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EDITOR´S NOTE

Stay curious and combined with a high-quality education you will become a good engineer!

This is now already the fourth time that the **TMAL02 Expert Conference** has been held as a part of the ***Aircraft and Vehicle Design (TMAL02)*** course at Linköping University. This course is one of the primer courses within the **International Aeronautical Master Programme (AER)** which was established in 2013 at Linköping University.

To show, analyse and explain the broad spectrum of aeronautical engineering topics ranging from basic physical effects to operational aspects, from state-of-the-art designs to novel concepts, and all kind of engineering domains included within aeronautical product development from the first idea to the final flight testing campaign, requires a sound and as complete as possible background of the involved actors. Making use of a conference with presentations and the proceedings written from students for students is a very suitable way of exploring new fields by the students on their own.

The 4th Expert Conference is the first time the proceedings of the Expert Conference are being published. Like in any reviewed conference proceedings, the students went through a whole review process, acting on their colleagues as blind reviewers. Not an easy task beside all the other duties in the tight curriculum. But as the organizer it is a pleasure to see the enthusiasm and curiosity, the time spend for investigations, writing and the presentation preparation by the students. This year, two students (Harmen Punte and Machiel Overmars) even created a video presentation explaining the Coandă effect*. This and no less than seventeen other interesting topics can be found in this proceedings.

Enjoy reading this proceedings and stay curious!

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*: Available at YouTube, see https://www.youtube.com/watch?v=oNLfg2v7ySg&feature=youtu.be

CONTENTS

Coandă effect

H.J. Punte, M.A. Overmars

Keywords: *H. Coandă, Coandă effect, V/STOL, ACHEON, NOTAR.*

1 Introduction

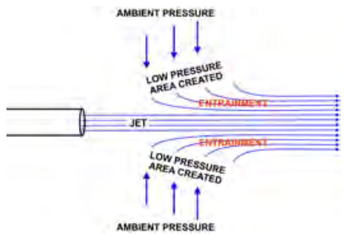
The Coandă effect is a phenomenon used in several applications such as health care, robotics and aeronautics [1, 2]. However, this effect is often interpreted incorrectly. The aim of this paper is to explain the Coandă effect and elaborate on the working principle behind it. In section 3 the common definition is given and additions are made to replenish it. It is explained when the Coandă effect is applicable for airfoils and finally, in section 4, some applications in modern-day aeronautics are presented, for example V/STOL, ACHEON and NOTAR.

2 Background

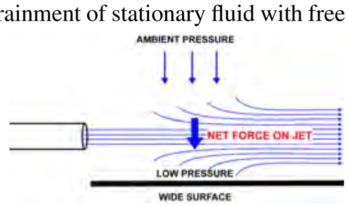
Henri Coandă (1886-1972) was an inventor and engineer born in Romania. In 1910 Coandă build arguably the first jet plane, the Coandă-1910 [3]. However, this plane caught fire and Coandă noticed that the flames followed the surface of the fuselage [3, 4]. Thomas Young also noticed this phenomenon with a candle in 1800 [5, 6]. But the crash of the plane caused Coandă to do extensive research which resulted in several patents and getting the Coandă effect officially recognized by Theodore von Kármán in 1934 [7, 8, 9].

3 Description

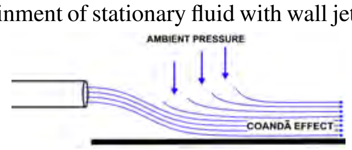
The most common explanation for the Coandă effect is the tendency of a fluid jet to attach to an adjoining surface [4, 6, 10, 11, 12]. Yet, certain additions should be made to this explanation to make it complete. First of all, the Coandă effect will still occur when the surface is removed. A free jet in a stationary fluid, so without a surface in the vicinity, drags along some of that stationary fluid. This results in an increase of the fluid's velocity around it. Since momentum is conserved, the jet will slow down as it moves through the stationary fluid. The surrounding particles that are dragged along with the jet will result in a decrease in pressure around the jet. This creates an inward suction of the particles nearby [4, 6, 10, 11, 12]. More and more particles are dragged along as the fluid moves through the stationary fluid, which is called entrainment, see Figure 1a. The suction of surrounding fluid along with the jet causes the Coandă effect [11]. In case the jet is in the vicinity of a surface, a wall jet, this entrainment is restricted. As a consequence, the fall in pressure cannot be compensated with surrounding particles, causing the jet to deflect towards the surface and eventually attach to it, see Figure 1b and Figure 1c [6, 10, 12]. The second addition to the earlier mentioned general explanation is the shape of the surface, which can either be straight or convex [4, 11].



(a) Entrainment of stationary fluid with free jet [13].



(b) Entrainment of stationary fluid with wall jet [14].



(c) Jet flow profile as a result of Coandă effect [15].

Fig. 1 : Diagrams illustrating the Coandă effect

However, it is of great importance not to confuse the Coandă effect with the flow following a curved surface on a regular aircraft airfoil. The air around an airfoil is all moving, so there is no stagnant fluid in which a jet mixes. Hence, there is no suction of fluid replacing the entrained fluid [11, 16].
Thus, the Coandă effect rarely occurs naturally on a wing, but can be produced when a part of the exhaust gasses is deflected over the wing, which could result in an increase of the lift by a factor of 3 [16]. These

fast exhaust gasses create entrainment of the air causing a regional pressure drop and delaying separation [17]. This could be applied in the future on controlled surfaces of an aircraft. These surfaces are mainly dimensionalized for high-lift situations and when the lift can be increased significantly in these situations, these surfaces can be reduced in size while still being able to deliver the required lift in normal operations.

4 Applications

In the aeronautic field, new technologies should be designed to meet the changing demands in terms of reducing environmental impact and cost while still increasing the overall performance [18, 19]. As described in section 3, the Coandă effect can be utilized for increasing the lift of an aircraft, but can be used in more applications. Applications discussed in this paper are: the V/STOL aircraft, the ACHEON nozzle and the NOTAR system.

4.1 V/STOL

Vertical and/or Short-Take-Off and Landing (V/STOL) aircraft can introduce new and greener technologies in aeronautics and can be very useful in specific mission profiles. However, helicopters are limited in the maximum horizontal speed and airplanes with V/STOL have problems with the large weight, as a result of the mechanisms needed for tilting the engines [18]. Besides, V/STOL has been introduced in the field of UAVs, being dependent on the amount of energy on board. Due to the limitations for these specific classes, a new class of V/STOL was introduced using the Coandă Effect. The vertical and horizontal thrust in these Coandă V/STOL aircraft is generated by a central rotor fan to create a controlled airflow that is vented over the fuselage. Consequently, low pressure around the fuselage will occur and the aircraft is lifted [20, 21]. These aircraft can produce maneuverability forces and lift more effective than the earlier described V/STOL aircraft [21].

4.2 ACHEON

The Aerial Coandă High Efficiency Orienting-jet Nozzle (ACHEON) project investigates a new propulsive system for aircraft with the main advantage being able to deflect the trust only by fluid-dynamic effects without any part in movement [18, 19, 22]. This trust vectoring is largely realized by making use of the Coandă effect. The ACHEON concept is based on two technologies: the HOMER (High-speed Orienting Momentum with Enhanced Reversibility) nozzle and the PEACE (Plasma Enhanced Actuator for Coandă Effect) concept. The HOMER nozzle is a thrust vectoring propulsive nozzle producing a controllable deflection of a synthetic jet and the PEACE concept extends the angle of operation of the nozzle. The integration of a HOMER nozzle with the PEACE concept can lead to a system that is applicable in new aerial vehicles and creating new possibilities with directionally controllable fluid jets focusing on more sustainable and all-electric propulsion systems [18, 23].

The original patented nozzle architecture (1), shown in Figure 2, is capable of mixing two primitive fluid jets (2) and (2’) and subsequently creating an adjustable synthetic jet (7), by changing the mass flow of both jets independently.

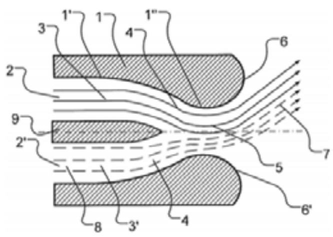


Fig. 2 : ACHEON configuration defined by the patent [24].

The study performed by Trancossi et al. [19], demonstrated the benefits of an ACHEON based civil aircraft and ensuring better performance. However, this is still a relatively new technology and should be further investigated before being implemented in commercial civil aircraft.

4.3 NOTAR system

The Coandă effect is also applied in helicopters without tail rotors. NOTAR (NO TAil Rotor), developed by McDonnell Douglas Helicopter Systems, is a system which replaces the tail rotor and thereby eliminating its mechanical disadvantage, such as noise and vibrations while also increasing safety [25].

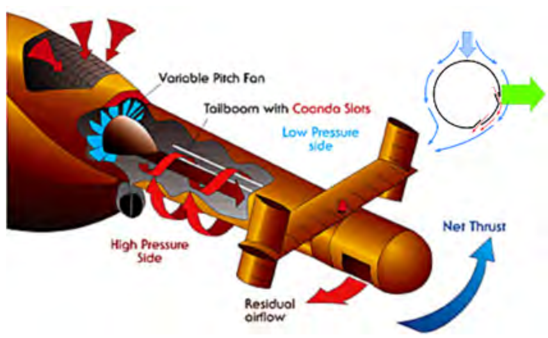


Fig. 3 : Configuration of a NOTAR tailboom [25, 26].

NOTAR, as shown in Figure 3, uses a fan inside the tail boom forcing an airflow to exit through two longitudinal slots, creating a boundary layer flow and utilizing the Coandă effect. This effect changes the direction of the airflow around the tail boom, creating an anti-torque to the torque effect impaired by the main rotor. However, directional control is still accomplished by a rotating direct jet thruster and the thrust created by the Coandă effect acts mainly as a stabilizer [27].

5 Conclusion

The Coandă effect is a phenomenon which can be used in a widespread of applications. It is commonly known for creating extra lift over the airfoils of airplanes. Besides this application, the effect can also have other uses within aeronautics. Such as: V/STOL, where the Coandă effect is used in a new type of aircraft to generate lift in an effective way; ACHEON, which is a new propulsion system where the direction of the thrust can be regulated creating possibilities for electric propulsion systems in aerial vehicles and the NOTAR system, a system in helicopters where the tail rotor has become redundant while increasing the performance. In conclusion, the Coandă effect applied within aeronautics gives rise to better aircraft performances and new opportunities for more sustainable aircraft.

REFERENCES

[1] Qudaisat I. Coanda effect as an explanation for unequal ventilation of the lungs in an intubated patient? *British Journal of Anaesthesia*, vol. 100, no. 6, pp. 859–860, 2008.

[2] Natarajan E and Onubogu N O. Application of Coanda Effect in Robots – A Review. Zhang T, editor, *Mechanical Engineering and Technology*, Advances in Intelligent and Soft Computing, pp. 411–418. Springer Berlin Heidelberg, 2012.

[3] Coanda effect.
URL http://www.edubilla.com/invention/coanda-effect/

[4] Ahmed N A. *Coanda Effect: Flow Phenomenon and Applications*. CRC Press, 2019. Google-Books-ID: XWytD-wAAQBAJ.

[5] Cantor G N. Thomas Young's Lectures at the Royal Institution. *Notes and Records of the Royal Society of London*, vol. 25, no. 1, pp. 87–112, 1970.

[6] Ltd S T. Coanda Effect.
URL http://www.thermofluids.co.uk/effect.php

[7] US Patent #2,052,869, 1936.

[8] Coanda H. Procédé et dipositif pour faire dévier une veine fluide pénétrant dans un autre fluide.

[9] Cîrciu I, Prisacariu V and Constantinescu C. Gas Turbine Mixed Jet Flows Based on the Coandă effect. 2015.

[10] Amit Bardia, Rabya Saraf, Andrew Maslow, Kamal Khabbaz, Feroze Mahmood. The Coanda Effect, 2016.

[11] Aaron K. What are the differences between Bernoulli's Principle and the Coanda effect when we apply them on aircraft wings? - Quora.com, 2017.

[12] Reba I. Applications of the Coanda Effect. *Scientific American*, vol. 214, no. 6, pp. 84–93, 1966.

[13] Cruithne9. Coanda Effect 1, 2016.
URL https://commons.wikimedia.org/wiki/File:Coanda_effect_1.jpg

[14] Cruithne9. Coanda Effect 2, 2016.
URL https://commons.wikimedia.org/wiki/File:Coanda_effect_2.jpg

[15] Cruithne9. Coanda Effect 3, 2016.
URL https://commons.wikimedia.org/wiki/File:Coanda_effect_3.jpg

[16] ARMD. Foam Wing (ARMD Resources - Museum in a Box).

[17] Hong S J and Lee S H. A Study on the Flow Characteristics around a Coanda Control Surface. *Journal of Ship and Ocean Technology*, vol. 8, no. 2, pp. 13–19, 2004.

[18] Páscoa J C, Dumas A, Trancossi M, Stewart P and Vucinic D. A review of thrust-vectoring in support of a V/STOL non-moving mechanical propulsion system. *Central European Journal of Engineering*, vol. 3, no. 3, pp. 374–388, 2013.

[19] Trancossi M, Madonia M, Dumas A, Angeli D, Bingham C, Das S S, Grimaccia F, Marques J P, Porreca E, Smith T, Stewart P, Subhash M, Sunol A and Vucinic D. A new aircraft architecture based on the ACHEON Coanda effect nozzle: flight model and energy evaluation. *European Transport Research Review*, vol. 8, no. 2, p. 11, 2016.

[20] Petrolo M, Carrera E, D'Ottavio M, de Visser C, Patek Z and Janda Z. On the development of the Anuloid, a disk-shaped VTOL aircraft for urban areas. *Advances in aircraft and spacecraft science*, vol. 1, no. 3, pp. 353–378, 2014.

[21] Nedelcuţ F. Towards a New Class of Aerial Vehicles Using the Coanda Effect. p. 8.

[22] Generalities | Acheon Project.
URL http://acheon.eu/project/

[23] Inside ACHEON | Acheon Project.
URL http://acheon.eu/acheon-concept/

[24] Baffigi F, Dumas A, Giuliani I, Madonia M and Trancossi M. Nozzle Capable of Deviating a Synthetic Jet in a Dynamic and Controllable Manner with No Moving Mechanical Parts and a Control System Thereof., 2013.
URL https://patentscope.wipo.int/search/en/detail.jsf?docId=WO2013005132

[25] NOTAR® Technology - MD Helicopters.
URL https://www.mdhelicopters.com/notar.html

[26] S V. NOTAR (NO TAil Rotor) System, 2007.
URL https://commons.wikimedia.org/w/index.php?curid=2746196

[27] Cîrciu I and Boşcoianu M. An analysis of the efficiency of Coanda - NOTAR anti-torque systems for small helicopters, 2010.

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Forward-swept Wings

Fredrik Lundvall, William Yachnin, Julien Perroud, Karl-David Läpple

Keywords: *forward-swept wing, FSW, aerodynamics, instability, Grumman X-29.*

Nomenclature

Designation	Denotation
ASW	Aft-swept wing
FSW	Forward-swept wing
AOA	Angle of attack
DFBW	Digital fly-by-wire
C_G	Aircraft center of gravity

1 Introduction

This article was written for an expert conference at Linköpings Universitet. In this short article the concept of forward-swept wings will be explained and some of its benefits and shortcomings presented.

2 General Characteristics

2.1 Packaging

A *FSW* has the wing-fuselage juncture much further towards the rear of the air-craft which could improve flexibility with the internal packaging [1]. This was the idea behind the Junkers Ju 287 which was able to accommodate a bigger bomb bay in its fuselage as it was not disturbed by wing or gear structures which were located further back [2].

2.2 Aeroelasticity

A reason why forward-swept wings are not seen very often nowadays is their aeroelastic behavior. During climb when the free-stream hits the wing tips they twist up. This leads to even more lift which promotes the described effect even more [1]. To be able to resist the high aerodynamic forces an *FSW* needs to be very rigid. This can be obtained through using composite structures. Today it is even possible to design the aeroelastic behavior of a wing which is called *aeroelastic tailoring* [3].

FWS have higher loads during high AoA compared to *ASW*. This is because at high AoA it forces the wing to twist up and hence increase the normal force of the wing, therefore the structure needs to be reinforced. An *ASW* will have the opposite effect and decrease the forces working on the wing. [4]

3 Inward Spanwise Flow & Stall Characteristics

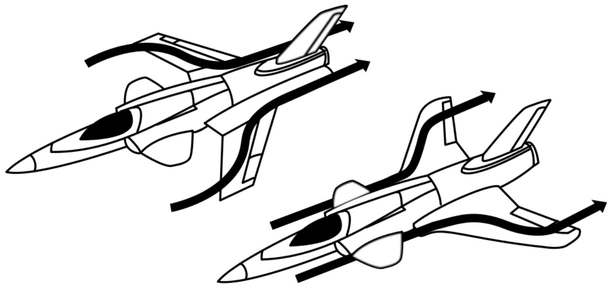

Fig. 1 Comparison of airflow of an FSW and ASW.[5]

An important aerodynamic property of an *FSW* is its stall characteristics. Wing-sweep in either direction retards the effect of wave drag by reducing the effective thickness-to-chord-ratio [6]. Both *ASW* and *FSW* divide the free flow into chordwise flow and spanwise flow. An *ASW* has its spanwise velocity component directed towards the wing tip, in turn creating a thicker boundary layer at the tip compared to the wing-root, which, could lead to a tip-stall and loss of aileron-control at high *AoA*. In contrast, spanwise flow over an *FSW* is directed toward the wing-root resulting in a root-stall, thus leading to more maneuverability at early onsets of stall compared to an *ASW* [4]. A clear visualisation of the oncoming airflow for both ASW and FSW can be seen in figure 1.

A result of *FSW* design is a reduction in drag (due to weaker wing tip vortices) and higher lift which allows a design with smaller wings. The higher lift can be explained by the fact that there is a better airflow at the wing root which in general has a larger chord and can therefore produce more lift than the wing tips.

Moreover, the locations of the stall (tip-stall for an *ASW* and root-stall for a *FSW*) can cause further aerodynamic issues. Since the C_G is in front of the tip (*ASW*) or root (*FSW*) a stall will create a moment which pitches the aircraft up, essentially progressing the stall even further [4]. The result is a more pronounced pitch-up effect in a *FSW* than an *ASW* due to the loss of lift at the root.

4 Instability

Most jet fighters do not have static stability which is the ability to come back to level flight position automatically. The goal of a jet fighter is to be highly maneuverable and instability can contribute to this. If an axis is unstable, only a little amount of energy is needed to initiate a big response/ maneuver. However, more energy is needed to stop or reverse the deviating motion. Instability is a question of balance between being able to make rapid extreme maneuvers and the ability to keep control of the aircraft [7]. Therefore, a lot of very quick adjustments must continuously be made by the aircraft to keep control.

4.1 Pitch Instability

Generally with *FSW*, the center of pressure is ahead of the C_G due to wing root being further back on the fuselage. This usually demands a canard configuration because the empennage would have to generate huge downward forces to compensate for the nose-down moment. Since both surfaces are lift surfaces, this encourages further instability [4].

Another property that promotes the pitch instability of *FSW* is the aeroelasticity of the wing especially at high AoA which has been explained in section 2.2

4.2 Yaw Instability

FSW designs are very unstable when yawing (turning around the horizontal axis). When the plane yaws in one direction the inner wing retreats while the outer advances. While retreating, the inner wings sweep angle towards the free-stream decreases which results in rising drag. The exact opposite happens on the outer wing which enforces the yaw instability. An *ASW* configuration in contrast will stabilize itself during yawing. This is because the advancing and the retreating wing are just swapped compared to the *FSW* which leads to aerodynamic forces that push the plane back into stable flight [8].

4.3 Case Study: Grumman X-29

The Grumman X-29 is probably the most famous example of a supersonic *FSW* aircraft. There were especially two factors that made the development of the X-29 possible in the early 1980s: *DFBW* and composite structures [7, p. 5].

