Coanda Effect Test Bench (CoETB) — Design enhancement of the CoandaJLT craft

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Coanda Effect Test Bench (CoETB) - Design Enhancement of the Coanda^{JLT} Craft

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***Abstract*—this paper presents the improved design of a Coanda Effect Test Bench (CoETB) and its experimental data. The CoETB is primarily setup to investigate the authors' hypothesis that a steerable Coanda effect can be used for flight directional control. The design is currently based on the Unmanned Aerial Vehicle (U.A.V) manufactured by GFS Projects Limited or known as the GFS-UAV. The CoETB experiment results showed variation of lift resulted by varying the Coanda curve profile angle. The authors presents the works in setting up the CoETB and its experimental results is discussed in this paper.**

***Keywords*—Coanda, Unmanned Aerial, VTOL, UAV, CoETB, Coanda^{JLT}, JLT Coanda Referencing.**

I. INTRODUCTION

The Coanda principle was discovered by a young Romanian-born engineer named Henri Coanda. The young engineer stumbled upon phenomena while building what known to many as the first jet aircraft where he observed that the exhaust gas adhere to the curvature of the aircraft surface. The experiment almost killed him if not been thrown away; the phenomenon of moving fluid tendency to adhere near a surface is now known to be the Coanda effect, named after him. Till this day there are many industry design application that based on the Coanda effect. It also plays a vital role in many high-lift devices found on today modern aircraft. 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. Thus, the authors would like to design a Coanda steerable design in a light weight UAV application.

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 useful for vertical takeoff and landing, especially when the vehicle body is in circular 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.

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 that the airstream should not be bent beyond 90 ° because a negative thrust would be formed.

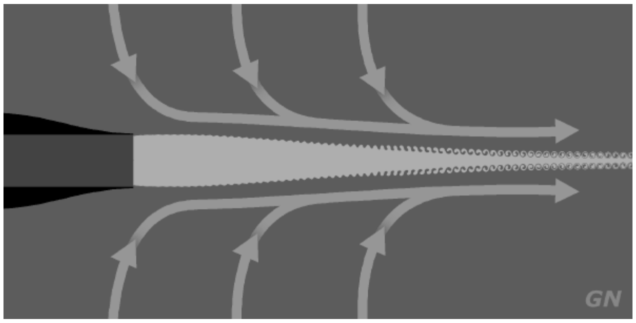


Figure 1. In the absence of a curved surface, the airstream would move in a horizontal direction (quoted from [4], publicly published data, Fig 1-6).

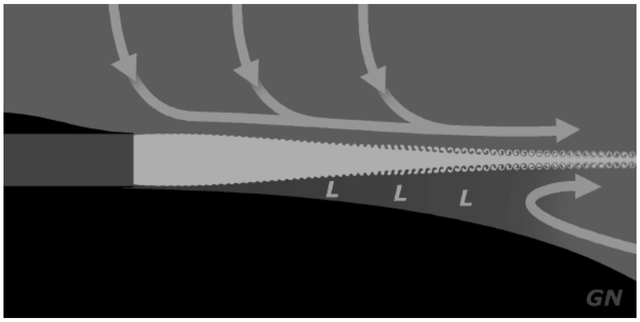


Figure 2. When close to a curved surface, a low pressure region (denoted by L) is formed between the airstream and the surface.

One of the main problems that the authors 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 (flow separation). 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).

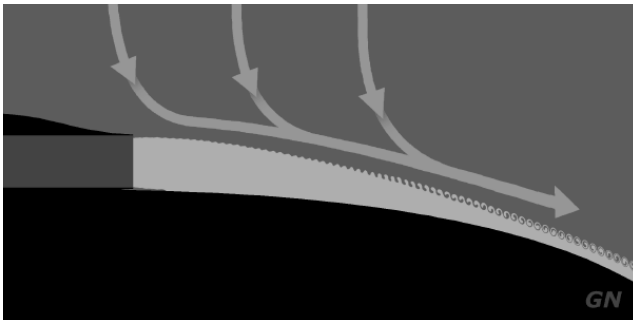


Figure 3. Due to the low pressure region, both the airstream and surface are pushed together, consequently generating a vertical thrust for the body

