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Design and Analysis of Winged Hovercraft

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Abstract

A flying hovercraft and ground effect vehicle design. The flat double-wing design for small, medium, and large cargo or military transport vehicles allows travel from very slow to medium to high speeds over water or land. The highly elongated, flat wing of very low aspect ratio provides a vehicle that is capable of traveling in ground effect flight at a safe distance above the water. Primarily a high-speed (150-200 kts), over-water, ground-effect, vehicle that is augmented with hovercraft capabilities for acceleration to flight speed, deceleration, and slow to moderate speed (0-75 kts.) operations. The vehicle design is adaptable from one-man units to large, ocean-going high-speed cargo ships of 400 feet and over, with carrying capacities over five million pounds. A vehicle of this design is 250% more efficient than modern aircraft, 15 times faster than cargo ships, and capable of going into true flight to overfly land masses for ocean-to-ocean and inland lake or river access. The design can be adapted to a multitude of fast, military, over-water vehicles of any size capable of travel over any terrain.

Keywords: Hovercraft; Analysis; CFD computations; Lift; Thrust force

Introduction

The wing was evaluated under different angles of attack, using CFD computations and measurements in a wind tunnel.

Hovercraft specification

Length=4 m

Width=1.25 m

Cross sectional area of Hovercraft=4*1.25=5 m^2

Weight of Hovercraft-Total weight= 325 kg

Normal operating speed-

V=40 km/h

Power requirement = 200 kW

Thrust requirement = 7000 N.

Skirt area = 5 m^2

Forces Acting on Hovercraft

Lift force

The lift force that we want to produce in our hovercraft is a force that is equal to or greater than the weight of the hovercraft. Blowing air into the hovercraft's skirt, creating a high-pressure pocket, produces lift.

Since the pressure in the skirt is greater than the pressure produced by the weight of the hovercraft, an upward force is created. Ideally, we want the lift force produced to be equal to the weight of the hovercraft in order to maximize ef [1-3].

If the lift produced is greater than the weight, air will escape the skirt through the bottom, thus lowering the lift force until equilibrium is obtained. The lift force can be calculated using the equation [4].

In general, air cushion vehicles use two design configurations namely the plenum chamber and the peripheral jet. Using the peripheral jet design configuration (Figure 1) under equilibrium conditions;

Weight of craft, w = Lift force, Fcu

Fcu = w = PcuAc + Jj Lj Sin qj

Where,

Jj = The momentum flux of the air jet per unit length of the nozzle

Lj = The nozzle perimeter

Tj = The thickness of the jet/nozzle width

Hj = The lift height

Rar = The average radius of the curvature of the length

Pcu = The cushion pressure

Acu = Cushion area

Qj = Total volume flow

Paj = The power required (lift power)

qj = The angle of the nozzle from the horizontal

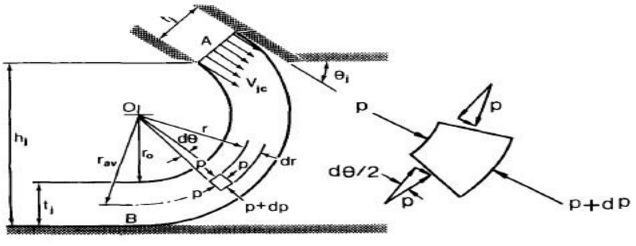

Figure 1: Geometry of Peripheral Jet System.

