Environment and climate impact of aviation

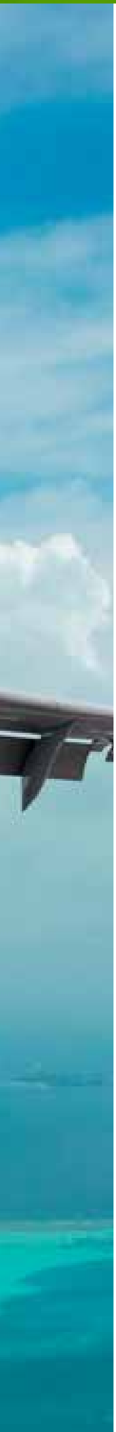
An excerpt from

NRIA Flyg 2020

innovair

Perspective: Environment and climate impact of aviation

Globalisation continues and aviation needs to be greener. Here we try to explain what opportunities exist within the technology paradigm we see ahead of us.



INCREASED FLYING REQUIRES SWEDISH INNOVATION

Not least in former developing countries, a new and wealthier middle class results in a rapidly growing group of new passengers who want to see the rest of the world. This increasing demand for travel is expected to contribute an annual 4–5% rise in air travel globally for at least a few more decades.

As suppliers to the major OEMs who in turn produce the aircraft and engines of tomorrow, Innovair's actors contribute to the development of new, safe, reliable and fuel-efficient aircraft and aircraft engines. The point for Swedish actors is that their products reach the global market as products incorporated in all new aircraft and engines, be it in Sweden or elsewhere. As Swedish products, by virtue of their design and development, reach this market, Swedish innovation actors participate in and contribute to environmentally friendlier solutions that lead to more sustainable aviation. In addition, aeronautical innovation in Sweden generates highly qualified jobs and export revenues.

ENVIRONMENTAL OBJECTIVES

The environmental objectives for the aviation sector in Europe have been formulated by the Advisory Council for Aviation Research and Innovation in Europe (ACARE) in several documents since 2001. This was done most recently in the document Flightpath 2050, where goals for 2050 (with 2000 as the reference year) were set:

- **CO_2:** reduction by 75%.
- **NOx:** reduction by 90%.
- **Noise:** reduction by 65%.

The Paris agreement and EU's political commitments to reduce CO2 emissions have since been added to ACARE's objectives.

Overall, this leads to a strong environmental focus for Europe's aviation research for the upcoming framework programme Horizon Europe.

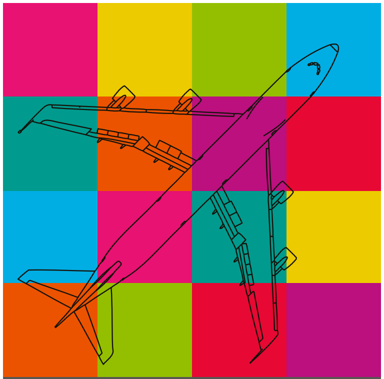
A good overview of aviation's environmental issues including noise can be found in the ICAO's latest environment report (see fact box). The report states that aviation's share of carbon-dioxide emissions resulting from human activity is just over two per cent. Of this two per cent, two thirds originate from international flights (expected to increase slightly by 2050). The reason is, of course, the increase in air travel across the globe, especially in Asia with increasing wealth in several large economies.

Innovair has compared various forecasts of how fast aviation is growing. Analyses thereof indicate a growth of 4.5 per cent annually until 2030, after which a slowdown is likely to occur to 2 per cent annual growth until 2070. If new environmentally smart technologies are introduced at the current pace, CO2 emissions, due to the increase in air travel, will still be twice as high in 2050 as it was in 2017.

Emissions will thus increase faster than the progress towards environmentally friendlier technology can counterbalance at today's pace. In order to halt the increase of aviation's global environmental impact, the pace of development must be accelerated and requisite measures taken.

OPPORTUNITIES IN SIX AREAS

We can group the various opportunities available to reduce the environmental impact of aviation into six different priority areas:



ICAO AND ITS REPORT

The International Civil Aviation Organization (ICAO) is a UN agency with global responsibility for maintaining safe, efficient, economical and sustainable aviation around the world.