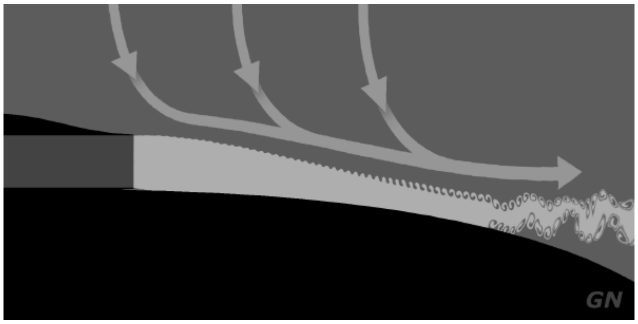


Figure 4. Existence of drag in the airstream cause the flow to detach from the surface

However, this problem can be solved by “gluing” the airstream to the surface using boundary layer control. This could be achieved by using suction or acceleration methods. The suction method literally sucks the airstream towards the surface even when the flow is turbulent. The boundary layer suction can be achieved by 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.

The boundary layer suction method is complex because the amount and position of optimal suction holes varies. If 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. This negative is shown in Figure 6.

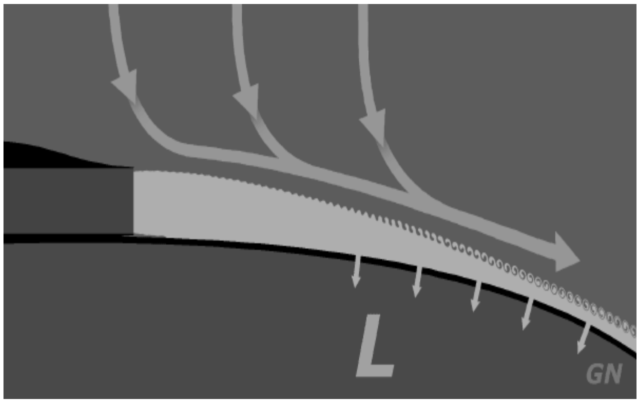


Figure 5. The air is sucked out through suction holes using the boundary layer control suction method, creating a low pressure region (L)

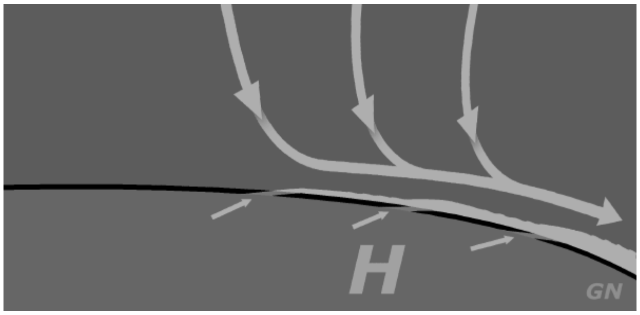


Figure 6. Air with higher velocities is added to the airstream.

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. THE GFS-UAV INVESTIGATION

The GFS-UAV (Figure 7) 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 buildings 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. Further investigation into the GFS-UAV shows that it uses flaps (Figure 7) around the edge of the UAVs as means of controlling the craft. Our test bench results show that such flaps when directed at certain angle causes flow separation which result in dissymmetrical of lift that enable the said craft tilted to the desire direction of travel. Based on the basic understanding of aerodynamic, such movement and arrangement of flaps will induce turbulence flow, while this reduces the lift that causes lift variation required for directional control; it also introduces uncertainty both in terms of resultant force vector and magnitude. This could be the reason behind the unstable flight as observed from the project website, later electronics gyros has been added to assist the pilot for subsequence successful flight.