The composite structures have been needed to build a wing that is rigid enough to withstand the high aerodynamic forces and have the desired aeroelastic behavior. Especially when flying at high *AoA* the aerodynamic forces on the tips of the wings are very high.

On the other hand the *DFBW* ensured that the plane was flyable despite its extremely unstable behavior in pitch and yaw. The X-29 had therefore a redundant system of three digital and three analog flight computers which made the probability of a total computer failure as probable as the failure of a mechanical component on a regular airplane [7, p. 30].

The main advantages of this concept were the capability to fly at high *AoA* (approx. up to 60 °) while maintaining good maneuverability and controllability. In addition to that the design of the X-29 which combined canards with a *FSW* reduced drag and as a result of this also fuel consumption [7, p. 18].

Fig. 2 The experimental aircraft Grumman X-29 and it's forward swept wings.[3]

5 Discussion

The concept with *FSW* is an interesting one and has its advantages and disadvantages. Nowadays, we should have the technological means to solve the problems that were encountered with *FSW*. As seen, *FSW* offers advantages in high maneuverability and good stall characteristics. However, *FSW* are not the only approach to make a plane more manoeuvrable. Thrust vectoring is used a lot in fifth generation fighters and is a proven concept for example. This does not mean that we will not see this technology in future concepts, it will depend on what the requirements of the industry will be, like stealth (radar cross section depends a lot on the geometry of the aircraft) or ability to fly unmanned missions.

REFERENCES

[1] Anderson, John David, Jr. *Introduction to flight*. 8th ed. Boston: McGraw-Hill, 2016.

[2] Flying Review International Vol 20 , Number 4: 43–45 Jan 1965 (2:nd hand source). Swept-forward bomber. URL `https://en.wikipedia.org/wiki/Junkers_Ju_287`

[3] NASA. X-29 in banked flight. URL `https://www.nasa.gov/centers/armstrong/news/FactSheets/FS-008-DFRC.html`

[4] Bertin, John J Cummings, Russell M. *Aerodynamics for Engineers*. 8th ed. Pearson Education Limited, 2014.

[5] NASA. Quest for performance: The evolution of modern aircraft:wings and configurations for high-speed flight. URL `https://history.nasa.gov/SP-468/ch10-4.htm`

[6] Staack, I. *2019-09-18*. Lecture 8: Aircraft Performance, Linköping University.

[7] Johnsen F A. *Sweeping Forward*. National Aeronautics and Space Administration, 2013.

[8] J, Miller (2:nd hand source). forward-swept wings. URL `https://en.wikipedia.org/wiki/Forward-swept_wing`

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Albatross Flight: Dynamic Soaring

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Florent Bel, Yvan Pradier

Keywords: *Albatross, Bird flight, Soaring flight, Dynamic soaring, Airspeed, Biomimetics*

ABSTRACT

This article presents the flight of an albatross, and more precisely the survey of the dynamic soaring. It is the flying technique used by the bird to save energy.

1 Introduction

With its 10 kilograms and its 3-meter-wide wings, the wandering albatross can spend weeks at sea without ever returning to land (Fig. 1). It allows the bird to fly for long distances without using a lot of energy and moving its wings, it is an unflapping flight. The albatross can fly in each direction, even against the wind easily. It operates in the shear wind field, an area of 10 to 20 meters above the surface of the ocean where the wind speed changes dramatically. Close to the water, the wind speed is dramatically reduced by friction.

Fig. 1 Albatross in flight [5]

2 Dynamic soaring

The flight technique used by the bird is known as dynamic soaring which allows it to extract energy from the shear wind [2]. Albatross use the wind lift as a propulsive force. This propulsive energy is just enough to overcome the winds drag. To improve the notion of dynamic soaring, scientists are using GPS tracking to analyse albatross flight and wind speed data [1]. The albatross flight cycle can be separated in four phases (Fig. 2).

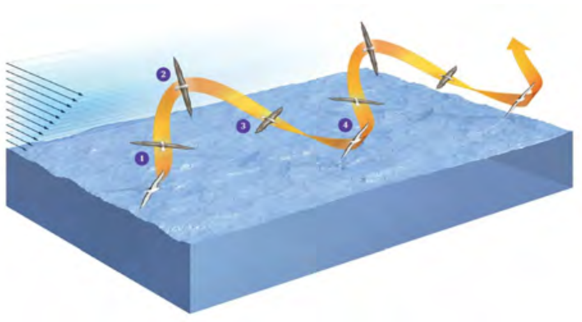

Fig. 2 The Albatross flight cycle [2]

The mechanism is simple, it is based on a cycle that it repeats again and again to gain energy and travel laterally to the wind direction. Each time it does the cycle, it starts with more ground speed and airspeed. The albatross can use this technique because a phenomenon appears close to relief and close to the water surface. Near the surface, there are two air masses with different velocities called wind gradient zones. (1) The first phase is the windward climb. The bird goes through the boundary between the two layers to gain energy. Facing the wind, the albatross gains a bit of altitude. (2) The second phase begins at peak altitude, after crossing the boundary between the two air masses. The bird describes a curve from upwind to downwind, it turns. (3) Then, the third phase is descending in wind direction, gaining speed and crossing once again the two gradient zones. (4) Finally, the last phase of the albatross flight cycle is close to the water. The albatross turns in the reverse direction to face the wind and start the cycle again.

When it is performing dynamic soaring, the albatross does a series of 180° turns so its path looks like a S-shaped maneuver. Moreover, the albatross can use these techniques because it has a specific shape and the ability to lock its wings when it is soaring in order to avoid muscle tension. This technique is used by gliders, but they fly in circles and not two rotations of 180° in opposite directions. Wind gradients are more important when the glider performs it than when the albatross turns close to the surface.

A research made by Philip L. Richardson, Ewan D. Wakefield and Richard A. Philips on the subject "Flight speed and performance of the wandering albatross with respect to wind" has provided interesting results [1]. During this research, the Leeway model, the airspeed model, the ground speed model and other relations have been found and defined. These seabirds regulate their velocities in relation to wind speed and relative wind direction. When the wind blows below 7 m/s, the optimal range speed of albatrosses is much higher when they fly upwind than for tailwind flights.

3 Biomimetics

Biomimetics is used by designers to help in solving human problems by creating nature-inspired solutions. In addition to this mechanism, albatrosses have the ability to lock their wings at the shoulder for long-distances soaring and unlock them when turbulence or gusts arise or when they need to maneuver. This trick allows the bird to reduce the drag and the effects of turbulence drastically. In that way, albatrosses can fly many kilometres without spending much energy [3]. It has inspired airlines companies such as Airbus which have the ambition to develop new wings with movable tips called "freely-flapping wing-tips". Currently as a model, the AlbatrossOne project would permit to cut down the drag forces, and thereby, induce lower loads transmission in the fuselage. The wing would not need to be heavily strengthened anymore. Therefore, it would be possible to decrease the aircraft weight and reach better fuel efficiencies.

Fig. 3 The Albatross UAV [4]

Albatross shape and dynamic soaring are not only used to design wings of different airplanes. A drone completely inspired from the albatross flight has been designed and commercialized since 2015: The Albatross UAV by Applied Aeronautics (Fig. 3). With its three-meter-wings and its ten-kilogram-MTOW, the electrical drone looks like the seabird. Every component is designed in order to reduce the drag and improve the efficiency of the cruise. The drone can take-off, fly and land autonomously for 4 hours. The Biomimetics is very present in this innovation.

4 Conclusion

To conclude, the dynamic soaring could be an interesting technique for airplane because it uses the wind energy to rise in the air. Whereas, it can not be used by civil or military airplane because the travel time would be too long.

REFERENCES

[1] Philip L. Richardson, Ewan D. Wakefield and Richard A. Philips. *Flight speed and performance of the wandering albatross with respect to wind*. In: Movement Ecology 6 (2018), Article 3.
ISSN: 2051-3933. DOI: 10.1186/s40462-018-0121-9.
eprint: https://rdcu.be/bSE9Y.
URL: `https://movementecologyjournal.biomedcentral.com/articles/10.1186/s40462-018-0121-9`

[2] Johannes Traugott, Anna Nesterova and Gottfried Sachs. *The Nearly Effortless Flight of the Albatross.*. IEEE Spectrum. [Online; accessed 2013-06-28]. 2013.
URL: `https://spectrum.ieee.org/aerospace/robotic-exploration/the-nearly-effortless-flight-of-the-albatross`

[3] Airbus Website, How the albatross is inspiring next generation of aircraft wings.,
`https://www.airbus.com/newsroom/press-releases/en/2019/06/how-the-albatross-is-inspiring-next-generation-of-aircraft-wings.html`

[4] Kicstarter, The Albatross UAV
`https://www.kickstarter.com/projects/164361630/the-albatross-uav?lang=fr`

[5] Pixabay, Albatross in flight
`https://pixabay.com/fr/photos/albatros-de-laysan-oiseaux-de-mer-848343/`

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Lift generation of forward flying helicopters/rotors

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Keywords: *Helicopters, Aerodynamics, Lift, Rotors, Forward, Flight.*

1 Introduction

This paper gives a fundamental introduction to the lift generation in forward flying helicopters and rotors. The paper proceeds by introducing the concept of basic lift generation in helicopters and the role of blade orientation in lift generation. Then a brief description about a forward flight of helicopters with comparison to different rotor configurations are presented to understand the lift generation influenced by the different rotor configurations. Finally the paper discusses the complexity involved in the forward flight and possibly discuss some futuristic ideas to overcome these convolutions in lift generation of forward flying helicopters.

2 Basic Aerodynamic forces

As soon as the helicopter lifts off the ground, the interaction of the geometry and velocity of the aircraft with the flow field generates four aerodynamic forces: lift, weight, drag and thrust. In helicopters, the lift force is generated due to the sudden change in direction of the fluid flow caused by the aircraft's rotor blade. The majority of this lift force is generated due to the result of decline in pressure above the rotor blade, rather than the high pressure developed at the lower surface of blade.

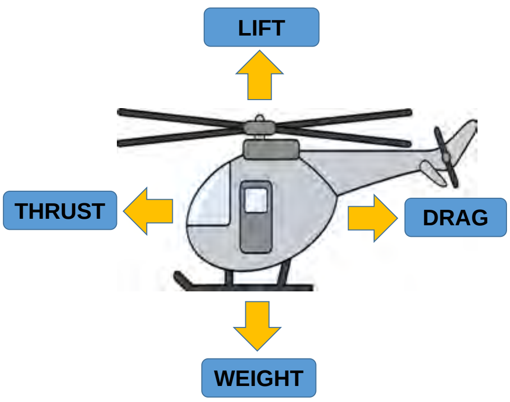

Fig. 1 *Aerodynamic forces*

The weight of the helicopter on the other hand is a fixed downward force that pulls the aircraft towards the ground due to the force of gravity. Thrust is a forward force produced by the propeller or rotor system. The tail rotor also generates a small portion of thrust, used to control the helicopter's yaw. Drag, on the other hand is a resistance force to the helicopter's movement through the air and caused mainly by the interference of aircraft components C_{Do} and lift generation C_{Di} (see Figure 1). [1]

3 Forward flight

For the helicopter to be in forward flight the main rotor must be tilted, which will induce a tilt in the coning axis backward and angled to the advancing side of the rotor. With the increasing coning angle, there will be an increment in the flapping angle. With higher flapping motions, there will be an increase in the backward tilt of the cone axis, which will boost the longitudinal force and thereby restricting the forward flight of the helicopter. So, the flapping motion is restricted by the centrifugal forces and flapping compensator. [2]

3.1 Airflow in forward flight

In forward flight, air flows opposite the aircraft's flightpath, so the velocity of the airflow is equal to the velocity of the helicopter in forward flight. However, relative velocity at each section of a blade will vary in accordance with different positions in a rotor disk. [3]

Therefore, the airflow meeting each blade varies continuously as the blade rotates. The highest velocity of airflow occurs over the advancing side of the helicopter, because the velocity of the air meeting this blade equals rotational velocity of the blade plus wind velocity resulting from forward airspeed, so the lowest airflow velocity is in the retarding side (see Figure 2). This is known as dissymmetry of lift, so if this dissymmetry were not controlled, the helicopter would be uncontrollable when there was wind. So the question is: How can avoid this dissymmetry?

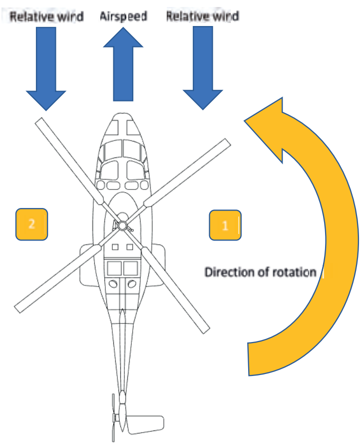

Fig. 2 *Airflow forward flight.*

The aerodynamic forces can be improved by changing the angle of attack of blades called feathering, which can be done in collective or cyclic manner. Dissymmetry of lift in the advancing and retarding side of rotor disk is compensated by coupling of cyclic feathering and flapping mechanism of the blade. [4]

In addition when the blade flaps upward (caused by the higher speed on the right side of the helicopter), the angle between the chord line and the resultant relative wind decreases. This decreases the AOA, which reduces the amount of lift produced by the blade. In this way, the helicopter is able to make an advance flight where the lift is the same throughout the helicopter.

3.2 Blade orientation in forward flight

Helicopter's blades are basically wings, so they have to change its pitch in order to vary its angle of attack and, then, generating forwards motion. There are different kinds of configurations in order to achieve these phenomena: by tilting the rotor hub or by tilting each blade. Both configurations have the same cons: (see Figure 3)

When the AOA of a blade increases, lift also increases and revolution of the rotor decreases. Thus, for a forward flight, the AOA on the advancing blades must decrease and the AOA on the retreating blades must increase.

Because of changing AOA, every blade generates different angular velocities which contributes to variation in the rotor rpm, and it should be compensated. A great solution is to generate a proportional alternation in power so that the rotor rpm keeps constant. Nowadays, a throttle control or a governor is implementing in helicopters so they can alternate its power automatically. [5]

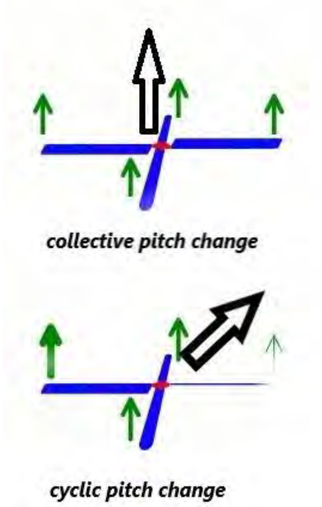

Fig. 3 *Collective and cyclic pitch.*

4 Types of rotors configuration in forward flight

There are three different configurations by which helicopters can generate thrust: semirigid, rigid and fully articulate rotor system (see Figure 4).

The semirigid configuration is capable of flying forward with a two blades mounted rigidly to the main rotor since it is free to tilt and a feathering hinge provides blades to change its pitch angle. Then, the rigid configuration is structurally complex since blades are rigidly attached to the main rotor hub. Thus, loads must be absorbed by bending as there are no hinges to do it, but the blade bending also provides the motion of the helicopter. On the other hand, this configuration is easier to design.

Finally, the fully articulate configuration lets each blade an almost free motion since it can lead, flap and feather self-reliant. On this configuration, these three degrees of freedom of each blade provides the pitch, roll and upward motion. But, this configuration is quite more complex to design than the others since blades must change constantly its pitch, yaw and roll angles while rotating in order to generate motion.[6]

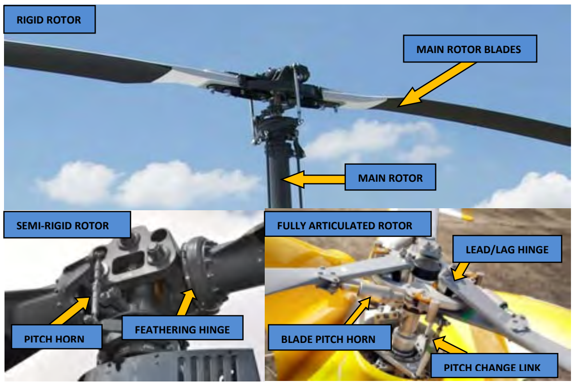

Fig. 4 *Types of rotors configuration.*

5 Conclusions

One of the major complexities in forward flight is the dissymmetry of lift, where the lift generated on the opposite sides of the rotor disc are uneven. This phenomenon of dissymmetry causes retreating blade stall, where the retreating blade experiences less airflow than expected to maintain lift. In modern helicopters to reduce the dissymmetry of lift, the mounting of rotor blades is oriented in such a way that in a rotor cycle, the angle of attack varies with the position. Even, the above-mentioned techniques of “blade flapping” and “cyclic feathering can be used to counter the dissymmetry effects.

Finally, in order to conclude this report, a forward sight in history is going to be done so that some ideas of what is coming up are projected. The futuristic innovations in helicopters focuses to infuse the ideas of lift and forward thrust. Some important research ideas include vertical take-off, hovering and attainment of fast cruise speeds by propellers in helicopters. To achieve these ideologies, the design characteristics must undergo some innovative modifications like addition of a fixed wing, box wings, larger diameter of rotors, lateral propellers, elimination of the tail rotor etc. Another major innovation is the morphing rotor blade twist geometries, which aims at the lift distribution variation along the spanwise direction without affecting the pitching moment. All these innovative ideologies signifies the vast scope for further research in lift generation strategies in forward flying helicopters/rotors.

REFERENCES

[1] Leishman J G. *Principles of helicopter aerodynamics*. Cambridge University Press, 2006.

[2] D B. *Helicopter Aerodynamics*. National Aeronautics and Space Administration, 1972.

[3] Ángel Cuerva Jose Luis Espino Óscar López Jose Meseguer Álvaro Sanz. *Teoría de los Helicópteros*. Ibergarceta Publicaciones S.L, 2012.

[4] Johnson W. *Helicopter Theory*. Dover Publications, INC, 1980.

[5] Rotaru C and Todorov M. *Helicopter Flight Physics*. 2017.

[6] Administration F A. *Helicopter Flying Handbook*. U.S Department of Transportation, 2012.

Concorde 2.0: On-going Supersonic Projects

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Keywords: *supersonic, projects, future.*

ABSTRACT

This report serves to inform about, which role supersonic projects will play in the future of aviation.
Therefore, two recent projects, which shall bring back the former euphoria for supersonic transportation get shown.
But first of all the *Concorde*, which was the only commercial used civil supersonic aircraft gets analyzed to work out, why supersonic transportation got forgotten.
Having a look in the past to see, what problems the *Concorde* faced, makes it possible to evaluate if the projects for the future are doing better.

1 The Concorde

The *Concorde* was mainly used to make traveling between London and New York, as well as between Paris and New York faster. Powered by four turbojet engines, produced by Rolls-Royce/SNECMA the *Concorde* makes use of a delta-wing design. This design allows to fly at a high angle of attack, which makes the airplane very agile and better in terms of maneuverability than many military airplanes. [1, 2]

1.1 High technology

The aircraft is popular for its pioneering technology, which is common now, but at the time represented a world first. This includes a computer controlled air intake system, for instance. It is needed because the air would be too fast for the engines to intake, when the airplane is at supersonic speeds. To avoid major damage on the engines the *Concorde* is able to change the geometric of the air inlet to slow down the air stream. Because of putting air flaps into a certain configuration to form a nozzle, a supersonic shock wave gets produced which slows down the air. In addition, besides the *Concorde*, only a few airplanes were controlled by the fly-by-wire technology at this time, what means that the commands by the pilot go to a computer first and then to the actuators, not directly to them. [1]
This led to many advantages like saving a lot of weight and making the plane safer. [3]
If the airplane was such a milestone in aircraft engineering, it makes sense to search somewhere else for the reason why it failed.

