Sustainable strategies for Aviation

Paper Greening of Industry Conference, Gothenburg 2002

Dr.ir. Karel Mulder, ir. Alexander de Haan, ir. Isabelle Vandamme
Technology, Policy & Management, Delft University of Technology
Jaffalaan 5, NL 2628 RZ Delft, Netherlands, k.f.mulder@tbm.tudelft.nl

Content

The need for sustainability in aviation

For several decades, aviation has been criticized for various external effects. Rather recently, the level of fuel consumption is added to the criticism. As aviation industry is growing rapidly, the problem cannot be reduced by optimisation, as efficiency increases by innovation can hardly keep up with the growth in passenger air transport. How much improvement is needed?

A simple way of calculating the necessary environmental efficiencies in 2050 can be carried out by the IPAT model (Ridken, 1972). Calculations based on IPAT lead to the conclusion that in general improvements in environmental efficiency ranging from a factor 4 to a factor 50 are needed (Cf. F. Schmidt-Bleek, 1993, Weaver at al., 2000). What does this imply for aviation?

First of all a baseline must be chosen that determines the acceptable level of inconvenience caused by aviation. Being completely sustainable does not automatically mean not flying at all. What is needed is that the environmental burden caused by air transport does not exceed the carrying capacity of the earth system. When knowing the dimensions of the carrying capacity, society must make a choice about the part that can be spend on flying.

Lets assume that the environmental burden of flying today is smaller than the Earth's carrying capacity, and acceptable for society, e.g. society accepts that this part of the carrying capacity cannot be used for anything else. The challenge for the aircraft designer is to reduce the environmental burden of aviation while also compensating for the growth of consumption.

The IPAT model is very simple, and there have been many discussions about its formulation. What this model convincingly shows is that the technological answer to the question for more sustainability must be efficiency leaps. Just 15 % improvement or even 50% is by far not enough.

Aviation therefore should seek and develop ways to keep on fulfilling its service while at the meantime raising its energy and material efficiency by a factor 5 to 50.

Technology: Part of the solution or part of the problem?

Though technology brought human beings a lot of welfare (as the controversial book of Lomborg (2001) rightfully states), the use of technology gave mankind also major local and global problems to solve. Still, the belief in a technology that can solve every occurring problem is substantial.

Some people see technology as something that is inevitably leading mankind to disaster. For instance the French philosopher Jacque Ellul argues in his famous works that technology can only solve a problem by introducing more new problems. Unfortunately he is only diagnosing and not giving any clues to break through this vicious spiral process.

Ellul’s interesting work forces engineers and other people to think about the role we would like technology to play in our society. Engineers are warned by Ellul’s work, but they are not that sceptical. Engineers see it as their responsibility to use technology to give their part of the answer on the call for a more sustainable society.

Lots of people think the problems of society today in terms of environment and sustainability can be solved by technology. By looking around it appears this is not happening automatically. Therefore, the question “Can technology change?” out of the last paragraph should be expended by one word: “Can technology *be* changed?”

According to Ellul, technological development is a complete autonomous process that cannot be influenced by men. The ultimate goal of the process is reaching optimal efficiency, and technology has been doing so ever since, according to Ellul.

If this were the case, no effort would have to be spent on making aviation more sustainable by introducing new technologies. The only way in which technology could contribute to sustainability would be when higher efficiency would incorporate more sustainability. This may be so in some occasions, but not in all. For instance, if raising the efficiency of burning fuels in aircraft engines leads to lower ticket prices, more people would fly. This requires more flights and will eventually burn up more fossil fuels than in the situation before, the so-called *rebound effect*.

Technology studies of the last decade show the seamless web of the technological, and the social. Technological change necessarily also involves social change and vice versa. (E.g. Rip (1995), Hughes (1983) and Bijker (1990)) It is therefore better to speak of socio-technical change, which implies that there is no single factor to blame for the problems and there is no single solution for them. We need socio-technical change to work towards sustainable aviation.