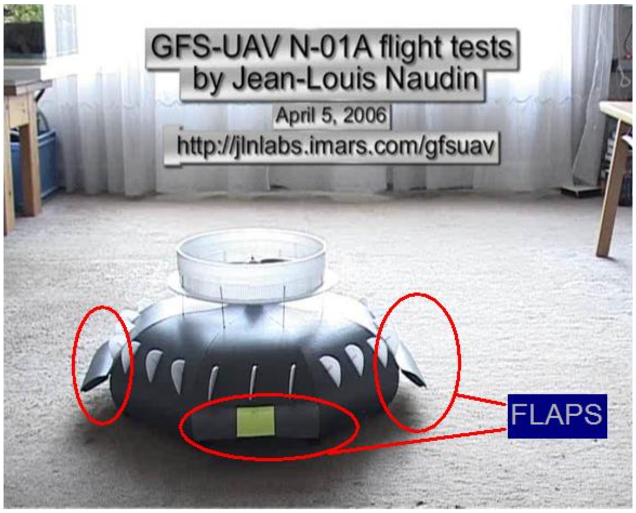


Figure 7. The GFS-UAV and Flaps that been used to control the flight direction. (Source : www.jlnlabs.imars.com)

IV. INTRODUCTION OF THE JLT COANDA REFERENCING LINE (JLT REF.) AND COANDA CURVE PROFILE

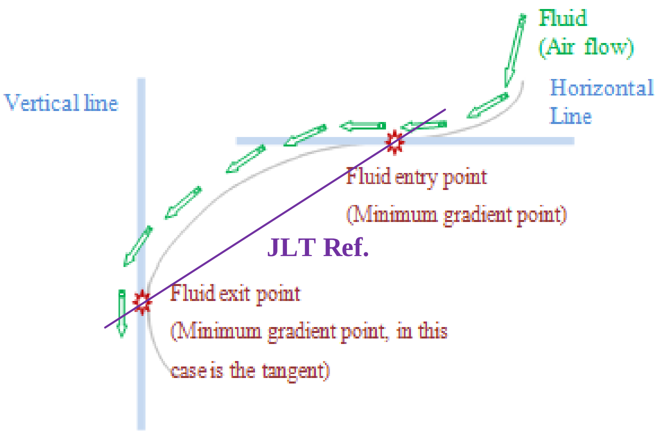


Figure 8. The JLT Ref. definition

The JLT Coanda Referencing Line (JLT Ref) has been introduced by the authors as a referencing line on the Coanda curve used on the craft or known as the Coanda profile. The JLT Ref. is defined as a line drawn from 2 point where at one point the gradient of the curve on the profile is at its minimum with respect to the horizontal line while the other is at the minimum gradient of the curve with respect to the vertical line (Figure 8).

It is argued that such line coincide with the changes of direction of flow over the curve therefore would be the point between the fluid entry point and the fluid exist point assuming there is no flow separation. Compared this to an analogy of an airfoil, where the referencing line of an airfoil or known as the chord line is the line drawn between two points [1], that is the stagnation point (Leading edge) or the fluid entry point and the trailing edge of the airfoil or the fluid exist point, assuming there is no flow separation (Figure 9).

The authors varied the angle of the Coanda profile (α) with respect to the JLT Ref, one can expect a relationship between lift force with the changing of angle, analogy of an airfoil and its angle of attack, A-o-A (Figure 10). The CoETB is setup to evaluate the angle α, namely will known as Coanda Angle of Attack or 'AOA_{Coa}', versus the surface flow pattern and the corresponding parametric analysis.

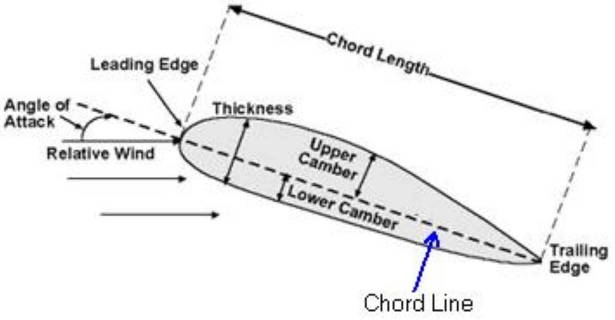


Figure 9. Airfoil and the chord line indicating the similarity between normal airfoil design to the designed Coanda profile.

