Let’s start the clear sky revolution
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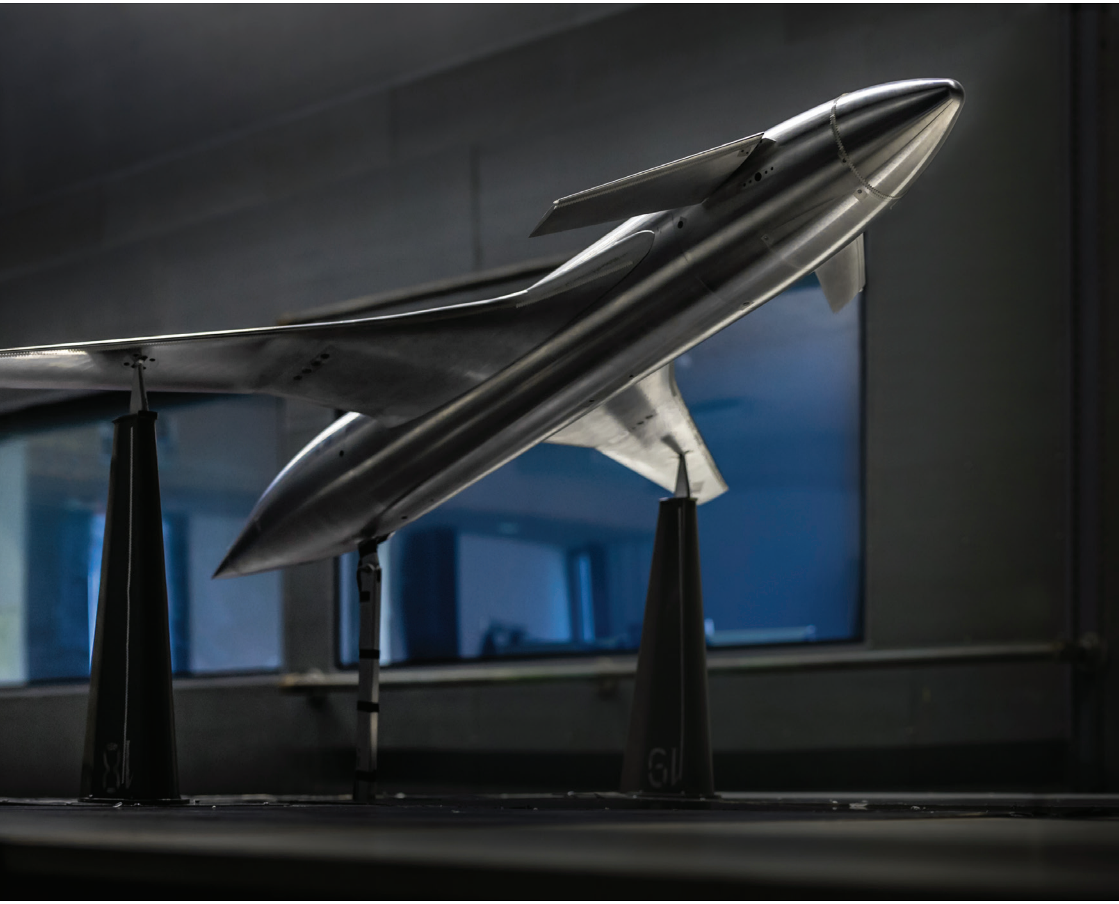
Faculteit Luchtvaart- en Ruimtevaarttechniek

Intreerede prof. dr. H. G. C. Werij
'Let's start the clear sky revolution'



TU Delft

Intreerede 6 april 2018

‘Let’s start the clear sky revolution’

Uitgesproken op 6 april 2018
ter gelegenheid van de intreerede voor het ambt van
decaan en hoogleraar faculteit Luchtvaart- en Ruimtevaarttechniek

door

Prof. dr. H. G. C. Werij

Mijnheer de rector magnificus, leden van het College van Bestuur,
collegae hoogleraren en andere leden van de universitaire gemeenschap,
zeer gewaardeerde toehoorders, ladies and gentlemen,
Thank you all for being here to witness my inaugural address as Dean of Aerospace Engineering at Delft University of Technology.

During this address I want to give you an insight in some of the challenges, we, the world, are facing, the role of aerospace in all of this and the direction we could or better should be heading. I will point out the relevance of all departments within our Faculty of Aerospace Engineering with respect to the required developments, but I will also make clear that the expertise of other parties, including several other faculties at this University is crucial as well.

I hope that I can take away some misconceptions regarding aviation, which I often hear in the outside world. But most of all, I hope to inspire you, my audience and our many students from all over the world to set off a much required change. No evolution but a revolution.

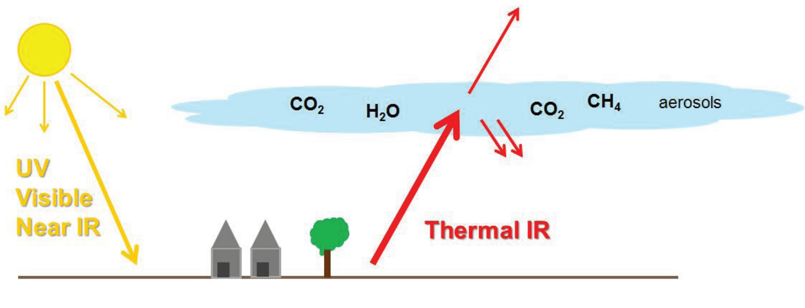


Fig. 1. Simplified picture explaining greenhouse effect

The title of my talk is ‘Let’s start the clear sky revolution’. Before I go into the actual topic of my address, which is about sustainability and about the combination of sustainability and aviation, I just want to zoom out and recap some facts about what’s happening to the climate. Actually, what I say here is fact, not fiction. I know that there is a lot of discussion, but we are talking about facts. The processes in the atmosphere are generally extremely well understood. The basic principle is as follows: Our Earth is illuminated by the Sun, mainly by ultraviolet, visible and near-infrared light. These contain the wavelengths that we can see (our eyes are sensitive to the most intense parts of the solar spectrum).

In return the warmed Earth radiates outward long-wavelength thermal infrared light. The ultraviolet, visible and near-infrared radiation passes through the atmosphere nearly unobstructed, but the outward thermal-infrared radiation is blocked a little bit by constituents like CO_2 and water in the atmosphere. These act like a blanket and keep the Earth warm. This so-called greenhouse effect is very fortunate for us, because otherwise we would not be here.

