MATHEMATICAL MODELLING OF MAV USING AERODYNAMICS CONSISTING OF COANDA EFFECT

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Abstract Design Micro Aerial Vehicle or Micro Air Vehicle [MAV], a hemispherical Coandă shape of body using theoretical approach. The major objective of this paper is, by applying fundamentals of fluid mechanics, flight mechanics and aerodynamics; we will analyze forces and moments of Coandă MAV configuration. A jet, deflected by hemispherical shape is used for hovering and translatory motion. For design requirement in various atmospheric conditions, a theoretical analysis will be performed utilizing by Coandă effect. The parameter affecting on body will be studied. Results will be obtained by making mathematical modeling.

***Keywords* —MAV, mathematical modelling, Coandă effect**

I. INTRODUCTION

A great scientist named Henri Coandă are generally predictable as the discoverer of aerodynamics. He had built first jet powered aircraft, for the duration of World War II. He invented the Coandă effect and obtained a patent in France for an effect presently named after Coandă, in 1934. The Coandă effect is described as: *"Deviancy of a plan jet of a fluid (airflow) that penetrates another fluid in the vicinity of a convex wall of surface"*. He gave role for lift produced by aircraft wings. When he discovered this phenomenon in their research work, is now called the Coandă effect. The use of Coandă effect to transport vertical thrust and hover ability. This thrust should be produced by a jet of air being curved by a curvature, known as Coandă surface. The surface is used for diverting the flow, that is also be used to fly horizontally like a normal aircraft. These type of vehicles are already present, however very less people is known about the principles and the performance of this system. The intense is to design and construct a demonstrator model which shows the abilities of this propulsion system of such kinds. To be able to design such a novel propulsion system the performance has to be found out. To verify this performance, the efficiency of the system and required lift in hover are examined by means of mathematical models. Circulation control can provide high lift to manipulative performance and to improve flying behaviour of MAV and aircraft. Taking advantage of recent efforts to introduce Coandă effect as a novel circulation control technique, this report starts with the research progress on the influences, effectiveness and configurations of Coandă jet fitted aerodynamic surface of MAV to improve its lift accretion with a view on its incorporation in the design.

A micro air vehicle (MAV), or micro aerial vehicle, is a tiny size vehicle that has a size restriction and may be autonomous. Modern craft are as small as 15 centimeters. The purpose of development is driven by commercial, research, government, and military; with insect-sized (means very small in size) aircraft reportedly expected in the future. The small craft allows remote observation of dangerous environments unreachable to ground vehicles. Nowadays, MAVs have been built for hobby purposes, such as aerial robotics contests and aerial photography.

II. DESIGN METHODOLOGY

A hemispherical model is taken for study of Coandă principles utilizing the conservative's equation. A mathematical model is developed in this research based on utilizing the equation as indicated in [14,15]. The model is shown below.

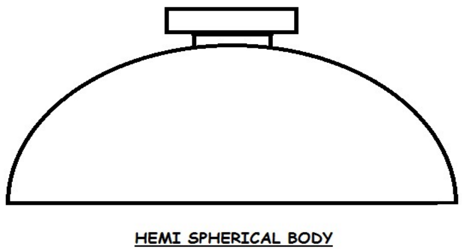


Fig 1 hemispherical body

The relationship between new performance measures is derived to some extent which can enable to describe the physical phenomena of the flow field of Coandă MAV. For Coandă MAV with the given configuration as depicted in the figure, an actuator disk is located at the centre of the body. Rotor can be small as possible for conceptual design.

The actuator is utilized for lift generation by establishing radial flow for Coandă jet blanket. Two dimensional analysis are done on the body. For that, the conservation laws are applied on the on the control volume.

Table 1. Design parameter

No	Parameters	Value
1	Inlet diameter	15 mm
2	Outlet diameter	35 mm
3	Jet slot thickness	1 mm
4	Height	15 mm

A hemispherical object is shown in figure. The air is coming from upward to downward through a slot. The air is stitched to Coandă surface. As flow accelerates trying to equalize the momentum transfer, a loss of pressure results across the jet and the jet is deflected closer to the surface, up to attaching to it.

III. MATHEMATICAL MODELING

Here, the two dimensional analysis are done to find the relationship between various parameters. The performance depends upon two effects; the Coandă jet effect and the actuator disc effect. The fundamental conservation principles of flight mechanics, aerodynamics and fluid mechanics.

