TAMARACK®

Aviation Sustainability Initiatives

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2 EXECUTIVE SUMMARY

Climate change is one of the most significant challenges currently facing human civilisation. Temperatures are climbing in the lower atmosphere as a consequence of increasing human polluting activities, which is affecting every region of the world. Despite aviation being a relatively small contributor of overall global carbon dioxide (CO_2) emissions at 2-3%, aviation is often cited in the media as a significant cause (Graver, Zhang, & Rutherford, 2019). As a result, the environmental impact of flying is breaking into the consciousness of passengers and the public, potentially influencing their perception of aviation. This, combined with media attention, is driving sustainability up the agenda for airlines and the aviation industry.

Aviation is heavily regulated at both an international and national level, which ensures the highest level of safety; but heavy regulations can also mean large-scale changes are slow to implement. In contrast, the rate of climate change is occurring rapidly - therefore, we must act now to tackle this global issue.
The industry is responding with several initiatives aimed at impact reduction, as described in section 5 of this report; however, most face major obstacles such as cost, time to market and scalability, which compromises their ability to have a meaningful impact. This is reflected in the difference between target CO_2 levels for 2040 and projected CO_2 levels, termed the emissions gap. The International Civil Aviation Organisation (ICAO) has predicted the emissions gap to be a deficit of 7.8 billion tonnes of CO_2 (ICAO, 2015). Cleaner, more efficient aircraft and engines have been developed in response to the climate crisis; however, replacing the global civil and cargo aircraft fleets with the latest fuel-efficient aircraft and engines is expensive and will take decades to accomplish. In addition, building new aircraft and scrapping old aircraft will carry a significant carbon footprint.

The industry needs technology that delivers meaningful reductions in carbon emissions, which can be applied to the existing fleet quickly and economically, and be effectively embodied in the production of future aircraft.

One such technology is Active Winglets, developed by Tamarack Aerospace. This innovation delivers a CO_2 and fuel burn reduction of up to 33% and stands out in many ways amongst other sustainability initiatives (Tamarack Aerospace Group, 2020). It is proven technology, available now, has been certified by the FAA and EASA, and has been retrofitted onto several current aircraft variants. They are scalable, as the design can be adapted to fit almost any aircraft type and produced using existing infrastructure. They can be rapidly retrofitted to the existing fleet as well as future designs to improve safety and reduce noise, and are inexpensive with a short return on investment, making them highly cost effective.

A case study conducted by Tamarack estimated that if Active Winglets were to be fitted onto the commercial jet narrow-bodied fleet (Airbus A320 / Boeing 737 variants) alone, 1.6 billion tonnes of CO_2 would be saved by 2040, reducing the emissions gap by approximately 20%. Tamarack's technology offers a greater reduction in fuel burn and carbon emissions for existing aircraft than any other retrofittable solution available at present.

Passengers and the wider public alike are increasingly demanding more sustainable practices, and research has shown that they are willing to pay additional fees for flights that are more sustainable (Rice, 2019). There is currently no single solution to combat aviation's role in climate change; however, if operators were to implement Active Winglets as well as adopting several other initiatives, they could become significantly more sustainable and contribute significantly to their own net carbon zero targets.

3 WE NEED TO ACT NOW

To meet the United Nation's Framework Convention on Climate Change (UNFCCC) target of a global temperature rise of no more than 1.5 °C, all carbon emissions will need to peak by 2030 and reach 'negative' by 2050 (UNFCCC, 2020). Currently, the urgent and necessary reductions in all carbon emitting sectors are not being executed - as a result, these targets will not be achieved. More needs to be done across all sectors, including aviation.

Fossil fuels, which are the greatest source of energy in aviation, are a finite resource. Therefore, the only future possible is green, and investors are interested in sustainably active companies that are developing solutions to tackle climate change. The aviation industry is often perceived by the public as the CO2 production industry, and with the projected decarbonisation of other transport industries, aviation could become a more significant contributor of carbon emissions. Perceptions of the industry and its efforts to tackle climate change are key; investors are looking for companies actively seeking sustainable practices and may even pull investment from companies that are not acting on climate change. If the aviation industry loses access to capital, it loses the ability to innovate.