Criticism considering Aviation

Several problems due to mass air transport can be identified and are listed and explained below. How these problems are perceived may differ in place and over time. For instance, the importance of a fast and frequent service between major cities may outweigh the negative effects that come with it. Therefore, the adverse effects may be perceived less negative by people in big cities than by people in rural areas. ‘To what extend do we need continued growth in air traffic?’ and, ‘What benefits do we receive from aviation?’ influence the perception of aeronautical burden substantially.

The majority adverse effects of aviation are:

Noise Hindrance – Near airports, were the planes have to fly relatively low, landing and departing airplanes cause a lot of noise. Several options for minimising this hindrance and still let the amount of landings and departures grow are: steeper climbs and descents as well as new high tech solutions like the 'Tunnel in the Sky' technique developed at the Aerospace Engineering faculty of Delft University of Technology in the Netherlands.

Safety and Health Hazards – The exhaust of burned and unburned kerosene in large quantities, cause lots of concern about health risks. Some studies have been published that show a relation between high concentrations of burned fuel and cancer. However, there are also studies that deny any relation.
Safety is a term that has always been attached to flying. As the sky gets much more crowded, increased chances for collision occur, especially near airports. New air control technologies might contribute to increased safety while enhancing runway capacities.

Emissions – Airplanes emit various substances into the atmosphere, like the greenhouse gas carbon dioxide (CO_2), water vapour, NO_x and 'black smoke'. There is a substantial lack of knowledge about the effects of these substances in different layers of the atmosphere. CO_2 and water vapour contribute to climate change, but the effects of these emissions are to be further determined.

Fuel Consumption – Although the amount of fuel an airplane uses can in some cases be compared to that of an average car if you compare for each person alone, the absolute quantity of airplane fuel consumption is very high. Fossil fuels are still available in large quantities and for a reasonable price. However, crude oil will become scarce within 50 years. Moreover, as part of international agreements, governments might implement measures to reduce fossil fuel consumption. Various technologies might contribute like engine design, aerodynamics and materials.

Use of Materials – Traditionally airplanes are made of aluminium because of its good buckling properties compared to for instance steel. By law, airplanes must be built from 'new' aluminium. Recycled aluminium can therefore only be used for other purposes. Not only is aluminium for airplanes hard to recycle and therefore economically not an interesting activity. Also, new aircraft are increasingly made from more exotic materials like glass fibre reinforced aluminium and composites. How to recycle or reuse these materials?

Hypersonic Developments – Are some parts of aviation already causing problems, the expectation for the future is not only a growth for the whole aviation industry, but also a new mode of air transport: hypersonic flight. That is, accelerating a plane up to several times the speed of sound (Mach 8-12), or even more to get in orbit around the Earth (7-8 km per second). Enormous distances can be travelled in just hours. For instance Amsterdam-Sydney should be possible in one hour, which opens the way for an afternoon shopping at the other side of the world. These speeds will require such large quantities of energy, that this technology will only be acceptable if a non-polluting source of energy would become available.

Social Dynamics in Perception of Air Transport

There exists a remarkable paradox concerning aviation: While travelling by air seems to be widely accepted, even by environmentalists, aviation is under serious criticism. Citizens groups protest against the growth of airports but hardly protest against the travel agency that sells weekend trips to New York, or vacations at the Fiji Islands. Therefore, it seems obvious, that options are to be preferred that combine the advantages of large-scale aviation with the demands of Sustainable Development. Put in a wider view: achieving the goals of sustainability without holding up general growth.

The criticisms towards air transport cannot be neglected. In the long run, air transport should be sustainable, or it will run into crisis. However, from the concept of 'sustainable development' it is not immediately clear what needs to be done. Naturally, mankind will have to establish a new equilibrium with its natural environment, but what does this imply for the issues mentioned above?
It is not very realistic to suppose that all issues might be solved completely, at least not in the foreseeable future. Developing solutions for some issues might create new problems or worsen other problems. However, solutions for some problems, like the depletion of non-renewable resources (mineral oil) by air transport might be solved outside the aircraft sector, e.g. by the use of bio mass derived fuels. However, do we want to allow future aircraft to annoy us, or to utilise valuable resources like biomass? What environmental scope do we want to offer to air transport? This question is not easy to answer. Criticisms towards air transport differ from country to country. National issues, culture and traditions, and local incidents, like the El-Al Amsterdam-Bijlmer crash, might influence local perceptions of problems related to aviation considerable.

