DESIGN, CONSTRUCTION AND TESTING OF AN AIR CUSHION VEHICLE (ACV)

Project Report submitted in *partial fulfillment* of the requirement of the

Degree of

Bachelors in Engineering

By

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DECLARATION

We declare that this written submission represents our ideas in our own words and where other's Ideas or words have been included, we have adequately cited and referenced the original sources. We also declare that we have adhered to all principles of academic honesty and integrity and have not misrepresented or fabricated or falsified any idea/data/fact/source in our submission. We understand that any violation of the above will be cause for disciplinary action by the Institute and can also evoke penal action from the sources which have thus not been properly cited or from whom proper permission has not been taken when needed**.**

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ABSTRACT

The design and development of a hovercraft with full hovercraft basic functions is reported. The design process is quite similar to that of boat and aircraft. In-depth research was carried out to determine the components of a hovercraft system and their basic functions; and in particular its principle of operation. Detailed design analysis was done to determine the size of component parts, quite in accordance with relevant standard requirements as applicable in the air cushion model. Test performance was carried out and the design was found to meet design expectations giving an air cushion of 0.5 inches.

A hovercraft is a vehicle that hovers just above the ground, or over snow or water, by a 'cushion of air' (Spedding, 2001). Also known as air cushion vehicle, it is a craft capable of travelling over land, water or ice and other surfaces both at speed, and when stationary. It operates by creating a cushion of high pressure air between the hull of the vessel and the surface below. Typically this cushion is contained between a flexible skirt. Hovercrafts are hybrid vessels operated by a pilot as an aircraft rather than a captain as a marine vessel. They typically hover at heights between 200mm and 600mm above any surface and can operate at speeds above 37km per hour. Locations which are not easily accessible by landed vehicles due to natural phenomena are best suited for hovercrafts. Today they are commonly used as specialized transport in disaster relief, coast ground military and survey applications as well as for sports and passenger services. Very large versions have been used to transport tanks, soldiers and large equipment in hostile environment and terrain. In riverine areas, there is great need for a transport system that would be fast, efficient, safe and low in cost. Time is spent in transferring load from landed vehicle to a boat. With hovercraft there is no need for transfer of goods since it operates both on land and water. It is said to be faster than a boat of same specifications which makes it deliver service on time.

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Chapter 1

Introduction

A hovercraft is a vehicle that hovers just above the ground, or over snow or water, by a 'cushion of air' (Spedding, 2001). Also known as air cushion vehicle, it is a craft capable of travelling over land, water or ice and other surfaces both at speed, and when stationary. It operates by creating a cushion of high pressure air between the hull of the vessel and the surface below. Typically this cushion is contained between a flexible skirt. Hovercrafts are hybrid vessels operated by a pilot as an aircraft rather than a captain as a marine vessel. They typically hover at heights between 200mm and 600mm above any surface and can operate at speeds above 37km per hour. Locations which are not easily accessible by landed vehicles due to natural phenomena are best suited for hovercrafts. Today they are commonly used as specialized transport in disaster relief, coast ground military and survey applications as well as for sports and passenger services. Very large versions have been used to transport tanks, soldiers and large equipment in hostile environment and terrain. In riverine areas, there is great need for a transport system that would be fast, efficient, safe and low in cost. Time is spent in transferring load from landed vehicle to a boat. With hovercraft there is no need for transfer of goods since it operates both on land and water. It is said to be faster than a boat of same specifications which makes it deliver service on time.

The first practical design for hovercraft derived from a British invention in the 1950s to 1960s. They are now used throughout the world as specialized transports in disaster relief, coastguard, military and survey applications as well as for sport or passenger service. Very large versions have been used to transport hundreds of people and vehicles across the English Channel, whilst others have military applications used to transport tanks, soldiers and large equipment in hostile environments and terrain.

Although now a generic term for the type of craft, the name *Hovercraft* itself was a trademark owned by Saunders-Roe (later British (BHC), then Westland), hence other manufacturers' use of alternative names to describe the vehicles.

Chapter 2

Review of Literature

2.1 Commercial

The British aircraft and marine engineering company Saunders-Roe built the first practical man-carrying hovercraft for the National, the SR.N1, which carried out several test programmers in 1959 to 1961 (the first public demonstration was in 1959), including a cross-channel test run in July 1959, piloted by Peter "Sheepy" Lamb, an ex-naval test pilot and the chief test pilot at Saunders Roe. Christopher Cockerell was on board, and the flight took place on the 50th anniversary of Louis Blériot's first aerial crossing

The SR.N1 was powered by a single piston engine, driven by expelled air. Demonstrated at the Farnborough Airshow in 1960,it was shown that this simple craft could carry a load of up to 12 marines with their equipment as well as the pilot and co-pilot with only a slight reduction in hover height proportional to the load carried. The SR.N1 did not have any skirt, using instead the peripheral air principle that Christopher had patented. It was later found that the craft's hover height was improved by the addition of a skirt of flexible fabric or rubber around the hovering surface to contain the air. The skirt was an independent invention made by a Royal Navy officer, C.H. Latimer-Needham, who sold his idea to Westland (by then the parent of Saunders-Roe's helicopter and hovercraft interests), and who worked with Christopher to develop the idea further.

During the 1960s, Saunders-Roe developed several larger designs that could carry passengers, including the SR.N2, which operated across the Silent, in 1962, and later the SR.N6, which operated across the Silent from Southsea to Ryde on the Isle of Wight for many years. In 1963 the, SR.N2 was used in experimental service between Weston-super-Mare and Penarthunder the aegis of P & A Campbell, the paddle steamer operators.

Operations by Hovertravel commenced on July 24, 1965, using the SR.N6, which carried 38 passengers.[15] Two 98 seatAP1-88 hovercraft were introduced on this route in 1983, and in 2007, these were joined by the first 130-seat BHT130 craft. The AP1-88 and the BHT130 were notable as they were largely built by Hoverwork using shipbuilding techniques and materials (i.e. welded aluminum structure and diesel engines) rather than the aircraft techniques used to build the earlier craft built by Saunders-Roe-British Hovercraft Corporation. Over 20 million passengers had used the service as of 2004 – the service is still operating (2015) and is by far the longest, continuously operated hovercraft service.

In 1966, two cross-channel passenger hovercraft services were inaugurated using SR.N6 hovercraft. Hoverlloyd ran services from Ramsgate Harbour, England, to Calais, France, and Townsend Ferries also started a service to Calais from Dover, which was soon superseded by that of Seaspeed.

As well as Saunders-Roe and Vickers (which combined in 1966 to form the British Hovercraft Corporation (BHC)), other commercial craft were developed during the 1960s in the UK by Cushioncraft (part of the Britten-Norman Group) and Hovermarine based at Woolston (the latter being sidewall hovercraft, where the sides of the hull projected down into the water to trap the cushion of air with normal hovercraft skirts at the bow and stern). One of these models, the HM-2, was used by Red Funnel between Southampton (near the Woolston Floating Bridge) and Cowes

The first passenger-carrying hovercraft to enter service was the Vickers VA-3, which, in the summer of 1962, carried passengers regularly along the north Wales coast from Moreton, Merseyside, to Rhyl. It was powered by two turboprop aero-engines and driven by propellers. The world's first car-carrying hovercraft was made in 1968, the BHCMountbatten class (SR.N4) models, each powered by four Bristol Proteusturboshaft engines. These were both used by rival operators Hoverlloydand Seaspeed (joined to form Hoverspeed in 1981) to operate regular car and passenger carrying services across the English Channel. Hoverlloyd operated from Ramsgate, where a special hoverport had been built at Pegwell Bay, to Calais. Seaspeed operated from Dover, England, to Calais and Boulogne in France. The first SR.N4 had a capacity of 254 passengers and 30 cars, and a top speed of 83 kn (154 km/h). The channel crossing took around 30 minutes and was run like an airline with flight numbers. The later SR.N4 Mk.III had a capacity of 418 passengers and 60 cars to the Isle of Wight. These were later joined by the French-built SEDAM N500 Naviplane with a capacity of 385 passengers and 45 cars; only one entered service and was used intermittently for a few years on the cross-channel service until returned to SNCF in 1983. The service ceased in 2000 after 32 years, due to competition with traditional ferries, catamaran, the disappearance of duty-free shopping within the EU, the advancing age of the SR.N4 hovercraft and the opening of the Channel Tunnel.

The commercial success of hovercraft suffered from rapid rises in fuel prices during the late 1960s and 1970s, following conflict in the Middle East. Alternative over-water vehicles, such as wave-piercing catamarans (marketed as the SeaCat in the UK until 2005), use less fuel and can perform most of the hovercraft's marine tasks. Although developed elsewhere in the world for both civil and military purposes, except for the Solent Ryde to Southsea crossing, hovercraft disappeared from the coastline of Britain until a range of Griffon Hovercraft were bought by the Royal National Lifeboat Institution.

2.2 Civilian Non Commercial

In Finland, small hovercraft are widely used in maritime rescue and during the rasputitsa ("mud season") as archipelagoliaison vehicles. In England, hovercraft of the Burnham-on-Sea Area Rescue Boat (BARB) are used to rescue people from thick mud in Bridgwater Bay. Avon Fire and Rescue Service became the first Local Authority fire service in the UK to operate a hovercraft. It is used to rescue people from thick mud in the Weston-super-Mare area and during times of inland flooding. A Griffon rescue Hovercraft has been in use for a number of years with the Airport Fire Service at Dundee Airport in Scotland. It is used in the event of an aircraft ditching in the Tay estuary. Numerous fire departments around the U.S./Canadian Great Lakes operate hovercraft for water and ice rescues, often of ice fisherman stranded when ice breaks off from shore.

In October 2008, The Red Cross commenced a flood-rescue service hovercraft based in Inverness, Scotland.[19]Gloucestershire Fire and Rescue Service received two flood-rescue hovercraft donated by Severn Trent Water following the 2007 UK floods.[20]

Since 2006, hovercraft have been used in aid in Madagascar by HoverAid, an international NGO who use the hovercraft to reach the most remote places on the island.[21] The Scandinavian airline SAS used to charter an AP1-88 hovercraft for regular passengers between Copenhagen Airport, Denmark, and the SAS Hovercraft Terminal in Malmö, Sweden.

In 1998, the US Postal Service began using the British built Hoverwork AP1-88 to haul mail, freight, and passengers from Bethel, Alaska, to and from eight small villages along theKuskokwim River. Bethel is far removed from the Alaska road system, thus making the hovercraft an attractive alternative to the air based delivery methods used prior to introduction of the hovercraft service. Hovercraft service is suspended for several weeks each year while the river is beginning to freeze to minimize damage to the river ice surface. The hovercraft is able to operate during the freeze-up period; however, this could potentially break the ice and create hazards for villagers using their snowmobiles along the river during the early winter.

An experimental service was operated in Scotland across the Firth of Forth (between Kirkcaldy and Portobello, Edinburgh), from 16 to 28 July 2007. Marketed as Forthfast, the service used a craft chartered from Hovertravel and achieved an 85%passenger load factor. As of 2009, the possibility of establishing a permanent service is still under consideration.[22]

Since the channel routes abandoned hovercraft, and pending any reintroduction on the Scottish route, the United Kingdom's only public hovercraft service is that operated by Hovertravel between Southsea (Portsmouth) and Ryde on the Isle of Wight.

From the 1960s, several commercial lines were operated in Japan, without much success. In Japan the last commercial line had linked Ōita Airport and central Ōita but was shut down in October 2009.

2.3 Recreational and Sports

Small commercially manufactured, kit or plan-built hovercraft are increasingly being used for recreational purposes, such as inland racing and cruising on inland lakes and rivers, marshy areas, estuaries and inshore coastal waters.

The Hovercraft Cruising Clubsupports the use of hovercraft for cruising in coastal and inland waterways, lakes and lochs.

The Hovercraft Club of Great Britain, founded in 1966, regularly organizes inland and coastal hovercraft race events at various venues across the United Kingdom.

In August 2010, the Hovercraft Club of Great Britain hosted the World Hovercraft Championships at Towcester Racecourse. The World Hovercraft Championships are run under the auspices of the World Hovercraft Federation. Similar events are also held in Europe and the US.

