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CONTENTS

Aerodynamic

Concepts

Supersonic, Space and Rockets

Rotor Vehicles

The Coandă Effect

Mantas Gudaitis, Emil Ireståhl, Georgios Sakkos and Laimis Urbonas
TMAL02, Linköping University, 2017

1 Historical Background and Discovery

One of the first descriptions of the phenomenon now known as the Coandă effect was given by physicist Thomas Young in a lecture in 1800 [1]. Almost one hundred years later it was fully described by the eponymous Romanian Henri Coandă. Henri Coandă conducted several experiments as early as 1905 but he identified the effect with one of his creations: The Coandă–1910 aircraft which is shown in Fig. 1, an unconventional sesquiplane aircraft powered by a ducted fan. He discovered that when a fluid jet is passing over a curved surface, it tends to follow the geometrical root of the surface, entraining large amounts of air as it does so [2].

The first official documents in which we encounter the Coandă effect are two patents published by him in 1936. One with the title "Device for Deflecting a Stream of Elastic Fluid Projected into an Elastic Fluid" [3] and the other as "Lifting Device Coandă Effect" [4]. This name for the phenomenon was accepted by the leading aerodynamicist at the time, Theodore Von Kármán. The two of them had a long and strong scientific relationship in solving aerodynamic problems [5, p. 177].

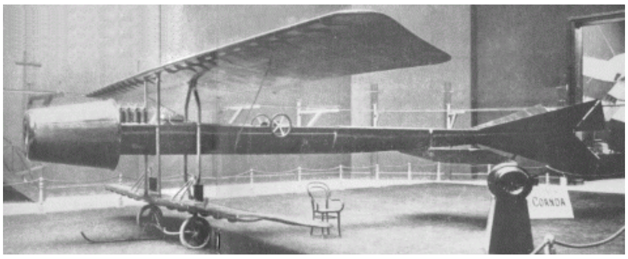

Fig. 1 . Coandă-1910 at the 1910 Paris Flight Salon.

2 Scientific Background

Fundamental to the understanding of the Coandă effect is the principle of entrainment. Entrainment is a phenomenon that occurs between two regions of differing velocities within a fluid. Of particular interest regarding the Coandă effect is the entrainment between a stream of high velocity air, such as a jet, and a stagnant, or otherwise of such low energy that it could be considered still in comparison to the jet, region of air. The high velocity, or high energy, region of the air moves past the stagnant region and imparts some of its energy to it, engaging some of the previously stationary air particles into the jet. These particles have been *entrained* in the jet [6].

The entrained particles are, in a sense, consumed by the jet, meaning that the concentration of particles in the surroundings suddenly diminishes. This is analogous to a pressure drop in the immediate surroundings of the jet which exerts a force on it. In the case of a free stream jet, the net force is zero. However, if a flat surface is introduced approximately parallel into the vicinity of the jet, the number of possible particles for entrainment decreases in the volume between them. This is due to the lower influx of particles as compared to the free side of the jet because of the obstruction caused by the surface [7]. This results in a pressure differential across the jet which forces it toward the surface to which it subsequently attaches [2].

Somewhat counterintuitively, the attachment can persist even if the surface curves away from the jet. The mechanism responsible for this is the same as for the initial attachment. The curvature must not be too severe, however.

3 Current Applications

Currently, the main application of the Coandă effect is in airfoils. The top of most of the modern airfoils is curved, and due to the effect, the airflow follows the surface of the airfoil. Since it has to travel a longer distance in the same time (higher velocity) compared to the bottom of the airfoil, application of the Bernoulli's equation shows that the pressure is decreased on the upper surface, and this pressure difference generates lift on the wing [8].

Another application of the Coandă effect that is underutilized at the moment, is using the exhaust gases from vehicles to improve their grip and comfort levels while driving. This was first used in Formula One cars in the late 2000's, with the concept created by Adrian Newey. An exhaust would be placed in a groove, as shown in Fig. 2 [9], and the walls of it, alongside the downwash, would guide the gas towards the diffuser, where the low pressure gas would create additional downforce [10]. It has been deemed illegal since, but new developments in vehicles could allow this type of exhaust to improve the grip of the vehicle, thus ensuring smooth driving at low and high speeds.

Another good application in modern aerodynamics is the NOTAR (No Tail Rotor) technology. It utilizes the Coandă effect in the tailboom, where the low pressure air is brought in via a fan. The tailboom expels the air through two slots, which causes the Coandă effect, creating a boundary layer along the tailboom [11]. This airflow, combined with the downwash of the aircraft, creates an anti-torque force. In addition, the air that has been expelled from the tailboom creates additional lift forces [12]. Currently, the technology is relatively young, since only three helicopters utilize the NOTAR.

Fig. 2 . Red Bull RB8 Coandă exhaust.

4 Future Applications

The Coandă effect offers a lot of potential for future aircraft propulsion systems. One of the fields of research ongoing today includes the use of the Coandă effect in the so called ACHEON project (Aerial Coandă High Efficiency Orienting Nozzle) [13]. Basically, it is a new approach for the vector and thrust propulsion system used in aircraft today. The aim of the project is to increase performance and maneuverability of the aircraft using the Coandă effect. Furthermore, research is focused also on reducing aviation impact on nature, by making it available in all electric aircraft is as well.

As seen from Fig. 3, the ACHEON nozzle works by mixing two streams of flow with different velocities together. It directs the outgoing flow stream without having any mechanical parts in the nozzle. At the end, the nozzle has a curvature which makes the diameter of the outflow hole contract. A flow will follow this curvature after the nozzle as well, as can be seen from Fig. 3. This is possible due to the Coandă effect, which turns the outgoing flow from the usual horizontal position. By mixing two separate flows together, it is possible to achieve a variety of angles in the flow after the nozzle.

This concept is the basic principle of the ACHEON project, which is still only in the early stages of research. However, first analysis and CFD simulations were made, comparing the performance of the Cessna 402 with traditional propulsion and by implementing an ACHEON nozzle in it. The earliest analysis was made in three areas of operation: take-off, climbing and landing. The results showed an increase in maneuverability, as well as reduced take-off and landing distances.

The early analyses of a Coandă based ACHEON nozzle propulsion system showed potential performance enhancements in both conventional and all electric aircraft in the future. It also demonstrated possibility of renovation of old aircraft by installation of the ACHEON propulsion system. However, it is still not sufficient enough to be available for use within the industry, so further research is needed before implementing the ACHEON propulsion system in future aircraft.

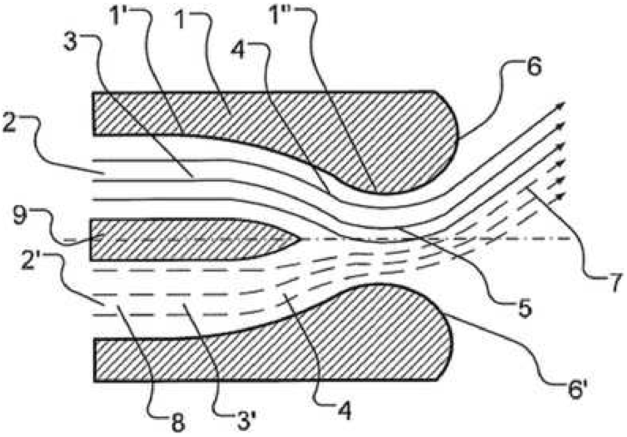

Fig. 3 . ACHEON nozzle architecture.

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Active Boundary Layer Control

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TMAL02, Linköping University, 2017

1 Introduction

Active boundary layer control is a method of keeping the boundary layer on an aerodynamic flow attached or to delay the transition to turbulent flow. This can be applied once the separation is detected or before turbulent transition, to keep the flow attached for an extended period of time.

1.1 Boundary layer flow

When a fluid flows past any object, their interaction causes the flow to slow down as it approximates the surface, until, when in contact with the surface, the fluid's velocity is considered to be zero. The region in which the fluid's velocity varies from zero to the freestream velocity is called the boundary layer.

Within a boundary layer, as a flow travels around a surface, it is subjected to multiple disturbances, which may be amplified and cause a laminar flow to become turbulent [1]. This transition is one of the most critical aspects for aerodynamics, and although dependent on many parameters, transition flows often contain the following steps, according to Bertin [1]:

1. Stable/laminar flow; **2.** Unstable flow, with *Tollmien-Schlichting* (TS) waves; **3.** Development of 3D unstable waves and hairpin eddies; **4.** Region of high shear caused by vortex breakdown; **5.** 3D fluctuating flow, due to cascading vortex breakdown; **6.** Region of turbulent spots; **7.** Fully turbulent flow.

Boundary layers around aerodynamic surfaces can be either laminar or or turbulent, and each of these has its own advantages and disadvantages. Whereas a laminar boundary layer produces less friction drag, due to the nature of its flow, it tends to have a more abrupt detachment process, transitioning to stall. Turbulent boundary layers have a smoother and easier to control stall process, and tend to stay attached to the surface longer on higher angles of attack due to its higher local velocities next to the surface and consequently higher kinetic energy [1].

The higher kinetic energy in the boundary layer, the greater its capacity to withstand adverse pressure gradients, which are the main cause of flow separation [2], showing that it is preferable to have as much kinetic energy as possible in order to delay separation. For these reasons, it is often desirable to introduce turbulence early on in the laminar boundary layer, in order to better maintain and control the flow.

Flow control devices are generally employed to delay a laminar flow, or to advance transition to a turbulent boundary layer, preventing separation in order to decrease drag and increase lift [3]. These devices can be classified as passive or active controls. Figure 1 shows different types of active controls, which are discussed in section 2 and are the focus of this article. Passive controls are briefly introduced and discussed below.

1.2 Passive boundary layer control.

Most common passive control devices consist of slots and slats, employed on the leading edges of wing sections, and vortex generators.

The slot is a fixed gap on the leading edge which allows high energy air from the lower surface to flow into the boundary layer on the upper surface during high angles of attack, increasing the boundary layer energy and delaying air flow separation. It means that the boundary layer keeps attached to the surface for higher angles of attack, generating also higher maximum lift coefficient and delaying stall [2].

The slat has the same operating principle as the slot, however with an automatic and moving arrangement. During cruise regime the slat is kept close to the leading edge by the high local pressure. At high angles of attack the slat is forced to move forward due local suction pressure on the leading edge, which opens a slot and allows the passage of airflow [2].

The vortex generator represents another passive control device that can be employed to delay boundary layer separation and keep it longer attached to the surface. As well as slots and slats, the vortex generator increases the kinetic energy of the boundary layer by creating a vortex next to the leading edge, which introduces a turbulent flow next to the surface and keeps the flow longer attached. As already discussed in section 1.1, the boundary layer must have the highest possible kinetic energy in order to prevent separation, and the turbulent flow often is preferable to the laminar flow, due to its higher velocity profiles and higher local velocities next to the surface [2].

2 Active Boundary Layer Control

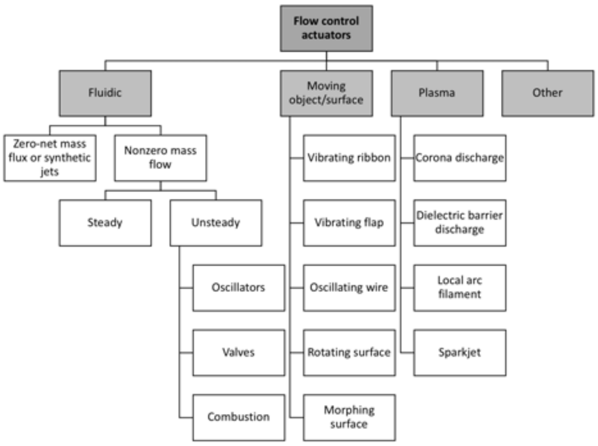

Fig. 1 . A type classification of flow control actuators based on function (according to [4].

The research on active boundary layer flow control focus mainly on reattaching/maintaining turbulent boundary layers, although there is also research in maintaining a laminar flow for longer sections of aerodynamic surfaces, by control of the *Tollmien-Schlichting* waves early on in the transition process. Active systems for the control of such flows, due to the complexity of this subject, require high-bandwidth actuators, which must be frequency tuned to adjust to cope with changing flow conditions [4]. This means that actuators for active flow control must be capable of rapidly adjusting frequency, phase and amplitude of its action to respond to complex signal waveforms [4]. As seen on Figure 1, active flow controls methods may be divided in four main categories. The first three will be briefly introduced here.

2.1 Fluidic actuators.

Fluidic actuators use fluid injection or suction to modify the boundary layer flow, ranging in scale from conventional macroscale sizes to submillimeter-scale, in the case of microjets [4]. One example of this, described by Petz and Nitsche in [5], in the injection of fluid close to leading edges of flaps, thus maintaining the flow attached to the surface. Fluidic actuators are mainly classified as:

(a) *Zero-net-mass-flux (ZNMF)*, which inject or expel working fluid in an oscillatory manner using orifices or slots, not requiring external fluid sources, but are typically limited to moderate subsonic speeds, being controlled by fast response valves, liberating pulses of fluid into or out of the flow (the control and synchronization of the valves (phase) is complicated, and they do not allow for closed-loop control) [4];

(b) *Nonzero-net-mass-flux*, which require a fluid source or sink in a steady or unsteady manner [4]. Examples of these are:

(i) *Pulsed jets*, which are a modified version of ZNMF, requiring and external fluid source [4];

(ii) *Powered resonance tubes*, based on acoustic resonance, when flow enters a closed tube and resonates, generating a combination of compression and expansion waves that reflect along the tube, being able to generate high-frequency excitation, which could potentially control oscillations on high speed flows. Although these actuators possess high bandwidth and tunable resonant frequencies, they have slow time responses, which do not allow the excitation signal to be change rapidly enough and to be phase controlled, thus not being suitable for feedback control [4];

(iii) *Combustion actuators*, which consists of a very small combustion chamber, in which the ignition of a gaseous fluid/oxidizer mixture ejects a pulsed jet, by a rapid pressure rise in the chamber, which typically lasts for several milliseconds. Experiments have been conducted with frequencies up to 150 Hz and Mach numbers up to 0.7 [4].

2.2 Moving object/surface actuators.

Mechanical actuators are designed to locally induce fluid motion [4]. May include moving surfaces (such as membranes [6]), piezo-electric flaps, shape memory alloys and electroactive polymers, and although they have the advantage of a high force to weight ratio, their performances are limited by power requirements and by working only at relatively low frequencies [3] [4].

Examples of mechanical actuators are:

(a) *Membrane actuators*, which may be excited under their surface by an array of loudspeaker coils or piezoelectric elements, for example, interacting with the flow close to the membrane in order to reduce the amplitude of Tollmien–Schlichting instability waves, using finely adjusted counter waves [6] [5];

(b) *Active dimples*, that are microfabricated using polymers, and by the application of a voltage, which causes them to buckle, produce unsteady depressions on the wing surface, which interact with the turbulent structures near the wall [4]. There is still research being made to predict the behaviour of these dimples, so that devices with appropriate size, gain and bandwidth requirements are designed [4].

(c) *Piezoelectric flaps*, which have been used successfully on multiple applications, and normally consist of piezoceramic composite beam configurations, which vibrate and have tip displacements of $\approx$ 10-100 μm on frequencies of about 1-2 kHz, and up to 1 mm for frequencies of a few hundred Hz [4]. There is a clear trade-off in gain, if higher frequencies are demanded, other than the fact that these are very susceptible to fluid loading and resonance [4].

Mechanical actuators must be carefully integrated to the wing surface, specially in the case where laminar flow is intended, as to avoid causing additional disturbances, which may introduce non-linear effects and induce TS waves, instead of reducing them [6]. Very good integration results are obtained by *membrane actuators* and by *active dimples* [6] [4].

2.3 Plasma actuators.

Plasma actuators can be used for active control by producing ionic winds of several meters per second on the surface of the structure. These actuators modify the airflow profile in the boundary layer and hence can delay or prevent transition. The advantage of the plasma actuator is that the design has no moving parts, low mass and a very rapid time response to the actuation [4].

The examples of plasma actuators, according to Cattafesta *et al.* [4], are:

(a) *corona discharge*, is a self-sustaining discharge which generally contains electrodes of very low radius curvatures, normally thin wires. These use high voltage DC power supply to produce the actuation between the electrodes. These produce localized ionic velocities of a few meters per second to energize the boundary layer and keep it attached. Depending on the voltage applied, these actuations can be pulsed or stable.

