Preliminary design of vertical take-off and landing (VTOL) UAV with steerable vertical thrust effect

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Preliminary Design of Vertical Take-Off and Landing (VTOL) UAV with steerable Vertical Thrust effect

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***Abstract*—This paper presents the preliminary design of an aerial vehicle testbed based on the GFS-UAV implementation, namely the "Coanda^{JLT}Craft". The modified GFS-UAV design uses the Coanda principle to provide lift with enough Vertical Thrust (VT) generated by the Coanda flow. The lift coefficient of the Coanda profile is investigated in our laboratory. A novel steerable design is introduced. This novel design provides an alternative for directional controls and for enhancing the flight stability. Our experiment shows that the steerable configuration is valid up to 10 m/s of Coanda surface flow speed for indoor applications.**

***Keywords*—Coanda, Unmanned Aerial, VTOL, UAV**

I. INTRODUCTION

Despite having been discovered at the dawn of flight itself, the Coanda principle to this day is largely unexplored in its application to flight and aerodynamics applications. It is not receiving well recognized as one of the main components in today aircraft industries[1]. Though there had been several attempts to construct Vertical Take-off and Landing (VTOL) aviation prototypes[2] that operates purely on the Coanda principle, most of the projects are largely unsuccessful due to diverse reasons and hence up till this day there exists very little scientific research and experimental data on the application of the Coanda principle in flight. However, with newer advancements in technology such as electronic gyroscopes constructing a VTOL Unmanned Aerial Vehicle (UAV) that operates upon the Coanda principle is possible.

GFS-UAV developed by GFS projects limited was formed in 2002 to design, develop and market a new form of flying platform [3]. Its aim is to create a stable, circular shaped Unmanned Aerial Vehicle (UAV) with enclosed propulsion unit hence enabling it to fly through obstacles such as buidlings without the risk of damaging the propulsion unit. It is also a low cost solution compared to other Vertical Take Off and Landing (VTOL) UAVs and its size can range from mere centimeters to several meters.

In this project, we investigate the Coanda curve profile lift coefficient used by the GFS-UAV and incorporating new methods of providing directional controls and flight stability as compared to the GFS-UAV design. We present the data collected in laboratory base on Coanda curve profile from the GFS project [3]. Base on the data obtain from the experiment, the first generation Coanda^{JLT}Craft-01 has been built with new methods of providing directional control and flight stability.

Section II visualize the Coanda air flow pattern based on works published by Njhius [4]. Section III demonstrates the flying module setup in laboratory condition. Section IV analyzes the lift coefficient that indicates the variation of airflow that correlates well with our prediction to modify the GFS design for steerable control design. Section V presents the design and fabrication works modified from the GFS-UAV projects.

II. THE UNDERLYING PRINCIPLES OF THE COANDA EFFECT

The Coanda principle, along with the third law of motion is primarily responsible for the effectiveness of curved wings rather than the Bernoulli Effect, as is often cited. The curved shape of the wing encourages the air passing over the wing to flow downwards. Thanks to Newton's equal and opposite reactions, this downward momentum must be balanced by an upward force, providing lift for the wing. Using the Coanda principle, we could generate a vertical thrust to lift the aircraft without the use of rotary wings or jets. No part of the propulsion system has to stick out of the body. This is particularly important because it reduces the vulnerability of the vehicle in certain circumstances like a flight through an obstacle-filled airspace. The Coanda principle is particularly useful for vertical takeoff and landing, especially when the vehicle body is disc shaped.

Basically, we utilize the Coanda principle to manipulate the air flow by "pushing" the airstream to the surface of the vehicle body. This is done by using a surface that is curved away from the direction of flow, hence creating a lower air pressure between the airstream and the surface (Figure 3). In the process, ambient air is added to the airstream. [4], [5], [6]. In the absence of the curved surface, the airstream would move in a horizontal direction as shown in Figure 1.

When an airstream is moving close to the surface, the interaction of the airstream causes a drop of air pressure between the airstream and the surface (Figure 2), hence causing the ambient air at the other side of the airstream to push both the airstream and surface together.

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A curved surface contributes to the increasing acceleration of the airstream, forming an area of low pressure between the airstream and the surface, generating a further vertical a lift for the vehicle. It should be noted however that the airstream should not be bent beyond 90° because a negative thrust would be formed.