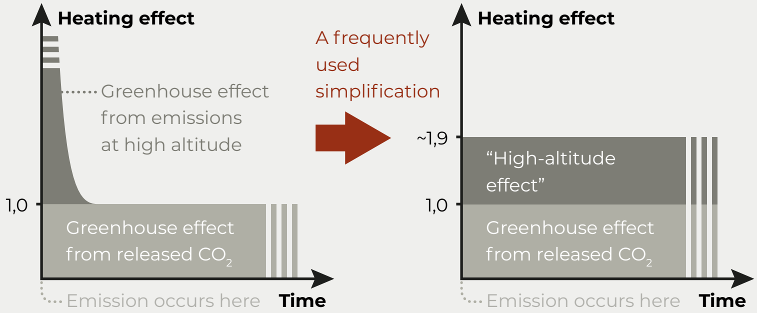
You can find ICAO's latest environmental report at **innovair.org/icaoreport**.

1. new, lighter, more efficient **aircraft;**
2. new, lighter, more efficient **aircraft engines** with new combustion-chamber technology for reduced particulate-matter emissions;
3. improved **traffic-management systems,** smart **flight routes, adaptive altitude** (to avoid contrail formation) and higher **load factors** (better filled aircraft);
4. introduction of **biofuels** and **synthetic fuels,** first for incorporation into today's fuels and later completely new fuels that require a comprehensive technology shift;
5. introduction of **electric propulsion;**
6. **legislative measures.**

RESULTS AND CHALLENGES DESCRIBED IN SUMMARY ON PAGES 38–41

HIGH-ALTITUDE EFFECT

Carbon dioxide in the engines' exhaust gases stays in the atmosphere for hundreds of years, creating a heat-insulating greenhouse effect. Another greenhouse effect occurs when exhaust gases are emitted at more than 8,000 metres altitude; water vapour and nitrogen oxides in the hot exhaust gases result in contrails and cirrus clouds. These contrails and clouds contribute to the greenhouse effect but are not as persistent as the carbon dioxide itself, disappearing after a few weeks. All in all, a very strong heating effect occurs in the first month, and considerably lower thereafter.



It is difficult to weigh these effects together because they have such different lifespans. One possible way to simplify the reasoning is to create an average value over time by multiplying carbon dioxide emissions by a certain factor. In 2010, it was suggested that this factor be set at 1.9, and at present this simplified way of thinking is widespread. However, neither the factor itself nor the value 1.9 are scientifically proven or even agreed upon. For this very reason, the factor is set conservatively and should be seen as a "worst case".

The German Aerospace Centre (DLR) is currently measuring real-time emissions under different conditions to build up knowledge in the field. Innovair will continue to monitor developments.

Source: see ***innovair.org/hoghojdseffekt****. (in Swedish)*

Intensive international collaboration already takes place in some of these areas, for others the initiatives have just begun. With regard to legislative control, some measures can be enforced nationally, but most must be implemented via global agreements. This means that timelines for the various priority areas are completely different.

Below we discuss the technical possibilities available for each priority area and thereafter provide a summary picture showing the effects to be expected from the six areas. This shows that aviation, with a realistically assumed passenger growth, can come down to manageable emission levels with regard to the goals in the Paris agreement by combining the six possible priority areas.

1–2. Aircraft and aircraft engines

With regard to points 1 and 2, responsibility lies with the manufacturing companies. To a large extent, this activity is structured via international collaboration, especially within the EU where, in addition to funding traditional research, major resources are devoted the Clean Sky programme, which is now in its second phase and where a continuation is expected within the new framework programme Horizon Europe that commences in 2021.

Both Saab and GKN Aerospace are strategic members in Clean Sky and contribute with intense activities to achieve the long-term objectives together with the other parties. When the results of the first Clean Sky programme were summed up after completion in 2017, it was found that the newly developed technologies can reduce CO2 emissions by 32%. Subsequently, the Clean Sky 2 programme has taken further steps. Examples of contributing – and prize-winning – technologies with key **13**

RESULTAT: MILJÖVINSTER, KONKURRENSKRAFT, EXPORT OCH SYSSELSÄTTNING Innovationsaktörerna inom flygteknik i Sverige har kunnat producera utsläppsminskande tekniska landvinningar, som i sin tur skapar konkurrenskraft (och möjligheter till deltagande i internationell utveckling) liksom direkta exportintäkter och sysselsättningsförtjänster. (Se **innovair.org/showcase**) **13**

Swedish involvement are the laminar-flow wing BLADE and the open-rotor engine concept.