The problem is that we, humans, have put a lot of extra carbon dioxide and methane in the atmosphere, thereby increasing the insulating layer. The thermal-infrared radiation cannot escape as well anymore, and the balance, the equilibrium, is disrupted. As a result the atmosphere and the Earth start to increase in temperature. You have probably all seen these pictures before, but I want to show them again anyway. What we see here (Fig. 2) is the CO_2 content in our atmosphere during the last 1000 years. The first measurements are from trapped air-bubbles in ice cores. These are direct measurements that show that when the population of the Earth started to increase, and the industrialisation took off, the CO_2 content in our atmosphere, here expressed in parts per million, also really started to rise. We are now above 400 ppm.

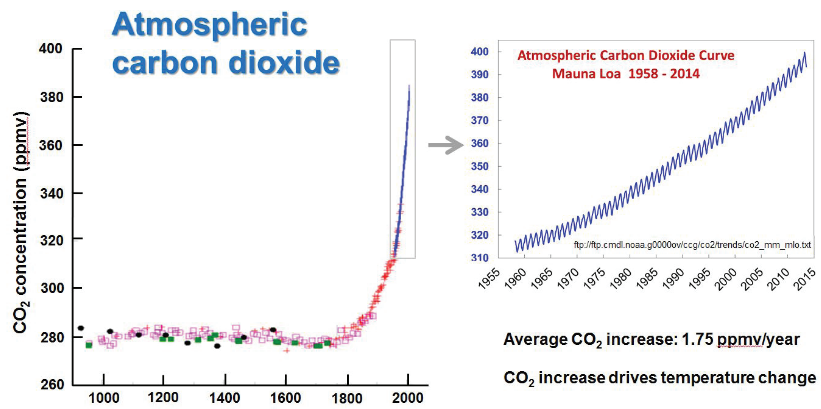


Fig. 2. CO_2 content in our atmosphere during the last 1000 years

I know that some people say: ‘This has already been going on for ages. There have been large fluctuations in the past’. Yes, that is absolutely true. Take a look at Figure 3: we indeed had wild fluctuations with the lows corresponding to the Ice Ages. These fluctuations were related to the orientation of the Earth’s axis and the activity of the Sun. What happened in the last 100 years is what we are talking about now. So please, nobody should say that nothing is going on.

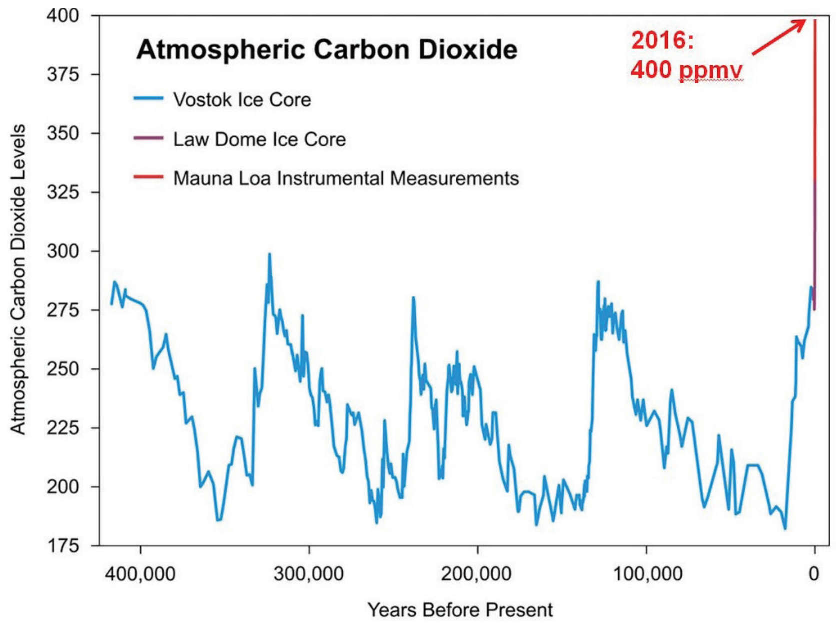


Fig. 3. Atmospheric CO_2 concentrations during past 400.000 years.

Then, can we understand why this is happening? The atmosphere and Earth may appear big, but are they? If we look at the Earth's atmosphere, it is indeed tens of kilometers high, but the further up, the thinner it becomes. The point is, if we would compress our atmosphere into a layer, which has a density comparable to where we live at sea level - meaning a pressure of one atmosphere - it actually is only 8 km thick. That is not a lot. It is less than the highest mountain on Earth, the Mount Everest, which measures close to 9 km. If you want to get a good idea of how thin the Earth's atmosphere is, just put a few layers of scotch tape on a standard size scale model of the Earth. This thin tape layer -on this scale it is only 200 micrometers thick - then represents our atmosphere! So the layer of our atmosphere is thin.

Then, on the other hand, the Earth is big, so plenty of space, you could say. However, take a look at this image of the Earth, taken from the International Space Station (Fig. 4). It shows that actually our entire Earth is populated. We have people all over the place, so you can understand that altogether we really do have an impact.

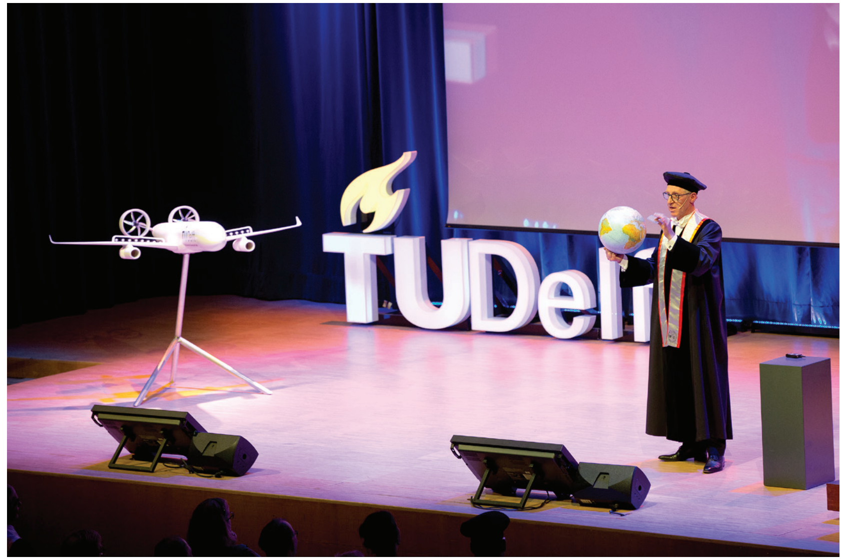
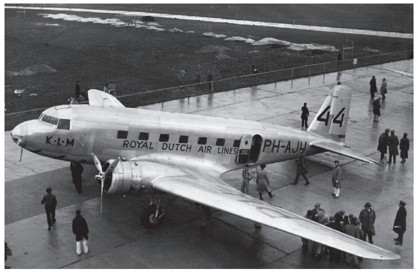