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Let maximum weight of crew = 700 kg

Also weight of craft = 325 kg

Let the nozzle angle to the horizontal = 71.20

Let the lift height = 0.2 m = hj

Thickness of jet, tj = 24 inch

tj= 0.6096 m

Weight force of craft and pilot,

W= mg

$= (700 + 325)\ \text{kg} \times 9.81\ \text{m/s}^2$

W = 10545.75 N = Fcu

Cushion Area, Acu = L × W

= 4 ×1.25

Acu $= 5\ \text{m}^2$

Fcu = PcuAcu +Jj Lj sinqj = W

Jj = Pcu × rav

$$rav = \frac{hj}{1 + \cos qj}$$

$$\frac{0.2}{1 + \cos 71.2}$$

rav = 0.1513

where, hj = 0.2 m

Jj= 0.1513 Pcu

Lj =π × tj

= π × 0.6096

Lj =1.9151

Fcu = PcuAcu +Jj Lj sinqj = W

10545.75 = (Pcu * 5) + (0.1513 Pcu x 1.9151 x sin 71.2) = 5 Pcu + 0.2743 Pcu

10545.75 = 5.2743 Pcu

$\text{Pcu} = 1999.46\ \text{N/m}^2$

The expression relating cushion pressure Pcu and total Pressure of the jet Pj is given

$\text{Pcu/Pj} = 1 - 3.1641 \times 10^{-4}$

$\text{Pj} = \text{Pcu}/[1 - 3.1641 \times 10^{-4}]$

$\text{Pj} = 2000\ \text{N/m}^2$

Total volume flow Qj (i.e. air flow rate by volume) is given by Qj $= 15.95\ \text{m}^3\text{/s}$

(i.e. assuming dry air density $\rho = 1.2754\ \text{kg/m}^3$)

Power required is given by; Paj = Pj × Qj

= 2000 × 15.95

= 31,909 watts

Paj = 31.909 kW

When designing our hovercraft we need to take lift into consideration.

The cross sectional area and the weight of the hovercraft will determine how much lift our hovercraft will need to produce. Therefore, considering the lift required is essential when determining the size and weight of our hovercraft.

We must also design our skirt so that it contains the air, but also allows air to escape from the bottom when the pressure is too high. To ensure perfect balance, we must control the hovercraft's pitch, vertical movement of the nose, and yaw, horizontal movement of the nose [5-7].

It is vital that the pressure is distributed evenly throughout the skirt and that the center of mass of the hovercraft is properly supported so that no unwanted moment will be created.

Thrust force

Thrust, which is created by the propulsion system, is the force that pushes the hovercraft forward. Having maximum thrust is critical for our hovercraft, as we are designing it so that it may travel a certain distance in the smallest amount of time [8].

The momentum of an object is given by

Q=m*v

Where, Q is the object's momentum in kg•m/s,

m is the mass of the object in kg

v is the velocity of the object in m/s

The mass of the object is given by

mass = Weight/gravitational force

m = 3188.25/9.81

m = 325 kg

According to Newton's Second Law, the force acting on an object is proportional to the rate of change of the object's momentum.

The force on an object can therefore be written as:

Ft=m (Vo-Vi)/(t2-t1)

Where,

Ft=Thrust force

m= mass of the hovercraft Vo=outlet velocity

Vi=initial velocity t2=final velocity

t1=initial velocity

Calculation of the mass flow rate

$\dot{m} = \rho v A$

Where,

$\dot{m}$ is measured in kg/s,

ρ is the fluid density in kg/m^3, v=velocity of the hovercraft,

A is the cross-sectional area of the propulsion system, such as a fan, in m^2.

$\dot{m} = 1.225 * 40 * 5$

= 245 kg/s

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The thrust force can then be written as: Ft = $\dot{m}$ (Ve-Vi)

= 245*(15-0)

= 3675 N

Where,

Vi is the entrance velocity

Ve is the exit velocity, to and from the propulsion system, in m/s.

When the thrust is produced, we must insure that the force is applied collinearly to the center of mass of the hovercraft to prevent any unwanted yaw, thus allowing the hovercraft to go straight. In selecting a propulsion system, we must consider these equations.

As an example, if we were to use fans for thrust, we would have to consider in our design, the area of the fan, and how fast we can make the propellers turn [9]. This will increase the velocity of the air exiting the fan, thus increasing the thrust.