We also see that these new technologies are gradually being implemented in the global commercial aircraft fleets. Each new generation of aircraft has at least 10% lower fuel consumption than its predecessor. Historically, upgrading of the global fleet has therefore reduced CO2 emissions by about two per cent per year. The objective with Clean Sky is to accelerate this reduction by moving more technologies faster to TRL 6 via demonstrators.

3. Traffic-management systems, flight routes, adaptive altitude and load factors

The airline industry has already reduced fuel consumption per passenger by about 70% in the past 50 years, which has been achieved through a combination of technological development, more efficient flights and better filled aircraft than before. Today, the average load factor for all flights is around 85% and, for example, thinner aircraft seats and similar smart solutions can further increase the number of passengers within a given cabin volume.

There is also potential for improvement in air-traffic management systems. These systems have essentially been national in character but now Europe has the ambition to create a common airspace called "Single European Sky" through, amongst other initiatives, JTI SESAR (Single European Sky ATM Research, where ATM stands for air-traffic management) with the intention of optimising each flight so that it uses the best route and altitude. On the technical side, this requires an increased level of automation, standardised and interoperable systems and a high degree of virtualisation. Here, AI is expected to offer increased opportunities based on the conclusion that collected data on individual aircraft, weather, timetables, etc, can provide the basis for creating optimised and dynamic route and altitude planning for both regional and intercontinental flights. The goal is to reduce the environmental impact of aviation, for example by avoiding holding with unnecessary fuel consumption or reducing exposure in areas with the risk of contrail formation, which, as mentioned earlier, make a significant contribution to the greenhouse effect.

In Sweden, participation in SESAR is funded primarily by the Swedish Transport Agency's research portfolio for aviation with the participation of Saab, the Swedish Airworthiness Authority (LFV) and academic actors.

4. Biofuels and synthetic fuels

If an aviation fuel is of fossil origin, the carbon dioxide of the exhaust gas does not belong to the natural cycle: it becomes an unwanted by-product. Alternative fossil-free fuels – biofuels, synthetic fuels, gaseous hydrogen, etc – will play an important role in aviation's transition to lower carbon-dioxide emissions as they do not add any carbon dioxide to the cycle.

Drop-in alternative fuels (see fact box), in this case aviation kerosene produced from biomass, often via gasified biomass, have potential in the near future as they do not require major technical modifications of aircraft and aircraft engines. Today, up to 50% biofuel is allowed for civil aviation, and a higher proportion is primarily an international certification issue (see legislative measures below).

In a joint project with the Air Force Research Laboratory in the USA, the Swedish Armed Forces have demonstrated the world's first single-engine flight with 100% biofuel, carried out

AVIATION EMISSIONS IN RELATION

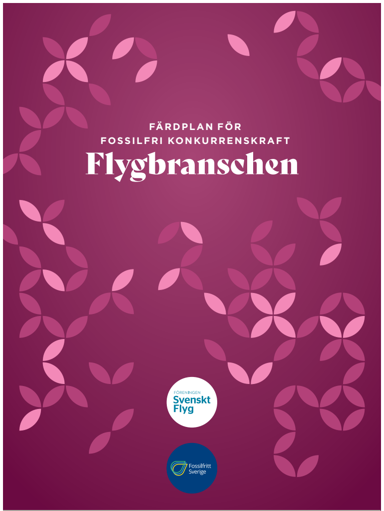
Global carbon-dioxide emissions from aviation account for about two to three per cent of total man-made carbon-dioxide emissions. With high-altitude effects (see fact box on page 32) included, global air travel accounts for four to five per cent of man-made emissions.

With regard to Sweden's emissions from aviation, domestic and international factors combined, we account for about one 5,000th (0.02 per cent) of global man-made emissions.