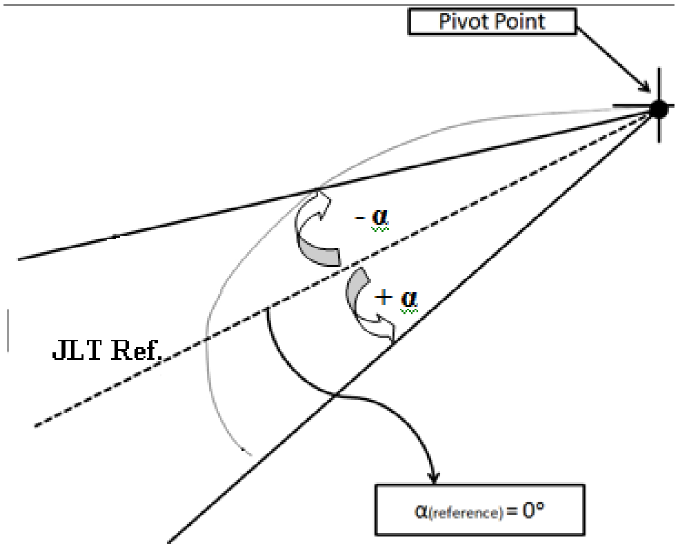


Figure 10. Establishment of AOA_{Coa} via the JLT Ref.

V. THE COANDA EFFECT TEST BENCH (COETB)

The CoETB is set up to evaluate the relationship between the thrust generated by the Coanda profile versus the changing of angle with respect to the JLT Ref. This thrust will be used as our steerable and lifting drives of the Coanda UAV. The basic layout is shown in figure 11. A weighing machine is used to record the magnitude of the lift force in terms of grams. Result is collected from angles ranging from '–' ve 26 degree to '+' ve 26 degree with 2 degree of resolution. The specific angle is achieved by installing a bar below the profile with specific length as seen in figure 11. A total of 27 bars with specific length has been built for these purposes. The basic measurement of the CoETB can be seen in figure 12.