Drag force

Drag must also be considered when designing our hovercraft. Assuming that our design produces enough lift to essentially make the surface frictionless, drag is the only force that opposes the hovercraft's forward motion.

However, we can reduce this force. The drag is caused when the hovercraft moves through a fluid, such as air. The drag force can be calculated using the following equation:

Fd=1/2* ρv2CdA

Where,

ρ is the density of the fluid,

v is the velocity of the hovercraft relative to the fluid,

A is the cross-sectional area of the hovercraft,

Cd is the coefficient of drag.

The coefficient of drag is a unit-less ratio between the drag force and the dynamic pressure times the area. This coefficient is usually found through experiment and can be calculated through the equation:

Cd = Fd/ρAv2/2

In Figure 2, the drag co-efficient for various shapes was given.

From these equations, we can determine that drag must be considered when designing the hovercraft's body shape and size. Our goal is to make our hovercraft design more aerodynamic by reducing the cross-sectional area of the reference face and eliminating any flat surfaces perpendicular to the flow of air. Selecting a streamlined design with a thinner tail end will reduce the wake produced by our hovercraft. A smaller wake means less drag produced and therefore, lowers opposing forces, resulting in a faster hovercraft. Since, as per the dimensions our hovercraft is a short cylinder, the Cd can be taken as 0.82.

Fd =1/2* ρv2CdA

Fd = 0.5*1.225*15*15*0.82*5

Fd = 40.18 kN

Therefore, Drag force acting on the Hovercraft is 2.4653 N that force also called as friction force. A drag force act on the Hovercraft is always negative.

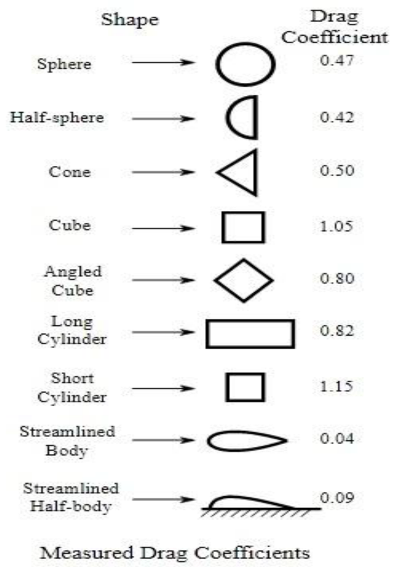

Figure 2: Drag Co-efficient for Different Shapes.

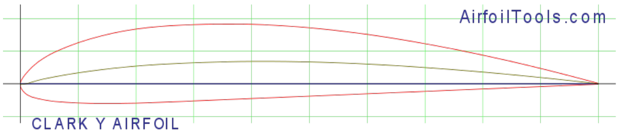

Figure 3: Clark Y Airfoil.

Clark Y Airfoil

The airfoil has a thickness of 11.7 percent and is flat on the lower surface from 30 percent of chord back. The flat bottom simplifies angle measurements on propellers, and makes for easy construction of wings on a flat surface [10]. The airfoil section is shown in Figure 3.

It gives reasonable overall performance in respect of its lift-to-drag ratio, and has gentle and relatively benign stall characteristics [11].

CAD Model

The Clark Y airfoil coordinates are imported and developed as a 3D model with the span of 1 m shown in below Figure 4.

The base structure of hovercraft SKIMA 4 with Clark Y airfoil wing was modelled using CATIA with dimensions of 4*1.5 m^2 is shown in below Figure 5.

Result and Discussion

Computational Fluid Dynamics

Computational fluid dynamics (CFD) is a numerical methods based computer program in which all the governing equations are approximated to find efficient results by averaging them. It's graphics interface is a good thing to see the accurate formation of the things that can happen in a experimental wind tunnel setup. Computational

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fluid dynamic results are directly analogous to wind tunnel results obtained in a laboratory--they both represent sets of data for given flow configurations at different Mach numbers, Reynolds numbers, etc. However, unlike a wind tunnel, which is generally a heavy, unwieldy device, a computer program (say in the form of floppy disks) is something you can carry around in your hand. Or better yet, a source program in the memory of a given computer can be accessed remotely by people on terminals that can be thousands of miles away from the computer itself. A computer program is, therefore, a readily transportable tool, a "transportable wind tunnel."