Fig. 4. The Earth at night, seen from the International Space (picture: NASA)

So, after this introduction, how does all this relate to aerospace? To answer this question let's look at the history of aviation during the past century. It all started, you might say, in 1903 with the Wright flyer, the first heavier-than-air propelled plane. Then a lot of development took place in the first World War. Unfortunately, wars always stimulate a lot of innovation. The commercial air transport of civilians started after the war. We had planes like the DC-3 and later on the DC-4, the Constellation and so on. Those were the days, the golden age of aviation, when propliners were the means of air transportation (Fig. 5).

1903

1926



1935

1946

Fig. 5. *Era of propliners*

Then there was another World War, initiating a lot of innovation again. During that period the jet engine was invented, drastically changing aviation forever. In 1952 there was the Comet, a very well-known, but not really successful plane and after that airplanes like the Boeing 707. Now we have modern planes like the Dreamliner (Boeing 787) and the Airbus A350 (see Fig. 6).

1952

1957

2009

2013

Fig. 6. *Era of jetliners*

All these planes look very familiar: a long tube-shaped fuselage and narrow wings. Did any innovation take place at all in all those years? In fact, it did. Compare for instance the pure jet engines from the early days to today's big turbo fans. In Fig. 7 the fuel consumption of jet planes during the last 60 years is shown. On the vertical axis I put the fuel consumption expressed in liters per passenger per 100 kilometers. I did that because this is a number that might relate to what you see in your car. When you drive in your car, and it tells you have a fuel consumption of 5 liters per 100 kilometers', you probably think: 'This is going well'. What we see here on the plot is that it started at about 15 and that at the moment, we are at less than 4 liters per 100 kilometers per passenger. That is actually not so bad, and believe it or not, the planes not only became more efficient, they also became a lot quieter. The jet engines of the early days were extremely noisy and extremely polluting. Now, they are more efficient, i.e. cleaner, and they are quieter.

We see a decrease in energy consumption and fuel consumption, but this is completely offset by the enormous growth of the population and how often we fly. This is a graph of the world population and it's staggering. Throughout the last century population growth really took off and we went from a little over 1 billion people to 8 billion people (Fig. 8). It is frightening.

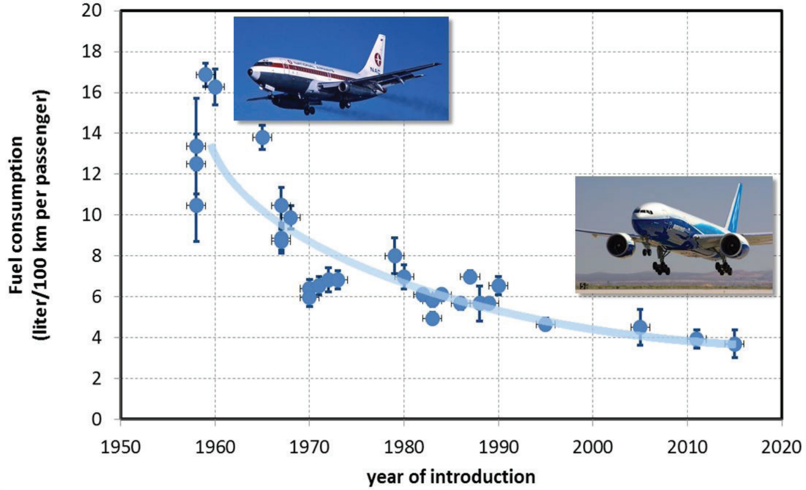


Fig. 7. Typical fuel consumption of jet planes (Source of data: IATA Vision2050 report)

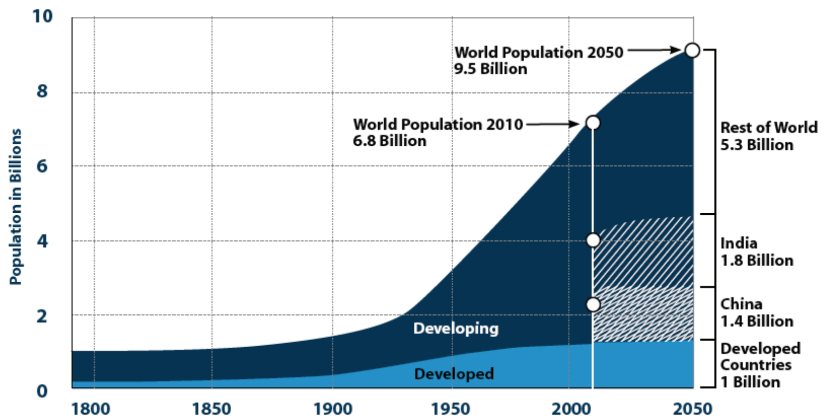


Fig. 8. Growth of world population
http://writings.basiliochen.com/?p=891

As we developed, we started to fly more, more often, and across larger distances. That leads to the following graph (Fig. 9), where I plotted the cumulated

passenger kilometers worldwide per year. The number on the vertical scale is actually so large, that it is hard to comprehend what it really means. What does 5000 billion passenger kilometers per year mean? When we look at the size of our solar system our furthest planet is Pluto, - well, it is nowadays not even called a planet anymore. Covering a distance of 5000 billion kilometers is the equivalent of travelling to Pluto and back 500 times! So that is what we are doing here, quite incredible.

