



THE DESIGN, CONSTRUCTION, AND OPERATION OF

LIGHT AIR CUSHION VEHICLES

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This handbook is written on a very practical level, and shows how to design an ACV which will work. A good many formulae are used, but they are reduced to the simplest possible, and won't frighten anybody.

However, if you want to know WHY, there is a list of reports at the end (page 49). These show how the formulae are derived, explain the basic theory in a lot more detail, and make the whole affair much more interesting to anybody who likes to understand the background of what they are doing, and perhaps contribute a little effort and push the science a bit further into the unknown.

1. AN ACV IS NOT A MAGIC CARPET

There are a lot of things an ACV can do, and a lot of things it cannot do. Let's start by sorting them out.

A light ACV is like any other vehicle, it has definite capabilities, and definite limitations. It can move over smooth land, soft land, water, thin or thick ice, and some snow.

But it cannot go over very rough land, long grass and other vegetation, loose pebbles, or up and down steep slopes.

Moving slowly, it can be steered quite accurately by a practised pilot. Moving fast, it needs a lot of room. But then, a car won't turn in a 15 foot radius at 30 mph, either!

It can go where no other vehicles can. But if it breaks down there, -- you are in big trouble. How can you get rescued? So it had better be reliable, and you had better be cautious and prepared. Driving it is not like driving a boat, or a car, or anything else. It is a breed on its own, and needs a skill that has to be learned.

So, if you have suitable terrain to drive it on, and still feel interested after all that, read on.

2. WHAT IS AN ACV?

It is just what its name says -- a vehicle which rides on a cushion of air. It is large for its carrying capacity, so that its "footprint" is large and very light, and air is pumped under it by a fan driven by a small gas engine. The "air cushion" is retained under it by a rubberized fabric curtain all round it, called the "skirt". There are various kinds of skirts, and their design is very subtle, and based on a vast amount of experiment and development. Another fan (or sometimes the same one) drives the machine along, just as does the propeller of an aeroplane. The design of these propellers is an expert's job, too. They must be efficient, strong, and as quiet as possible, none of which is easy.

The whole affair is mounted on a light but strong hull, on which the pilot sits, and which must have enough built-in buoyancy to float if the engine quits.

3. HOW DO YOU GET INTO THE GAME?

It is better to build a simple basic machine first, have fun and learn on it, and then go on to a more advanced Mk 2, than to try to start with an advanced one and get frustrated.

Read this book first. Then write down in detail just what you want -- size, power, ground over which it has to operate, cost you can afford, etc., and think it over.

Kits of parts can be got in the U.S.A. and in England, but not yet in Canada (November 1981). Detailed drawings and instructions can also be got in the same way, to build reliable, simple, well-proved designs.

Or you can work carefully through this book and design and build your own. But whichever way you go, get an expert to check your designs before you buy any materials. He may save you a lot of frustration and expense by sharing a little of his experience with you. And get him to check the craft before testing it. This could save your craft and your neck!

4. BASIC DESIGN

Simple.)
Light .) are beautiful.
Quiet .)
Safe .)

Complicated goes wrong too often.
Heavy is safe, because it won't go anywhere.
Noisy will get you (and the rest of us) banned from using ACVs.

First, a few simple sums are in order, to get the possibilities and outlines settled.

1. What is the load? This means YOU, plus a motorcycle helmet, a life jacket, and a few pounds for luck -- say 200 lbs. If you want a two-seater, add 200 lbs for the passenger. Don't think of more than two people at this stage.
2. For a craft of this kind, experience has shown that the cushion pressure (air pressure under the craft, supporting it) should be not more than 2" of water gauge -- about 10 pounds/ft². As a

very rough first guess the craft might weigh 300 lbs, (for a single seat type) so the total weight would be $300 + 200 = 500$ lbs. Since $\text{cushion pressure} = \frac{\text{total weight}}{\text{footprint area}}$, $\therefore 10 \text{ pounds/ft}^2 = \frac{500 \text{ lbs}}{\text{area ft}^2} \therefore \text{area} = 50 \text{ ft}^2$.

3. The width of the craft should be between half and $\frac{2}{3}$ of the length, so we come up with a planform of about 9 ft x 5- $\frac{1}{2}$ ft. The hard-hull structure will be a little bigger than this, so a guess 10 ft x 6 ft would give a small margin, as a first guess.
4. The obstacle clearance of the craft will be about 7% of its length, in this case about 0.7 ft (8").
5. The static thrust of the propulsion system should be about 15 lbs/per 100 lbs of craft total weight (including crew) so the present 500 lb craft will need 75 or 80 lbs of thrust. The thrust fans available will generate something like 5 lbs of thrust per horsepower, so 16 HP or so will be needed for thrust, on a 30" to 36" diameter fan in a duct.
6. A lift power of about 4 or 5 HP is required for a craft of this size, so if we combine the two functions onto one engine, 20 HP is actually needed. It would be very wise to install a 30 to 35 HP engine, and have some power in hand.

From these quick sums the size and shape of the craft begin to emerge, and the much more detailed design process can begin.

It is probably best to consider thrust, control, lift, skirt, and hull separately. The hull will be considered last since its only function is to support the other systems (and the crew). It is just as important as the other systems, but its design obviously must depend on their requirements, so the other systems are designed first.

5. SKIRTS

The first hovercraft retained the cushion of pressurized air under the hull simply by pointing a peripheral air jet curtain inwards to feed it, but only a very small hoverheight could be obtained unless a very large airflow was used. A rubberized fabric "curtain" was therefore put down under the hull to surround the cushion of lift air, while at the same time any solid obstacles on the ground could push through this curtain without harm. A

number of types of curtain "skirt" evolved, and a few are now firmly established. The simplest is the "bag" skirt, while a version of the "HDL" skirt is also suitable for light craft. The "BHC" skirt is more suited to larger machines, and the French Bertin "Jupe" skirt is also not particularly suited to light craft. In this book we shall deal only with the simple "bag" skirt.

Material - The skirt material has to be light, flexible, non-porous (to water and air), of high tensile strength, and reasonably abrasion resistant. For use in Canada, it has to retain these properties at low temperature, otherwise the craft is out of action for at least half the year. For this reason, the PVC-proofed fabrics often used for skirts on British vehicles are useless for Canadian applications. These requirements are usually met by a nylon fabric coated on both sides with a synthetic rubber such as hypalon, in thickness varying from 0.020" down to .004" for a very light craft for use over smooth soft terrain or water.

For a limited amount of experimenting in warm weather it is possible to get by with .004" builders plastic sheeting, or even plastic garbage bag material, secured with contact cement and office staples, but this won't hang together for more than an hour or so's running, and goes stiff if the temperature gets much below +10°C. It is worth remembering for a quick cheap first shot, to get the hang of the job, though.

Bag Skirt - This is the simplest skirt to design and build, and is very stable in roll and pitch. This stability is likely to result in a rather "hard" ride if the terrain is at all bumpy, or if the water has a short chop on it, and a torn bag usually loses its inflation pretty completely. However, a bag is the starting point for most builders.

It is possible to have only a small air feed to the bag, with no exit holes at all, but even a slight tear will deflate the bag in a quick and dangerous manner. It is therefore much better to use the so-called "full flow" system, where all the lift air is blown into the bag. Vent holes on the inner walls of the bag then let this air into the cushion area (with a slight pressure drop in passing through the vent holes) after which the air escapes between bag bottom and ground.

The problem is how to design and build the skirt so that when inflated it will assume the desired shape in a strong and stable manner. We set about solving it as follows.

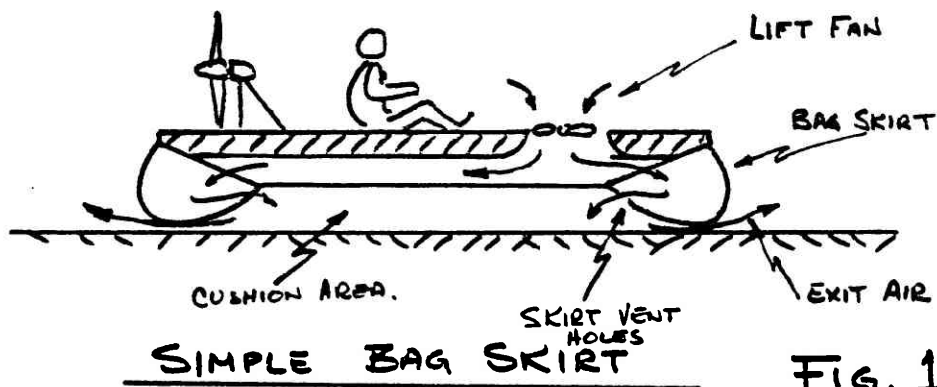


FIG. 1.

Firstly, we have to decide the clearance we want under the hull while hovering. This should not be too small, otherwise rough ground will defeat us, and not too large, or the craft will become unstable and tend to over-balance. A height of about 7% of the length is a good compromise, so for our estimated 10 ft length we shall arrive at 8-3/4" - say 9" of clearance.

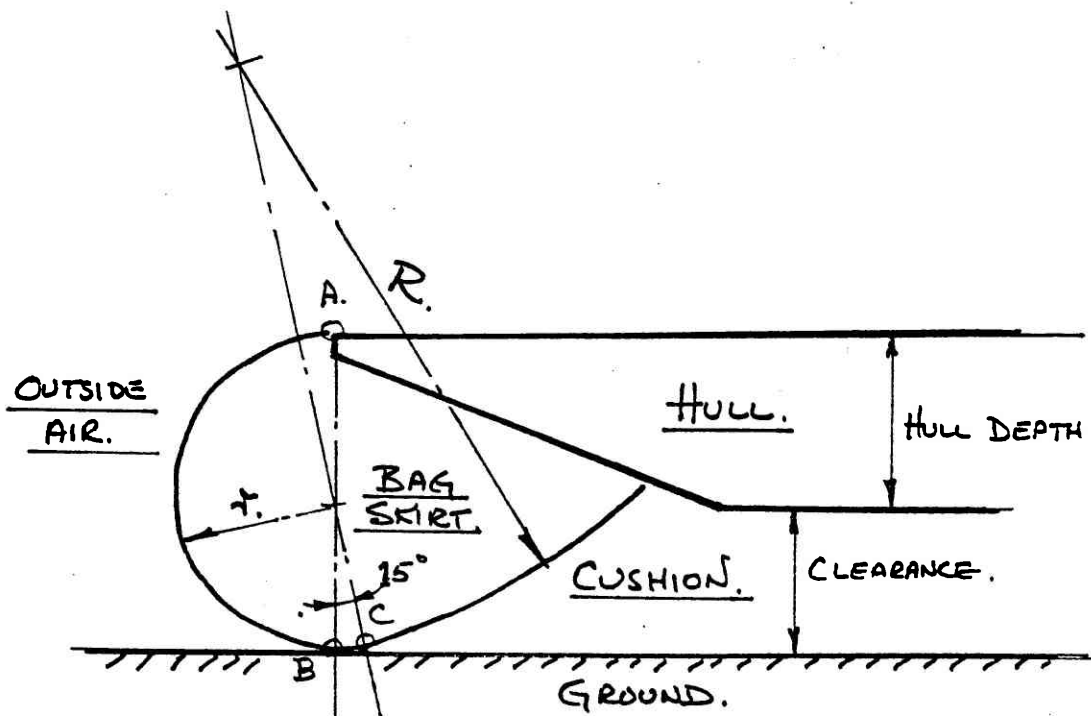


FIG. 2.

Drawing a diagram like this, we can put in the outer curve of the skirt as a semi circle of radius r , coming from the hull outer edge A to the ground at B (vertically below A). The hull depth is likely to be about 12" for this kind of craft.

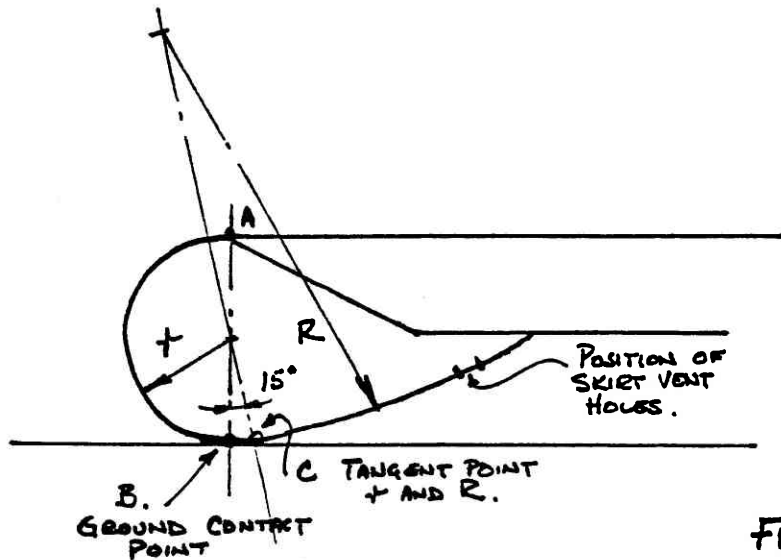
The skirt inner radius (R) has to be decided from the table below. This table has been calculated so that for a given pressure ratio between bag and cushion, the skirt will assume the shape shown when it is inflated. The larger this pressure ratio (i.e. the higher the bag pressure) the stiffer the bag will be, like a well-pumped up tire, and the "harder" the ride. A reasonable value to try is about 1.3:1, which means that the bag pressure is 1.3 times the cushion pressure. (We are talking about "gauge pressures", as read on a U-tube manometer, open to the air on its second limb.) Those are pressures above atmospheric.

A "U"-tube manometer is a very simple pressure gauge, which in its most elementary form consists of a glass tube bent into a "U" shape and half-filled with colored water. When there is a pressure difference between the two arms of the "U", this pressure difference is equal to the difference in height of the liquid in the two arms, and is stated as "so many inches of water". Often one arm is left open to atmosphere and the pressure in the other arm is a "gauge pressure" (as distinct from "absolute pressure") and is "so many inches of water above (or below) atmosphere. The distinction between pressure (+pressure) and suction (-pressure) is most important, and must be stated carefully to avoid confusion. A sketch of a U-tube manometer is shown at the back of the book (Fig. 30).

Measure both bag and cushion pressures separately in this way. Don't try connecting a U-tube between bag and cushion. In the present case, with 2" of water gauge pressure in the cushion, we shall need $1.3 \times 2 = 2.6$ " of water gauge in the bag, with the 0.6" being the loss through the vent holes. Assuming a further 0.4" water gauge pressure loss in getting the air from the fan into the bag, this will mean that the lift air fan has to produce the required flow at 3.0" water gauge pressure.

PRESSURE RATIO	SKIRT INNER RADIUS
$\frac{\text{Bag Pressure}}{\text{Cushion Pressure}}$	R
1.2	6.0xr
1.3	4.5xr
1.4	3.5xr
1.5	3.0xr

So if, for example, we choose the 1.3 pressure ratio, then $R = 4.5 r$. We can now draw the skirt section, and notice that the two curves join at 15° inside the vertical line AB. The point A can be moved up to 2" outside this, but never cut back inside this line, as this will make the bag an unstable structure.



The peripheral line through B the Ground Contact Point, is in simple theory the boundary of the cushion area, and defines the footprint area we estimated in our first rough calculations.

We have now drawn the cross section of the skirt along the sides and stern of the craft. The bow needs to be a little different, because here the bag is pushed back by the ground or water hitting it as the craft moves forward.