(b) *dielectric barrier discharge*, these actuators use a dielectric medium between the two electrodes to produce a more stable plasma region. These generally use high voltage AC power supply in the range of $\approx$ 15-20 kV with frequencies from 50 Hz to 20 kHz.

(c) *sliding dielectric barrier discharge*,is similar to the DBD but includes an extra electrode flush mounted on the surface, to reduce the electromagnetic effect from the plasma discharge. The frequencies are varied to obtain the desired strength of plasma.

3 Conclusion

As the field of active flow control depends on the interaction of multiple complex and diverse areas, its development correlates to individual advances on these separate areas, as well as unified studies and collaboration between them. Although many of the active control methods described here have been deeply studied, these studies were often performed in controlled conditions (laboratories and wind tunnels), frequently at slow speeds (low values of Reynolds number), so that their level of readiness has not yet reached a point where their application in civil aircraft is feasible, due to robustness, cost, reliability, certification and integration [3].

There is great optimism that active flow control will have a great impact on the aerodynamics of future aircraft. However, as mentioned above, its progress is yet on very early stages, so that much more research and effort are still required before practical implementation is achieved.

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Control Reversal

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1 Control reversal - Definition

Control reversal is a steady state phenomenon in which at a certain speed and height, control surfaces (ailerons) activation will not produce extra lift, so the pilot will not have any control over the aircraft. It was first discovered during World War II, where high roll velocities along with high flight speeds were essential for combat performance, and control reversal was a major disadvantage for the pilot.

2 Theoretical Formulation of the Problem

There are two possible ways of explaining this phenomenon: considering the reference as the plane on the ground before flight or considering the reference as the plane on a cruise flight with constant speed. We will focus on the second one since it's the most typical one the difference between them will be explained in the subsequent section.

2.1 Simplification of the Wing

Theodorsen and Garrick [1] defined a characteristic section, which is the profile situated at 0.7 times the semi-span of the wing from the root. This two-dimensional model simplifies the behavior of the whole wing accurately.

The wing-box (which consists of the spars, ribs, stringer and skin) provides the torional resistance to the wing. To represent it we will use a torsion spring whose coefficient depends on the material properties and construction of the structure.

2.2 Condition for Control Reversal

The elastic axis (EA) is the line where all the elastic capacity of the wing is concentrated. The aerodynamic center *ac* is the point on the airfoil about which the aerodynamic moment is independent from the angle of attack (AoA). These two are separated by a distance e, which is considered a constant. For a typical airfoil, the *ac* is one-quarter of the chord away from the leading edge. We also assume a constant flight level and flight speed.

Consider an airplane cruising at an AoA α_0. The forces experienced by the section defined in section 2.1 are shown in Fig. 1a. Since the airplane is in equilibrium, the net moment around the EA is zero.

$$\sum M_{\text{EA}} = 0 \tag{1}$$

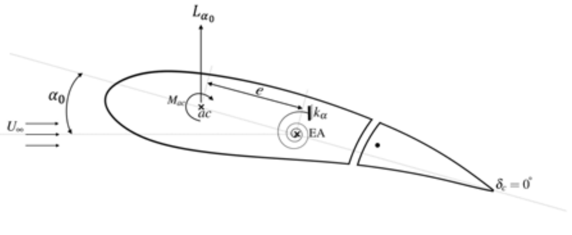
Substituting, we get

$$k_\alpha \alpha_0 = L_{\alpha_0} e + M_{ac} \tag{2}$$

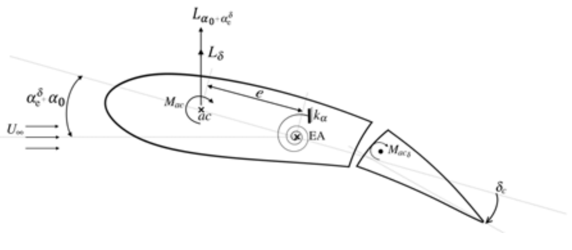
where:

k_α = Torisonal stiffness of the wing.
L_{α_0} = Lift at AoA α_0.
M_{ac} = Moment about the *ac*.

When the control surface is deflected by δ_c, it will generate and extra lift L_δ, and a moment about the *ac* (M_{ac}) due to the deflection of the control surface. Additionally, it will create torsion about the EA, and effectively changes the AoA by $\alpha_{\text{e}}^{\delta}$. This will generate an extra lift $L_{\alpha_{\text{e}}^{\delta}}$.



(a) Force diagram with control surface undeflected.



(b) Force diagram with control surface deflected.

Fig. 1 . Forces and moments on the lifting surface with undeflected and deflected control surfaces.

Figure 1b shows the new forces and moments created due to the control surface activation. Here lies the main difference between the two methods described in section 2. If the reference is the plane in the ground, M_{ac} will not appear in the original equilibrium equation, but it will in the incremental moment equilibrium due to deflection. However, since we used the second approach, the equations of equilibrium about the EA can be expressed as:

$$k_\alpha \alpha_{\mathrm{e}}^{\delta} = (L_{\alpha_{\mathrm{e}}^{\delta}} + L_\delta)e + M_{ac_\delta} \tag{3}$$

where:

L_δ = Lift increment at control deflection. δ_c
$L_{\alpha_{\mathrm{e}}^{\delta}}$ = Lift increment at torsional angle. α_{e}
M_{ac_δ} = Moment about *ac* at control deflection. δ_c

The original forces and moments (corresponding to undeflected control surfaces) are not considered here since they already sum to zero. Expressing the lifts and moments in coeffficient form, we get:

$$k_\alpha \alpha_{\mathrm{e}}^{\delta} = ((C_{L_\alpha} \alpha_{\mathrm{e}}^{\delta} + C_{L_\delta} \delta_c)e + C_{M_{ac_\delta}} c) q_\infty S \tag{4}$$

where:

$C_{L_\alpha}, C_{L_\delta}, C_{M_{ac_\delta}}$ = Lift and moment coefficients.
q_∞ = Freestream dynamic pressure.
c = Chord of the wing section.
S = Reference area of wing.

Rearranging, we get:

$$\frac{\alpha_{\mathrm{e}}^{\delta}}{\delta_c} = \frac{q_\infty S e}{k_\alpha - q_\infty S e C_{L_\alpha}} \left(C_{L_\delta} + \frac{c}{e} C_{M_{ac_\delta}} \right) \tag{5}$$

The net extra lift generated by the control surface can be expressed as control efficiency:

$$\begin{aligned} \frac{\Delta L}{L} &= \frac{L_\delta + L_{\alpha_{\mathrm{e}}^{\delta}}}{L_\delta} \\ &= \frac{q_\infty S (C_{L_\alpha} \alpha_{\mathrm{e}}^{\delta} + C_{L_\delta} \delta_c)}{q_\infty S C_{L_\delta} \delta_c} \\ &= 1 + \frac{C_{L_\alpha}}{C_{L_\delta}} . \frac{\alpha_{\mathrm{e}}^{\delta}}{\delta_c} \end{aligned} \tag{6}$$

Substituting the value of $\frac{\alpha_{\mathrm{e}}^{\delta}}{\delta_c}$ from (5), we get:

$$\frac{\Delta L}{L} = 1 + q_\infty \frac{Sc}{k_\alpha} . \frac{C_{L_\alpha} C_{M_{ac_\delta}}}{C_{L_\delta}} \tag{7}$$

According to the definition in section 1, control reversal occurs when $\frac{\Delta L}{L}$ becomes zero. The corresponding value of freestream dynamic pressure is q_{R}.

$$q_{\mathrm{R}} = -\frac{k_\alpha}{Sc} . \frac{C_{L_\delta}}{C_{L_\alpha} C_{M_{ac_\delta}}} \tag{8}$$

We also know the dynamic pressure depends on the speed and altitude (density). So, therefore, for a concrete height we can calculate the speed at which control reversal occurs. Lift and momentum coefficients in the expression above are considered constant as well.

3 Graphical representation

We conclude the report by presenting Fig. 2, which is a graph of the extra lift generated by control surfaces over dynamic pressure dimensionless (with divergence pressure).

If control efficiency remains at 100 percent until the wing fails due to divergence (Induced torsion higher than the wing can withstand), the aircraft will break and crash. Therefore, it is desirable to first lose control before divergence is reached. This is why wings are designed so that they progressively lose control before reaching divergence, in order to warn the pilot that the limit of the structure is close (with values of qR$/q$D lower than 1, where the extra lift is zero before the divergence appears).

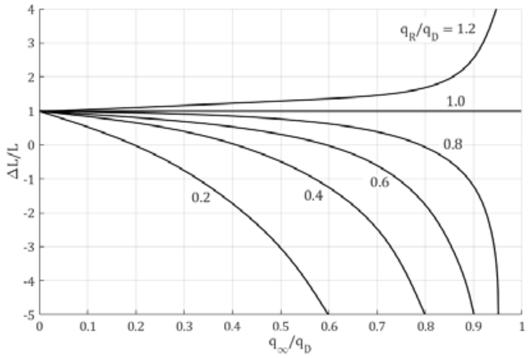


Fig. 2 . Graph of extra lift against dimensionless dynamic pressure with divergence pressure. Figure adapted from Pablo [2]

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Forward Swept Wings

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TMAL02, Linköping University, 2017

Today, the wing design of most aeroplanes presents a sweep angle, that is a wing that angles backward (positive sweep) or forward (negative sweep) from the root. Sweeping the wings of subsonic aircraft delays the drag divergence to higher Mach number [1]. In other words, the Mach critical number of the wings is increased, hence allowing the aircraft to fly at higher velocities. For supersonic aircraft, swept wings delay the shock waves and the aerodynamic drag due to compressibility near the speed of sound. Although the general trend for aircraft design is having the wings sweeping backwards, forward swept wings (FSWs) offer as many advantages as the conventional wing configuration.

On an FSW, the air flows inwards towards the root. This ensures that wing tip vortices are not developed by allowing the air flow to stay attached to the wing surface (figure 1). This effect is observed even at high angles of attack (AoA). This translates as very high manoeuvrability in the stall region of the aircraft. [2] Another factor influencing manoeuvrability is that FSWs allow the wing root to be placed further aft, moving the centre of lift closer to the fuselage's centre of gravity, further aft due to the engine location.

Winglets are not necessary for FSWs as the oncoming freestream makes contact with the tip of the wing before it does with the root. This reduces the wake vortices that are formed and thus, the boundary layer at the tips is not affected by the inner portion of the wing. One of FSWs main issues is that wing twist is amplified by aerodynamic forces. This occurs when the wing loading due to lift forces is larger than the structural elastic restoring forces. If the wingtip for a rear swept wing is bent upwards due to turbulence, then the increased pressure at the top portion of the wing would result in pushing the wing back to a flat shape. Inversely, as the tip of a FSW is twisted upward, the increased pressure on the bottom pushes the wing in the direction of the twist. In consequence, FSWs need to be much stronger at higher velocities.

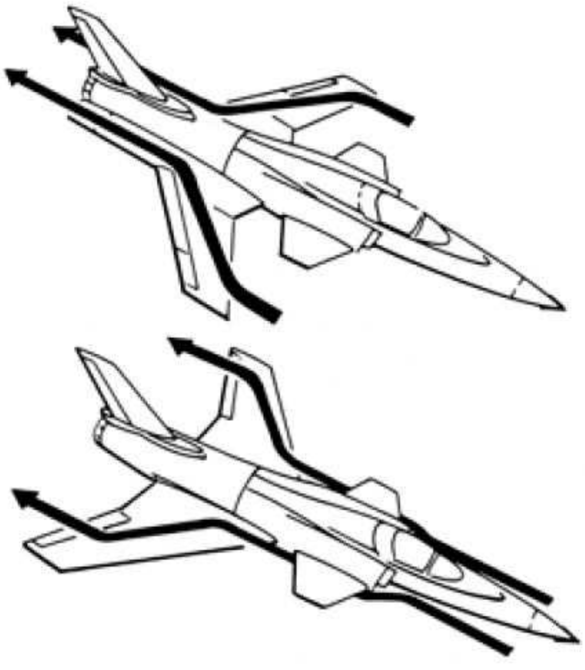

Fig. 1 . Flow pattern over FSW and BSW aircraft [3]

A very stiff FSW would lead the entire airframe to be pulled in the direction of any wingtip twist. This inherent instability gets worse at higher speeds, severely affecting the stability of the aircraft. One way to mitigate the problem would be to make the leading edge of the wing stiff. For a FSW aircraft, stall takes place inboard first and this results in an upward pitching moment. The tail assembly needs to be strong enough to counteract the pitching moment to avoid "super" stall of the aircraft[4]. An FSW has to be much stronger as there is positive feedback from wing bending, and needs to have an increased wing strength or passive/active flutter dampening devices. In fact, if the wings start to bend or flutter, then the primary aero-elastic forces are in the same direction of deflection which is of primary concern. To compensate such an event from happening, the wings need to be stronger and thus, heavier [5].

Another disadvantage of FSWs is Aeroelastic Divergence, which occurs when the wing loading due to lift forces is larger than the structural elastic restoring forces. This results in an increase in the deformation until the failure of the structure. To overcome divergence, the material and construction of the wing must be able to handle the associated high wing-loading forces. Hence, composite materials would be a viable choice for FSWs manufacturing, adding the required stiffness to the structure whilst maintaining a minimum weight. Research shows that a 35-sweep angle FSW made of composite materials is roughly 10% of the weight of an equivalent structure made of Aluminium[3].The component lay-up and/or stacking procedure as well as the composition of each composite component used in the design of an FSW can be effectively calculated using the ‘Aeroelastic Tailoring’ optimization method [2]. Aeroelastic Tailoring optimizes the structure of the composite in order to reduce aircraft weight, improves stability whilst maintaining good manoeuvrability and aerodynamic performance. Research shows that as the forward-sweep angle is increased, the optimum structural mass increases. Also, the Bending Stiffness, Flexural Rigidity and Torsional Rigidity decreases from wing root to wing tip [2].

Ever since the 1980s, the forward swept wing aircraft had been long studied and left behind. Except for the failed Russian attempt to compete against foreign military aircraft with the SU-47 "Berkut" in 1997, the concept of FSW was left to aviation history pages [6]. Nevertheless, in more recent times, FSW seem to come back into consideration for new modern aircraft designs. Nowadays, some designs for gliders include FSW with a small sweep angle. The LET L-13 Blanik, originally designed in 1956, remains a model for current glider designs (L-23NG [7]). The use of this particular wing configuration for gliders is mainly explained by their relatively low speed where the wing twist, stiffness and stability being well managed without over increasing the wing structure weight.

The Institute of Aeroelasticity of the German Aerospace Center (DLR) also recently conducted projects concerning a short to medium range commercial aircraft using FSW. The aim of those, such as the LamAiR and iGreen aircraft projects, was to modify the existing Airbus A320-200 model by adding a FSW in order to reduce fuel consumption and emissions. The DLR projects concluded that the design of such aircraft was plausible, reducing up to 9% and 10.8% the fuel consumption and emissions, respectively [8].

Another example of this old technology resurrection is the SR-10 trainer aircraft designed by KB SAT (Modern Aviation Technologies). With a 10 degrees FSW, the Russian modern composite aircraft, accommodating two passengers in a tandem scheme, made its maiden flight on the 25th of December 2015. KB SAT claims this configuration makes the SR-10 highly maneuverable and hence a great asset for sport aircraft competitions. The Russian army has already ordered four of these new full-composite aircraft and KB SAT is expecting a mass production over the next few years [9]. Based on the recent success of the SR-10, KB SAT announced at the 2017 MAKS Air Show (Moscow) an upcoming Unmanned Combat Aerial Vehicle (UCAV) variant. Indeed, in addition to its weapon payload, KB SAT specified that the future so-called AR-10 UCAV would have an extended range of 100 km compared to the SR-10 model (ref KB SAT).

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Strut-braced Wing and Boxwing configurations. A future scenario in air transportation?

Teresa Aparicio Nieto, Alejandro Grande Caballero,
Kevin Morales Mc Lernon and Javier Sempere Caro

TMAL02, Linköping University, 2017

1 Introduction

Most of the lift is produced by the wing. In cruise, this lift is equal to the weight so, because of the forces and the stresses the wings are subjected to, we will have to design the wing structure taking this into consideration.