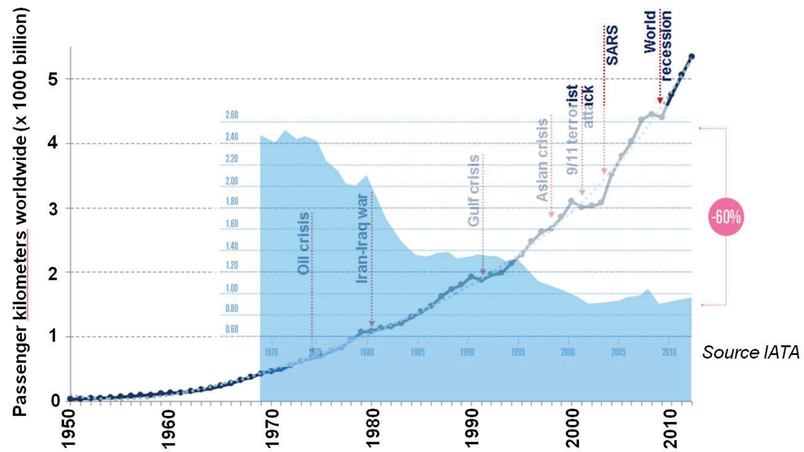


Fig. 9. Total number of passenger kilometers worldwide per year (left scale) plus graph (blue) showing price development.

The number of passenger kilometers is growing continuously at about 4.5-5.0% per year. This means that it doubles approximately every 15 years. At the same time the prices dropped quite a lot. Nearly everyone seems to like that. I often hear people say that we should fly less. What they apparently mean is ‘We should fly less, but not me, because I want to go on holiday’. What you see is that the price, of course corrected for inflation, went down by a factor of 2.5, making it fairly cheap to fly nowadays. If this trend continues we are definitely going to have a problem.

To put things into perspective, the fuel consumption of a plane as such is actually quite good. If you have the choice to go to Southern France by car on your own or by plane, it would be better if you took a plane, because it is more efficient. The problem is that we are flying such enormous distances and so many people are doing it. That is the main thing. One thing I would like to mention is that aviation currently accounts for about 2% of the global CO_2 emissions. That might be a bit less than what people think, but that's the number we have right now. Of course, if we continue like this and we bring down the CO_2 emission in other areas, the percentage related to aviation is going to grow. We will have to do something about that, which is the actual topic of my talk.

So what can we do? Here is a graph of a plane and it is actually showing in a simplified manner all the forces acting on an aircraft.

Of course, a plane has to defeat gravity; or else, it does not stay aloft. We need lift to defeat gravity and we want to fly forward and when something moves through the air you feel drag. Drag is also related to lift, like every aerodynamics person knows. In order to compensate for the drag we need propulsion.
You can for instance reduce weight. If a plane becomes lighter or if it is slicker, aerodynamically, we can reduce the drag, thus reducing the required energy (i.e., fuel) for propulsion. We can also make the engines more efficient, or we can use alternative fuels. We do not have to use kerosene for instance. Finally, we can also improve air traffic management, such that a plane flies more directly from A to B. At the moment the flight path isn't always the shortest distance. It has to fly a zigzag pattern from one airport into the other. There are ways to improve that as well.

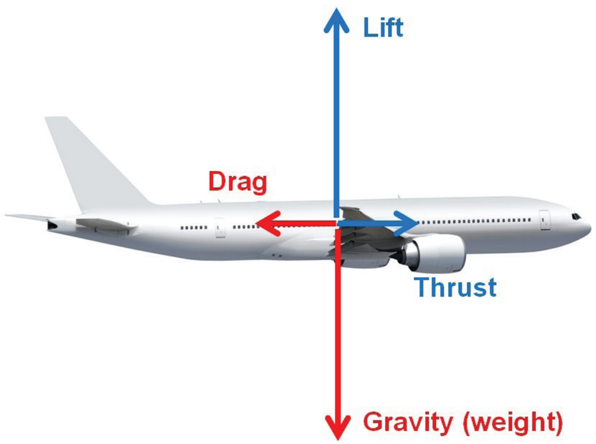


Fig. 10. Forces acting on an aircraft

All of this relates to what we are doing at this university and at this faculty. In reducing weight, we have to take care of the material choice. We want to improve the aerodynamics: we want to have very slick planes. We want to have different propulsion systems. It could be electrical propulsion. We could use biofuels, but need to figure out how to obtain them in a sustainable way. Finally, we have to do something about air traffic management. This is the line of my talk.

Now let's take a look at different energy carriers.

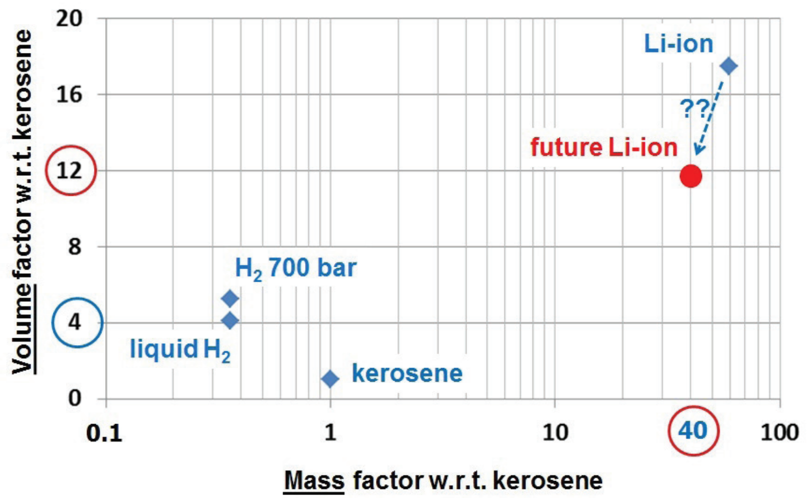


Fig. 11. Graph showing how much (or less) mass and volume is needed to carry same amount of energy as kerosene.