This means that while the back end of the hull can be cut off square, and have the same skirt section, the bow must be cut off differently and to hold the skirt into a different section.

The simplest way to set this out is to make a model, (full size or 1/4 full size) and set out skirt templates on this. This will also give the shape of the pieces to be cut to form the stern corners of the bag.

The hull shape is made, and set upside-down on the floor or on a board. Templates to the skirt section already designed are fixed onto the hull along the sides and stern, with extra ones at the stern corners as shown below.

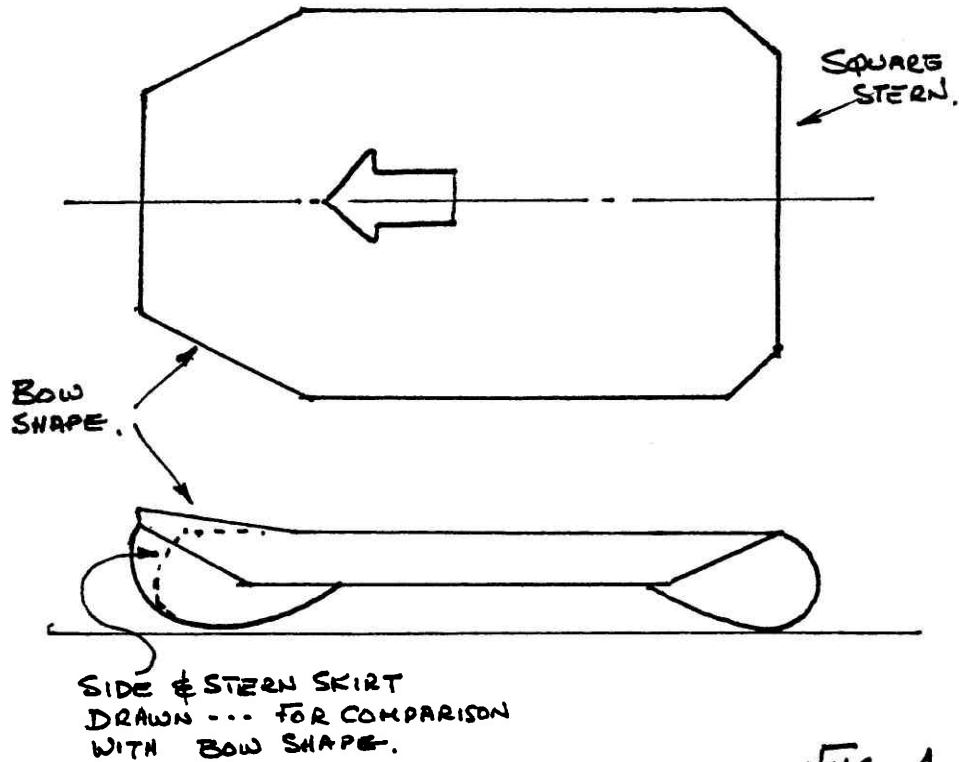


FIG. 4.

The stern corner sections are drawn in position to give a smooth transition round the corner. A simple "mitred" corner would lead to a weak and wrinkled fabric structure.

The bow is a little more complicated.

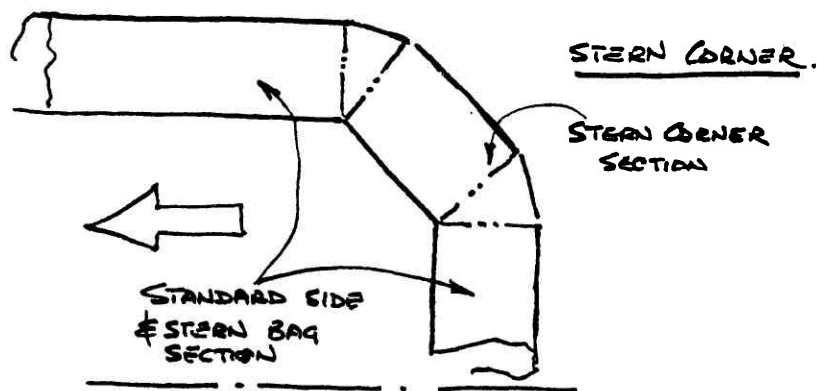


FIG. 5.

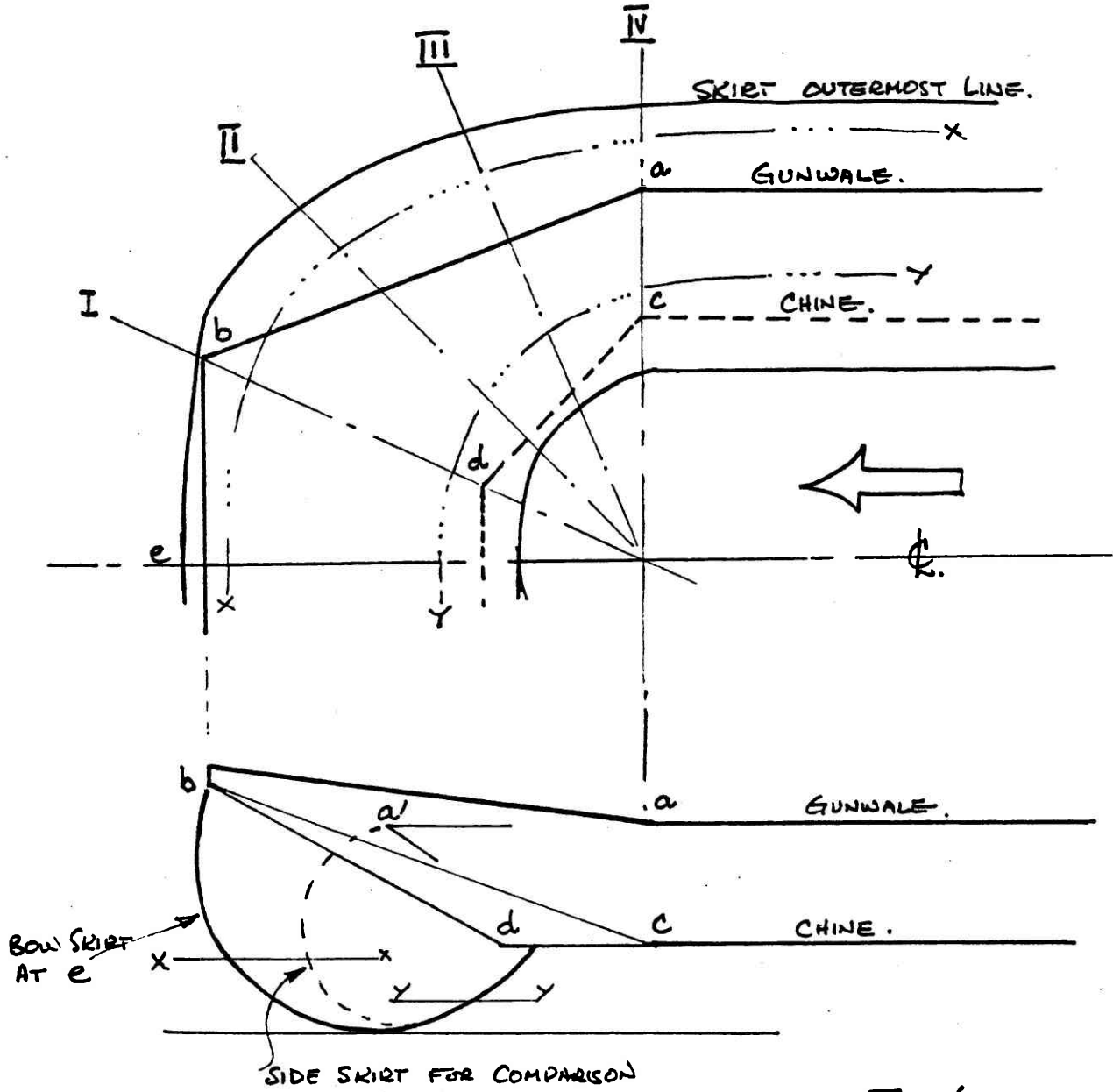


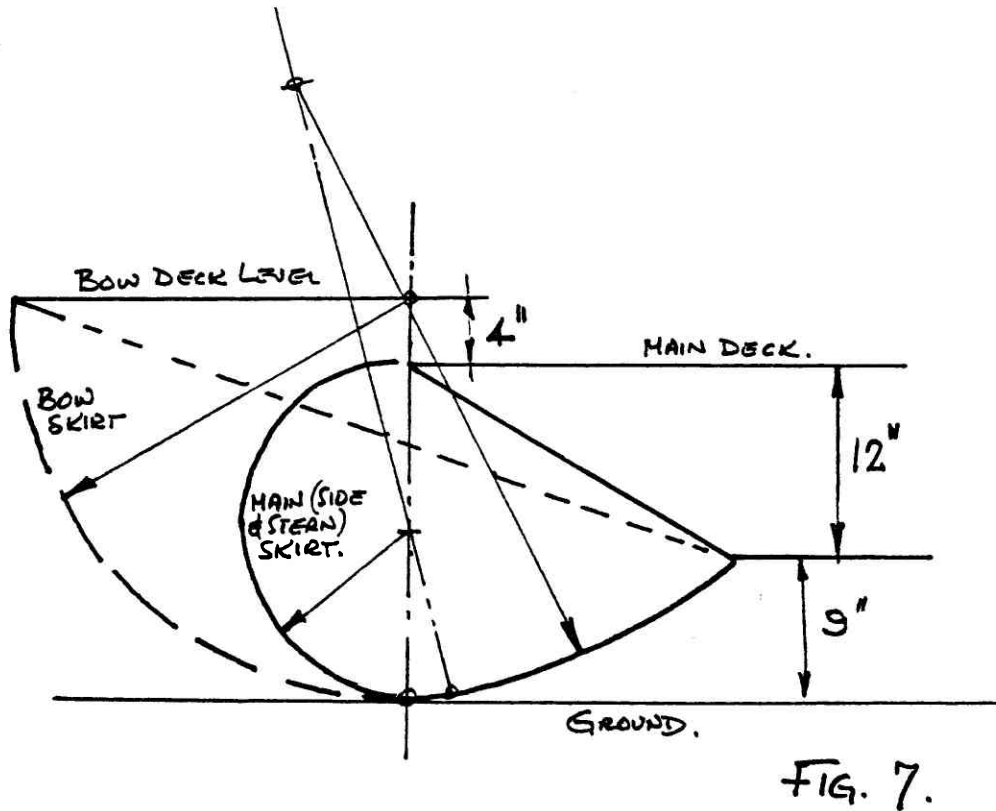
FIG. 6.

The lower view in Fig. 6 is a side view, in which the side section of the skirt bag (as already designed) is laid in, to show how it relates to the shape of the bow section.

You will see that the bow of the hull has been raised somewhat, to allow the craft to rise over waves or obstacles instead of nosing into them.

Now, on the hull model we have made, with the bow part in position, more skirt section templates are put in place at I, II, and III, with the last of the existing side sections at IV.

The pair of views in Fig. 6 show the way to approach it. The upper view is a view from above, showing the upper edge of the bow of the hull (the gunwale) and lower corner (chine), with the skirt also shown.



The section at III is drawn in very much the same way as the side section, except that the outer face is made as a circular arc with its centre at bow deck level, and its centre vertically above Ground Contact Point. This

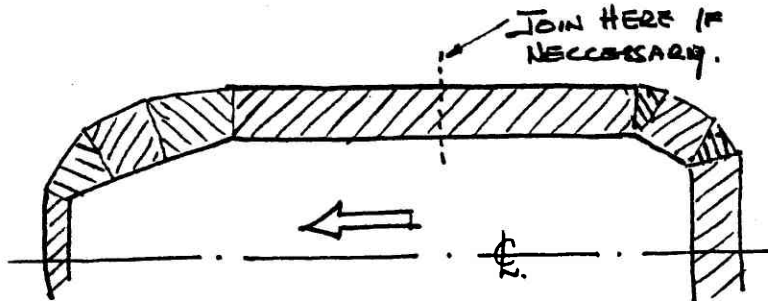
will define the length of the hull at the bow.

When this section has been drawn, as in Fig. 7, and set up in cardboard on the model, the blank cards for sections II and I are set up, and cut to shapes which will transform smoothly from S to III. This can be checked by bending a thin strip of wood or wire round the surfaces along a horizontal plane, such as XX or YY, and seeing that it makes a smooth curve (Fig. 6).

These sections define the cross sectional shape of the skirt. The shape of the pieces of skirt material is now found by laying pieces of brown paper over the sections, to form the skirt surface, and cutting them to fit, with adequate allowance round the edges for seams and attachment tongues. The extent of the pieces will depend on the width of skirt material available, there being as few joints as possible, and the shading in Fig. 8a suggests the extent of the separate pieces. However, it is essential to note that the weave of the material must run horizontal and vertical in every piece when installed, as shown by the arrows in Fig. 8b.

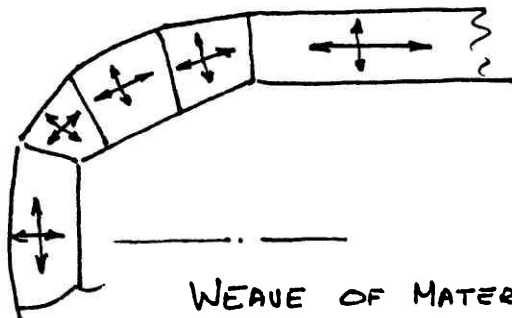
The joints are very critical. If they are not substantial enough, they will come apart; if they are too substantial they will act as stiff ribs in a thin membrane, and the fabric will tear away from these stiff elements.

For the bag skirt, the joints should be plain lap joints, made with contact cement and machine-sewn with strong thread (preferably one of the synthetic threads) and covered with a cap strip on the inside of the bag. At the stern corners it is very helpful to reinforce the joints around the bottom with pop rivets as shown, put in from the inside, and using steel washers (1/8" I/D, 3/8" O/D) on the outside and inside.



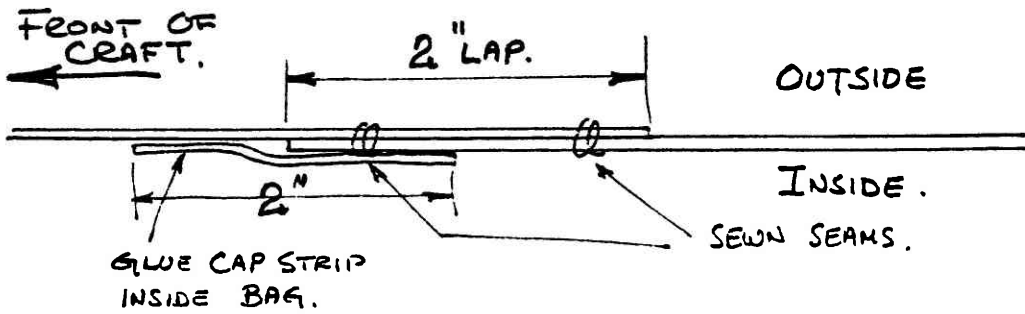
MAKE-UP OF SKIRT FROM SEPARATE PIECES OF MATERIAL.

FIG. 8.a.