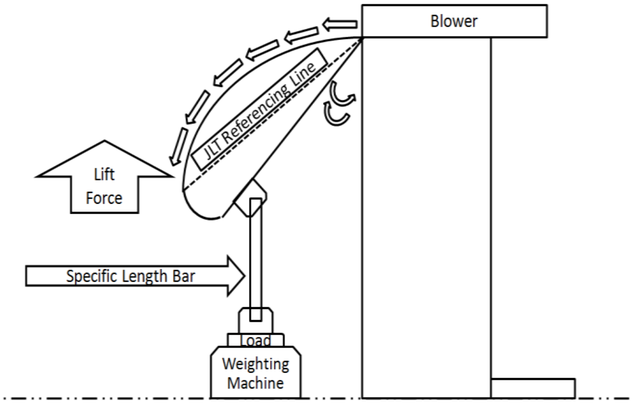


Figure 11. CoETB basic layout

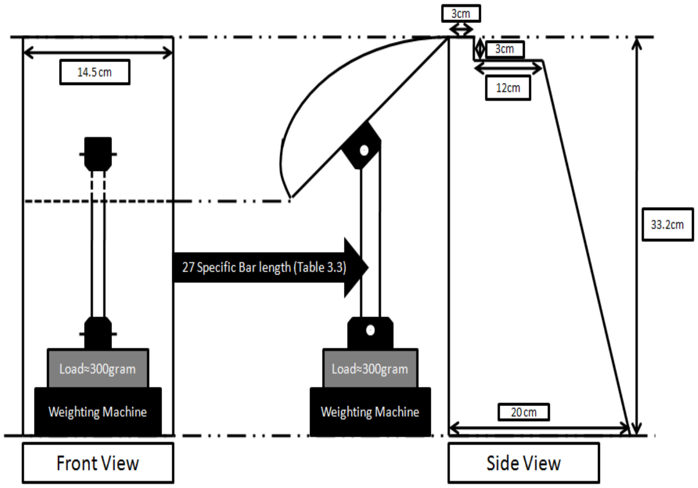


Figure 12. CoETB basic design layout with measurement

A 300 grams load is use with the weighing machine. The weighing machine is then preset to zero value with the initial load, hence any lift force generated by the Coanda profile due to airflow will then register a negative reading on the scale which is then can be use. In actual construction, fin is added on the side to avoid flow 'spilling' over the side which can cause undesirable effect on data collected. (figure 13)

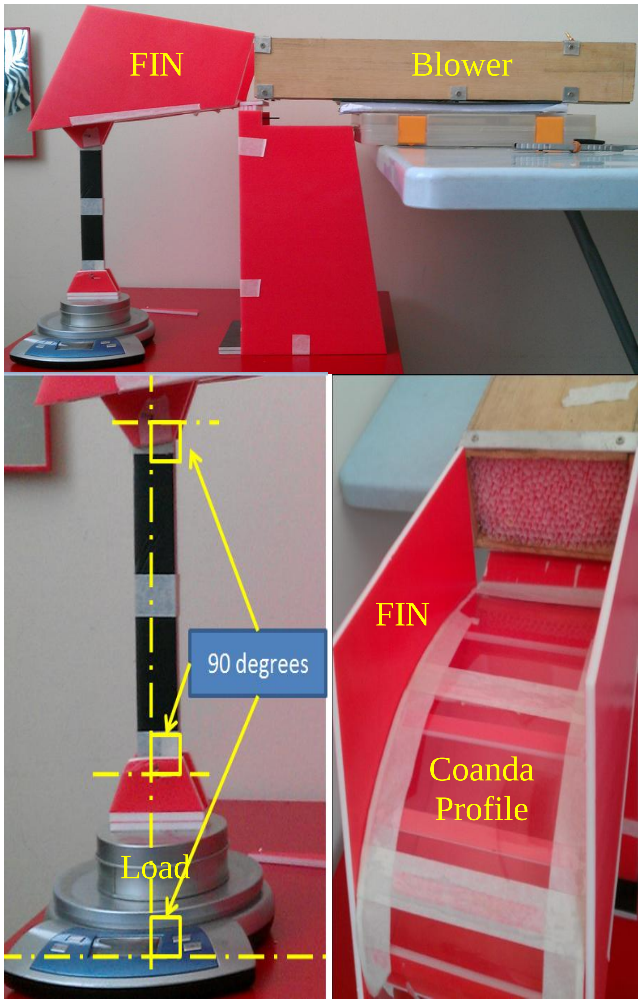


Figure 13. Actual construction with 'Spill over fin'

VI. THE EQUATION AND EXPERIMENTAL DATA

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]:

$$L = \frac{1}{2}\sigma V^2 C_L S_w \qquad (1)$$

Where L is the lifting force in Newton, the air density 'σ' wind speed in meter per second 'V' and Coanda lifting area 'S_w'. All lift taken was in Gram units and converted into Kilograms:

$$\text{Lift} = \frac{L_{\text{recorded}}}{1000} 9.81(\text{gravity}) \qquad (1)$$

Coanda lifing area S_w :

$$Sw = (effective\ length\ \times profile\ width)m^2$$
$$Sw = \left(\frac{23}{100}m\ \times \frac{14.5}{100}m\right) = 0.03335m^2 \qquad (3)$$