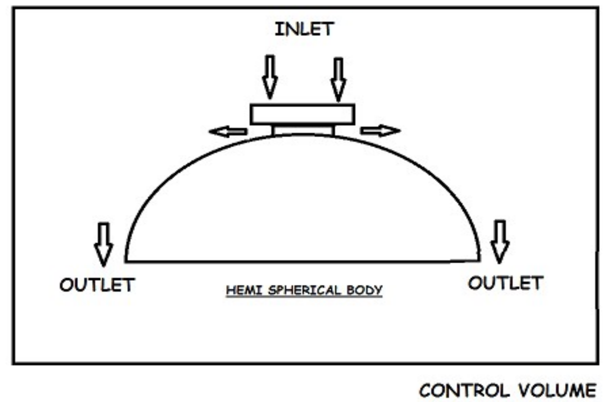


Fig 2 Configurations of MAV

The continuity equation [6] at inlet and outlet along the Coandă jet blanket is given by,

$$V_{j\text{-}out} = \frac{\dot{m}}{2\pi\rho_i h_i} = \frac{R_i h_i}{R_o h_o} V_{j\text{-}in}$$

$$V_{j\text{-}R} = \frac{\dot{m}}{2\pi\rho_i h_i} = \frac{R_i h_i}{R h_R} V_{j\text{-}in}$$

The total lift is given by:

(Total lift force due to Coandă blanket) = (Vertical component of momentum balance due to Coandă blanket) + (Pressure difference on the body of MAV subject to Coandă blanket)

The lift contribution from the momentum flux through the control volume CV in the vertical direction is given by:

Force in the y-direction = Momentum out in the y-direction − Momentum out in the y-Direction

In the radial direction momentum does not contribute to produce lift. The momentum equation in y- direction is given by,

$$F_{COJB} = \dot{m} V_{j\text{-}out} = 2\pi R_i h_i \rho \cdot V_{j\text{-}out} \cdot V_{j\text{-}in}$$

The contribution of lift from the pressure difference between the upper which is curved MAV body covered by Coandă Blanket and the lower part of the MAV body, is given by,

$$F_{IPD} = \pi(R_o^2 - R_i^2)p_a - \int_{\theta i}^{\theta o} \left(p_a - \frac{h}{R}\rho \left(\frac{\dot{m}}{2\pi R h}\right)^2_{j-R} \right) 2\pi R^2 \sin 2\theta \, d\theta$$

The jet flow is assumed to be uniform outflow separating at the sharp edge of the Coandă MAV curved surface. Then the contribution of the pressure difference for lift across the surfaces of the body.

$$F_{IPD} = \left(\frac{\dot{m}^2}{2\pi Rh}\right)_{j-R}$$

Hence the total lift due to Coandă jet blanket momentum and Coandă jet blanket induced pressure difference is given as:

$$Lift_{\text{spherical-COJB+IPD}} = 2\pi R_i h_i \rho V_{j\text{-in}} \times V_{j\text{-out}} + \left(\frac{\dot{m}2}{4\pi\rho Rh}\right)_{j-R}$$
$$= \dot{m} \times V_{j\text{-out}} + \frac{1}{2}\dot{m}V_{j-R}$$

Applying the energy conservation equation to control volume:

<u>Assumptions</u>:
Uniform properties across input and output.
Ignoring the entrainment energy exchange between the ambient air and Coandă jet blanket.

$$\left(\frac{p}{\dot{m}}\right)_{in} + \frac{1}{2}\left(V_{j-in}^2\right) = \left(\frac{p}{\rho}\right)_{out} + \frac{1}{2}\left(V_{j-out}^2\right)$$

Noting that from the outset, the flow is considered incompressible, above equation reduces to,

$$\frac{1}{2}\rho V_{j-in}^2 = \frac{1}{2}\rho V_{j-out}^2$$

Hence, by the application of the conservation energy principle for incompressible flow, the following velocity relationship between the inlet and outlet sections of the Coandă jet blanket is given by:

$$V_{j-out} = V_{j-in}$$

This latter equation should simplify the solution given in previous equation and reduce the use of idealization or the number of assumption since fewer unknowns are included in the equations.

$$Lift_{Spherical-COJB+IPD} = \frac{3}{2}\dot{m}V_{j-in}$$

The flow deflected by the body is producing lift by given equation. The total lift using Coandă jet blanket and induced pressure difference is directly proportional to mass flow rate.