Apart from the craft designed as "racing hovercraft", which are often only suitable for racing, there is another form of small personal hovercraft for leisure use, often referred to as cruising hovercraft, capable of carrying up to four people. Just like their full size counterparts, the ability of these small personal hovercraft to safely cross all types of terrain, (e.g. water, sandbanks, swamps, ice, etc.) and reach places often inaccessible by any other type of craft, makes them suitable for a number of roles, such as survey work and patrol and rescue duties in addition to personal leisure use. Increasingly, these craft are being used as yacht tenders, enabling yacht owners and guests to travel from a waiting yacht to, for example, a secluded beach. In this role, small hovercraft can offer a more entertaining alternative to the usual small boat and can be a rival for the jet-ski. The excitement of a personal hovercraft can now be enjoyed at "experience days", which are popular with families, friends and those in business, who often see them as team building exercises. This level of interest has naturally led to a hovercraft rental sector and numerous manufacturers of small, ready built designs of personal hovercraft to serve the need.

Chapter 3

Brief History

3.1 First Successful Hovercraft

The idea of the modern hovercraft is most often associated with a British mechanical engineer Sir Christopher Cockerell. Cockerell's group was the first to develop the use of an annular ring of air for maintaining the cushion, the first to develop a successful skirt, and the first to demonstrate a practical vehicle in continued use.

Cockerell came across the key concept in his design when studying the ring of airflow when high-pressure air was blown into the annular area between two concentric tin cans, one coffee and the other from cat food. This produced a ring of airflow, as expected, but he noticed an unexpected benefit as well; the sheet of fast moving air presented a sort of physical barrier to the air on either side of it. This effect, which he called the "momentum curtain", could be used to trap high-pressure air in the area inside the curtain, producing a high-pressure plenum that earlier examples had to build up with considerably more airflow. In theory, only a small amount of active airflow would be needed to create lift and much less than a design that relied only on the momentum of the air to provide lift, like a helicopter. In terms of power, a hovercraft would only need between one quarter to one half of the power required by a helicopter.

Cockerell built several models of his hovercraft design in the early 1950s, featuring an engine mounted to blow from the front of the craft into a space below it, combining both lift and propulsion. He demonstrated the model flying over many Whitehall carpets in front of various government experts and ministers, and the design was subsequently put on the secret list. In spite of tireless efforts to arrange funding, no branch of the military was interested, as he later joked, "the navy said it was a plane not a boat; the air force said it was a boat not a plane; and the army was 'plain not interested.

3.2 SR.N1

This lack of military interest meant that there was no reason to keep the concept secret, and it was declassified. Cockerell was finally able to convince the National Research Development Corporation to fund development of a full-scale model. In 1958, the NRDC placed a contract with Saunders-Roe for the development of what would become the SR.N1, short for "Saunders-Roe, Nautical 1".

The SR.N1 was powered by a 450 hp Alvis Leonides engine powering a vertical fan in the middle of the craft. In addition to providing the lift air, a portion of the airflow was bled off into two channels on either side of the craft, which could be directed to provide thrust. In normal operation this extra airflow was directed rearward for forward thrust, and blew over two large vertical rudders that provided directional control. For low-speed manoeuvrability, the extra thrust could be directed fore or aft, differentially for rotation.

The SR.N1 made its first hover on 11 June 1959, and made its famed successful crossing of the English Channel on 25 July 1959. In December 1959, the Duke of Edinburgh visited Saunders-Roe at East Cowes and persuaded the chief test-pilot, Commander Peter Lamb, to allow him to take over the SR.N1's controls. He flew the SR.N1 so fast that he was asked to slow down a little. On examination of the craft afterwards, it was found that she had been dished in the bow due to excessive speed, damage that was never allowed to be repaired, and was from then on affectionately referred to as the 'Royal Dent'.

3.3 Improvements in Design

Testing quickly demonstrated that the idea of using a single engine to provide air for both the lift curtain and forward flight required too many trade-offs. A Blackburn Marboré for forward thrust and two large vertical rudders for directional control were added, producing the SR.N1 Mk II. A further upgrade with the Armstrong Siddeley Viper produced the Mk III. Further modifications, especially the addition of pointed nose and stern areas, produced the Mk IV.

Although the SR.N1 was successful as a testbed, the design hovered too close to the surface to be practical; at 9 inches (23 cm) even small waves would hit the bow. The solution was offered by Cecil Latimer-Needham, following a suggestion made by his business partner Arthur Ord-Hume. In 1958, he suggested the use of two rings of rubber to produce a double-walled extension of the vents in the lower fuselage. When air was blown into the space between the sheets it exited the bottom of the skirt in the same way it formerly exited the bottom of the fuselage, re-creating the same momentum curtain, but this time at some distance from the bottom of the craft.

Latimer-Needham and Cockerell devised a 4 feet (1.2 m) high skirt design, which was fitted to the SR.N1 to produce the Mk V displaying hugely improved performance, with the ability to climb over obstacles almost as high as the skirt. In October 1961, Latimer-Needham sold his skirt patents to Westland, who had recently taken over Saunders Roe's interest in the hovercraft. Experiments with the skirt design demonstrated a problem; it was originally expected that pressure applied to the outside of the skirt would bend it inward, and the now-displaced airflow would cause it to pop back out. What actually happened is that the slight narrowing of the distance between the walls resulted in less airflow, which in turn led to more air loss under that section of the skirt. The fuselage above this area would drop due to the loss of lift at that point, and this led to further pressure on the skirt.

After considerable experimentation, Denys Bliss at Hovercraft Development Ltd. found the solution to this problem. Instead of using two separate rubber sheets to form the skirt, a single sheet of rubber was bent into a U shape to provide both sides, with slots cut into the bottom of the U forming the annular vent. When deforming pressure was applied to the outside of this design, air pressure in the rest of the skirt forced the inner wall to move in as well, keeping the channel open. Although there was some deformation of the curtain, the airflow within the skirt was maintained and the lift remained relatively steady. Over time, this design evolved into individual extensions over the bottom of the slots in the skirt, known as "fingers"

Chapter 4

Basic Principle and Working of an ACV

4.1 Principle behind Working of a Hovercraft.

A hovercraft comes under the category of amphibian vehicles, which means that it can, not only travel on land, but also over water, sand or any surface that is not very uniform.

The hovercraft works on the principle of lift due to the thrust produced by an impeller. This impeller is mounted on an engine and pulls air perpendicular to the travelling surface. The engine is fixed on the hull of the vehicle. The air is sucked in from the top and thrown in to the bottom. The skirt is fixed all around the perimeter of the hull, which does not allow the leakage of the air to the sides and pushes it to the bottom, towards the ground. The high pressurized air then hits the surface, which generates a reactive force, which in turn is the reason of the force that lifts the vehicle.

Now, basically hovercraft deigns differ on the grounds on the lift theory they follow

1. The open plenum theory
2. The closed plenum or momentum curtain theory

4.1.1 The open plenum theory

In the open plenum theory, the hovercraft is designed according to the figure shown below.

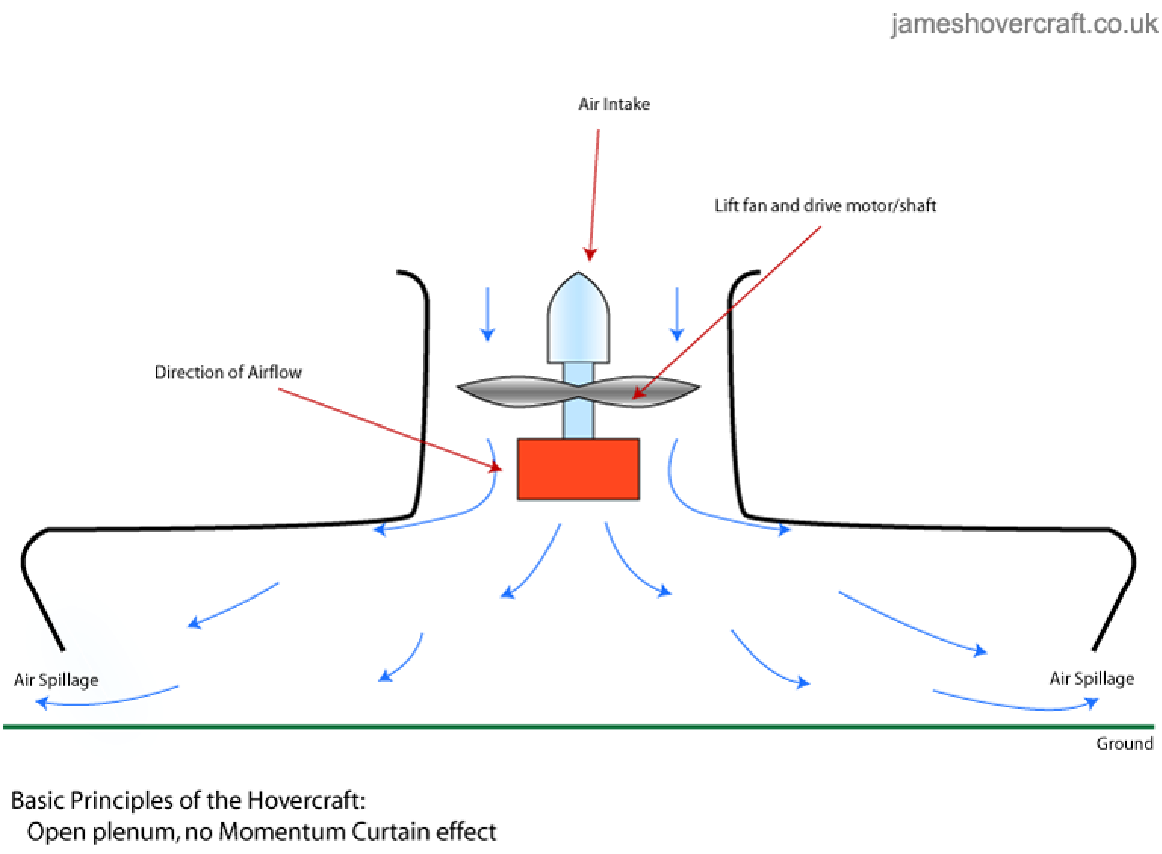


fig 4.1 open plenum theory

It can be observed that the impeller sucks in the air from the atmosphere and pushes it down in the skirt chamber. This pressurized air hits the surface and creates a reaction force, which in turn creates the lift. The reaction force is given by “F” in the diagram.

If we increase the power of the motor, the air will be pressurized further, but more air will escape from underneath the skirt, which in turn will only increase the lift by a very small magnitude.

4.1.2 The closed plenum theory

In the closed plenum theory, the modification made in the vehicle is shown below:

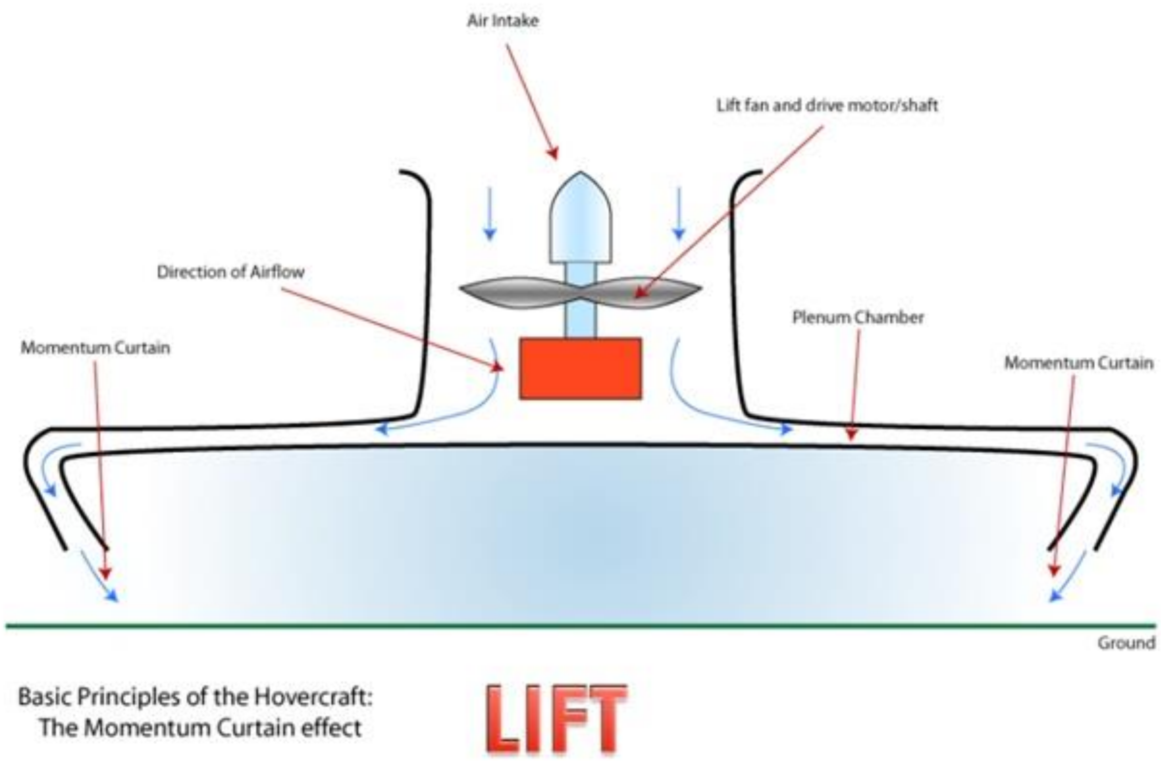


fig 4.2 closed plenum theory

The skirt area consist of a closed surface concentric to it, inside of the vehicle. This secondary surface acts as channels for the air to flow.