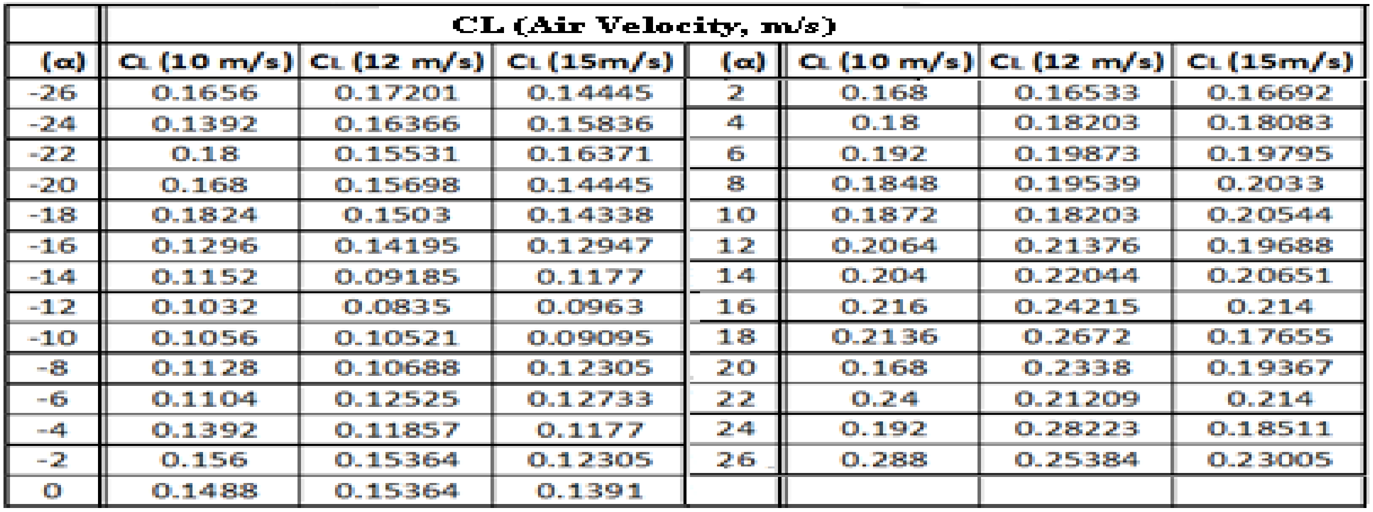
Data collected is shown in figure 14 where the C_L has been calculated across three type of air velocity, 10m/s, 12m/s and 15m/s. The graph of C_L versus AOA_{Coa} can be seen in figure 15.

VII. RESULTS AND DISCUSSION

The best fit line was determined between the AOA_{Coa} of -16^o to 16^o. The best fit polynomial line equation for each speed is determined to be:

$$C_{L,10m/s} = 0.00005\alpha^2 + 0.003\alpha + 0.151 \qquad (4a)$$
$$C_{L,12m/s} = 0.00009\alpha^2 + 0.004\alpha + 0.149 \qquad (4b)$$
$$C_{L,10m/s} = 0.00007\alpha^2 + 0.003\alpha + 0.148 \qquad (4c)$$

The polynomial regression is found to be 0.963, 0.884, and 0.860 respectively.



	CL (Air Velocity, m/s)						
(α)	CL (10 m/s)	CL (12 m/s)	CL (15m/s)	(α)	CL (10 m/s)	CL (12 m/s)	CL (15m/s)
-26	0.1656	0.17201	0.14445	2	0.168	0.16533	0.16692
-24	0.1392	0.16366	0.15836	4	0.18	0.18203	0.18083
-22	0.18	0.15531	0.16371	6	0.192	0.19873	0.19795
-20	0.168	0.15698	0.14445	8	0.1848	0.19539	0.2033
-18	0.1824	0.1503	0.14338	10	0.1872	0.18203	0.20544
-16	0.1296	0.14195	0.12947	12	0.2064	0.21376	0.19688
-14	0.1152	0.09185	0.1177	14	0.204	0.22044	0.20651
-12	0.1032	0.0835	0.0963	16	0.216	0.24215	0.214
-10	0.1056	0.10521	0.09095	18	0.2136	0.2672	0.17655
-8	0.1128	0.10688	0.12305	20	0.168	0.2338	0.19367
-6	0.1104	0.12525	0.12733	22	0.24	0.21209	0.214
-4	0.1392	0.11857	0.1177	24	0.192	0.28223	0.18511
-2	0.156	0.15364	0.12305	26	0.288	0.25384	0.23005
0	0.1488	0.15364	0.1391				