The most obvious effect will be the bending moment, along with some other, less evident effects. As a result, a shear stress will appear on the union between the wing and fuselage which the structure will have to withstand.

Compression and tension stresses will also appear in the upper and lower surfaces of the wing respectively.

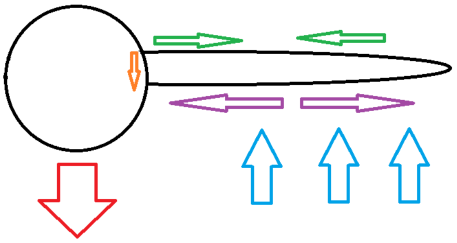

Fig. 1 . Forces: 1.Weight (Red), 2.Lift (Blue); Stresses: 1.Shear(Orange), 2.Compression (Green), 3.Tension (Purple)

Also a torsional moment is produced because of the difference between the position of the center of the lift resultant and the elastic axis of the profiles along the wing. On this basis we have make sure that our wing is designed in ways that guarantee the structural integrity of itself.

2 A strut-braced wing approach

Strut bracing is a design that is result of the structural requirements of an aircraft.

The bending moment that occurs because of the lift that is distributed along the span means that the wing must be rigidized to be able to withstand these loads. The cantilever wing uses a combinations of spars, ribs and strings for this purpose and so does the strut-braced version.

The difference lies in the fact that the strut provides relief to these loads by absorbing part of the loads through tension (if there is a high-wing configuration as seen in Figure 2) or compression (if it is a low-wing configuration).

This means that the structure of the wing can be lighter, or perhaps even bigger for the same amount of mass [1]. This means that a structurally lighter, longer, and thinner wing with a higher slenderness ratio results in an increased aerodynamic efficiency or L/D ratio. Also, the increased efficiency would mean that the aircraft would also need to carry less fuel, thus reducing weight.

Although, there are some disadvantages to this configuration too, since the strut itself also adds mass to the aircraft and it increments the wetted surface of the aircraft, thus incrementing its parasitic drag. The interferences and added structural complexity also must be noted, and the aero elastic problems that can result from this configuration [2].

This design is especially interesting for short-haul aircraft , where a more aerodynamic wing can provide with a higher climb speed and more glided CD (continuous descent).

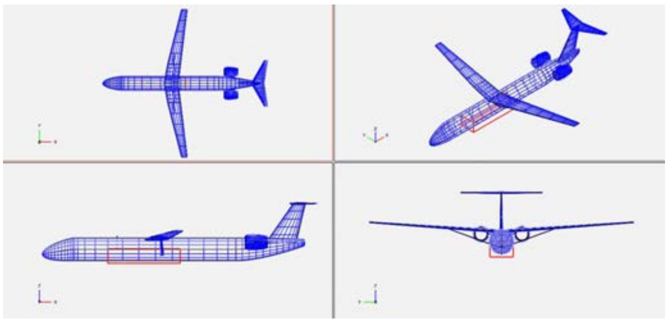

Fig. 2 . Four view of a strut wing aircraft

Also, for short distances (where the time of the trip is not as relevant as for long-haul, and also the stages of climb and descent which comprise a bigger percentage of said flight fly at lower speeds), flying at lower speeds is feasible and would reduce the parasitic drag that is added by the strut.

3 Box wing aircraft

Box wing aircraft are far from being an innovative idea; they are, in fact, an update of biplanes that were dominant in the aviation first years. However, the reason why this type of aircraft claims to be the future of aviation is based on the current trend of trying to increase the whole efficiency of aircraft. Not only in terms of structural behavior and performance, but also in terms of money.

The main characteristic of this aircraft design is that it uses two set of wings in two parallel planes joined by a fin at the tips of each wing. One pair wing configured as usual and a forward-swept second one. The engines in this kind of design are located in the rear part of the plane. An example of this configuration is shown in Figure 3.

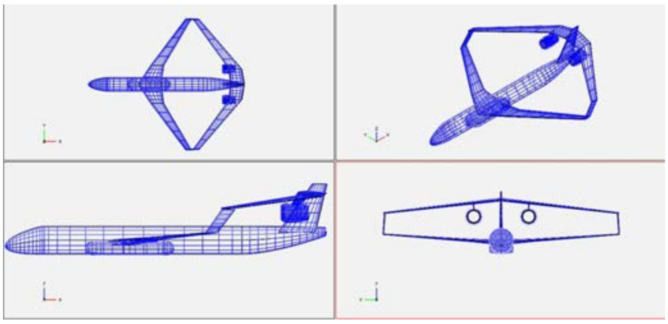

Fig. 3 . Four view of a box wing aircraft.

The objectives pursued by this design-concept are the following: **maximization of lift production** due to the double set of wings producing the lift; **reduction of the lift-induced** (by the reduction of tip vortexes and an increment of the wing slenderness) and **parasite drag** (only if carrying out the rules exposed in [3]; so that these former objectives lead to a significant **increase in the aerodynamic efficiency** (E=L/D) that ultimately results in the craft using less fuel and, consequently, fly the same routes as a conventional aircraft with less cost. This **fuel saving** could also allow the aircraft to fly for longer the same size fuel tank.

In addition, just as it occurs with the strut-braced, this shape allows it to make steeper descents and ascents safely than current conventional jet liners. As a result of the designed shape, there is an improvement in the stiffness of the wing-fuselage structure lightening the wing structural reinforcements. Moreover, box wing aircrafts can be used in the current airports, which is one of the main disadvantages of other future aircraft design, the blended wing body concept.

The increased rigidity of a non-cantilever configuration would limit aero elastic problems compared to a conventional wing, although a more in depth analysis must be performed.

The geometry of the wing results in a greater moment of inertia relative to the longitudinal axis of the aircraft, therefore reducing roll responsiveness, which coupled with the increase in rigidity with negative impacts for the maneuverability of the aircraft.

It also must be noted that the geometry and distribution of lift surfaces must be very carefully studied to avoid aerodynamic interference (which is more complex in these aircraft compared to conventional configurations) and could result in loss of controllability if a control surface is affected.

4 Conclusions

A strut braced-wing allows a span increment for the same aircraft weight and, therefore, an increment in the aspect ratio which results in a more aerodynamic efficient wing. However, the strut adds parasitic drag, aerodynamic interferences and an extra weight.

For the box wing design, in the same fashion, an increment in the aspect ratio is pursued and achieved in a more efficient way, since a decrease in the structural weight and drag performance is reached along with an increase in the lift production, thus reducing fuel consumption.

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Channel Wing airplane

Rémi Gimbert, Adrien Clos and Sylvain Baty-Ferry
TMAL02, Linköping University, 2017

1 Introduction

Vertical take off and landing (VTOL) or short take off and landing airplanes (STOL) have been and are still a great challenge for engineers. Helicopters can land everywhere but they are slow and expensive to operate. Some VTOL aircrafts combine the advantages of airplanes and helicopters. But most of these hybrids between helicopters and airplanes bring also the drawbacks of the 2 technology in term of maintenance, performances or range. A possible short take off and landing configuration is called the Channel Wing. Developed in the 40s' by Willard Custer, the advantages of this powered lift concept have still a great potential for future airplane designs.

2 The concept

The channel wing in its original configuration consists of a pusher configuration with the propeller located at the trailing edge of the wing as shown in the figure 1.

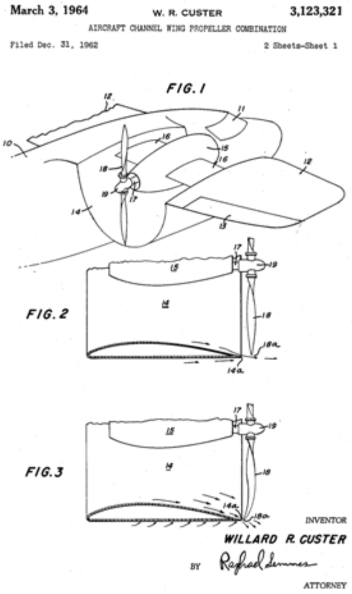

Fig. 1 . From Willard Custer's patent: US3123321 A, published on: 3 mars 1964 [1]

The Wing is made in a half cylindrical shape in order to have the propeller tip very close to the wing trailing edge. This configuration is shown in the figure1 extracted from Willard Custer's patent.

When the propeller rotates, a relative airflow is generated at the upper surface of the airfoil in the channel. That permits to generate lift even if the airplane airspeed is 0. An other phenomena is added, the Coanda effect. It is the tendency for a flow to stay attached to a convex surface. Just after the propeller, a large downstream is generated. This added lift can only be achieved with a propeller. That's why the channel wing implies a propeller driven airplane configuration.

3 Performances

This wing configuration increases tremendously the lift created by the wing and the lift coefficient is around 5 while for a classic airplane it can reach only around 2. The major advantage of this technology is the possibility for taking off very shortly and with an low speed. In fact, the most advance airplane Willard Custer made is the Custer CCW-5. It was based on the Baumann B-290 Brigadier, a four seat twin engine pusher propeller airplane. It can take off and land in a very short distance at 20mph according to Custer. If the plane were immobilized, it might take off vertically if the engines are enough powerful. Moreover, thanks to the high lift on the wings, the plane can carry out important payload more than an equivalent classic airplane. This performances are desired by the Air force to shuffle payload in hostile areas where they do not have large runway and where they are only dirt track. This kind of performance are useful for humanitarian mission in some place in the world for the same reasons. Besides, we can see in the figure 2 that the lift coefficient increases when the attack angle increases too. That means that more the airplane is climbing more the lift works. So the airplane is able to stay in the air at a very high angle of attack of more than 20 degrees. In fact, it can reach around 60 degrees without stalling. That is useful for a short take off and if a plane has to climb fast to reach an altitude.

4 Limits

The limits that this wing geometry are firstly about the drag. There is a high lift so in the same time the drag is important, that induces that the max speed of the plane is low. In the same time to reach a high speed, the engine have to turn fast and so the lift induced by the propellers is higher that makes climbing the plane. Moreover, the airflow created is important and directly oriented in the horizontal tail that creates a huge pitch moment.

The second important limit of the technology is about engine failure. In fact, if one engine knows a failure, the lift created by it will be null. So, the lift distribution over the wings will be unbalanced. Usually to deal with this kind of problem, just by increasing the engine power the plane can reach a airport to land but in our case, the pilot has to reduce the power of it to reduce the asymmetry that can be jeopardizing to reach a airfield.

5 Concept improvements and future designs

The original concept of channel wing can be improved in many ways. The original drawbacks, mainly a high drag in cruise mode can be minimized using different solutions. One of them is the control of the propeller position. The best position depends on the flight configuration and the channel best performance is not with the propeller at the trailing edge according to *Pneumatic channel wing powered-lift advanced super STOL aircraft* from[2]. In this publication, many tests have been conducted showing the real potential of the channel wing to create high lift coefficient. An example is shown in the figure2 from the same document.

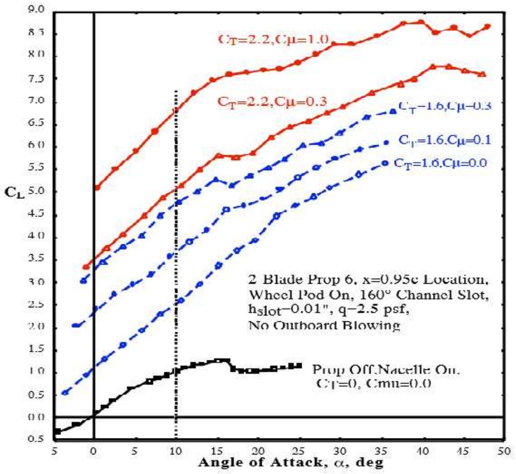

Fig. 2 . Lift coefficient achieved during the tests conducted in the publication [2] We can clearly see the impact when the propeller is on (CT = thrust coeff of the prop)

6 Conclusions

The Channel wing is a compromise as many aircraft technical solutions. Contrarily to other unusual STOL planes, as the XC-142 which goal was to create more lift by turning the plane propeller into a kind of helicopter rotor, there are no special moving parts for the channel Wing. It just adds a half-cylinder shape which can be a bit more complex to build. Anyway, it still ensues less maintenance than for a helicopter rotor. Very good super STOL performances can be achieved but with an increase of drag at high speed. A transportation cargo aircraft needs to have a high payload and so a high lift, speed is less important. Military cargo applications are offering good perspectives too with the need to land on short unprepared runways. Here is a view of a potential transportation airplane that was the object of the publication [2].

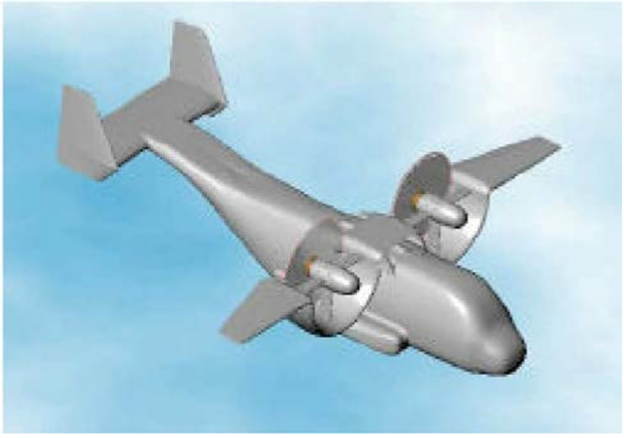

Fig. 3 . From publication [2] "Conceptual Pneumatic Channel Wing Super STOL Transport Configuration"

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Custer CCW-5 Channel Wing 1/4 scale model

Simon Vanderbauwede
TMAL02, Linköping University, 2017

1 Introduction

The Custer Channel wings are an original way to achieve STOL capabilities for an airplane. After reading about the story of Willard Custer and his designs, I decided to make a replica of his late design, the Custer CCW-5. The goal was to investigate the channel wing capabilities by real flight testing and to build my first large composite rc plane.

2 Preliminary design

At first I had to choose the scale of the model. The constraints were to build a model large enough so the aerodynamic effects could be compared to those on the real airplane. Then in France rc models with a mass of more than 24kg must have special authorizations to operate. The Choice of a 1/4 scale was a compromise between theses constraints and also to have an airplane that can fit inside a car for transportation and that is not too expensive to build.
Then finding documents about the CCW-5 is not an easy task. An accurate 3 view drawing was almost impossible to find. The solution was to use several photos from the CCW-5, to correct the perspective effects on each picture and to use reference points and projections to rebuild an accurate numerical 3d model.

Fig. 1 . Numerical model on Solidworks, 2013

3 Detailed design

The real CCW-5 uses a naca 4418 on the channel and a 4412 on the wing tip. Theses 2 airfoils have good properties for model airplanes and the 4418 is very thick. It creates a lot of drag but it makes the structure easier to build so they were taken for the model. Taking the fuselage as a reference the "Channel" have an incidence of 3 degrees and the wing tip are at 0 to make stall less brutal.
To estimate the loads on the wings the following method was used. A maximum speed is roughly determined as if the plane was making a vertical dive (weight and drag compensates each other) then you recover as quickly as possible so you are at maximum speed and maximum Lift coefficient so you are at the maximum load on your structure. For this plane the conclusion was that it has to resist to a 6g acceleration. The channel were not easy to design and so large safety coefficients were taken, the main target was to be below the 24kg category at the end.
At first, the model was designed to fly with 2 gaz engines. Engine nacelles were large enough so two 40cc flat twin engines can fit in. But this solution was expensive and I had not at this time the experience of dealing with the vibrations coming from such engines. So I choose two 3kW brushless motor to have a maximum power to weight ratio of 300W/kg.
I had also to deal with the landing gear design and that everything could fit in the airplane. At the end the internal structure looks like the one on the figure2. Most of it was made of a sandwich of wood and glass fiber. A large part of the structure strength is coming from the skin with the use of some carbon-epoxy composite.