The wing is selected and the proper angle of attack is selected by calculated the lift and drag coefficient. So that the drag and lift can be calculated for necessary angle of attack.

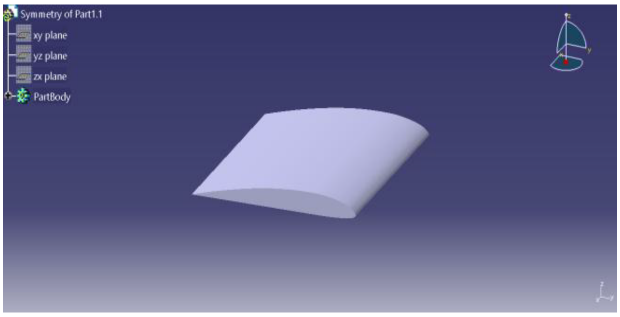

Figure 4: Isometric View of Clark Y Wing.

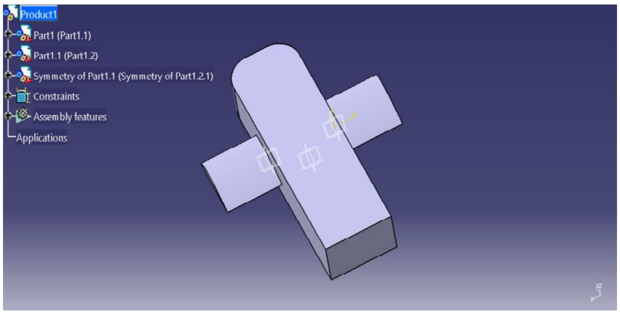

Figure 5: Isometric View of Winged Hovercraft.

Angle of attack 0°

The pressure contours and the pressure graph with respect to the wing co-ordinates for angle of attack 0° attached in the hovercraft is shown in below Figure 6.

The pressure difference at the wing upper surface and the lower surface produces the lift force which may meet the necessary requirements. By this the lift force produced by attaching the wing at the noted angle of attack can be calculated.

The air passes through the structure causes friction along the surface of the wing which causes drag force. The wall shear contours and the wall shear graph with respect to the wing co-ordinates for angle of attack 0° attached in the hovercraft is shown in below Figure 7.

By this the drag force produced by attaching the wing at the noted angle of attack can be calculated

Angle of attack 5°

The pressure contours and the pressure graph with respect to the wing co-ordinates for angle of attack 5° attached in the hovercraft is shown in below Figure 8.

By this the lift force produced by attaching the wing at the noted angle of attack can be calculated.

The wall shear contours and the wall shear graph with respect to the wing co-ordinates for angle of attack 5° attached in the hovercraft is shown in below Figure 9.

By this the drag force produced by attaching the wing at the noted angle of attack can be calculated.

Angle of attack 10°

The pressure contours and the pressure graph with respect to the wing co-ordinates for angle of attack 10° attached in the hovercraft is shown in below Figure 10.

By this the lift force produced by attaching the wing at the noted angle of attack can be calculated.

The wall shear contours and the wall shear graph with respect to the wing co-ordinates for angle of attack 10° attached in the hovercraft is shown in below Figure 11.