Options for paradigm shifts in aviation

Glare

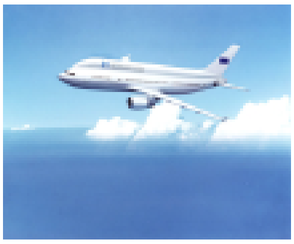
Modern civil aircraft are almost completely made out of aluminium skin panels, stiffeners and frames. In the traditional world of aviation, with its high investment risks, advanced materials like composites are already promising for a long time. At this very moment, one of these composites, Glare, appears to make a breakthrough after 20 years of development.
In aircraft design, a dominant feature is reducing weight. Mostly, fatigue characteristics are the dominant design criteria for airplanes. It is only recently, when a new category of Ultra High Capacity Aircraft are being introduced, that some places in the casco of these aircraft have a static strength dominant design criterion. Therefore, in producing lighter aircraft, most effort is put in avoiding the occurrence of metal fatigue. The relatively fatigue sensitive material aluminium is used because of it buckling properties it has considering the thickness of the material needed in aeronautical applications.

Glare could change this, as it has terrific fatigue properties. Next to that, it makes fewer joints necessary, due to its possibility of splices. Overall Glare makes it possible to reduce the weight of an average aircraft by no less than 20%.
How can this 20% weight saving be used? In a study by Tempelman (1999), a section of the Airbus A-320 was redesigned in Glare. A Life Cycle Analysis showed a 27% less harmful impact on the environment. A number that is larger than the weight savings, due to secondary

weight effects. This effect has both local and global benefits for the humans and their environment, so one can speak of a contribution to Sustainable Development.

The question, however, is whether using a lighter structure for savings of consumed transport energy is the best way to reach sustainability.
A negative comment is that weight savings are used to transport more, and therefore, the total effect for sustainability could even be negative. That is the case only if transporting more tons of payload results in cheaper transport, and with it creating more transport due to lower prices.
Using the weight saving for transporting more, could also lead to less flights. This could be preferable above using less fuel in the same amount of flights, because the vehicle empty weight does not need to be transported (De Haan, n.y.p.).
Clearly, Glare has good opportunities to contribute to Sustainable Development. By itself Glare cannot be called Sustainable or Environmental Friendly. It totally depends on the way it is used and under what circumstances.
Whether society will use this engineering part of the sustainable puzzle for either short-term optimisations or long term optimisations, e.g. Sustainable Development, is both a necessity, and a matter of debate (Brundtland, 1987; De Haan, 2000; Tempelman, 1999)

Cryoplane
Al current aircraft are using kerosene, this kind of fuel provides a good balance between the required properties for an aviation fuel, such as energy density, operational issues, costs, and safety… In this chapter the concept of using alternative fuels will be treated and in special the cryoplane (alternative fuel is hydrogen in the cryoplane). The studied model will have a passenger capacity of 1000 people and a range of 8000 nautical miles.
However the use of an alternative fuel has consequences on all fields. Significant modifications are needed in airport infrastructure for supply, delivery, and storage of the alternative fuel. These major modifications will be a significant effort and cost.



The major advantage of the cryoplane is that the emission of CO_2 will be excluded and that this gives probably an improvement of the greenhouse effect. For the most part the gaseous and the emissions of the engine are determined by the design of the combustion chamber.
There are only limited opportunities to influence these emissions through the use of alternative fuels. Nitrogen for example comes from the air, not the fuel. NO_x is a by-product of combustion, created by the oxidation of nitrous oxide (N20) in the air. Normally, the higher the temperature and pressure in the aircraft engine, the higher the amount of NO_x that is produced. CO_2 and H_2O are influenced by fuel composition