Now the main difference between the two designs is that in open plenum theory, the force exerted per unit pressure is less, as the entire area of the vehicle has to be covered.

Whereas in closed plenum design, due to the channels, the force is concentrated on an annulus of the surface. Due to this the force exerted per unit area increases by quite a margin and thus a greater lift is achieved at the same output power of the motor used in open plenum design.

Furthermore even lesser air escapes from under the skirt, thus providing a very nice cushion or air.

4.2 Working of a Hovercraft

As we can observe from the figure below, a minimum of two fans are required for the functioning of the hovercraft vehicle, an impeller to lift the craft and a propeller to move it forward.

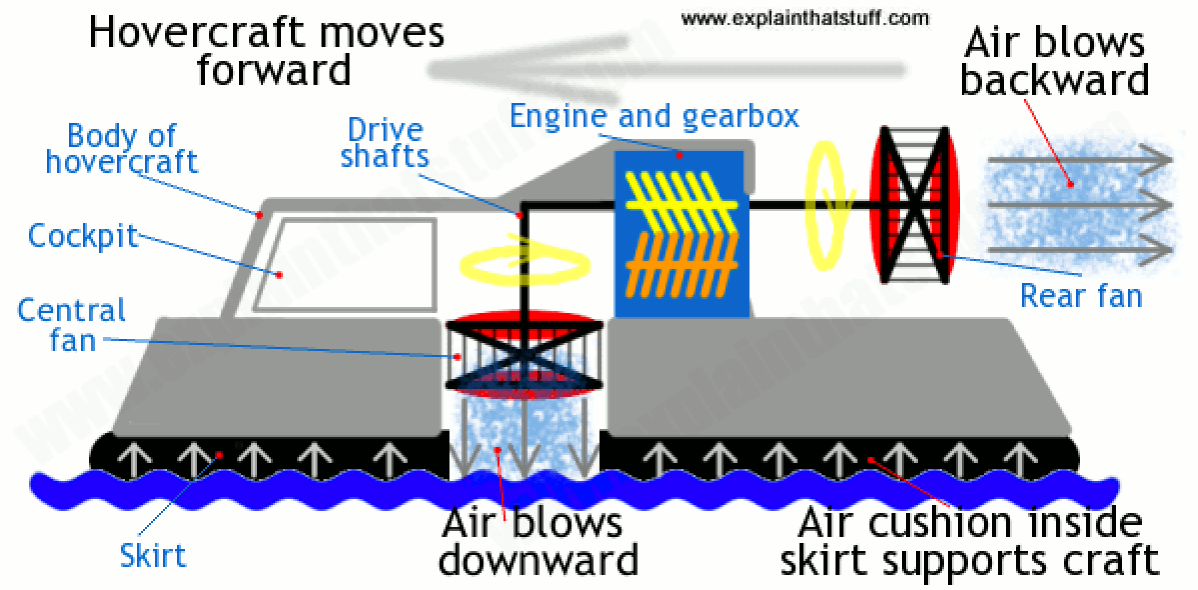


fig 4.3 working of ACV

Considering that a single internal combustion engine is used for both the processes, then the propeller is connected to a shaft which is connected the shaft of the engine via a reduction gear.

The propeller shaft is also connected to the impeller. Both the propeller and the impeller are connected to the shaft through a clutching mechanism, which can engage or disengage the power transmission whenever required.

First the impeller is engaged which causes the vehicle to lift. Then the propeller is engaged and movement is acquired. The control of the vehicle like tuning is done with the help of rudders. They are connected mechanically to the steering mechanism.

Chapter 5

Analysis and Study of Components

5.1 List of Components

Item	Description	Quantity
1	The hull base	1
2	Lift duct	1
3	Seat assembly	1
4	Thrust duct assembly	1
5	Thrust engine and fan assembly	1
6	The skirt	1
7	Stand	1
8	Rudder	3
9	Lift engine mount	1
10	Thrust engine mount	1
11	Lift engine and fan assembly	1
12	Plenum chamber	1

Table 5.1

5.2 Research and Design of Components

5.2.1 The Hull Base

5.2.1.1 Comparison of Hulls Used In a Commercial ACV

A comparison of hull structural systems as relevant to hovercraft, in particular commercial hovercraft in the weight range of 600kg to 8,000kg payload capacity.
The Composite Fiber Reinforced Plastic (FRP) and Polyvinyl Chloride (PVC) foam sandwich system of construction can have many variations. The basis of comparison used here is based upon typical structures and construction systems as used in commercially produced hovercraft today. This is a balance between good structural performance, practical production techniques and to a lesser extent commercial considerations causing some downgrading of the structure and materials compared with the ultra-high construction techniques and materials as used in the aerospace industry today. As a comparison if the most basic FRP boat was rated at 0 and the highest tech composite aircraft was rated at 100, then we consider that the structural performance of the hovercraft construction systems described here would rate at about 85 with a cost factor of about 60. This is a good balance between performance and durability in a marine environment while still using commercially viable construction techniques.

It is not appropriate for us to assess where the Aluminum based construction systems lie on a similar continuum. The last hovercraft hulls constructed in Aluminum according to the style of aircraft construction finished with the Saunders Roe series of hovercraft. All hovercraft built in Aluminum today use an advanced version of the typical Aluminum boat building style of construction. What is compared here is a direct relationship of the various properties of the described construction systems as they relate to hovercraft built today and in particular commercial/military hovercraft in the stated weight range.

By making this comparison a prospective client will gain a better understanding as to why the construction systems are so radically different and the many advantage the FRP/Sandwich system has over Aluminum when used for building hovercraft. It is also thought that the perseverance of some manufacturers with Aluminum may be related more to habit, ease of controlling their sub-contractors and certain complacency in the market place than to the technical reasons described below.

- Limited Energy absorption
- Damageability
- Non-Homogenous Construction
- Reparability
- Low Panel Stiffness
- Corrosion
- Low Tech Approach
- Construction Cost

5.2.1.2 Hull Base Design Parameters

The hull of the ACV is made up of a wood base on a metal frame

Wood base:

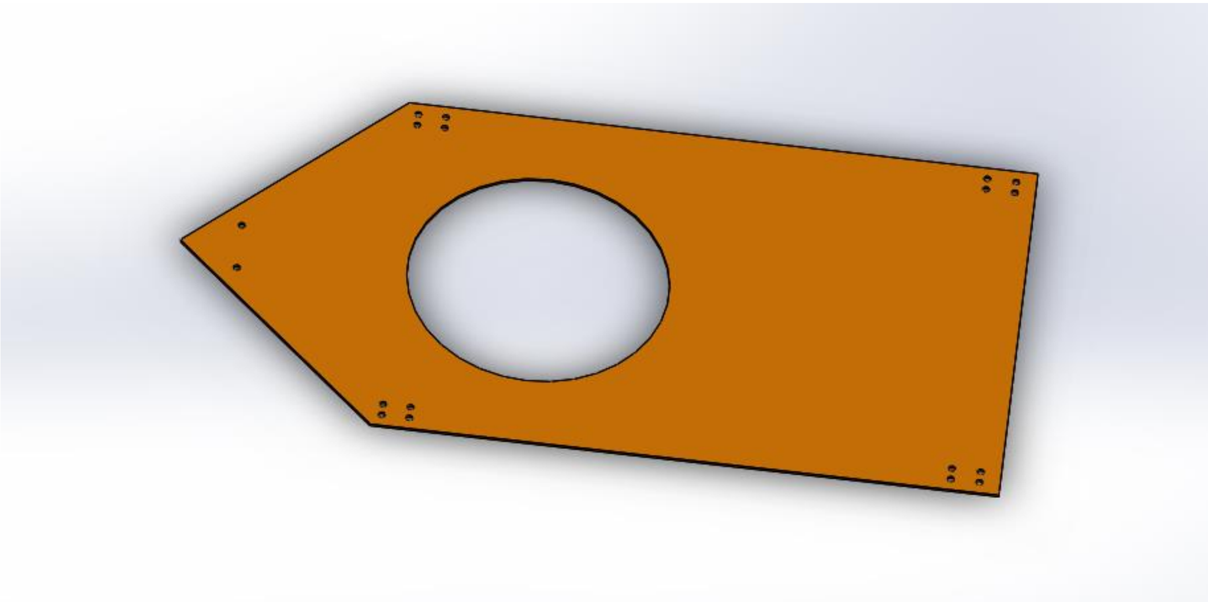


fig 5.1 wood base sw model

Width = 4ft

length = 6ft

Slant length = 2.83ft

Total area of base = 2.492m^2

Base frame:

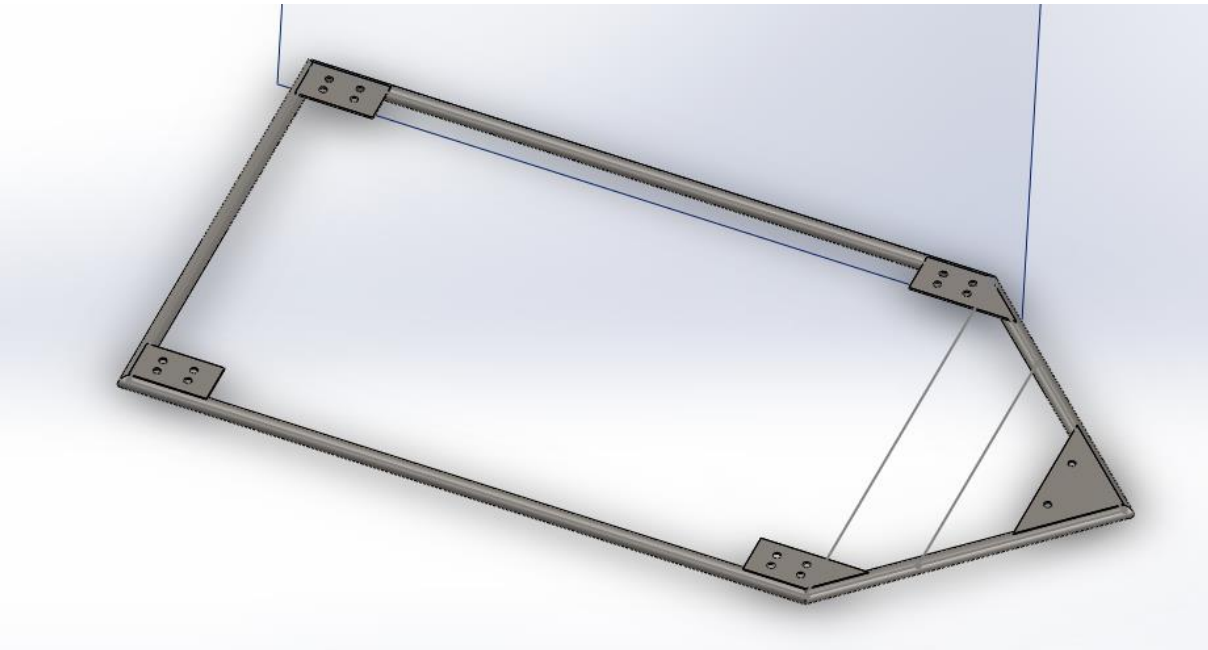


fig 5.2 base frame sw model

The Base frame is of the same dimensions but constructed using welded pipes.