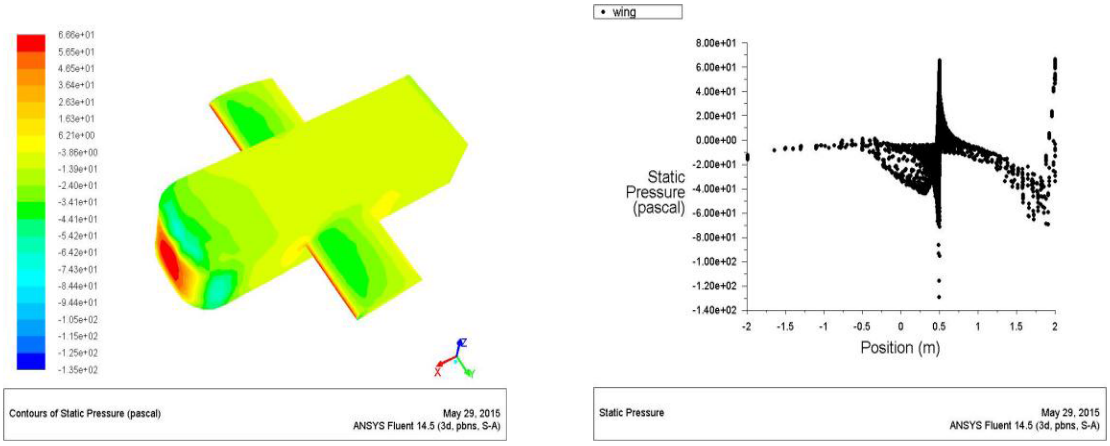

Figure 6: Static pressure contours and Graph for 0°.

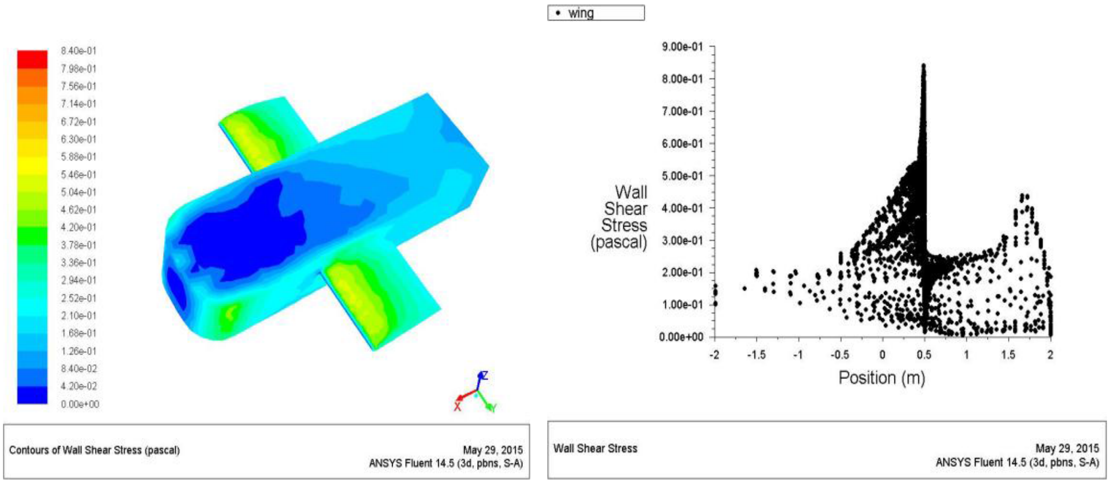

Figure 7: Wall shear contours and Graph for 0°.