1/5000

DROP-IN FUELS

Alternative fuels of drop-in type are such that they can replace fossil fuels without the need to adjust or replace aircraft or infrastructure.



FOSSIL-FREE AVIATION

During 2018, Innovair collaborated with Svenskt Flyg on the development of a roadmap for fossil-free competitiveness within aviation on behalf of the initiative Fossilfritt Sverige.

fossilfritt-sverige.se

with the Gripen. In addition to positive environmental effects, biofuels have a strategic value for the Swedish Armed Forces as access to domestically produced fuel would give us independence from fuel imports in a crisis situation.

The primary problem with biofuels is that the initial investment is too heavy for any commercial actor to bear. In addition, it takes time to build up competitive production facilities. RISE is running biofuel projects in Sweden and in meetings with Innovair it has been indicated that methods are now being developed where the raw material is waste from the forest industry, which may be a possible future solution. With such a scenario, the price of biofuels can be expected to fall significantly.

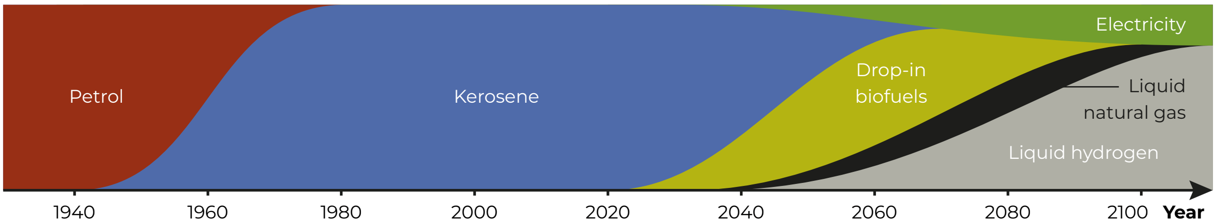
In the longer term, non-drop-in fuels, which require entirely new fuel-management systems, are also of great interest. Liquid biogas (LBG) looks promising as does liquid hydrogen and liquid methane. However, several technical challenges remain regarding transport and storage as well as the need for radical changes in vehicles and infrastructure. There are also uncertainties about fuel cells and hydrogen as solutions for aviation in the long term because the gas turbine is considerably more suitable for fast power output and many times lighter than (today's) fuel cells.

However, it is important to understand that a change to non-fossil fuel only addresses the CO_2-related aspect of the emissions. If one considers the high-altitude effect (see page 32), almost half of the total heating effect remains as long as flights take place higher than 8,000 metres.