IV. COMPUTATIONAL FLUID DYNAMICS

The simulation area of the hemispherical MAV is shown in the figure. The inlet is the jet slot thickness (h=1 mm) at the centre of the body. The outlet area is at the bottom of the MAV. The simulation is carried out in the ANSYS software.

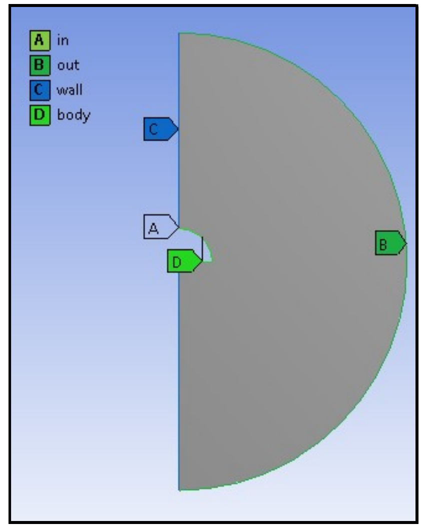


Fig 3 geometry with control volume

Generating the most appropriate mesh is the foundation of advanced engineering simulations. ANSYS Meshing is aware of the type of solutions which is used in the project with the appropriate criteria to create the best suited mesh. Meshing is automatically integrated with each solver within the ANSYS Workbench environment. Meshing chooses the appropriate options based on the analysis type and the geometry of the model. Meshing is an integral part of the computer-aided engineering (CAE) simulation process within the software. The mesh influences the accuracy, convergence and speed of the solution based on the type of meshing. Furthermore, the time it takes to create a mesh model is often a significant portion of the time it takes to get results from a CAE solution. Therefore, the better and more automated the meshing tools, the better the solution. The mesh is generated using ANSYS fluent Mesh. The property of mesh is unstructured with fine mesh. Then, from grid independence test we checked the results. The variation of velocity is negligible with coarse, medium, and fine mesh. It indicates, the results are accurate with different elements.

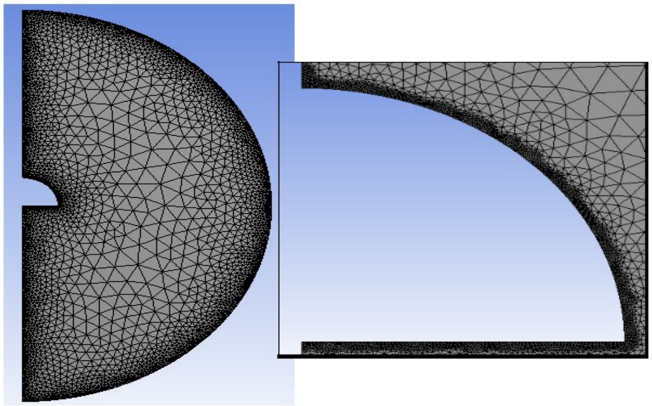


Fig 4 Meshing

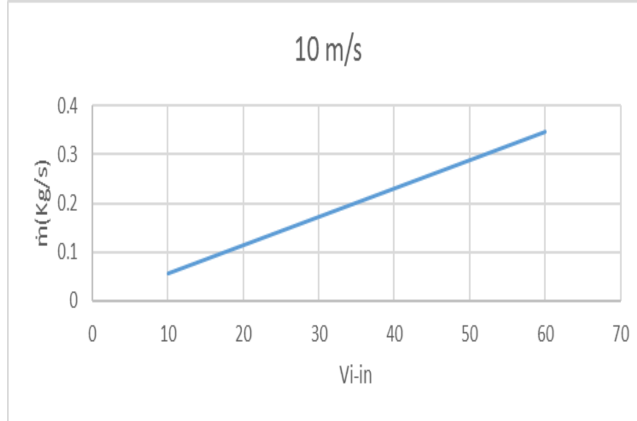


Fig 5 Mass flow rate vs Inlet velocity (V_{j-in})

Table 2 Meshing details

No	Parameter	value
1	Nodes	5183
2	Elements	9554

The details of the boundary conditions are given below:
Inlet velocity – 10 m/s
Ambient pressure – 101325 pa
Density at sea level – 1.223 kg m/s
The outlet conditions are required to calculate itself based on geometry meshing.