Through this change of fuel, the aircraft need larger and better-isolated tanks. The tanks need to be larger because the significantly lower energy density compared with kerosene.
The tank has to be isolated well because of two reasons. First the pressure has to be constant in the tank; otherwise the hydrogen will boil till the equilibrium is reached. Second, air in contact with hydrogen will freeze. The frozen particles can block the supply of hydrogen to the combustor.
An advantage is the low temperatures of hydrogen combined with the high specific warmth. Through this the parts in the engine can be cooled efficiently. The compressor does not have to do extra work and the turbine temperature can be increased. This cooling function can be

used to cool the fuselage and the wings. Thereby the air flow-aircraft contact is improved. In this way, vortexes are avoided and so there is less drag. Wind tunnel tests have confirmed this prediction.
The construction of the tank is preferable a sphere. This construction shape is the best for taking care of the high pressure combined with low weight. However a sphere is not the best shape for an aircraft.
The exhaust of CO_2 would be reduced till zero but the exhaust of H_2O will increase. Due to the increased exhaust of H_2O the formation of contrails will rise. Contrail formation is due to the increase in relative humidity that occurs in the engine plume as a result of mixing of the warm and moist exhaust gases with the colder ambient air. Contrails, may influence thin cirrus formation, reduce the amount of short wave radiation reaching the earth and reduce also the long wave radiation leaving the earth to space. The net effect is a heating of the earth, i.e. climate change. The observation shows persistent contrails becoming several 100 km long and more than 100 km wide.
The improvement for the environment by using hydrogen is dependent on the flight altitude. More research has to be conducted to have a certain view on the benefits of using hydrogen. It has no benefits if a fuel that is as bad or even worse for the environment replaces the kerosene.

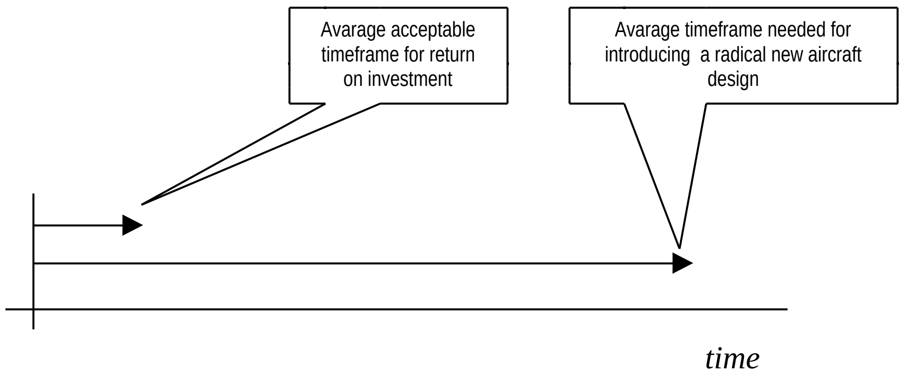
Airship
Airship technology has been developed long ago. The technology has not changed much, as large airships were not in operation after the Hindenburg accident in 1938. At this moment some people speak of the ‘revival of the airship’. In Europe three large firms, SkyCat (UK), Zeppelin Neuer Technologie (Germany) and CargoLifter (Germany) developed new technology and introduced flying models of their design. The German authorities have recently certified the Zeppelin NT design.
The public criticizes airlines, as for instance the Royal Dutch Airline KLM, upon their sustainable responsibilities. Why does the aviation industry not introduce airships to reduce their environmental impact? Technically this cannot be done, as an airship does not have the capacity to transport the same amounts of passengers and cargo at comparable speeds as current aircraft. The lower speed is not just inconvenient for the passenger, but also reduces the transport capacity, in passenger*miles, dramatically.
The idea behind the reintroduction of the airship is merely based on the assumption that transport growth will be there anyway. Given this growth, it is better to introduce a more sustainable system next to the existing system to reduce the environmental burden of the transport growth. The intention therefore, is to introduce a more sustainable system of transport by air, with other characteristics and therefore operating on particular niche markets.

Flying wing, Dual fuselage and other highly radical options
In aviation future studies, sometimes highly irregular shapes of aircraft can be seen. They are either extremely large (three decks, more than 1000 passengers), or differ in shape (as the flying wing, or dual fuselage design)
Designs such as this are preliminary designs. There is no clear view on the exact characteristics of such designs. The are drawn with the intention to make flying more efficient, mostly in a technical way by using less fuel or with lower empty weights.