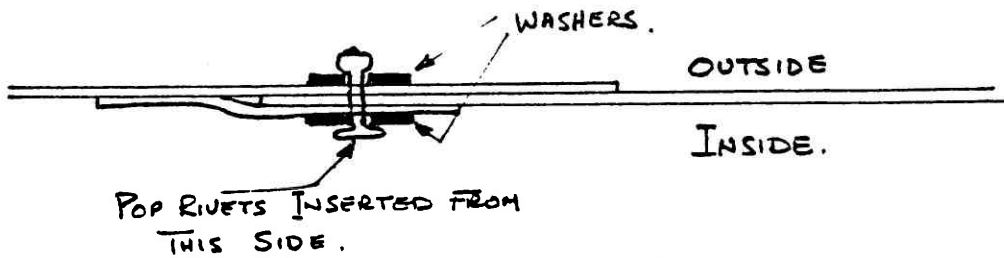
WEAVE OF MATERIAL.
(ALWAYS PARALLEL TO HULL GUNWALE EDGE.)

FIG. 8.b.



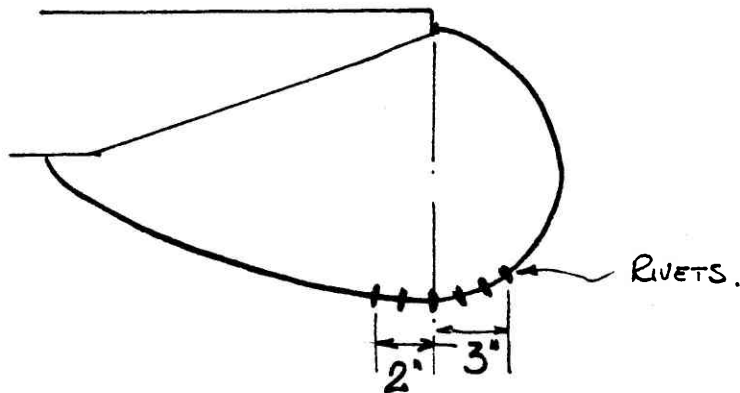
ALL JOINTS IN BAG SKIRT

FIG. 9.a.



RIVET INSTALLATION (REAR CORNER JOINTS ONLY)

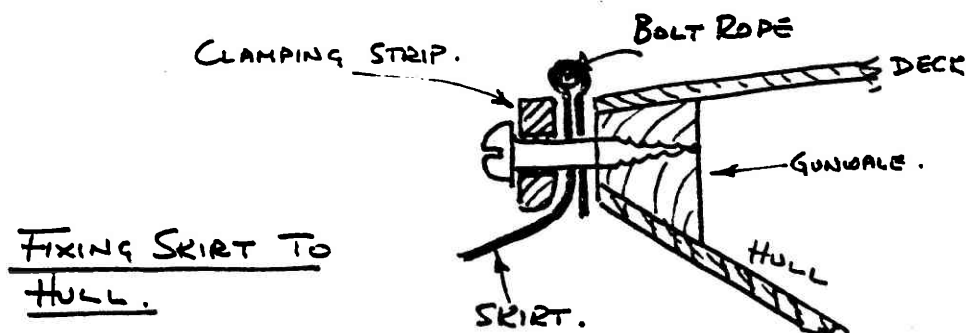
FIG. 9.b.



PLACING OF RIVETS AT REAR CORNER JOINTS.

FIG. 9.c.

The fixing to the hull is fairly simple. The tongue of material left on the skirt is doubled over a 1/4" diameter polypropylene rope (the "bolt rope") and is clamped onto the gunwale of the hull (and the underside) by wood or aluminum strips, held in place by wood or sheet metal screws. Note that the edge of the clamping strip must be nicely radiused or chamfered as shown, to avoid wearing through the skirt fabric. "Half-round" moulding may be conveniently used, with the rounded side next to the skirt.



(NOTE, CLAMP STRIP MAY BE "HALF-ROUND" STRIP,
EASILY AVAILABLE.)

FIG. 10.

Air Vent Holes - The air feed into the bag will be dealt with later -- under the lift air system, but the bag skirt design involves the air vent holes from the skirt into the cushion space. It is the pressure loss through these holes which controls the bag/cushion pressure ratio which we used at the beginning of this section.

The holes are cut in the inner face of the bag, high up near the hull underside so that they are well away from snagging and tearing on rough ground or vegetation, and they are on the front end and sides. They are not put at the stern, as forward motion over water could then scoop the water into the bag through them (Figs. 1 and 3).

The holes are 5-1/4" diameter, (i.e. of 0.15 ft² area per hole), and the number of holes is calculated from the formula:

$$N^{\circ} = \frac{Q}{7 \sqrt{\frac{P}{b} - P_c}}$$

Where N° = Number of 5-1/4" D holes
 Q = Lift airflow (ft³/sec)
 P = Bag pressure ("H₂O)
 b
 P_c = Cushion pressure ("H₂O)
 c

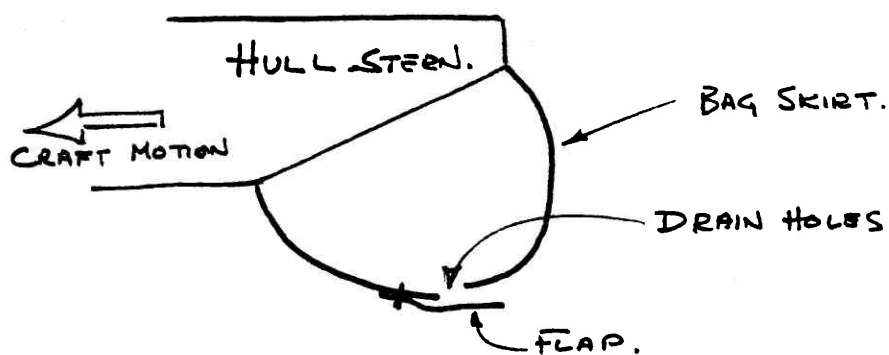
If in the present example we needed a lift airflow of 100 ft³/sec, with a bag pressure of 2.6" H₂O and a cushion pressure of 2.0" H₂O, we should therefore need:

$$N^{\circ} = \frac{100}{7 \sqrt{2.6 - 2.0}} = 18 \text{ holes}$$

It would be very wise to cut about 10 holes of the 18, and check the bag and cushion pressures while the craft hovers, with full designed load on board, using a U-tube pressure gauge with colored water in it. Probably the bag pressure will be too high, so more holes are cut, one or two at a time, until the pressures should settle to the required values, hopefully at about 18 holes. Plot a graph of pressures against number of holes as you go, to get warning of the correct moment to stop cutting!

Skirt Drain Holes - If the craft is left floating on the water with the lift engine shut down, the bag skirt will get water in it through the skirt vent holes. To blow this out when we start up again, we need drain holes in the skirt, which will not let too much air escape.

A row of from 5 to 10 holes, 2" diameter, is therefore cut in the bottom of the skirt at the stern, and is covered by a flap on the outer surface, which is normally kept shut by the water or ground sliding past below it. This allows a small leak, and drains water in a reasonable time without too much loss of air from the bag. (Try first with 5 holes. Draining can be speeded up by cutting more holes, but not so many as to lose too much lift air or to weaken the bag pressure.)



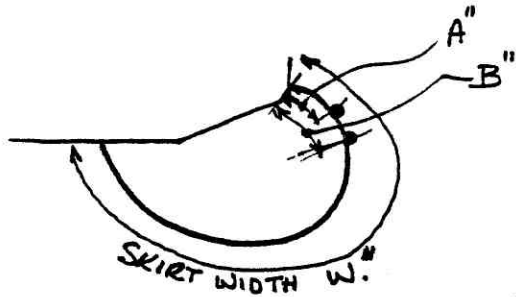
DRAIN HOLES IN SKIRT AT STERN.

FIG. 11.

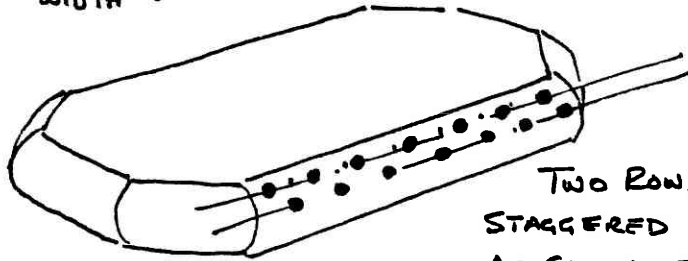
Skirt Buzz - A bag skirt, particularly when hovering over hard smooth ground or smooth water, will often vibrate. This can be a minor annoyance, or it can be severe enough to wear the skirt and even hammer the craft to such an extent that things begin to crack and fall off. The buzzing usually stops as soon as the machine gets onto rougher ground, or grass.

This buzz is very quickly cured by taping or glueing small packets of sand onto the skirt in the right places. If you want to be technical, it is a kind of "violin-string" vibration, which can be damped by placing a small mass on the "string" at an antinode (place of maximum motion) to absorb the energy of vibration. The masses (the small packets of sand) go by the highly scientific name of "buzz-dingers".

The positioning and size of the packets is shown in Fig. 12. It is usually good enough to fit them just down the two sides of the craft, but if the skirt still buzzes, add them at the ends as well.



$$A = \frac{W}{5}$$
$$B = \frac{W}{4}$$



TWO ROWS OF 7 DINGERS EACH STAGGERED AND EQUALLY SPACED AS SHOWN, TO FILL THE LENGTH OF SKIRT SIDE PANELS.

BUZZ-DINGER ARRAY
FOR 10'x6' A.C.V.

EACH BUZZ DINGER IS A FLAT (SKIRT MATERIAL) ENVELOPE OF SAND, WEIGHING ABOUT 2 OZ (60 GMS) GLUED TO SKIRT SURFACE.

FIG. 12.

There are more advanced types than the bag, but it is better to start with this, and progress to more complicated types later.

So much for skirts.

6. THE LIFT SYSTEM

This covers the blower and ducting that supply the air to the skirt and cushion.

There are many ways of supplying lift air, and like all engineering, successful design lies in selecting the best compromise for the purpose in hand.

Mechanically, the simplest system is to have one engine driving one fan which supplies both lift and thrust air. However, the efficiency is rather low, control gets rather complicated, and if the engine quits the craft is just dead. One engine can also be used to drive separate lift and thrust fans, but this is difficult mechanically and has the same disadvantage in the event of failure.

Two separate engines for lift and thrust raise the price and weight somewhat, but give better control, better efficiency, and more reliability. Surprising as it may seem, tilting the craft will provide a little thrust from the lift system alone, and get the craft to shore when over water. If the lift engine quits, the thrust system will push the craft to the shore, slowly but surely.

The lift fan itself can be either an axial flow or a centrifugal flow type; both have been used successfully. However, for a light small craft such as we are considering here, the choice is almost inevitably an axial fan running as slowly as possible with a step-down belt drive from a small two-stroke engine. We are forced into this choice owing to the large size and weight of a centrifugal fan to pass the same airflow.

Just as important as the fan itself is the design of the air duct configuration required to feed the bag.

The first thing is to get some idea of the amount of lift airflow required to hover the craft. We will continue to use as an example the 500 lb craft, 10 ft x 6 ft, with a cushion pressure of 2.0" H₂O and a bag pressure of 2.6" H₂O. There are many ways of arriving at the required lift airflow, varying all the way from "scrounge a fan and see if it lifts" to the somewhat involved calculations used on large vehicles. We will take a fairly simpleminded but soundly based approach, using a simple equation with constants derived from the more complicated methods.

The lift airflow required for reasonable performance over water and land is given by:

$$Q = \frac{K L W}{S \sqrt{P}} \\ c \quad c$$

		<u>units</u>
Where	Q = lift airflow	ft ³ /sec
	L = skirt footprint perimeter	ft
	W = total weight	lbs
	S = footprint area	ft ²
	^c P = cushion pressure	"H ₂ O
	^c K = constant	0.444 (Bag Skirts)

So, for our example,

$$Q = \frac{0.444 \times 32 \times 500}{60 \times \sqrt{2}} = 83.72 \text{ ft}^3/\text{sec}$$

If we suck this in through a 19" diameter lift fan, which will have (allowing for fan hub, etc.) about a 1.75 ft² area, the air speed will be about $\frac{84}{1.75} = 48 \text{ ft/sec}$, which will cause no problems.

The fan tip speed will be around 270 ft/sec, which will result in a decently quiet fan.

The fan horsepower required is roughly equal to:

$$\text{Power} = \text{Press. Rise} \times \text{Airflow} \times K$$

Where Press. Rise is in "H₂O
 Flow is in ft³/sec
 and K = 0.016
 and Power is in HP

Allowing for 3"H₂O at fan exit to produce 2.6" in the bag and 2.0" in the cushion, and allowing a 0.6 efficiency in fan and ducting (which is included in the K factor above) the power will be:

$$\text{Power} = 3.0 \times 83 \times 0.016 = 4.0 \text{ HP}$$

If the fan tip speed is 270 ft/sec, on a 19" fan, this means a fan speed of 3200 RPM. To produce 4.0 HP, many small engines will run at more than 3200

RPM, so they will need a step-down belt drive. This is not complicated, but the belt does put a side-load on the motor shaft, which will rapidly wreck the crankshaft bearings if they are not meant to stand it. Most lawnmower motors have the cutter mounted straight on the crankshaft, and therefore have fairly flimsy bearings, so if you use one, you must put an extra bearing beyond it and a flexible coupling between crankshaft and the jackshaft on which the drive pulley is mounted. However, if the engine is meant to take a belt drive, all well and good -- no extra bearing is needed. And it is very strongly advisable to get a two-stroke engine, which will use oil-fuel mixture. The propulsion engine will be more powerful, and almost certainly run at higher speed. It will be a snowmobile engine, definitely a two-stroke, so the two of them should use the same fuel.

Now some people will tell you to avoid the bother of belts by fitting a fast running fine pitch fan straight onto the crankshaft, and revving it up to suit the engine.

DON'T! It will make a noise which will bore your ears out, leaving an empty hole between them, and will annoy the neighbours so much that you (and the rest of us) will be banned from running ACVs.

How to choose a fan? There is available in Canada a range of axial fans particularly suitable for light ACVs, consisting of hubs into which varying numbers of a range of blades of different pitch angles can be fitted. These fans are light, and can even be turned down on a lathe to fit various size ducts. They are the "Multiwing" fans, and enquiries should be directed to the Sheldon Fan Co., in Cambridge, Ontario. A specimen performance curve for fans of this general type is shown in Fig. 13.

Under the circumstances, in this particular case we should probably use a 12 blade fan running at 3000 RPM or else use 35° blades, and use 10 blades in a fan running at 3000 RPM or so. A few graphs like Fig. 13 plotted from the manufacturer's catalogue sheet would soon put us on the right track.

Now any rotating machinery is a bomb which doesn't need an explosive charge. If a fan blade breaks, or is broken by sucked-in debris, the fan can just explode and the flying pieces can kill. So don't give it a chance! The inlet to any fans must have a tough wire guard over it, of say 2" mesh, which will keep hands, caps, spanners, lumps of mud or ice, etc., out of the fan.

The fan MUST also be enclosed in a strong cylindrical duct, to catch the bits if it does burst. And in order to get the air into the fan in good order, so that the fan blades get a fair chance to work efficiently, we need a "bellmouth inlet".