Figure 11 might be a little bit complicated, but what I would like to show here is a look at different fuels or, in this case, also batteries, compared to jet fuel. What I show on this graph is how much heavier the [alternative] fuel, or the batteries, are going to be compared to the jet fuel. And how much more volume we would need to carry the same amount of energy. For the equivalent of one kilogram of jet fuel we would need 40 kilograms of new types of lithium ion batteries that still need to be developed. What I did here is to extract a bit what could be possible in a few years from now. So, forty times heavier and at the same time this would take 12 times as much volume. You are seeing where we are getting into a problem if we want to get into lithium ion batteries. Another thing that is quite often mentioned is using hydrogen, either compressed or liquid. Hydrogen itself has more energy per weight, so it is a third the weight for the same amount of energy, but it requires about four times more volume. This could work, possibly. What we do have to take into account is the structures needed to carry compressed hydrogen (here at 700 bars) or liquid hydrogen, which it is at temperatures of 20 K (-253 °C). We need for instance cryogenic vessels and you can imagine this will add to the weight a bit as well. This is an important graph and it is important to remember: 40 times more weight if you want to use batteries.

Is that going to happen, 40 times more weight? It is one good thing that electrical engines probably are a factor of two more energy efficient than normal conversion engines, jet turbines. We gain a factor of two, but that still means we need 20 times as much weight to carry the same energy in order to cover your distance. And then, if you think about a modern airliner, it can take you 15 thousand kilometers, so you can fly from here to Australia in one go. These planes can carry about about 140 tonnes of fuel. Times 20 that would mean 2.8 million kilograms of batteries and that is never going to happen. This is not feasible.

Pipistrel

Extra 330LE - Siemens

Airbus E-Fan 2

Lilium

***Fig. 12.** Several electric aircraft*

Do I say that electric flying is not going to happen? No, that's not what I am saying. Electric flying is happening today and it is really a very interesting development. What I show here is a two-seater, a general aviation plane by Pipistrel. Then there is a plane developed by Siemens, who are doing a lot on electric engines. Also Airbus is active in the field of electric flight. And the futuristic plane we see here is not a computer animation. It's an actual flying prototype. This is designed as a two-seater flying with all electric engines. It will take-off vertically, reach a speed of 300 kilometers per hour and fly for about an hour and then land vertically. This is really a very impressive new development. There are new aerodynamics, new engine concepts and that is wonderful. But the point is that I do not think electric planes will be useful for the transport of a lot of people over really large distances. For small numbers of people and short distances, yes, I am sure it will happen.

Some people say, 'Let's put solar cells on the wings'. Yes, we can and it has been done.

In Fig. 13 we see a remotely operated NASA aircraft, which has a huge span. Its span is larger than that of a big airliner. As you can see, it is also very delicate. It actually broke in rough air. It flew very slowly, at less than 100 km/h with an extremely small payload. An example of a manned solar-powered plane is the Solar Impulse, which flew all around the world using only solar cells, so it is possible. At the moment in Switzerland, there are even plans to fly to the edge of space, or more precisely, into the stratosphere. The Solar Stratos team wants to go up towards 24-25 kilometers altitude using only solar cells, but again, huge wings, very slow flight, and a very small payload.

***Fig. 13.** Helios prototype in flight (picture NASA)*

***Fig. 14.** Solar Stratos impression*

What would happen if you take an A320, the one you take when you go on holiday, cover all the wings, take the best possible solar cells you can get, space-grade quality, and fly at the equator at noon? It is not what you typically do, but the sun is coming from above nicely. You only have 0.1% of the energy you need, which is hardly sufficient even for the on-board entertainment system. Thus, this is also not going to be the solution.

What is it going to be then? Actually, I think the only way to carry enough energy up into the sky for the larger distances is by means of some chemical energy storage. You need a fuel, or a compressed gas, and there are several possibilities. I think this is what we will have to work on.

Biofuels are a very serious possibility. At the TU Delft Faculty of Applied Sciences, colleagues are working on just that. The important point is that we have to take into account that biofuel has to be obtained in a sustainable way, so there are some issues there. We can also use synthetic fuels, by converting electricity into fuel, and we can convert electricity into hydrogen. And, as I said, hydrogen storage is a big challenge. We could use fuel cells, which is something the colleagues of Mechanical Engineering are working on. Whatever fuel we use, we have two options: we can burn them and just use them for combustion engines, or we use them to create electricity and in that way start using electric engines. I think that in aerospace the first development route we are going to witness might involve hybrid planes. That is a bit what you can see in this model over here, which we are working on in the faculty. We have engines, which are just turbine engines that use fuel, biofuel for instance. They convert this to electricity, which is being used to propel smaller, distributed engines over the wings and on the tail section. I think planes could start to look very different from what we see now.

Fig. 15. *Concept of a hybrid aircraft (turbines plus electric engines) developed at TU Delft.*

I was talking about electricity and considering this address is about sustainability, I want to make a small side step to another important development we are working on at this university and of course also at our faculty: it is about wind energy or let's say wings on a stick. I hope the colleagues over at Wind Energy do not mind me calling it like that. I want you to appreciate how large these wind

turbine blades have become. When you look at a picture of a modern windmill, you have no clue how big it actually is. Now compare this to a very big, modern plane like a Dreamliner, the plane that takes you to the Caribbean. It is a big plane, with a span of 60 meters and a huge, wide body. Now, I put this plane above a blade of this wind turbine. If you look like this, you see the enormous scale of these wind turbines, it is flabbergasting, and I would say it is an interesting development. Also in this area, a lot is being done to improve the aerodynamic quality of the wind turbine.

Fig. 16. *Dreamliner versus modern wind turbine*

Now let us go back to propulsion of an aircraft. The big advantage of using electric engines, compared to the turbo fans we are using nowadays, is that you can use many smaller engines distributed over the plane, over the wing. You see it on this model as well, here are seven smaller engines per wing propelled by electricity, and they have an effect on the airflow. They improve the aerodynamic properties of the wing, thus improving fuel efficiency. We also have electric engines at the very end, and it is all driven by electricity which in this case is created by the turbines up front. The coming developments will involve that we have to think about the distribution of the engines on planes. We will see many aircraft and engine designs, and we have to think not only about fuel storage space for alternative fuels (Fig, 17), but also about altitude and speed we are going to fly at.

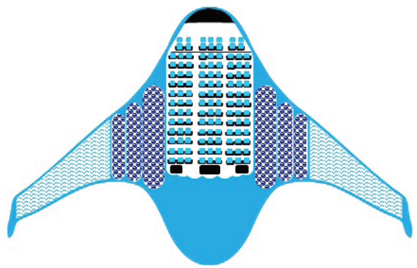


Fig. 17. *Passenger and fuel distribution in a blended wing concept*

Regarding modelling: to design a modern aircraft we have the possibility to use state-of-the-art modelling, using high-performance computational power. We can model and calculate the airflow, but at the same time, we now understand what happens when the airflow hits a structure. We can calculate where the sound is generated. How sound propagates? This is very important as well, because certainly in the Netherlands, we are extremely worried about noise. We know that we have to do something about that and that is what we are tackling as well.