1.2 Different problems

In many people's opinion the retirement was caused by the fatal accident in 2000, but in fact the airlines thought about stopping the use of the *Concorde* earlier. [2]
The decisive reason was that many expensive hardware updates were necessary to modernize the aircraft and the airlines decided, that this is not worth it, because of the main problems which the *Concorde* had. [1]
The *Concorde* has the two major problems of being a very noisy aircraft with a high fuel consumption. Especially in comparison to the Boeing 747, the disadvantages get clear. With the same fuel consumption the *Concorde* was only able to carry 100 passengers whereas the Boeing has 440 seats. [4, 2]
In table 1, you can see that the *Concorde* has a range of around 3500 nautical miles, while the Boeing 747 had a range of 5600 nautical miles [5, 4]
Regarding to the noise emissions, it can be said that these are quite high in comparison to other aircraft. Especially in the take-off phase, because here the *Concorde* makes use of an afterburner. [5, 1]
The *Concorde* with a maximum take-off weight (MTOW) of 185 tons is approximately 350 EPNdB loud, whereas a Boeing 747 with a MTOW of around 500 tons just emits a noise of 290 EPNdb. [5]

2 Presentation of two on-going projects

After this brief presentation of the *Concorde*, two on-going supersonic projects, that will be develop in the near future (five to ten years), will be analysed. Knowing the reason why the *Concorde* failed to thrive is going to be useful to understand how these new projects intend to deal with the *Concorde*'s problems.

One of the first projects is called Boom (Fig. 1).

Fig. 1 Image of Boom, Overture, extracted from Boom Website [6]

Boom is a Northern American company developing the next supersonic commercial airplane, planned to fly at a top speed of Mach 2.2, faster than any possible competitor (table 1), and promising ticket prices comparable to a seat in business class. It can change the transportation the way we know it. Boom is developing their first flight prototype, a 1/3 scale 2-seat Jet engine named XB-1, with first flights taking place in 2020. Their first passenger supersonic plane, named Overture (Fig.1) is planned to arrive in the mid-20s, after enduring some thorough examination and certification, all optimized through their XB-1 test model.

The other on-going project we chose to discuss, is called Spike (Fig. 2). This plane is developed to be a business jet able to carry about twenty passengers at Mach 1.6. It is powered with two engines. Its design, as seen in figure 2, has been studied to minimize the drag.

Fig. 2 Image of Spike S-512 extracted from Spike Website [7]

2.1 Boom

2.1.1 Materials

The main difference between the *Concorde* and Boom is the technology: from computation power, aerodynamics, new materials, engine improvements. Boom's SST will be mainly built from a material which *Concord* engineers could only make smaller parts: carbon fiber, the main material used in the fuselage and wings and some others structural parts. This material allows a reduced weight which is a big factor to take in consideration when developing a plane for supersonic flights. It will have Delta wings (as Spike will) due to their better characteristics at supersonic speed and a smaller size, which was one of the *Concorde*'s disadvantages for its high noise or fuel consumption.

2.1.2 Engines

The prototype XB-1 will need afterburners to achieve mach 2.2. However, due to engine improvements in the last few years, Boom will not have the need to use afterburners for Overture, one of the main cause of noise pollution and a setback towards approval to fly overland and get to a country further from the sea, which was one of the *Concorde*'s problems and limited it to transatlantic flights. It will have 3x non-afterburning engines, a medium-bypass turbofan and proprietary variable geometry intake and exhaust making it more silent, and with a fuel per seat comparable to subsonic high range planes. As seen in table 1, Boom is a optimized aircraft for the amount of passengers it can hold, it has the smaller aspect ratio of the three models analysed which contributes to a reduced sonic boom. However, it is longer than Spike in order to carry more payloads.

Furthermore, Boom is developing a sustainable supersonic commercial traveling, taking in consideration the UN's existing goal of carbon-neutral growth in aviation by conducting several alternative-fuel tests, and they plan to achieve environmentally and socially sustainable travel.

2.2 Spike

2.2.1 Noise

As seen earlier, one of the problem of supersonic flight was the noise, the *Concorde* was not allowed to fly at supersonic speed above land. That is why, one of the purpose of this project is to reduce the noise in order to fly overland and be able to reach more inlands destinations. Thanks to its design, Spike S-512 (Fig. 2) will be able to have a quiet supersonic noise at his cruising speed of Mach 1.6. This speed is lower than the *Concorde* in order to improve the L/D ratio of the plane. When the speed is higher than Mach 1, as the mach number increases, the $(L/D)_{max}$ decreases [8].

In order to be quieter, supersonic planes need to have an optimized aerodynamic fuselage, from the front to the back. Comparing the length of planes and the numbers of passengers for each aircraft in Table 1, one of the conclusion is that length needs to increase in order to reduce the sonic boom. However, it won't be possible to fit as many passengers as subsonic planes can. One cannot imagine a long aircraft as it will require to redesign all airports so that the plane may fit at its gate or turn while taxing. That may be one of the reason, Boom is only able to carry 50 passengers.

2.2.2 Size

Moreover, due to the high speed required, lots of characteristics have to be taken into account for high-speed or high-lift aerodynamics. With the two projects developed in this paper, as seen in table 1, the size of supersonic planes (in term of passengers) decreases. As the most effective surface (flat plate) to get the best L/D ratio has the least effective payload capacity [8], that means supersonic planes will be much smaller than subsonic aircraft.

As one know the high fuel consumption of the *Concorde*, the future of the two on-going projects can be doubtful. Their L/D ratio is lower than the *Concorde* which will certainly lead to a high fuel consumption as well.

3 Tables

This table sums up the different characteristics of the different planes cited in the document. As the purpose is to present the different projects, it seems relevant to compare these data with the past supersonic plane : the *Concorde*.

Some of the following data are likely to change as the two projects are still being developed.

Table 1 Supersonic planes characteristics [5]

	Concorde	Boom	Spike 2
Nb of passengers	100	45-55	12-18
Cruise Mach	2	2.2	1.6
Length (m)	61.66	51	37
Wing area (m^2)	358	218	164
Wingspan (m)	25.6	18	17.7
Range (NM)	3500	4500	6200
Aspect Ratio	1.83	1.49	1.92
Max L/D ratio	7.14	5-6	5-6

4 Conclusion

Building a supersonic aircraft is made of concessions. Choosing to improve the supersonic rather than subsonic, the high speed aerodynamics over the high lift aerodynamics. In order to overcome the different difficulties brought by the Concorde, supersonic planes have to respect some obligations; that is why planes tend to be smaller as seen with the projects analysed.

Moreover, to reduce the fuel consumption, as seen in Boom aircraft, it is possible thanks to latest improvements in engines and these parts of the plane would certainly keep improving in the future years.

Finally, if one wants to know if supersonic flight would be feasible in the future, one can optimistically say yes, because many projects will be developed in the future and one of them would be profitable and respectful of the different standard. However, the ticket price would certainly be more expensive than a subsonic aircraft.

REFERENCES

[1] Concorde. [Used on 26.09.19].
URL http://concordesst.com/

[2] Engineering I. Concorde: The Real Reason Why the Supersonic Passenger Jet Failed, 2017. [used on 27.09.2019].
URL https://interestingengineering.com/concorde-the-real-reason-why-the-supersonic-passenger-j

[3] Cox J. Ask the Captain: What does 'fly by wire' mean?, 2014. [Used on 26.09.19].
URL https://eu.usatoday.com/story/travel/columnist/cox/2014/03/30/fly-by-wire-cockpit-controls/7026935/

[4] Boeing. Historical Snapshot. [Used on 27.09.2019].
URL http://www.boeing.com/history/products/747.page

[5] de Jolimont A O. From Concorde to new supersonic aircraft projects. Ancien Observatoire de Jolimont, 2019. [used on 27.09.2019].
URL https://academieairespace.com/wp-content/uploads/2019/06/AAE_D46_UK_WEB.pdf

[6] Boom. Boom supersonic, 2019.
URL https://boomsupersonic.com/

[7] Aerospace S. Spike s-512, 09/2019.
URL http://www.spikeaerospace.com/

[8] Anderson, John David, Jr. *Introduction to flight*. 8th ed. Boston: McGraw-Hill, 2016.

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Hypersonic Flight

Niklas Olsson , Pranav Uday Rane , Rahul Rajan Sourirajan , Kevin Savio Swamy

Keywords: *aerodynamic heating, shockwaves, hypersonic propulsion, hypersonic vehicles, re-entry vehicles.*

ABSTRACT

The main areas of focus within hypersonic flight were hypersonic propulsion and re-entry vehicles. Findings of the study states, self sustained hypersonic flight need an advanced engine that can function through all Mach regimes. Aerodynamic design of re-entry vehicles require a different approach compared to atmospheric hypersonic flight.

1 Introduction

The first man-made object to fly hypersonic, Mach greater than 5, was the WAC Corporal in 1949, a rocket developed in the United States. It was part of a multi-stage rocket, made to achieve high velocities and altitudes. The WAC Corporal was ignited when the first stage, a V-2 from Germany, had achieved a velocity and an altitude of 1500 $[m/s]$ and 161 $[km]$ [1].

Russia sent the first human flying hypersonic early 1961. The Russian made Vostok I, a spacecraft, achieved Mach 25 during re-entry into the atmosphere. The United States sent a human flying hypersonic, late 1961 in X-15, a rocket powered aircraft that achieved Mach 5. The first aircraft to exceed 1609 $[km/s]$ (one mile per second). In 2004 the first sustainable hypersonic flight was made by the Americans with the X-43, a flight that verified predictions based on wind-tunnel experiments as well as data from CFD. The X-43 was a multi-stage aircraft that, after releasing it's booster rocket, reached Mach 10 with a scramjet engine [1].

One clear difference between hypersonic and subsonic, supersonic aircraft are the integration of components. For regular aircraft, that is subsonic and supersonic, the different parts that they consist of are distinct and easily identifiable. For a modern hypersonic aircraft all the main parts are integrated in each other, ending up in what seems to be a flying wing [1]. The hypersonic technology vehicle as seen in Fig. 1 clearly shows the resemblance of a flying wing.

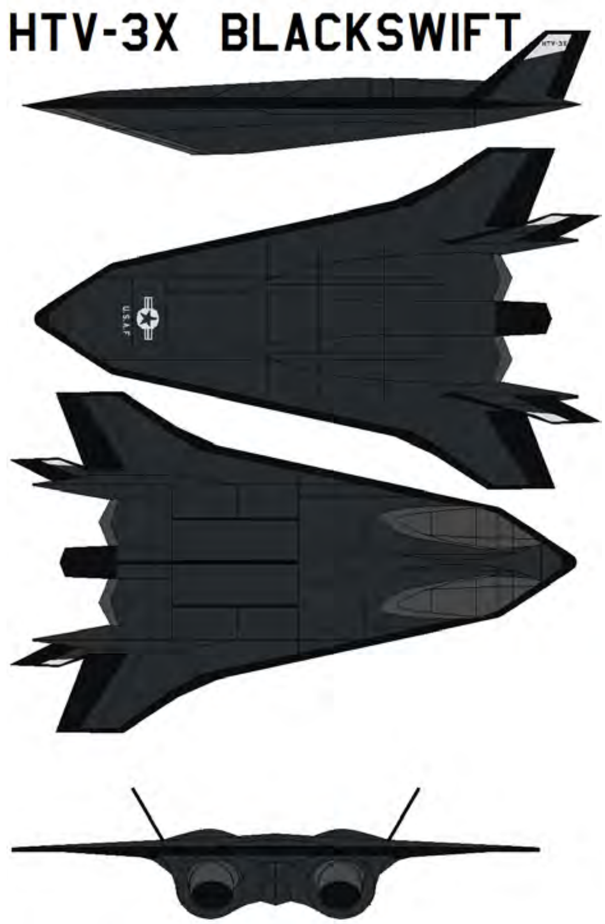

Fig. 1 Lockheed HTV-3X Blackswift, available at [2] under the Creative Commons Attribution 3.0.

2 Hypersonic Propulsion

Scramjets (Supersonic Combustion Ramjet) are used to fly hypersonic through the atmosphere where combustion occurs at supersonic velocities. A scramjet uses the speed of the aircraft to compress the air before combustion of the fuel to give the desire thrust. The only downside to scramjet propulsion is the requirement of assisted take off to initially accelerate the aircraft to hypersonic velocities [3].

Fig. 2 shows the different power plants used by aircraft in different Mach regimes, (a) represents a typical turbo jet engine where the Mach number is subsonic throughout, (b) represents a ramjet engine where the flow speed is reduced to subsonic before combustion and (c) represents a scramjet engine where the flow is supersonic throughout the engine.

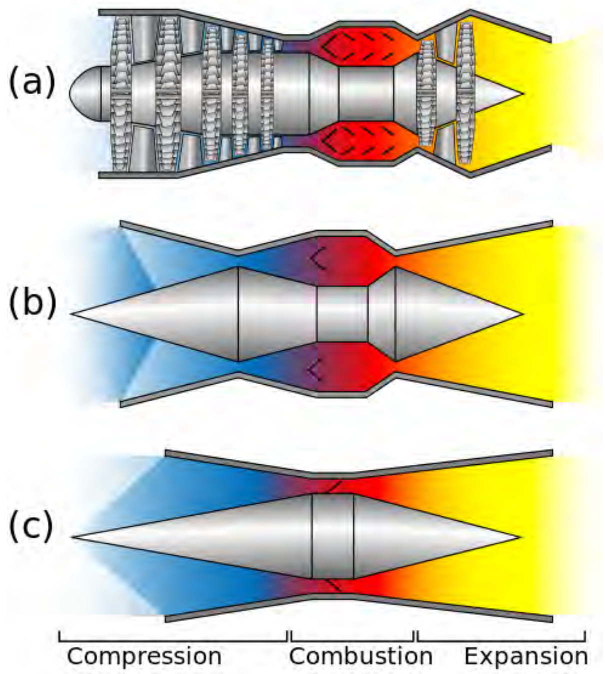

Fig. 2 Various power plants used in different Mach regimes. a) Turbo Jet Engine b) Ramjet Engine c) Scramjet Engine, available at [4] under the Creative Commons Attribution 3.0.

3 Re-entry Vehicles

Hypersonic flight is also applicable to re-entry vehicles, a typical Mach number for re-entry vehicles entering the atmosphere is around 25. At such high velocities aerothermal heating is a significant problem. The air friction accompanied by radiative heat from the shock layers accumulate an enormous amount of heat on the body. In order to manage and dissipate the heat evenly, these bodies are designed with large curvatures rather than sharp edges [5].

Sharp nosed bodies produce less drag and reduce the risk of a normal shock wave in front of the body. Fighter jets and missiles in the supersonic and low hypersonic Mach regime, as in Fig. 1, optimize their designs based on the fact that sharp nosed bodies produce less drag. Applying this design principle to bodies in hypersonic Mach regime has proven to be difficult. The oblique shock waves generated by the sharp edges will generate an immense amount of heat. This heat will be concentrated locally on the edge, eventually melting it. Because of the heat concentrations, heat dissipation is quite often more critical than drag reduction when designing for hypersonic speed. Bodies designed for high hypersonic speeds are thus designed with large round bluff noses in front, as seen in Fig. 3. The blunt nose body will cause a bow shock and increased drag but it will still be more optimized in heat management [5].

Decelerating the module is a also a critical aspect to consider while planning the trajectory. Conventional methods of deceleration using drag devices such as parachutes will fail to work in the hypersonic regime since the air density will be very low at high altitudes. Furthermore, the heat generated will burn the tether line connecting the drag device to the re-entry vehicle [6].

Current methods of hypersonic deceleration in re-entry vehicles involve using the geometry of the module itself. Atmospheric re-entry modules are typically axisymmetric bluff bodies. These bluff bodies will generate drag as well as significant lift when trimmed at an angle of attack. Achieving this aerodynamic lift component for axisymmetric bodies can be achieved by shifting the lateral position of the Centre of Gravity. This will enable the module to trim at the required angle of attack and attain better aerodynamic efficiency (L/D). The lift component will also reduce the loads acting on the astronauts inside the module [7].

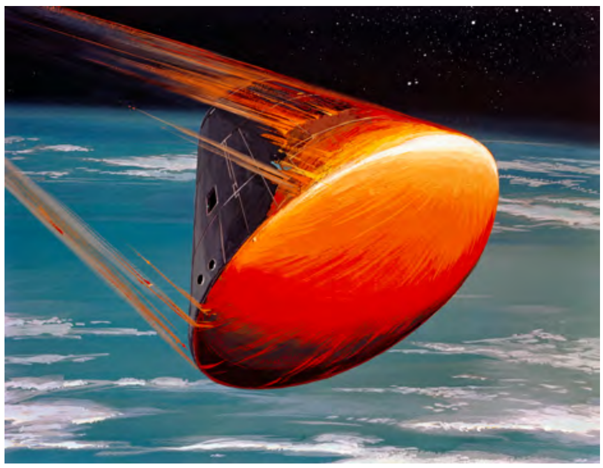

Fig. 3 A blunt nosed re-entry module entering the atmosphere illustrating the temperature difference along the surface [8].

4 Conclusion

Hypersonic flight is limited due to the available engine technology and materials. To fly hypersonic today, aircraft needs at least a two stage propulsion system to be able to reach and maintain sustained flight in the hypersonic Mach regime. Development of engines that can operate across all Mach regimes will pave the way for hypersonic atmospheric flights in the future.

REFERENCES

[1] Anderson, John David, Jr. *Hypersonic and High-Temperature Gas Dynamics; Second Edition, 2006*. Reston: American Institute of Aeronautics and Astronautics, 2006.

[2] Lockheed htv-3x blackswift by bagera3005. URL `https://www.deviantart.com/bagera3005/art/Lockheed-HTV-3X-Blackswift-151300504`

[3] Saeed Farokhi. *Aircraft Propulsion; 2nd Edition, 2014*. John Wiley Sons, 2014.

[4] Turbo ram scramjet comparative diagram by graytrafalgar. URL `https://commons.wikimedia.org/w/index.php?curid=10785559`

[5] Anderson, John David, Jr. *Modern Compressible Flow: With Historical Perspective; 3rd Edition, 2002*. McGraw-Hill Education, 2002.

[6] Krischke M, Lorenzini E and Sabath D. A hypersonic parachute for low-temperature re-entry. *Acta Astronautica*, vol. 36, no. 5, pp. 271 – 278, 1995.

[7] Ernest R Hillje . Entry aerodynamics at lunar return conditions obtained from the flight of apollo 4, 1969. Tech. rep., 1969.

[8] NASA. A north american rockwell corporation artist's concept depicting the apollo command module (cm), oriented in a blunt-end-forward attitude, re-entering earth's atmosphere after returning from a lunar landing mission. URL `https://spaceflight.nasa.gov/gallery/images/apollo/apollo8/html/s68-55292.html`

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Aircraft Based Rocket Launch

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Keywords: *rocket, aircraft, virgin, boeing, aerospace.*

ABSTRACT

Rocket launches are risky, expensive and statistically more likely to fail as compared to a conventional aircraft take-off. Additionally, a larger amount of energy is needed, primarily in the lower troposphere, to propel the rocket upwards[1].
It was theorized that if a rocket is launched above the earth's troposphere, the amount of fuel and subsequently the size of the rocket would be reduced by a significant margin. This report aims to explore, and also provide a basic understanding on, the methods that are currently implemented in *aircraft based rocket launching systems*.

1 History

Military conflict is an excellent catalyst for development in the aeronautical field. In 1941, a feasibility test was carried out in Germany, to air launch the V1 using a bomber. It was a crude attempt to increase the effectiveness of the V1. The concept never entered the realms of reality, planting a seed which would then be nurtured by the world in the future. In the mid 1950s, the need to better understand the aerodynamics at supersonic speeds gained momentum; it was envisioned that the tests be carried out in the upper reaches of the Stratosphere. In order to accomplish that, aircraft-based launch systems were developed, such as the famous X-1.
An aircraft would carry the test vehicle to the launch altitude. Subsequently, the vehicle propelled itself using rocket motors. This concept bore results not only in the realms of experimental studies, but also delivered practical results such as air-to-air missiles.