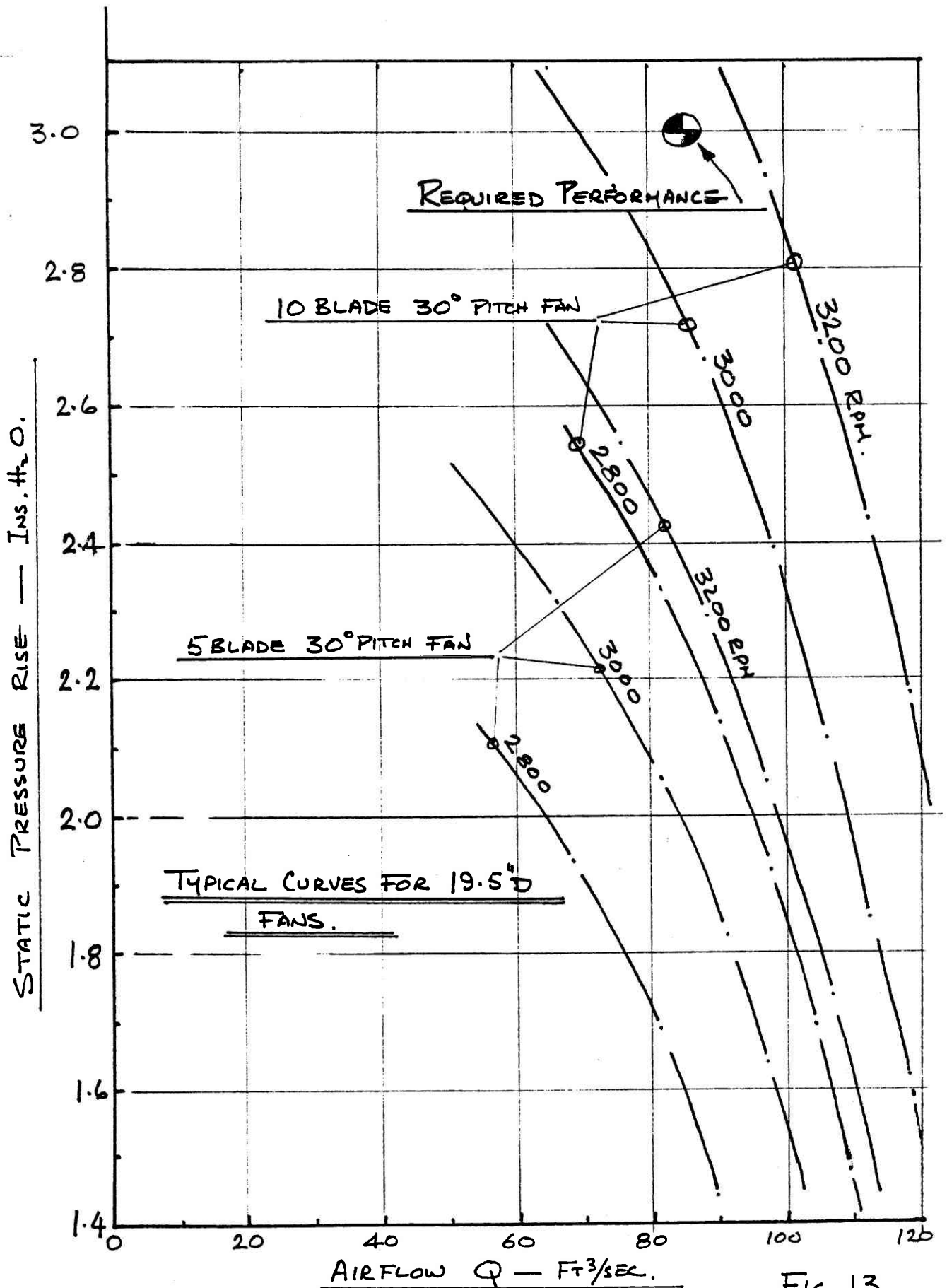
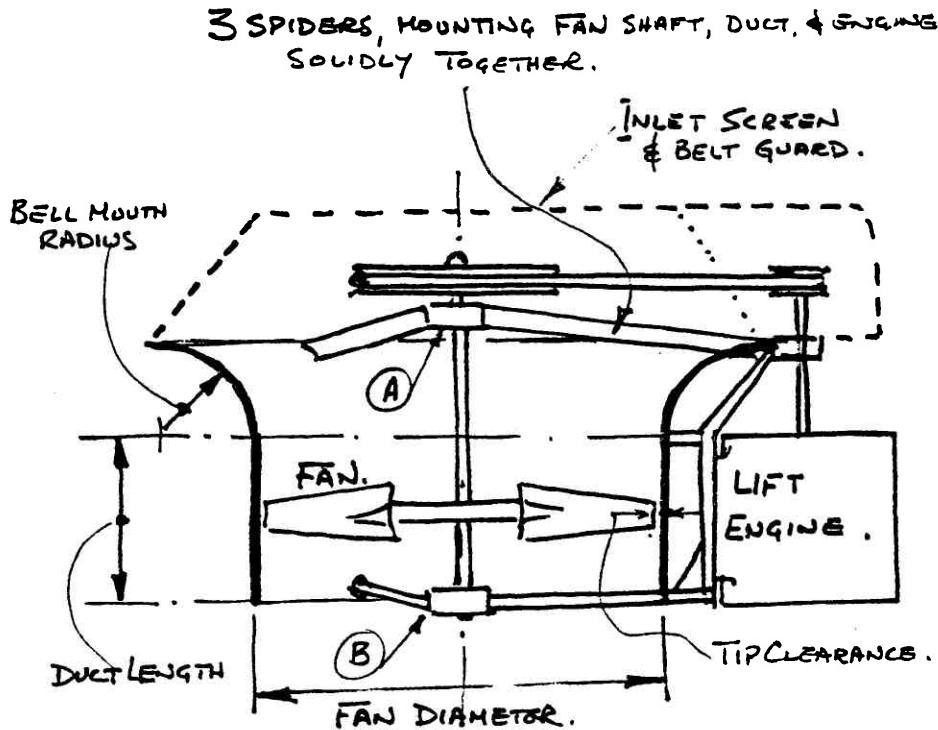


FIG. 13.

All of which just about crystallizes the lift-fan installation into something like Fig. 14.



$$\begin{aligned} \text{FAN DIAMETER} &= 19'' (\text{SAY}) \\ \text{DUCT LENGTH} &= \frac{\text{FAN DIAM.}}{3} (\text{SAY } 6'') \\ \text{BELL MOUTH RAD.} &= \frac{\text{FAN DIAM.}}{4} (\text{SAY } 4\frac{1}{2}'') \end{aligned}$$

TOP BEARING (A) SELF-ALIGNING, SLIDING IN HOUSING.
BOTTOM BEARING (B) SELF-ALIGNING THRUST BRG., FIXED IN HOUSING,
TAKING WEIGHT OF FAN (DOWNWARDS) & LIFT (UPWARDS) WHEN RUNNING.

LIFT FAN INSTALLATION.

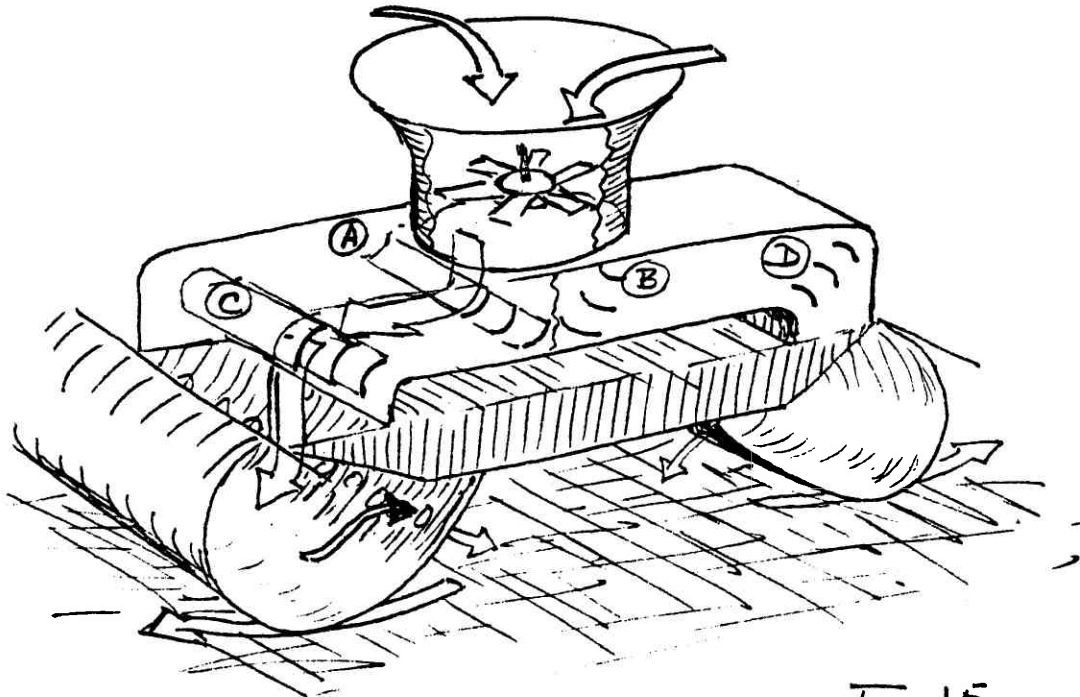
FIG. 14.

Note that the belt is on top of the unit, where it can be seen, inspected, and got at easily. BUT underneath the screen, which will catch it if it flies off. And DO NOT run the engine, even for a quick test, without the screen on and bolted down!

Having got the air into and through the fan, it now has to be ducted into the skirt with as little loss as possible. This points out one of the disadvantages of the bag skirt, it does impose quite a pressure loss on the air before reaching the cushion, where the required pressure is fixed by the size and weight of the craft. The fan therefore has to produce that much extra pressure, so the ducting must be carefully designed to cut down the extra pressure required to the minimum possible.

The pressure loss of air moving along a duct and round corners is proportional to the energy of movement, the "kinetic energy" or "dynamic head", and this is proportional to the $(\text{speed})^2$ of the air, so to cut down the loss, the speed must be kept down by using the biggest ducts possible. Pressure is also lost by changing direction, so the smallest possible number of bends is also a requirement. And finally, the loss in those bends can be cut by putting vanes in them to keep the air organized and filling the duct as it goes round, instead of crowding to the outside of the bend and speeding up in the process.

So the best solution to this complex problem is along the lines shown in Fig. 15.



LIFT AIR DUCT.

Fig. 15.

Sets of "turning vanes" are set in the duct at A, B, C, and D, to get the air from the fan down into the skirt. These vanes are very simple, and cut down the loss of dynamic head from about 100% at each bend to something like 15%. They are shown in more detail in Fig. 16.

This assembly is best placed at the front end of the craft, since most and highest pressure air is needed at the bow skirt, to stiffen the bow skirt, to prevent nosing in when traversing waves or land obstacles.

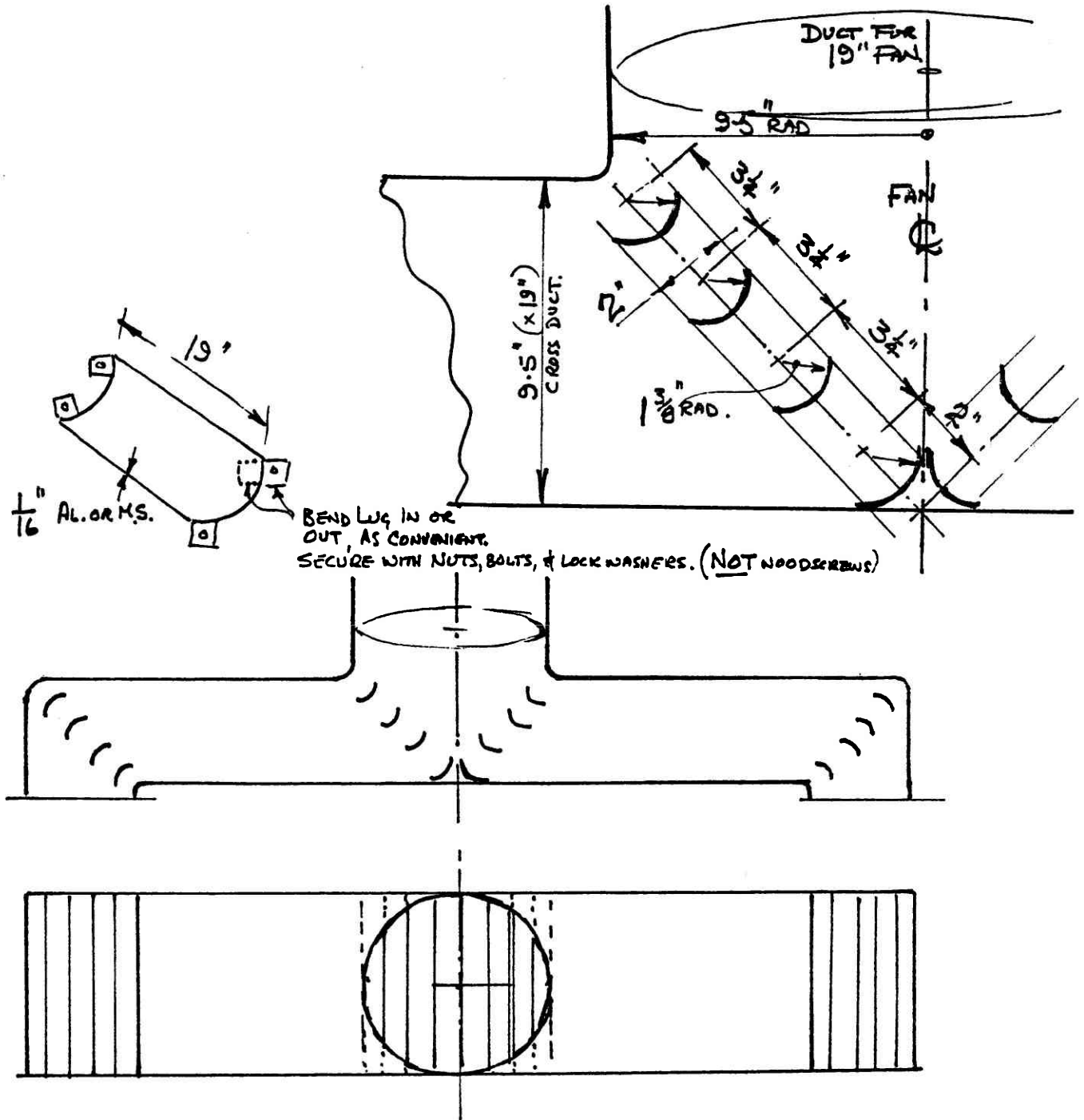
7. THE THRUST SYSTEM

Much of what was said about the lift system also applies to the thrust system, which almost always uses a large fan or propeller in a duct at the rear of the craft. Some machines have been driven by centrifugal fans, which make control with reverse thrust an easy proposition, but the efficiency of these units is very low in terms of thrust per horsepower, so we will only consider the axial fan or propeller. And since putting a proper duct round it makes it as effective as an unducted propeller of twice the area, as well as keeping fingers out the fan and retaining the bits should it burst, we will consider only the ducted type.

The fans used are axial flow multibladed fans of the same general type as for the lift system, but rather larger -- say 30"/36" diameter for the kind of craft we are using as our example. We shall start by finding out how much thrust we shall need, and then what fan and motor is necessary to produce it.

The starting point is the total weight of the craft and pilot, which we decided would be about 500 lbs. There are three critical values: the thrust to get through "hump speed" and plane over water, the thrust needed to get the craft over the worst ground we are likely to traverse, and the thrust to get up the steepest slope we want to climb.