V. RESULTS

The calculated data from the previous equation of conservative laws are given below.

Table 3 Theoretical data

No	Inlet velocity(m/s)	Outlet velocity(m/s)	Mass flow rate(kg/s)	Lift (N)
N	10	4.28	0.0576	0.5351
2	20	8.57	0.1152	2.1406
3	30	12.85	0.1728	4.8164
4	40	17.14	0.2305	8.5625
5	50	21.42	0.2881	13.3789
6	60	25.71	0.3457	19.2657

Table 4 Various parameter at velocity 10 m/s

No	Radius (R) m/s	Vj-out (m/s)	Mass flow (kg/s)	Lift (N)
1	0.075	4.28	0.057	0.5351
2	0.08	4.57	0.061	0.5884
3	0.085	4.86	0.065	0.6438
4	0.09	5.14	0.069	0.7014
5	0.095	5.42	0.073	0.7612
6	0.1	5.74	0.076	0.8233
7	0.105	6	0.08	0.8875
8	0.110	6.28	0.084	0.9539
9	0.115	6.57	0.088	1.0222
10	0.12	6.85	0.922`	1.0933
11	0.125	7.14	0.096	1.1663
12	0.13	7.42	0.099	1.24
13	0.135	7.71	0.103	1.3189
14	0.14	8	0.107	1.3985
15	0.145	8.28	0.111	1.4803
16	0.15	8.57	0.115	1.5643
17	0.155	8.85	0.119	1.6504
18	0.16	9.2	0.123	1.7567
19	0.165	9.42	0.126	1.8294
20	0.17	9.71	0.13	1.9221
21	0.175	10	0.134	2.0171

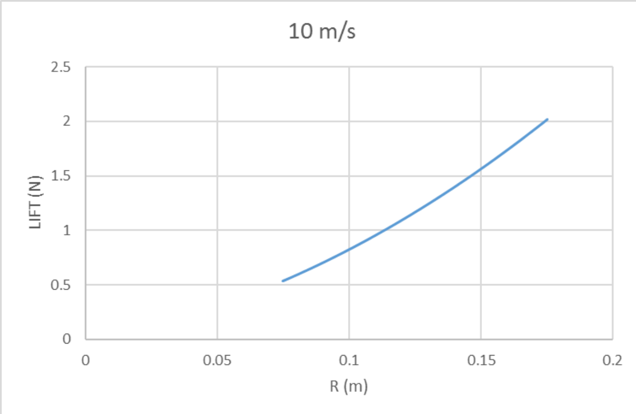


Fig 14 lift at different position of radius (R)

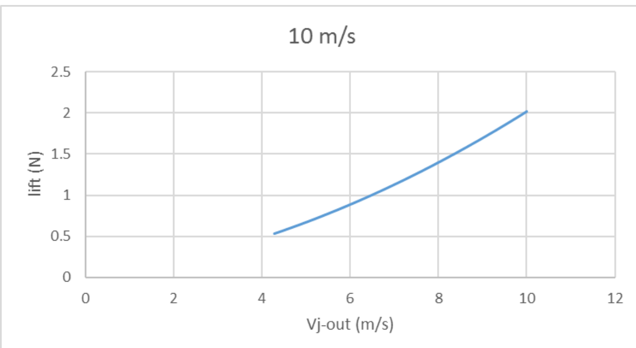
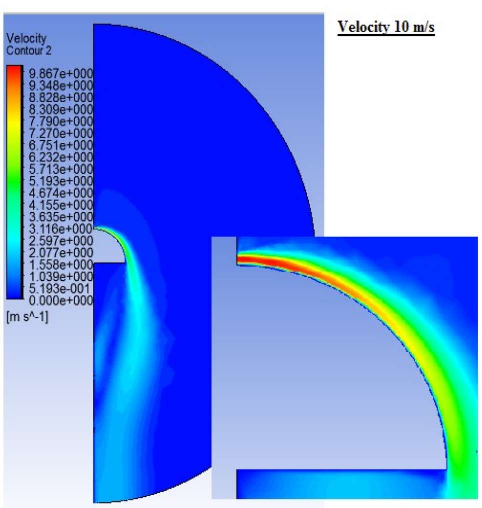


Fig 15 lift at outlet velocity for 10 m/s

This above results are for the inlet velocity of 10 m/s. there are various graphs plotting for Particular velocity. Likewise, we calculated same results for the 20 m/s, 30 m/s, 40 m/s, 50 m/s, 60 m/s. All the graphs plotted for respective all the velocity.