2 Engineering Aspects

Decades of launches from various platforms have resulted in a detailed paradigm for aircraft-based rocket launches. The predominant factor being, the aircraft be capable of carrying the test vehicle to the desired altitude - with minimum structural wear and tear due to aerodynamic forces.

The most successful launch platforms , the Boeing NB-52(NASA) and the Boeing 747 (Virgin Aerospace), have a couple of things in common - a high aspect wing and high-bypass turbofans - that enable the aircraft to carry a range of payloads to the desired altitudes[2][3].

Fig. 1 Pegasus Rocket being launched from a Boeing 747

During the mid-2000's a new application to the concept was envisioned, a low-cost way to insert satellites into the low Earth orbit (LEO). Virgin Galactic's LauncherOne was designed to insert "SmallSats" in the LEO at a fraction of the cost of traditional rockets. Contemporary developments in the field focus on increasing the payload carrying capacity while developments in material science, engine technology, autonomous systems, and avionics suites have further economized the operation[4][5].
Scaled Composites Model 351 Stratolaunch (fig 2)

Fig. 2 Scaled Composites Model 351 Stratolaunch during maiden flight[6]

embodies these developments in a much wider scale. It has been designed in a twin fuselage configuration, which lets it carry payloads of up to 250 000 kg. Boasting the longest wingspan among all aircraft, it will emerge as a direct competition to the conventional systems in operation[6].

Exploring space has been a childhood dream for many individuals. A business model was developed, utilising aircraft-based rocket systems, to simulate the experience of space travel. A suborbital flight would provide these experiences to customers.

3 Pros and Cons

3.1 Pros

The primary advantage is the reduced amount of thrust needed by the rocket - as the atmosphere is less dense - which in turn reduces the amount of fuel required, as the delta V requirements are lower[7].

The system could chase orbits and achieve the desirable launch azimuth without out-of-plane orbital manoeuvres.

Launch can occur on demand during contingencies.

Rockets can be smaller, and carry a bigger payload.

Launch can be conducted at an inclination, independent of the weather effects.

Nozzles can be designed for low ambient pressures, and therefore don't have to deal with over-expanded/under-expanded conditions at exhaust.

3.2 Cons

The payload is limited by the size and load carrying capacity of the launching aircraft. The payload might also be damaged by the lateral forces generated by the aircraft[8].

Additional parameters that need to be taken under consideration are the time to launch, proximity to the launcher aircraft during the launch and its inclination. Launchers should be designed to withstand, and more importantly recover from, the abrupt forces that arise from the launch and should also be equipped to quickly manoeuvre away from the launch site.

Another aspect to consider, is the effective mode of separation between the launch vehicle from the carrier aircraft. Even the slightest deviation induced, could majorly affect the launch vehicle trajectory.

While it can be argued that launching from the equator - at a 0°inclination - is possible, it is not always feasible for the launcher to carry the rocket to that point. Hence the inclination, and thereby the power needed by the projectile to escape the Earth's atmosphere should also be considered.

4 Conclusion

Contemporary methods of air launch are currently limited to projectiles and low Earth satellites; there exists a scope for further improvement.

Keeping present day developments in focus, a reduction in the size of the launch vehicle, and thereby its weight, can be envisioned. Subsequently, with operations becoming more economically feasible and simultaneous improvements in Aerospace Technology, the ability to launch heavier payloads can be expected.

REFERENCES

[1] Flight Safety Foundation. ASN data show 2017 was safest year in aviation history. "https://news.aviation-safety.net/2017/12/30/preliminary-asn-data-show-2017-safest-year-aviation-history/", 2017.

[2] The National Aeronautics and Space Administration, USA. NASA Armstrong Fact Sheet: B-52B "Mothership" Launch Aircraft. "https://www.nasa.gov/centers/armstrong/news/FactSheets/FS-005-DFRC.html", 2014.

[3] Virgin Galactic. Virgin Orbit LauncherOne Data Sheet. "http://www.spacelaunchreport.com/launcherone.html", 2017.

[4] Virgin Orbit LLC. Launcher One Service Guide. "https://virginorbit.com/wp-content/uploads/2018/11/Virgin-Orbit-Service-Guide.pdf", 2018.

[5] NASA. What are smallsats and cubesats? "https://www.nasa.gov/content/what-are-smallsats-and-cubesats/".

[6] StratoLaunch Systems. "https://www.stratolaunch.com/who-we-are/".

[7] Marti Sarigul-Klijn, Nesrin Sarigul-Klijn, PhD. Flight Mechanics of Manned Sub-Orbital Reusable Launch Vehicles with Recommendations for Launch and Recovery, 2003.

[8] Guy Norris. Design space. *Aviation Week and Space Technology*, vol. 177, no. 2, 2015.

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Sabre-Rocket

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Keywords: *sabre,s.a.b.r.e,rocket,skylon,reaction engines,ssto,precooler,sabrerocket,sabreengine,engine*

ABSTRACT

An informative paper on the saber-rocket, a new type of rocket engine currently in development at Reaction Engines inc in the UK.

1 Introduction

This report aims to introduce and explain the concept of a new type of rocket currently in development by Reaction Engines inc in the UK. The Sabre which stands for "synergetic air-breathing rocket engine" is easiest explained as a sort of hybrid between a normal jet engine and a rocket engine meaning that it can operate at higher speeds than normal engines and works both within our atmosphere and in space [1]. This technology has the opportunity to drastically help evolve both planetary and space travel.

2 History

Reaction Engines inc was formed by three former Rolls Royce workers that previously had been assigned to work on the HOTOL project. The HOTOL project was a horizontal take-off and landing spaceplane designed in the late 80s, it is also the predecessor to the Skylon space plane currently in development wich will in fact use the SABRE engine. [2]. It was during the HOTOL project that the use of an air breathing engine was going to be developed and used. When the project was cancelled the three workers went on to form Reaction Engines and started working on the new SABRE Rocket using the knowledge from the previous air breathing engine work to assist in the development of this new revolutionary engine. Right now the rocket is in the testing phase of the development [1].

3 Function

The saber engines main function is that it has the ability to switch between two different engine modes. The two modes are open cycle and closed cycle. When in open cycle mode the rocket functions more or less like a normal jet engine and the air intake at the front is open and allows air to freely flow through the rocket, in this mode the rocket is capable of operating at speeds up to mach 5. The second mode is closed cycle mode where the rocket closes the air intake at the front and uses hydrogen and liquid oxygen as fuel. This allows the engine to function more or less like a normal rocket engine and it can reach a speed up to mach 25.

One of the main problems that the sabre rocket is currently faceing is the fact that when you approach hypersonic speeds the air flowing into the air intake gets extremely hot, around 1000 celsius[3]. To cope with this issue the saber rocket uses a pre cooler that is located between the air intake and the rocket engine itself. The way this pre cooler works is that it recirculates Helium between the precooler and the cryogenically cooled hydrogen pumped from the tanks [4]. This process is so fast that it occurs within 1/100th of a second [3].

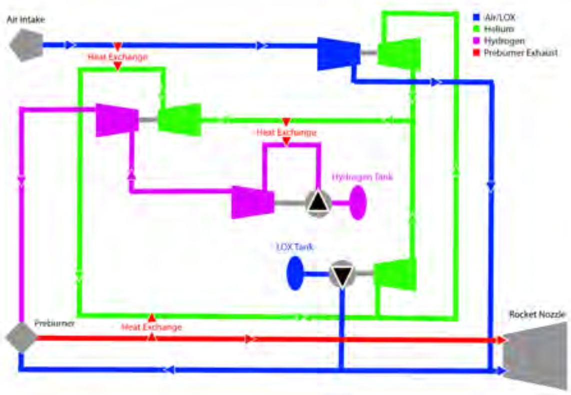

Fig. 1 Schematic of fluid flows in SABRE engine [4]

4 Innovation

The greatest innovation of the SABRE system is the precooler. The capacity to provide atmospheric properties akin to sea level subsonic speeds while flying at 20 000 meters approaching mach 5. This capacity allows the airframe to save weight on liquid oxygen, increasing the effective payload capacity. This effectiveness can most easily be shown in the Specific Impulse of the engine, which in open cycle is near 22 000 sN/kg at Mach 5, compared to the closed cycle capacity of 4500 sN/kg in the vacuum of space. This effectiveness is the main point of the SABRE [1].

The engine core is also innovative utilizing the heat coming from the precooler to drive itself, mainly having an impact during open cycle. With pumps driven with the excess heat [5], using the coolant of the hydrogen to attain a temperature differential, it saves on fuel by not wasting the propulsive energy to drive itself, as is common in other types of engines, both jet and rocket [4].

Another important feature of the SABRE is the fact that the design is completely modular. This means that each key part of the rocket can be removed by it self. This greatly enhances the ability to exchange malfunctioning parts but it, also allows for the development team to test each part of the rocket by it self in different straining environments and situations akin to the expected working conditions [3].

5 Problems

Currently the main obstacle is the engine core, which is still to be tested successfully. When that have been achieved the next step is the full system, combining the four components of the engine. The Shock cone, which is of a proven design, the precooler which has been tested successfully, the engine core and last the rocket exhaust.

As late as Aug 7, the precooler was undergoing high mach number testing, and has , among other, successfully proven it's innovative frost control system, according to Adam F. Dissel [5].

6 Future

The near future of the SABRE engine is looking promising. With the successful test of their precooler in their LA based high temperature test Facility as mentioned above. They intend to perform a system test of their engine core during 2019, with a test of the system in its entirety, precooler and engine core combined, by 2020 [6]. The 2020 test will see the entire system tested from static at sea level to mach 5 at 25 km to prove the systems viability.

Beyond this, the precooler stage of the engine has plenty of other potential uses. As a precooler it can be used on regular turbofan engines to expand their working envelope and increase the effectiveness of the engines [1].

Reaction Engines have also explored the Scimitar engine, a derivative of the SABRE designed to be utilized in a new supersonic passenger aircraft [7].

7 Conclusion

Because of how new this technology is and with parts of the engine still in testing and development there isn't very much specific information about the engine and how exactly each part functions. This is because much of the development is still very secret and there's only so much information available. This paper has brought forward as much information as possible to provide greater insight into the SABRE project. Hopefully more information will be released as new progress is made and the rocket moves forward to full flight testing. We believe that the SABRE is a very innovative piece of technology and will be a big leap forward in rocket development and future space and planetary travel.

Terminology

Specific Impulse: The energy released for every unit of mass of fuel

REFERENCES

[1] Reaction Engines. *Reaction Engines.co.uk*. Reaction Engines, 2018, (accessed 2019:09:30).

[2] Kadhim Shubber. *Skylon: Alan Bond's mission to replace space rockets with spaceplanes*. WIRED, 2013, (accessed 2019:09:30).

[3] David Szondy. *Air-breathing SABRE rocket engine set to enter test phase*. NEW ATLAS, 2019, (accessed 2019:09:30).

[4] Reaction Engines. *SABRE: How it works*. Reaction Engines, 2013, (accessed 2019:09:30).

[5] Adam F Dissel, PhD. *Power Point, Reaction Engines and High-Speed Propulsion*. Reaction Engines, 2019, (accessed 2019:09:30).

[6] Stuart Nathan. *ESA go-ahead heralds core testing on SABRE air-breathing hybrid rocket engine*. the ENGINEER, 2019, (accessed 2019:09:30).

[7] F Jivraj, R Varvill, A Bond and G Paniagua. *The Scimitar Precooled Mach 5 Engine*. EUCASS, 2007, (accessed 2019:09:30).

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Verticle Landing Rockets

Sucheth Krishna Kumar Bysani , Anoop Karpur, Nirnay Arun

Keywords: *Vertical landing vehicle, retropropulsive landings, RCS(reaction control system), GPS, Grid fins,Thrust vector control, Cold gas thrusters, Deployable landing gear, Terrene mapping.*

ABSTRACT

The concept of Vertical landing Rockets was developed to achieve re-usability of the rocket in order to decrease cost and time of Rocket launching . Successful attempts of vertical landing rockets have been attempted by SpaceX and Blue origin with the motivation of reduction of manufacturing and research costs, these have led the path for the re-usability of rocket engines and autonomous recovery of rockets. This paper will discuss the challenges to meet the precision landing of rockets on earth and other planets and also factors required to extend this technology to implement it in future space tourism.

1 History

The history of Vertical landing rockets dates back to 1961 where this concept was demonstrated by Bell Rocket belt i.e a rocket pack. An individual was equipped with a low power rocket propulsion device that allowed him to safely travel over small distances[1]. This gave birth to the concept of Vertical Landing of Rockets. Apollo lunar module was a 1960's two-staged Vertical take-off and vertical landing (VTVL) vehicle for landing and take-off from the moon. In 1990's Mc Donnell Douglas "Delta clipper" demonstrated the Vertical Take-Off and Landing capabilities of a scaled rocket[2] . In successive years Blue Origin developed on this concept to build a VTVL suborbital reusable launch vehicle named "New Shepard" which had its first ever successful test flight on November 23rd,2015[3]. The greatest breakthrough was when SpaceX "Falcon 9" made it's first successful landing on their autonomous drone ship on March 30th 2017[4]. Subsequently other space agencies around the world are developing their own concepts of VTVL such as ISRO's 'Admire' rocket. The challenges faced in achieving this is discussed in the next section.

2 Theory

Every Heavy Launch Rocket will have multiple stages in its functioning. The VTVL concept concentrates more on the first stage, where they want to retract the first stage of the rocket rather than drowning it in the sea. This not only saves a lot of investment in manufacturing, it also builds a reusable system which reduces time and human effort. The vertical landing of a rocket weighing almost 500,000 kg from an altitude of roughly 70 km descending at a speed of nearly 8000 km/h on a landing path of just 50m wide requires the highest grade of engineering brilliance. A typical trajectory of the VTVL rocket is shown in the figure 1.The requirements to achieve a safe vertical landing is discussed below:

1) Thrust vector control: The control of the descending rockets are achieved by the Gimbled nozzles and Grid fins. The Gimbled nozzles are gimbled in particular angles to orient the rockets to its landing path[3]. Gimbled nozzles are used in thin atmospheres where other aerodynamics surfaces are ineffective. It helps in decelerating the rocket during its re-entry or descent into the atmosphere.

2) Cold gas thrusters: The rockets are employed with nitrogen cold gas thrusters that are mounted towards the top of the first stage. They are critical in performing the flip maneuver which orients the rocket towards it's landing path[4].

3) Re-ignitable engines: Since VTVL rockets have a complex re-entry trajectory, it is required that the engine is ignited several times. Due to this companies are using Re-Ignitable liquid propellant rocket engines. They are designed to re ignite in the upper atmosphere at supersonic speeds as well as in the lower atmosphere at transonic speeds[4]. In case of Falcon 9, Spacex uses Merlin engines which are powered by burning Liquid Oxygen(LOX) and rocket-grade kerosene (RP-1) propellants. Whereas the New Shepard of Blue Origin employs BE-3 bi-propellant rocket engine burning liquid hydrogen and liquid oxygen.

4) Inertial navigation and global positioning system: The rockets are equipped with INS which uses several sensors to measure the position, orientation and velocity of the vehicle, whereas the GPS is used to measure the geolocation. The on board computers takes inputs from these systems and if there is any deviation in the flight path then it instructs the rocket to adjust its position using the grid fins or the thrusters[4].In case of landing on other planets the Gps doesn't come of any use, so the telemetry from earth stations should guide the rocket or the space craft to land on the desired area. However as the distance from earth to the destination increase there will be delays and accuracy of the landing will decrease, there might be communication loss for a while if the signals are out of reach or due to eclipse between the earth, extra-terrestrial object and the spacecraft. The possible solution would be to use visual based navigation[3]. The orbiter can take images once in orbit and the same image can be fed to the lander where it can compare the image it sees with the reference image and develops a flight path to land, this also increase accuracy of landing.

5) Deployable landing gear: The rockets are equipped with light weight landing legs which are made up of carbon fiber and aluminium. They are deployed right before touch down using high pressured helium and consist of impact attenuators in case of hard landings[3].

6) Deployable grid fins: Titanium grid fins are mounted at the first stage of the rocket and are deployed during the decent of the rocket into lower atmosphere. The fins are aerodynamics control surfaces that are used for precise control of rockets position and orientation prior to landing. They alone are responsible for the precise landing that is achieved during vertical landing[3][5].

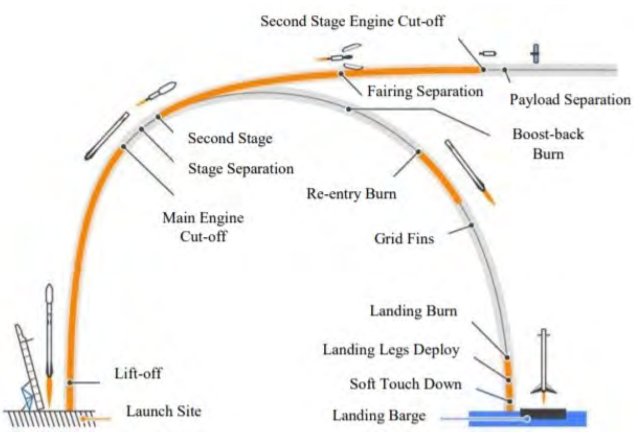

Fig. 1 SpaceX Falcon 9 launch profile [3]

3 Conclusion

The technology required to successfully achieve retro-propulsive landings or vertical landing are, the thrust vectoring (gimbaled nozzle), guidance which is capable of calculating the position and altitude of the vehicle, engines that can re-ignite at different conditions, RCS (Reaction control system) to keep the vehicle at the correct angle, additionally grid fins are used for attitude control during landing.

The additional weight of fuel, larger tank, landing legs, and their deployment mechanisms will usually reduces the payload capacity. The main benefit of the technology is seen in the potential for substantial reductions in space flight costs as a result of being able to reuse rockets after successful vertical landings. In order to enhance the precise landing of rockets on other planets, terrene mapping can be implemented. The GPS based navigation doesn't work on other planets, hence a visual-based navigation system is required which maps the terrene and compares it to the previously taken image to reach the landing site [4].

REFERENCES

[1] Gaubatz W A, Nowlan D, Charette R, Leonard B, Schweikle D, Smiljanic R R, Dumbacher D and Sponable J. Summary report on the delta clipper-experimental flight demonstration programs. *IAF, International Astronautical Congress, 48 th, Turin, Italy*. 1997.

[2] Nonaka S, Nishida H, Kato H, Ogawa H and Inatani Y. Vertical landing aerodynamics of reusable rocket vehicle. *TRANSACTIONS OF THE JAPAN SOCIETY FOR AERONAUTICAL AND SPACE SCIENCES, AEROSPACE TECHNOLOGY JAPAN*, vol. 10, pp. 1–4, 2012.

[3] Ferrante R. A robust control approach for rocket landing.

[4] Blackmore L. Autonomous precision landing of space rockets/lars blackmore. *Frontiers of Engineering: Reports on Leading-Edge Engineering from the 2016 Symposium.–2017.*

[5] Nonaka S, Ogawa H and Inatani Y. Aerodynamic design considerations in vertical landing rocket vehicle. *10th AIAA/NAL-NASDA-ISAS International Space Planes and Hypersonic Systems and Technologies Conference*, p. 1898. 2001.

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When Do I Need to Change a Part? – Lifetime Analysis of Dynamic Helicopter Components

Fabian Maletzke

Keywords: *helicopter, fatigue, lifetime, rainflow counting, linear damage accumulation.*

1 Introduction

Numerous examples from the past show that a failure of a single part of an aircraft can lead to a catastrophic event. Therefore aircraft and all their dynamically loaded parts are required to have a finite Service Life Limit (SLL). This paper gives a brief overview of a calculation method used to determine lifetimes of dynamic helicopter components (fatigue evaluation) using linear damage accumulation. It is based on the Certification Specification for Large Rotorcraft CS-29 of the European Union Aviation Safety Agency [1].