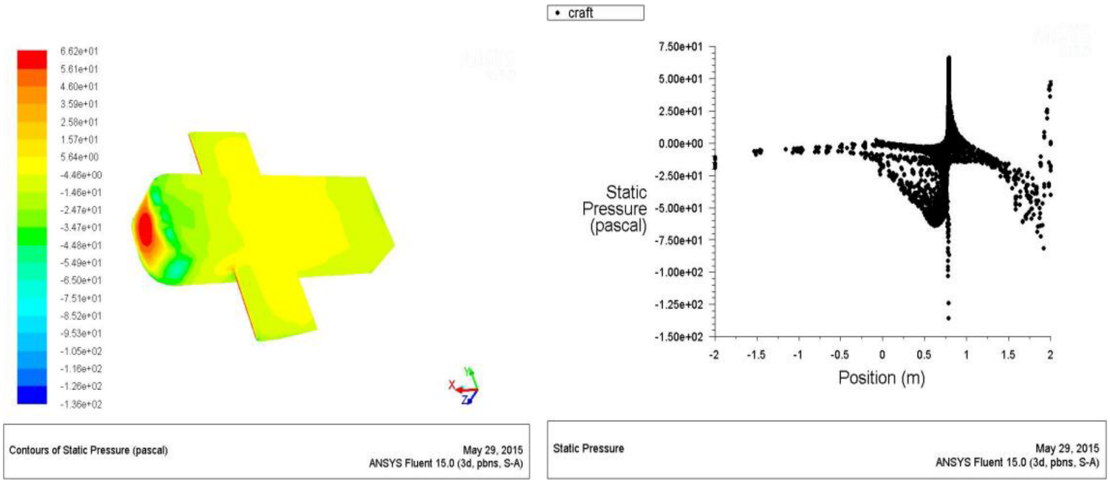

Figure 8: Static pressure contours and Graph for 5°.

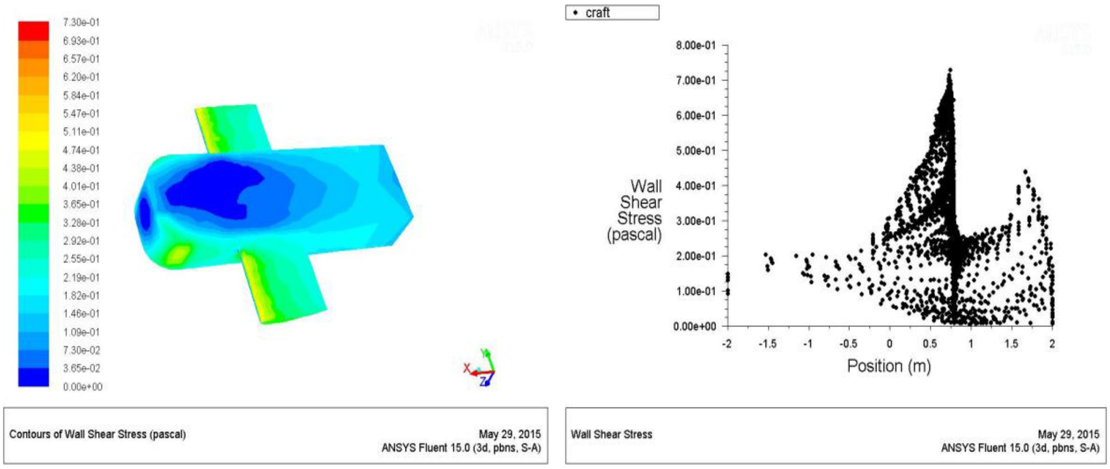

Figure 9: Wall shear contours and Graph for 5°.