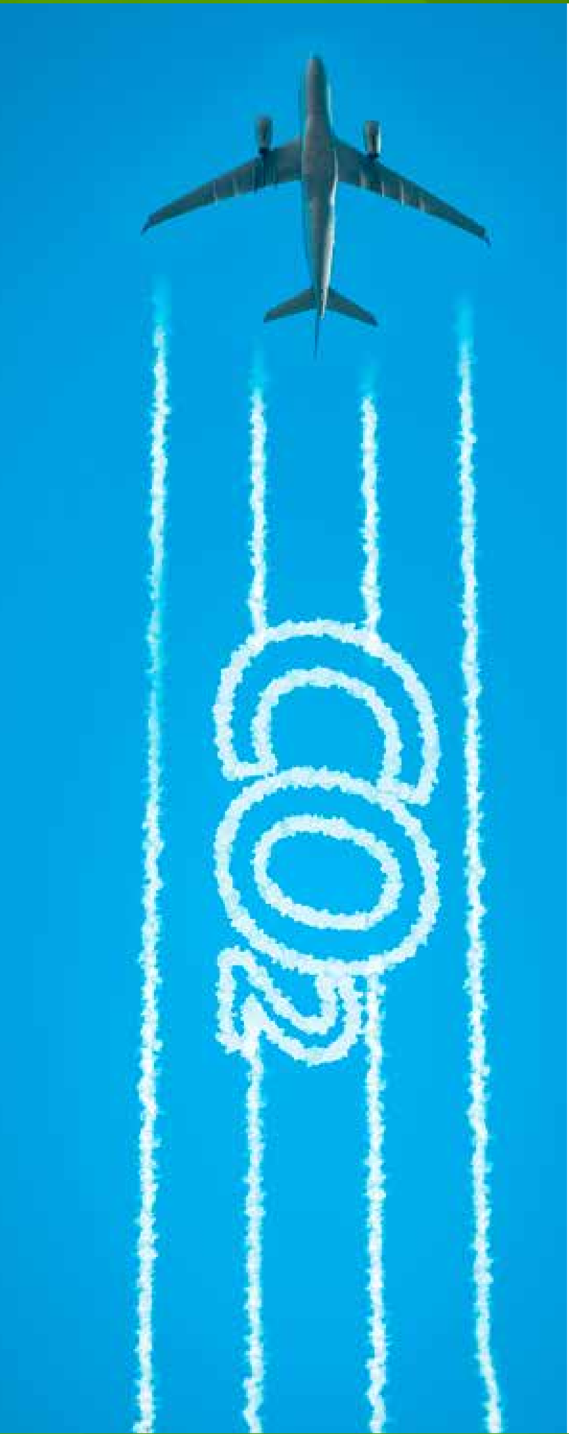
5. Electric propulsion

The increased degree of aircraft and engine electrification is a trend that will continue to grow. However, fully electrified propulsion is expected to be limited to smaller regional aircraft due to batteries having a low energy content per weight ratio. The energy content of aviation kerosene is around 12 kWh/kg and today's best batteries are around 1/70 thereof, which means that the batteries required for a given flight would weigh 70 times as much as liquid fuel for the same trip. However, the efficiency is better for electric motors than for typical turboprop engines and therefore the ratio between conventional aviation fuel and batteries is approximately 30. Even with batteries ten times better than today, aviation kerosene would still have a lead in terms of weight by a factor of three, which in practice would mean that an electric-powered airliner for more than 100 passengers and distances exceeding 700 km could not become a reality – and it is the long-distance segments that account for the bulk of aviation emissions.

Consequently, the aviation sector



History and forecast of different fuels for aviation. *Source: Andrew Rolt, Cranfield University.*



predicts that full electrification is primarily reserved for smaller aircraft flying shorter distances at lower altitudes, typically for regional purposes. Pure electric propulsion, using current technology, will be further developed up to 2040–2050, but only for the "small end" of the turboprop market – which currently consumes one per cent of aviation fuel globally.

Hybridisation – a combination of traditional turbojet engines and electric motors – is, however, an alternative that may have a positive effect on larger commercial aircraft. This provides new opportunities for reduced fuel consumption even for medium and long-haul flights. Engine manufacturers predict fuel reductions of up to 10% through hybrid operation of commercial aircraft. Here, too, the technology is expected to be introduced in smaller aircraft first.

Another possibility is to use electric motor systems for the taxiing of aircraft on runways without the use of the main engines. In addition, various electrical systems are being introduced to aircraft where they, amongst other things, replace hydraulic systems.

6. Legislative measures

There is a strong political will to reduce the environmental impact of aviation. With regard to the five points discussed above, this can be achieved in slightly different ways.