The over water case is about the most definite, so we will look at that first. When an ACV moves slowly on water, it behaves just like an ordinary boat, and displaces water under it to equal its own weight. It moves forward making the usual pattern of bow waves until it is running fast enough to climb out of the displacement hollow, at "hump speed", and start planing. The wave pattern then almost vanishes and the craft accelerates rapidly. A large proportion of the low speed drag is caused by the energy put into making the waves, so once the wave pattern almost vanishes, this wave-making drag also nearly disappears. Other components of the drag build up, but the result is a pronounced "hump" in the graph of drag vs speed -- whence the name "hump speed".



DRAWN FOR 19" D. FAN. FOR OTHER SIZES, SCALE IN PROPORTION.

TURNING VANES IN LIFT-AIR DUCT.

FIG. 16.

This hump speed depends on the length of the craft, and is given by:

$$V_H = 3.24 \sqrt{l}$$

Where V_H = Hump Speed (ft/sec)
 l = Hull length (ft)

Then the wave-making drag at Hump Speed is given by:

$$D_H = \frac{0.049 \times W^2}{S \times l^c} \times \text{Factor}$$

Where D_H = Hump wave drag (lbs)
 W = Craft Weight (lbs)
 S = Cushion footprint area (ft²)
 l = Hull length (ft)

The Factor depends on the state of the water:

Smooth deep water = 1
Rough deep water = 2 (waves = skirt height)
Shallow water = 3 (2 ft deep or less)

In order to be able to accelerate readily through hump speed into the planing mode, it is usually recommended that the thrust should be about twice the hump wave drag.

So with the craft of our example, we have that:

$$\text{Hump speed} = 3.24 \sqrt{l} = 3.24 \sqrt{10} = 10.3 \text{ ft/sec (7 mph)}$$

And D_H - (using factor 2 for rough water)

$$D_H = \frac{0.049 \times W^2}{S \times l^c} \times 2 = \frac{0.049 \times 500^2}{60 \times 10} \times 2 = 40.8 \text{ lbs}$$

So a thrust of $40.8 \times 2 = 82$ lbs should be aimed at, for the over-water requirement.

Now, over land the vehicle behaves in a frictional manner, with coefficients of friction varying from 1% or less over smooth ice or glazed snow, to 5% for short grass, and up to 30% for long grass and scrub, with values up to 20% over rough ground.

This means that, at the sort of lift airflows we have built in, the drag of the craft over these types of terrain will be so many percent of the total weight, moving at low speed (4 mph or so). The very high values through tall grass and scrub are really due to the effort to push aside the vegetation, and are greatly reduced on second or third passes along the same trail.

So if we take 15% as a figure which will allow us to operate over quite a wide range of terrain, $15\% \times 500 \text{ lbs} = 75 \text{ lbs}$. We therefore need to install at least 75 lbs for operation over flat land.

This will allow us to get up a good speed over smooth flat open ground, but this sort of operation could lead to very severe skirt wear, which seems to increase as $(\text{speed})^2$ or even $(\text{speed})^3$.

The worst surface for wear is hard ground such as asphalt or concrete, which can destroy a skirt in half an hour of operation at 20 mph.

Thirdly, we must consider the thrust to get the craft up a slope. This thrust is needed to overcome the component of the weight acting down the slope, which is equal to the total weight multiplied by the sine of slope angle:

$$T = W \text{ Sine } \theta^\circ$$

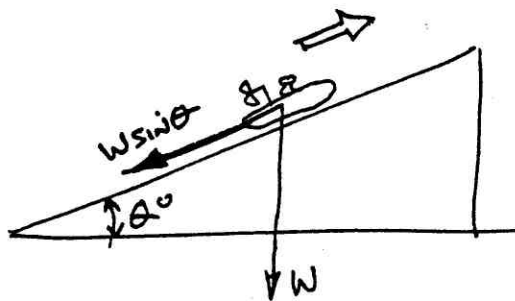


FIG. 17.

If we settle for a slope of 10° , that is a grade of 1 in 5.7, we need a thrust of greater than $W \sin 10^\circ$, that is, greater than $W \times 0.174$, so that for our 500 lb craft we need $500 \times 0.174 = 88$ lbs or more.

So we have the three figures,

Minimum Thrust Requirement over water = 82 lbs
Minimum Thrust Requirement over land = 75 lbs
Minimum Thrust Requirement up grades = 88 lbs

So if we can generate 90/100 lbs maximum, we should have quite a useful vehicle.

The next step is to look at the performance of a thrust fan. As was explained above, a guard round the fan is essential for safety, and a duct increases the effective fan diameter, so it is assumed that these two functions will be combined in the one correctly shaped duct.

The curves of Fig. 18 make it very clear that the best conversion of engine horsepower into fan thrust is obtained by using the largest possible fan, to get the lowest loading of horsepower and thrust per square foot of fan disc area. It is also very well established that fan tip speeds should be kept below 400 ft/sec if at all possible to produce a tolerably quiet fan, as well as reducing stress levels. On the other hand, there are strong reasons why the size (and weight) of the fan should not be allowed to rise too high. The sheer unwieldiness of a very large propeller on the back of a light craft is obvious, and because it is placed high up it becomes top-heavy. Also, the necessarily high thrust line will tend to push the nose down when full thrust is applied. Finally, the gyroscopic force of the large rotor could become quite difficult to control.

So if we look at Fig. 18, trying as a first estimate a 30" diameter fan for 100 lbs thrust, the area is 4.9 ft^2 , and hence the disc loading is $\frac{100}{4.9}$

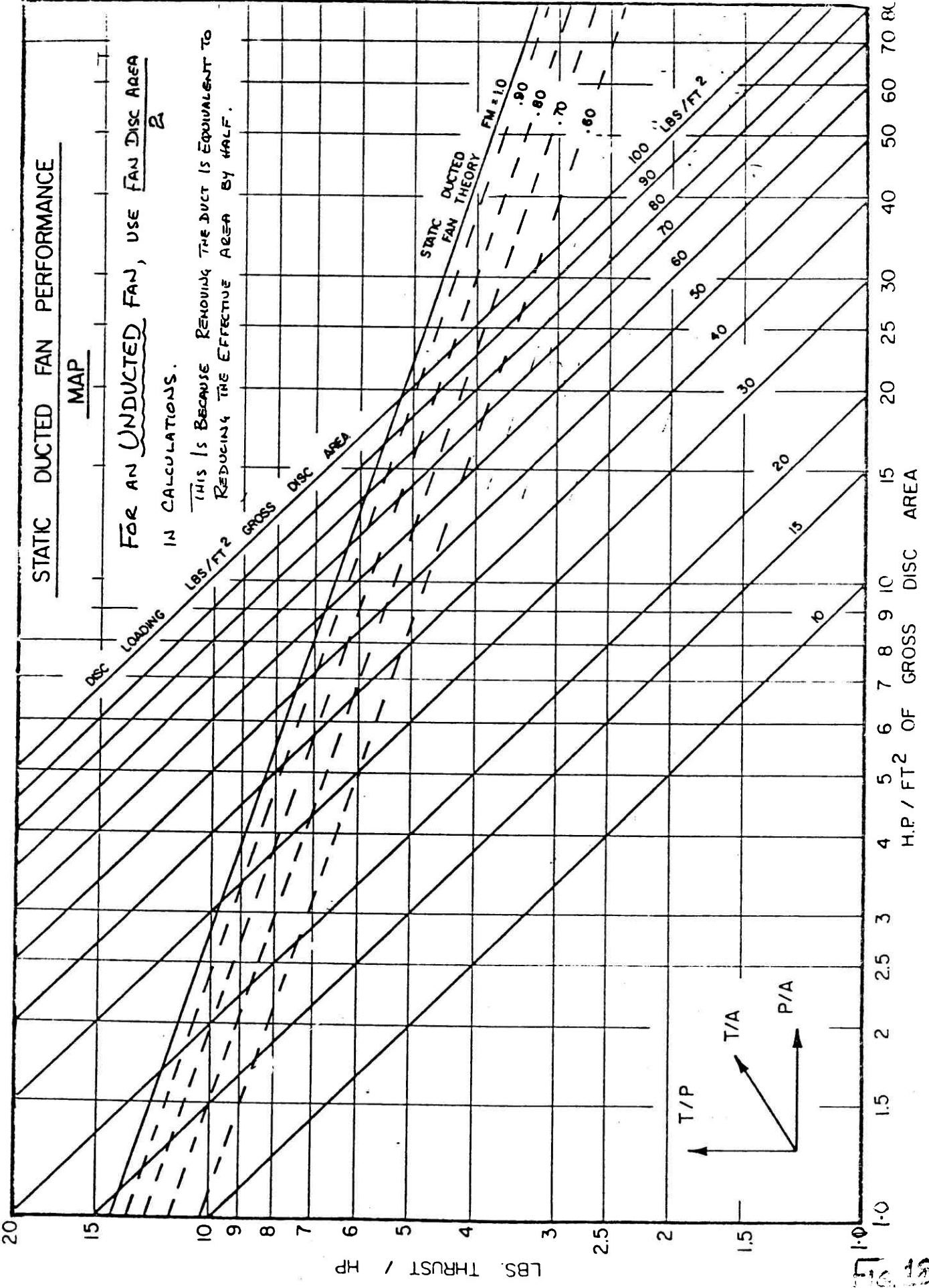
20.4 lbs/ft^2 . From Fig. 18, assuming a Figure of Merit (FM) of 0.60 (a sort of efficiency) the fan will give about 7.5 lbs of thrust per horsepower, so that to produce 100 lbs of thrust, $\frac{100}{7.5} = 13.3$ HP will be required.

An 18/20 HP snowmobile or go-cart motor should therefore be suitable, and a V-belt drive will easily transmit this power. A toothed timing belt is even better, but the shaft alignment is very critical if the timing belt is not to drift endwise against one pulley rim and tear itself to pieces, jump the pulley, or even force the rim off.

STATIC DUCTED FAN PERFORMANCE MAP

FOR AN UNDUCTED FAN, USE $\frac{\text{FAN DISC AREA}}{2}$ IN CALCULATIONS.

THIS IS BECAUSE REMOVING THE DUCT IS EQUIVALENT TO REDUCING THE EFFECTIVE AREA BY HALF.



100 120

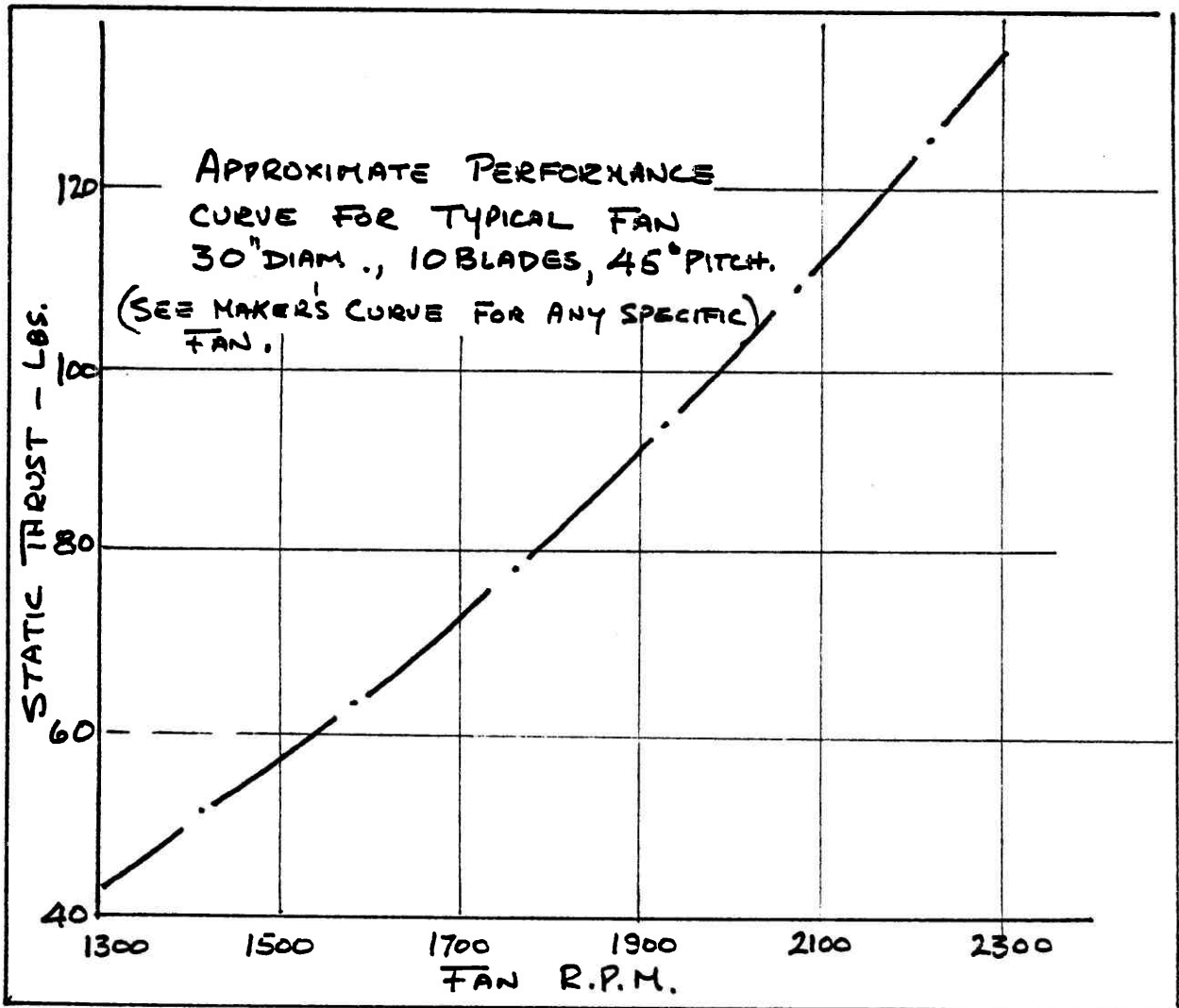


FIG. 19.

Going again to the fan, Fig. 19 shows a typical curve for the same type of fan as was discussed in the section on lift systems.

This tells us that a fan speed of about 2000 RPM will be needed to develop the 100 lbs of thrust. This is equivalent to a tip speed of 262 ft/sec, which should result in a reasonably quiet fan.

The 18/20 HP engine will probably run at about 5000 RPM to give the 13.3 HP we need, so a 2.5:1 step-down in the belt drive will be needed. This should present no problems, except that aluminum pulleys must be used. The weight of steel pulleys would be far too high when we are scraping to get rid of every bit of surplus weight. The actual engine speed must be checked from the maker's curve of power vs speed, to find the proper engine speed to develop 14 HP.

The design of the duct to surround the fan is very simple. The essential points are:

- (a) a moderate inlet radius,
- (b) a short length of parallel duct, and
- (c) a small fan tip clearance.

Since the craft speed is not excessive, the shape of the outside of the duct is not important, and weight should not be expended in streamlining the outside.

The duct for a 30" diameter fan should therefore be approximately as shown in Fig. 20.