The requirements for the fatigue evaluation of parts are shown in articles 29.307, 29.571 and 29.573 of [1] and apply to significantly loaded parts. These parts are called Principal Structural Elements (PSE) and must include "rotors, rotor drive systems between the engines and rotor hubs, controls, fuselage, fixed and movable control surfaces, engine and transmission mountings, landing gear, and their related primary attachments" [1, CS29.571(d)]. Lifetimes below the SLL of the aircraft have to be published in Chapter 4 of the Aircraft Maintenance Manual (AMM) as required by [1, A29.4]. Figure 1 shows a possible approach to calculate lifetimes which will be explained in the following chapters.

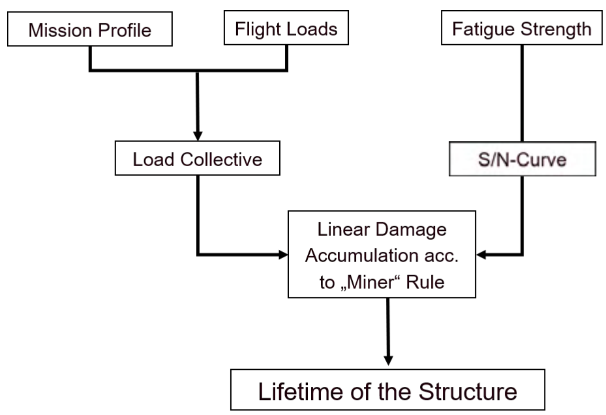

Fig. 1 : General approach to lifetime calculation of dynamically loaded helicopter parts using linear damage accumulation

2 Strength of a Part

2.1 Destructive Testing

Article CS29.571(e)(6) states that the fatigue evaluation has to be "supported by test evidence" [1]. Therefore destructive testing is the main method used to determine the fatigue strength of a part. Depending on the complexity of the part, the necessary tests can vary from (aged) material tests over subcomponent tests to full-scale (pre-damaged) component tests as described in [2].

Usually components are subjected to constant amplitude dynamic loading similar to loads experienced during normal flight. During the test, changes in stiffness and the growth of damages are documented. At the end of a test, a residual strength test is performed which "must show that the remaining structure, after damage growth, is able to withstand design limit loads without failure" [1, CS29.571(f)].

2.2 Creation of S/N-Curves

Based on several component tests as well as material values, S/N-curves can be established. They show the endurance strength of a part based on the number of amplitude load cycles until failure. In a first step a curve is fitted to the test points. This curve is called mean curve, as it represents a survival probability of 50%. Based on the scatter of the points and the severity of a failure of this part (for structural parts often catastrophic [2]), a load reduction factor is calculated for the curve. The reduced curve is called safe curve.

3 Loading of the Part

3.1 Mission Profile

During design of an helicopter a mission profile is established. It is usually based on past experience as well as customer surveys. According to [1, CS29.571(e)(2)] the mission profile has to cover all critical conditions as well as all other maneuvers the helicopter is able to do. In addition, the time share of each maneuver of the complete profile is defined.

3.2 Flight Loads

Based on the mission profile load classification flights are conducted. The helicopter is equipped with flight test instrumentation and all relevant strains, vibrations, temperatures, etc. are recorded by sensors for each flight maneuver.

By using rainflow counting [3] the number of load cycles as well as their mean and amplitude values are extracted from the time data of each flight maneuver. A typical rainflow matrix is shown in Figure 2. The horizontal axis shows the mean load classes, the vertical axis the amplitude load classes. Each field contains the number of load cycles for the given mean and amplitude load combination.

Mean Load Classes

Amplitude Load Classes		-1500 -1000	-1000 -500	-500 0	0 500	500 1000	1000 1500	1500 2000	2000 2500	2500 3000	3000 3500	3500 4000	4000 4500	4500 5000	5000 5500	5500 6000
0	300	2	22	82745	1329673	8307051	12317927	6147919	608900	38888	652	64	17	10	6	2
300	600	0	0	144	5046	384223	934379	84315	5130	84	15	9	4	0	0	0
600	900	0	0	0	590	93017	472562	133102	260	54	15	7	6	2	0	0
900	1200	0	0	0	47	3149	74085	35591	351	28	13	8	4	2	0	0
1200	1500	0	0	0	0	199	5203	1897	156	20	13	9	5	0	0	0
1500	1800	0	0	0	0	15	243	733	40	21	12	10	2	0	0	0
1800	2100	0	0	0	0	0	128	271	46	14	4	4	2	0	0	0
2100	2400	0	0	0	0	0	22	39	34	11	0	0	0	0	0	0
2400	2700	0	0	0	0	0	4	19	18	15	0	0	0	0	0	0
2700	3000	0	0	0	0	0	1	14	11	14	3	0	0	0	0	0
3000	3300	0	0	0	0	0	0	4	9	6	9	2	0	0	0	0
3300	3600	0	0	0	0	0	0	3	3	8	6	2	0	0	0	0
3600	3900	0	0	0	0	0	0	0	3	3	7	1	0	0	0	0
3900	4200	0	0	0	0	0	0	0	2	2	1	0	0	0	0	0
4200	4500	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0

Fig. 2 : Rainflow matrix of a measured load

3.3 Load Collective

In the load collective the rainflow matrices of all maneuvers are combined, weighted by their respective time shares. It is usually scaled to a fixed time basis (e.g. 1000 flight hours $[Fh]$). Each aircraft component has its own load collective.

4 Linear Damage Accumulation and Lifetime Calculation

To calculate the lifetime of a part, the cumulative damage method shown by Miner in [4] is used. Each field of the load collective represents the number of load cycles n_i for a specific mean and amplitude value combination. It is divided by the number of load cycles until failure N_i for these load combination, which is derived from the safe S/N-curve (Figure 3). This ratio is called damage. It is assumed that a part fails when the damage reaches 1. The time basis of the load collective (in this example 1000 Fh) is divided by the sum of all damages (equation 1), the result is the lifetime of the part.

$$L = \frac{1000\,Fh}{\sum \frac{n_i}{N_i}} \tag{1}$$

Alternatively this method can be used to for a damage tolerance evaluation by using crack growth tests and the resulting S/N-curves.

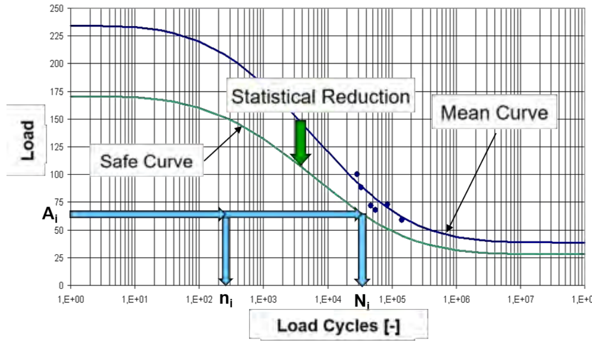

Fig. 3 : Linear damage accumulation based on a safe S/N-curve

5 Limits of this Method

One limit of this method is that Miner's rule does not account for the sequence in which high and low loads are applied to a part, which has influence on the fatigue strength. Cycles of low stress followed by cycles of high stress can cause more damage than what the rule predicts [5]. In addition the lifetime is highly dependent on the mission profile as well the flight data. It can be influenced by how specific test pilots fly.

6 Summary

This paper shows a method of how to calculate the lifetime of dynamically loaded helicopter components based on the rainflow counting method and linear damage accumulation.

REFERENCES

[1] European Union Aviation Safety Agency. *Certification Specifications and Acceptable Means of Compliance for Large Rotorcraft CS-29. Amendment 7.* 2019.

[2] Federal Aviation Administration. *Advisory Circular AC29-2C – Certification of Transport Category Rotorcraft. Change 4.* 2014.

[3] Endo T, Mitsunaga K, Takahashi K, Kobayashi K and Matsuishi M. Damage Evaluation of Metals for Random or Varying Loading – Three Aspects of Rain Flow Method. Gakkai N Z, editor, *Mechanical behavior of materials: proceedings of the 1974 Symposium on Mechanical Behavior of Materials*, pp. 371–380. Society of Materials Science, 1974.

[4] Miner M A. Cumulative Damage in Fatigue. *Journal of Applied Mechanics*, vol. 12, no. 3, p. A159–A164, 1945.

[5] Eskandari H and Kim H S. A Theory for Mathematical Framework and Fatigue Damage Function for the S-N Plane. *Fatigue and Fracture Test Planning, Test Data Acquisitions and Analysis*, pp. 299–336. ASTM International, 2017.

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Cloud and Weather Phenomena based on the Temperature Gradient

Yu-Cheng, Lu , Chun-Leung ,Ho

Keywords: *atmosphere, dew point, temperature gradient, cloud, weather.*

1 Introduction

Most of cloud and weather phenomena occur in the troposphere. With ISA atmosphere model by US Standard Atmosphere 1976 [1], we can obtain the temperature gradient in the atmosphere, which is an important cause of those phenomena. And combined with basic thermodynamics and meteorology knowledge, we can further know about the details of how clouds and weather phenomena occur and the influences to flight.

2 Theory

2.1 Air Properties in the Atmosphere

There are several layers in the atmosphere, and most of weather phenomena occur in the troposphere. They are related to air properties and water vapor behavior directly. Applied with ISA atomsphere model in US Standard Atmosphere 1976 [1], the air properties in troposphere is shown in *eq.*1 and Figure 1.

$$T = T_0 - 6.5 \cdot H \quad (1)$$

Designation	Denotation	Value	Unit
T	Temperature		K
T_0	Sea Level Temperature	288.15	K
H	Geopotential Height		m

While the air going up, with less atmospheric pressure, the air will start an *adiabatic cooling* process and then expand.[2] In order to increase the volume, the air have to do $P-V$ work to the surroundings. With the first law of thermodynamics, the internal energy will decrease because of doing $P-V$ work at the surroundings. The temperature, which represents internal energy, therefore decrease.

2.2 Thermodynamics for Gas-Vapor Mixtures

Air and water vapor mixture plays important roles in most of weather phenomena. When the temperature

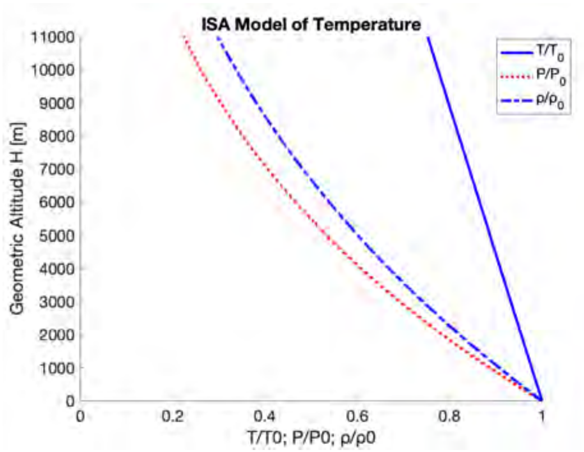


Fig. 1 Temperature Variation in Troposphere by ISA Model.

comes to the saturated temperature at certain pressure, it is called *Dew Point Temperature,* T_{dp}. We can check the dew point temperature on *psychrometric chart*, which elaborated by the relations between properties of gas-vapor mixture in the air.[3] The higher geometric altitude is, the less saturated pressure of gas-vapor mixture is. Moreover, with the same content of water, the specific humidity of gas-vapor mixture would increase. At the same time, the dew point becomes lower with the increasing of altitude. Therefore, at different pressure and dew point temperature, clouds develop in various type, which will be discussed later.

2.3 Temperature Inversions

It is known that the temperature lapse rate is $2^o/1000ft$ according to the international standard atmosphere (ISA). However, the temperature can increase in an short range of altitudes which is called temperature inversion. This is a special phenomena that occurs near the ground. Due to the specific heat difference of solid ground and air, the huge temperature gradient variation causes the convection and condensation of air and water vapor. There are several types of inversion which are surface inversion, subsidence inversion and frontal inversion.

Inside the inversion layers, the visibility is poor. Also, vertical windshear and turbulence will appear. These will diminish the climb performance of aircraft. But the thickness of an inversion layer is about $500ft$, so that it does not affect the safety of aircraft [4].

Fig. 2 Surface inversion [4]

2.4 Types of Cloud

There are several ways to form clouds. These are convection, orographic lifting, mixing and converge.[5] The concept of convection and orgraphic lifting are the same. When the moisture air moving upward in the atmosphere, it will be condensed as cloud according to temperature gradient and dew point temperature. There are three major type of cloud which are low-level cloud, middle-level cloud and high-level cloud.

Table 1 Cloud Type

Altitude	Name
Low	Nimbostratus, stratocumulus, stratus, cumulus, cumulonimbus
Middle	Altrostratus, Alrocumulus
High	Circus, cirrostratus, cirrocumulus

Fig. 3 Cumulonimbus could in early forming stage [4]

Fig. 4 Altrostratus [4]

Fig. 5 Hair shaped circus [4]

Thunderstorm are developed from many well-developed and active cumulonimbus. Strong convection occurs because of temperature difference in a wide range altitude distribution of cloud. The signature of thunderstorm are lighting, strong wind and heavy rain. There are three major state during the the life cycle of thunderstorm which are building stage, mature stage and dissipating state. In building state, the weather will become very windy and dark. During the mature stage, there will be lighting and heavy raining. Finally in the dissipating stage, it will keep raining for a period of time and the sky will become clear [6].

Fig. 6 Thunderstorm in mature stage [4]

2.5 Weather Phenomena

2.5.1 Icing

Icing is an serious hazard in flying activity. When icing occurs on the wing surface, it will change the shape of airfoil, and the weight of aircraft. It may affect the generation of lift and decrease the controllability of aircraft. Due to temperature gradient in troposphere, the surface temperature of aircraft varies with respect to altitude. When air moisture is attached on objects whose temperature are less than 0^oC, icing will occur. There are many types of airframe icing, such as rime ice, clear rice and mixed rice. Clear ice is the most dangerous icing behaviour. It is because the ice is not easy to be removed and discovered. When the super cool water droplet attach the airfoil, the freezing process will be happened. Rime ice will be formed when the supper cool water droplet is frozen with some air. Since some air bubbles are inside the ice, it is in white color. Therefore, it can be removed and discovered easily.

2.5.2 Fog

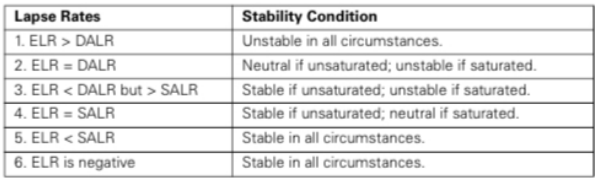
Fog is an important phenomena in ground-level aviation. It will affect the visibility while landing or taking off. According to temperature difference between ground-level air and the ground, when the temperature of moisture air drop to the dew point in heat equilibrium process, it will transform into fog. There are several kinds of frog, which are radiation, advection, upslope and frontal fog.

3 Discussion

The air stability and humidity are the most important factors to cloud formation, which are based on temperature gradient.

3.1 Environmental Lapse Rate

The environmental lapse rate helps us to determine the stability of a certain parcel of air. An unstable air means that a parcel of air remains warmer than surrounding after some vertical convection. It will keep rising which can produce the cloud in column shape in different altitude. On the other hand, stable air means that the air have the same temperature after having small vertical movement. It will produce the cloud in layer - shaped. From the ISA model temperature gradient, it is found that the dry adiabatic lapse rate and saturated adiabatic lapse rate are $3^oC/1000ft$ and $1.5^oC/1000ft$ respectively. There are 3 kinds of lapse rate: environmental lapse rate (ELR), dry adiabatic lapse rate (DALR) and saturated adiabatic lapse rate (SALR). These different temperature gradient determine the stability of air, which provide reasonable reference to determine the air stability. 7 shows the air stability condition.



Lapse Rates	Stability Condition
1. ELR > DALR	Unstable in all circumstances.
2. ELR = DALR	Neutral if unsaturated; unstable if saturated.
3. ELR < DALR but > SALR	Stable if unsaturated; unstable if saturated.
4. ELR = SALR	Stable if unsaturated; neutral if saturated.
5. ELR < SALR	Stable in all circumstances.
6. ELR is negative	Stable in all circumstances.

Fig. 7 The table shown the stability of different kind of air under different environmental lapse rate [4].

3.2 Temperature Gradient and Cloud Formation

The dew point temperature indicates the humidity of air. With air temperature and dew point temperature, we can determine where the cloud would start forming by the following equation. [4]

$$h = \frac{T - T_{dp}}{2.5} \tag{2}$$

Designation	Denotation	Unit
h	Cloud base height	*1000ft
T	Air Temperature	$^\circ C$
T_{dp}	Dew Point Temperature	$^\circ C$

According to ISA model and observation data, temperature gradient in the troposphere is predictable. Compared with the dew point temperature, we can make a prediction about the type of cloud and decide the flying path to avoid these kinds of cloud to ensure the safety of flying.

REFERENCES

[1] United States Committee on Extension to the Standard Atmosphere. *U.S. standard atmosphere, 1976*. National Oceanic and Amospheric Administration : for sale by the Supt. of Docs., U.S. Govt. Print. Off., 1976.

[2] JP O'Connell and JM Haile. *Thermodynamics: fundamental for applications*. Cambridge University Press, 2005.

[3] Yunus A Cengel and Michael A Boles. *Thermodynamics: An Engineering Approach 6th Editon (SI Units)*. The McGraw-Hill Companies, Inc., New York, 2007.

[4] David Robson. *Meteorology for Private Commercial Pilot Licences*. Aviation Theory Centre, 2015.

[5] Dennis Lamb and Johannes Verlinde. *Physics and Chemistry of Clouds*. Cambridge University Press, 2011.

[6] *Meteorology: JAA ATPL Training*. Jeppesen Sanderson Inc., 2004.

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Box-Wing Con igurations: A Future Scenario?

Edin Trumic, Dirk Rechkemmer, Rafael Bölsterli

Keywords: *box-wing, joined-wing, prandtl-wing, induced drag.*

1 Introduction

The aviation industry has witnessed great development in the last 40 to 50 years including but not limited to deeper understandings of aerodynamics, materials, different types of drag affecting aircrafts and efficiency progress regarding internal combustion and jet engines. Ongoing research is taking place in search for the next future airliner configuration with the aim of bringing further improvements in fuel efficiency, reductions in noise and noxious emissions from the engine(s). One of these "future airliner configurations" is the so-called box-wing or joined-wing, where researchers are claiming potentials of reduced structural weight and direct operating costs by lowering or eliminating the induced drag. This improves overall fuel efficiency and therefore makes the configuration interesting to investigate further. [1]

Fig. 1 Joined-wing aircraft concept of "the future". [2]

2 Nomenclature

All nomenclature used in this report will be stated in the following table:

Designation	Denotation	Unit
C_{Di}	Induced Drag Coefficient	-
C_L	Lift coefficient	-
e	Oswald Efficiency Factor	-
AR	Aspect Ratio	-
δ	Induced Drag Factor	-

3 Drag Theory

When aircrafts (airfoils) are moving through a fluid e.g air in this case, lift is produced because of the aircraft's wing characteristics. The wing enforces a higher airstream velocity above it than below it, resulting in higher pressure beneath than above the wing, creating lift. With a traditional wing configuration, since there is a lower pressure above than beneath the wing, some air will slip from the high pressure side to the low pressure side at the wingtips resulting in vortices and so called induced drag or vortex drag. Since

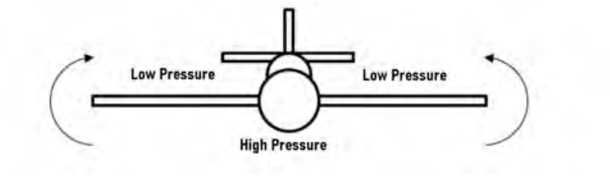

Fig. 2 Vortex flow behaviour for aircraft wing tips when producing lift.

a box-wing has no wingtips the slip of air is greatly reduced which decreases the total drag and therefore improves the lift-to-drag ratio. The overall effect of implementing a box-wing will be improvements in range and endurance, or reductions in fuel consumption. [3]

3.1 Comparison of the induced drag coefficient

The induced drag coefficient is defined as:

$$C_{Di} = \frac{C_L^2}{\pi \cdot e \cdot AR} \text{ [4]}$$

To compare different results with each other it is most convenient not to use the Oswald Efficiency Factor, but the induced drag factor δ, which has the following relationship with the Oswald Efficiency Factor:

$$\frac{1}{e} = (1+\delta) \text{ [3]}$$

This leads to the following induced drag coefficient:

$$C_{Di} = \frac{C_L^2}{\pi \cdot AR} \cdot (1+\delta) \text{ [3]}$$

The ideal lift distribution of an aircraft wing would be a halve ellipse which would have an induced drag factor of 0. Unfortunately these wings are hard to manufacture and expensive to build, so the industry came up with different approaches for decreasing the induced drag factor. One example is the implementation of a dihedral, which reduces δ by 0.029. Another well know optimization is the use of winglets or wingtip fences, the latter can reduce the induced drag factor by up to 0.28 [3].