Material AISI 4130 steel annealed at 865^oC

Outer diameter 1.5”

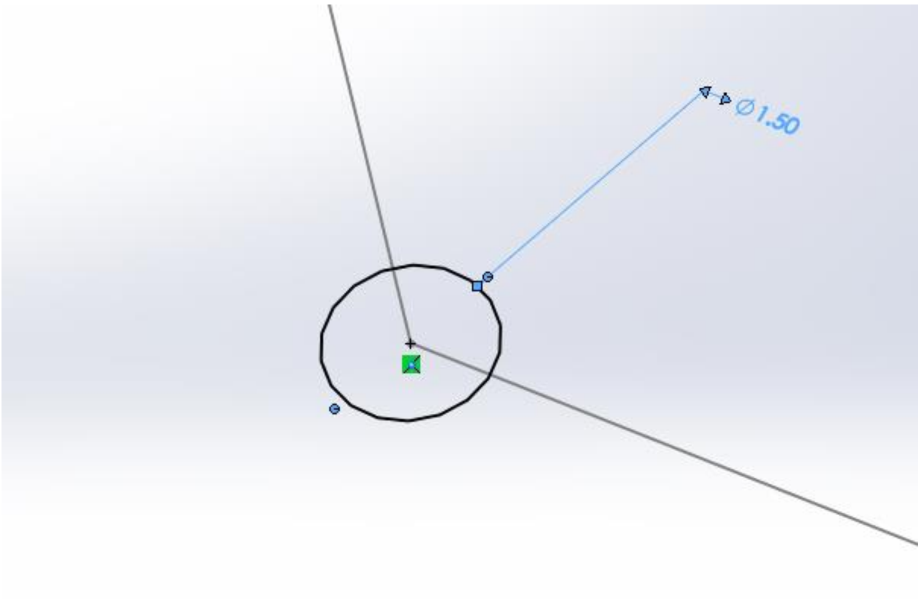


fig 5.3 Outer dia of pipe sw model

Thickness 2mm

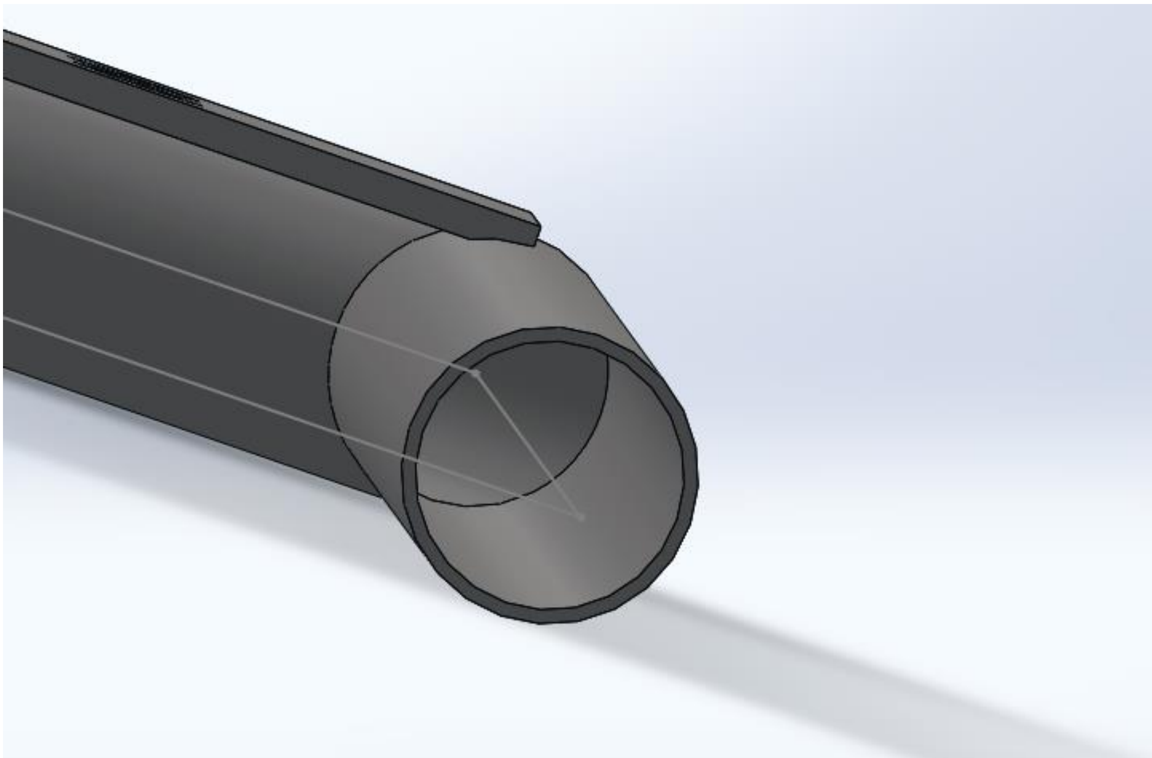


fig 5.4 cross section of member

The wood is connected to the base frame via bolts of 20mm diameter on connector plates that are welded to the frame

The dimensions of the plates are as given in the figures

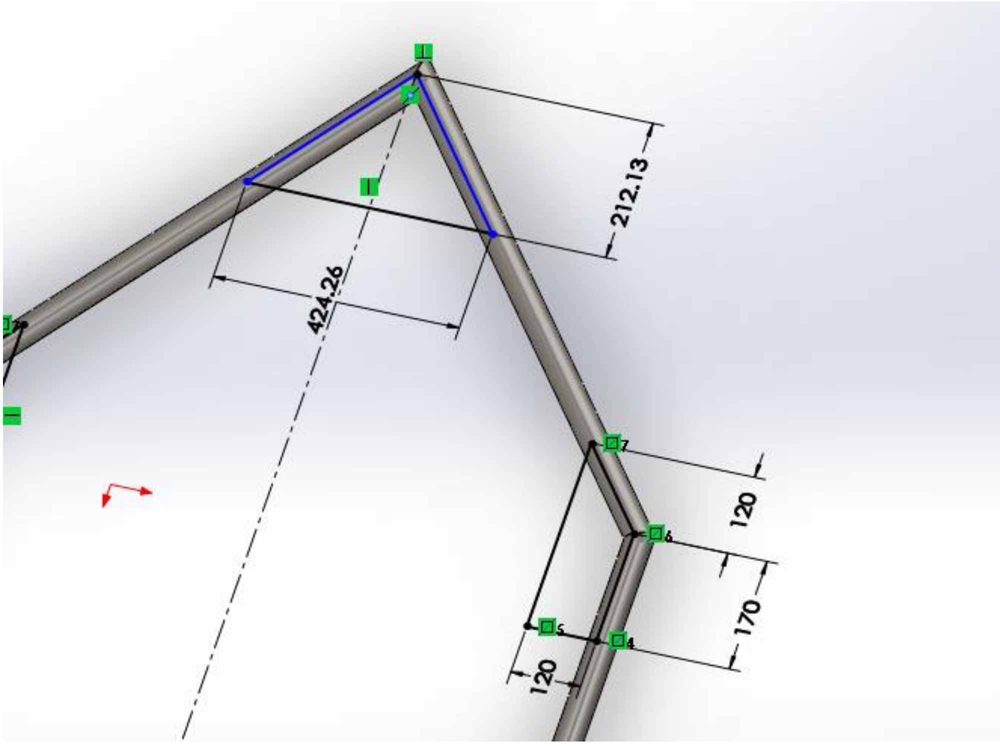


fig 5.5 dimension of connector plates .a

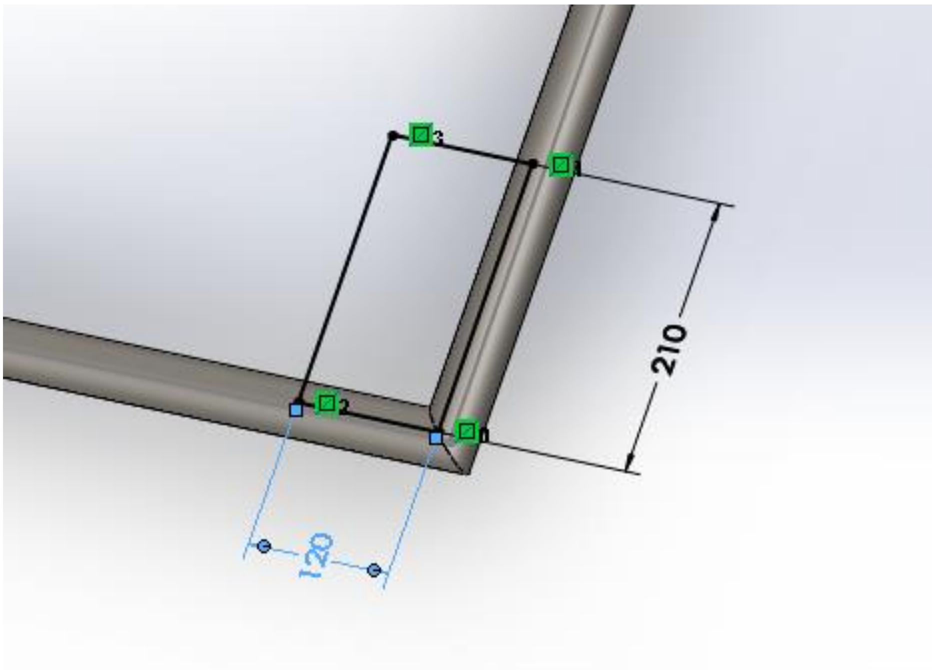


fig 5.6 dimensions of connector plates .b

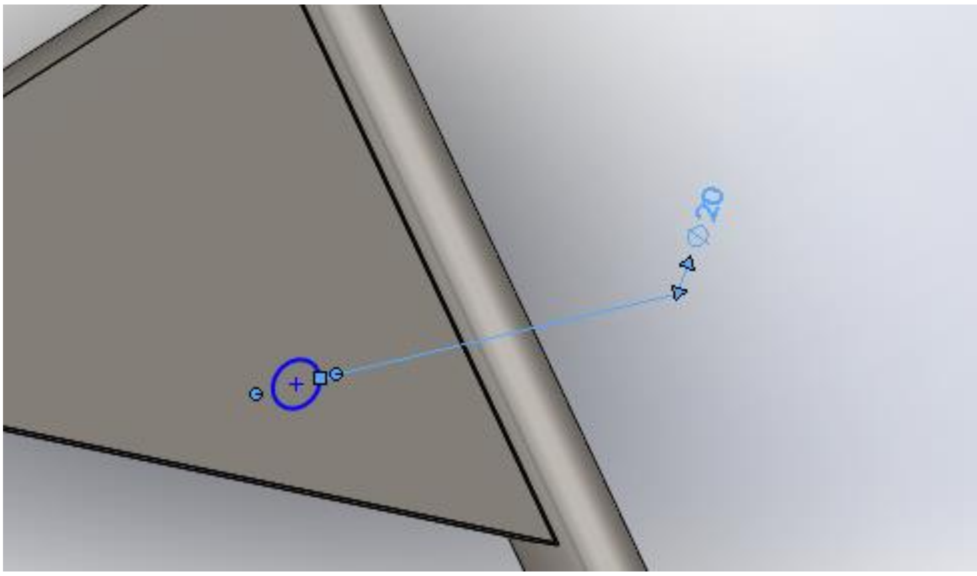


fig 5.7 bolt diameter

The thickness of the plates is 10mm.

5.2.2 Thrust Engine and Fan Selection

The AVC comprises of two separate systems for its lift and thrust respectively. The thrust system imparts the thrust to the vehicle for it to move forward. Many hovercrafts usually use a single system for both thrust and lift. This is achieved by providing a splitter in the thrust duct. This construction uses about 1/3rd of the thrust air to the bag skirt for lift generation, therein reducing the net thrust of the vehicle. This in turn reduces the maximum available speed that the ACV can achieve.

