Fig.25).

Centrifugation : La faible vitesse d'entrée ne peut vaincre la force centrifuge générée par la pale et la veine d'air dévie vers la périphérie laissant un vide relatif dans la zone proche du moyeu Ffig.26).

Deux remèdes à cette situation :
1 - Réduire la longueur des pales pour que les vitesses exter et inter se rapprochent tout en diminuant les possibilités de grand débit d'air.-

2 - Ajouter une deuxième roue en aval de la roue principale (Fig.27). Ce ventilateur auxiliaire tournant à 170 m/sec à la périphérie ajoute son action à celle du ventilateur principal pour augmenter la vitesse d'entrée d'air dans la zone faible du pied de pale.
Le ventilateur auxiliaire est encagé dans un tube de Φ inter 0,55. Un redresseur donne l'angle d'entrée d'air au bord d'attaque des pales et un deuxième, en aval, harmonise les vitesses des bords de fuite des pales principales et auxiliaires.





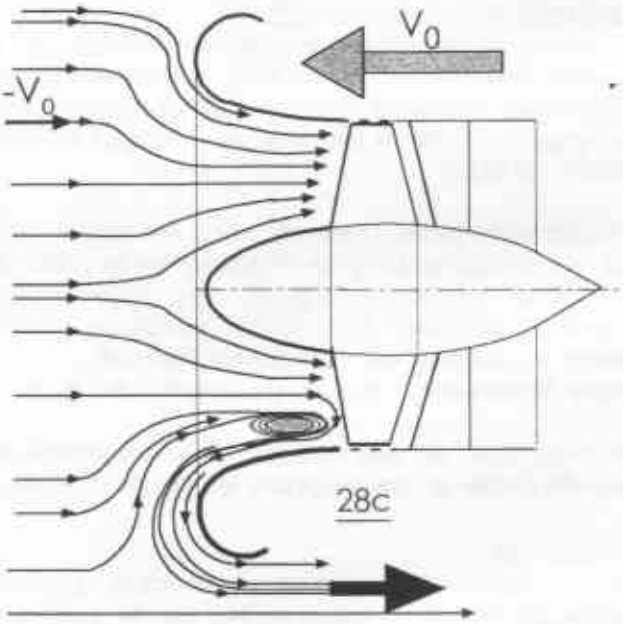


Fig.28 - Influence du Pavillon d'entrée sur la veine d'air.

28a - Pavillon pour mesure de poussée statique au Banc d'essai.
28b - Pavillon réduit. Aéroglisseur au point fixe et à basse vitesse.
28c - Vitesse de translation élevée, Saturation de la veine d'air.

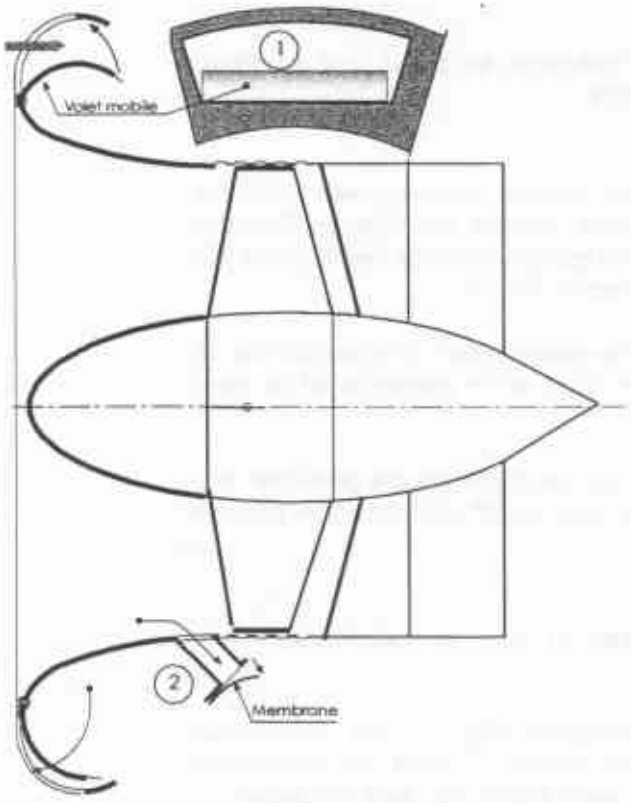


Fig.29 - Dispositifs simplistes anti-saturation de l'écoulement.
1 - par Volets mobiles, articulés sur le Pavillon.
2 - clapets, à membrane, de décharge.