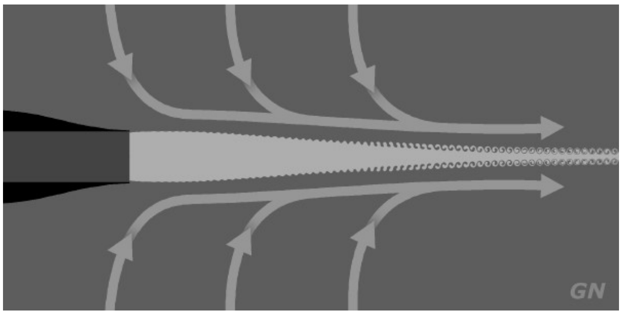

Figure 1. In the absence of a curved surface, the airstream would move in a horizontal direction (quoted from [4], publicly published data, Fig 1-6).

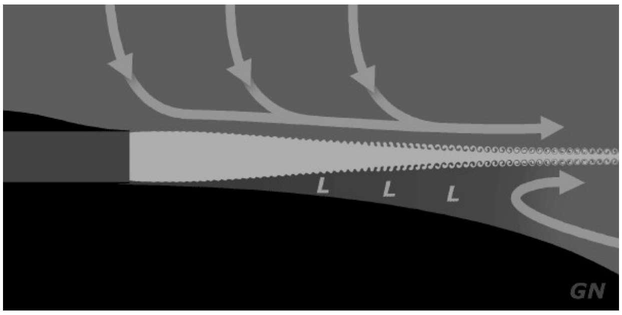

Figure 2. When close to a curved surface, a low pressure region (denoted by L) is formed between the airstream and the surface

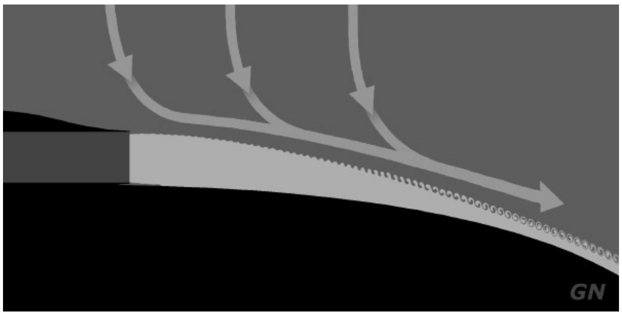

Figure 3. Due to the low pressure region, both the airstream and surface are pushed together, consequently generating a vertical thrust for the body

One of the main problems that we face from the application of the Coanda principle is that the airstream becomes turbulent and detaches from the surface, similar to a stall in an aircraft wing. A drag in the airstream is usually caused by loss of energy due to the difference in velocity between the airstream and surface causes turbulence. This causes the airstream to separate from the surface, hence eliminating the low pressure region and causing the upward thrust to cease (Figure 4).

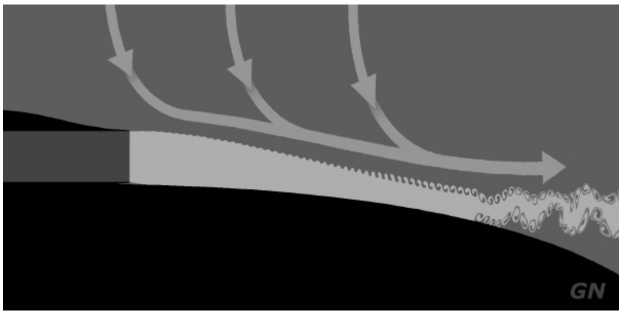

Figure 4. Existence of drag in the airstream cause the flow to detach from the surface

However, this problem can be solved by "gluing" the airstream to the surface using boundary layer control. This could be achieved using suction or acceleration methods.

The suction method literally sucks the airstream towards the surface even when the flow is turbulent. The said suction could be delivered using a wing filled with holes where the air inside the wing would be pumped out quickly through the holes (Figure 5). Extremely low pressure regions could be formed using this method, hence forcing the flow to remain close to the surface.

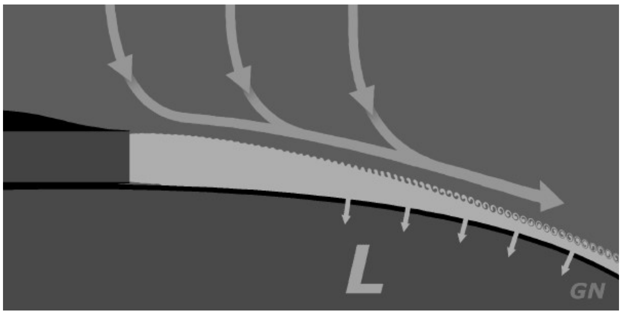

Figure 5. The air is sucked out through suction holes using the boundary layer control suction method, creating a low pressure region (L)

The boundary layer suction method is complex because the amount and position of optimal suction holes varies. Besides that, should the airstream be stronger than the suction, the air would then be sucked out instead of in, causing the airstream to detach from the curved surface and further contributing to the turbulent flow.