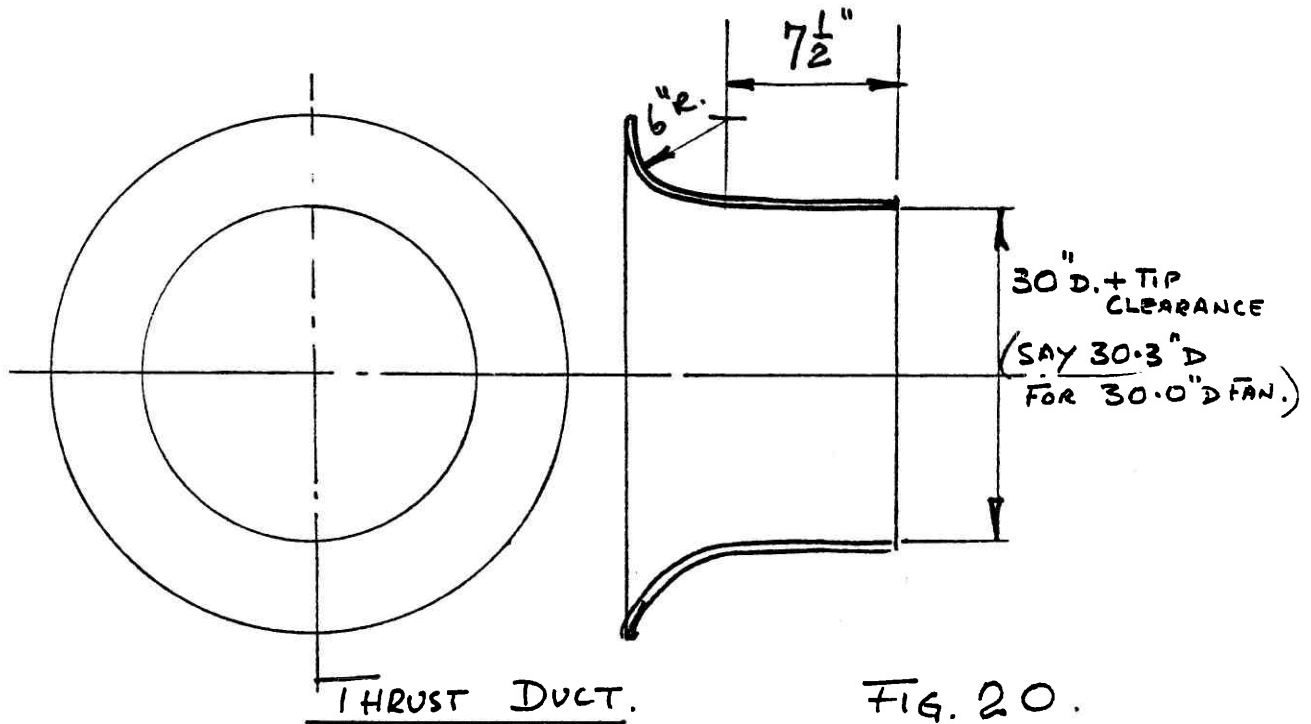


FIG. 20.

With the small running clearance, which is most important for good fan performance, the duct must be mounted very firmly on the engine/fan mounting. A suitable system is shown in Fig. 21. Steel or aluminum tubes make very good struts, with the ends squeezed flat for attachment lugs. Notice that there is a good length between propeller shaft bearings, and that the front bearing and large pulley stand well out in front of the duct, to avoid in-

terfering with the airflow, and also to provide a good rigid cone of struts to hold the duct firmly. Notice also that the propeller shaft can be shimmed up on top of the main pillar, to adjust the drive belt tension, taking the duct up and down with it. Note too that the inlet screen is shaped to cover the drive belts and pulleys as well as the fan intake.

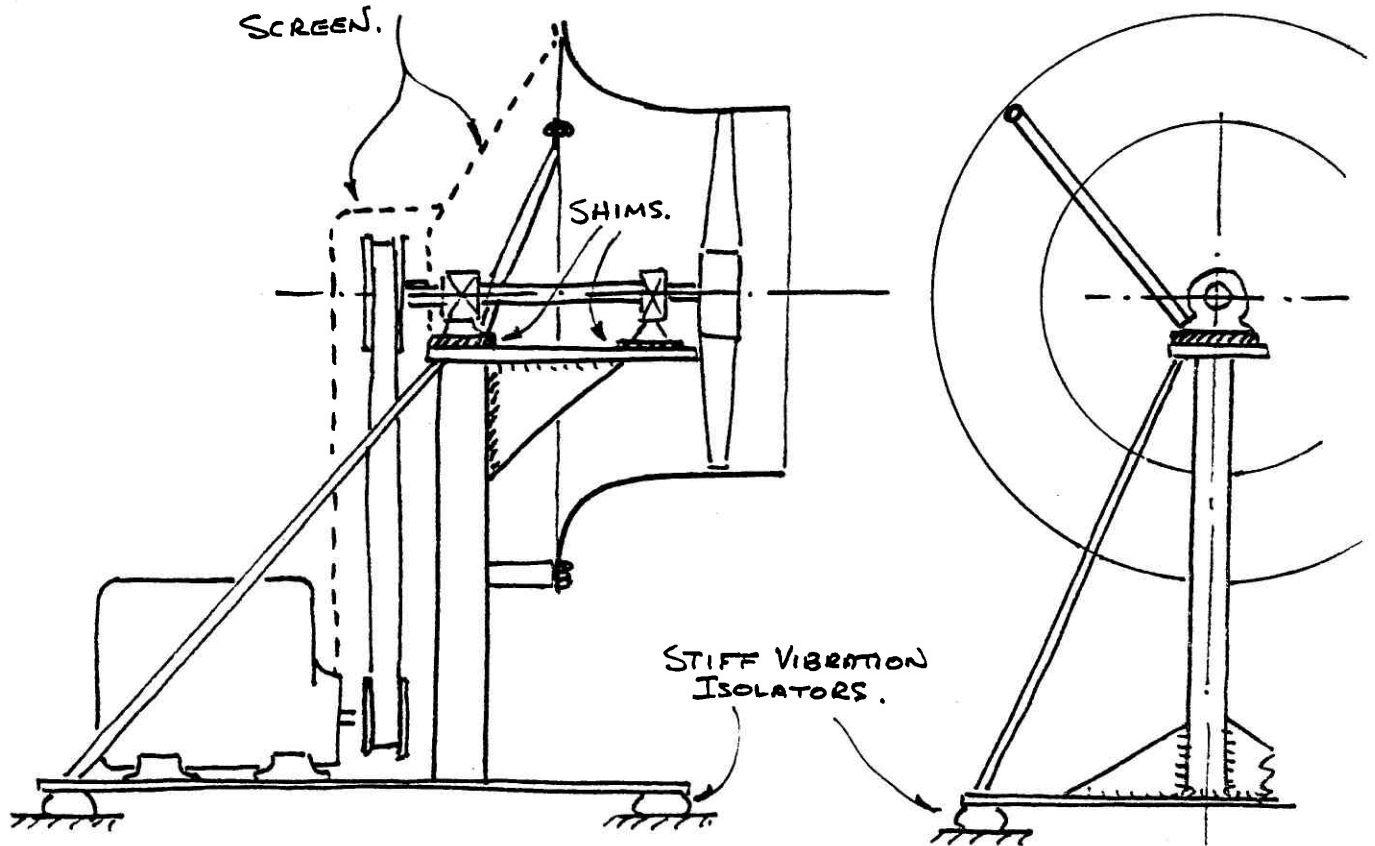


FIG. 21.

8. CONTROLS

Most light ACVs are controlled simply by the lift and thrust engines and a rudder. Very light machines also use movement of the driver's weight as a control aid, and an increasing number of machines have simple thrust reversers.

The driver's input is usually by push/pull knobs (quadrant levers as second choice) for throttles, and steering wheel, tiller bar or joystick for rudder. In the case of a tiller or joystick, the thrust engine control is sometimes a twist grip or trigger type on the tiller or stick.

The main principle is that the controls should be simple and natural to operate, simple and reliable to install and maintain, and light in weight. It is also wise to spring-load the thrust throttle so that it closes automatically when released, in case the driver is upset overboard.

In normal operation the lift throttle is set and left set (as by locking a push/pull type). The thrust throttle is likely to need continuous adjustment, and is therefore held in the hand continuously. A pedal could also be used for the thrust throttle.

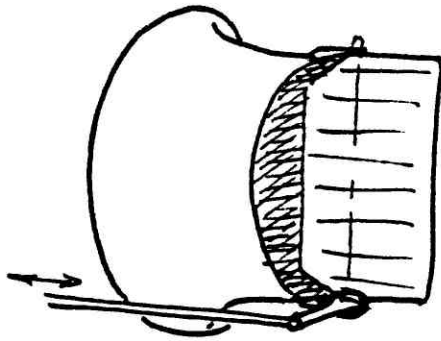
The rudder is also likely to need continuous input, so that either rudder and thrust throttle are in one hand (e.g. tiller bar with twist grip) or one hand rests on each (steering wheel and quadrant lever). Natural movements (throttle push for "go", pull back for "stop", natural steering, etc.) are quite essential. Engine controls should be sensibly placed, too. It is useless to have ignition key (with electric start), choke, and throttle placed far apart, so that a mere two-handed driver cannot start the machine.

Connections from these controls to the "works" need to be strong, well anchored, and reliable. Bowden or similar cable, push/pull rods, torque tubes, or pulley/cable all have their places.

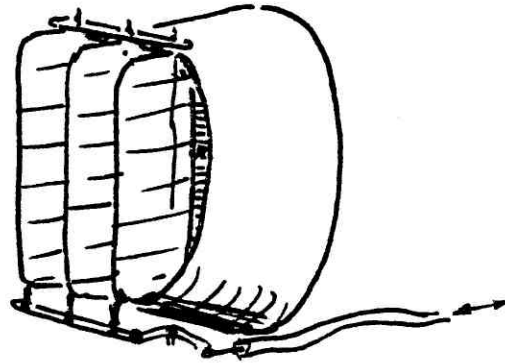
The rudder assembly is placed directly in the slipstream of the thrust fan, close up against the thrust duct. In the lightest craft, a single rudder may be used, but from two to four smaller rudders acting together provide much larger turning moment for less loss of thrust and muscular effort on the controls. This is simply because a "venetian blind" of vanes turns the jet of thrust air more efficiently than a single "barn door".

Any rudder needs to be mounted very firmly, in good bearings, as the blast of turbulent air from the fan hits it with great violence, and can rattle it to pieces very quickly if it is not very rigidly made and secured. The position of the pivots is also very critical, to avoid heavy loads on the driver's control. As a general guide, one can try pivoting the rudder 1/3 back from its leading edge, but a range of positions around this should be tried. It is most awkward to have a rudder which needs constant heavy force, and it is disconcerting to have one which is light up to a point and then whips hard over, leaving the craft in a spin while the driver rubs his knuckles.

The air coming off the thrust fan does so in a spiral (unless de-swirl vanes are fitted behind the fan) so it does not meet the rudder in a straight axial direction. It might therefore be an improvement to bend the rudder leading edge to pick up the swirling air cleanly, (one way at the top, the other way at the bottom of the duct). This swirl accounts for the very peculiar steering characteristics which have mystified some builders. However, try a simple rudder first, and work up to refinements later.



SIMPLE RUDDER.



3-RUDDER ASSEMBLY.

FIG. 22.

Thrust reversers take a number of forms. Probably the simplest to start thinking about is a pair of "buckets" which swing into the jet behind the thrust duct when a lever is pulled. These catch a portion of the jet and throw it out forward, thus giving either zero resultant thrust, or actual resultant reverse.

Clearly, if the driver is allowed to operate either bucket independently, he has a very powerful added steering mechanism here.

The use of these simple controls is dealt with in the section on driving technique.

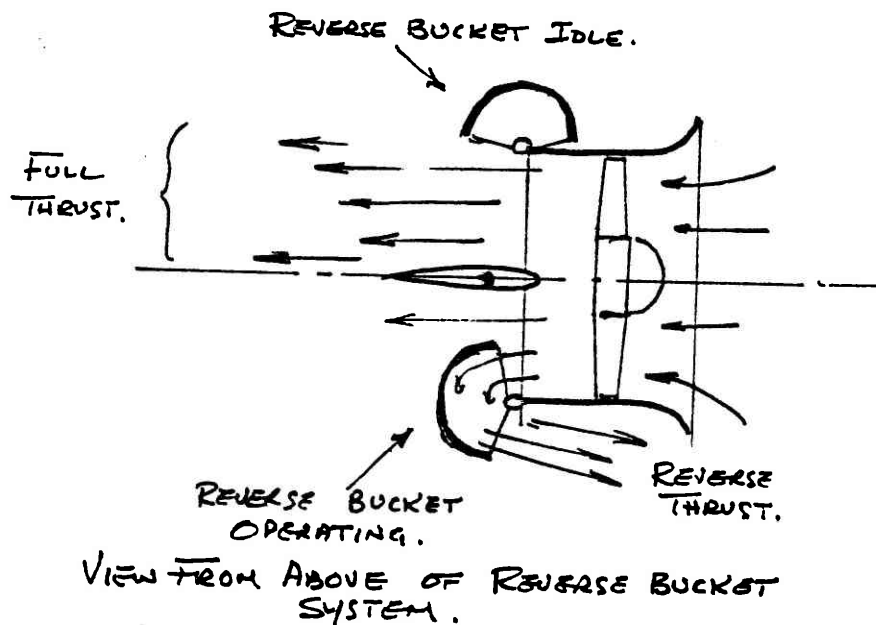


FIG. 23.

9. HULL

The hull has many functions. It is the framework which holds all the other components rigidly together, it is the airtight top of the air cushion cavity, it is a raft which floats, it is a boat which can be dropped into the water at high speed in any direction without going under or cartwheeling if the lift engine quits, it is a sled which can do the same thing on ground, and it weighs as little as possible.

A formidable list of requirements! There are many ways of laying out the hull as a structure. At one extreme, a stiff spine girder is used, with engine(s), driver, and fans mounted on it, and the "hull" is a light structure built out from the spine. In the middle-of-the-road, a rigid girder outer frame supports the skirt, and the driver, engines, fans, etc., are supported inside it.

At the other extreme, an inflated-boat is used, and the various components sit in it with a minimum of stiffening members.

In any event, there is the problem of anchoring a number of heavy concentrated loads and forces to a light structure. Some feeling for light aircraft construction is very useful here.

The design process has a number of distinct steps, so we will go through these, to see how a hull might evolve.