Climate change also has a negative impact on global aviation operations. Increasing ground level temperatures in the troposphere result in decreased air density, which can reduce the lifting force on aircraft wings. Lift reduction at take-off can cause significant take-off performance degradations, especially in high altitude regions or on short runways. This could limit payload capability or fuel carriage in certain regions. Additionally, rising sea levels have the potential of threatening coastal airports, and more extreme weather will cause disruptions and delays (ICAO, 2016). Stratospherically, further research is taking place to understand how temperature changes will affect flights in cruise. It is suggested that changes in jet stream wind patterns could affect flight route optimality, and increased shear within jet streams could increase chances of turbulence (ICAO, 2016).

Governments are starting to provide grants for emissions innovative companies. For example, the United States Federal Aviation Administration (FAA) Continuous Lower Energy, Emissions and Noise (CLEEN) program has already contributed $225 million through phases I and II of CLEEN, and the industry has contributed $388 million. The 2020 grants under CLEEN III are to be issued soon (FAA, 2020).

4 SUSTAINABILITY IN AVIATION

Global warming is the result of greenhouse gases trapping heat in the atmosphere. Carbon dioxide (CO2) is widely accepted to be the most prevalent greenhouse gas emission in the atmosphere, produced when fossil fuels, solid waste and trees, or other biological material are burnt. The steady rise of carbon emissions since the 1950's is shown in Figure 1. In aircraft exhausts, CO2 has been found to make up 70% of all emissions in contrast to contrails contributing approximately 30%, and less than 1% from nitrous gases and other particulates (Overton, 2019). Therefore, it is evident that reducing the amount of CO2 emitted is imperative to ensuring global temperatures rise by no more than 1.5 °C (UNFCCC, 2020).

