CREATE: A REVOLUTIONARY NEW AIRCRAFT

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1 Introduction

"These airplanes we have today are no more than a perfection of a toy made for children to play with. My opinion is we should search for a completely different flying machine, based on other flying principles. I consider the aircraft of the future, that which will take-off vertically, fly as usual and land vertically. This flying machine should have no parts in movement."
(Henri Coanda, 1967)

This vision of Henri Coandă might very well form the basis for a new approach to personalised (air)travel in the most flexible way thinkable. With the expected growth in the worldwide demand for transport, a vehicle that has vertical take-off and landing capabilities within a limited space will decrease the need for present day transport and will relieve congested airports and expressways. Since oil reserves are diminishing and the environmental impact of fossil fuels is a growing issue, these future transportation systems will ask for an alternative, sustainable way of propulsion. The technology envisioned by Coanda of creating lift by blowing air over a convex surface, will allow an aircraft design that can more easily be modified into a sustainable design, with respect to noise and emissions. A personal air vehicle that is both sustainable and provides on-demand transport: that is the future of personal transport.

2 Requirements

The objective of this project is thus to create a Personal Air Vehicle that provides a solid solution to all logistical problems. Based on the issues addressed in the introduction, a Mission Needs Statement (MNS) is formed:

Fly and be capable of taking-off and landing vertically using the Coanda effect, transporting a payload of 200 kg (i.e. two passengers and luggage) over a range of 1000 km while complying with the applicable Vision2020 goals.

From this MNS five important requirements can be identified:

- Use the Coanda effect to provide lift
- VTOL capability
- 200 kg payload including at least 2 passengers
- Achieve a range of 1000 km
- Comply with Vision2020 goals on emissions, noise and safety

In order to comply with the need for on-demand transport and customer demands, other requirements are:

- Small size: 8m by 8m maximum
- Low weight: 950 kg
- Low cost: 150,000 euro
- Competitive: cruise speed of 200 km/h
- Low noise: 75 dB for use in urban areas
- A minimum of moving parts

3 Theory

The Coanda effect is a phenomenon that occurs when a gas or fluid flows over a solid surface, which is convexly shaped. The flow will tend to follow the surface if the curvature of the surface is not too strong. Consider a gas or fluid flow emerging from a nozzle flowing above a curved surface. Because of the viscosity that exists between a moving flow and a flow at rest, the flow just behind the curved surface is sucked into the moving flow. This would generate a vacuum above the surface if nothing else occurred. The pressure gradient induces vortices just above the surface in the incoming flow, as depicted in figure 9.1. This potential vacuum area is filled by fluid from the incoming flow. The fluid is deflected downward and flows along the curve of the top surface. This will result in a negative pressure gradient toward the surface, creating a lower static pressure above a convexly curved surface, shown in figure 2.

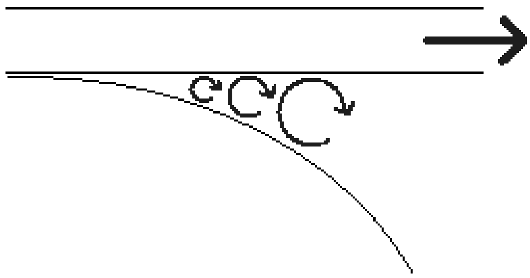

Figure 1: Vortex creation between surface and flow

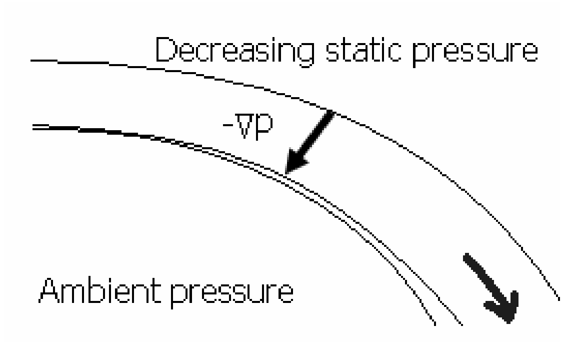

Figure 2: Airflow attaches to surface

The lift force on a curved surface is created by the pressure difference between the upper surface and the lower surface, where the atmospheric pressure holds. The higher atmospheric pressure below the Coanda surface pushes in a perpendicular direction on the surface. The Coanda effect together with the theory of Bernoulli gives an explanation for the generation of lift on wings. For a concave surface there is a positive pressure gradient, increasing the static pressure on the concave surface.

