PRANDTL'S BEST WING SYSTEM

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Minimizing induced drag

Innovation in the field of Aerospace Engineering is driven by the need for more sustainable aircraft with lower emissions, lower operating costs and lower noise pollution: 'sustainable growth'. These goals for the future have never been more relevant than now with the weak economy, global warming and the ever-growing need for air travel. That is why engineers are beginning to look for unconventional solutions for the future of aviation.

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SUSTAINABLE GROWTH

There are multiple fields in Aerospace Engineering where there is room for innovation to attain sustainable growth. The most prominent fields are propulsion and material technology, but also innovation in air traffic management, accident survivabilty, passenger comfort and many others play a role. A more drastic way to achieve sustainable growth would be to look at completely new aircraft configurations. A lot of research is already being done on several new concepts, the possibly most well known is the blended wing body. There are, however, many more innovative concepts under development, one of the most interesting being the Prandtl plane.

REDUCING DRAG

Reducing the drag on aircraft is one of the most important ways to create more fuel efficient and therefore more economically competitive aircraft. A drag reduction of just one percent can save 400,000 litres of fuel and 5000 kg of emissions per year (W. Schneider, 2000). The two most important types of drag for aircraft are parasitic drag and induced drag. Parasitic drag is created by air hitting the front of an aircraft. Induced drag is created when a wing produces lift and the high-pressure air from beneath the wing and low-pressure air from the top of the meet, generating a vortex at the wing tip. This effect depends mostly on the shape of the wing and the lift coefficient. Currently on many aircraft, winglets are used to reduce the effect of wing tip vortices. The Prandtl plane takes the concept of these winglets to a whole new level in an attempt to eliminate the wing tip vortices.

THE CONCEPT

The key attributes of the Prandtl plane are its wings, which form a closed box-wing system. The two wings are connected to each other with long winglets and are attached to the fuselage at the front and at the tail of the aircraft. This configuration is named after the German scientist Ludwig Prandtl whose research in the early 20th century formed the basis for (in)compressible aerodynamics. In 1924, Prandtl published a paper in which he described that the box-wing configuration could reach much lower values for induced drag than equivalent monoplanes (Figure 2). Additionally, an optimum equivalent triplane will have a lower induced drag than the biplane version. This effect holds when the number of wings is increased towards infinity. Prandtl called this the 'best wing system' (L. Prandtl, 1924). However, when the number of wings is increased the design becomes increasingly more impractical due to problems with the manufacturing and parasitic drag. Therefore current research only focuses on biplane configurations.

To obtain this minimimum induced drag several conditions must be satisfied. The lift distribution and the total lift must be equal on both wings and the vertical wings should have a butterfly shaped lift distribution. The efficiency can be further improved by decreasing the vertical distance between the wings and increasing the wingspan (L. Prandtl, 1924). Researchers from multiple universities in Italy have done extensive research on Prandtl planes in the early 2000's. Their research led to several results. For example, to satisfy the aforementioned condition of equal lift on both wings the high rear wing should be connected to the top of the vertical tail. Another conclusion was that the reduction of induced drag still occurs with high-lift devices extended, as long as they are extended equally on both wings. Most importantly the researchers concluded that that the Prandtl plane configuration

Figure 1. A mockup of the AOK_Spacejet as on display at the Paris Airshow 2013.

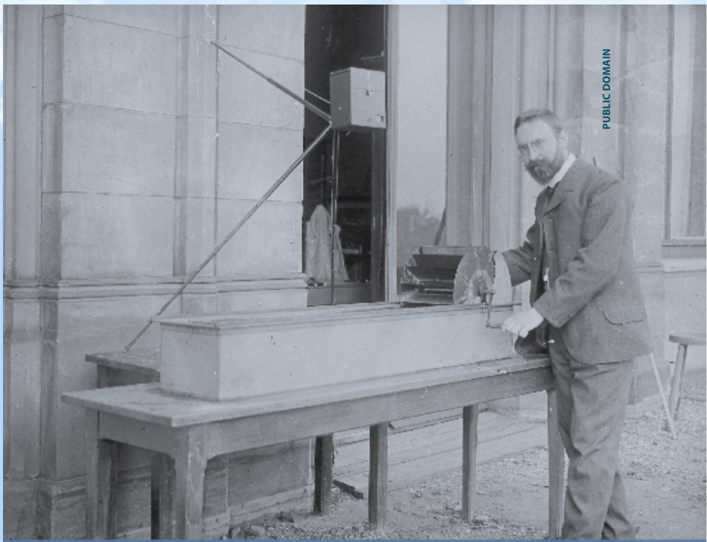

Figure 2. Ludwig Prandtl with his fluid test channel.