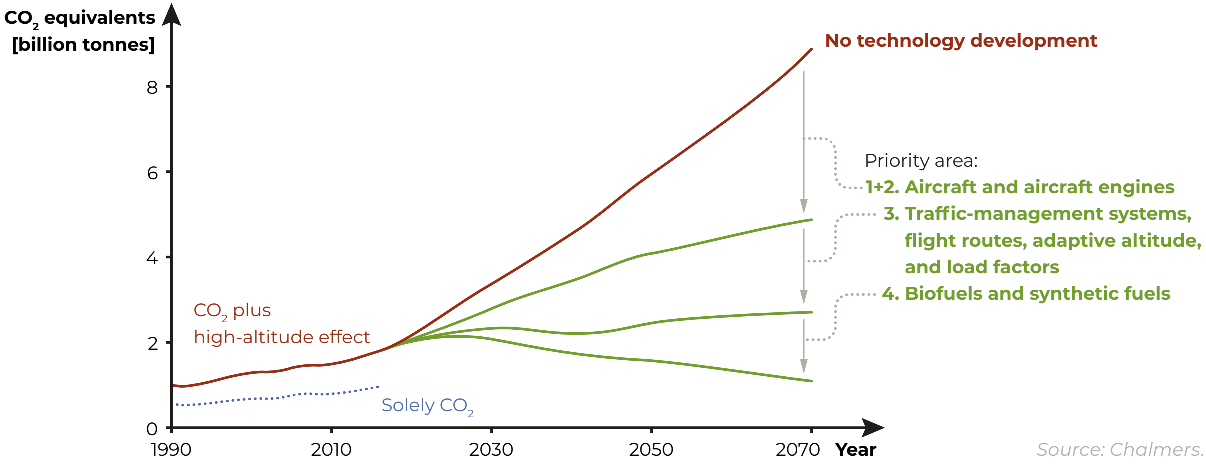
In Sweden, political decisions that lead to increased investments in innovation, including demonstrator programmes, are expected to have a strong positive environmental impact on the next generation of aircraft. This is where Swedish components and systems will contribute to lower emissions from the world's entire aircraft fleet, their effects benefitting passengers worldwide, including the group in Asia that completely dominates the current growth in air travel.

With regard to air-traffic management systems, a common approach to the introduction of new standardised and interoperable systems in the European air-traffic system is something where policies can clearly contribute.

With regard to biofuels, political decisions can be made on a purely national level or together on a Nordic, European or global level. Political tools and instruments to reduce the use of fossil fuels within aviation by way of taxes and fees should be focused on stimulating new, environmentally friendlier technologies, lower fuel consumption, and new types of fuel. The EU's greenhouse-gas-emission-trading system (EU-ETS) can be a good tool to this end. There is a strong likelihood that a reduction obligation for aviation fuel will be introduced in Sweden during 2021 or soon thereafter. This means that the incorporation rate of fossil-free fuel components into fossil fuels will rise from 1% in 2021 to 5% in 2025, 30% in 2030 and subsequently – with international certification in place – will move to 100% in 2045 when Swedish airports will cease to provide fossil fuel. Similar initiatives exist in other European countries.

Ultimately, all political initiatives must be evaluated weighing their costs against the results obtained. These can be measured in two ways: partly in terms of global impact on the environment, and partly the signal value that is achieved when a developed country such as Sweden shows the rest of the world what we want to invest in. However, it is important that initiatives and investments are based on facts, so the best results can be achieved.

RESULTS AND CHALLENGES DESCRIBED IN SUMMARY ON PAGES 38–41



Weight-of-evidence forecast of how the climate impact of global aviation can be reduced. Some things should be noted:

- *The high-altitude effect (see page 32) is included in the graph and gives the curve a "worst-case" appearance.*
- *The only chance that biofuels and synthetic fuels (**4**) will suffice to the extent shown in the graph is that fuel consumption is continuously reduced.*
- *There is no measurable global effect of electric aviation (**5**) before 2050 because the potential market within the time span is predicted to be only one per cent of global aviation.*
- *Legislative measures (**6**) have not been included as they vary from country to country and therefore produce an integrated result that cannot be assessed today.*

WEIGHT-OF-EVIDENCE SUMMATION

Researchers at Chalmers have studied various contributions that can reduce global fossil carbon-dioxide emissions, including high-altitude emissions that also contribute to global warming caused by aviation. Above, we show a weight-of-evidence prognosis up to 2070.

Here, some gradual decline in growth is assumed, caused both by political decisions and by the fact that Asia's increase in travel will also slow down, in the same way it already has done in the USA, Europe and Sweden. The single largest contribution is the assumed technological development for aircraft and engines as well as more efficient use of aircraft capacity that results in reduced fuel consumption by 1.5% annually. Accumulated, this will result in a large reduction in total emissions from aviation. This reduction is also necessary for the introduced volumes of biofuels to sufficiently cover the needs of the entire global fleet of aircraft (hypothesis): 0% year 2020, 100% year 2070*).

To this can be added the introduction of adaptive altitude which reduces the high-altitude effect of emissions at high altitudes.