According to [3] Fig. 7, the box-wing is shown to have the highest reduction of induced drag factor, being equal to -0.32.

Ludwig Prandtl also searched for the most efficient wing system and came up with a biplane configuration. For this reason, the box-wing is sometimes also referred to the Prandtl-wing [5].

4 Discussion and Conclusion

The aim of this paper was to investigate the properties of a possible "future" aircraft, in this case the use of a box-wing. The European Union has concluded a number of challenges for the aviation industry with goals to be fulfilled starting from the year of 2020 [6]. These challenges include goals for increased comfort and safety regarding civil transport while minimizing environmental pollution through less emissions of e.g noxious gasses and a more energy efficient aviation industry. The European Union strives for more available space and comfort, faster boarding times and disembarkation of passengers and luggage partially by minimizing approach and landing separations due to wake vortex turbulence of larger aircrafts. There is also an aim for increased allowed cargo weight for passengers, 30% reduction of Direct Operating Costs and minimized maintenance costs with a 0.85 Mach minimum cruise speed. The level of survivability to accidents especially regarding take-off and landing is a main requirement for the future where e.g design against crash and/or spreading of fire, safer fuel tanks, use of new materials and evacuation systems are of main focus regarding aviation safety according to the European Union.

All these mentioned improvements require the investigation and development of new technologies, regarding the aviation industry. The aerodynamic design for aircrafts is of highest importance for minimizing drag which leads to more efficient aviation and a more successful transport aircraft programme. Noise and noxious emissions during take-off and landing produce the worst impact on people living in the surrounding areas, which calls for improved possible lower velocity take-offs and landings. "In a large transport aircraft during cruise flight, drag is mainly due to friction drag (45-50%), and induced drag (40-45%)" [7]. The opportunity to minimize the induced drag through new aircraft design is possible which would have a great impact on the aviation industry, in this case the box-wing.

Since box-wing configurations use double wings to produce lift, there is a higher total lift to drag ratio if one compares a conventional airliner to a box-wing aircraft with the same wing span. This means that with the use of a box-wing configuration, the use of smaller wings is possible to produce the same amount of lift. The fuselage could also be increased in size while the wing span stays the same. This higher lift leads to the engines not having to be as powerful and could be held smaller which also gives a better fuel efficiency by decreasing the operating fuel consumption, decreasing the pollution as well as the noise.

Since the induced drag stands for almost half of the total drag in today's civil aviation, decreasing it would have a huge impact on the industry.

REFERENCES

[1] Paul Olugbeji Jemitola. *Conceptual Design and Optimization Methodology for Box Wing Aircraft*. School of Aerospace Engineering, Cranfield University, Cranfield, UK, 2012.

[2] NASA. *Lockheed box wing aircraft concept*. NASA, 2011.

[3] Somerville A, Marino M, Baxter G and Wild G. Understanding box wing aircraft: essential technology to improve sustainability in the aviation industry. *Aviation*, vol. 20, pp. 129–136, 2016.

[4] Ingo Staack. *6th Lecture: Drag Component Build-up Method*. Linköping University, 2019.

[5] Ludwig Prandtl. *Induced drag of multiplanes, NACA Technical Note 182*. United States, 1924.

[6] Directorate-General for Research and Innovation. *European aeronautics: A vision for 2020*. European Commission., 2002.

[7] Prof Aldo Frediani. *THE PRANDTL WING*. Pisa University-Italy., 2005.

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A Study on Flight Mechanics of Tailless Aircraft

Shree Harsha Vijaya Kumar, Arcot Manjunath Shreepal

Keywords: *Rudderless flight, delta wing, flying wing, induced drag, reflex, winglets, wingtip vortices, stability, RCS, stealth*

1 Introduction

Flying Wings or Tailless aircraft are fixed-wing aircraft defined by their lack of a definite or pronounced fuselage and absolute absence empennage. Jack Northrop defined these aircraft as *'A type of airplane in which all of the functions of a satisfactory flying machine are disposed and accommodated within the outline of the airfoil itself'*. These aircraft are designed specifically to make best use of the aerodynamics effects of the wing design in order to reduce induced drag due to inclusion of empennage in the airframe and tail section vortices. A typical Flying Wing/Tailless Aircraft is shown in Fig.1.

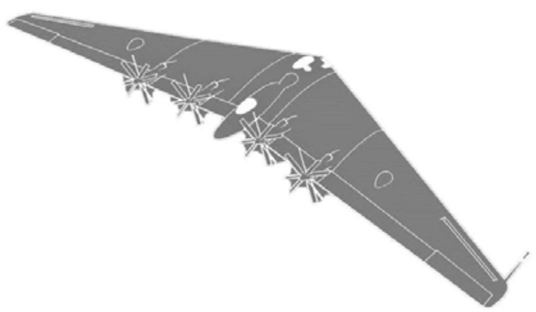

Fig. 1 Flying Wing design mockup. Courtesy: Sridhar Kota, Illustration: John MacNeill, IEEE Spectrum

The military application of building flying wings initially began as a method to minimise radar signature by reducing the Radar Cross Section (RCS), done by eliminating the tail section. This configuration gave rise to development in better stealth technology to drop payloads behind enemy lines undetected. The civilian applications include utilising the low induced drag to the advantage of increasing fuel efficiency for passenger aircraft. In this regard, Blended-Wing Bodies (BWB) have been seeing considerable progress towards replacing conventional aircraft.

2 History

Flying Wings or Tailless aircraft have been a topic of study since the early days of aviation. The earliest known work on flying wings was done by Hugo Junkers in 1910 on his biplane. In his patent No.253 788, he famously said *"The wings should provide space for not only their engines and fuel, but also for payload and crew"*, but he was limited by the technology of his time to realise this. Early developments in building flying wings were successful only in the 1940s when the Horten Brothers of Germany won the tender to build advanced flying wing concepts, the *Horten Ho series* (Fig.2) to aid in the war efforts for the German Third Reich. [1]

Fig. 2 The Horten Ho 2, 3 and 4 Gliders. Courtesy: Nickel and Wohlfahrt [2]

After the war under 'Operation Paperclip', Jack Northrop got his hands on a few of these concept aircraft and developed them further with some of his own findings and consequently came up with the YB-49 Flying Wing in the late 1940s, the predecessor to the infamous B-2 Spirit which was developed later in 1989.

3 Aerodynamic Control and Stability

Flying Wings, just like conventional aircraft work on the balance of the four forces on the wing. As we know, lift is created by a combination of both Bernoulli's Principle and Newton's Third Law of motion. Much like conventional aircraft, flying wings use control surfaces distributed across the wind span for direction control. In modern tailless aircraft, it has become easier with technology development related to on-board flight controllers which work better and are more reliable than compared to manual flight. Examples of these unmanned flight systems are found in the Lockheed F-117 Nighthawk, Northrop Grumman X-47B, Boeing X-45C and others [3, 4, 5]

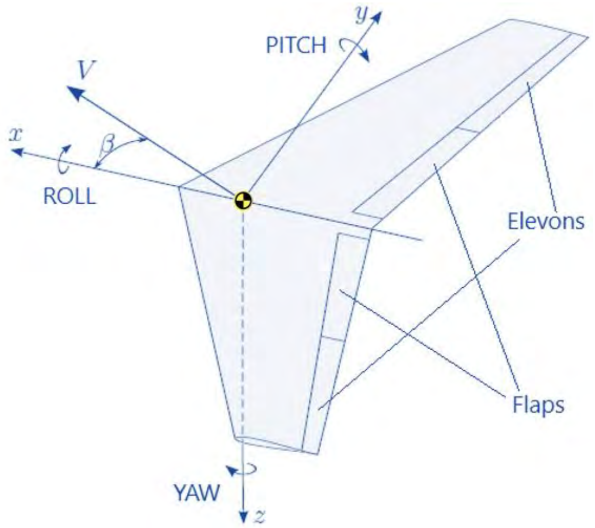

Fig. 3 Axes Notation and Sideslip angle β definition.

Fig.3 shows the pitch, roll and yaw notations in a flying wing along with the sideslip angle β. To control the pitch, inboard flaps on both sides of the wing are deflected together like a typical elevator. For yaw control, the flaps on either the left or right are deflected up and down to create drag on that wing in that direction, thereby turning the aircraft. Roll control is achieved by deflecting the flaps on both wings in opposite directions, just like a conventional aircraft.

3.1 Pitch Stability

Consider a cross section of the wing of a conventional aircraft as shown in Fig.4. In the first image, at a low Angle of Attack (AoA) the pressure distribution is as shown, where the Centre of Pressure (C_p) is towards the aft. At higher positive AoA, the C_p shifts towards the leading edge. Conversely, at a negative AoA the C_p shifts further towards the trailing edge. This shift causes negative instability where the wing (aircraft) tends to flip at the slightest deviation from the perfect AoA which is accentuated by the chord length of the airfoil.

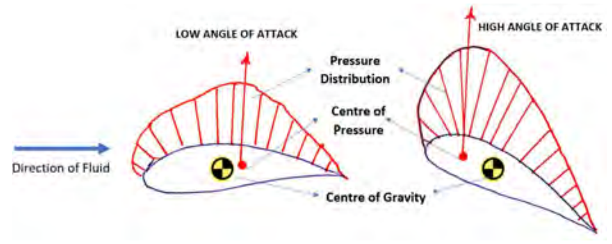

Fig. 4 Pressure distribution and shift of C_p along the airfoil with increase in AoA.

For this reason, conventional wings have tails to counter and control this instability with a positive difference in the elevator called *decalage*. But in flying wings, due to the absence of elevators, the airfoil itself is given a positive *reflex* at the trailing section to compensate for this decalage. This produces the corrective force that tends to bring the aircraft back to level whenever there is a pitch up or pitch down. It is for this very reason that flying wings have a forward Centre of Gravity (CG) ahead of the C_p much like a dart, but controlled by the reflex.

Although reflex seems to be a wonderful solution, it has its drawbacks. For one, it is not as efficient as a conventional wing due to low C_{Lmax} requiring higher AoA at takeoff and also because it loses some of the Newtonian lift produced in order to stabilize the wing.

3.2 Roll and Yaw Stability

The Control Surfaces of flying wings are designed to compensate for the stability provided by a tail. Yaw stability is achieved by a method called *differential drag*, where the drag on one side of the wing is increased more than on the other side causing a directional change of the aircraft in that direction.This is achieved by one of the following methods:

- Spoilers: A spoiler surface is raised on the topside of the wing which functions as airbrakes creating drag in that direction.
- Split-type Ailerons/Elevons: The Ailerons/elevons on the trailing section are designed to split into two surfaces on the top and bottom opening to the aft of the aircraft. By actuating them differentially, more drag is create on one side, causing a directional change.

- Spoilerons: This is nothing but creating a higher deflection of the ailerons/elevons on the top side of the wing to function as both aileron and spoiler.

It can be seen that flying wings have are designed with a sweep. In most cases, wings are swept in order to achieve higher speeds and reduce the onset of pressure drag over the leading edge. But in the case of flying wings, this has more to do with stability. With the sweep, the CG is shifted forward and due of the absence of the tail, it needs a longer moment arm to stabilize the flight. Here, the sweep increases the length of the moment arm thereby helping restore the aircraft to equilibrium. [6]

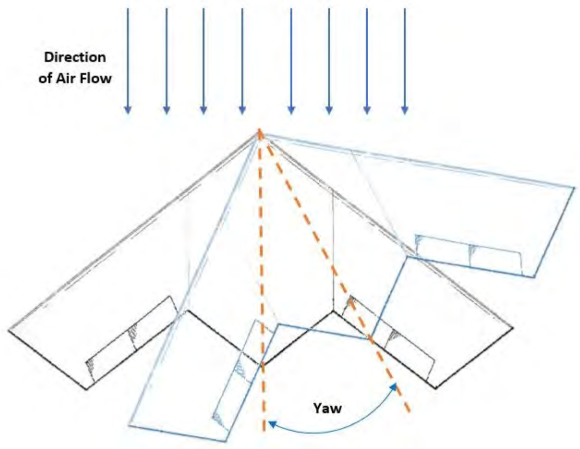

Fig. 5 Yaw and Roll self correction for stability

When the aircraft performs a yaw as shown in Fig.5 at an angle to the direction of incoming air, we see that the starboard side of the flying wing has more projected area compared to the portside. This generates more lift on the right of the wing. This lift causes an induced roll motion. Thus, in a flying wing, there exists a yaw-roll couple, and also a corrective yaw motion to bring it back to equilibrium. So every time the aircraft performs a yaw, a corresponding roll in that direction also persists, which is used to the advantage of banking the flying wing [7, 6]
The downside of this is that the aircraft is constantly unstable at turning and banking due to the continuous cyclic correction producing a wobble that tries to stabilise the aircraft normal to the flight direction.
This wobble effect can cause instability and is avoided by trying to correct the airflow over the wing to flow normal to the axis of the aircraft again. The way to do this is by introducing *Wing Fences* [8] on the surface of the wing as shown in Fig.6.
Using wing fences over the surface of the wing prevents spanwise airflow and redirects airflow longitudinally. This produces a corrective yaw force that prevents the wobble effect.

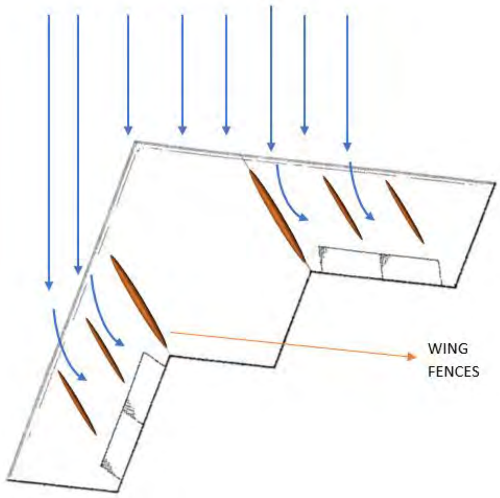

Fig. 6 Using Wing Fences to redirect airflow

4 Future Outlook

Flying Wings are continuously being developed for future applications pertaining to military, passenger aviation and also for logistics. Due to the high instability of these aircraft, a flight computer/autopilot is usually the one doing the flying. NASA has been working on the X-56 platform to study the flight characteristics of flying wings as a way to counter the adverse yaw and directional instability [9]. NASA has also greenlit and funded the 'Silent and Efficient Supersonic Bi-Directional Flying Wing' [10]. Many commercial aircraft corporations are also looking into flying wing concepts for passenger aircraft, which looks to be the future of aviation. It can thus be presumed, the future for Flying Wings/Tailless aircraft is shaping up to be bright and is gaining momentum in academic and industrial fields to become a viable option for the future of aviation.

Fig. 7 NASA X-56 test platform and Bi-directional flying wing concept

REFERENCES

[1] Myhra D. *The Horten Brothers and Their All-Wing Aircraft*. Schiffer military/aviation history. Schiffer Publishing, Limited, 1998.

[2] Nickel K and Wohlfahrt M. *Tailless aircraft in theory and practice*. AIAA education series. Edward Arnold, 1994.

[3] Lockheed Martin Corporation. F-117 Nighthawk feature, 2019. URL `https://www.lockheedmartin.com/en-us/news/features/history/f-117.html`

[4] Northrop Grumman Corporation. X-47B programme overview, 2019. URL `https://www.northropgrumman.com/Capabilities/X47BUCAS/Pages/default.aspx`

[5] The Boeing Company. X-45 joint unmanned combat air system, 2019. URL `https://www.boeing.com/history/products/x-45-joint-unmanned-combat-air-system.page`

[6] Etkin B and Reid L. *Dynamics of Flight: Stability and Control*. Wiley, 1995.

[7] Stevens B and Lewis F. *Aircraft control and simulation*. Wiley-interscience publication. Wiley, 1992.

[8] Hurt H and Administration F. *Aerodynamics for Naval Aviators*. Igal Meirovich, 2012.

[9] Conner M. X-56a multi-utility technology testbed, 2017. URL `https://www.nasa.gov/centers/armstrong/research/X-56/index.html`

[10] Espinal D, im H, Lee B, Dominguez J, Sposato H, Kinard D and Zha G. Supersonic bi-directional flying wing, part ii: Conceptual design of a high speed civil transport. *48th AIAA Aerospace Sciences Meeting Including the New Horizons Forum and Aerospace Exposition*, 2010.

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Unconventional Take-off and Landing Methods

Wenli Kong , Mehmet Deniz Firat , Till Behler

Keywords: *Take-off, Landing, CATOBAR, STOBAR, VTOL, Water landing, Autonomous landing.*

1 Introduction

The take-off and landing process is the challenge for an aircraft to start and end the actual flight successfully. It has always been invested a lot of research to make optimization for more comfort, safety, etc.
Next to the conventional take-off and landing methods where the aircraft is started and landed at a long runaway by the execution of the pilot, there are – also because of the variety of applications of modern aircraft - a lot of other take-off and landing methods that are required due to the circumstances or even because of better appropriateness or given technology and design.
This paper gives a short overview of a few unconventional and modern take-off and landing techniques and presents them regarding application fields, potential and challenges and also focuses on future relevant aspects.

2 Unconventional take-off and landing techniques

2.1 CATOBAR

CATOBAR (Catapult Assisted Take-Off But (Barrier) Arrested Recovery) is a horizontal unconventional take-off technique mainly used in aircraft carriers where usually is not much space on the runaway to accelerate. With the assistance of so-called catapultes the aircraft is accelerated to the required launch speed.
The catapult technique was used in 1903 by Samuel Langley for his flying models first. The first successful catapult launch from a ship took place in 1915.[1]
Most modern CATOBAR systems contain of steam catapultes which are commonly used since World War II. The main challenge for launching the aircraft is to provide enough steam pressure. When the aircraft is about to accelerate, the valves of the catapult pressure tanks filled with high pressured steam underneath the short runaway are opened and the steam supports a piston with the necessary force to speed up the aircraft to take-off velocity.
One of the latest advancements for the CATOBAR technique is the Electromagnetic Aircraft Launch System EMALS where the acceleration is achieved by electromagnetic alternating fields. Compared to the steam catapultes, EMALS has more energy capability. Because of the nowadays trend to faster and heavier aircraft this aspect becomes more important. Additionally, EMALS has next to less weight and volume, also the advantage of better controllability, availability and efficiency.[2]
For landing operations, a arresting gear system is used to slow down the speed of aircraft over the short runaway. During the landing process the pilot has to hook into one of the arrestor steel wires that are fixed on the ground. The wire decelerates the aircraft within seconds to a standstill.