could reduce the amount of induced drag up to thirty per cent with respect to an optimum monoplane, which is quite significant (A. Frediani, 2005). Currently, TU Delft is also doing research on the Prandtl plane.

The design also has several other advantages besides the reduction in drag. It provides much more room for high-lift devices, its box-shaped wings provide high strength against torsion and high stability of flight. But there are also some disadvantages that come with this design, most importantly the problems with storing the landing gear and fuel and a complicated pitch control system (A. Frediani, 2005).

APPLICATIONS

The Prandtl plane is a versatile aircraft concept and can be adapted for various aircraft designs. The design is well suited to be used for small sporting aircraft as they fly at lower airspeeds where the effect of induced drag is much more important than at high airspeeds. The extra parasitic drag this concept experiences from its larger frontal area due to its biplane configuration also has a smaller impact at lower airspeeds. The AOK Spacejet, brainchild of the French aircraft designer Remi Cuvelier, is a great example. Its maiden flight is scheduled later this year. A mockup was presented during the Paris airshow 2013 and it can be seen in Figure 1. Another example of a single-seater Prandtl plane is the Finnish FlyNano Nano. It has succesfully completed its first flight in 2012, but is not yet in production.

Even though well suited for smaller, slower aircraft the Prandtl plane can just as well be used for large aircraft. In fact, the Prandtl plane has the potential to easily outclass the Airbus A380 in terms of capacity. This is significant as current generation aircraft are limited in dimension to a 80x80 m square surface area to be compatible with current airports. For that reason, current aircaft cannot be bigger than the A380 (A. Frediani, 2005). The Prandtl plane has the possibility to increase the width of its fuselage where the A380 has not, for the biplane configuration allows for shorter individual wings. Because of this quality the Prandtl plane is also very suitable to be adapted to a cargo aircraft. It can be designed as a wide-body aircraft that is close to the ground such that it provides lots of room for cargo and is easily loaded. Probably the most effective design would be a combined passenger/cargo aircraft.

OTHER CLOSED WING CONCEPTS

The box-wing is not the only shape of a closed wing system that has been explored; there have been several different types that have been suggested throughout the history of aviation. The earliest example would be the Blériot 3 built by French aircraft builders Louis Blériot and Gabriel Voisin in 1906. It consisted of two elliptical wings, one in the front and one in the back. Unfortunately, the aircraft was never able to succesfully lift off. Famous aircraft designer Ernst Heinkel and the French company SNECMA both researched the coleopter design, which can only be described as a fuselage built straight through a ducted fan. It has the capability to lift off vertically and then fly horizontally using the duct as a circle-shaped wing. However, after SNECMA tested the design it proved to be too unstable and dangerous to fly so the development was halted. Lockheed also worked on an aircraft with a circular wing called the 'Lockheed Ringwing'. The wing of this aircraft forms a swept back ring around the aircraft. The wing is connected to the fuselage at the bottom, and to a taller than normal, forward swept vertical tail at the top. The design, however, proved to be quite impractical and research was discontinued. A recently patented new type of winglet called the spiroid also aims to reduce the amount of induced drag by forming a closed loop winglet at the wingtip. It is currently being tested by the company Aviation Partners, based in Seattle.

ENGINEERING THE FUTURE

The Prandtl plane is a concepts that will change the future of aircraft design. But it is far from being the only one. Even though designs as the Prandtl plane and the blended wing body are still far from being realised as passenger aircraft, it is good to learn that innovation in the aerospace world is still thriving.

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Aviation Department

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