But here, we have used a separate system for thrust as well as lift.

It was agreed upon that that the maximum speed of the craft would be 50km/hr.

Which means 14m/s.

Now,

Thrust Tg= Vd x Qd x ρ

Where,

V_d is the velocity of discharge

Q_d is the discharge

ρ is the density of air.

Now,

Momentum drag, Dm = Qd x ρ x (Vd-Vo)

Where,

Vo is the velocity with which the craft is moving.

More the velocity Vo less will be the thrust imparted to the craft.

At Vo=Vd, thrust imparted = 0.

It was agreed upon that max velocity of craft to be 50km/hr (14m/s).

Therefore,

Vd = 14m/s.

Thus thrust Tg = 14^2 x A x 1.1455

= 14^2 x 0.3848 x 1.1455

Tg = 86.394 N. is the amount of thrust that is to be generated.

Which is equal to 19.42 pounds of force.

Now, we found out that the following fan would be necessary

Parameter	
Diameter	24”
Pitch	30degrees
No of blades	4
Thrust generated	28lbf
Power required	5.5Hp

Table 5.2 dimension parameters of thrust fan

Thus the thrust engine power should be 5.5 Hp or greater @3600 rpm.

To achieve the fore said parameters a,

Briggs & Stratton Horizontal Shaft Engine with the following specifications was selected which gives power output of 6.5Hp @ 3600 rpm

fig 5.8 thrust engine

Brand Name	Briggs & Stratton
Material Type	Sleeve: Cast Iron
Speed	3600 rpm
Item Weight	14 kg
Series	550
Model	83100
Number of Items in Pack	1
Key Features	Fuel Tank and Muffler Straight Keyway Shaft Recoil Start Petrol Engine

Table 5.3 Dimension parameters of thrust engine

5.2.3 Lift Engine Selection

In response to modifying the hull and skirt size, it was decided to reexamine the fluid dynamics of the lift system. This involved calculating the cushion pressure, volumetric flow rate and the pressure inside of the hull. The estimated weight of the hovercraft is 180 kg and the craft footprint is 8ft x 4ft. Based on these characteristics, the pressure required inside the air cushion to negate the craft's weight can be found from:

Pressure = F/A

Pcu = 180 x 9.81/2.4982

Pcu = 595.54 Pa

Exit velocity coming out through the hover gap Ve

Ve = $\sqrt{\frac{2\,Pcu}{\rho}}$

Ve = $\sqrt{\frac{2\,x\,595.54}{1.1455}}$

Ve = 16.699m/s

Area of lift = lift perimeter x hover height

Al = 3.657 x 0.02

Al = 0.073m^2

Q = Al x Ve

Q = 0.073 x 16.66

Q =1.216m^3/s ……………………………………………………………………………..…(1)

For proper lift to be avhieved the bag pressure should be atleast 20% greater than the cushion pressure

Pb = 1.3 Pcu………………..........................……………………………………………….(2)

Now,

For flow from bag to cuchion area

Q = 0.86 x Anet x $\sqrt{\frac{2(Pb-Pcu)}{1.2041}}$

1.216 = 0.86 x Anet x $\sqrt{\frac{2\,x\,0.3\,Pcu}{1.2041}}$ ………………………………………………..(from 1, 2)

Anet = 0.8617 m^2

Now,

Flow from hull to the bag,

Pb = 1.3 Pcu

Pb = 1.3 x 595.54

Pb = 774.202 Pa

Q = 0.53 x Ah x $\sqrt{\frac{2(Ph-Pb)}{1.2041}}$

1.216 = 0.53 x 0.15 x 3.657 x $\sqrt{\frac{2(Ph-774.202)}{1.2041}}$

Ph = 784.561 Pa

Now,

Q = (Pin x ηeng x ηduct x ηfan)/Ph

1.216 = (Pin x 0.6 x 0.6 x 0.67)/ 784.561

Pin = 4416.78 Watt.

Pin = 6Hp.

Thus according to the above results the following engine was selected

fig 5.9 lift engine

Parameter	
Brand	Briggs & Stratton
Shaft	Vertical Shaft
Engine Technology	Single cylinder, 4-stroke, air cooled, OHV (Overhead Valve)
Model Number	21R5
Gross Torque (Nm) @ 2’600 rpm	20,78*
Gross Power HP (kW) @ 3’600 rpm	10.5Hp@3600rpm
Displacement (cc)	344
Cylinder	Cast Iron Sleeve
Bore (mm)	87,3
Stroke (mm)	57,5
Fuel Tank Capacity (l)	2,6
Oil Capacity (l)	1,4
Dry Weight (kg)	26,8
Dimensions Length (mm)	452
Dimensions Width (mm)	393
Dimensions Height (mm)	327

Table 5.4 dimension parameters of lift engine

5.2.4 Research and Design of Rudder for ACV

5.2.4.1 Control Device in an Air Flow System

A rudder is a primary control surface used to steer a ship, boat, submarine, hovercraft, aircraft, or other conveyance that moves through a fluid medium (generally air or water). On an aircraft the rudder is used primarily to counter adverse yaw and p-factor and is not the primary control used to turn the airplane. A rudder operates by redirecting the fluid past the hull (watercraft) or fuselage, thus imparting a turning or yawing motion to the craft. In basic form, a rudder is a flat plane or sheet of material attached with hinges to the craft's stern, tail, or after end. Often rudders are shaped so as to minimize hydrodynamic or aerodynamic drag. On simple watercraft, a tiller—essentially, a stick or pole acting as a lever arm—may be attached to the top of the rudder to allow it to be turned by a helmsman. In larger vessels, cables, pushrods, or hydraulics may be used to link rudders to steering wheels. In typical aircraft, the rudder is operated by pedals via mechanical linkages or hydraulics.

5.2.4.2 Rudders Used in Marine Vessels

Boat rudders may be either outboard or inboard. Outboard rudders are hung on the stern or transom. Inboard rudders are hung from a keel or skeg and are thus fully submerged beneath the hull, connected to the steering mechanism by a rudder post which comes up through the hull to deck level, often into a cockpit. Inboard keel hung rudders (which are a continuation of the aft trailing edge of the full keel) are traditionally deemed the most damage resistant rudders for off shore sailing. Better performance with faster handling characteristics can be provided by skeg hung rudders on boats with smaller fin keels.

fig 5.10 marine rudders

5.2.4.3 Rudder used in Aircraft

On an aircraft, the rudder is a directional control surface along with the rudder-like elevator (usually attached to horizontal tail structure, if not a slab elevator) and ailerons (attached to the wings) that control pitch and roll, respectively. The rudder is usually attached to the fin (or vertical stabilizer) which allows the pilot to control yaw about the vertical axis, i.e. change the horizontal direction in which the nose is pointing.

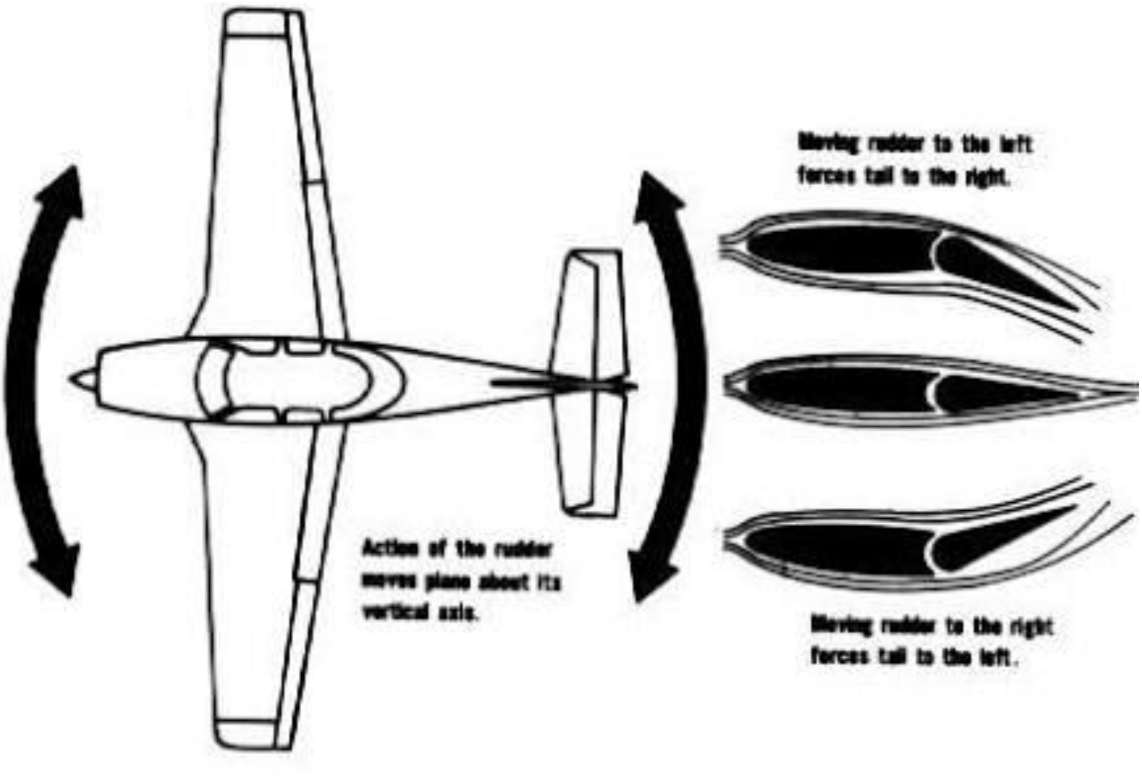


Figure 4–6 Use and Effect of Rudder

fig 5.11 use and effect of aircraft rudders

5.2.4.4 Classification of Rudders

1. Spade or Balanced Rudder:

A spade rudder is basically a rudder plate that is fixed to the rudder stock only at the top of the rudder. In other words, the rudder stock (or the axis of the rudder) doesn't run down along the span of the rudder. The position of the rudder stock along the chord of the rudder (width meaning, from the forward to aft end of the rudder) actually decides whether the rudder is a balanced of semi-balanced one.

2. Unbalanced Rudders:

These rudders have their stocks attached at the forward most point of their span. Unlike balanced rudders, the rudder stock runs along the chord length of the rudder. The reason is simple. In this case, the torque required to turn the rudder is way higher than what is required for a corresponding balanced rudder. So, the topmost part of the rudder has to be fixed to the spintle so as to prevent it from vertical displacement from its natural position. However, unbalanced rudders are not widely used now.

A. Semi- Balanced Rudder:

If you have been able to visualize a balanced and unbalanced rudder by now, it should be pretty easy to visualize a semi-balanced rudder. In fact, the rudder you see on most ships are semi-balanced in the modern industry. The name semi-balanced itself implies, that the rudder is partly balanced, and partly unbalanced.

The top part being un-balanced will help in acting as a structural support to the rudder from vertical displacement. And the balanced part will render less torque in swinging the rudder. As a result, a semi balanced rudder returns to the centerline orientation on its own if the steering gear equipment fails during a turn.

b. Flaps Rudder:

You must have watched an aero plane’s wings closely. Did you watch those flaps coming in and out of the aft end of the wing? It is done primarily to change the effective angle of attack of the entire aero foil section of the wing. You’ll see, during a takeoff, how all the flaps are completely deployed. That actually helps in attaining the effective angle of attack so as to get the maximum lift force.
The same principle, when used in rudders, provides a similar result. Just that, in case of rudders, the flaps are not retractable and they have their significant effects when the rudder is given some angle of attack.

c. Pledger Rudder:

Perhaps one of the most innovative rudder mechanisms you will ever come across. Suppose you have a ship, too large to be man oeuvre in a basin with size constraints, such that the ship cannot use it’s propeller during the man oeuvre. This situation often arises in case of large ships operating in space constrained basins, or in any case of low speed maneuvers.