Wind tunnel experiment

Before proceeding to the performance analysis, there is the need for an analytical tool that describes the air flow over a curved surface. Because of the lack of theoretical background information and no access to valid experimental data about the Coanda effect, there is the necessity of doing an experimental trial. The results from this test can be used to check the validity of the Euler equations for a 2D source flow that were used to approximate the effectiveness of the Coanda surface. As can be seen in figure 3, the experimental results for the Cp are almost similar to the theoretical approximations, which prove it is a valid solution.

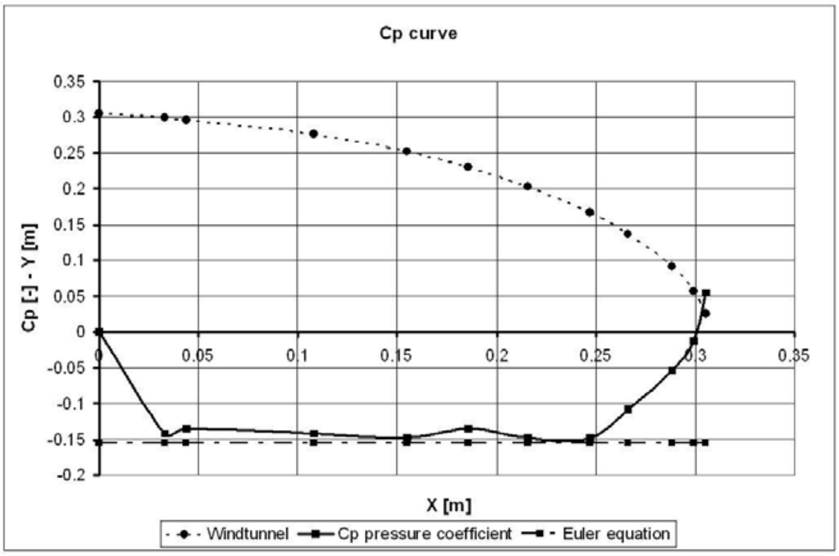

Figure 3: Comparison of test results with applied theory

4 Concept study

Three viable brainstorm ideas were further developed into conceptual designs: the Multipod, the Blown Wing and the Single Lifting Body where the airflow is used for both lift and propulsion. These concepts are discussed briefly below.

Multipod concept

The idea behind the Multipod concept is to have, instead of one large dome with a ducted fan on top, several smaller ones with a separate fuselage in the centre (see figure 4). Each propulsion pod creates lift by making use of the Coanda effect by blowing air over the top surface of a dome shaped structure. The design does not have a wing for the creation of lift during horizontal flight. It is tilted forward like a helicopter to move in forward direction. Only a two-pod and three-pod configuration was taken into account during the investigation of this design. This is done because more pods will obviously lead to more moving parts and an increase in weight and complexity. The advantages are: increased stability control since the lift force can be varied over each pod separately, excellent VTOL characteristics and simple design integration. Disadvantages are the extra engines required (more moving parts and less sustainable) and bad forward flight performance (high drag).

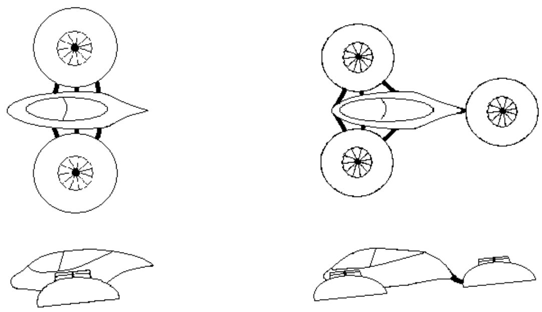

Figure 4: Multipod concept

Blown wing concept

The blown wing concept is a conventional aircraft with VTOL capability. However, the difference lies in the application of the Coanda effect during VTOL. This is achieved by using a wing ejector system schematised in figure 5. The exhaust gases from the engine are redirected to the wing and ejected through nozzles. Due to the Coanda effect the airflow attaches to the curved surfaces below the nozzles and draw in more air from above, thus increasing the overall downward thrust. This makes it more efficient than direct systems like the one used in the Harrier. Main advantage of this concept is: good forward flight performance (high lift over drag due to conventional aircraft design), while the disadvantages are: high rate of power (jet engine required), complex VTOL systems and it scores really low on noise and emission requirements.