Figure 14. CoETB experimental data

Figure 15. C_L Versus AOA_{Coa}

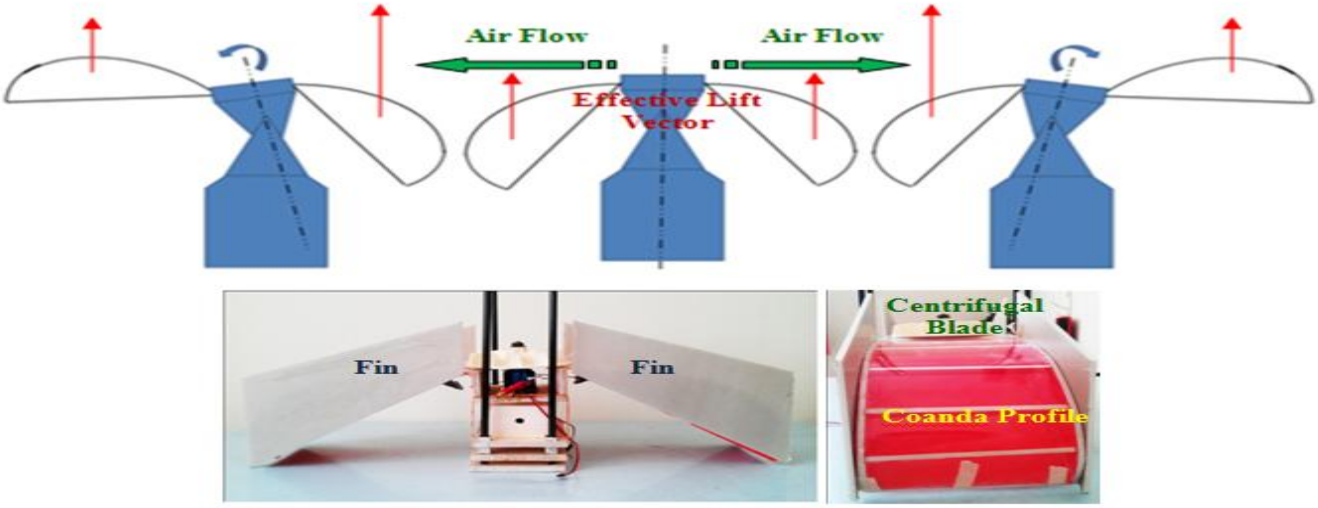


Figure 16. Directional control apparatus

It is clear from the results that there is a distinctive variation of lift at changing of AOA_{Coa}, analogy of those observed in that of airfoil. With the highest C_L close to 0.3, it is therefore possible, as determined by the author to use such means for directional control in similar craft like that of GFS-UAV. Means such as discuss in figure 5 and 6 can be considered to greatly delay the boundary layer flow separation. Similarly, the vortex generator deployed in most commercial aircraft over the wings can also be employed. An apparatus has been built and successfully demonstrated the workability of using Coanda effect for directional control. (Figure 16)

VIII. CONCLUTION

The experiment results agree with the authors' hypothesis that variation of lift does occur at changing of AOA_{Coa}. The establishment of JLT Ref to evaluate the relationship of flow pattern and the thrust generated. From figure 15, the thrust generated varies from angle of -10^0 to $+10^0$. The high C_L value coupled with said linear relationship shows such means of achieving directional control for GFS-UAV type of Coanda Craft can be more predictable and efficient as one can achieved directional control by varying the lift without introducing unstable element such as flow separation or turbulence flow. Standard means of delaying flow separation can also be use for future craft as outline in figure 5 and 6. A vortex generator can also be installed to further improve the overall performance.

ACKNOWLEDGMENT

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