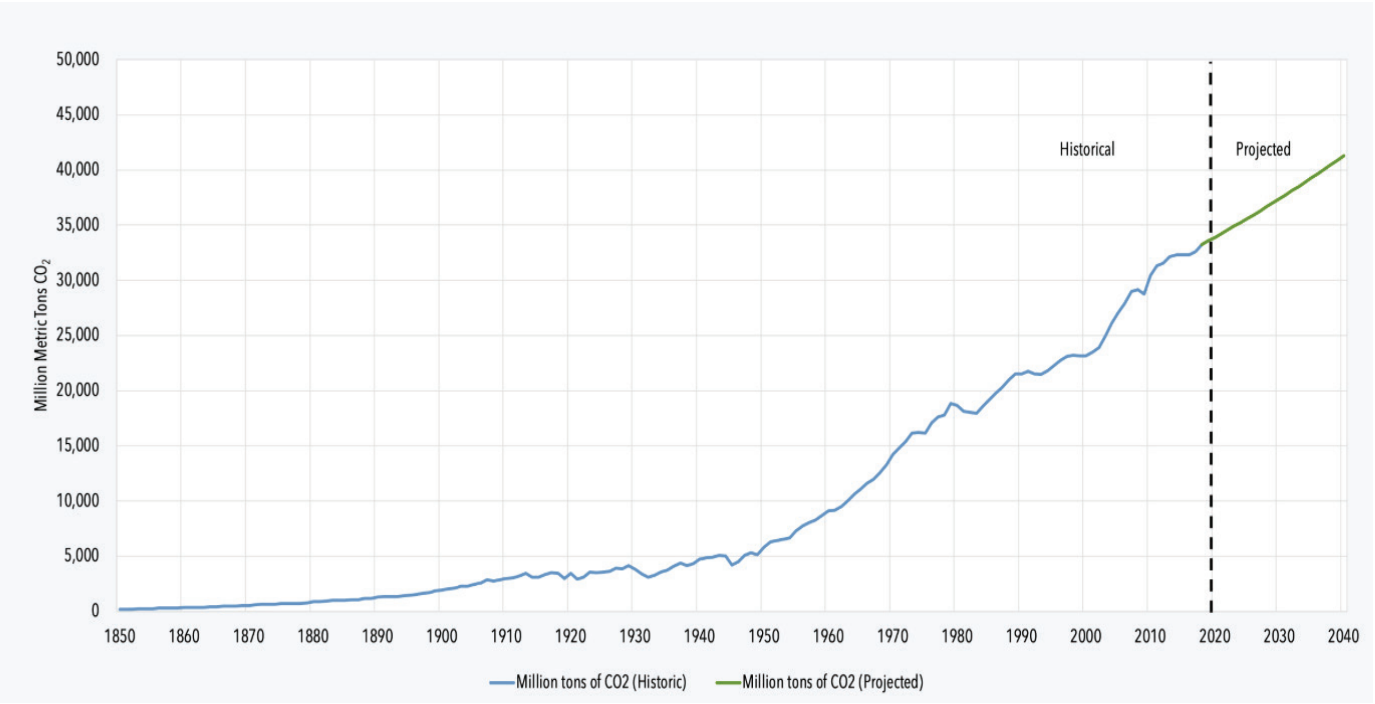

Figure 1. Global Carbon Dioxide Emissions, 1850-2040
Source: (Centre for Climate and Energy Solutions, 2020)

4.1 AVIATION'S CONTRIBUTION TO CLIMATE CHANGE

Part of the reason that aviation is gaining so much attention is due to its dependence on fossil fuels paired with its rapid growth. Global emissions from air transport have grown by 75% since 1990 (double than that of the rest of the economy), and will double again by 2050 (UNFCCC, 2014). The transportation sector accounts for 12% of European CO2 emissions as demonstrated in Figure 2; however, only 2-3% of global carbon emissions comes directly from aviation (Graver, Zhang, & Rutherford, 2019). Although 2-3% appears a comparably small amount, the amount contributes to climate change and affects the public's perception of aviation. Forbes contributor Stephen Rice (2019) highlights this public consciousness, stating that "…the public is becoming aware that 2-3% of [all] global greenhouse gas emissions are caused by aviation-related travel, and are starting to demand more sustainable practices. Research also shows they're willing to pay for it" (para. 1).

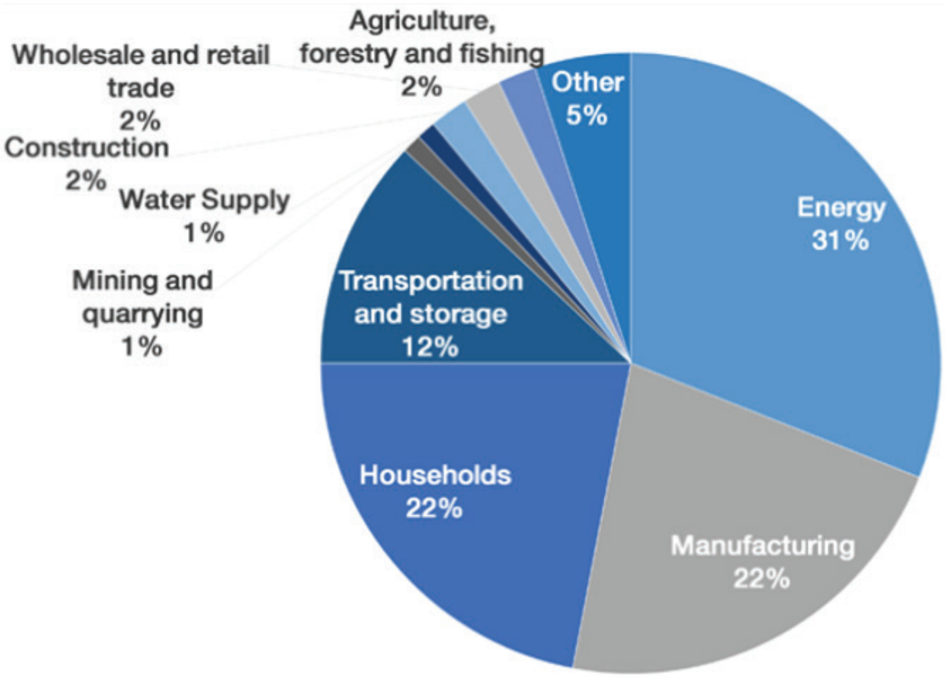

Figure 2. Sources of European CO2 Emissions
Source: (Myers & World Economic Forum, 2015)