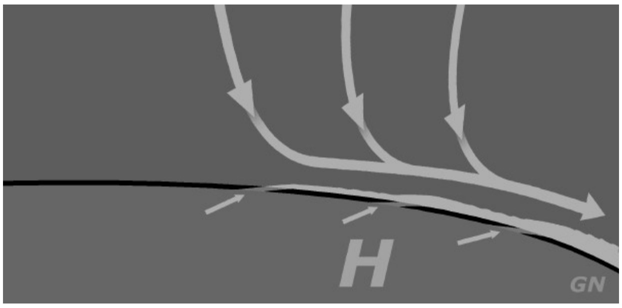

Figure 6. Air with higher velocities is added to the airstream.

The acceleration method is a far simpler method compared to the suction method. Using this method, air with higher velocities is added to the airstream. This in turn accelerates the boundary layer and the airstream (Figure 6).

III. TEST BENCH FOR COANDA CURVE LIFTING SURFACE PROFILE

Our first task is to conduct an experiment to measure the thrust forces provided by the body at different wind speeds. In order to further our understanding of the Coanda Effect and its application to a curved surface, we decided to use a method called the Coanda Effect Test Bench (CoETB) as shown in Figure 7. This experiment is designed to test the various shapes of hull and thus understand how to find the best curve, as well as to gauge the lifting force of the Coanda curve at different wind speeds.

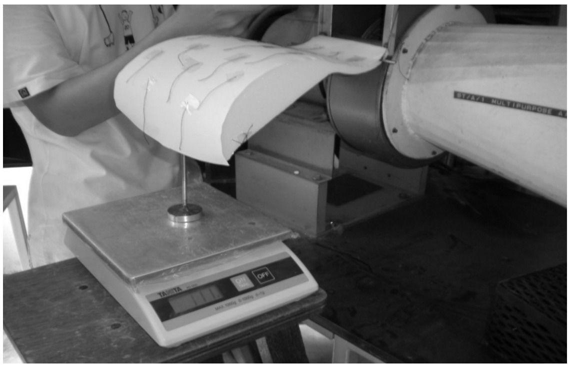

Figure 7. Coanda Effect Test Bench (CoETB)

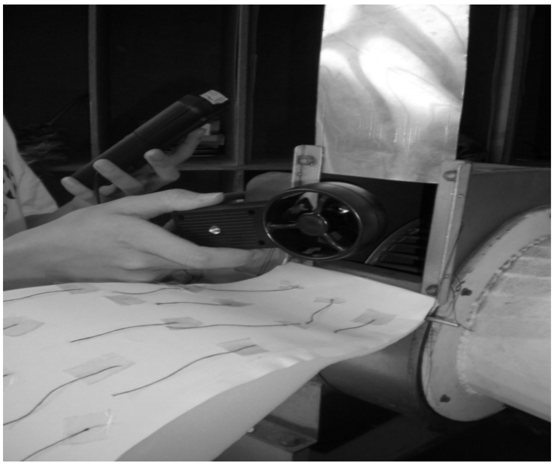

Figure 8. Wind speeds measurement

To perform this experiment, we attached a sample of the lifting profile base on Coanda curve with an lifting surface area (S_w) of 0.019 meter square to the wind tunnel located at the college Mechanical Lab. In order to measure the thrust force provided, we attach an 113grams 'weight' to the Coanda curve which rests on the electronic weighing machine (Figure 8). In order to spread out the flow of air from the blower more evenly, we have placed a funnel to be attached to the exit of the blower.

When the blower is turned on, we measure the thrust force provided by the wind at different speeds by reading the reduction of the weight measurement on the weighing device.

The wind tunnel is the operated at different speeds. A wind speed sensor is then utilized to measure the different wind speeds, and the corresponding difference in the weight measurements is recorded. Assuming uniformly distributed flow and no distortion of the curve, we conclude that the decrease of the weight readings as recorded on the weighing machine is equal to the lift force provided by the Coanda curve.