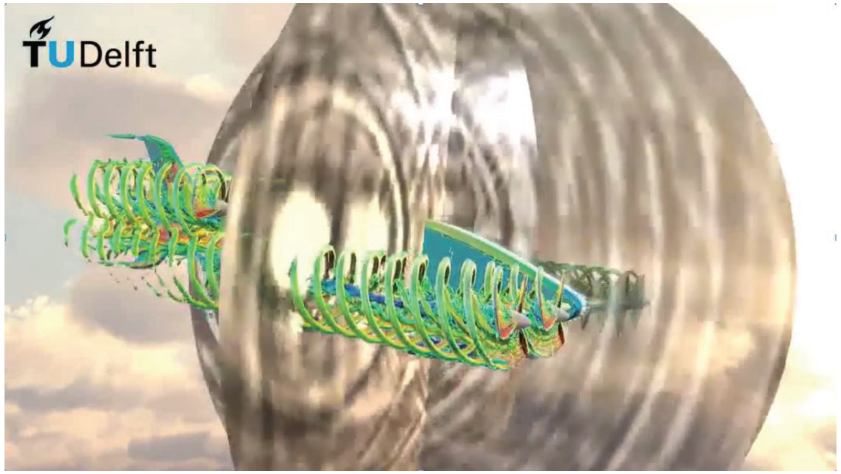


Fig. 18. Still taken from a movie showing calculated airflow as well as noise generation.

Once we have an aircraft design, we want to test its actual performance. For that purpose scale models are created. Such models are used in a wind tunnel (Fig. 19), of which we have several at our faculty. One of the inventions involves the use of soap bubbles filled with helium, - so that they are weightless - to monitor the airflow. You can monitor it using a high speed camera to see the airflow over a wing. We can calculate what is happening with the wings, the airflow, and the effect of turbulent airflow on the wings, and how to make it more efficient.

I was talking about weight, which is an important factor. We want to decrease this. We also want to include extra functionality in the materials we use. We do not just want to use it to support the airplane, but you would like to have other functionality in it as well. That is what we are working on as well. For instance together with industry, we are going to set up a smart advanced manufacturing lab, a robotized lab for large composite structures.

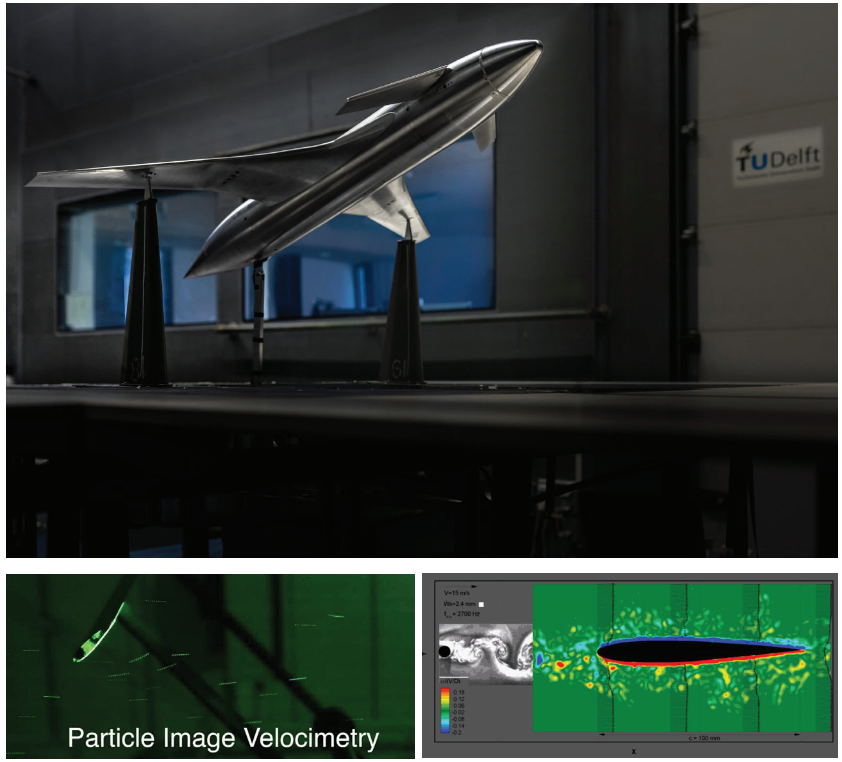


Fig. 19. Wind tunnel experiments

We are also working on self-healing materials. What you see here is a piece of material, which you cut and just put together again. After waiting a couple of seconds the cut had disappeared. When you start pulling at it hard, the material will break, but not at the place where you had the original cut. Imagine you have a new car and you get a scratch on it, wouldn't it be nice if it would just disappear by itself?

But we are talking about aviation. Hopefully, all of this is going to lead to different airplanes. You see that they sometimes look completely different from what we are used to. This is related to the fact that we use different engines requiring storage of different fuel as well, like hydrogen. In 20 years from now, things will look different and we should be at the forefront of this development.

Fig. 20. Stills from a movie showing a self healing material, taken less than one minute apart.

If we design something, we also want to test it. We do not only want the model, but we also want to know how a plane behaves in reality. This is why we make scaled models, and perform scaled flight-testing. I think this is going to be a very important development as well. In Fig. 22 we see an earlier model that we have flown. This is something we want to do quite a bit more at the faculty: to really build scaled models of the designs that we come up with and fly them.