Fig. 1 Shenyang J-15 accelerating for take-off, Copyright China's Ministry of National Defense

2.2 STOBAR

In contrast to CATOBAR, STOBAR (Short Take-Off But (Barrier) Arrested Recovery) utilizes inclined ramps to assist take-off. Therefore additional energy generators which cause cost and technical difficulties are not required. The aircraft only uses its own power to take-off. Even if the velocity is not enough to keep constant height in the moments after take-off, the aircraft has time to accelerate further on because the ramp ensure a sufficient climb rate.[3]

2.3 VTOL

A vertical take-off and landing (VTOL) aircraft is a general title for an aircraft that is able to take-off and

land vertically. VTOL includes a variety of types of aircraft including fixed-wing aircraft as well as helicopters and other aircraft with powered rotors, such as cyclocopters and tiltrotors.[4]
In future mobility concepts vertical take-off and landing might play a bigger role for smaller airborne vehicles. As a big advantage the aircraft can take-off and land almost everywhere and has very low space requirement.
There are currently two types of VTOL aircraft in military service: aircraft using a tiltrotor, such as the Bell Boeing V-22 Osprey, and aircraft using directed jet thrust such the Hawker Siddeley Harrier and its successor models. (see figure 2) The basic principle of vertical take-off for a rotary wing airborne vehicles is always the same: Because of the spinning blades, the pressure on the top of the rotor is reduced, and the pressure underneath is increased. Therefore thrust is generated. To move forward, the aircraft tilts slightly to direct some of its thrust forward. In case of directed jet thrust, the jet engine of the aircraft and therefore the thrust vector is aligned vertically to produce a vertical elevating force but is able to change its direction later to move horizontally.[5]

Fig. 2 Hawker Harrier GR1a in hover, Copyright 2019 BAE Systems [6]

2.4 Water landing/ditching

Another technique focused on is landing on water or so-called ditching for aircraft that are not designed for that. This kind of maneuvers only appear in forced and special emergency cases but nevertheless the Federal Aviation Regulations (FAR) prescribe that a regular airplane should also be able to land on water in a preferably secure way.[7]
Those situations are usually not practiced on a flight simulator but there are some things the pilot can pay attention to, e.g. slow down velocity to minimize forces when hitting the water surface or to land parallel to the waves.[8] When the aircraft is not touching down symmetrically the resulting yaw moment can cause immense damage to the aircraft. In order to analyze occurring forces and their effects when the aircraft is hitting the water surface, there were made many numerical simulations with main focus on different pitching angles.[9] It can be concluded that beside the dependency on the aircraft shape and flight approach the pitching angle has mainly impact on the normal load. It is recommended to have a comparatively high initial pitch angle around 10°-12° to prevent the aircraft nose to dip into the water. The chances of leaving the aircraft unscathed and saving the lives of the passengers can therefore be increased. Although the chance success rate of ditching is not estimated very high, there are again and again impressive examples like in 2009 when a pilot managed to land his aircraft on the Hudson River in New York successfully and saved the life of all passengers.(see figure 3)

Fig. 3 Airbus A320 after landing on Hudson River, Copyright Janis Krum

2.5 Development of autonomous take-off and landing

As the importance of autonomous means of transport will increase in the future, also aviation will be affected by this change. New challenges regarding the take-off and landing in particular will occur. Today there are already unmanned aerial vehicles (UAV) like drones and the potential of flying autonomously is not exhausted, at all. This paper will also have a look on the latest trends and approaches for improving the take-off and landing performance of existing autopilots which might be relevant for serial production of larger airliners in the future as well.
Many existing landing support systems as the instrument landing system (ILS) which supports the pilot with the landing when there is bad visibility, require information that are transmitted from the ground.

However, to be independent from the airport system has to be fully on-board.
Latest developed systems mainly focus on vision-based autonomous landing and take advantage of the greatly improved camera techniques in the last years. A research group of the Technical University of Munich (TUM) developed together with the Technical University of Braunschweig a fully automated landing system that extend the usual GPS system with two cameras to prevent disturbances.[10] In figure 4 the detecting of the runaway is depicted. One camera is in the infrared range to be resilient at poor visibility. The optimal landing approach is determined with sensor-fusion which estimates the relative position of the aircraft better than before.

Fig. 4 Visual runaway detecting, Copyright Technische Universität München [10]

To improve the performance of the autopilot recent researches also concentrate on Artificial Neural Networks and Supervised Learning. Training datasets obtained from flight simulators experiments can be used for control models that imitate the behaviour of a human pilot which can be learned and adapted to the autopilot.[11] Therefore the autopilot is be able to perform more take-off and landing tasks without human intervention.
This is only a small insight of the various possibilities to improve autonomous take-off and landing.

3 Conclusion

This paper presented a short abstract of the most common unconventional take-off and landing methods as well as techniques that came up in the last years and are still in their infancy. All of them will become more important in future as the fields of applications for aircraft will definitely be exposed to a huge change. Therefore, the existing methods are continuously refined and enhanced with modern technologies.

REFERENCES

[1] Gibbs-Smith, Charles H. *Hops and Flights: A roll call of early powered take-offs*. www.flightglobal.com, 1959.

[2] Michael R Doyle, Douglas J Samuel, Thomas Conway, Robert R Klimowski. *Electromagnetic aircraft launch system-EMALS*. Transactions on Magnetics, IEEE, 1995.

[3] Artyom Beilis. *STOBAR Carrier Ski-jump Simulator*. http://cppcms.com/files/skijump, 2015.

[4] Laskowitz I B. *Vertical Take-Off and Landing (VTOL) Aircraft*. Annals of the New York Academy of Sciences, March 1963.

[5] Shuhe Zhang. *Review of vertical take-off and landing aircraft*. Institute of Marine engineering, Dalian Maritime University Dalian, China, 2017.

[6] BAE SYSTEMS. *The only true STOL (short take-off and landing) aircraft in the world*. https://www.baesystems.com/en-uk/heritage/hawker-siddeley-harrier2, 2019.

[7] Federal Aviation Administration. *Transport airplane cabin interiors crashworthiness handbook*. Advisory Circular, 2009.

[8] Niels Klußmann, Arnim Malik. *Lexikon der Luftfahrt*. Springer Verlag, 2019.

[9] Guo Baodong, Liu Peiqing, Qu Qiulin, Wang Jiawen. *Effect of pitch angle on initial stage of a transport airplane ditching*. Chinese Journal of Aeronautics, 2014.

[10] Kügler M, Wolkow S. *"Augen" für den Autopiloten*. Technische Universität München, https://www.tum.de/nc/die-tum/aktuelles/pressemitteilungen/details/35553/, 2019.

[11] Haitham Baomar, Peter J Bentley. *Autonomous Navigation and Landing of Large Jets Using Artificial Neural Networks and Learning by Imitation*. IEEE Symposium Series on Computational Intelligence (SSCI), 2017.

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Electric flying vehicles

Jorge Ocaña Dominguez, Adrian Martinez De La Morena, Maria Beriain Telleria, Javier Iriarte Azcona

Keywords: *Electric, Prototype, Aircraft, Batteries*

1 Introduction

Although the electric aircraft are a quite new concept, the first attempts were in 1970s. Since then, considerable advances have been made in order to overcome the environmental impact. The biggest challenge nowadays are still the batteries.

2 History

In the 1970s, experimenting with electric and solar power got a jump start [1]. Between 1967 and 1969, the Austrian Brditschka family created the first prototype. In 1973, the first aerodyne electrically powered aircraft could fly 300m above the ground during 14min. Then in the 80s, two French army officers, carried out a hydrogen powered aircraft with huge batteries (Ronald Berger [2] and Airspacemag [3].)
Even so, between 1974 and 1983 solar energy and energy achieved by pedaling was used satisfactorily. Kremer Prize and David Williams were the pioneers of creating this new way of human to fly.
Then, promoted by NASA, the industry of UAV (unscrewed aerial vehicle or drone) got a huge importance in the society of late 90s and beginning of the 2000s. Among others, the Helios broke records by getting an altitude not achieved until then, 29524m (in 2001).
In the past 15 years several numbers of notable electric flights takeoff have been seen, lasting 20 minutes to several days. Big companies as Airbus (2010) or Boeing (2008) had created their own electric light aircraft and started using lithium-ion batteries.
Although there are only mentioned electric aircraft, electric flying cars are also having great importance and incredible progress.

3 Today's challenges

Nowadays, it is being trying to turn everything into electric in order to reduce pollution, but there is a long path to go to finally achieve the 100 percent electric. One of the main problems is the energy density. The common fuel for the aircraft is kerosene that has an energetic density of $43MJ/kg$ while the energetic density of the Lithium-Ion batteries is only $1MJ/Kg$ [4]

One of the main flying factor is the weight of the aircraft. Clearly, if kerosene is used, less volume would be needed than using batteries. An increase in weight needs to increase the lift and so more power is needed. The power formula (after some basic calculations [5]):

$$P = \dot{m} \cdot V$$

$$\dot{m} = \rho \cdot L^2 \cdot V$$

$$P = (2 \cdot M^2 \cdot g^2)/(L^2 \cdot p \cdot V)$$

Where, "M" is the Mass of the aircraft, $\dot{m}$ is the mass-flow, ΔVz is the velocity, "g" is the gravity, "L" is the length of the aircraft, "p" is the density of the air and "V" is the velocity of the aircraft.

The power needed to fly should be minimized. Adding more mass in order to change the energy source to batteries, will increase the power needed. As an illustrative example, if the fuel of a conventional Airbus is substitute into batteries $(0.340kW/Kg)$[5], it will need 31 Tonnes of batteries for a seven hours flight. The average mass of an empty plane is around 12 tonnes what means that it will be needed 3 times the weight of the plane in batteries.

Another point to highlight, is the price of the fuel: The kerosene is around 2.23 per litre, so it would cost 330 to fill up an airplane. $554kWh$ of electricity costs about 0.17dollars per kWh, so it would cost 94 dollars to charge the airplane. Looking it this way batteries are much cheaper.

Likewise, in order to integrate batteries into the aircraft, a need to change the distribution of the batteries, higher voltages, aerodynamic considerations, wiring or new manufacturing techniques. Not only in the aircraft but the logistic also should be changed in order to be able to charge tones of batteries in a short time under any weather conditions.

4 The existing electric flying vehicles

Nowadays we already have some working electric flying vehicles, but the majority of them are only capable to flight short distances, and carry low weights. We have the example of the Alpha Electro [6], a 2-seat electric trainer with an endurance of 1 hour, and a 30 minutes reserve, which has certificates to fly in several countries.

The company H55 [7] has developed the "BRM Aero Energic". As the Alpha electro, it is a 2-seats trainer with a maximum endurance of 90 minutes and an energy cost per 1 hour flight of $US 7.00, incredibly cheap if it is compared with non-electric planes.

Fig. 1 Picture taken from [6]. An Alpha electro during a flight

Small electric flying vehicles are proven to be already working, but large commercial electric aircraft are still a challenge. As the BBC news [4] reported, the company Eviation [8] launched on July 2019 the the world's first commercial all-electric passenger aircraft: Alice. Designed to take 9 passengers at a cruise speed of 240 knots (around 440 km/h) and perform medium-range flights up to about 1500 km. This aircraft is expected to start its service in 2022. This is the largest electric aircraft nowadays and is yet far from a large 200 passengers prototype.

Is it to consider that the batteries are the major limitation for development of this electric devices. The need for a sufficient range to account for a power reserves and the ability to generate a full power on the take off. One important idea is that the batteries that have reached the end of their useful life for an aircraft could be repurposed in a similar manner rather than being discarded.

5 Future

In the next years the aviation sector is expected to have a huge growth [9]. In fact, by 2030s almost 200,000 flights per day are expected to take off and land all over the world. In order to face this change, sustainable solutions are considering. These propulsion systems are the ones in the spotlight: All electric, hybrid electrics and turbo-electric.

What is of interest on this topic is to know if companies are betting on using totally electric systems. It can be seen in the latest news [4], that many start-ups and big companies are involved in promoting the electrical propulsion systems and for it investing a large amount of money. For instance, Airbus, Rolls-Royce's, Siemens and Easy Jet which have a bunch of demonstration projects in development.

One of the most emerging start-ups is Wright Electric, founded in 2016. It is developing an airplane that uses battery energy for 2027. This electric airplane will have 180 seats and 500km of range. In 2018 they have evaluated the electric propulsion system. Big companies, such as Airbus [10] and Boeing, have their own future aircraft.

Other propulsion systems can be seen in development. For instance, there is one created by a Massachusetts Institute's research recently [11]. It is the first aircraft with an ion drive point and has earned comparisons to Wright brothers for its similarity in design. The propulsion system has no moving parts and it consist of thin wires strung horizontally creating a movement of ions between two electrodes (see Figure 2).

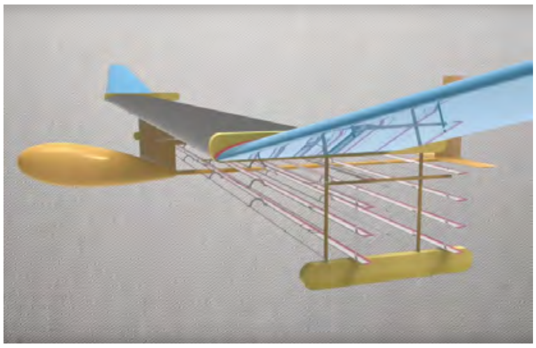

Fig. 2 Picture taken from [11]

At the same time models with jet engines are succeeding too (turbo-electric) based on distributed propulsion technology [5]. An American start-up company, Boom Technology, it is working on a supersonic air travel. Their target is to be able to fly from Los Angeles to Shanghai in 5 hours to be introduced in 2023.

6 Discussion and/or Conclusion

There is no doubt that it is a current and worrying issue. The expected demand of future mobility is increasing that much that something must be done. The problem is that, totally electric flying vehicles do not seem to be the solution to this problem, not at least the only one. Their capacity limitation it is a difficult problem to face. That's why another clean an more efficient alternatives are constantly appearing.

REFERENCES

[1] artscom. *A journey through the history of electric aircraft*. arts.com, 2019.

[2] Berger R. *Aircraft Electrical Propulsion – The Next Chapter of Aviation?* Ronald Berger, sept 2016.

[3] Garrison P. *The Electric Airplane*. Airspacemag.com, 2009.

[4] Bowler T. *Why the age of electric flight is finally upon us*. bbc.com, 2019.

[5] Peter Merlin P A. *LEAPTech to Demonstrate Electric Propulsion Technologies*. NASA Armstrong Flight Research Center, 2018.

[6] Pipistrel. *Alpha Electro*. pipistrel-aircraft.com, 2019.

[7] h55ch. *MAKING AIR TRANSPORT QUIET AND CLEAN*. h55.ch, 2019.

[8] Eviation. *Alice Commuter*. eviation.com, 2019.

[9] icaoinc. *Future of Aviation*. icao.inc, 2019.

[10] . *A giant leap towards zero-emission flight*. A giant leap towards zero-emission flight, 2019.

[11] Bogaisky J. *First Test Of Aircraft With An Ion Drive Points To A Radically Different Future For Aviation*. forbes.com, 2019.

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Electric aircraft: Alternative power sources

Victor Hjärpe, Thijs Hobbenschot, Marcus Hedlund, Viktor Hjort

Keywords: *Electric aircraft, battery, Eviation, Alice, power source*

1 Introduction

The development of electric aircrafts is going on to a great extent today. Many large well-known companies in the aerospace industry are working hard to achieve functional and useful aircrafts that can handle the demands required for longer and more efficient air travel.

This project examines how electric aircraft work today and the limitations that exist. How they can be developed and function in the future. The aim of this project is to understand how electric aircrafts work and why they are not used today, as well as what is required for them to function as commercial aircrafts in the future.

Fig. 1 The company Eviation prototype electric aircraft "Alice"

2 Theory

The idea of developing an electric aircraft is to reduce the emmsions coming from the aviation industry. According to a study published in the article Forget cars. We need electric airplanes [1] there is a possibilty to reduce the aviation fuel usage by as much as 15 percent if all short flights only used electric aircrafts. Short flights are in this case is flights less than 600 nautical miles, in which range the about half of all flights fits. The main problem with this vision today is the battery capacity and weight. However, the battery energy density has increased by 3-4 percent per year in the last years, and if this trend holds up, we could have batteries packing up to 800 Wh per kg. Electric aircrsafts might be viable for short domestic flights up to around 600 nautical miles as mentioned briefly in the article.

On MIT's website there is an "Electric aircraft range calculator" where it's possible to play around with four different variables which then gives you the theoretical range of such an electrical aircraft. The variables are: Specific energy [Wh/kg], Lift to drag ratio, efficiency, and battery mass fraction.

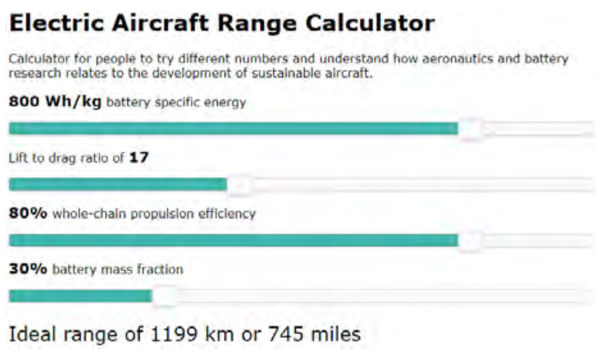

Fig. 2 Electric aircraft range calculator

3 Existing electric aircraft

A company that has developed an all-electric aircraft is Eviation with their Alice. This plane is designed to carry 9 passengers up to 650 miles at a cruise speed of 445 km/h. it has a length of 12,2 meters and a wingspan of 16,2 meters. The maximum takeoff weight is 6350 kg and it is powered by 3 propellers with 260 Kw each. It is estimated that the cost per flight hour will be around 200 dollars which is about 20 percent of the cost for a regular propeller aircraft. The company aims for the aircraft to be certified and used commercially as early as 2021 according to Nyteknik.

4 Discussion and/or Conclusion

The problem with todays electrical aircrafts is that the batteries are not powerful enough. The most commonly used batteries for aircrafts today is Lithium-ion batteries. The reason why is because lithium-ion batteries has the highest energy density. Lithium-ion batteries however do have one disadvantage, they can short-circuit and end up combusting. In the beginning of a NASA-project one cell in a lithium-ion battery was short-circuited and that resulted in the entire battery caught on fire

Currently the best lithium-ion batteries have an energy density of approximately 250Wh/kg. That is more than good enough to power an electric car but advances in battery technology is needed before these batteries will be good enough to power a large passenger airplane. For example,A-1 jet fuel have a minimum energy density of circa 11700 Wh/kg.

The energy density of the battery is not the only variable that limits the range of electric aircrafts. The range of an electric airplanes also depends on its battery to mass fraction, that is the weight of the battery divided by the total mass.

Using the equations (1)-(4), with a battery mass fraction of 0.8, a lift to drag ratio of 25, a propulsion efficiency of 80 percent and an energy density of 300Wh/kg we get a range of 1763 km.

Even with very optimistic future estimates of energy densities of 750 Wh/kg in batteries the range is still only around 4400 km, about the distance of LA to New York.