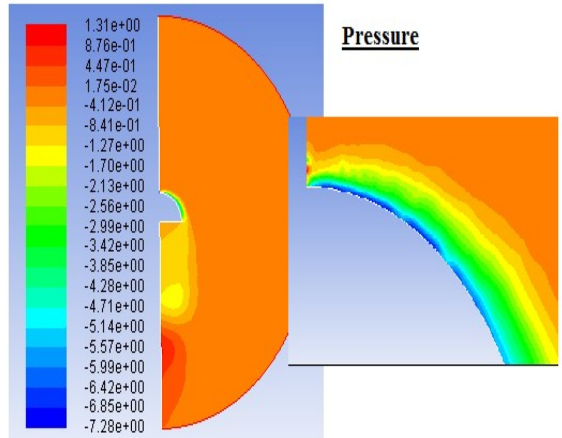


Fig 6 Computational results (velocity and pressure contour)

Table 5 Comparison of lift

No	Inlet velocity (m/s)	Lift (theoretical)	Lift (CFD)
1	10	0.020171	0.011229
2	20	0.080686	0.044915
3	30	0.181542	0.101059
4	40	0.322742	0.17916
5	50	0.504285	0.280718
6	60	0.72617	0.404234

Comparison of the theoretical and CFD results are done below.

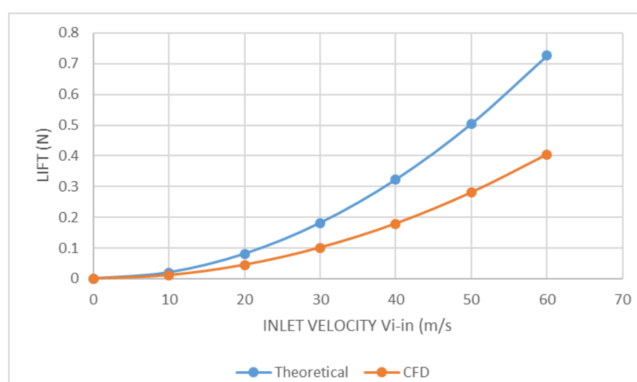


Fig 7 lift vs inlet velocity

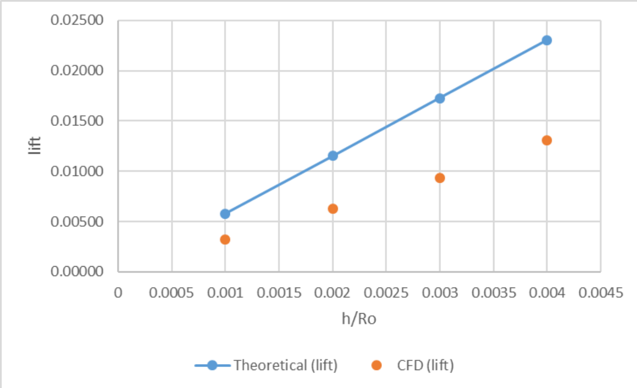


Fig 8 lift at various jet slot thickness

VI. CONCLUSION

The conclusion from this work is given as, the jet which is deflected by and from the curved surfaces is used for maneuvering of Micro Air Vehicle, this concept reduces the moving parts in the structure. The curved shape is used as a regular wing in horizontal flight. There is small difference in lift generation as increase in velocity as shown in figure (graph). A comprehensive effort is done to analyse and describing the governing equations applicable to Coandă MAV in hover. It is utilized first principles, articulated in fluid dynamics and flight mechanic. We are using conservation principles for a control volume and free-body diagram for the application of Newton's law of motion. We are successful to achieve lift at various velocity at various thickness. This principle is applied at particular limits of velocity for particular value of thickness for a particular Coandă shape, Because of flow separation occurs due to boundary layer is generated at outer surface of MAV.

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