5.2.4.5 Material Used and Properties in the Construction of Rudders

Wood

The rudders can be hand-crafted out of a Douglas fir 2x8 and mounted on a sliding bracket that pivoted on base mounts. The top of the rudders were held in place by brackets and a pin that spins freely

Characteristics of aluminum:

The mechanical and anti-corrosion characteristics of aluminum depend on the alloy elements. Pure aluminum is not usable for a high strength purpose like a rudder shaft. The most popular aluminum alloy for rudder shafts is AlMgSi1 (EN 6082). The addition of the alloy element manganese extremely increases the mechanical properties proof stress and tensile strength. The addition of the alloy element silicon extremely increases the corrosion resistance of the aluminum. A hard and strong layer of silicon oxide $SiO2$ protects the aluminum even against the most hostile seawater. We use the following types of aluminum:

- Aluminum AlMgSi1 (EN 6082)
  the tensile strength is 340 N/mm^2, the 0.2 % proof stress is 280 N/mm^2, the specific weight is 2.700 Kg/m^3.
- Aluminum AlZnMgCu1,5 (EN 7075)
  The tensile strength is 520 N/mm^2 , the 0.2 % proof stress is 460 N/mm^2, the specific weight is 2.700 Kg/m^3

Characteristics of stainless steel:

The mechanical and anti-corrosion characteristics of steel depend on the alloy elements and the heat treatment. By adding carbon, chrome and nickel to iron and heat tread it correctly, one achieves the alloy stainless steel. The protection against corrosion is not achieved by an oxide layer like aluminum, but the added chrome and nickel make sure the metal itself will not oxidase. We use the following types of stainless steel:

- Stainless steel aisi 316 (1.4401)
  The tensile strength is 600 N/mm^2 , the 0.2 % proof stress is 200 N/mm^2, the specific weight is 7.900 Kg/m^3.
- Stainless steel aisi 329 (1.4460)
  The tensile strength is 750 N/mm^2 , the 0.2 % proof stress is 450 N/mm^2, the specific weight is 7.900 Kg/m^3.

- Stainless steel aisi 630 (1.4542)

  The tensile strength is 1.100 N/mm^2 , the 0.2 % proof stress is 900 N/mm^2, the specific weight is 7.900 Kg/m^3.

5.2.4.6 Design Parameters of Rudder for ACV

1) Duct Dimensions

   Large duct diameter - 90 cm

   Small duct diameter - 70cm

2) Rudder dimensions

   Thickness of rudder- 4.34 cm

   Length – 45 cm

   Width- 16 cm

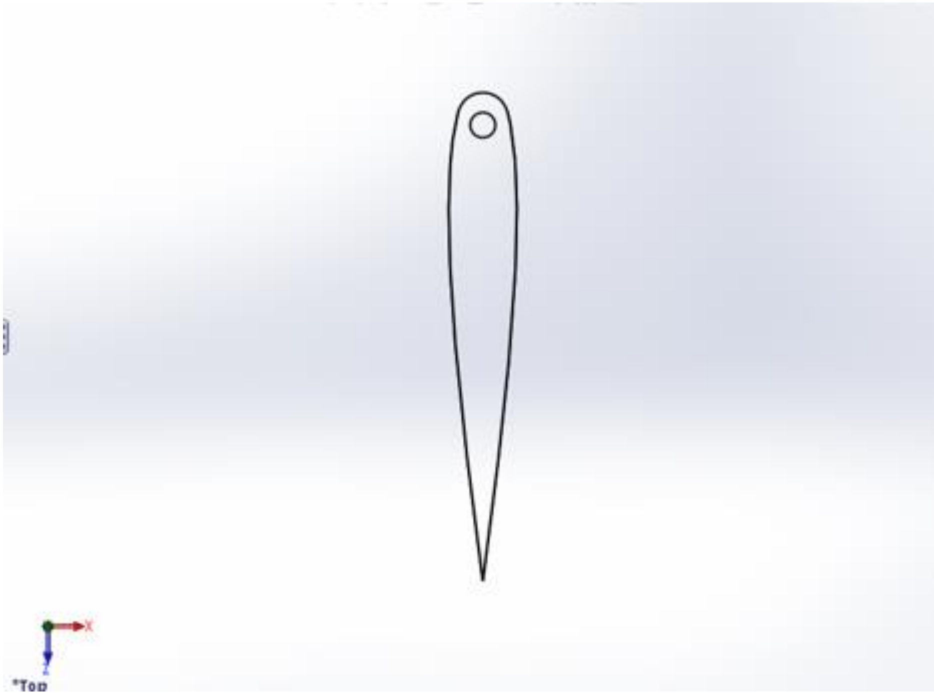


fig 5.12 rudder profile sw model

Thrust dynamics

The total thrust force from fan is 130 newton

Therefore, Area of duct = πr^2

Large duct area= 6361.72 cm^2 = 0.6361m^2

Small duct area= 3848.45 cm^2 = 0.3848 m^2

Thrust pressure = 130/0.3848

= 337.83

Rudder forces

Rudder area = 0.45 m * 0.16 m

=0.072 m^2

Actual force acting on rudder = Thrust pressure * Rudder area

= 0.072 * 337.83

= 24.32 newton

Stresses on rudder

Force = 24.32 newton

Angle of rudder direction = 45°

Actual force on rudder = 24.32 * sin (45)

= 17.19 newton

With the forces calculated the force on the rudder was set up as a beam calculation. Notice from the figure that there will be two pins holding the rudder. These will act as supports for the beam. The rudder was designed out of balsa wood.

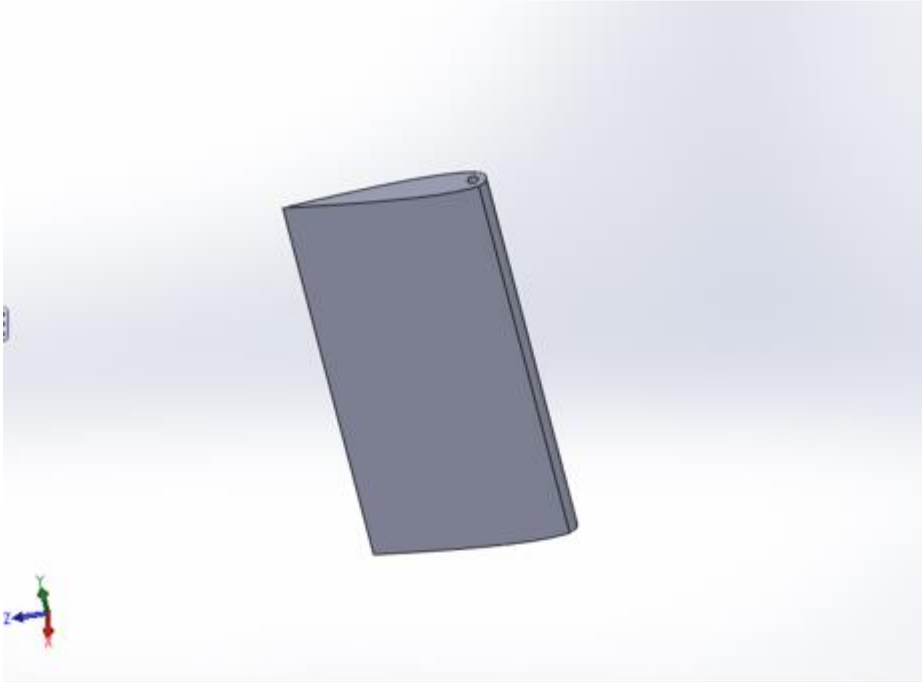


fig 5.13 rudder sw model

Parameter	
Material	Balsa Wood
Thickness	4.34 cm
Length	45 cm
Width	16 cm

Table 5.5 dimension parameters of rudder

5.2.5 Research and Design of Thrust Duct for ACV

5.2.5.1 Thrust fan or ducted fan

A ducted fan is a propulsion arrangement whereby a mechanical fan, which is a type of propeller, is mounted within a cylindrical shroud or duct. The duct reduces losses in thrust from the tips of the props, and varying the cross-section of the duct allows the designer to advantageously affect the velocity and pressure of the airflow according to Bernoulli's

Principle Ducted fan propulsion is used in aircraft, airships, airboats, hovercraft and fan packs.

Ducted fans normally have more and shorter blades than propellers and thus can operate at higher rotational speeds

Duct Physics :

We begin by looking at a ducted fan operating statically (zero free-stream velocity or airspeed).

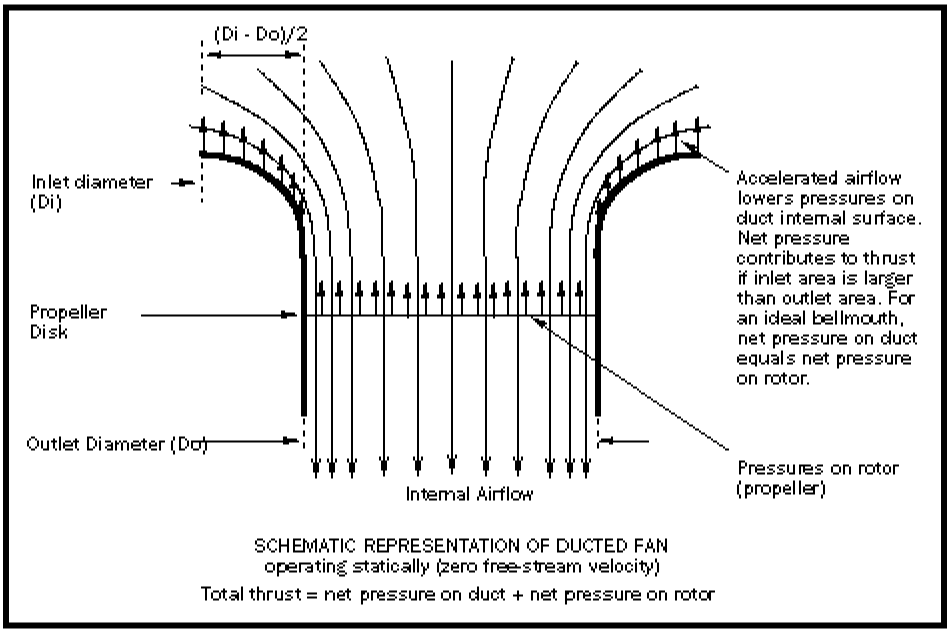


fig 5.14 schematic presentation of ducted fan

According to this simplified approach, for a ducted fan system operating statically, net pressures on the duct inner surface will contribute to thrust if the inlet area is larger than the outlet area (called positive camber). In reality, it has been shown that even a zero-camber duct can contribute to thrust, due to the complex 3 dimensional flow around and through the duct. For a given propeller there is an ideal duct shape (bell mouth) which will optimize the duct's contribution to static thrust. The magnitude of this contribution from the duct can be significant; a theoretical result (from Theodorsen's Theory of Propellers) states that the thrust of a ducted fan with an ideal bell mouth will be equally divided between pressures on the rotor and pressures on the duct!

A further important factor is "diffuser ratio", being the ratio of exit_area/disk_area. Theoretically, static thrust increases with diffuser ratio: as the induced airflow is slowed by the expanding duct aft of the propeller disk, pressures increase on the inner duct wall, thus contributing to thrust. In practice, diffuser ratio is strictly limited by the requirement to avoid separation. In summary, ducted fans can produce more thrust than a free propeller of the same diameter for the following reasons:

- The duct extends the reach of the propulsion system radially to work on a larger mass of air (by analogy, “non-planar” propulsion system) and thus the system takes on the characteristics of a free propeller of larger diameter.
- If clearances between the propeller tips and duct wall are kept small compared to tip chord, the presence of the duct wall will maintain pressures on the blade towards the tip, improving blade L/D.

Since the total thrust of a ducted fan/shrouded propeller is the sum of pressures on the propeller and pressures on the duct, to increase thrust one increases the net propulsive pressures on the duct and/or on the propeller. To increase net pressures on the propeller for a given power input, one increases the blade L/D by keeping tip clearances small. To increase net pressure on the duct, one optimizes the duct geometry for a specific airspeed.

5.2.5.2 Applications of Ducted Assembly with Axial Fan

In aircraft applications the operating speed of an unshrouded propeller is limited since tip speeds approach the sound barrier at lower speeds than an equivalent ducted fan. The most common ducted fan arrangement used in full-sized aircraft is a turbofan engine, where the power to turn the fan is provided by a gas turbine Turbofan engines are used on nearly all airliners, fighters, and bombers. However, a ducted fan may be powered by any source of shaft power such as a reciprocating engine, Wankel engine, or electric motor. A kind of ducted fan, known as a fantail or by the trademark name Fenestron, is also used to replace tail rotors on helicopters. Ducted fans usually have an odd number of blades to prevent resonance in the duct.