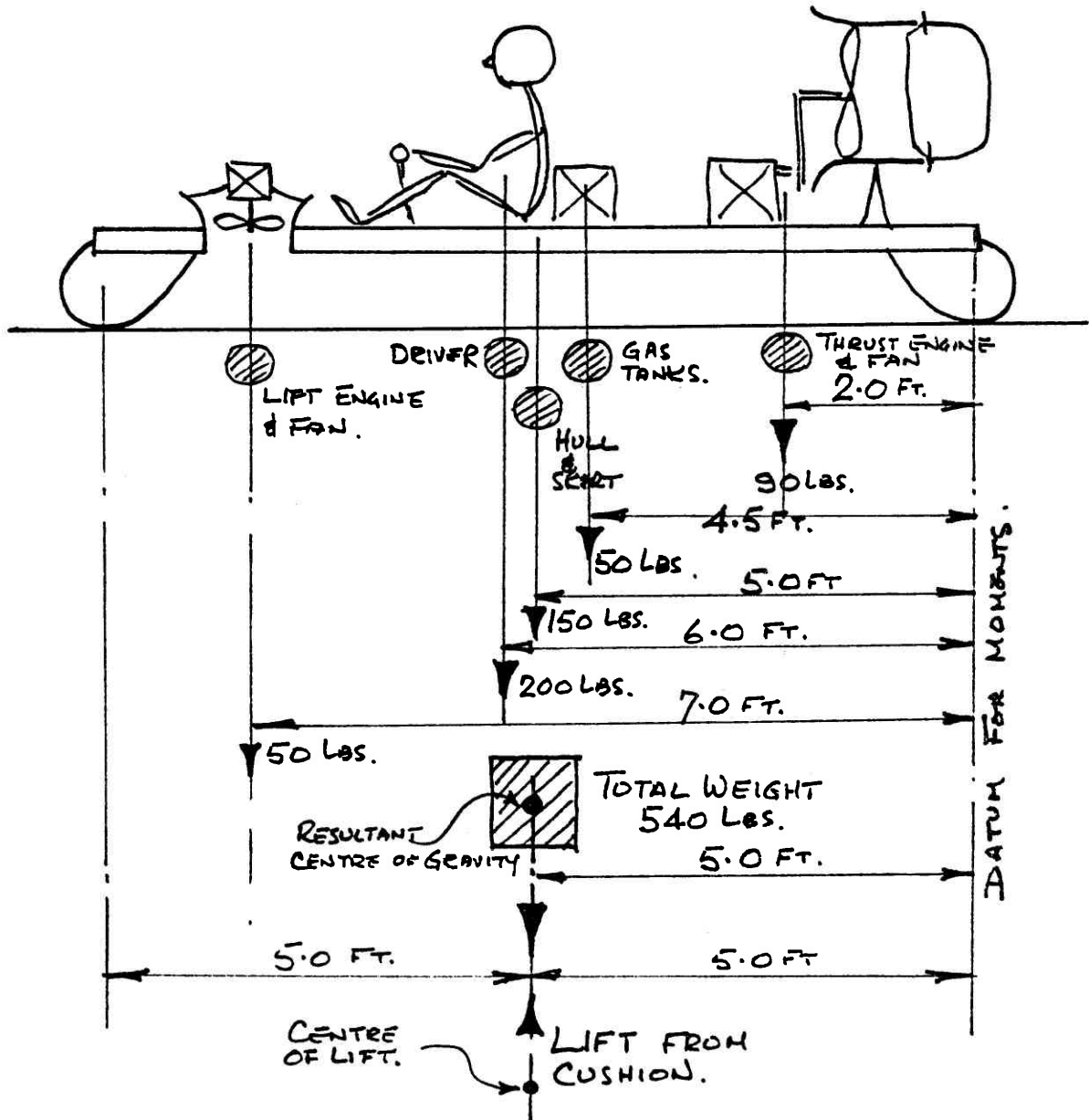


FIG. 24.

Layout of Components - Knowing the weight and size of the various components, and the overall size of craft, the position of each unit has to be decided so that the combined centre of gravity is on the centre of lift (the geometrical centre of the skirt footprint). This is done by taking moments about some convenient datum, for example the hull stern. An example is shown above using approximate numbers for the light single seat machine we have been considering.

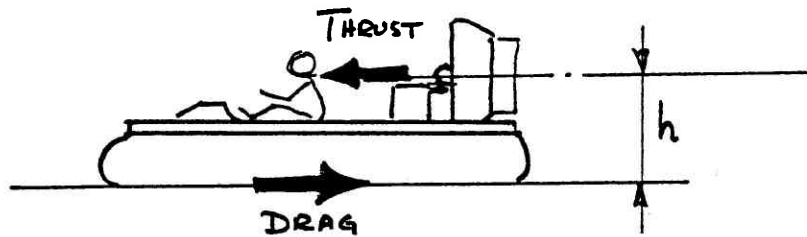
Taking moments about the stern datum,

$$(50 \times 7) + (200 \times 6.0) + (150 \times 5.0) + (50 \times 4.5) + (90 \times 2.0) = (540 \times 5.0)$$
$$\therefore 2705 = 2700 \text{ lbsxft}$$

This distribution is therefore satisfactory, but must be rechecked and modified if necessary as actual weights become available.

The driver and gas tanks are placed as near the CG as possible so that variations in their weight will have the least possible effect on the trim of the vehicle.

Since the thrust duct is high, and the main drag on the vehicle is at ground level, due to skirt/terrain interaction, thrust will exert nose-down moment on the craft. It is often useful to trim the craft a little tail heavy to reduce this effect.

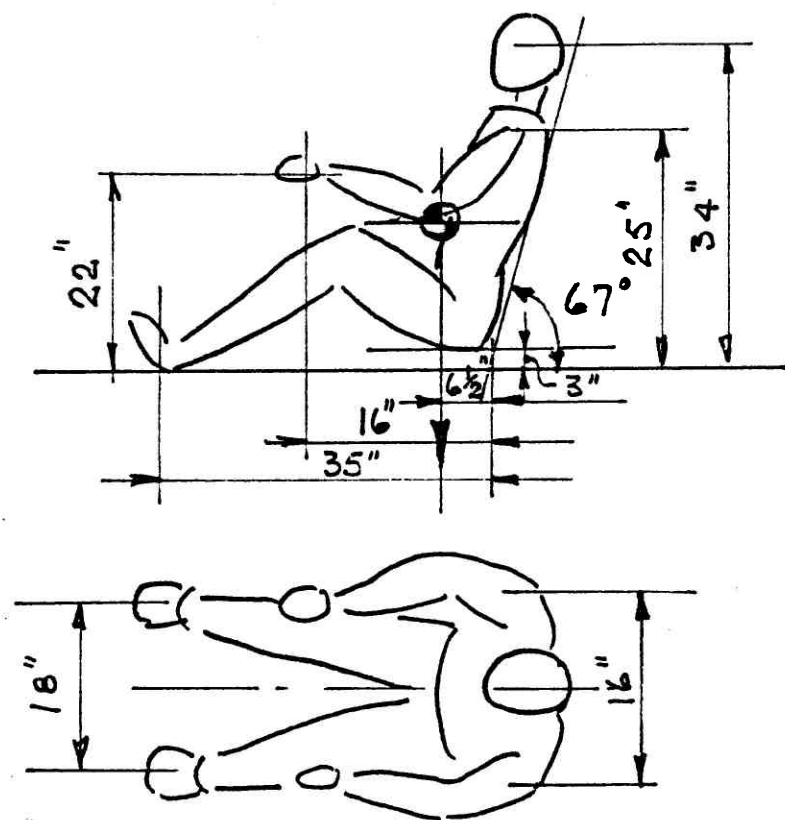


$$\text{THRUST} = \text{DRAG} = T \text{ lbs.}$$

FIG. 25.

The nose-down moment = Txh lbs ft. It is quite useful to misplace the CG of the vehicle aft so as to leave a nose-up out-of-balance = $\frac{Txh}{2}$ in the previous calculation, otherwise when attempting to accelerate at full thrust, the nose is apt to dig in and acceleration is very poor.

The "component" whose shape, CG, and dimensions are least known is usually the driver. The size and shape of an average adult driver are shown below. Various schools of thought place the driver riding high, as in a motorcycle, or sitting low as in a racing car. The latter position keeps the craft CG low, increasing stability, and reduces aerodynamic drag and pressure losses at the thrust fan intake.



DIMENSIONS OF TYPICAL 6' DRIVER.

FIG. 26.

Opinions vary, again, but the present writer considers it essential to have at least a standard automobile lap-belt (with quick release) and to use it over land. Over water it is usually not used. In any case, a motorcycle helmet is always worn. The present writer also insists on a strong roll-bar behind the pilot's head. Nobody wants to get thrown out of an ACV over land for want of a seat belt, or trapped under an overturned craft on land or underwater for lack of a roll-bar or belt quick-release.

Needless to say, all the items of equipment, -- engines, gas tanks, battery, driver's seat, etc., must be very firmly anchored to the main frame of the hull. Nobody wants these heavy objects flying loose if the hull hits a rock or stump and stops suddenly.

Hull Shape - The main requirement for the hull shape is that the bottom should be flat, with protruding landing pads or skids (so that it is not punctured by odd stones, etc., when sitting on the ground) and gently sloping sides, bow, and stern (so that in whatever direction it is moving or skidding, in the event of loss of lift it rides up over water or ground, rather than digging in). The bow is often given a raised form, to enable the craft to rise over waves easily, and enter the water safely from a sloping ramp.

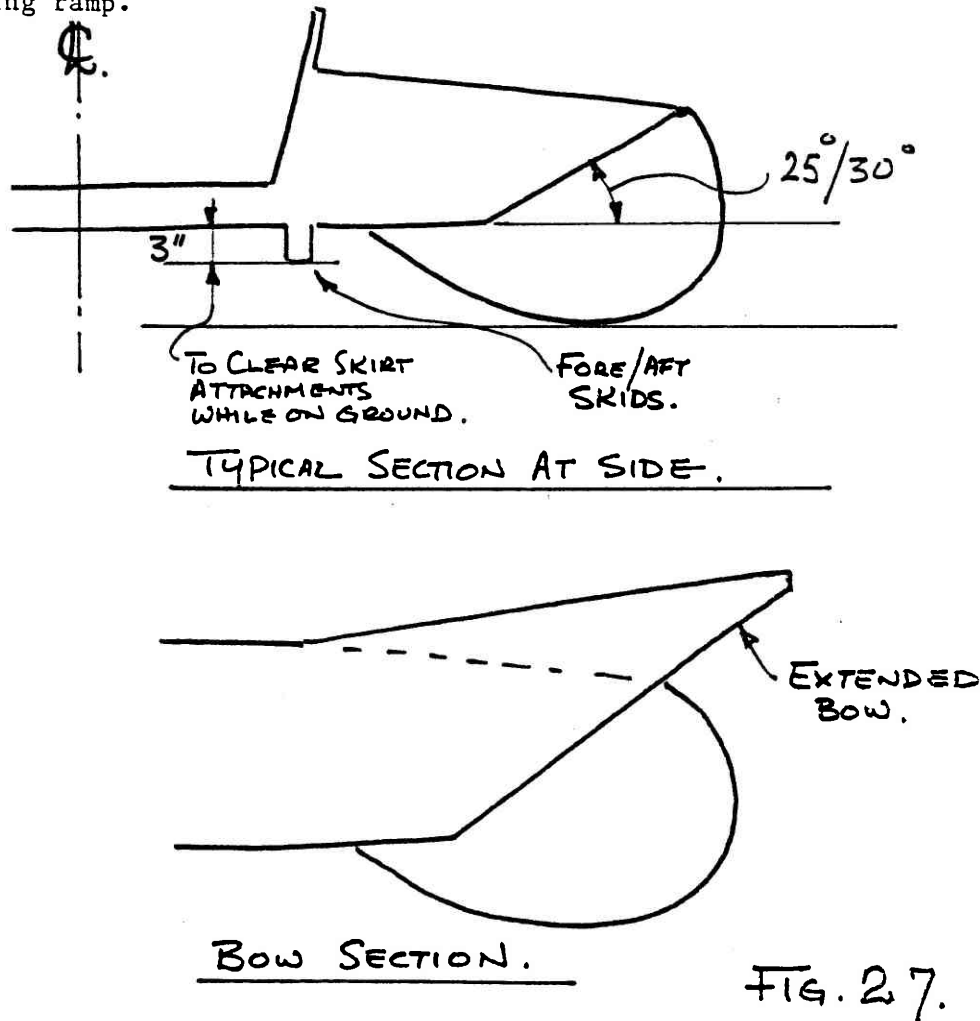
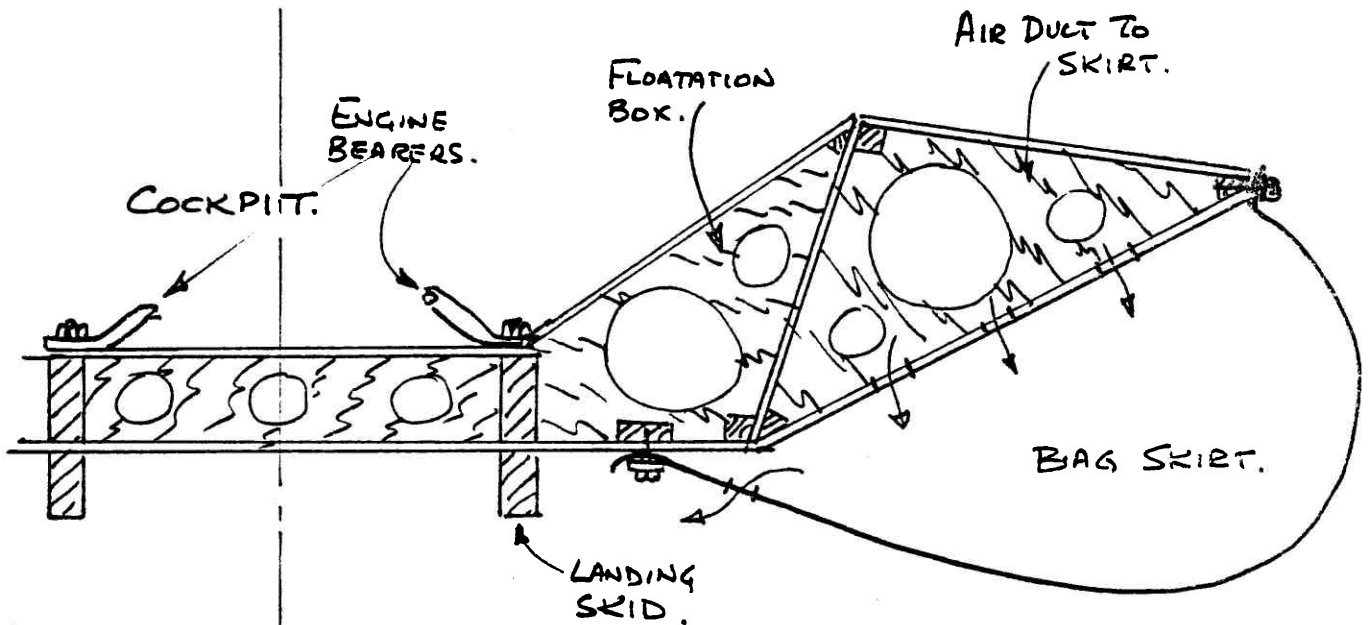


FIG. 27.

Hull Structure - As was remarked earlier, there are many ways of building the hull. An increasing number of builders in Britain are forming groups to build moulds to make fibreglass hulls, larger (6-10 seat) vehicles are often built of rivetted aluminum, and small commercial craft are built very successfully on the inflatable-boat principle. However, most amateur craft are built of 1/8" plywood, with fibreglass tape reinforcement at joints, and 1" x 1" framework added to distribute concentrated loads. Engine mounts are usually of thin-walled steel tubing, with carefully fabricated plugged ends and attachments. Welding has to be done well, to withstand continuous vibration and to avoid ruining the properties of the tubing by overheating. Glueing should be done with the best waterproof glue obtainable, and the plywood should be of the exterior grade. Even a nominally "overland only" craft is going to get wet at times.



ALL BULKHEADS HAVE HOLES

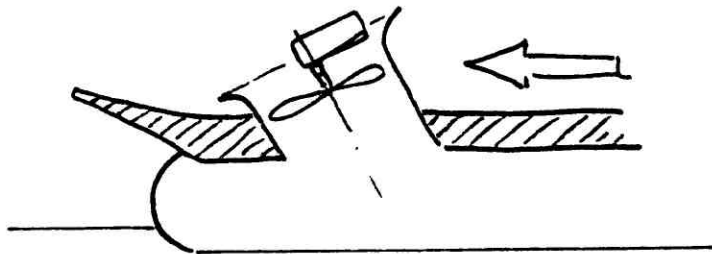
FIG. 28.

FOR LIGHTNESS, & TO DUCT AIR TO SKIRT.

In order to combine the various requirements set out above, a possible hull might have a typical cross section as shown in Fig. 28.