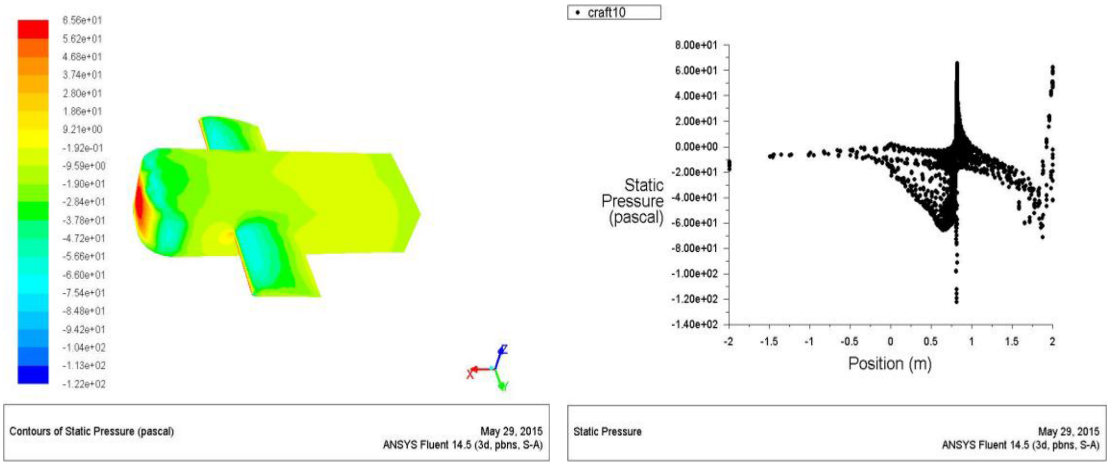

Figure 10: Static pressure contours and Graph for 10°.

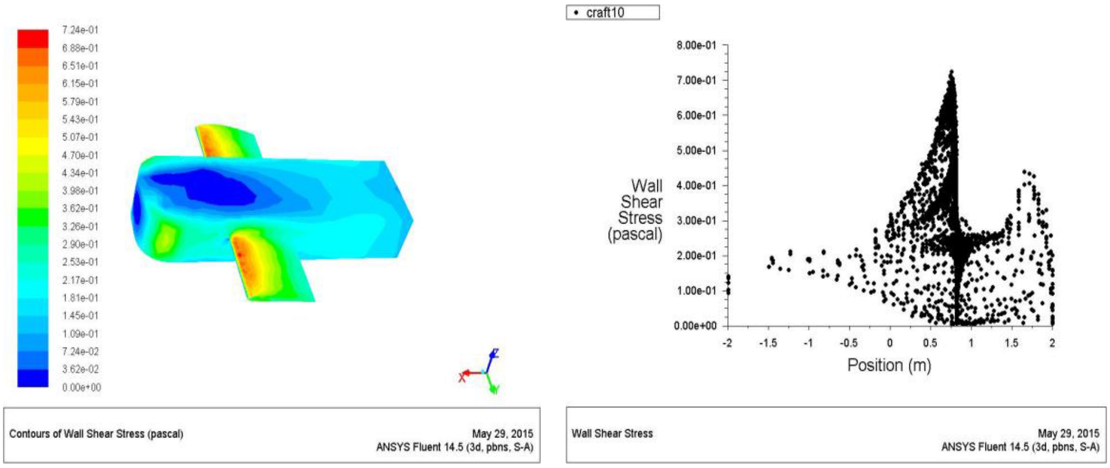

Figure 11: Wall shear contours and Graph for 10°.

CFD cl and cd values are presented in Table 1.

By this the drag force produced by attaching the wing at the noted angle of attack can be calculated.

Angle	CL value	CD value
0 deg	0.192	0.453
5 deg	0.632	0.296
10 deg	9723	0.1523

Table 1: CFD cl and cd values.

Wind Tunnel Experimental Study

The use of wind tunnel is to test models of proposed aircraft. In the tunnel, we can carefully control the flow conditions which affect forces on the aircraft. By making careful measurements of the forces on the model, we can predict the forces on the full scale aircraft. And by using special diagnostic techniques, we can better understand and improve the performance of the aircraft against Flutter.

The wind tunnel has played a leading role in aerodynamic performance analysis since the first days of powered flight when the Wright brothers used a wind tunnel to evaluate the lift and drag of their airfoil profiles.

A wind tunnel simulates the movement of an object (e.g., an aircraft or a car) through air by placing a stationary scale model of the object within a duct and either blowing or sucking air through the duct. Mounting the model on a force balance allows measurement of forces, such as drag and lift or drag force, as the air interacts with the scale model.