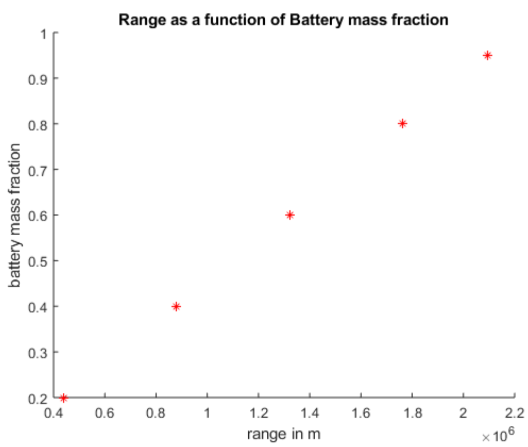

Fig. 3 Range as a function of battery mass fraction

5 Formatting

5.1 Equations

$$E = TR \tag{1}$$

$$E = E^{*} m_{batt} \eta_{total} \tag{2}$$

$$R = v \frac{L}{D} I_{sp} ln \left(\frac{m_{fuel}}{m} \right) \tag{3}$$

$$R = E^{*} \frac{m_{batt}}{m} \frac{1}{g} \frac{L}{D} \eta_{total} \tag{4}$$

Nomenclature

Designation	Denotation	Unit
E	Energy	J
T	Thrust	N
R	Range	km
E*	Battery specific energy	Wh/kg
m_{batt}	Battery weight	kg
η	Efficiency	-
L/D	Lift-drag ratio	-
v	Velocity	m/s
I_{sp}	Propulsion efficiency	-
m_{fuel}/m	Fuel-mass fraction	-
g	Gravitational constant	m/s^2

Fig. 4 Table of the different variables used in the equations

6 References

[1] Forget cars. We need electric airplanes
https://www.vox.com/2019/3/1/18241489/electric-batteries-aircraft-climate-change
[2] Range calculator
http://web.mit.edu/lochie/www/erange/main.html
[3] Eviation Alice
https://www.eviation.co/alice/
[4] NyTeknik
https://www.nyteknik.se/fordon/elflygplanet-alice-visas-upp-lanseras-2021-6962303
[5] Nasa-project-one
https://spinoff.nasa.gov/Spinoff2019/t_1.html
[6] A-1 jet fuel
http://large.stanford.edu/courses/2012/ph240/greenbaum1/

Contactless Energy Transfer Systems

Blanka Tonsic, Avish Bhambhani, Manel Galan, Javier Villena

Keywords: *contactless, energy, wireless, CET*

ABSTRACT

The main purpose of this paper is to introduce the Contactless Energy Transfer (CET) systems and its state of art naming current applications. The wireless power transfer consists of a technology capable of transferring energy contact-less. It is not a new technology but is gaining importance nowadays in many cases where the use of wires are an impediment [1].

1 Historical development

The first attempt to get a wireless power transfer was made by Nikola Tesla in the late nineteenth century, who wirelessly lights up phosphorescent lights using a method called "electro-dynamic induction" [2]. Due to the fact that power transfer methods are more demanding than signals transfer systems, power transfer did not experience the same development [3].
The first reported researches on energy transport by inductive coupling dates in the 1960s, and the first applications like wireless toothbrushes appeared in the 1990s. Power transfer systems are currently evolving rapidly since the Wireless Power Consortium created the protocols related to inductive CET systems in 2008 [3].
The CET systems can be classified depending on the gap between both parts of the system. It can be found Near-field methods and Far-field methods, discussed in the following chapters of this paper.

2 Near-field methods

The simplest way of contactless energy transfer is non - resonant inductive transfer, also known as transformer, based on two coils with different voltage. The variable current will lead to development of the alterable magnetic field as well as a magnetic flux which will lead to induced voltage. Because of the change of the value of the initial current in the first coil, on the second coil the current will be induced. The described process is based on Faraday's law.
However, this is not the most efficient way of transferring energy, it depends on the geometry and magnetic field is stronger if the coils are closer so it can transfer energy only on low distances. Resonant inductive way of transmitting energy is much more efficient and is divided into capacitive CET systems and inductive CET systems [4].

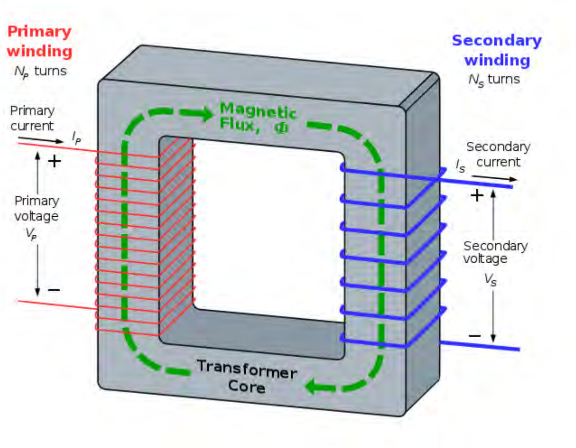

Fig. 1 Idealised single-phase transformer also showing the path of magnetic flux through the core. (source: BillC at English Wikipedia.)

2.1 Capacitive CET systems

The capacitive CET system is based on getting displacement current. It consists of energy source, high frequency resonant power converter DC/AC, metal plates, AC/DC converter and load. Firstly, electrical energy goes through high frequency power converter and than splits to two metal plates from which it goes to secondary plates where alternating electric field forms. For direct current, capacitors represent the break of the circuit, while for alternating electric field circuit closes through displacement current. Currents go again through converter and the power is transferred to load. The power of this type of CET system is 5 - 50 W [5].

2.2 Inductive CET systems

The inductive CET system is based on previously described transformers. What is added to it is primary DC/AC resonant converter, resonant circuits and secondary AC/DC converter. The converted electric en-

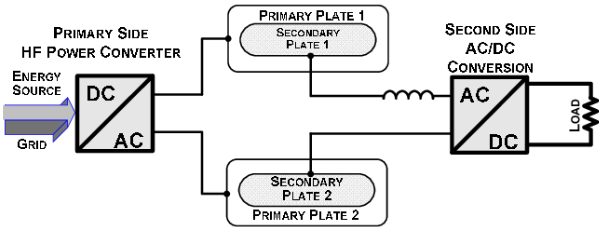

Fig. 2 Basic principles of capacitive CET system [5]

ergy runs through the transformer and again through secondary converter to load. The power depends on which transformer is used. If there is a need for low power than transformers with higher gap between coils are used as described at the beginning. In contrary, if there is a need for high power transfer, transformers with low gap between coils are used consisting of magnetic cores [3, 5].

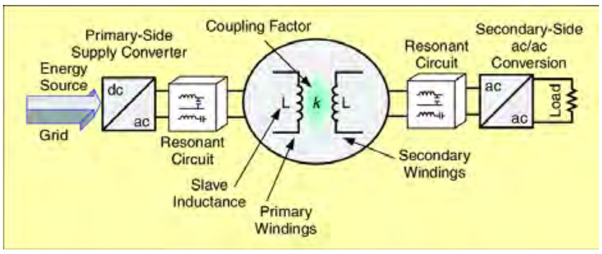

Fig. 3 The basic principles of the inductive CET system [5]

3 Far-field methods

Methods previously described are highly inefficient when it comes to long distances. The solution to this problem is using far-field methods. It can be subdivided in two main techniques.

3.1 Microwave energy transmission

Energy transmission using microwaves consists in sending an electromagnetic beam to a receiver. This energy will later be conducted to a rectenna or "rectifying antenna" which transforms the microwave energy into electricity. One of the disadvantages of this method is the losses along the distance the wave has to travel until arriving at its target. These losses, caused by the diffraction, could be minimized by using big aperture sizes of antennas. However, this solution means a substantial increase in both the cost and space required. Since diffraction depends on the wavelength of the transmitted wave, the frequency could be increased to minimize the diffraction effects, but this would have a negative effect since the atmosphere causes more absorption at smaller wavelengths. An example of the magnitudes involved in the NASA study of solar power satellites, which require a one-kilometer diameter for the transmitting antenna for a microwave beam at 2.45 GHz [6].

3.2 Laser energy transmission

Far distance energy can also be transmitted by sending a laser beam. This mechanism, also known as 'power beaming', consists of converting electrical energy into a laser beam, pointed to a photovoltaic cell that converts the electromagnetic energy of the laser into electric energy again.
Although this energy transmission method is pretty similar to the microwave case discussed in the last section, their biggest difference lies in the wavelength used. While microwave transmission uses wavelengths of the magnitude of the meter, laser energy mechanism works in the range of some hundred nanometers, taking advantage of the atmospheric transparency window in the visible or near field infrared spectrum as shown in Fig. 4 [6].
One of the most important advantage of this method is the lack of reduction in power when increasing the distance from the transmitter to the receiver thanks to the collimated monochromatic wavefront propagation. On the other hand, must be said that its efficiency can considerably decrease for many factors such as photovoltaic cells (40%-50%), atmospheric absorption and scattering by clouds[7].

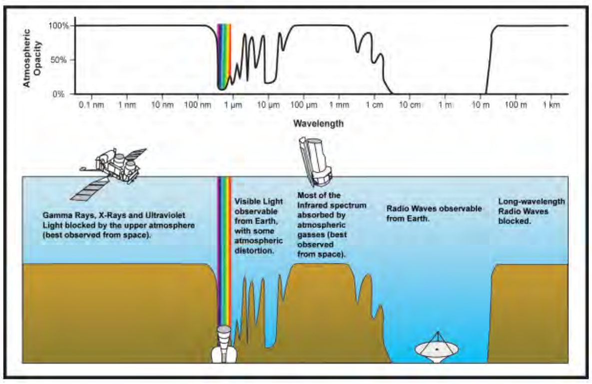

Fig. 4 Absorption spectrum of the atmosphere. (source: NASA)

4 Applications

For future terms of wirelessly transmitted energy, the applications seem to be infinite. From medical devices to satellites, from transportation systems and vehicles to household appliances. Developments in this field would certainly have a high impact in technology as known today and produce a before-after

effect in some of the daily aspects of society.
Nowadays, near field methods are being used for development of products such as contactless-stands to charge smartphones. Applying these methods to a vehicle, it could be charged not only while being parked, but also while being driven in special charging lanes. This would solve some current range issues for some of the electrical vehicles present in the market today [1].
For the astronautics side, far-field energy transfers are the next step. Radiative electromagnetic waves, also known as microwaves, and lasers are viable options for energy transmission. Solar power satellites, which would absorb heat from the sun and convert it into microwaves, would produce power and send it down to earth, which would be received by special antennas, and from those antennas directly as electric power [1]. Empowering electrical aircraft in flight with this method could maybe be possible soon.

REFERENCES

[1] Lokesh Dutta, Farhana Haque Sumi. *Future with Wireless Power Transfer Technology*. Journal of Electrical Electronic Systems, 2018.

[2] Sadegh Vaez-Zadeh,Saeed Hasanzadeh. *A Review of Contactless Electrical Power Transfer: Applications, Challenges and Future Trends*. 2014.

[3] Arash Momeneh. *Inductive Contactless Energy Transfer Systems for Residential Areas*. Department d'Enginyeria Electronica,UPC, July 2016.

[4] Romina Dubajic. *Physical Foundations of Tesla's Wireless Energy Transmission*. Department of physics, Faculty of science, University of Zagreb, 2016.

[5] Marian PKazmierkowski; Artur JMoradewicz . *Unplugged but connected: Review of CET Systems*. IEEE Industrial Electronics Magazine, 2012.

[6] Leopold Summerer O P. *Concepts for wireless energy transmission via laser*. ESA - Advanced Concepts Team, 2009.

[7] *Power Transmission Via Lasers*. Laser Focus World, 2009.

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Electric Cars or Trucks with Just in Time Energy-Reception

Bala Murali Krishna G , Akhil Rajendran , Albin Parappilly Albert

Keywords: *Electric Road System, Conductive Power Transfer, Inductive Power Transfer.*

1 Introduction

Electric Vehicles (EV) are the future of transportation and a possible solution to reduce the greenhouse gas emissions. But electric vehicles are run on batteries that are less energy dense when compared to the fossil fuels used in Internal Combustion Engines (ICE). This has given rise to range anxiety along with other concerns such as expensive batteries, poor charging infrastructure and huge recharge times when compared to a fill-up at the fuel station. Automotive companies, old and new, are constantly working on improving the range on their EVs, mostly by installing batteries with higher capacities. This in turn leads to an increase in the cost and weight of the vehicle. However, there is one solution being researched that could make EVs as competent as their ICE counterparts and it involves providing them with a continuous supply of energy while on the move. The energy supply can be used either to charge the batteries or for direct propulsion purposes. With batteries being the most expensive component in an EV, a simple upgrade in the current road infrastructure could help manufacturers downsize batteries and offer their vehicles at a lower cost. Similar to electric rails, electrified roads between cities is a concept that has been gaining popularity in the world of EVs. The concept is based on the principles of dynamic charging wherein Electrified Road Systems (ERS) [1], supply EVs with energy from the grid and either directly propel or charge the batteries of an EV. With Autonomous Electric Vehicles[1] being touted as the future of personal mobility, dynamic charging systems just might be the solution enabling their growth.

2 Types of charging a EV

With the help of ERS, there are distinctive technological arrangements available that transfer energy to the vehicle from the roads. Based on the contact between the source and EVs, there are two types of charging. [2] 1. Conductive Power Transfer (CPT) 2. Inductive Power Transfer (IPT). Conductive Power Transfer technology involves drawing power from overhead transmission cables, similar to electric trains, by establishing a physical contact with the Electric Road Systems. Inductive Power transfer is wireless power transfer between the coil under the road and another coil mounted underneath the vehicle. Besides these there are a few more methods like Magnetic Gear Wireless Power Transfer, Resonant Inductive Power Transfer and Capacitive Wireless Power Transfer[2]. Resonant Inductive Power Transfer (RIPT) is a popular technique which uses two or more tuned resonant tanks which resonates at same frequency[3]. RIPT edges out IPT on increased range, higher frequency operation, higher efficiency and reduced electromagnetic induction (EMI).

2.1 Conductive Power Transfer

In conductive type, the car or truck uses energy that is directly drawn from the grid. Based on how electricity is drawn, conductive can be classified into two types: 1. Overhead/Catenary 2. In-road rail

Fig. 1 Conductive Power Transfer(Overhead) for Electric Vehicle[4]

2.1.1 Overhead/Catenary

In overhead/Catenary conduction systems, the vehicle is supplied with electricity from overhead power cables. The vehicle is equipped with an extendable pantograph power collector that can connect with the overhead cables at any highway speeds. Power is directly supplied to the vehicle's powertrain. It is a proven technology that has already been in use across the world, driving trains and trolley buses. Overtaking, first and last mile connectivity are ensured by virtue of batteries or a hybrid drivetrain which employs conventional internal combustion engines. Siemens is currently testing the technology on freight trucks in Sweden (Gavle) and Germany (Frankfurt) [1], [4] and [5].

2.1.2 In-road Rail

Fig. 2 Conductive Power Transfer(In-road Rail) for Electric Vehicle[6].

This type of conduction involves drawing power from rail tracks embedded in the road. The tracks, in or on top of the road surface, are segmented and electrified as and when an approaching vehicle is detected. Once the vehicle aligns with the groove, a moving arm attached to the bottom of the vehicle automatically lowers itself and draws power. Power is drawn from the grid with the help of conducting elements located under the road. Due to shorter distance between the power source and the vehicle, this type is applicable to all vehicles including cars, trucks and buses. This method is currently being tested by the Swedish Government on a 2km stretch near Stockholm[1].

2.2 Inductive Power Transfer

Inductive Power Transfer (IPT) is a contactless power transfer system that supplies electricity to vehicles without any mechanical contact. The principle of IPT is the same as that of a transformer, but the distance between the coils is larger in IPT. The primary coils are installed into the road and the secondary coils are firmly fixed underneath the vehicles. On supplying high voltage, high frequency AC source to the primary coil, the EV receives a magnetic field when it passes over these coils and converts the AC to DC either to charge the battery or for propelling the vehicle. Considering present generation EV's, IPT method reduces the total battery requirement by 20% .

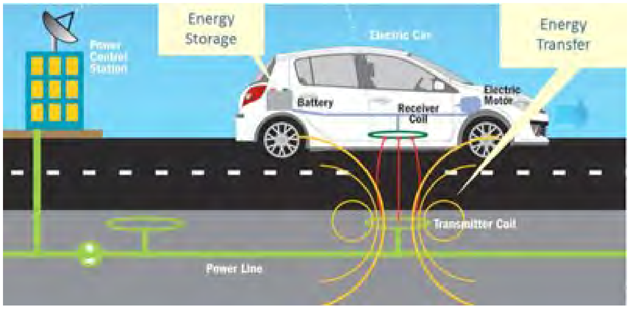

Fig. 3 Inductive Power Transfer for Electric Vehicle[7].

Fig. 4 Inductive Power Transfer for Electric Vehicle[7].

3 Future Concepts

3.1 Primove Highway- Bombardier

The Primove Highway system by Bombardier[9] uses inductive charging to charge the heavy vehicles and power transfer above 150kW is achieved for speeds between 20-70(km/h).Very small magnetic fields which are below the standard exposure limits are found and this system is designed to operate in all conditions.

3.2 Dongwon OLEV

Dongwon OLEV charges electric vehicles wirelessly while moving by using electromagnetic induction. An efficiency of 91% is achieved with power ranging between 12-85kW and suitable for buses, passenger vehicles and Light Duty Vehicles[1].

Table 1 Comparison of different Power Transfer Systems[2] and [8].

Type of charging	Cost (Million Euros)	Efficiency	Power	Frequency(kHz)	Safety
CPT(Overhead)	1.7-4.1	Medium/High	High	16-100	Low
CPT(In rail road)	1-1.5	Medium/High	High	16-100	Higher
IPT	1-2	Medium	Medium/High	10-50	Medium
RIPT	1-2	Medium	Low/Medium	10-150	Low

eHighway by Siemens , Elways by Elways AB and eRoadArlanda, Slide-In/ APS by Alstom and Volvo, ElonRoad by Elon Road Inc. and Lund University are the ongoing research works using conductive power transfer. [1]. INTIS by Integrated Infrastructure Solutions(Sweden) , Momentum Charger by Momentum Dynamics, Unplugged by European Consortium are a few of the ongoing researches involving inductive power transfer.[1]

3.3 Hybridization of Energy Storages

The hybridization of energy storage involves combining two or more energy storages together for better overall performance. Hybridization of chemical battery with an ultracapacitor can achieve high specific energy and high specific power. Hybridization of the fuel cell system with a peaking power source is also an effective technology to provide excess energy when required [10].

4 Conclusion

Conductive and Inductive Power Transfers have a lot of potential as they can be implemented with minimal improvements to the present infrastructure. Even though Conductive Power Transfer (CPT) technology has been in use for decades, CPT-overhead cannot be uniformly applicable to every type of vehicle due to the variation in sizes of light motor vehicles and heavy duty vehicles. While In-road rails can be used by vehicles of all sizes, the rail grooves can prove dangerous to motorcyclists plying on these roads. Inductive Power Transfer (IPT) and Resonance IPT are more convenient in this regard, but they do not have a power transfer rate high enough to meet the requirements of heavy duty vehicles. With the backing of Governments, more research and experiments are underway to improve on these technologies and Just in Time Energy-Reception in EV's could soon be the norm.

REFERENCES

[1] PIARC. Electric road system. `https://www.trafikverket.se/contentassets/2d8f4da1602a497b82ab6368e93baa6a/piarc_elvag.pdf`, 2018. Accessed on 2019-10-09.

[2] Panchal C, Stegen S and Lu J. Review of static and dynamic wireless electric vehicle charging system. *Engineering science and technology, an international journal*, vol. 21, no. 5, pp. 922–937, 2018.

[3] Mayordomo I, Dräger T, Spies P, Bernhard J and Pflaum A. An overview of technical challenges and advances of inductive wireless power transmission. *Proceedings of the IEEE*, vol. 101, no. 6, pp. 1302–1311, 2013.

[4] Scania. `https://www.scania.com/group/en/worlds-first-electric-road-opens-in-sweden-2/`. Accessed on 2019-10-09.

[5] Siemens. `https://new.siemens.com/global/en/products/mobility/road-solutions/electromobility/ehighway.html`. Accessed on 2019-10-09.

[6] eroadarlanda. `https://eroadarlanda.com/about-the-project/`. Accessed on 2019-10-09.

[7] `http://evtalk.co.nz/nz-wireless-electric-/vehicle-charging-technology-takes-major-/step-forward/`. Accessed on 2019-10-09.

[8] Musavi F, Edington M and Eberle W. Wireless power transfer: A survey of ev battery charging technologies. *2012 IEEE Energy Conversion Congress and Exposition (ECCE)*, pp. 1804–1810, 2012.

[9] Bombardier. Primove-bombardier. `https://rail.bombardier.com/en.html`. Accessed on 2019-10-09.

[10] Ehsani M, Gao Y and Emadi A. *Modern Electric, Hybrid Electric, and Fuel Cell Vehicles: Fundamentals, Theory, and Design, Second Edition*. Power Electronics and Applications Series. CRC Press, 2009.

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