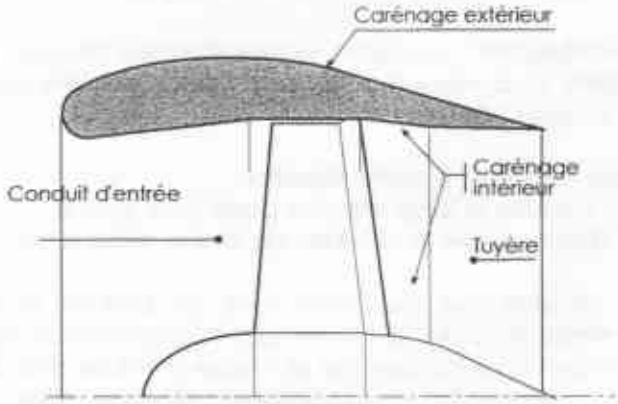


Fig.30- Carénage de la veine d'air - 1/2 vue en coupe.

Entrée d'air -

Deux formes sont habituellement utilisées pour définir l'entrée d'air (S_0).
1 - le pavillon d'enrée.

(Fig.28) - Pour point fixe et déplacement lent (0 à 50 km/h)

fig 19a - Pavillon égal à 3 diamètres de roue pour mesure de la poussée au point fixe, sur banc d'essai. La dépression créée par la roue de ventilateur doit être nulle aux limites extérieures du pavillon.

(fig.28b) - Pavillon réduit convenant aux basses vitesses.
A noter que la dépression (par effet Coanda) agit encore vigoureusement en arrière de l'entrée d'air. Visualisation par brins de laine et mesures par tube de Pitot et Badin.

(Fig 28c) - Tout étant clair au point fixe, lorsque la vitesse de translation augmente, donc la vitesse d'entrée d'air, le ventilateur n'absorbe plus le débit total et sature
Un tourbillon - bouchon se forme, aggravant l'écoulement et l'air excédentaire reflue vers l'extérieur.

2 - Le carénage de section fuselée -

L'entrée d'air (Fig.30) de section rayonnée suivie d'un divergent (pente 3°) convient pour les vitesses supérieures à 50 km/h et doit être adaptée à la vitesse d'utilisation maxi.

Si l'on adopte le pavillon d'entrée, l'aéroglisseur aura de puissants démarrages mais, rapidement, il perdra de l'énergie allant à la limite jusqu'au décrochement du ventilateur (pales masquées par le bouchon et tournant à vide).

Un délestage d'air (Fig.29-2) par des tubes à clapet peut éviter partiellement la saturation mais la résistance aérodynamique du pavillon demeurera.
Des volets mobiles (Fig.29-1), articulés dans des fenêtres découpées dans le pavillon, s'ouvrent ou se ferment suivant la dépression interne ou la pression du déplacement.

Si l'on choisit l'entrée d'air carénée, l'appareil manque de débit d'air au point fixe et à vitesse lente. Son accélération sera molle jusqu'à une vitesse suffisante qui compense son débit d'air. Alors il accélérera franchement et sa vitesse max. sera bien supérieure à celle d'un aéroglisseur muni d'un pavillon d'entrée.

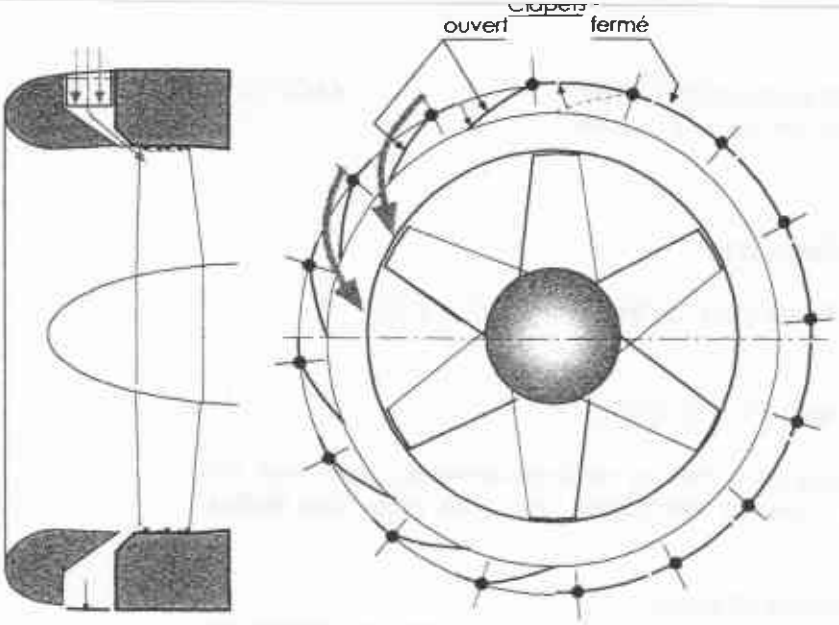


Fig.31 - Ouïes d'appoint d'air pour Point fixe et basses vitesses.