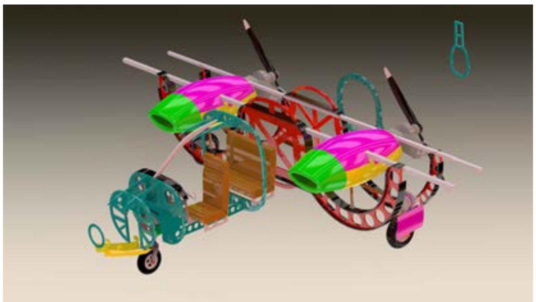

Fig. 2 . Fuselage and center section structure (gaz powered version), 2013

4 construction

The fuselage nose, the channels and the engines nacelles are made of glass-epoxy composite with carbon reinforcement where needed. The numerical model was discretized into sections and each section was then cut in high density foam. The final shape is covered with glass fiber, mastic, paint.. in order to reach a good surface finish. Then some scale effects are added. In figure 3, the result for the nose section of the fuselage. We are now ready to make the molds out of our model. Not less than 20 molds made of Glass-polyester were needed for the entire airplane and it represents a lot of time and energy in the building process.

Fig. 3 . Nose section master ready for the mold manufacturing, December 2013

The airplane standard skin layup is made of light gelcoat, a 50gr/m^2 and two or three 200gr/m^2 glass fabrics. Carbon Unidirectional fabric is added for spars and bidiagonal in the channels leading edges and near every area submitted to mechanical constraints. To save weight and time, the wings and tail are directly vacuum molded on a foam core. The outer surface is made on wood with carbon reinforcement between the wood and the foam.

At the end, the model has the following characteristics :
- Take Off weight : 18kg
- Wingspan : 3.20m
- length : 2.5m
- fuselage section size : 0.35*0.4m
- Engines : (2) 3kw 192kv outrunner brushless motor
- propellers : (2) 19*10 APC electric
(diameter of the channel wings)
- speed controllers : (2) max 120Amp (140 burst)
- Batteries for propulsion : Lipo 12s 6600mAh
- Batteries for radio electronics : 2s 2200mAh Lifepo4

Fig. 4 . composite parts. Carbon reinforcement for the "channel" spar, leading and trailing edge and in the fuselage nose to transmit the forces from the nose gear , 2014

Fig. 5 . Scale CCW-5 ready for takeoff , 2015

5 Flying a channel wing airplane

5.1 Takeoff

To take off, wait until you have some speed on the runway. That can be very short (this is still a short take off airplane) but if you put full power to early, the channels creates enough lift but you don't have enough airspeed for the moving surfaces to operate effectively. When you have enough horizontal speed you can put more power. Take off is inevitable. Be prepared to push the elevator stick. When the airplane is no more on ground effect, a huge nose up pitch moment is coming from the channel effect and remember that you still don't have a lot of speed. The airplane can climb with a very high slope angle that can reach up to 60 degrees .

5.2 Cruise flight

Flying the CCW-5 is not flying an airplane. A large part of the lift is coming from the Channel-engine association. The only aircraft that is close to that is for me the autogyro. The elevator stick is here mainly to control the airplane attitude and then if you want to

Fig. 6 . The CCW-5 model during a high angle climb.

dive or to climb, use the throttle. The throttle stick is mainly a "Lift" stick. The horizontal speed range is not large. If you try to fly fast, you must adopt a negative incidence attitude to counter the Channel effect.

Fig. 7 . Just after a turn, the airplane unusual wings are clearly visible, 2015

5.3 maneuvering capability

The model can fly at high angles of attack. It is almost impossible to stall as long as your propellers rotate. But control in this configuration is not easy. There is still pitch and yaw control because the tail is blown by the propellers but it is not the case for the ailerons. Turning radius can be reduce to almost a point! You have the feeling that the airplane is just turning around the inner channel. But pay attention to anticipate the inertia and a large coupling between the 3 axis.

5.4 Landing

Short landing is theoretically possible. But in practice it is not easy to made. Compared to the cruise speed, the approach speed is not as slow as we can expect. The main reason is that you are in a high lift configuration when you land which also means that you need to have engine thrust. You can increase your angle of attack on final approach and reduce the power gently when you are on ground effect. The Airplane will stop rapidly.

Finally Never cut off the engine at any moment during flight! You will loose all your lift and you are near a "normal" stall speed. The only solution if you have an engine failure is to cut of the other propeller and dive vertically to recover when your airspeed is sufficient. Then you have a glider with a very very poor glide ratio and a tremendous amount of drag so don’t hesitates too much to find a landing field.

Fig. 8 . Landing at high angle of attack

6 Conclusion

Designing and Flying this Custer Channel Wing airplane is not easy. It took me more than 2 years, hundreds of hours and requires all attention during flight. But it was a great challenge to build my first composite "large" model airplane and I learned a lot. It improved my mechanical, designing, composite manufacturing and aerodynamics skills. For the Channel Wing itself. Of course they are drawbacks but many of them can be reduced or avoided. There is, in my opinion, still a large potential for such type of powered lift systems.

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FanWing

Benoist Morin, Rasmus Svantesson, Adam Andersson and Jiaxing Li
TMAL02, Linköping University, 2017

1 The concept, FanWing

The FanWing is a propulsion-system for aircrafts using horizontal rotor blades, rotating as a radial turbine to increase the speed of the airflow and thereby generating lift and thrust. The FanWing concept was patented by Patrick Peebles in 1997. Moreover, the idea with spinning wings was already invented in the 1930's but the concept then failed after a crash and it was quite different from Peebles invention.

2 Operating principle

The front part of the wing is, compared to the usual fixed wing construction, now replaced by a horizontal rotor cage which covers all the span of the aircraft and approximately up to 50% of the wings chord.

According to the rotors large length, the whole wingspan, is in operating conditions now accelerate air with a large intake of air along the whole wing.

With the air flow passing through the rotating fan, it's now inside the rotor cage is now building up a low-pressure vortex that "pumps" the air through the fan and accelerate the flow towards the trailing edge to produce thrust (see figure 1) . By stirring this large amount of air, the low-pressure zones increase the CLmax [1] and thereby also the lift.

Approximately 2/3 [2] of the rotor diameter exceeds the top of the wing just after the leading edge. The speed of rotation of the rotor is low, about 1200 RPM [1] (wind tunnel test) in any case, compared with an ordinary shaft engine propeller aircraft in cruseing speed operates around the double.

By speaking of engines, the FanWing which is powered by at least 2 engines that are located inside the rotor cage at the tip of each wing.

A planetary gear mechanism is adapted to permit changes in the angle of each single blades of the rotor. This makes it possible to variate the thrust and the lift of the aircraft. Furthermore, if this is used differentially on the FanWing it also allows the pilot to control the aircraft in roll and in yaw by adapting the velocity of the airflow at different cords of the wing.

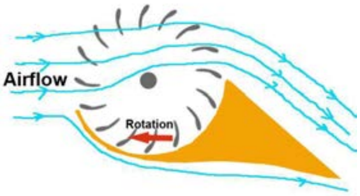

Fig. 1 . The fan cage, where the velocity of the airflow increases with help of the fan towards the trailing edge.

3 The prototypes

FanWing, the society of the inventor of this technology, build several prototypes in order to improve its technology [3]. The second version of a short-take-off-and-landing (STOL) prototype flyed for the first time in 2008 with these following features: Weight: 6[kg], Rotor Span:1.6[m], Flight Speed: 29[km/h], take-off length: 1[m] roll without payload, MTOW: 12[kg]. In the last version (2011), they used twin tail configuration to avoid the strong down-wash flow directly behind the wing and exploits the up-wash from the wingtip vortices. Thanks to this technology, the the FanWing is able to reach speeds of over 70[km/h] but still can be stable between 20 and 30[km/h]. Moreover, figures calculated from on-board logging demonstrate an increase in lift efficiency of between 10 and 15%.

Fig. 2 . FanWing prototypes: 2008 version (left) and 2011 version (right) [3]

4 Advantages and drawbacks

Here is the Advantages and disadvantages of using a fan wing instead of the conventional fixed wing.

4.1 Advantages

- The FanWing generates a lot of lift and can therefore take off and land in a much shorter distances than a fixed wing.
- It have a good maneuverability at low flight velocities and good stability in turbulence, insensitive to wind directions.
- Higher cruise efficiency than a helicopter and is more silent, good for discretion or less disturbance.
- Very good heavy lift capability, up to 5 times more than a helicopter.[2]
- It is cheap and could be a good compliment for helicopters in rescue operations and surveillance.

4.2 Drawbacks

- Low speed, currently the maximum speed of the fan winged aircrafts is around 70-100[km/h].
- The throttle can directly affects the pitch. This means increased throttle can decelerate the aircraft.[4]
- In case of a power-failure the FanWing can still glide if the rotors can auto-rotate, but the glide ratio is quite low.
- There can be a problem with defrosting the rotor when flying in icing conditions, it is not yet investigated or solved.

5 The SOAR Project

The SOAR project is the main project around the FanWing technology. This European project began in 2013 and ended in 2015. It was driven by 3 groups: FANWING LIMITED (Patrick Peebles is the director, UK), INSTITUT VON KARMAN DE DYNAMIQUE DES FLUIDES (Belgium) and UNIVERSITAET DES SAARLANDES (Germany) [5]. The aim of this project was to investigate the technical and environmental performance characteristics of the open-fan wing technology through wind tunnel test and computational modeling [6]. For example, they modified the shape of the blades to increase their performances. We can see in the figure 3 that the CLmax is over 6 which is quite impressive for an aircraft. The experimental data of the project was also used to create a non-dimensional performance model which is combined with a business model in order to identify potential new and existing markets for various FanWing payload and speed designs. Thanks to this study, they decided to focus on the design of 2 full scale aircrafts: A transport aircraft with about eight tons of freight capacity and a passenger aircraft for 60-70 passengers.

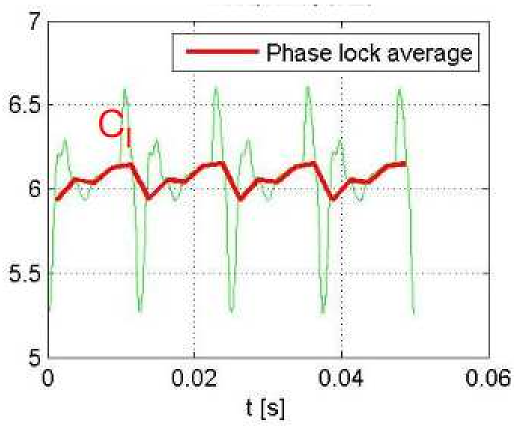

Fig. 3 . Lift coefficient results of the SOAR project team [1]

6 Future

6.1 Application

Due to the several advantages of FanWings, such as low noise, low emission, high handling, FanWing can be used in many approaches. Here are some examples.[3]

- Short distance transport, such as transporting the sick to hospital in case of emergency.
- Rescue, such as delivery the goods or looking for the missing, because FanWing has a high load capacity and low speed flying ability.
- Amphibious usages, the FanWing has a high duration and stability in turbulent. So it can work well both on the ocean and the land.

6.2 Development

Although it has been proved that the FanWing perform well in modeling test, it is still a great challenge to transform a model into a commercial passenger aircraft.[6] It still takes time to make more sufficient wind tunnel experiments to understand the force on the aircraft and the aircraft's performance. Besides, electrical motors will be used in FanWing to prove its low noise and stability. Furthermore, the FanWing still needs to enhance its properties in many way.It's expected that the FanWing can reduce its take-off distance to 100[m] and it's velocity can up to 180[km/h].

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Dynamic Soaring

Arthur Devillard, Emilien Boichon and Sidhant Sood
TMAL02, Linköping University, 2017

1 Introduction

The technique of dynamic soaring utilized by the albatross has been observed over many years as an efficient alternative approach to long distance flight regimes typically used by aircrafts in the current era.

The albatross exploits the phenomenon of wind shear over the surface of the ocean in order to maintain flight. Wind shear is defined as a difference in wind speed over a relatively short distance in the atmosphere. Directly above the surface of the ocean, the wind speed is almost zero, whereas going higher in altitude, there is an appreciable value of wind speed, which leads to a region of wind shear above the surface of the ocean. The albatross extracts energy from this wind speed gradient by ascending in the windward direction, and by descending downwind, continuously gaining a net increase in the value of its ground speed. It is an awe-inspiring flight mechanism which allows albatrosses to sustain flight over large distances, for large periods of time and without having to flap their wings a lot, as seen in Figure 1. Dynamic soaring, which is therefore based on the difference in air mass velocities, must not be confused with slope soaring that simply uses the wind which is forced upwards over an obstacle like a hill.

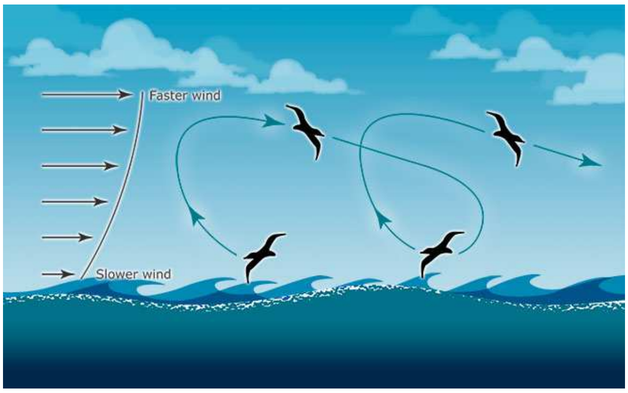

Fig. 1 . An illustration of the typical flight path of the albatross.

2 Definition

In order to fully understand the principle of dynamic soaring, we first need to make sure that the definitions of groundspeed and airspeed are unambiguous.

- Groundspeed: The groundspeed is the speed of a body by taking the ground as referential.
- Airspeed: We can define the airspeed as the difference between the groundspeed of a body and the air velocity of the environment. It means that in that case the referential is the wind. Therefore the groundspeed will always be greater than 0 for a moving body, while its airspeed could be equal to 0.

3 Mechanism

There are several modes of dynamic soaring that can be performed by albatrosses with a series of 90° or 180° turns over the surface of the ocean[1]. However, for UAVs, dynamic soaring is usually achieved flying a loop. We will focus on this simple pattern in order to investigate what happen during one loop (figure 2) and see how an aircraft can gain energy with this technique.

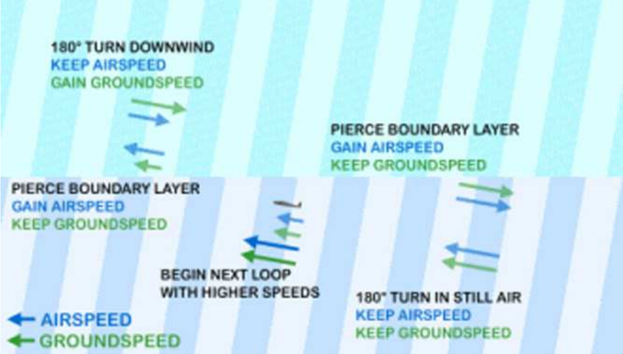

Fig. 2 . Dynamic soaring simplified mechanism.

The aircraft needs to pierce the boundary layer at a sharp angle. The airspeed will thus increase when going from the stationary airmass to the moving one. Then, a 180° turn in the moving airmass, changing the glider from flying upwind to flying downwind, will make the ground speed increase while the airspeed remains constant. Its airspeed will be almost (as the boundary is not perfect in reality) instantly increased again when crossing the thin wind shear area in the other direction, since the airspeed will go from a high forward value to zero, and the groundspeed will again remain constant thanks to inertia. Finally, the glider returns to the starting point with an increased groundspeed and airspeed. The process can be repeated in order to increase the speed once more, until a maximum value is attained.

In fact, some simplifications have been made in the previous explanation since drag forces would continually act opposite to the aircraft motion, thus decreasing its speed. Therefore, the maximum speed will be reached when, with increasing speed, the drag forces will offset the energy gained with dynamic soaring. This can be seen on data from a dynamic soaring simulation over 10 loops (figure 3)[2]. The fluctuation that we can see, which was also not considered in the simplified explanation, is simply due to the kinetic energy converted into potential energy when climbing, and vice versa.

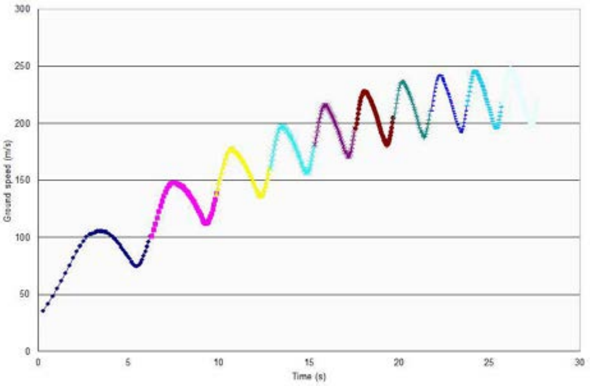

Fig. 3 . Ground speed of a RC glider over time in a dynamic soaring simulation.