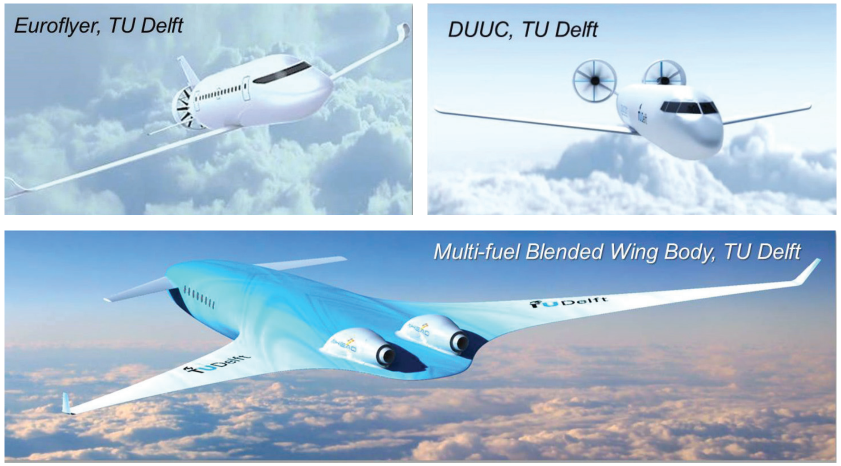


Fig. 21. Several aircraft concepts developed at TU Delft.

Finally, I want to mention the developments on fight path optimization. We are working on this with many parties including industry. We also look into topics such as continuous descent approaches (Fig. 23), where an aircraft descends like a glider instead of following a step-like path where you have to throttle up the engine all the time, thus making more noise, and using more fuel.

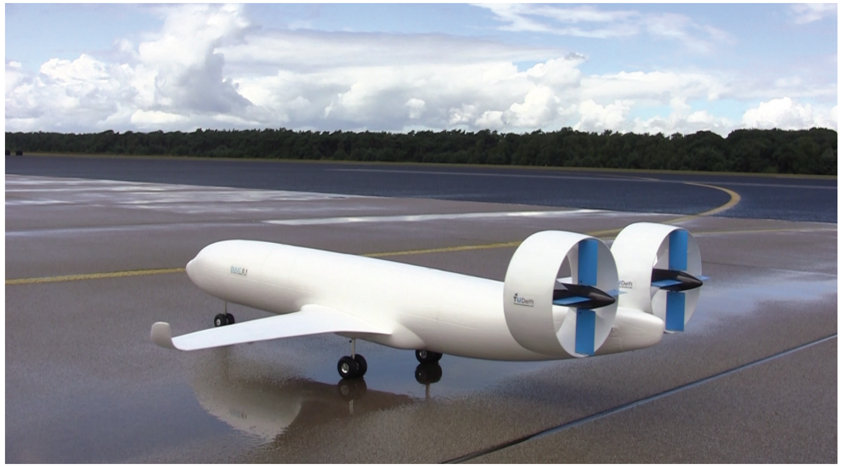


Fig. 22. Scaled flight testing of TU Delft aircraft concept

I talked about several ways to make aviation more sustainable, but even if we would start using hydrogen, we are going to affect to atmosphere. When burning hydrogen, we create water. Water is fine you would say, but water is also a greenhouse gas. It will not stay in the atmosphere forever, it is going to condense and become part of the water cycle. But something we are certainly

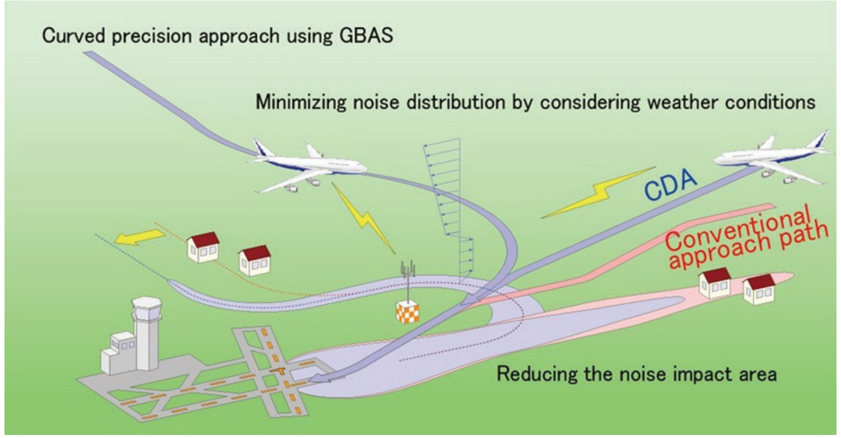


Fig. 23. Continuous Descent Approach

concerned about are contrails and high altitude cirrus clouds (Fig. 24), which lead to global warming as well. I think that this is something we really have to look into. Perhaps this means that we have to fly at a lower altitude, where the lifetime of the clouds is shorter, or where they do not build at all. I want to point this out, because this is an important area for future studies. Of course, we would have to make a trade-off, because when you are flying lower, you are flying slower and you need more fuel.

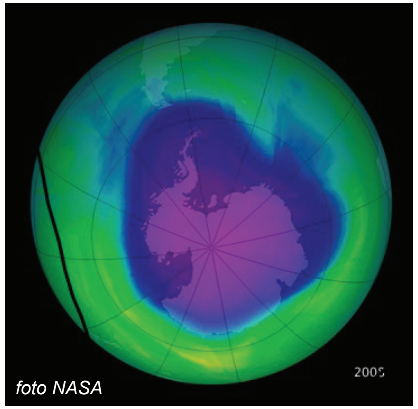
***Fig. 24.** Aircraft contrails leading to high-altitude cirrus clouds*

Talking about our atmosphere, let's change topic slightly and talk about what we are doing in space. Most people do not know what is going on here, and certainly in the Netherlands we do not appreciate enough what great things we are doing in this particular area. In fact, the Netherlands is a leading country in monitoring the Earth atmosphere (Fig. 25). During the past 25 years several instruments have been built here, in particular by the following parties:

TNO, renowned for its opto-mechanical designs, Airbus for its overall systems engineering, and KNMI and SRON responsible for the scientific part of these missions. These four parties built several instruments, which as I would say, continue to change the knowledge of our atmosphere.

***Fig. 25.** Dutch heritage: Three spaceborne instruments (spectrometers) for monitoring the Earth atmosphere*

Let me show you two graphs. The first one shows the ozone hole (Fig. 26). Because of all the measurements from space we performed on this ozone hole, we knew we had a serious problem. The amount of ozone above the poles was decreasing and thus we were losing a fundamental protective layer against harmful ultraviolet radiation. Because of this insight the world came into action. We banned certain chlorofluorocarbons and we now see that the ozone hole is slowly recovering. So we can really make a difference. This image by NASA by the way was made using one of the instruments developed here in the Netherlands, the Ozone Monitoring Instrument OMI.