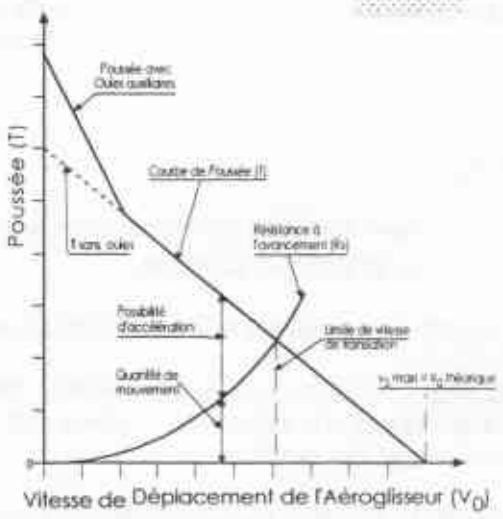


Fig.32 - Courbes de Poussée (T) & de Résistance à l'Avancement (Rx).

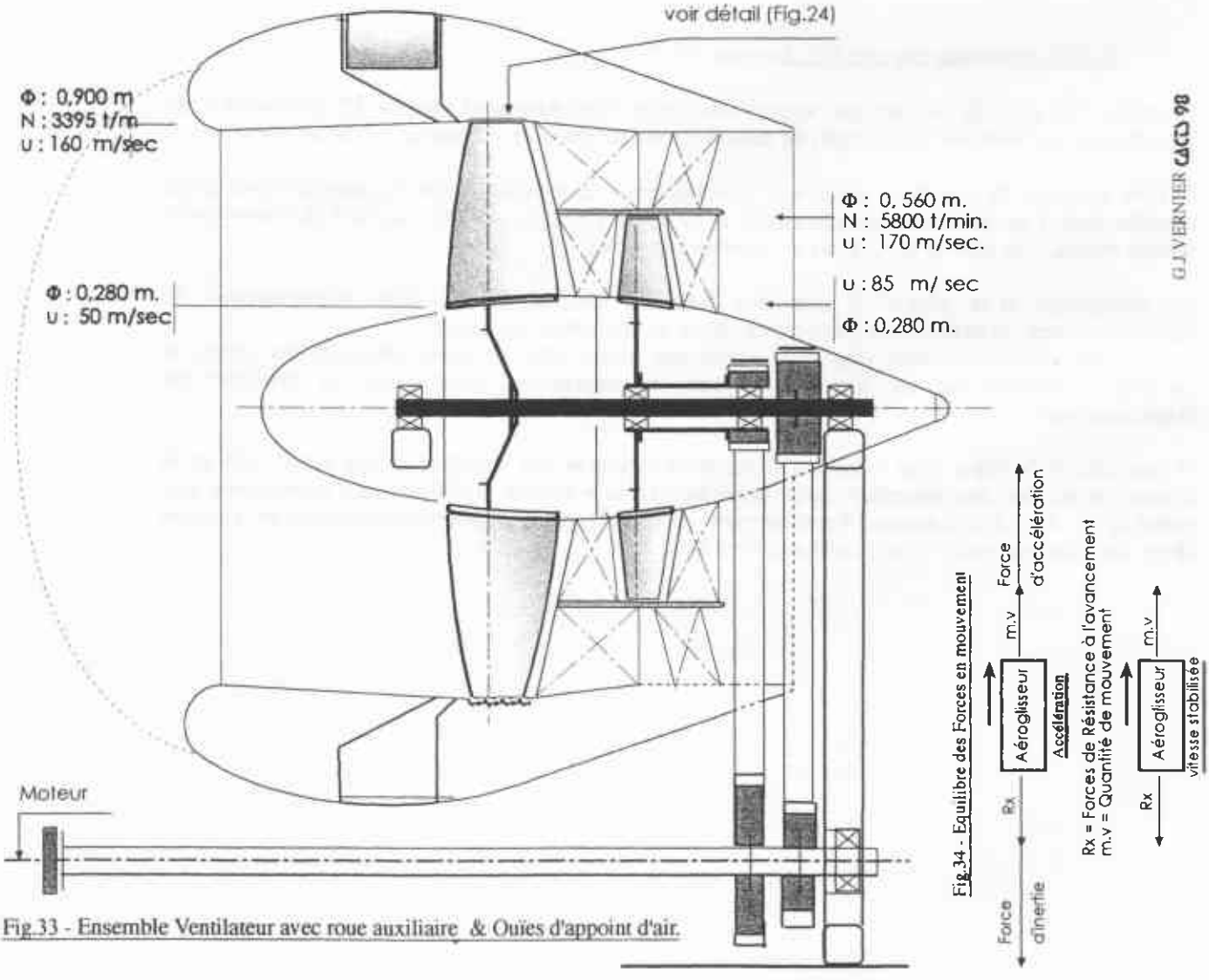


Fig.33 - Ensemble Ventilateur avec roue auxiliaire & Ouïes d'appoint d'air.

Fig.34 - Equilibre des Forces en mouvement

Ouïes auxiliaires d'appoint -

Nous devons satisfaire aux deux exigences :- Accélérations à basses vitesses,
- Accélérations à hautes vitesses,

Si nous utilisons une entrée d'air fuselée, propice à la vélocité de l'aéroglisseur, nous devons alimenter correctement le ventilateur, au point fixe et aux basses vitesses.

Des ouïes, à clapet mobile (Fig.31), découpées à la périphérie du carénage; communiquent avec l'intérieur par des canaux convergents débouchant en S_1 devant les pales du ventilateur.

Lorsque la dépression règne devant la roue, les clapets pivotent et dégagent les ouïes. L'air aspiré pénètre et s'ajoute au débit venant de l'entrée principale.
Lorsque la pression devient positive dans la chambre précédant la roue, les clapets se ferment et l'alimentation a lieu exclusivement par l'entrée frontale (S_0).

Le fonctionnement automatique, théoriquement parfait, vibre sous certaines configurations et nécessite une commande manuelle ou barométrique des clapets.

L'air, considéré comme immobile à l'extérieur du carénage, doit acquérir, pendant son passage dans le canal convergent, en dépression, la vitesse débitante (v_1) en débouchant devant les pales.

La courbe de poussée évolue et montre, par son inflexion (Fig.32) l'appoint de débit, donc de poussée, dû aux ouïes auxiliaires.
On y trouve en plus les éléments de mécanique classique : quantité de mouvement (m.v) et accélérations possibles, ainsi que la courbe des forces (Rx) de résistance à l'avancement. Ces éléments sont visualisés (Fig.34).