By selecting a special combination of air flow (speed, viscosity and density) and model (scale) parameters, the non-dimensional force results (e.g., lift and drag coefficients) obtained for the scale model in the wind tunnel will mimic those of its full size equivalent moving in still air. For this flow mimicry to be accurate, the Reynolds number of the scale model and that of the full size model should ideally be the same, but at worst the Reynolds number needs to be close enough to ensure the same air flow characteristics, e.g., both models experience turbulent rather than laminar flow. Herein lies one of the key weaknesses of wind tunnels, in that if the Reynolds numbers aren't equivalent then the flow characteristics, and force measurements will be wrong. The subsonic wind tunnel model basic diagram is shown in Figure 12.

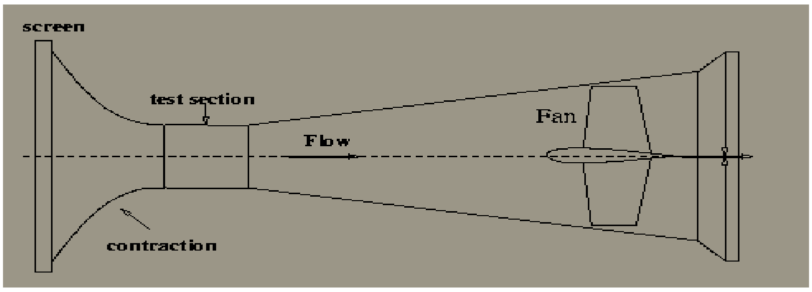

Figure 12: Subsonic wind tunnel.

The walls of the test section (duct) in a wind tunnel influence the results obtained for the scale model. This effect can be acute and invalidate results when the model's cross section is more than 10% of the overall duct's cross section. Wind tunnel wall correction factors are often cited to make the results equivalent to wall-free results.

Calculation of cl and cd

For angle of attack 10°

Upper pressure average = 8.69152 kpa

Lower pressure average = 66.08841 kpa

Experimental Pressure difference = 57.3969 kpa

dy. pressure = (ρv2)/2

= (1.145837 * 15*15)/2

dy. pressure =57.29135 kpa

Force = pressure * area = 57.3969 * 3.22

= 184.81 kN

Lift force = force * cos α

= 184.81* cos 10

Lift force =182.01 kN

Drag force = force *sin α

=184.81*sin10

Drag force = 32.09 kN

cl = Lift force/(dy. pressure * area)

= 182.01/ (59.29135 * 3.2)

cl = 0.9592

cd = Lift force/(dy. pressure * area)

= 32.09/ (59.29135 * 3.2)

cd = 0.1691

Experimental cl and cd values are presented in Table 2.

Comparison of lift and drag

Comparison of Lift and Drag values in Table 3.

Conclusion

The hovercraft base model name SKIMA 4 has been taken as a design model, its size and performance has been studied with the available journals and books. The base structure was designed and its lift, thrust and drag has been determined. The Clark Y wing was attached to hovercraft to produce the lift which was already produced by fan. Hovercraft with winged model design will be carried out at an optimized angle of attack. The performance measures of hover flight will be done using Computational Fluid Dynamic(CFD) software's and the total coefficient of lift to drag ratio will be calculated against the various angle of attack, manipulating the initial thrust required to make lift and opting maximum propulsion force for forward movement. The scaled wooden model was developed and experimentally analyzed by using wind tunnel experiment. The lift force required to hover the craft is produced by the attached wing. In traditional model the power from single engine unit is split into two part for getting thrust and lift. In this winged hovercraft the most engine power will be delivered to propulsion alone, thus it is possible to hover the vehicle at higher speed with built in lift wings.

Angle	CL value	CD value
0 deg	0.2325	0.465
5 deg	0.6532	0.326
10 deg	0.1691	0.9592

Table 2: Experimental cl and cd values.

Force	Without Wing	CFD Result	Experimental Result
LIFT	105.45 Kn	205.12 kN	182.01 kN
DRAG	40.18 kN	29.46 kN	32.09 kN

Table 3: Comparison of Lift and Drag.

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