Ducted fans are favored in VTOL aircraft such as the Lockheed Martin F-35 Lightning II, and other low-speed designs such as hovercraft for their higher thrust-to-weight ratio.

In some cases, a shrouded rotor can be 94% more efficient than an open rotor. The improved performance is mainly because the outward flow is less contracted and thus carries more kinetic energy

Among model aircraft hobbyists, the ducted fan is popular with builders of high-performance radio controlled model aircraft. Internal-combustion glow engines combined with ducted-fan units were the first achievable means of modeling a scaled-size jet aircraft. Despite the introduction of model-scale turbojet engines, electric-powered ducted fans remain popular on smaller, lower-cost model aircraft. Some electric-powered ducted fan airplanes can reach speeds of more than 320kmh (200mph)

5.2.5.3 Advantages of Ducted Assembly

- By reducing propeller blade tip losses, the ducted fan is more efficient in producing thrust than a conventional propeller, especially at low speed and high static thrust level (airships, hovercraft).
- By sizing the ductwork appropriately, the designer can adjust the air velocity through the fan to allow it to operate more efficiently at higher air speeds than a propeller would.
- For the same static thrust, a ducted fan has a smaller diameter than a free propeller, allowing smaller gear.
- Ducted fans are quieter than propellers: they shield the blade noise, and reduce the tip speed
- Ducted fans can allow for a limited amount of thrust vectoring, something normal propellers are not well suited for.
- Ducted fans offer enhanced safety on the ground.

5.2.5.4 Disadvantages

- Less efficient than a propeller at cruise (at lower thrust level).
- Good efficiency requires very small clearances between the blade tips and the duct.
- Requires high RPM and minimal vibration.
- Complex duct design, and weight increase even if constructed from advanced composites.
- At high angle of attack, parts of the duct will stall and produce aerodynamic drag

5.2.5.5 Design Parameters of the Thrust Duct

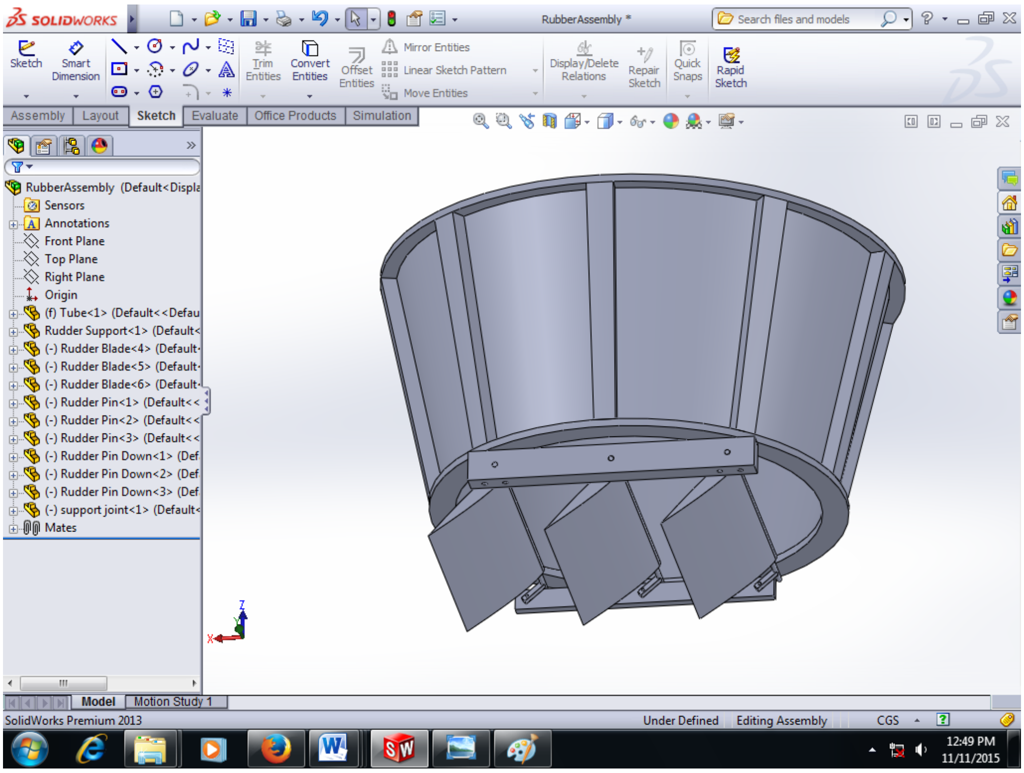


fig 5.15 rudder and thrust duct assembly sw model .a

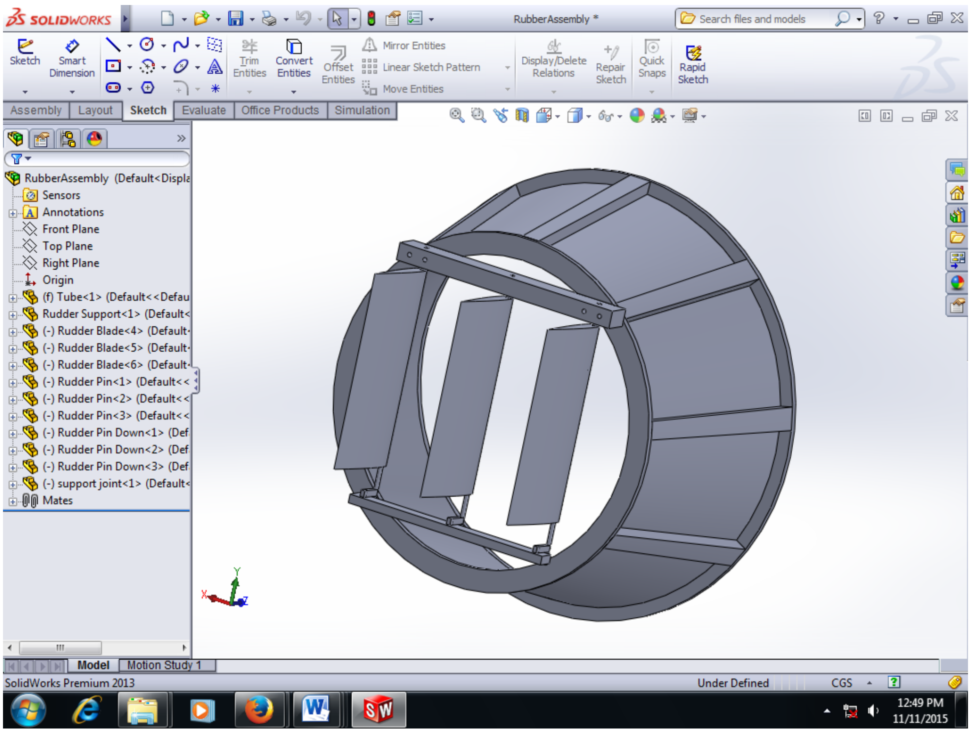


fig 5.16 rudder and thrust duct assembly sw model .b

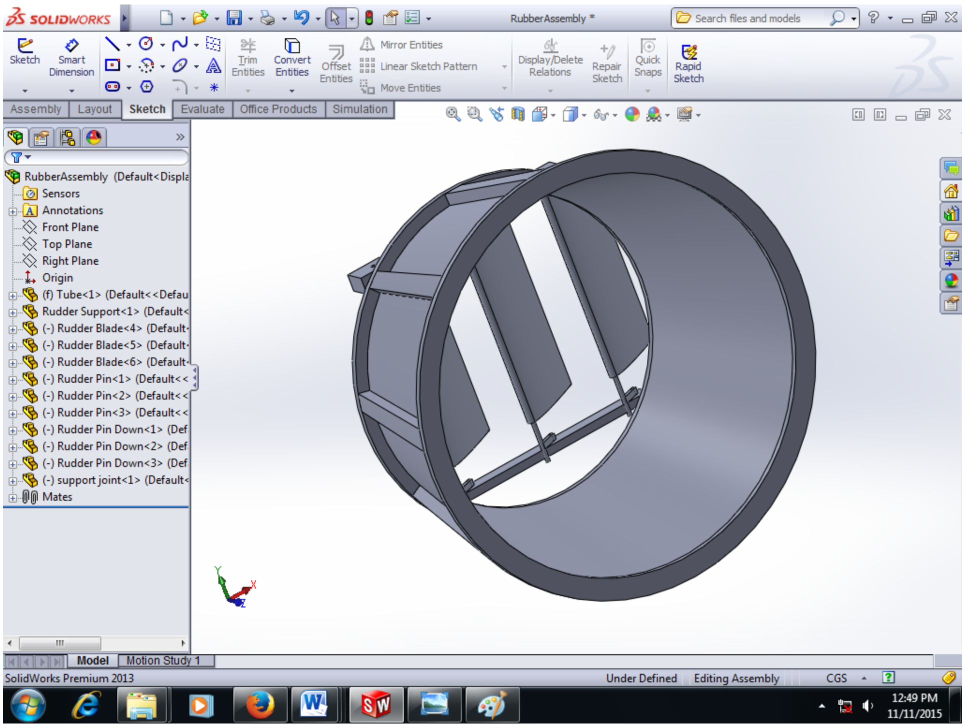


fig 5.17 rudder and thrust duct assembly sw model .c

Duct Dimensions:

Large duct diameter	90 cm
Small duct diameter	70cm
Large duct area	6361.72 cm^2
Small duct area	3848.47 cm^2

Table 5.6 design parameters of duct

5.2.6 Research and Design Parameters of Flexible Skirt

Skirt is a cushion like structure that is attached to the hull on its edges. When the skirt is inflated it forms a dough-nut kind of shape below the hull. All modern hovercraft - large and small - use a skirt of one sort or another for their suspension system so that the power required to lift the craft can be minimized.

A hovercraft skirt is required to fulfill the following functions:

- Contain the cushion of air beneath the craft at the required hover height.
- Have the ability to conform or contour efficiently over obstacles so as to keep the loss of cushion air to a minimum.
- Return to its original shape after having been deformed.
- Give adequate stability.
- Offer little resistance to the passage of obstacles beneath it.
- Have the ability to absorb a large proportion of the energy which is produced on impacts or collisions with obstacles greater than hover height or cushion depth

5.2.6.1 Types of Flexible Skirts

Skirts are basically divided into two categories:

A. Based on the shape of the skirt

1) Bag Skirt

fig 5.18 bag skirt

2) Finger Skirt

5.19 finger skirt

3) Bag and Finger Skirt

fig 5.20 bag and finger skirt

B. Based on the different Fields where hovercraft are used

1) Land
2) Water
3) Desert
4) Ice
5) Grass

A hovercraft skirt should have the following features:

- Be easily maintained on site without the need to lift or jack-up the craft.
- Have a long operating life.
- Be relatively simple to make and fit.
- Have a low maintenance cost. The initial cost of making the skirt may not be very low but it is important that once made and fitted, the skirt be cheaply maintained.
- Be tailored so that it is even in height above the ground all the way around the craft. One part of the skirt should not drag whilst another is 20 or 30 millimetres above the ground.

5.2.6.2 SKIRT MATERIAL

Hovercraft skirts are usually constructed of heavier fabrics and a coating on one side such as polyurethane which allow for a decrease in the coefficient of friction with the environment.