IV. TEST BENCH RESULTS

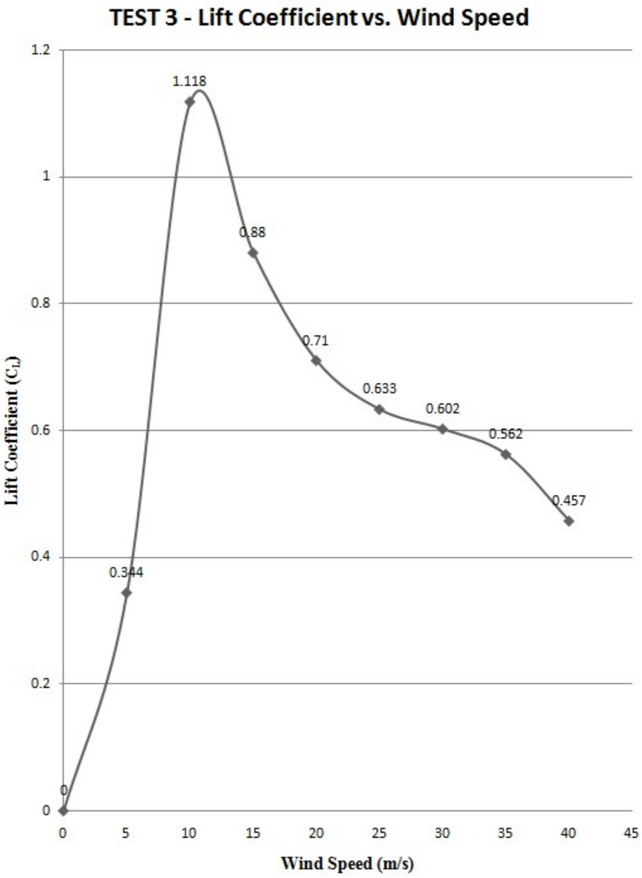

Figure 9. Experimental Results

Results obtained from the experiment are used to calculate the Lift Coefficient (C_L) of the Coanda curve. The Lift Coefficient is obtained from the formula given [6]:

$$L = \frac{1}{2}\sigma V^2 C_L S_w \tag{1}$$

Where L is the lifting force in Newton, the air density, σ and wind speed, V in meter per second.

The lifting force is obtain by the resulting weight reduction (W) measured by the weighing machine, as follow:

$$L = (113 - W) \times g \qquad (1)$$

Where 'g' is the gravitation acceleration taken as 10 meter per second square to ease the calculation. The experiment is repeated many times to ensure consistency. The selected result is shown in Figure 9.

As shown in the graph, the lift coefficient for the Coanda curve peaks at the wind speed of 10 meter per second, at the value of 1.118. As the wind speed accelerates, the lift coefficient steadily drops to a value of around 0.45, it is notice that at such speed there is a visible distortion on the Styrofoam built surface and turbulence occurred as notice from the thread behavior which is attached to the surface. From the observation, the reduction of lift coefficient may mainly due to flow separation that occurred due to phenomena explained for figure 4 and turbulence due to deformation on the surface. From the experiment we conclude that the experiment revealed that the Coanda curve managed to achieve a reasonably effective lift coefficient.

V. PROTOTYPING

Using compact Styrofoam as our primary building material, we aim to construct the body of the vehicle that adheres to the Coanda curve base on the profile tested with the CoETB . The profile is developed by a French scientist called Jean-Louis Naudin.

We first constructed a master template of the profile using a cardboard so that it enables us to fabricate the Coanda curve faster and more accurately and efficiently. This is especially difficult as we are fabricating the curves by hand and could never be as precise as, say, a CNC machine. However, we compensated for whatever inaccuracies or defects along the curve by using sandpaper with a very fine roughness to smooth out the curves to ensure a proper air flow along it.

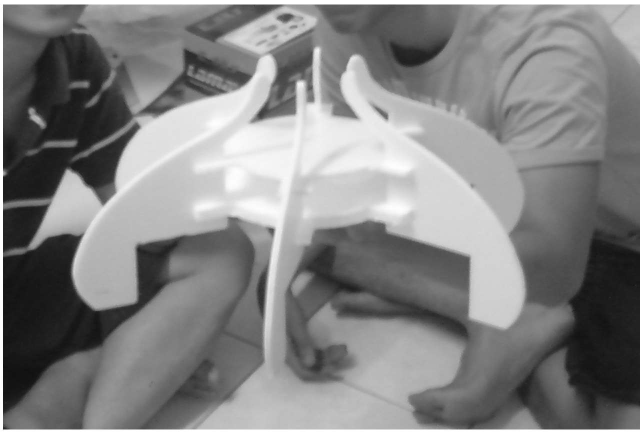

Figure 10. The main chassis with the Coanda Curve profile

of the overall prototype body. The challenge is to successfully design and construct a saucer-like body using the profile we fabricated which is capable of housing the propulsion system (Figure 10).