The infographics below (Figure 3 and Figure 4) express key findings from a report published by the International Council on Clean Transportation (ICCT) with the purpose of providing an inventory on CO2 emissions for commercial aviation in 2018. The data expressed, such as the majority of CO2 emission being linked to narrowbody aircraft (43%), is vital in influencing how governing bodies and innovative companies tackle the rising CO2 emissions within the aviation industry (Graver, Zhang, & Rutherford, 2019).di

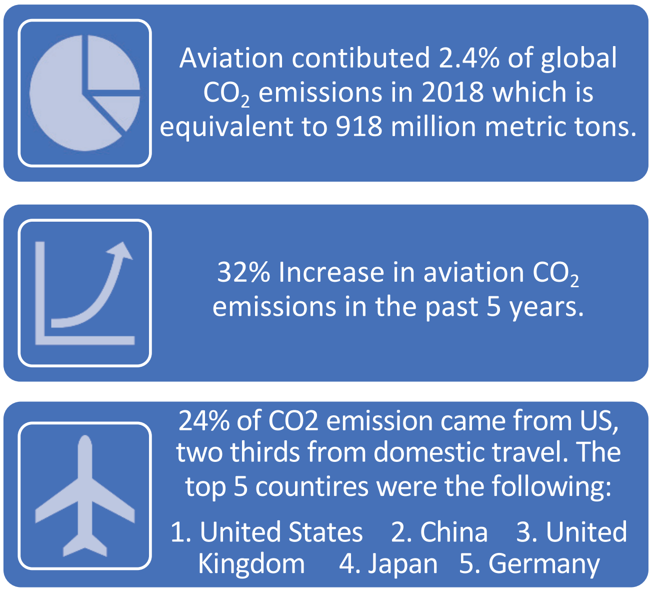

Figure 3. infographic of data from the ICCT
Source: (Graver, Zhang, & Rutherford, 2019)

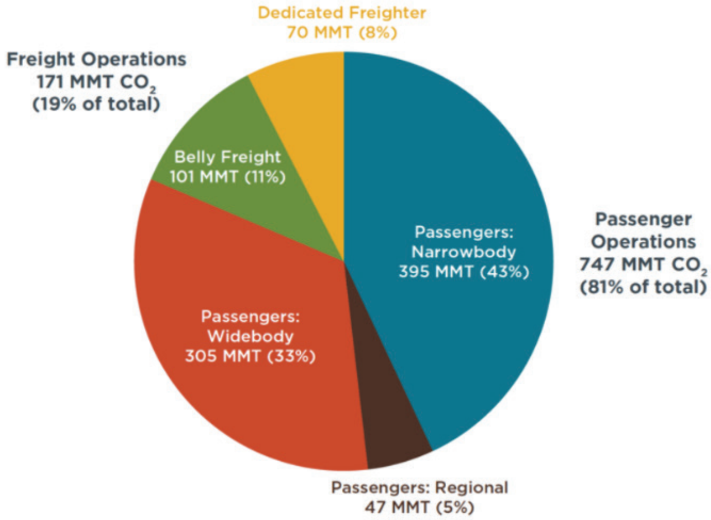

Figure 4. CO2 Emissions in 2018 by Operation and Aircraft Class
Source: (Graver, Zhang, & Rutherford, 2019)