All this means that it is possible to attain the Paris Agreement's goal of a maximum 1.5°C temperature increase, if aviation can be allowed to account for 7% of the total global emissions permitted within the 1.5°C target. The solution will have to be a combination of measures in different areas of action. Sweden's contribution to this development lies within efficient and competitive innovation, providing the market with environmentally sustainable solutions that are more attractive to OEMs than other solutions. Swedish innovation will have to continue to be one of the world's foremost for this to succeed in the foreseeable future.

As a result of the current debate on the impact of aviation on climate change, Innovair believes that there are reasons to raise the level of ambition in technology development and implementation of Swedish environmentally friendlier products in the market. Therefore, our ambition is to achieve our established 2050

* By "biofuels" we mean drop-in fuels up until around 2050, thereafter also other synthetic fuels (see page 34).

goal of doubling sales and increasing exports (compared with 2010) already by 2035. This requires a continued political will to increase national initiatives and investments in the aeronautical area for the facilitation of increased participation in European programmes, which in turn is a prerequisite for future business.

D

DISRUPTIVE OPPORTUNITIES

The aforementioned weight-of-evidence prognosis of what impact the six different priority areas will be able to deliver is based on widely accepted assumptions about the pace of technology development in the aeronautical field and that the development takes place continuously, without interruption and with reasonably predicted growth.

However, as in all areas, there are opportunities for leaps in technology, so-called disruptive innovation, that significantly change the pace of development. The problem with this disruptive innovation is that it cannot be predicted. We know little or nothing about what technological advances might disrupt the current technology paradigm enough to allow us to experience a drastically increased pace of development. Especially when the time horizon is beyond 2050.

But what we can do is create the best possible conditions for disruptive innovation. Major technological shifts are sometimes based on entirely new discoveries, but more often on findings from a context that suddenly turns out to be applicable in a completely different context (however, for obvious reasons, at a significantly lower TRL level). In the latter case, there are theoretical possibilities to build mechanisms that facilitate technology migration from one area to another. In theory, these mechanisms do not differ too much from the innovation-facilitating mechanisms of various kinds that Innovair has already built up within our own innovation area and which are presented in this agenda.

However, there are challenges, mainly in the fact that undirected research and innovation often live in relatively different worlds. The undirected research comes under the Ministry of Education and Research and is largely funded by the Swedish Research Council, while innovation is mainly managed by the Ministry of Enterprise and Innovation and funded primarily via Vinnova. Here is another area of application for the syncrete innovation (see page 29) that Innovair has long since identified as critically necessary for increased understanding and clearer collaboration in the public sector.

If one wants to actively create conditions for disruptive innovation, one needs to consider the following:

- The division into two types of research – the one more or less directed towards finding its application in an innovation context and the one that should not be guided by the needs of industry – is cemented by the fact that the two types are separately ”owned” by two completely different funding agencies (Vinnova and the Swedish Research Council). Here, unnecessary walls are created between research areas which should ideally have a larger contact surface. A
- More generally, the continuity of the funding – at all TRL levels – is of the utmost importance. With the oblique wave principle, Innovair has clearly illustrated the need for all TRL levels to operate without interruption in order for Sweden to be able to maintain innovation capability and to continuously deliver competitive solutions to the market. E
- Disruptive innovation takes time, because the migration itself means ”losing” some TRL levels. If Sweden wants to create conditions for disruptive innovation to improve the efficiency of innovation, facilitating mechanisms need to be introduced as soon as possible and in such a way that no unnecessary gaps occur in the innovation chains. B

EXCERPT FROM NRIA FLYG 2020

Text: *This is an excerpt from NRIA Flyg 2020, the strategic agenda for Swedish aeronautics research and innovation. The objective of the agenda is to strengthen the preconditions for international competitiveness within the field of aeronautical innovation. The document has been compiled by key people at universities/colleges, institutes, business enterprises, interest organisations and authorities (ACS, Chalmers, FMV, FOI, FTF, Försvarsmakten, GKN Aerospace, KTH, LiU, LTU, RISE SICOMP, Saab, SARC as well as SMEs and arenas) under the process management of Innovair, who together own all rights to the document. The content herein may be quoted provided the source is clearly acknowledged.*

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