4 Applications and perspective

The first pilot to use the dynamic soaring in order to fly successfully was Ingo Renner in 1974 with a single-seat sailplane [3].

In 90's the first Remote Control gliders appeared. These mini aircrafts are mainly use to fly as fast as possible without traveling distance, only by making loop. According to some calculations and observations, the acceleration during a loop can reach 100 g [1]. That is why the gliders are built with composite materials capable of resisting to hard conditions. The unofficial world record is today hold by Spencer Lisenby who reach the speed of 835 km/h (0.68 M) with his RC glider in april 2017 [4]. The theoretical maximum speed by using the dynamic soaring is about 9,5 the wind speed velocity of the upper zone [1]. Some characteristics, mainly inspired by the albatross shape, are required to performed successfully a dynamic soaring. A high Lift-to-drag ratio (approximately 30 for albatrosses or RC gliders) allows to reduce the drag as much as possible in order not to lose the energy gained thanks to dynamic soaring. That is why dynamic soaring can only be observed with particular vehicles that have such properties.

The NASA VISTA office investigated the feasibility of dynamic soaring through a UAV able to cross the ocean by using the dynamic soaring to fishery surveillance and monitoring [5]. Inspired by the albatross shape, this glider concept would be able to fly indefinitely as long as there is wind. Two turbines on the tip wing are able to extract the power due to the vortex in order to recharge a battery. This battery is exclusively used in order to take off after a period of no-wind or if the UAV needs to maneuver away from an obstacle.

However this project has limits because of the flight complexities. It is very difficult to imitate an albatross flight as they are indeed able to feel where is the best region to fly. Also they can easily fly close to, and sometimes scrape, the water, which is difficult and dangerous for a UAV. Therefore, as UAVs could hardly take full advantage of the shear wind effects over the ocean, dynamic soaring is, at the present time, mainly used in areas where the dead air behind a massive obstacle like a mountain creates an substantial wind gradient.

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All Electric Airplanes

William Chermanne, Juan Brion, Clément Vandingenen and Federico Brillo
TMAL02, Linköping University, 2017

ABSTRACT

This report aims to give a brief overview of the concept, the development and the performances of electric planes. First, an introduction looks back to the first steps of electric aircrafts. Then, some important technical aspects of electric aircraft design are explained. In the following section, a comparison between the electric aircraft and the traditional aircrafts is made. Finally, a short conclusion highlights the future trends in the sector of electric aircrafts.

I. Introduction

Airplanes release about 700 million metric tons of CO_2 into the atmosphere [1], and it should be increasing considerably in a near future. Indeed, the International Air Transport Aviation [2] expects 7.2 billion passengers by 2035 (a near doubling of the 3.8 billion travelers in 2016) due to an increasing demand from the Asia-Pacific Market. Due to a diminution of fuel resources and a significant contribution to global warming, alternatives to fuel aircrafts such as electric aircrafts are being studied.

An electric aircraft is powered by electric motor using energy from different possible methods: battery, fuel cells, solar cells and others. This type of aircrafts can be considered as locally zero-emission (depending on how the electricity is produced), and are thus cleaner than classical aircrafts. The first prototype, a Brditschka HB-3 motor glider converted to an electric aircraft, the Militky MB-E1, has been developed in 1973 after the apparition of the NiCad batteries. Due to the lack of better batteries, only a few electric aircrafts have been developed until 2003 where the Lange Antares 20E, a self-launching 20-meter glider equipped with Li-ion batteries, was designed. From this point, the development of electric aircraft has started and lot of planes have been created. As for the automotive industry, the development and the performance of electric aircrafts is really influenced by the battery technologies.

II. Technical Aspects

II.a Battery

The fundamental element of an electric propulsion system is the energy storage and the conversion of chemical energy to electrical energy, and finally to mechanical energy. As a good indicator of efficiency, the specific energy density E^* can be used, which is expressed in $[\frac{Wh}{kg}]$.

Nowadays, the most used batteries for electrical aircrafts are **Lithium-Ion** type. Such batteries can be produced relatively cheap and can be scaled to build larger systems of several hundred kWh energy capacity.

The batteries are the main limitation when talking about electrical aircraft. Other technologies such as **Zn-Air**, **Li-S** and **Li-O_2** are in development and should gain in specific energy density in the next few years [3].

II.b Range

The range of an aircraft is an important characteristic. In this section, the calculation of the range is made, taking into account that the energy sources are batteries. The range can be expressed as

$$R = v \cdot t \tag{1}$$

where t, the time needed to drain all the batteries, is

$$t = \frac{m_{battery} \cdot E^*}{P_{battery}} \tag{2}$$

with the battery power $P_{battery} = \frac{P_{aircraft}}{\eta}$. Assuming a cruise flight, the thrust compensates for the drag and the lift for the weight. This gives

$$P_{aircraft} = \frac{W \cdot v}{L/D} \tag{3}$$

Using Eq.1, 2 and 3, the range can finally be expressed as

$$R = \frac{m_{battery} \cdot E^* \cdot \eta \cdot L/D}{W} \tag{4}$$

II.c Electric Motor

Today the studies of new electric motors for aircraft are focused on two configurations which are distributed engines and Brushless DC Motors. The most efficient engine available on the market, Siemens SP260D [4], has a power output of 260kW and weights 50 kg. That gives a high Power-to-Weight ratio of 5. The result is obtained from an accurate study on material of the end-shield, decreasing the aluminum part by a factor of 2. The rotor is composed by permanent magnet, where the stator is a cobalt-iron alloy. This technology will enable to develop larger electric aircrafts in the future (with a maximum 2 tons MTOW) .

III. Technologies comparison

III.a Advantages and disadvantages

In Table 1, the main advantages and disadvantages of classical and electrical aircrafts are shown.

Classical aircrafts	
Pros	**Cons**
Low to long range	High fuel consumption
Decreasing weight	High flight costs
Low to high PAX	High CO_2 emissions
Electrical aircrafts	
Pros	**Cons**
High power to weight ratio	Low range
Low flight costs	Constant weight
High efficiency	Battery limitations
Low CO_2 emissions	Low PAX
Less noise	Battery charging time

Table 1. Comparison between classical and electrical aircrafts

III.b Energy conversion and efficiency

The conversion from the energy source to the actual propulsion involves several steps. In Fig.1, three different technologies are compared, respectively batteries, turboprop and turbofan. For each step of the conversion, a typical efficiency η has been assumed, regarding the current trends the battery system shows an efficiency of more than 70 %, whereas classical kerosene based technologies have a lower efficiency of around 30%. The main reason for this difference is the conversion from fuel to electricity in the classical fuel combustion systems, which exhibits a low efficiency of 50%

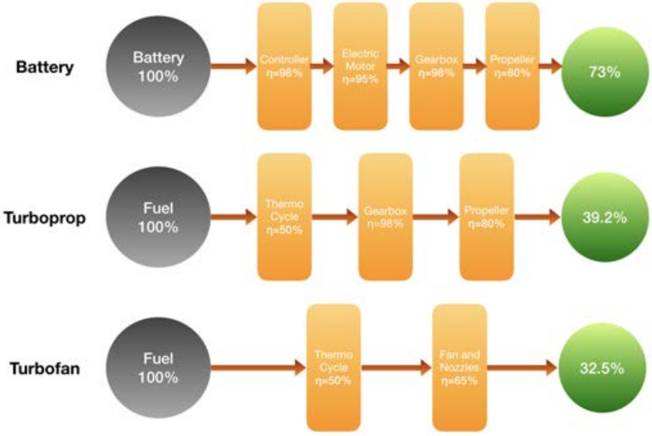

Fig. 1 . Conversion chains for different technologies. Figured inspired from the document [3]

III.c Power to weight ratio

Traditional piston and turbine engines can reach higher output powers but are also heavier, which reduces their power to weight ratio.

IV. Conclusion and future trends

The development of electric airplanes is still limited at the stage of small aircrafts and small ranges by the batteries. Hybrid aircrafts which combine both advantages of classical aircrafts and electric aircrafts seems more realistic in a near future. Elon Musk[1] [5] said that commercial electric airplanes will be possible once the battery energy density will be over 400 Wh/kg. Indeed, with this capacity, the technology could be power 150-seats planes with a maximum range of 300 miles (30 percents of the flights) and using electric aircrafts should be interesting for airlines since the flight cost is low. This is the reason why important airlines such as Easyjet have signed collaboration with research companies in electric aviation.

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[1] CEO of **Tesla**

Blended Wing Body - Chances and Problems of a new Aircraft Concept

Andreas Wittenberg, Fabian Neumann, Michael Göbel, Philipp Podzus
TMAL02, Linköping University, 2017

Fig. 1 . Boeing, NASA, and AFRL Blended Wing Body Concept[1]

1 Introduction

Since the beginning of all public air transport the drake configuration dominated the aircraft market completely and was improved over the time on aerodynamical, flight systems, propulsion and many other aspects. Many other configurations were considered, tested or even produced in smaller series. The most famous example might be the flying wing concepts of the Horten company which were basis for the Northtrop B2 stealth bomber. Other concept were for example the box wing, strut-braced configurations or aircraft designs with three lifting surfaces. This paper will discuss the possible advantages and disadvantages of a long distance passenger aircraft with a "Blended-Wing-Body" configuration (BWB). A BWB is an aircraft with no clear dividing line between it’s body and the wings, but were you can still recognize these parts which differentiates it from a flying wing. The main purposes for researches on this design are the potential drag reductions due to reduced wetted area and interference between body and wing as well as the better lift contribution resulting from an airfoil shaped lifting passenger cabin.

2 Aerodynamics

Due to the special design of the BWB where the fuselage is integrated into the wing, a nearly elliptical lift distribution can be obtained. This leads to a lower induced drag compared to a drake configuration. Additionally the BWB has a lower amount of transitions between the aircraft components so there is reduced interference drag. Because the BWB has the benefit to place seats in the wing and therefore has many seats abreast, the total length of the aircraft is shorter compared to a A380 which has the same amount of seats. So due to the short fuselage length and therefore a lower amount of wetted area, the BWB does also have reduced parasite drag. However the wing has a high thickness to chord ratio which leads to a bigger wave drag because of the lower drag divergence and critical Mach number. Because of the better lift distribution and the reduced drag the BWB has a better lift to drag ratio and a lower specific fuel consumption than other conventional aircraft configurations.[2]

3 Structure

In section deals with the structure of the BWB due to transverse force, bending moment and the pressure inside the cabin. Regarding to the transverse forces, Figure xx shows that the resulting transverse forces for the BWB are smaller in comparison with a conventional airplane. For this reason, the bending moment are also smaller. This means that BWB could have a reduced structure weight or a bigger span. The benefit of this is more space inside the airplane to include more seats.

A further topic regarding to the structure is the pressure inside the cabin. Generally, the fuselage should have a circular cross section so that only tension appears in the fuselage profile. For the BWB exists two different concepts. The first possibility is to integrate several circular cabins inside the wings. Another potential to get more seats is the integration directly into the wings. For this solutions, the wings have to laying up for higher critical bending moments and also for permanent occurrence of the pressure inside the cabin. To summarize this the wings need a high fatigue strength and high stiffness.[2]

4 Compatibility with further circumstances

A new vehicle concept normally leads to problems according to the compatibility with the existing infrastructure and acceptance by further actors like passengers or workers.

Passengers

An important aspect of safety feeling and travel comfort is the possibility for all passengers to look out of the aircraft window. This goal is hard to achieve with a BWB concept aircraft since the rows are much wider and the enclosing aircraft structure is not possible to be built with glass in this area (front edge of the wing).

Furthermore, you always have to take care about the inertial loads for passengers during the flight. Constructing an aircraft with a higher width of the seat rows will induce problems at the outer seats since their distance to the rotation axis x. With a higher distance the inertial forces will increase for a fix angle phi, given by the flight conditions. It doesn't seem realistic to limit these conditions like rolling angle because they are necessary for an economical cruise flight.

On the other hand, a BWB concept could cause a significant reduction of cabin noise. The reason is the position of the engines far behind the passenger areas within the BWB. You can compare it with the tail position at classical aircrafts. Additionally, this engine concept leads to lower noise problems during flight with low altitudes because the BWB will protect the ground against the strongest influence of the noise. [2]

Airport handling

This directly leads to the next aspect: the airport handling which is an important factor for development of every new aircraft. The most sensible engine position causes lots of problems for maintenance of the engines which are very easy to access in the normal position under the wing. Here we expect a significantly larger amount of time and techniques which will be necessary for this work.

Furthermore, you have to think about the airport infrastructure compatibility according to existing aircraft buildings. At the moment it's possible to deal with aircrafts until a length and width of 80 meters since this is the size of a standard aircraft box. Obviously, it would not be sensible to construct a larger aircraft which is not possible to handle at the existing destination airports. Therefore, BWB solutions with a foldable wing concept will be necessary. We can see that this is basically possible because such airplanes already exist (see aircraft carriers).

At least, an important point is the emergency evacuation time for the whole aircraft: There is a need for new concepts but studies already showed that it is possible to reach this necessary goal, so that BWB aircrafts can be permitted to passenger flights from this point of view.[2]

5 Conclusion

All in all, and after weighing up the pros and cons of the BWB it is clear, that this concept has the capability to improve the aerodynamic efficiency and the passenger capacity as well as to reduce the direct operating costs. On the other hand side, the investments which would have to be undertaken to be able to handle these new aircrafts at the airport would be rather high. But the most important reason for a possible failure of a new introduced BWB passenger airplane would be the public acceptance which is to be assumed very low due to the fact, that there are only few chances to have a look outside the window. Feeling like trapped in a can might lead to underused flight connections which would overweigh the reached improvements stated above. Because of this the BWB might be a nice aerodynamical, but not economical feasible concept.

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Health risks from cosmic radiation

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1 What is cosmic radiation?

Cosmic radiation is a form of space radiation which consists primarily of ionizing radiation which exists in the form of high energy charged particles. Most of these energetic particles originate from outside the solar system, though the sun is an important source during solar storms. Cosmic radiation consist of protons, helium and ions. Showers of these high energy particles occur when energetic cosmic rays strike the top of the Earth's atmosphere and collide with molecules of nitrogen and oxygen and decay into different secondary particles which strike earth from all directions. Earth's magnetosphere, which acts as a giant magnetic shield, blocks most of the radiation from ever reaching the planet. However, cosmic rays have free access over the polar regions where the magnetic field lines are open to interplanetary space.
The high energy radiation which contains atomic nuclei and protons are cosmic rays. It also consist of galactic nuclei. They are of 2 types, Galactic cosmic rays, which are found outside the solar system and Solar energetic particles, which are directly from the sun. The rays which comes from outer space is cosmic ionizing radiation. Cosmic radiation consist of protons, helium and ions. They enter the earth's atmosphere and collides with the atoms present in the atmosphere and produces cosmic radiation. While compared to the ground level, the cosmic radiation is 100 times higher in altitude of 35,000 [ft]. At high altitude the air gets thinner, this thinner air deflects which produces cosmic rays. In galactic cosmic radiation, it contains 85 percent protons which is hydrogen, 14 percent helium and 1 percent of heavy ions HZE- high energy nuclei. The nuclei of atoms travel at the speed of light. Galactic cosmic radiation decreases at solar maximum and increases at solar minimum.

2 How does cosmic radiation affect humans?

Considering that we are always getting bombarded with cosmic radiation, is there any risk with it?
According to the World Health Organization (WHO) and International Agency for Research on Cancer (IARC) [1] state that these kind of radiation do cause cancer and other issues with the reproductive system. A single cosmic ray has enormous amounts of energy which if collides with the DNA ends up destroying a part of the DNA strand. This can cause cell change (mutation) that could eventually become cancer cells shown in fig. 1. If we consider a fetus which is already undergo changes during it's development, avoiding these mutations is important.

But when is the amount of exposed to much for the body?

