One of last year’s Design Synthesis Exercise (DSE) groups dived into the concept of fuel saving by letting aircraft fly in formation. They took their project even a step further and applied for the National Aviation Prize, a contest which encourages innovation in aerospace applications. The prize was taken to Delft, and the reason why is explained by team member Tobias Gutleb.

Formation flying for airplanes sounds as a rather new concept, can you explain what it is and is it as new as it sounds?

Let me answer your second question first, because it is rather important to make this very clear. Actually formation flying is not a new concept and the advantages have been known for many years. There have been several studies of commercial and military airplanes flying in formation, but until now only the military is using extended formation flight. The main purpose of military formation flight however, is to decrease the chance of being detected by radar. As with many things, only now, where we face increasing oil prices and more and more pressure to reduce the carbon footprint of flying, such ideas are looked into again.

During our project we actually were the first that looked at the feasibility to implement formation flying together with the next generation of aircraft around 2030. We did this from an operations, aircraft design, aerodynamics, and control point of view. The reason why formation flying is such a promising idea is that it can save huge amounts of kerosene, especially over long distance flight. By benefiting from the wing tip vortices of the leading aircraft, a total formation can reduce its induced drag by approximately 36% according to our simulations. When you compare this to a similar aircraft, such as the B787, energy savings of up to 54% can be achieved for a typical mission.

The exact reason why this works is because a trailing aircraft can fly with its wing tip in the upwash region of the wingtip vortex of the leading aircraft. This results in tilted lift and drag vector, which results in an increase in lift and a decrease in drag.

Where did your inspiration for formation flying come from?

Of course it is not very hard to see the link with migrating birds. Geese for instance travel several thousand kilometers every year and they only can do that because the fly much more efficient in formation, compared to their solo flight. So in light of this and the fact that airspace becomes more crowded every year, the idea to combine several airplanes into one single formation, according to not only save fuel, but also airspace, seems quite logic.

However, for us it was also part of the project description, provided by our tutor Wouter Beelaerts van Blokland. The main goal was to research if it would be feasible to implement formation flying from a technical, operational, and value driven point of view. So if it is actually possible to fly in formation, if there is enough demand and traffic, and if it makes economic sense to do so.

What are the biggest challenges in the specific design of airplanes and how can these be solved?

When we were designing the aircraft ca-
pable of formation flight we found out that there are several aspects one has to account for. Firstly, due to safety, aircraft will fly in an echelon (dash) formation instead of the typical “inverted V” formations, like birds do. Due to this, only one wing experiences the benefit of the leading aircraft and this results in an asymmetric lift and drag distribution. This will again lead to an undesired, pitch, roll, and yaw moment. The pitch moment can be relatively easy trimmed out, but the other two pose some bigger problems. The yaw moment could also be trimmed out, but at cruise speed the needed deflection would result in structural failure of a conventional rudder. In our design we solved this by increasing the strength, and thereby the weight, of a conventional tail. With traditional engine placement under the wing, the yaw moment could probably also be counteracted by trust differentiation. Flying with a sideslip angle is however not an option, since this would negate all positive effects of the formation. The roll moment lastly was in our design counteracted by a morphing wing, which is currently under development at our faculty. This is also the biggest question mark for the actual realization of our design, since such a structure is completely untested. If future, more detailed, studies show the same savings as our simulations, we are sure that emphasis would be shifted to systems necessary for formation flight.

**How many airplanes can fly in one formation?**

According to our calculations, flying in formation is already very beneficial from three airplanes on. Formations should however be as big as possible as it can be seen from figure 1 that with increasing formation size, the average benefit for every aircraft increases until a formation of around eighteen aircraft. From an operations point of view there is already enough demand today, with over thirty aircraft leaving from Europe to the US every hour during peak hours. Still, for our simulation we used a formation size of seven aircraft, leaving from four airports in Europe with several destinations along the east coast of the US.