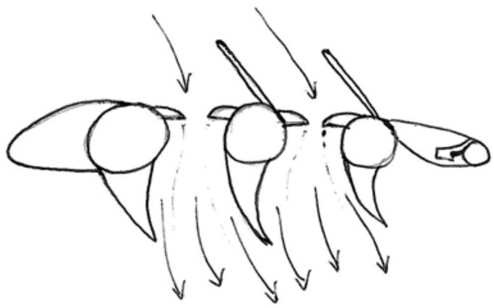

Figure 5: Blown wing ejector system concept

Single lifting body

The third concept is the single lifting body with a separation of airflow to provide both lift and forward thrust (see figure 6). The general idea behind this concept is combining the lifting body technology with the ‘conventional’ Coanda air vehicle. This design takes off in vertical direction in the same way as a conventional Coanda air vehicle using the wings as Coanda surface, but the lift in forward flight is generated by the wings and also by the fuselage which is shaped as a lifting body. This combination makes the vehicle versatile; it has good characteristics for both VTOL and horizontal flight. The actual wing surface area will depend on the amount of lift that is needed for VTOL. The advantages are its combination of good VTOL and good forward flight characteristics and the possibilities the design offers to meet the sustainability requirements (small engine, cold flow, many different fuels and propulsion possible).

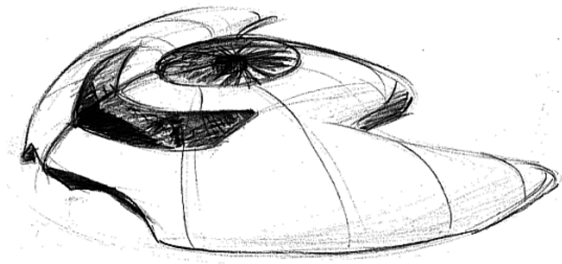

Figure 6: Single lifting body concept

After comparing all three concepts on compliance with the requirements, the single lifting body was determined to be the best choice for realising the project objective. Although it is the hardest concept to analyse, it is also the most versatile.

5 Final design

The single lifting body (hereafter the Coanda craft) was designed in detail by analysing several subsystems. The most important subsystems will be briefly discussed: propulsion, performance, stability and control and structures. A brief overview of several important design parameters are given in table 1.

Propulsion

The main propulsive device is the ducted propeller on top of the fuselage. This accelerates the airflow over the wing, creating lift during VTOL. During forward flight, the entire airflow is directed through the duct in the fuselage to provide forward thrust. The propeller is driven by a Rolls-Royce Model 250-C20W turboshaft engine with a power output of 289 kW. This engine was preferred, because it is a compact, lightweight propulsive system with a relative high efficiency (low specific fuel consumption) compared to other combustion engines such as piston and rotary engines.

As a fuel, liquid hydrogen is preferred above other alternatives. Hydrogen is an ideal fuel when compliance with emission requirements is needed. CO2 emissions are zero for the aircraft itself and since the aircraft operates at low altitudes (2000 m cruise altitude) the effect of water vapour in the atmosphere is minimal. Hydrogen also scores high on performance with two and a half times more specific energy per kilogram than kerosene. This comes at a price of a four times higher specific volume. The Coanda craft design leaves plenty of room under the wings for a larger fuel tank volume, so that decreases the problem considerably. To keep the liquid hydrogen at the right temperature, Multi-Layer Vacuum Superinsulation is used for the fuel tank. This vacuum reduces the thermal conductivity to about 0.0001 W/mK. This reduces the heat convection to acceptable levels and it saves energy for cooling.

Performance

Since the design must be capable of VTOL, there is a lot of excess power available for horizontal flight. Taking all losses into account, this leaves about 200 kW for forward propulsion, which results in a top speed of almost 288 km/h. The optimum cruise speed for most efficient flight is determined to be 230 km/h. This is higher than stated by the requirements. This extra power also results in a higher rate of climb (12 m/s instead of 5 m/s). The maximum lift over drag ratio is about 8, which is still acceptable considering the unconventional configuration of Coanda craft. In short, the performance in horizontal flight of the design is better than expected, mainly due to the excess VTOL power.