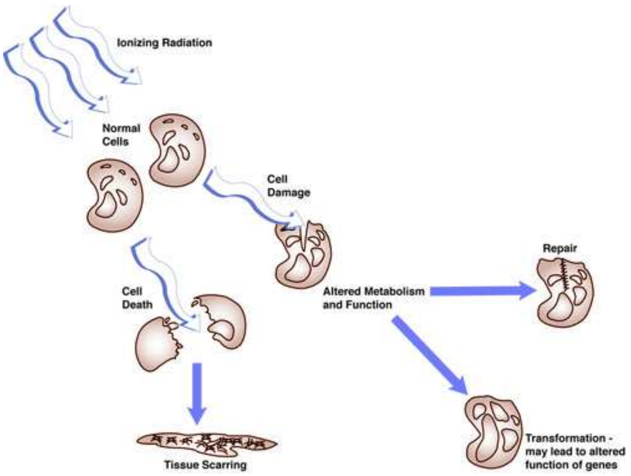

Fig. 1 . Illustrating how ionizing radiation affect the cells.

The International Commission on Radiological Protection (ICRP) [1] recommend that radiation workers should not get exposed to more then 20 mSv/year. That is a rather high value if you compare with the European Union members that state an limit of 6 mSv/year for aircrew. But both agree on pregnant women should not exceed 1 mSv during there pregnancy, and no month alone exceed 0.5 mSv.
How easy is it to gain these amounts?
Division of Radiation Safety [2] say if you fly at 39,000 feet for one hour the exposed is 0.005 mSv. With the 6 mSv/year for the aircrew they can fly at that altitude for 1200 hours, if you work 40 hours/week then you could only work for 30 week per year, also the recommended limit for pregnant women was only 1 mSv which is calculated to 200h

or just 5 weeks.
A study [3]was conducted of pilots to see if they got more cancer then the general population, it showed an increase risk to get cancer of a certain type, especially Malignant melanoma where it was 10 times more likely that a pilot get it then a regular person.

3 Prevention/Shielding

Now that you know more about what cosmic radiation is and how it affects aviation, I guess you are thinking, “Then how can we shield ourselves from radiation?”. Is it even possible? Luckily the Earth has its own natural shield in the form of the magnetosphere and the atmosphere that shields Earth from most of the radiation. Though the amount of radiation exposure grows rapidly the higher you get in the atmosphere. The exposure is about 100 times higher at 10 km than at sea-level. In low-earth-orbit you are still protected by the magnetosphere, but the amount of radiation is about 1000 times higher than back on the surface of Earth. It is even worse when leaving the orbit of Earth and moving into interplanetary travel, then you don’t really have any protection at all and you get completely exposed to solar winds and radiation from other parts of space. This is a huge issue for an eventual manned mission to Mars.

Studies has been made on different kind of shielding strategies against cosmic radiation. Material shielding can be used, but it requires a certain thickness or otherwise is may cause an increased amount of secondary radiation from high energy rays. Scientists has been experimenting with making spacecraft in hydrogen-rich plastics instead that have better shielding properties than aluminum. They have also tested using liquid hydrogen (fuel) and water placed around the vehicle to be used as shielding. One hypothetical alternative is also to use magnetic deflection which creates a shield similar to the magnetosphere but on a much smaller scale. Though this method requires a lot of energy compared to the other alternatives.
Research has also been made into developing drugs that can mimic or enhance the body’s natural capacity to repair damage caused by radiation. Of course, one alternative is also to time the trip with the current state of the cosmic radiation. So you don’t take off while a huge solar flare is happening. What you may have noticed is that most of these methods are developed for astronautical vehicles, because that is when radiation exposure can get severe consequences. As an occasional flyer you don’t really get enough radiation exposure for it to be affecting your health. Therefore, there has not really been a huge investment in developing radiation shielding for aeronautical vehicles. To reduce cosmic radiation we can try to reduce the working time on longer flights. Some aircraft have some extra shielding in the form of some type of material shielding that can be helpful for aircraft flying at higher altitudes, like the U-2.

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Hypersonic Flight

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TMAL02, Linköping University, 2017

1 Introduction

Hypersonic flight means reaching speed over Mach 5, that is, flying five times faster than sound speed.

First hypersonic flight was in 1949, when a German V-2 rocket achieved a top speed of 5150 mi/h as it entered the atmosphere [1]. In 1961, the Russian astronaut Yuri Gagarin became the first person to experience hypersonic flight [1]. Since that, reaserchers have been developing this field of study in order to achieve practical hypersonic flight.

In hypersonic flight, the air surrounding the aircraft gets so hot that it is ionized. So, the design of an hypersonic vehicle, does not only consist in reaching hypersonic field, but it must achieve high resistance to thermal efforts that appear in the surface of the aircraft, and capacity of evacuating the heat that it recibes.

Fig. 1 . Aircraft X-15

2 Physic phenomena and aerodynamics.

In this section, the different physics phenomena occurring when the aircraft reaches high Mach number values are going to be explained [1]. Hypersonic flights are placed when Mach number is 5 or greater but it does not mean that these physical consequences appears at this exact point (as it happens when exceed Mach 1). The Mach 5 value is just a convenient rule of thumb, so these phenomena take place at different Mach numbers depending on altitude, vehicle shape or size.

Thin shock layer : During hypersonic flights shock waves lie close to the surface and therefore the shock layer is very thin. Because of that, surface pressure distribution at hypersonic flights can be calculated assuming some aerodynamic simplifications. The thin shock layer can also produce a merging between shock layer and boundary layer which ends with some physical complications[2].

Entropy layer and high temperature effects : When the shock layer is very thin and curved around the nose, it produces high velocity gradients and high thermodynamics changes in the flow. This region is known as entropy layer and it gets bigger on hypersonic flights. The interaction between entropy layer and boundary one produces high temperatures along the whole surface. Also, at elevated Mach number values, the free stream kinetic energy is significantly higher than internal energy. However, when the flow enter a boundary layer it is slowed down because of friction and the kinetic energy decreases rapidly as well as internal grows very fast. This phenomenon produces a notable increase on gas temperature because it is directly proportional to internal energy.

Low density flow : Sometimes, low density flow conditions might be taken into account. At certain altitude, air can't be considered as a continuum medium. Particles collisions distance become bigger and aerodynamic perspective might also change.

Viscous interaction : The laminar boundary layer thickness depends rigidly on the Mach number (d = $M^2/Re^{0.5}$). Therefore, during hypersonic flight, the boundary layer is very thick and it interacts with the outer layer that is call inviscid flow. The interaction between inviscid flow and boundary layer is called viscous interaction and it has some practical consequences such as: increase of surface pressure, increase of skin friction, more drag and more dynamic heating.

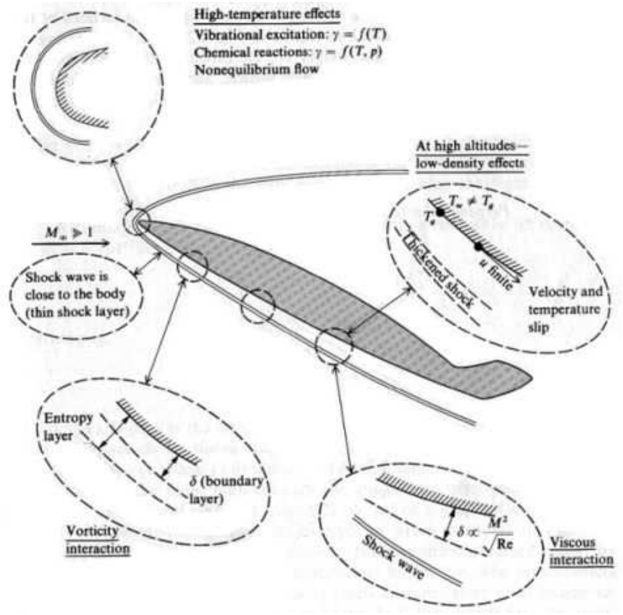

Fig. 2 . Physic phenomena and aerodynamics.

All these physical variation points are strictly relevant for the understanding of the aerodynamics and the materials used on the aircraft. Even though there is some refrigeration system, titanium or steel is needed due to its high temperature resistance properties. From the aerodynamic point of view, the best shape would be a flat plate because lift to drag ratio at hypersonic speed is the highest possible. However, the flat plate shape is not useful in terms of payload and fuel storage. Therefore, hypersonic airplanes have an even geometry, wing area don't need to be as big because lift coefficient is already created with the high speed[3]. Also, as it will be explained in next section, the type of engine used in hypersonic flights need a bottom part as flat as possible to allow the air flow.

3 Engines

The actual commercial aircrafts use turbofans or turboprops. They get the thrust by a combination among propeller and turbojetm and they reach subsonic velocities ($M \approx 0.8$).

But to go faster, to supersonic velocities (1 < Ma < 5), that types of engines are not the most adequate due to the shock waves can damage the mobile parts. Furthermore, thrust is the result of multiplicate the air mass flow by the difference between flight speed and outlet nozzle speed.

So, the low speed vehicles try to take advantage of increasing the mass flow increasing the bypass ratio, even 1:12 in the new planes. However, for supersonic is used a less ratio than 1.

Both types of engines reduce the air velocity until Mach 0.4-0.5, regardless of flight speed. That jet engines that can fly supersonically include usually an afterburner to increase the nozzle speed. So as to go faster is necessary use ramjet engine, the SR-71 Blackbird was the fastest jet and ramjet hybrid powered plane, reaching Mach 3.35 [4], but above Mach 6 ramjet is inefficient due to the shock waves presents in the inlet [5]. Scramjet resolves this problem operating with supersonic airflow instead of subsonic.

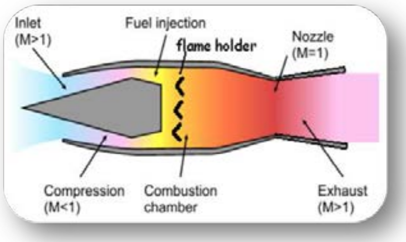

Fig. 3 . Ramjet

Moreover, the problem of these type of engines is that they cannot produce thrust if they are not in moving. Therefore, they need to be assisted to take off. It has been realized in the case of the unmanned X-43A by a B-52. Next, to reach Mach 5, the X-43A used rockets and, then, the scramjet entered in action achieving Mach 9.8. But it is being studied an aircraft (TBCC, [3]) which use turbine engine to accelerate so that ramjet engine can work until Mach 5 and, then, change to scramjet.

Scramjet engines do not need have oxygen reserves since they use the atmospheric air for combustion. This supposes a lower weight and a higher efficiency, ideal for atmospheric hypersonic flights.

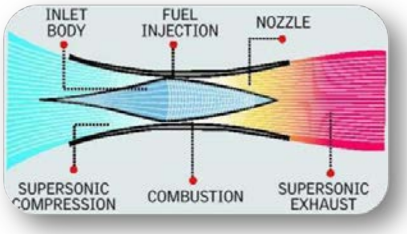

Fig. 4 . Scramjet

4 Challenges and applications

4.1 Challenges

Heat: To withstand the adverse effects of such speeds where the surface temperatures can go up to 1000 °C the materials to be used are special and used to be cooled nickel or titanium. But with advancements in R&D special ceramic materials are coming into the picture. For example, The Falcon HTV-2, recorded surface temperatures of 1.927 °C during its test flight.

Manoeuvring: To attain such speeds and fly effectively it is necessary that our "objects" fly high. Flying high can provide cover, it is also a way for the "object" to avoid the higher pressures present at lower altitudes, which could cause it to burn up. But the problem here is that thinner the air, the more difficult it becomes to steering. Some hypersonic aircraft are manned vehicles, but high altitude's thin air along with the extreme speeds means a human pilot cannot react fast enough to potential issues. This means manned hypersonic crafts have to be controlled by a computerized system that can control it while the pilot can direct the larger manoeuvres.

Breaking the barrier: A sonic boom can generate a 160-decibel noise that travels to the ground and can potentially damage human ears. The retired Concorde airplane used to produce noise up to 135-decibel on the ground which is way too much than the average commercial plane today. Another problem is that of the 'superboom' which develops when a supersonic airplane changes its speed, turns or manoeuvres. In a superboom the ground noise of a sonic boom can be two or three times louder than compared to one at the plane's altitude. Thus, with increasing altitude of the plane's flight, its ground shock waves can spread out and produce smaller shock waves.

Fuel: Going with the usually used aviation kerosene fuel is not feasible for going hypersonic. Hence, the liquefied oxygen/nitrogen/hydrogen comes into place. But hydrogen being able to give the highest specific impulse (a measure of the efficiency of rocket and jet engines) and its ability to un-pollute the air when oxidized with liquid oxygen (as its by product is only water) has become one of the preferred choice of fuel. Also, in case of mishaps, hydrogen burns 20% less hotter than its kerosene counter-part.

If the hydrogen can be sourced from natural gas, instead of from the electrolysis of water, the airfare tickets of a hypersonic trip could drop to about half the price of a business-class ticket. Based on current projections the ticket price will be about three times more expensive on average than current business-class subsonic tickets. Even though hydrogen-fuelled airliners would not emit gases such as carbon dioxide, sulphur oxides etc like today's subsonic airplanes, which increases the greenhouse effect. But there is another concern, water vapour produced by the combustion of hydrogen remains in the stratosphere for a long time, and could be a major contributing factor to global warming. Studies earlier have shown that the lifetime of water vapour decreases exponentially, taking from 30 years at 25 kilometres altitude to less than one year above 32 to 34 kilometres. An alternative fuel which could seem promising could be liquefied natural gas such as super-cooled liquid methane. It also occupies far less space than other gases when stored as liquid.

4.2 Applications

Development of hypersonic technologies came up mainly for/through military purposes and space programs like the development of X-15, X-51, Spaceship one and two by NASA along with the US Air Force and manufacturers like Boeing and Lockheed Martin. In space programs, USA started off with space shuttles and the Soviets followed with their Buran Project which is now on hold. India recently developed and tested RLV-TD all aimed to develop a reusable launch vehicle. There are countries that have developed and currently using hypersonic missiles/warheads also like Zircon (Russia), Shaurya (India) and Brahmos (India and Russia).

Within the recent/upcoming projects, The Defence Research & Development Organization of India has developed an unmanned scramjet demonstration aircraft for hypersonic speed flight aimed to develop for both civil purposes (low cost satellite launchings) as well as military purposes (long range cruise missiles). The project is called HSTDV (Hypersonic Technology Demonstrator Vehicle). There are many projects and research undergoing currently as well like the WU-14 hypersonic glide vehicle (China), Falcon HTV-2 (USA), AVATAR (India), SHEFEX (Germany), LAPCAT (EU) to name a few. For civil purposes there is a huge research and extensive testing going on mainly focused on human transportation within the globe as well as to outer space. Virgin Galactic and Space-X are such private firms into this.

Fig. 5 . Sharuya Missile

5 Conclusions

Human beings have always been curious about airspace and aviation. The improvements since the beginning of XIX century are astonishing but there is still some room for progression. Probably, the next main challenge is dominating the hypersonic flight. The aim is to develop an aircraft able to fly longer periods of time at hypersonic speed.

However, this is a hard challange. Aerodynamics, propulsion and structure demands on hypersonic flights are significantly more complex than in subsonic airplanes. Here lies the biggest problem and the technical issues that have to be solved before hypersonic flight becomes a reality.

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Sonic Boom reduction of supersonic aircraft

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TMAL02, Linköping University, 2017

1 Introduction

The concept of supersonic aircrafts and jet engines come from the age after the second world war and pushed the speed limits of aircrafts forward. Supersonic flight has always been a topic of great interest due to the potential to reduce inter-continental travel time. However a long row of problems arose and hampered the development of the supersonic aircraft and in the end only two civilian aircraft ever became operational, the Concorde and the Tupolev Tu-144. One of the problems that severely limited the use of supersonic aircrafts was the Sonic Boom. When breaking the sound barrier a high energy shock wave is created trailing the aircraft. Although not heard by anyone in the plane it's a big nuisance on the ground. It is heard as a loud explosion or boom, can shatter windows and makes animals panic. Therefore Supersonic flight is banned over most countries, limiting the possible supersonic flight routes of the Concorde (when it was still flying) just above water. Removing or reducing the Sonic boom is therefore of great interest if it could lead to supersonic flight above land.

This article will not discuss the change in properties when an airplane travels from subsonic to supersonic flight, but rather try to explain the different solutions for reducing the sonic boom that exist to be able to fly above land.