La (Fig.33) montre une vue schématique de l'ensemble ventilateur (voir Fig.27) avec les ouïes d'appoint d'air et le ventilateur auxiliaire d'aide à la circulation d'air au pdp

Voici résumées quelques réflexions personnelles sur la conception et le fonctionnement de la propulsion des aéroglisseurs légers dans leur technique actuelle.
Je suis conscient que les modifications que je viens de proposer, du moins certaines, représentent un gros travail de réalisation. Bien entendu nous pouvons garder nos mécaniques actuelles. On s'amuse bien avec.
Cependant, il est de notre devoir de relativiser et de juger simplement et sans états d'âme l'aéroglisseur parmi d'autres véhicules courants, l'automobile, par exemple. Avec 50 hp, elle atteint facilement une vitesse de 130 -140 km/h avec de bonnes accélérations, un rendement global acceptable et un certain confort. Plus nos performances, notre fiabilité et notre efficacité se rapprocheront de celles de l'automobile, plus grand sera notre crédit auprès du grand public qui attend impatiemment ce futur appareil pour faciliter ou agrémenter ses déplacements.

Nous sommes sortis des pannes et des réparations constantes, il faut maintenant aborder un nouveau challenge: la recherche des rendements.

Le premier avion à moteur (Clément ADER) vola en 1890 (50 mètres). Le premier avion à moteur traversa la Manche (Louis Blériot) en 1909, 20 ans plus tard.
Les avions vraiment fiables volèrent en 1940 (50 ans après). Le premier aéroglisseur évolua en 1958, il y a 40 ans. Il nous reste 10 ans pour en faire un véhicule reconnu, utilitaire, performant et rationnel.

Je vous remercie pour votre attention.