Stability and control

Because of the unconventional design of the Coanda craft, stability is a real issue. In VTOL the driving parameter for the design is the large, downwards curved wing surface that is needed to create enough lift with the Coanda effect. Because the aircraft has an integrated fuselage, it can almost be considered a flying wing. This places the aerodynamic centre in front of the centre of gravity, making the aircraft highly unstable. In normal flying wing design, this is solved by using reflexed airfoils and highly swept wings. For the Coanda craft however, this is not an option since this would reduce the effective 'Coanda surface' considerably up to the point where the aircraft will not fly anymore. The only solution therefore is a large horizontal en vertical tail section behind the aircraft. This provides sufficient longitudinal, lateral and directional stability. Routh-Hurwitz' approximations on the dynamic stability of the aircraft show that that should not be a serious problem, although this can only be determined for certain with actual (flight) testing the design.

Structure

The most challenging aspect of the Coanda craft is its completely doubled curved structure. For the entire structure, it was decided that a carbon fibre reinforced polymer (CFRP) would be used instead of a metal structure. The advantage of CFRP is that it is stronger than metals in the fibre direction. A downside is the weak ability to cope with shear loads. These properties can be used to optimize the structure for weight and therefore the structure can be made lighter than a metal one. It can also be custom manufactured to add extra strength only in those areas where absolutely needed. Composites can also be made so that extra stiffeners, such as stringers, can be co-cured along with the skin panels. This means that the structure is all one piece and eliminates the need to drill holes in the structures in order to bolt them together. This saves not only weight (of bolts and reinforcements) but also reduces stress concentrations (around bolt holes). To support the fuselage and internal duct, four CFRP frames are required. The duct also requires the use of two wing spars (at the leading and trailing edge) instead of one through the centre of the wing.

Specifications	Value
MTOW	1100 kg
Payload	200 kg (2 people)
Cruise speed (at cruise altitude)	230 km/h
Top speed	288 km/h
Range	1000 km
Cruise altitude	2000 m
Climb rate	12 m/s
Wingspan	8.00 m
Length	9.53 m
Height	3.02 m
Consumer price per unit	€ 1.500.000

Table 1: Specifications of several important design parameters

6 Conclusion and recommendations

It is possible to build and fly an aircraft that makes effective use of the Coanda effect. The wind tunnel experiments have shown that it is justified to use the theoretical Euler formula's to obtain an approximation for the Coanda effect. These obtained values for VTOL performance calculations, prove that sufficient lift can be generated to lift an object in this way. The effects on the boundary layer when the total surface is increased have not been investigated during the project and is not information that is freely available (if it exists). A drawback of performing calculations on such a revolutionary design is that there is no empirical data available to crosscheck theoretical results. Because of this, many assumptions and linearisation that have been used during the design process might not entirely be applicable to this particular Coanda craft. CFD-modelling and actual flight testing might give a better understanding of all complications involved, but within the given timeframe, there was no time to do either of them.

In conclusion: for the assumptions considered, this Coanda craft is capable of flying stable in forward flight and take-off and land vertically using the Coanda effect. The current configuration satisfies most of the given requirements, but since it is a completely new design, it will definitely not be cheap to build. It will take a long time before these transport vehicles can be afforded by the general public, so the revolution will have to wait.