Data from the EASA 2019 Environmental Report (2019) highlighted similar trends, with CO2 emissions of all flights departing from the European Union (EU-28) and European Free Trade Association (EFTA) increasing from 88 to 171 million tonnes between 1990 and 2016 (an 95% increase). Comparing this amount to passenger aircraft, the average fuel burn per passenger per kilometre flown, excluding business aviation, lowered by 24%. This has reduced at an average rate of 2.8% per annum between 2014 and 2017 (EASA, EEA & Eurocontrol, 2019). The decrease per passenger is indicative of an increase in efficiency. However, this gain is not sufficient to counterbalance the increase in CO2 emitted due to increased flying demand. The flying demand is expected to increase considering future advances in sustainable technology, and by using base traffic forecast we can expect CO2 emissions to increase by a further 21% to reach 198 Mt in 2040 (EASA, EEA & Eurocontrol, 2019). The report also highlighted successful initiatives stating that "The annual purchase of allowances by aircraft operators under the EU Emissions Trading System (ETS) since 2013 resulted in a reduction of 27 Mt of net CO2 emissions in 2017, which should rise to about 32 Mt by 2020" (EASA, EEA & Eurocontrol, 2019).

It should be noted that the aviation sector is not fully comparable to other sectors of the economy, as emission reductions can be more difficult to achieve in aviation. This is partially due to the relatively long lifespan of aircraft, which can remain in operation for 25 years or more. Cap-and-trade systems, as well as offsetting schemes, provide emission compensation from aviation through reductions achieved more easily in other sectors. However, aviation will need to deliver more in-sector emissions reductions.

4.2 AIRCRAFT'S CONTRIBUTION TO CLIMATE CHANGE

The most prevalent conversations when it comes to aviation and the environment tend to focus on carbon emissions. However, it is important to note that aircraft produce other polluting emissions as well, as highlighted in Figure 5. Other sources of greenhouse gases, such as nitrous oxides (NOx) emissions, should be considered along with the formation of contrails, which absorb solar radiation and can contribute to the heating effect potentially at a similar level to that created by carbon emissions. It is suggested that addressing contrails could help mitigate, in the short term, the rate of heating caused by aviation (Cranfield University, 2019). This can be achieved by switching to synthetic fuels, which contain less contrail-forming particles, or changing the altitude of flights to fly at optimal temperatures to avoid contrails forming. Changing routes poses the threat of creating air traffic difficulties or adding CO2 emissions because flights may be longer (Cranfield University, 2019).

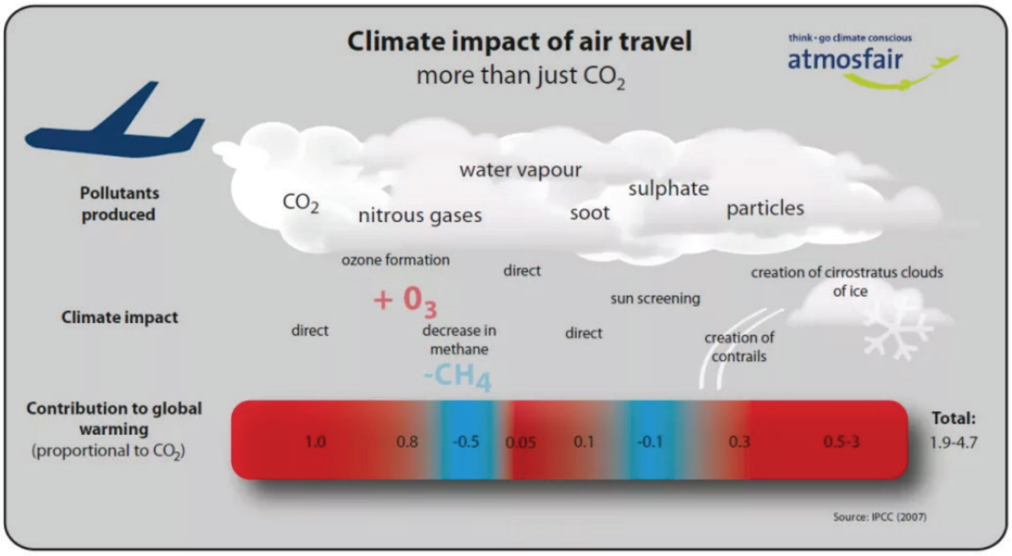

Figure 5. Climate Impact of Air Travel – more than just CO2
Source: (Atmosfair, 2017, as cited in IPCC, 2007)