These preliminary designs do not include economic analyses. If they would it would soon be clear that no firm in the world today is able to invest such an amount of money. And if they could, they would not take the risk.
Design with such a high rate of radicalism will only be designed in more detail if there is an absolute need for it. When current designs cannot meet the requirements of future aviation, there is a change that manufacturers will brake with the tradition to optimise existing designs. A paradigm shift may then take place.

What barriers exist that prevent technological changes?

Economics
The time horizon between a traditional *return on investment* and the time it takes to introduce large technological changes in aviation differs substantial. For economist a profit after at least five years is almost unacceptable. Designing, certificating and producing an aircraft takes much longer. Aircraft stay in service for about 30 years. Radical changes in the technology that is used in aviation can therefore only be introduced in comparable time frames.



Another important aspect that hinders technological changes is the low profit margins of airliners. Margins are very small and no airliner wants drastic, money consuming changes, or new aircraft that have many benefits, but at high cost.
One of the reasons that only a few airlines operate with a stable profit is that aviation is historically the nations proud. A national airline is important for image, or simply because people in a country want to have something to be proud off.
Governments tend to put extra money in national airlines (flag carriers) much more easily than in other industries. With it comes an artificial creation of more seats available in aircraft than the market asks for. To fill their aircraft, operators lower their prices.

Entrenchment
With the fast growth of the aviation industry and the large amount of aircraft being produced, the need for standardization came up after World War II. International agreements were made

on all kind of criteria for aircraft, airports etc., such as kind of fuel, level of safety, air traffic control and size of aircraft.
The last one is an important example as its negative effects are clearly visible in the recent attempts to create so called *Very Large Aircraft* as the Airbus 380. The A380 is designed for 600 passengers, but larger versions are on the drawing board. When constructing a plane for more than 800 passengers, the criterion of size prevents it. Aircraft are expected to have a size within a box of 80 times 80 meters, and all airports in the world are constructed to it. Introducing a new kind of aircraft that may have all kinds of benefits would result in rebuilding a lot of existing infrastructure. It therefore blocks the introduction of these very large aircraft until all other capacity possibilities do not answer the demand satisfactory.

Certification
Air travel is safe, at least much safer than travelling by car. The amount of casualties due to car accidents in the small country of the Netherlands is equal to the worldwide casualties due to air disasters each year.
In order to keep the safety at acceptable high levels, new technologies have to be certified by the aviation authorities. This process is a slow process, as so many parameters influence safety and as the required level of safety compared to other modes of transport is very high.
A negative effect of certification is that it also prevents new technologies to be introduced, or even to become more real than the drawing board version. In some cases it is economically not feasible to spend much money on a certification process, as the expected advantages of the new technology are less. Also for the reason of time (a radical new design takes at least 5 to 9 years to be certified completely), the decision not to build is easily taken. The time frame of the economy does not match the time frame required to develop and introduce new promising sustainable technology.

References

Wiebe E. Bijker, 1990, The Social Construction of Technology, dissertation, Eijsden,

Thomas Hughes, 1983, Networks of Power. Electrification in Western Society, 1880-1930
The John Hopkins UP, Baltimore and London,

Bjorn Lomborg, 2001, The Sceptical Environmentalist

Arie Rip, 1995, Introduction of new technologies: Making use of recent insights from sociology and economics of technology In: Technology Analysis & Strategic Management, Vol.7, no. 4, p. 417-431

R.G.Ridken (edit), 1972, Population, Resources and the environment Washington: US Government Printing Office

F. Schmidt-Bleek, "Wieviel Umwelt braucht der Mensch - MIPS, das Mass für oekologisches Wirtschaften", Birkhaeuser, Basel, Boston, Berlin, 1993

Erik Tempelman, 1999, Sustainable Transport and Advanced Materials Delft: Eburon

P.Weaver, L. Jansen, G. van Grootveld, E. van Spiegel, Ph. Vergragt, 2000, Sustainable Technology Development Sheffield: Greenleaf Publishers

World Commission on Environment and Development (WCED), 1987, Our Common Future Oxford University Press, Oxford-New York