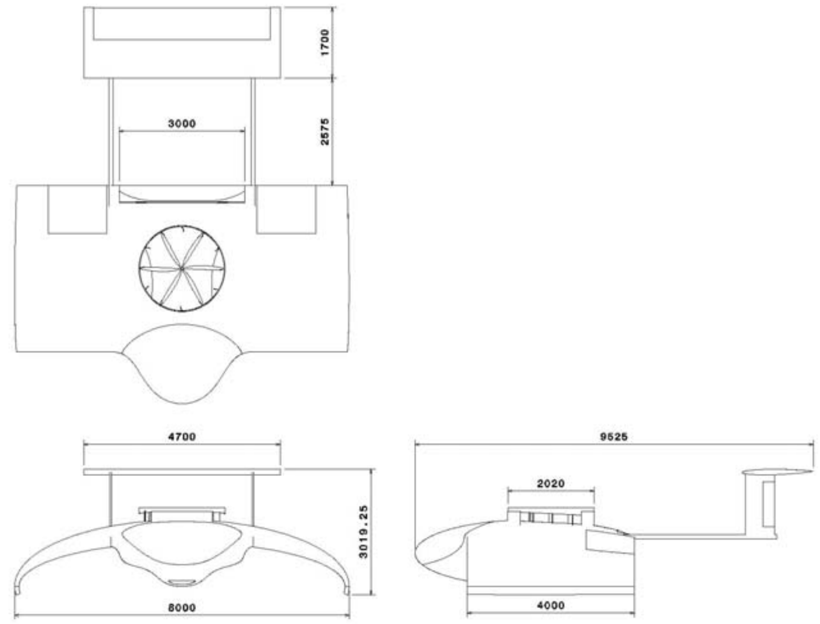

Figure 7: Dimensions of the Coandă craft

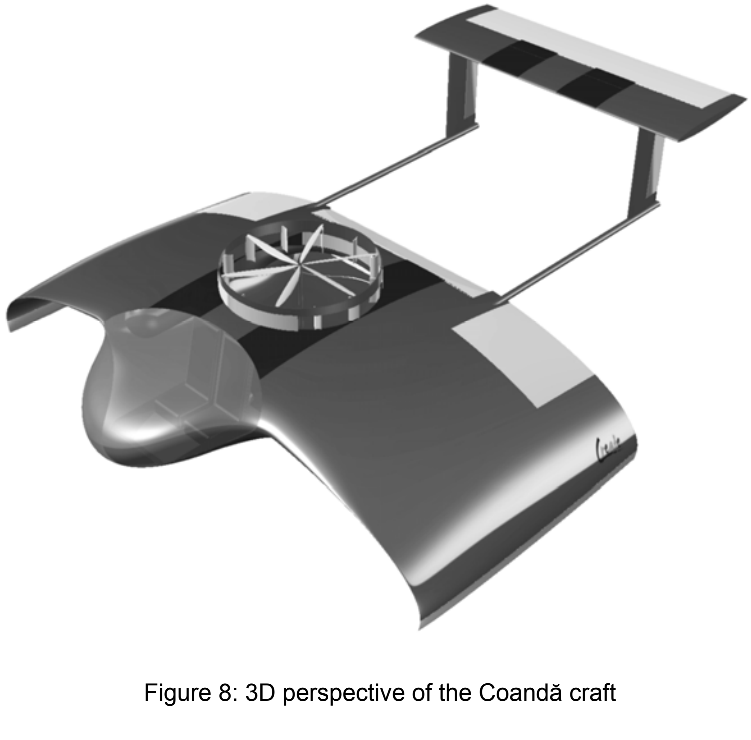

Figure 8: 3D perspective of the Coandă craft

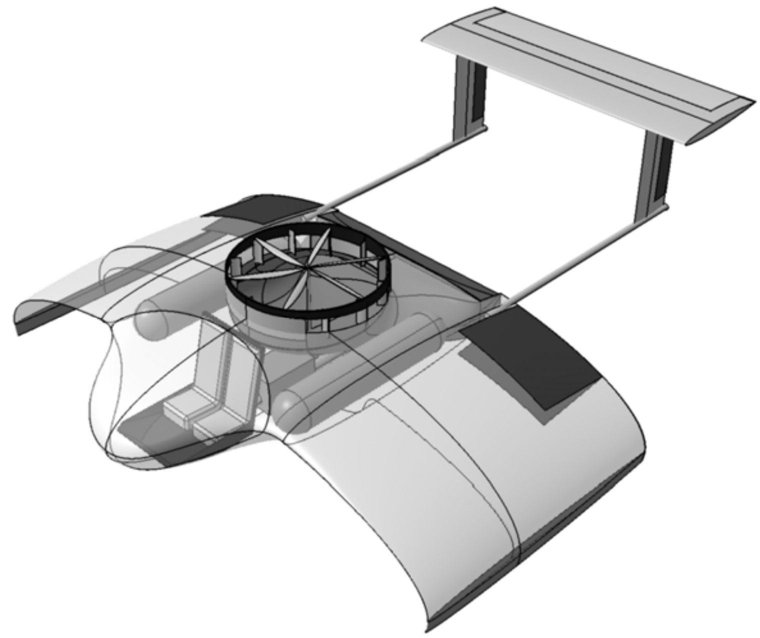

Figure 9: Transparent perspective