The floatation boxes are airtight compartments, whose enclosed volume of air will give 62 lbs of buoyancy per cubic foot of water displaced when immersed. The machine should contain such buoyancy equal to 150% of its total loaded weight. The use of foam blocks to achieve this is not wise, since the foam will absorb water in time. In one case a 500 lb machine gained an extra 400 lbs of weight in this way in two years. If you must use foam blocks, they must be sealed into plastic bags, and should be inspected at intervals to see that the bags have not got punctured. However, sealed tanks formed by hull members, or filled with inflated bags, are far better. Even sealed tanks can leak and take in water, so they should have inspection covers which are opened from time to time, to ventilate against "dry rot" as well as to check for the absence of leaks. All in all, inflated air bags are the best way of providing buoyancy.

It is essential to note that the bow of an over water craft has to deal with wave impacts. Any airfeed holes in this area should be small (less than 3" diameter) so that the skirt cannot get pushed back through them. If the lift fan blows straight down into the cushion, its duct should be sloped back, so that water cannot easily get forced up into the fan in a rough landing.



LIFT FAN MOUNTED AT ANGLE
TO AVOID WATER INGESTION.

FIG. 29.

10. TRAILER

Unless the machine can be operated straight out of your back door, a trailer is almost essential. This can be very simple, but must be fully road worthy, and needs a licence.

The best approach is to buy the hardware from the local auto parts store and mount a flat plywood deck on it. Walls 1 ft high round the sides and front end help to prevent the craft sliding off while it is being hovered off and on, and the space inside the walls needs to be a few inches wider than the inflated skirt. However, the 8 ft maximum vehicle width in force in almost all provinces should be checked and adhered to.

To get the craft on and off, it is almost essential to tilt the trailer deck, and the tilting point must be chosen carefully to give stability. Probably a detachable or slide-out ramp at the tail end will be needed also. Strong tie-down points to secure the craft are also required, capable of holding the craft firmly during emergency stops or turns.

11. DRIVING

You have got to understand that the ACV is not a magic carpet which can go anywhere. It has limits, which are quite severe with a small craft, but they are different from those of other vehicles.

It can go over smooth land and water, but not over very rough land or water. It can go over moderately rough land, with occasional potholes, much faster than a wheeled vehicle, without shaking the driver's teeth out. But loose gravel or pebbles, or long grass, soak up all the lift air and bring it abruptly to a halt. It has too little thrust to climb steep hills, except short slopes which it can take a run at. It is very difficult to manage in a cross-slope or cross-wind, and may need to be "crabbed" along at up to 45° or so to its direction of motion to keep on course. You need to start a turn well in advance, as it is slow to answer to the controls. Always "think 50 yards ahead"!

It has no brakes! It is much easier to start than to stop, so slow down far ahead of your intended stopping point.

And most of all, beware of running down wind! It is very difficult indeed to stop, and you have very little control at all. "Tack" across wind like a sailing boat, if you have to go down wind.

Snow, too, has its problems. If it is soft and deep it is very easy to dig a deep pit and stay there. If it is hard and glazed, you may set up a new land speed record, until you meet some trees or boulders!

Now, how do you start to learn to drive?

Hovering - First find a really flat level piece of ground, preferably with very short grass or asphalt, and without loose dust or sand. Get the craft to the middle of the site by setting the lift engine to hover it, and towing it. Don't get fingers near lift (or thrust) fans, don't let any bits of rope loose near the fans, and don't let a hat or scarf get near them.

Then, with the craft on the ground and the lift engine ticking over, get in, strap yourself in, with bike helmet on, look round carefully, and start lesson one. Slowly advance the lift throttle and notice the rpm at which the craft begins to stir, and at which it lifts off properly. Lower the rpm and let it settle back gently. Try this a few times, and then set it at hover.

Have someone see that the skirt is developed properly all round, and is not vibrating.

With yourself properly seated, have someone check that the craft hovers level. It probably doesn't, so adjust the centre of gravity by adding some ballast until it does. Note the weight and position of the ballast accurately, and have it fixed in position permanently as soon as this test is finished.

Now lean far to one side. The craft will roll that way, and probably begin to drift in that direction due to lift air escaping on the opposite side. This is worth remembering; if the thrust engine quits over water you can get to shore this way!

Beginning to Move - Put the machine in the middle of the large flat space again, and have everyone else get well clear. Check that the lift engine tank contains at least as much fuel as the thrust engine tank. If the thrust engine runs out and quits, no great harm is done, but if the lift engine quits at full speed a very fierce stop with skirt and hull damage, if not an overturn, can result. When you are strapped in, with helmet on, and both engines idling, look round carefully. This "looking round" is most important, and particularly necessary before starting either engine. Helpers have a habit of fussing round the thrust fan, behind your back, just when you want to start it. Look round first.

Now, bring the machine up gently onto hover, and then notice that even low thrust will edge the machine forward. At full lift rpm it moves easily, at low lift rpm it scuffs along with difficulty. Reducing lift is therefore a way of braking, but it wears out the precious skirt very quickly and also reduces stability so that the craft can nose over and dig in. DO NOT reduce lift when moving fast, over water or land. You will stop alright, but maybe upside down!

Now try the rudder. At low thrust rpm it is fairly useless, so give a burst of thrust and see how it immediately becomes effective.

Try full rudder at low thrust, and slowly increase thrust a little so that you turn round in a full circle. Try this both to left and to right. You may find one way much easier than the other (due to fan exit swirl hitting the rudder unevenly). Remember this. In an emergency, a 270° turn one way may be quicker than a 90° the other.

You will find the craft changes course slowly, although it points in the new direction quite quickly. You will also find that once it is swinging, it needs a touch of opposite rudder to stop the swinging. A lot of practise at low speed is needed before you start going anywhere.

Stopping - We have already seen that lowering lift rpm will drag the skirt and slow the craft down, but at the expense of skirt wear and some loss of stability. Never do this when moving fast, over land or water. Decide well ahead where you want to stop, reduce thrust well ahead, slow down, and then reduce lift at the end and settle gently.

If there is a wind (or a slope) and you have enough room, go round to down wind of the stopping place and approach it up wind (or uphill). Come in slowly, reduce speed to a crawl, lower the craft onto the ground and switch off.

If you must stop in a hurry, the 180° spin is the answer. Try it slowly, first. Moving slowly forward, keep on full lift, put on hard rudder and give a blast of throttle. As you spin round, at about 120° put on full opposite rudder to stop the spin, with another blast of throttle. This should leave you heading at 180° and moving backwards (i.e. still on the original course). Now keep the rudder central and give full thrust until you come to a standstill.

Try this gently and slowly, over smooth ground, with plenty of room, and do not reduce lift power. It is an emergency procedure, but it needs to be practised.

Slopes or Winds - Going up a hill is easy. Going across a slope is more difficult. Coming down a hill is not at all easy until you know how. The same goes for upwind, cross wind, and down wind.

Try it on a gentle hill. Start on the flat ground at the bottom, going at a smart walking pace towards the hill, and keep on up it. If you lose speed and slide backwards, there is no problem. Keep headed up the slope and slide slowly backwards down to the bottom. If you want to stop on the slope, reduce lift to set the craft down first, and cut the thrust afterwards, otherwise you will slide back while the lift is decaying, which may take 10 seconds or so.

To run across the slope, point up it and then use the rudder momentarily to turn off a bit in the intended direction. You will then crab sideways across the hill side, adjusting heading and thrust to keep on course.

Downhill is the difficult direction. If the hill is gentle and the ground not too abrasive, go down forwards at very low lift, dropping completely onto the ground if the speed begins to build up. If the hill is steeper, do a 180° turn at the top and go down backwards using thrust as a brake. Again, if speed builds up, drop the craft on its skids with the thrust still on.

Running down wind, especially over water, is quite hazardous. You only have control when you have a fair thrust on, and the speed then rises alarmingly. And any attempt at turning is likely to drop the nose in and roll the craft at high speed. Any attempt to reduce lift and drag the skirt will lose stability and make the roll inevitable. A down wind course should therefore be run as a series of cross wind "tacks". If the wind is really strong, the turn from one tack to the next should be 270° through the wind, not 90° down wind.

Overwater - Overwater the seat belt is often not used, the helmet is sometimes left off, but a life jacket is always worn. If the water is cold, an exposure suit is strongly advisable. A person can live only for a few minutes in near-freezing water. Snowmobile suits, incidentally, are death traps in water. They are not waterproof, and the thick lining absorbs many pounds of water in a few moments, dragging the wearer down. A yachtsman's "exposure suit" is the answer in cold weather.

As explained earlier in Section 7 (thrust) a craft can be driven below hump speed (say 5 mph or less) or above hump, say 8 mph or more. Below hump is used only in restricted spaces or in coming alongside moorings or ramp. It usually generates a lot of spray, which erodes the fans, and wastes power.

If the craft has proper thrust installed, it should accelerate through hump, lose its spray and wake, and surge forward without difficulty. It may perhaps help if the driver moves forward in his seat in the process. When starting on the water, the craft is first gradually lifted, with a little thrust to keep the spray away from the bow, until all the water is drained out of the skirt. Then the lift is throttled back and full thrust applied. When at full thrust, full lift is given, the craft pops up, and is away with a minimum of spray. This is important, as if lift is opened up first the craft sits surrounded by spray which soaks the driver and erodes the fan until thrust builds up enough to get it moving. Pointing the craft into the wind helps to give the driver a clear view.

When making a turn over water, the speed drops. Therefore when above hump speed, make only gentle turns, otherwise you may fall below hump speed and drop into the water with a splash and a sudden deceleration. If this is done in a turn it can very well lead to a "plough-in", where the leading outer corner of the craft digs into the water and can even cause an over-turn. This is almost inevitable if lift air is reduced, softening the cushion.

And remember that turns will be very flat and skidding, needing a lot of room.

It is because the ACV can skid sideways or backwards that a flashing yellow light is required on top of it, to warn other mariners that port and star-board lights do not necessarily give any clue as to the craft's course.

To get into or out of the water it is essential to have a gently sloping beach or ramp. The craft cannot be expected to climb up a step or a steep bank. When starting from a beach, provided the beach and water are clear of obstructions, boats, or swimmers, go down the beach fast and the craft will already be over hump speed when it reaches the water, giving an excellent spray-free start.

Over Snow and Ice - If ice surface is smooth, the drag on the skirt is very small and very high speeds can be reached. However, manoeuvring power is minimal, and stopping or obstacle avoidance requires a great distance. Coming off ice onto water at high speed leads to a sudden increase in drag, which can cause a fatal nose-in.

Snow with a glazed surface will usually support the craft, just like ice.

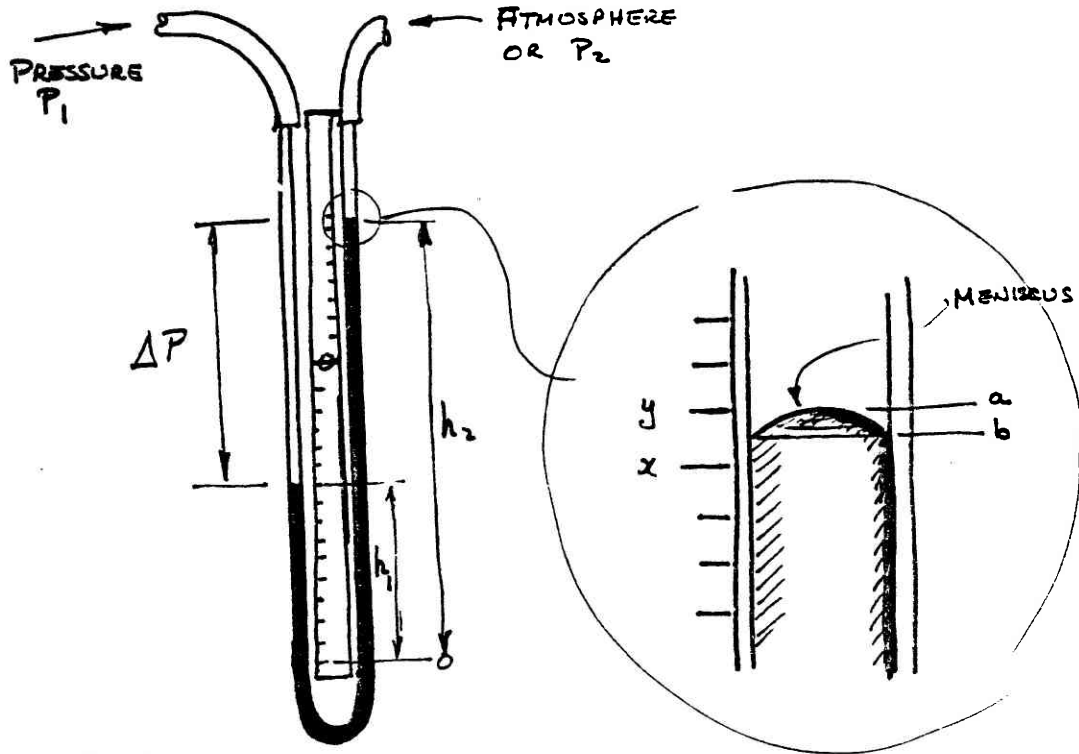
Fluffy or damp snow is difficult to traverse. It blows up in a great cloud, and the craft quickly digs itself a hole, out of which it is difficult to get it to climb. Also the blowing snow can erode the propeller badly. A start in such conditions should be made as when over water; full thrust is applied first and then the lift throttle is opened quickly, so that the vehicle immediately moves forward, instead of digging itself in.

For safety, in harsh climatic or terrain conditions, vehicles should operate in pairs, and a trip plan should be left with a responsible person, who will check after arrival time to see that the machine and crew are safe.

It is also to be remembered that over water at freezing temperatures, the spray builds up on the craft as ice. The craft weight can increase to the point at which it will no longer hover, and engine or rudder controls can freeze.

An ACV driven with care and forethought is a unique vehicle and can be great fun. Driven carelessly or without proper planning, it can be annoying, frightening, and even fatal to you, to others, and cause a ban on the machines in general.

12. THE "U"-TUBE MANOMETER



"U"-TUBE MANOMETER OR PRESSURE GAUGE.

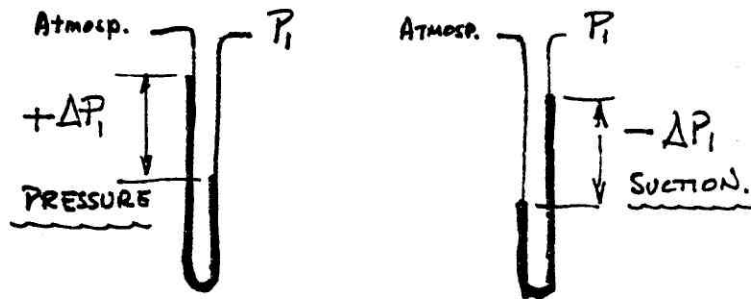


FIG. 30.

Always measure to the same point on the meniscus of the surface of the liquid in both columns. For example, in the enlarged view at the right, if we measure always at the top of the meniscus, the reading will be y.0" (opposite a). If we measure to the bottom of the meniscus, the reading will be x.5" (opposite b).

In the manometer shown on the left, either we can measure both arms from a zero near the bottom of the scale, so that the pressure difference $\Delta P = h_2 - h_1$ of water; or we can measure ΔP directly.

Note that P_1 is at a higher pressure than P_2 . The lower figures show the difference between positive pressure and suction (negative pressure) relative to atmosphere.

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