2 Reduction of sonic boom

There are several ways to reduce the sonic boom, all of the solutions aim to achieve a desirable shape of the aircraft. A critical part is the installation of the engines. By installing them on top of the wings the sonic boom can be diffused upwards instead of towards the ground, however, this will cause some performance penalties. The engine can instead be placed on the centerline above the wing to avoid this problem. The most common way to install the engines are below the wings, in which case the wings need to be tailored to different types of delta shaped wings or a highly swept wings. [1] It is not only the placement of the engines that affect the sonic boom it is also the nozzle. The contribution from the nozzle can be reduced by installing a convergent-divergent nozzle on the exit of the engine [2].This installation increases the area of affect that the pressure is distributed over when the shock wave reaches the ground.The same effect can be observed at higher altitudes.[3] Another way to reduce the sonic boom is to make the fuselage sleeker, many design are focusing on the nose of the aircraft, such as the project Quiet Spike that Gulfstream Aerospace and NASA developed[4]. There is some research about minimising the turbulent flow over the wing, that produces the shock waves. This should be done with special airfoils that are constructed to induce laminar flow control, this would mean that the leading edge of the wing will remain in subsonic state when the plane flying at supersonic speeds.[5]

3 Quiet Spike

Quiet Spike: The name that Gulfstream gave to the telescoping nose-boom concept, which it began developing in 2001. Quiet spike is a telescoping forward fuselage extension that alters the bow shock of the classic N-wave pressure signature generated by aircraft traveling at supersonic speeds[6]. This Quiet Spike shows a significant potential for reducing the sonic boom by creating just a mild nose shock. This is done by producing weak shock from its narrow tip followed by cross-section transition between the adjacent telescoping section. Thereby developing an asymmetrically shaped, less powerful pressure wave, that propagates parallel to the ground. [4]

4 Quiet Supersonic Technology

Since the Quiet Spike project, NASA has shifted their focus towards a low boom flight demonstration (LBFD) aircraft. Together with Lockheed Martin, NASA is working on the Quiet Supersonic Technology Experiment Aircraft, that aims to reduce the sonic boom. Their main goal with this project is to "Beat the Boom" and improve the experience of those on the ground, that deal with a supersonic aircraft flying over them. As described by NASA, the QueSST is a preliminary design concept of the unique X-plane. Currently the design is based on computer models in order to confirm that all the pieces of the aircraft will come together properly, for a future real aircraft. The X-plane has a long nose with highly swept wings and a sleek fuselage.[7]

One of the milestones for the NASA-Lockheed team was to verify the aerodynamic performance predictions for the fuselage, control surfaces, and the nacelle diameter. To investigate these predictions the team built a scale model of the QueSST X-plane for wind tunnel testing, at the NASA Glenn Research Center. As of 4th September 2017, NASA claimed to have successfully accomplish their milestone of fulfilling the LBFD for the QueSST X-plane. Which was to reduce the sonic boom created to a softer "thump" instead, while flying at supersonic speeds. The next step for the NASA-Lockheed team is to initiate proposal acceptance procedures in order start awarding contracts for the construction of the X-plane. NASA claims this process will start as early as next year and during this process, the data for the preliminary design review will also be made available to successful bidders. This is a huge step forward in the field of supersonic flight and test flights can be expected as early as 2021. [8]

5 Conclusion

The interest in supersonic flight has picked up in recent years [9]. NASA has been working for a long time on reducing the sonic boom with different methods and has recently awarded Lockheed Martin with a contract to design a supersonic experimental aircraft, the QueSST X-plane [10].

Physics tells us that we can never get rid of the sonic boom altogether but these experiments show that it can be reduced and that the sound can be made softer for the human ear. Whether this is enough to make supersonic flight over land possible remains to be seen. If that is the case, there might just be a market for supersonic airliners again.

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SABRE Rocket

Nour Sanchez Abad, Marcus Lång, Logeshkumar Srinivasan Venkatesan
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TMAL02, Linköping University, 2017

1 Introduction to SABRE

SABRE (Synergistic Air-Breathing Rocket Engine) is a hypersonic pre-cooled hybrid air-breathing rocket engine. It is a concept of a single stage rocket engine, curently in development by *Reactions Engines Limited*. The engine is to be mounted on the *Skylon spaceplane*, which would be able to fly as high as entering Earth's low orbit.

2 Subsystems

The SABRE rocket basically contains of 5 main subsystems.[1] These subsystems, as well as some other components can be found in Fig.1. Let's start from the nose and go back to the thrust chambers (from right to left).

- Air intake: The air intake is used to feed the engine with air. Its task is also to slow the speed of the air down to subsonic speeds. Its set to operated between Mach 0 and 5. If the speed is higher that that it will enter rocket mode.
- Pre-cooler: Air that travel in supersonic speeds, or even faster, becomes hot due to the compressibility effects. The pre-cooler is capable of transferring 400 MW of heat with less than 1 tonne of hardware.
- Compressor: It has a 2-stage axial compressor which is driven by a helium turbine. The pre-cooled air enter the compressor and get compressed to about 140 atmospheres before going to the rocket combustion chamber.
- Rocket engines: It uses a high performance LH2/LOX engine combined with other SABRE subsystems.
- Ramjet: The ramjet is the part at the back of the rocket around the nozzles. It is used to generate thrust during the acceleration with the use of air and evaporated hydrogen.

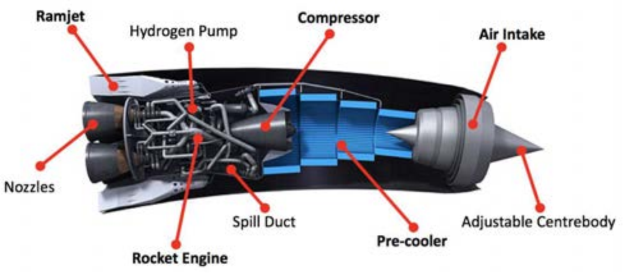

Fig. 1 . Showing a split view of the SABRE rocket and its subsystems/components (adapted from [2]).

3 Operation principle

The SABRE is a combined power cycles of rocket engine and jet engine. Initially it works as a regular jet engine by breathing air from the atmosphere and ignites the hydrogen fuel. As the altitude increases, the air gets too thin the engine switches its oxygen supply from on-board LOX tank then its works as a regular rocket engine with higher Mach number. When atmospheric air enters the SABRE the inlet of shock cone reduces the flow to subsonic speed due to this air temperature raises to very high because of compressibility effects. Then some of the air passes through pre-cooler and the remaining air goes to bypass of the engine. In the pre-cooler the air temperature reduces from 1000 °C to −150 °C in a 1/100th second without ice formation. This process is done by powerful heat ex-changer using helium as a coolant. The hot helium is cooled by a liquid hydrogen fuel in a heat exchanger and its heat energy is used to vaporize the hydrogen fuel. After passing through the pre-cooler the atmospheric air enters the high-pressure ratio turbo compressor there its pressure increases to 140atm and then it feeds into the combustion chamber of the engine. Unlike conventional jet engine the compressor runs by a turbine which is powered by a helium loop. The helium loop recycles the heat energy to power the turbine and liquid hydrogen pump thus increases the efficiency of the engine. After reaching higher altitude the engine switches to rocket mode by burning the hydrogen as a fuel and liquid oxygen as a oxidizer from the on-board tank. [3] [4] A schematic of the working process can be seen in Fig.2.

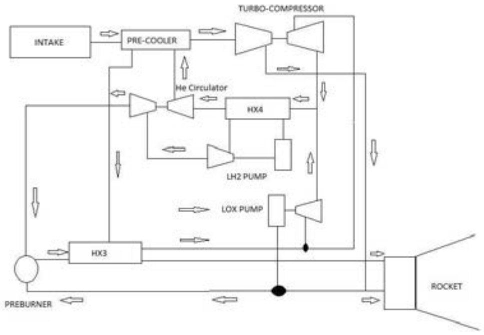

Fig. 2 . Box schematic of SABRE's working principle. (adapted from [3])

4 Comparison

With the intent of putting SABRE into context, the following aims to provide a comparison with current state of the art single-stage-to-orbit (SSTO) engines.

Nevertheless, this comparison is not without its flaws as, to date, no SSTO launches have been performed. The driver of this scarcity is intrinsic to the SSTO concept as the whole mass of the vehicle is put into orbit. This leads to vehicle dry mass minimization and engine efficiency being critical in SSTO design which in turn requires the highest level of technology available [5]. Therefore, the present analysis will be relegated to a mere theoretical standpoint.

Being the main proponent of the SSTO rocket engine family, liquid H_2/O_2 rockets attain high thrust/weight ratios compared to SABRE but lower specific impulse (i.e. efficiency). These characteristics encourage vertical take off and thus do not require lifting surfaces. Their single-stage nature does reduce the payload fraction significantly (near 1%), therefore multi-stage rockets are widely used [6]. However, the technology has been thoroughly researched and tested providing high levels of reliability as compared to SABRE.

Turborockets are part of the air-breathing family and are based on a multi-mode concept for different Mach conditions. Beginning from sea levels conditions, turbojets are used as in conventional aircraft. As thrust output is impaired above Mach = 3, the ramjet engine is operated which uses a compressor-less geometry to compress the incoming flow. Nevertheless, as flow is slowed at the combustion chamber to perform subsonic combustion, at about Mach = 6 efficiency drops and so the scramjet is employed. In this transition a new engine per se is not used but rather the geometry of the ramjet is reconfigured to allow for supersonic combustion. Finally, although the scramjet could reach scape velocity, above Mach = 15 efficiency is hindered and thus it has been proposed to use rocket power to finalize the climb [7]. The obvious flaw in this design is that off regime engines generate an overall low thrust/weight ratio as compared to SABRE.

Finally, compared to current launcher vehicles, SABRE offers to reduce maintenance and other reoccurring costs yet the high technological requirements are currently driving development costs up excessively. It will remain to be seen whether or not the benefits of SABRE and other SSTO vehicles can outweigh the comparatively low costs that economies of scale produce for expendable multi-phase launchers.

5 Conclusion

The technology behind this type of engine cooling is a breakthrough in the aviation industry. The engine itself is capable of drastically lowering the price of space travel and thus changing the aerospace industry completely. But for now the future stands in the hands of the engineers from *Reactions Engines Limited.*

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Aircraft Based Rocket Launch

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TMAL02, Expert Conference, Linköping University, 2017

1 Introduction

Space launching has the disadvantage of being costly. Also, there is a large fuel consumption and difficulties in fuel storage (due to boil-off phenomenon). Air launching is a possible alternative. Launching the rocket in air at a higher altitude skips the most dense portion of the atmosphere where drag has the biggest influence on performance. Although the reduction of the escape velocity is not big, the flexibility and reusability this technique provides will lower the overall costs of space missions.

The purpose of this paper is to review the main concepts of rocket air launches.

2 History

The first case of air launching was when bi-plane fighters were secured under airships (dirigible balloons). This system was used to boost the range of the bi-planes, but as the technology improved this method was abandoned. The historic event of traveling faster than speed of sound was accomplished by launching the rocket powered Bell X-1 from B-29 Superfortress bomber, followed by X-15 being launched by B-52 bomber. The inquisitive nature of humans and the technological advancement led to the development of programs to launch rockets to space from an aircraft.

3 Methods of Air Launch

As the name says itself, the rocket is carried by an aircraft to a particular altitude where air is thinner and launched. Based on the configuration of the rocket and carrier aircraft, the following classification can be made:

- Direct Carry
  - Top Carried
  - Bottom Carried
  - Internally carried
- Towed Glider

3.1 Direct Carry

The simplest way to bring a rocket to the launch altitude is to mount it directly on an aircraft. This method might help the development of space industry in parts of the world where there are no common launching options (for example launching pads). The direct carry can be divided in 3 parts as follows.

3.1.1 Top Carried

The main advantage of this method is that the ground clearance issues are avoided. However, the heavy payload on top creates stability and control problems. The position of the center of gravity changes significantly between take-off and landing. Also additional drag is created which limits the launching altitude (for example the launch altitude for Boeing AirLaunch is 7300 m [1]).

3.1.2 Bottom Carried

The launch vehicle in this method is attached at the bottom of the carrier aircraft. This idea of direct launch has proven to increase the stability and ease of separation from the carrier aircraft. Stratolaunch is an example for this method of direct carry. It is said to be functional by the end of this decade [2]. Stratolaunch is a twin fuselage airplane which presently has the largest wings span from all aircraft. It carries the rocket between the fuselages. It has six Boeing 747 engines for a payload capacity of over 226 700 kg. The main drawbacks of Stratolaunch are the limited payload size and the lateral forces on the rocket created by the carrier aircraft.

3.1.3 Internally carried

The SwiftLaunch Reusable Launch Vehicle (RLV) is one of the feasible concepts when it comes to internally carried method. In this case the rocket is carried within the fuselage of a large cargo plane like Antonov An-124 Ruslan or C-5 Galaxy. At the launch altitude the aft door opens, a parachute is released which in turn pulls the rocket out of the fuselage. The rocket falls with the parachute approximately 600 m until the rocket engines starts. Some of the advantages can be:

- no permanent modification of aircraft needed;
- it saves 1000 m - 3000 m of lost altitude in comparison to horizontal oriented launch.

The biggest 2 limitations are:

- size of fuselage limits the size of rocket;
- cryogenic fueled rockets pose a great risk of explosions.

3.2 Towed Glider Air-Launch System

In this method a jet aircraft will tow a special built glider that carries the payload and booster. Once they reach the launch altitude, the glider is released. Using a small rocket engine the unmanned glider performs a pull-up maneuver such that the payload launches almost vertically. Then both glider and airplane return to the ground.

Fig. 1 Illustration of towed glider air-launch system.[3]

According to [4] and [5] the main advantages of this technique are:

- *reduced costs* due to reusability of glider and jet airplane, less demanding maintenance;
- *increased flexibility* regarding launching areas, weather or propagated delays in launch schedule;
- *increased safety* because the crew is not in the proximity of a rocket (in contrast with the other air-launched methods);
- *better payload capacity* as the reorientation of rocket is done by the glider, which saves a lot of energy compared to the horizontal launch. This means that less fuel is needed and useful payload can be added.

Towing is more efficient than direct carry mainly because the excess thrust is used in a better way. The launch vehicle has its own high performance wing (the glider) and the extra drag produced is far less little than the extra drag produced in the conventional top or bottom carried configurations. In article [5] a nice analogy is made with a pickup truck that pulls a heavy trailer: it would transport much more weight than it could directly carry itself.

Concerns in this topic include carrier airplane take-off abort and heating of the fuel tank during the ascent for liquid propellant rockets. As the temperature of the tank increases (due to solar radiation and air convection) the pressure inside starts to build up and it has to be released. When the vapors escape and pressure drops the liquid oxygen starts to boil, phenomenon known as boil-off [6].

4 Conclusions

Conventional rocket launches tend to be expensive because the rocket stages currently used are not reusable. In this paper a short review of an alternative solution (air launch) has been made. These ideas provide a better performance only if the launch attitude is near vertical. The concepts generally require more advanced technologies and they are still under development.

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Lift generation of forward flying helicopters/rotors

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TMAL02, Linköping University, 2017

1 Introduction

The basic difference between helicopter and fixed-wing aircraft is that the the generation of lift, thrust and control is strictly separated for fixed-wing aircraft. In contrast to that the rotor of a forward flying helicopter has to fulfill all three functions [1]:

- generate vertical lift force
- generate horizontal propulsion force
- generate moments and forces to control attitude and position

Nevertheless, the general concept to use airfoils to generate these forces is basically the the same. However, the incident flow is created by the rotation of the rotor blades and not by a straightforward movement through air [2]. This article concentrates on the question how the lift is generated by the rotor, how it can be calculated and which effects this has on the helicopter.

2 Aerodynamics of helicopters

A good way to analyze the aerodynamics of helicopters is to differentiate the various flight regimes. The most basic ones are hover, climb and descent and and forward flight which are explained more detailed in the following. All other complex maneuvers can be obtained by a combination of these. [1]

2.1 Hover flight

As there is only an axis-symmetric flow through the rotor the hover flight is the easiest of the defined flight regimes [1]. Assuming a simplified one-dimensional, quasi steady, incompressible and inviscid flow through the rotor a control volume can be obtained to calculate the flow through the rotor. This control volume is shown in Figure 1. In the hovering regime there is an equilibrium of thrust T and weight W. For the hovering flight applies additionally $T = L$, so that the thrust equal to the lift. With the help of the mass conservation and conservation of fluid momentum one can obtain equation (1).

$$T = W = L = 2 \cdot \rho \cdot A \cdot {v_0}^2 \tag{1}$$

where v_0 is the velocity of the air-stream in hovering flight [3].