Material Type
Kevlar
Polyester
Ballistic Nylon

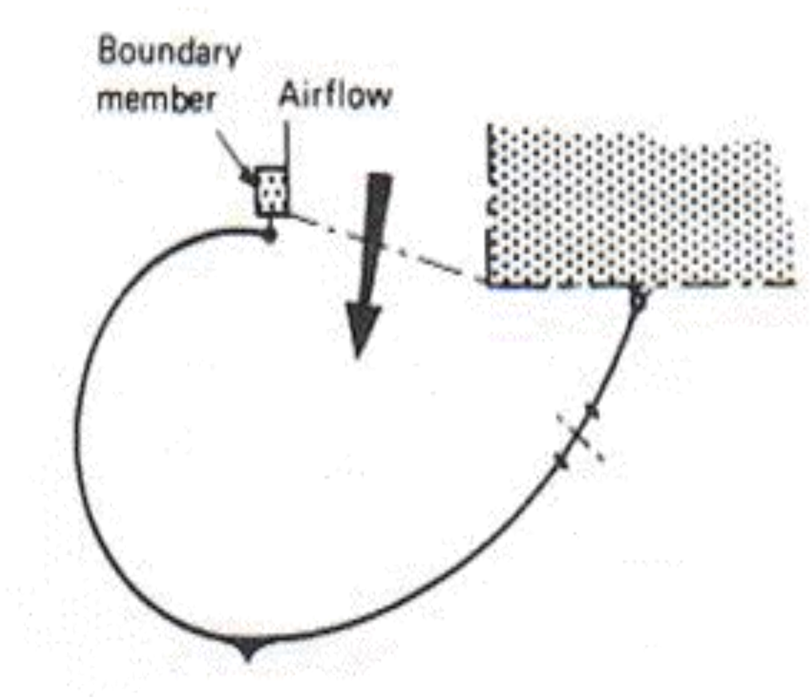
Table 5.7 bag skirt material

Due to a limited time frame and budget the choice was to use the least expensive, and also the lightest material of the three. A bonus of their material is that it is Ballistic Nylon does have some properties which are useful for resisting impact from an explosion.

5.2.6.3 Design Parameters of Skirt for ACV

THE BAG SKIRT CROSS SECTION.

To design the cross section, the height must first be established and this should be about one eighth of the craft width. The cross section of the bag is comprised of two radii, the outer curve and the inner curve. For simplicity it can be assumed that the ground contact point is directly beneath the outer extremity of the hull and therefore the outer radius is equal to half the distance between the ground and the upper fixing point.



5.21 bag skirt cross section

The ground contact point can in fact be positioned fractionally in from the outer hull edge but for the sake of stability, it must never be outside. To design the cross section, make a scale drawing of the craft lower hull at the appropriate hover height and draw in the outer semi-circle.The radius of the inner circle is calculated by multiplying the outer radius by a factor given in the following table.

Pressure Differential bag pressure / cushion pressure	Factor Inner radius / outer radius
1.2 : 1	6.0
1.3 : 1	4.53
1.4 : 1	3.5
1.5 : 1	3.0
1.6 : 1	2.66
1.7 : 1	2.43
1.8 : 1	2.25

Table 5.8 outer radius multiplying factor table

The choice of pressure differential is based upon the degree of stability required. The higher the ratio the greater the stability, but at the expense of undulating surface performance and higher skirt wear on uneven terrain. As such please don't shoot for a to stiff skirt. After calculating the inner radius, draw in the inner circle. This will give the inner skirt fixing point and note that the changeover from the small radius to the larger radius is at a point 15 degrees in from the ground point. The skirt cross section calculated in this way has balanced geometry and will automatically take up this shape, provided that the pressure differential is accurately predicted.

THE BAG SKIRT - PERIPHERAL JETS

The bag skirt requires a number of holes on the inner fact to transfer air from the skirt to the cushion. These holes vary in size but are generally 3 - 6 inches in diameter.

The total required area of these holes can be calculated using the following formula:

$$A = \frac{Q}{20 \times \quad Pb \times Pc}$$

Where A = Total area of peripheral jets (sq. ft)

Q = Air Flow (cu ft / sec)

Pb = Pressure in the bag (lb. / sq. ft)

Pc = Pressure in the cushion (lb. / sq. ft)

Cut about 90% of the calculated number of holes and then slowly cut out the remainder, checking regularly the relative pressures with a simple water manometer until the required differential is obtained. Holes should only be cut in the bow and side sections of the skirt. No holes should be cut in the rear section as this can cause water scooping

Bag Skirt Calculation:

Height of the cross section of the skirt= $1/8^{th}$ of the width of the skirt

Width of the craft=4feet=1.219m

Therefore, Height of the cross section=1/8x1.219=0.152m=6 inches

Pb=1.3Pu

Ri=4.53x6
=27.18inches

Therefore length of inner arc=27.18x11.02xπ/180
=5.22inches

Therefore length of outer arc=3xπ=18.849inches

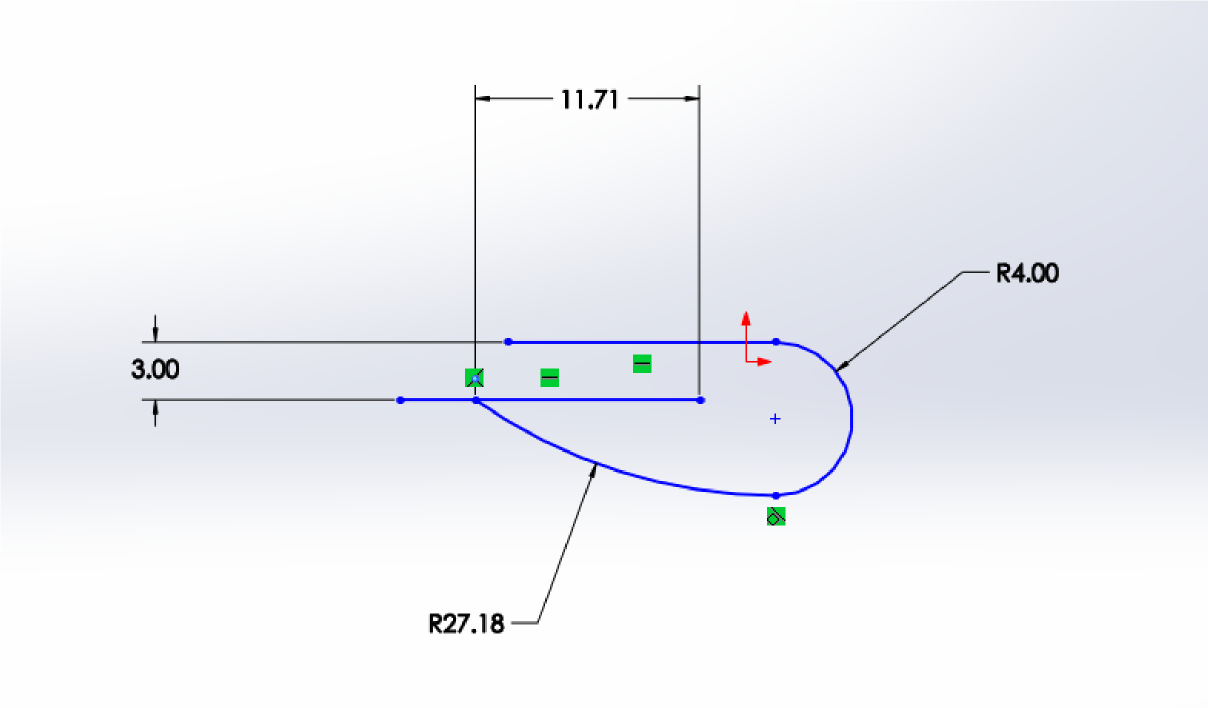


fig 5.22 bag skirt sides dimension sw model

Inner arc length<16.7499

Outer arc length = 12.566inches

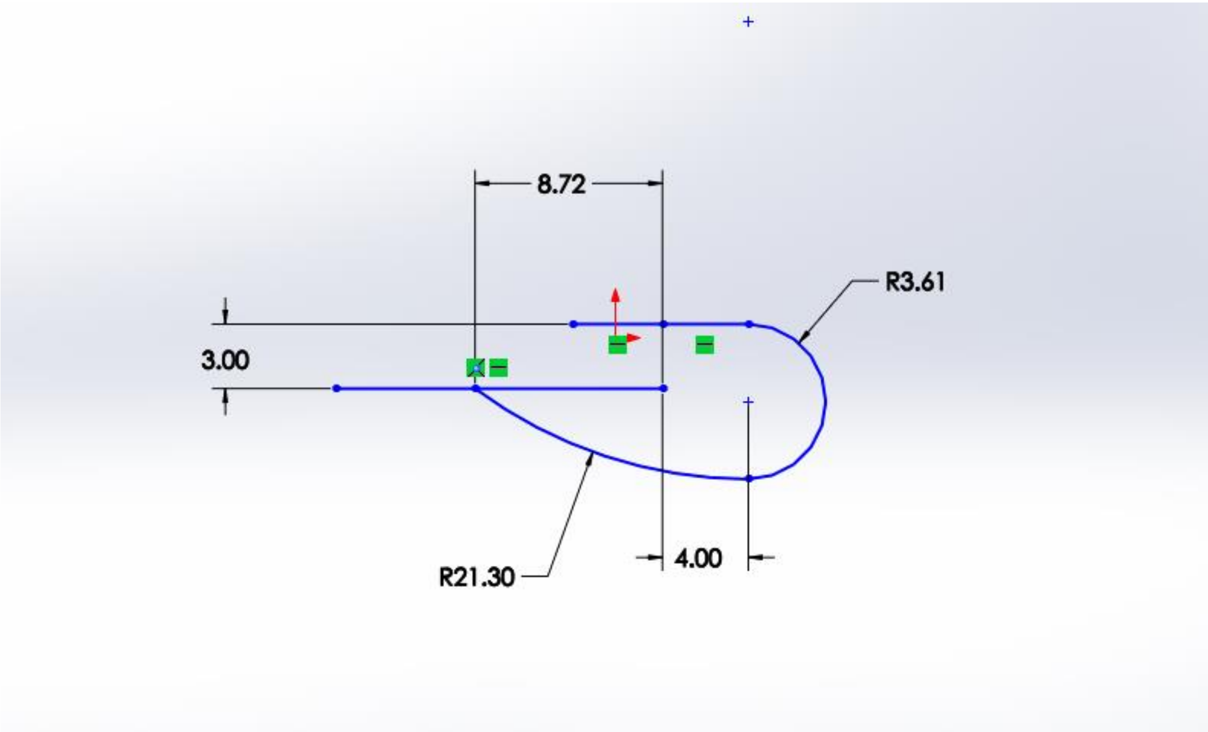


fig 5.23 bag skirt bow section dimensions

Bow section outer diameter=8x0.85=7.21719inches

Bow section inner diameter=21.295inches

Dimensions of Bag Skirt:

Sides	
Outer diameter	8inch
Inner diameter	27.18inch
Outer arc length	12.566inch
Inner arc length	16.74inch
Bow	
Outer diameter	8inch
Inner diameter	21.30inch
Outer arc length	7.217inch
Inner arc length	21.295inch

Table 5.9 design parameters of bag skirt

Chapter 6

Result and Discussions

Lift Engine	6Hp power required @3600rpm to generate 1.216m^3/sec of discharge and 2cm of hover gap.
Thrust Engine	5.5 Hp power required @3600 rpm to generate 28lbf of thrust to achieve maximum speed of craft at 50 km/hr
Thrust Fan	24” diameter at 30degree pitch fiberglass reinforced blades
Rudder	Thickness of rudder- 4.34 cm Length – 45 cm Width- 16 cm
Duct	Large duct diameter - 90 cm Small duct diameter - 70cm
Bag Skirt	Outer arc length-18.849inches inner arc length<16.7499

Table 6.1 design parameters results table

Chapter 7

Conclusions

Hovercrafts are generally simple mechanisms in theory. Yet the process from theory to manifestation is not as easy as it may seem. A plethora of problems exist and must be faced in order to attain a well-functioning hovercraft.

We studied the components used for construction of a Hovercraft and selected wood and carbon steel AISI 4130 as our building material. Calculations to find out the horsepower required for each engine- thrust and lift were carried out and the engines were selected. As per requirement a 6 hp vertical shaft Briggs and Stratton for lift and for thrust a 5.5 hp horizontal shaft Briggs and Stratton Engine were selected. Then forces acting on the Rudder was calculated and Balsa wood was selected as desired rudder material. The Skirt material selected was rubber.

We are much under satisfaction because each and every aspect of design was taken into consideration. We have also kept in mind the cost factor of our project. Right now the cost of our material isn't exceeding our budget, even while considering a factor of safety in each design parameter.

The analysis of each load bearing design was conducted and the load stress was found out to be well whithin the critical limits.

The only parameters left are the engine mounts and the axial fan design which will be completed after the seventh semester exams. Both the engines will be purchased at that time and according to that the mounts will be designed. This will lead to the completion of the chassis which can then be analysed.

Chapter 9

References

Books

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