**Could it be implemented for continental flights too?**

A recent study of MIT, also about the feasibility of formation flight, looked especially at continental formation flight. In that case however, aircraft almost certainly would have to perform parallel runway starts. Otherwise the time the aircraft had to wait for each other to fly in formation or the distance penalty for not flying the ideal route would outweigh the benefits on such short distances. Nevertheless, once we master intercontinental formation flight, I wouldn’t rule out a continental solution as well.

**Is it possible to combine different aircraft or is it preferred to use only one type?**

That is something we did not really include in our simulations, although it is clear that combining multiple aircraft with a big difference in size and weight, will result in a wider variations in optimal cruise speed and altitude. Since the entire formation, more or less, has to fly on the same altitude and speed this results in more penalties when flying in formation. So ideally a formation would consist out of aircraft of similar size and weight, but from a technical point of view, there is no reason not to combine aircraft of different types.

**What happens when a failure or accident happens in the air?**

To fly in formation a new type of autopilot is needed that can control the aircraft to such an extend that flying in close proximity (about ten spans) behind each other, does not impose unacceptable risks. The good thing is, is that the navigation for such a system is already in place. When using a carrier phase based positioning system, accuracies of up to centimeter level can be achieved. Once the European Galileo system is in place normal formation flight should be no problem. In the case of extreme weather conditions or unexpected events during formation flight, the aircraft would increase the relative distance or leave the formation com-
It must be said that an aircraft capable of flying in formation is also a very good aircraft flying solo and it should always be possible for the aircraft to reach its destination or another safe airport solo.

Is it necessary to change air traffic control for formation flying?

In our concept we envisioned a Formation Regulation And Control (FRANC), which coordinates the formation. In the scenario we simulated, the formation would be formed above Ireland and collectively cross the Atlantic, after which it would break apart above the Canada. For the forming and break-up process FRANC would be responsible, but for the actual crossing of the Atlantic the entire formation would communicate as if it was one single entity. That is thus the reason why this concept would decrease pressure on ATC and airspace.

In the beginning the forming of the different formation during the course of a day will probably be quite a devious task, but we think that in time, and with an increasing number of airlines operating formation flying capable aircraft, the entire system will be dynamic. This means that an automated system combines scheduled flights into optimal formations, both the number of aircraft as the exact formation location.

Another thing we envision FRANC to do is the cost and benefit division. In our opinion the concept can only work efficiently if multiple airlines work together. Due to different origins, destinations, and weight of the aircraft, the benefit, and therefore also cost, must be divided in a fair manner between all participating airlines.

Which target group do you have in mind and how would you sell your product to them?

One of the partners of the project was Airbus and they have expressed interest in further investigation of this concept. Boeing is also currently working together with NASA and MIT on further development of formation flying. A study of MIT, published in December 2010 came to almost the same conclusion as we did, and although their work was much more elaborate (they even had real flight tests with several F18’s) we certainly touched on some new areas. So to conclude, a collaboration with MIT on this is planned and of course involvement of at least one of the major manufacturers.

You won the National aviation prize (NAP), how are you planning to evolve this flying concept further using the money you have won?

This was of course a great experience. To reach that far and to actually win that prize was really amazing, see figure 3. It shows that if you are dedicated and enthusiastic about your project, you can really contribute to the scientific world. We had a great team and to be fully honest put in a lot more effort than average. Not because we had to, but because we wanted to. All of us enjoyed working on this topic and it was easy to work some late hours. Besides winning the National Aviation Prize, we also wrote two papers that both got accepted and will be presented at the 11th Aviation Technology, Innovation and Operations (ATIO) conference in late September of this year in Virginia Beach, US. The money won with the NAP will be used to pay the registry fee, transport and stay for this and future conferences. With visiting those conferences we want to further increase awareness and support for this concept. Four of us are currently also writing a proposal for a EU research program around formation flight. Hopefully this will also be accepted and more research can be done.

We also created a website to keep track of everything related to this concept. On this website there are also some movies that explain the entire concept in more detail. The address of the website is: www.formationflying.nl.