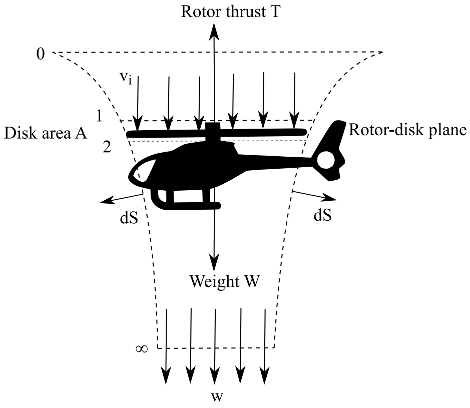

Fig. 1 . Flow model for momentum theory analysis of a rotor in hovering flight adapted from [1]

2.2 Axial climb and descent

By adding a vertical speed V_C (climb) or V_D (descent) to the previous analysis of hovering, the aerodynamics can be analyzed rather easily as axis symmetry is still present. Thrust is, when climbing or descending with constant speed, still equal to the lift. This results in the equations (2). Where v_i is the initial velocity of the air-stream in flight (so just before the air passes the rotors).

$$\begin{aligned} T = W = L = 2 \cdot \rho \cdot A \cdot (V_C \cdot v_i + v_i^2) \\ T = W = L = 2 \cdot \rho \cdot A \cdot (V_D \cdot v_i - v_i^2) \end{aligned} \tag{2}$$

From this it all seems rather easy, but this is just theoretical. In reality vortex flows are present and affect the aerodynamics heavily. Mostly when descending slowly, problems arise since the vortices form and stay around the tips of the blade. This creates vibrations which make controlling the helicopter even harder.

2.3 Forward flight

During forward flight two main differences can be seen in comparison to the hover flight and axial climb and descent situation. The rotors blades have to generate aside from the lifting force also a propulsion force. This propulsion is parallel to the rotors blades. As a result, the blades should be tilted at a certain angle (Angle of attack α). Furthermore, the helicopter experiences a free stream velocity (V_∞) as a result of going forward. Both can be seen in figure 2 and have an influence on the lift calculation as discussed before.

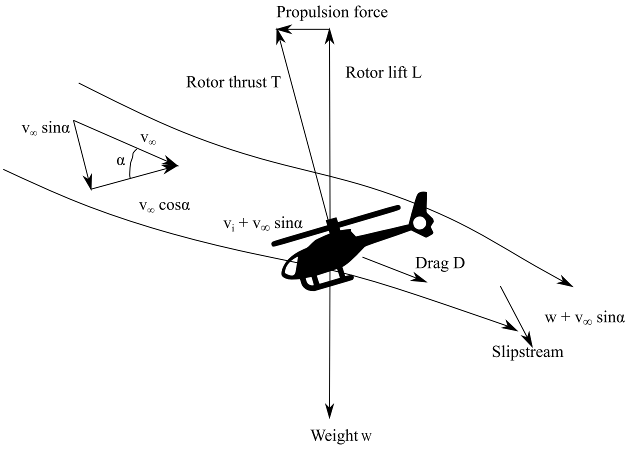

Fig. 2 . Flow model for the momentum analysis of a rotor in forward flight adapted from [1]

To calculate the generated thrust by the rotor blades (3), the local stream velocity (U) at the rotor blades has to be estimated first. The velocity can be determined by equation (4)

$$T = 2 \cdot \rho \cdot A \cdot U \cdot v_i \tag{3}$$

$$U = \sqrt{V_\infty^2 + 2 \cdot V_\infty \cdot v_i \cdot sin\alpha + v_i^2} \tag{4}$$

In comparison to the situation discussed before, the total thrust is not only used to generate lift but also for the propulsion force. The vertical part of the generated thrust is equal to the lift. The horizontal part of the thrust is equal to the propulsion force (figure 2). As a result, the rotor blades need to generate more thrust, as in a hover situation, to maintain the helicopter at a constant height.

3 Ground effects

Concerning the lift generation of a rotor there occur two different forms of lift generation during normal flight and near the ground. These are presented in the schematic sketches in Figure 3 and discussed briefly in the following. Near the ground the air-stream is deflected by the ground. This causes an increasing pressure and a resulting lower velocity in the flow area. Because of the fact that this is an induced velocity there is a less power needed to generate it. This has advantages for take off. [2, 4]

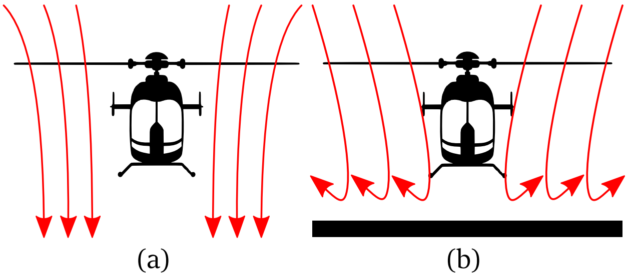
(a) (b)

Fig. 3 . Lift generation in normal flight (a) and lift generation near the ground (b)

4 Conclusion

The described effects are only the basic principals of lift generation of forward flying helicopters. The theoretical calculation of the aerodynamics of a real helicopter are considerably more complex than this [1]. At this point for example vortexes of the rotor, rotor flapping or the resulting swinging movements should be noted. See the referred literature for further detailed information.

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High-velocity helicopter concepts

Mervin Thomas Abraham, Otto Kellerman, Marcus Pettersson and *Martin Wiberg*
TMAL02, Linköping University, 2017

1 Introduction

What are some differences between a helicopter and a high-velocity helicopter?
In this report we'll be taking a look at some different aspects of a high-velocity helicopter that differentiates it from a regular helicopter. The main topics include drag, propulsion, and lift.

Fig. 1 . Picture of the Sikorsky S-97 Raider. Utilizing a coaxial main rotor and an aft propeller as well as retractable landing gears. *Photo courtesy Lockheed Martin*

2 High-velocity helicopters

High velocity helicopters have potential in a large amount of use cases. Military applications such as reconnaissance and troop movements. Also for civilian uses where speed is of the essence, for example air medical services, where minutes could mean life or death. However, these high-velocity helicopters are not widely used today, and there are some different reasons for that. High speed travel introduces some design difficulties, mainly in regards to drag, propulsion and lift. These three points will be discussed in detail below.

2.1 Drag

Since regular helicopters fly relatively slow the drag does not become a very big problem. When designing and creating a helicopter for high velocities it becomes one of the most important aspects of the aircraft. If the helicopter produces too much drag, any sort of high velocity flying becomes too difficult, or too much of a power waste to be worth the cost.

There are different types of drag. Parasite drag is created from the components that protrude into the airflow, like the landing gear, doors etc. The fuselage itself is also a source of parasite drag.

There is also drag created by the blades passing through the air. This is known as profile drag. Profile drag remains relatively constant at different speeds, only increasing slightly as the speed increases.

Features such as landing skids, sponsons, and components such as search lights and cameras can be removed or integrated into the fuselage to reduce drag. This in addition to a more streamlined fuselage can together significantly reduce drag.

If we compare a fixed wing aircraft and a helicopter rotor, the lift generated is according to the same principles. With more lift, more drag or resistance is produced. The fixed wing of an aircraft would produce balanced drag, as both wings are traveling in the same velocity. However in a helicopter the rotors are moving in two different directions, which makes it challenging to manage. If we have a fixed wing for a high velocity helicopter the drag could be balanced, and we could generate vertical lift as well.

2.2 Propulsion and Lift

The forward thrust for helicopters is generated by the main rotor, which also generates the lift. The helicopter can only pitch down so far before the lift force becomes lower than the weight of the helicopter, and its height starts to decrease.

This is solved by separating the lift generation and forward thrust generation. For example the Sikorsky S-97 Raider [1] in Figure 1 uses a coaxial main rotor and a propeller on the tail. The coaxial main rotors remove the need for a tail rotor. Similarly, the Airbus Racer [2] uses one main rotor and two pusher propellers in a box wing design.

Torque - If we consider the torque of a helicopter, as the rotor generates lift, reverse torque acts on the helicopter. This results in a spin of the helicopter fuselage in the opposite direction of the rotor. To overcome this problem a vertical rotor is fixed at the tail of the helicopter. This tail rotor generates thrust in the opposite direction. Because of this the torque is balanced out, but it introduces a new problem. The helicopter will be pushed sideways and this has to be adjusted for by the pilot. However the tail rotor takes up to 6 percent of the engine power and to reduce this power waste the vertical tail rotor could be replaced with a vertical stabilizer. With this the torque could be managed and the power supply could be reduced for high-velocity helicopters.[3]

3 Conclusion

The model of the helicopter has been remodeled in future for the high velocity helicopter. By adding wings the drag has been stabilized, which makes it better than the old model. The tail rotor is used in a helicopter for pitch control and it takes 6 percent of the engine power, without producing any lift. However in a high-velocity helicopter it also generates forward thrust alongside stability. By this model the drag is balanced and the stability problem of the helicopter is solved for high velocity. In new model mostly the X-shape blades are fixed, so that the noise could be reduced. The tail rotor neutralizes the entire torque produced in helicopter which results in more power to forward lift.

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Autogyro

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1 Work description

The aim of this document is to describe an autogyro. The work has been divided in main architecture, where the different parts of the autogyro are explained; flight performance, where through aerodynamics flight is explained; rotor aerodynamics, in which the complexity of the rotor is described; and finally, the main control system of the autogyro.

2 Autogyro Description

The autogyro is an aircraft invented by the Spanish engineer Juan de La Cierva in 1923. It is classified as a rotorcraft because its lift is generated by a rotor, and it is defined as a STOL (Short Take-Off and Landing) vehicle. According to the Annex II of Basic Regulation (EC) No 216/2008 of the European Parliament and of the Council (20th February of 2008), the autogyro is inside the F category of ultralight aviation with a MTOW (Maximum Take-Off Weight) of 560 kg.

3 Architecture

The main parts of the autogyro are the fuselage, the stabilizers, the propeller and the rotor, all shown in the Figure 1. The fuselage joins all the components and contains the cockpit of the aircraft. There are different configurations of the cockpit, it can be covered or uncovered. The tail formed by vertical and horizontal stabilizers allows flight control. The propeller provides the forward propulsion of the autogyro. It can be allocated at the front or at the rear part of the fuselage. Apart from the propeller, the autogyro has a rotor that provides lift to the aircraft. This is the main difference between an airplane and an autogyro, so the lift is not generated by a wing but by a rotor. The rotor of the autogyro is not connected to a shaft-engine so it rotates freely by the action of the air passing through the blades. This is the main difference between an autogyro and a helicopter, in which the main rotor is powered by an engine. Due to this reason, the autogyro is not able to stop in the air or take-off and land vertically, so it needs a horizontal speed to maintain the blades rotation in order to create lift.

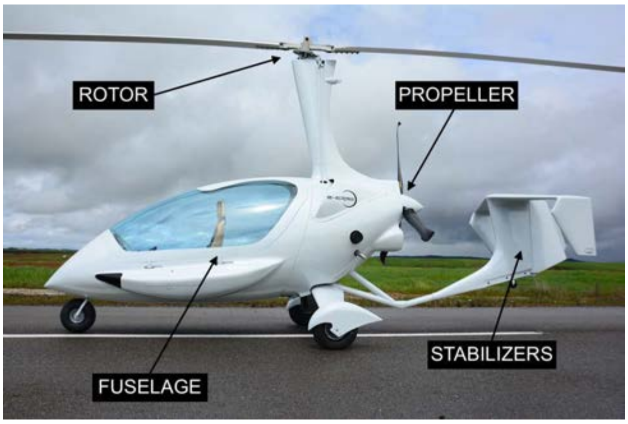

Fig. 1 . Different parts of an autogyro with the propeller in the rear of the fuselage.

4 Performance

The autogiro performance is based in lift creation by the auto-rotation phenomenon. To make this phenomenon take place, a flow upwards the rotor is required. This flow is achieved either with a forward motion and a backward tilted rotor or with a descending flight. [1]

4.1 Auto-rotation

The auto-rotation is defined as a self-sustained rotation of the rotor without any shaft torque from the engine. In this case, the power to drive the rotor comes from the relative airstream that passes through the rotor upwards due to the rotor being tilted backwards or a descending flight.

During the forward auto-rotation the regions in the rotor follow the Figure 2 shape. The dissymmetry of the right image in Figure 2 is explained below.

On the other hand, the flow distribution in the rotor tilts the lift vector as the Figure 3 shows. In the driving region (Figure 3a), the induced velocity is going upwards which entails a force component in the rotation direction, providing torque to the rotor. In the autorotation circle (Figure 3b), the lift is completely perpendicular to the rotor plane, not providing any force against the rotation motion nor favouring it. In contrast to that, the driven region (Figure 3c) takes

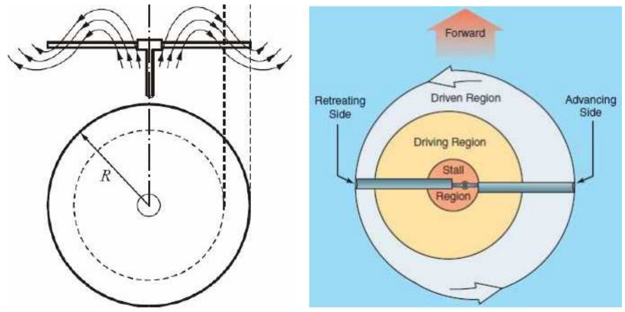

Fig. 2 . Rotor flow (left) and rotor regions in forward flight autorotation (right) [2].

an induced flow speed downwards which tilt the lift backwards creating a force against the rotor motion, creating a negative par.

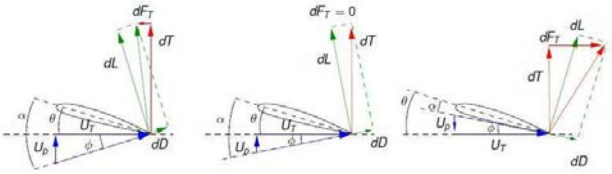

Fig. 3 . Forces in each region: a) Driving region; b) Autorotation circumference; c) Driven region

4.2 Aerodynamics

During forward performance, the rotor blades rotate counter-clockwise when viewed from above. Blades can be divided between ones that advance into the oncoming airflow and those which are moving away from it. The first ones occupy the semi-circle on the right-hand side of the centreline and are called advancing blades, while the retreating blades occupy the left-hand side of the rotor disc area.

The rotation velocity of the whole rotor is the same, but the difference produced by the strike or subtraction of the forward speed incident to the blades in each side of the centreline produces a variation of the airflow speed. Since the lift is related to this speed, the lift produced by the advancing blades side is higher than the other one. This phenomena produces that all driven, stall and driving regions move towards the retreating blades and then, driven area in the retracting region is smaller than the advancing blade region. This difference in the lift is known as dissymmetry of lift and produces a roll moment to the left.

This difference on the lift at both sides is avoided by hinging individually the blades, allowing them to flap up and down slightly as they move advancing to the wind or away of it. The advancing side blades decrease their lift by decreasing the angle of attack teetering up, while the retracting side blades teeter down.

During the descent in landing, the autogyro only uses the auto-rotation phenomenon using rotational kinetic energy acquired by the rotor. To do so, the pilot increases the rotor speed and then he progressively increases the collective pitch to increase the lift and reduce the vertical and forward velocity. [1]

5 Flight controls

In the beginning the autogyro was quite hard to control for pilots. It was equipped with a rotor, stub wings, a rudder and an elevator. The autogyro got a bad reputation amongst pilots for its tough controllability.

To get rid of this bad reputation, a new design was invented, the so called directly orientable rotor control. In this design, the rotor was placed on a universal joint, which allowed the entire rotor shaft to be tilted in any direction. In this way, the lift force could be influenced by inclining the rotor in a specific direction. The stub wings and the elevator could be eliminated in this design.

Pitch and roll are done by the directly orientable rotor control. The rudder is retained on the autogyro for yaw control. The controlling by the pilot was done by a hanging stick in the cockpit. The hanging stick increased the ability of taking good control of the autogyro.

Furthermore, the control forces were quite low. However, vibrations in the rotor made their way to the hanging stick and this made the autogyro exhausting to fly.

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