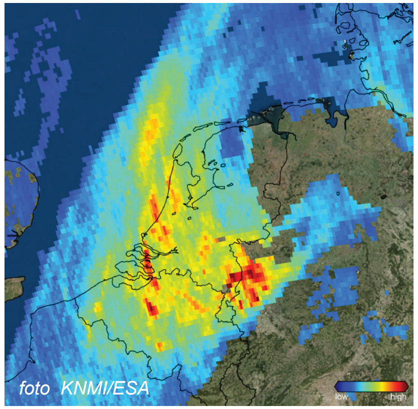
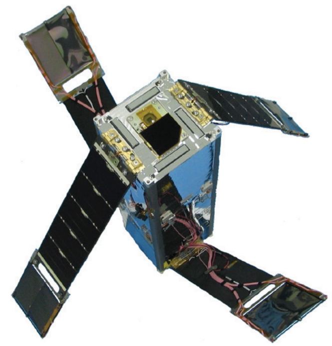


Fig. 26. *Ozone densities measured by the Dutch Ozone Monitoring instrument (OMI) on board of the NASA EOS-Aura satelite.*

Fig. 27. *Highly detailed NO_2 densities measured using the Sentinel-5 Precursor TROPOMI*

Next I show a picture of the NO_2 distribution above the Netherlands, measured with the recently launched instrument TROPOMI, and again the same parties were involved that I mentioned before. We see the NO_2 distribution with an unprecedented spatial resolution of about 3.5x7 kilometers. There is a southerly wind and we can clearly see Brussels, Antwerp, the Rotterdam area, the Ruhrgebiet district, and Amsterdam. You can imagine that it is important to know what is going on. If you do not know where the pollution is coming from, it is also harder to act. Again, the Netherlands is doing an incredible job in this area. And what are we doing at our university? The instruments that I mentioned are very big. They weigh several hundreds of kilograms and they are about the size of a washing machine. What we are working on is how to make things smaller. We are talking about so-called cube satellites. I do not want to go too much into detail, but here are some interesting developments: For instance we use engines working on water. And if you have a small instrument it would still need big optics to obtain a decent performance. How can you fit such large optics in a small satellite? For that purpose we are developing deployable optics, together with our partners. You can use the radiation pressure of the sun, from the incident photons, to propel your space vehicle, by employing a solar sail. Finally, you can use a constellation of very small satellites to measure something, for which you would otherwise need a big one. I think these developments are very relevant.



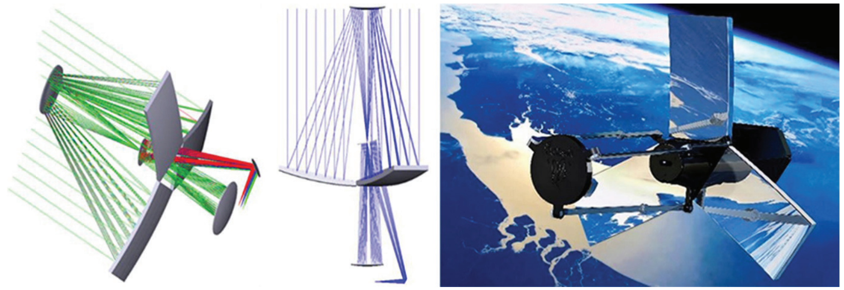


Fig. 28. *Deployable optics*

Now, after having heard all of this, how do we go forward? I was talking about the environment, the strong need for a sustainable future and I think that this is extremely important. We have to act now. It is not something that can be tackled by only looking for technical solutions. All the directions I discussed so far were just technical solutions, but you also have to take into account the economic feasibility. We have to think about the social acceptance as well. We really have to make sure we will be looking at all these aspects, because otherwise the required transition is not going to happen. Like I said in the very beginning, many changes came about during WWI and WWII. It is really too bad that it is wars that lead to increased innovation, but in this case, I think we are actually fighting a war on climate change. We can deny it, but it is here, and we have to do something about it. Drastic changes are needed and this requires that we bring all the disciplines together, not only the disciplines of my faculty, but also the disciplines of the other faculties, and many other parties.

We need the collaboration between academia, knowledge institutes, government, industry, and the general public. We all have to put our hands together and create the right boundary conditions so that changes are going to happen. Actually, what is most important in all of this is the mindset. We all have to get the proper mindset. And mindset is what is bringing me to the last sheets of my address. It is the most important thing we are delivering by being at a university, because what a university is about, it is not only about research, but also about educating young men and women. That is what we are doing; we are delivering hundreds and thousands of students who are going to get a job all over the world. These people have to have in their heads, in their DNA, that we have to be sustainable. They are going to change the world and this is going to be my appeal to them: go out, and change the world. We should do it now; you should do it and make it happen. This is the last official sheet of my talk, but I am not completely done yet.

What I would say is: let us start the clear sky revolution; this is what we have to do, all of us here, the industry, but certainly our students.

I want to finish this address by saying a few words of thanks.

First of all, I want to thank the Board of the University, and in particular the previous Rector Magnificus Karel Luijben and the present Rector Magnificus and chairman, Tim van der Hagen, for trusting me to become Dean of this renowned and prestigious Faculty of Aerospace Engineering.

I thank all of my inspiring colleagues at the Faculty, without whom I could not have obtained my vision of the aerospace field and composed this inaugural address. You make my days at the University a learning adventure, where I feel like a child in a candy store.

I also want to thank the colleagues from other faculties who also enriched my thoughts by sharing their knowledge. Your expertise too will be crucial to realize the dream of sustainable aviation. And like all of my current and previous colleagues know, I do not believe in borders between faculties or other entities.

This day would not have been possible without the great help of so many TU Delft colleagues. The logistics required for a day like this are quite overwhelming and it makes me feel humble. Thank you so much.

A word of thanks goes to my former colleagues at TNO for all I have learned over there, especially in the field of space instrumentation. Quite relevant knowledge for my current position as you all might imagine.

Finally I want to thank my family, Nienke and our two sons Niels and Jasper. I know that you have shown an incredible amount of patience with me during the past 25 years when I sort of continuously was just a bit busy. I cannot imagine how often I said “It is only for a short period of time.” I guess I did not grasp the meaning of short yet. Anyway, without your continuous support I would not have been here.

Ik heb gezegd.

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