Next, we fabricate the curved surface. We split the compressed Styrofoam into 2mm thin slices so that it is easier to bend and could be adapted to suit the Coanda curve. In order to perform this task, we plugged a guitar wire to a power supply. By adjusting the voltage and current provided by the power supply, we can sufficiently heat the guitar wire to a point where it could slice through the Styrofoam easily. Subsequently, we obtained a flat board so that we could string the guitar wire around the nails we drove into the board to ensure that the tension in the guitar wire is always maintained. This is especially important because if the guitar wire were to slacken during the splitting process it could damage the entire Styrofoam board.

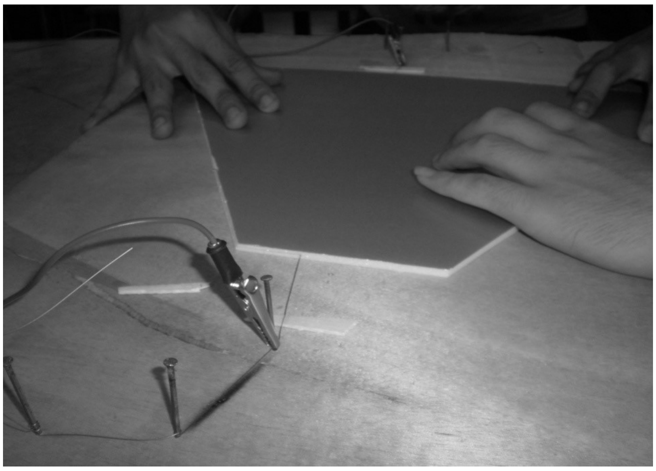

Figure 11. A closer look at how the heated guitar string splits through the Styrofoam

Figure 12. The Completed prototype

In order to ensure a constant thickness of the split Styrofoam, we inserted small pieces of plywood between the guitar wire and the board (Figure 11). The Styrofoam board is then moved slowly through the guitar wire, with us watching carefully for any deviations from the 2mm thickness that is supposed to be the original dimensions of the split Styrofoam.

Using this method, we have successfully split the compressed Styrofoam to a thickness where it is flexible enough to adapt to the Coanda curve and used as the entire cover of the prototype body (Figure 12).

VI. Direction Controls, Propulsion and Stability

There are few new design incorporated into the Coanda^{JLT}Craft-01. Firstly, coaxial rotor system is used as mean of propulsion. This eliminates the need of multiple "fins" for yaw control as used by the original Coanda craft design by the GFS-UAV developed by GFS Limited. The flexible type of rotor is preferred to provide natural stability into the craft, which eliminates the need of using multiple gyros in assisting flight controls as of the GFS-UAV. The GFS-UAV uses a minimum of at least three gyros. However, only one gyro are used on the Coanda^{JLT}Craft-01 by using flexible rotor blades, that is to make sure each rotating rotor of the coaxial system cancel each other out in terms of torque and eliminates the need of using complex gear mechanism. Coanda^{JLT}Craft-01 directional controls are achieved via tilting the rotor plane or better known as collective control without manipulating the Coanda curve as with the GFS-UAV. The GFS-UAV achieved this via flaps installed at the end of the curve and with this either by reducing effective lift or introducing drag, which causes the GFS-UAV tilted at the desired direction of travel. By no mean at any occasion or intention that this project claim and should not be quoted that the Coanda^{JLT}Craft-01 is a more effective platform than that of GFS-UAV. The Coanda^{JLT}Craft-01 however as a prototype for further investigation into this type of craft design.

VII. Conclusions

The experimental result obtain from the CoETB has been presented in these paper. The results clearly showed, with the profile used, the Coanda curve able to generated reasonable lift which makes it feasible to be use in the design of the Coanda Craft. A prototype base on the Coanda profile has been created and test flown successfully. The experiment provides the quantitative result for VT evaluations. A new design is introduced to allow steerable VT, subsequently giving the alternative for Coanda flying UAV.

Acknowledgment

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