CO2, NOx and other pollutants are the product of jet fuel combustion, as shown in Figure 6. During combustion, the carbon atoms in the hydrocarbon compounds (jet fuel) combine with oxygen in the air to produce CO2 and water vapour. The carbon dioxide, a greenhouse gas, contributes to atmospheric heating in the troposphere. NOx from the exhaust react to form ozone (O3), although this can eliminate methane in the atmosphere, the reaction produces a net warming effect (Atmosfair, 2017). Other particles formed are soot, which can contribute to contrail formation, and sulphates, which have a small cooling affect and hydrocarbons. If the amount of jet fuel burned is decreased, the production of carbon dioxide and the other emissions described above are also decreased.

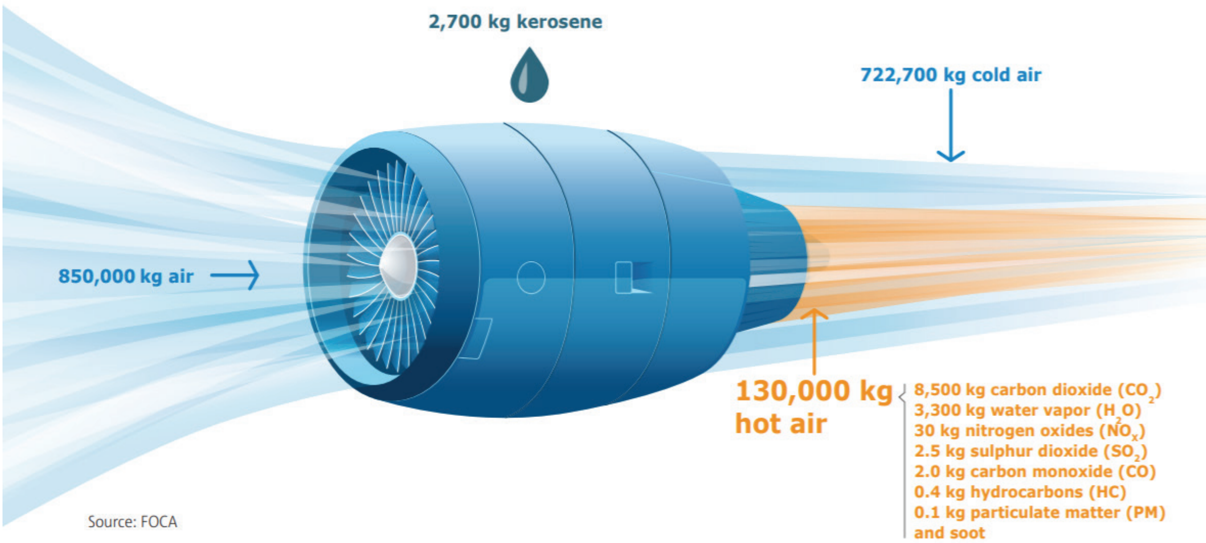

Figure 6. Emissions from a Typical Two-Engine Jet Aircraft During 1-hour Flight With 150 Passengers
Source: (EASA, EEA & Eurocontrol, 2019)

In level flight, thrust is equal to drag. Therefore, to reduce the amount of jet fuel burnt, aircraft need to become more efficient. Section 5 highlights numerous initiatives in development to help create better aircraft efficiency, therefore reducing the quantity of emissions produced. Each of the initiatives suggested can obtain fuel efficiency benefits by utilising one of the four opportunities expressed in Figure 7. Thrust efficiencies are based on designing and creating engines, which are more efficient and produce less harmful particles (such as soot and sulphates). Weight efficiencies involve the designing or redesigning of components with a lower weight. It can also include reducing payload or payload placement such as initiatives that create a more aft Centre of Gravity. The principal measure of aerodynamic efficiency is the Lift to Drag ratio (L/D). This parameter is key to aircraft range and endurance, and a high L/D ratio is associated with a high aspect ratio and increased range (Anderson, Introduction to Flight, 2016). Finally, finding

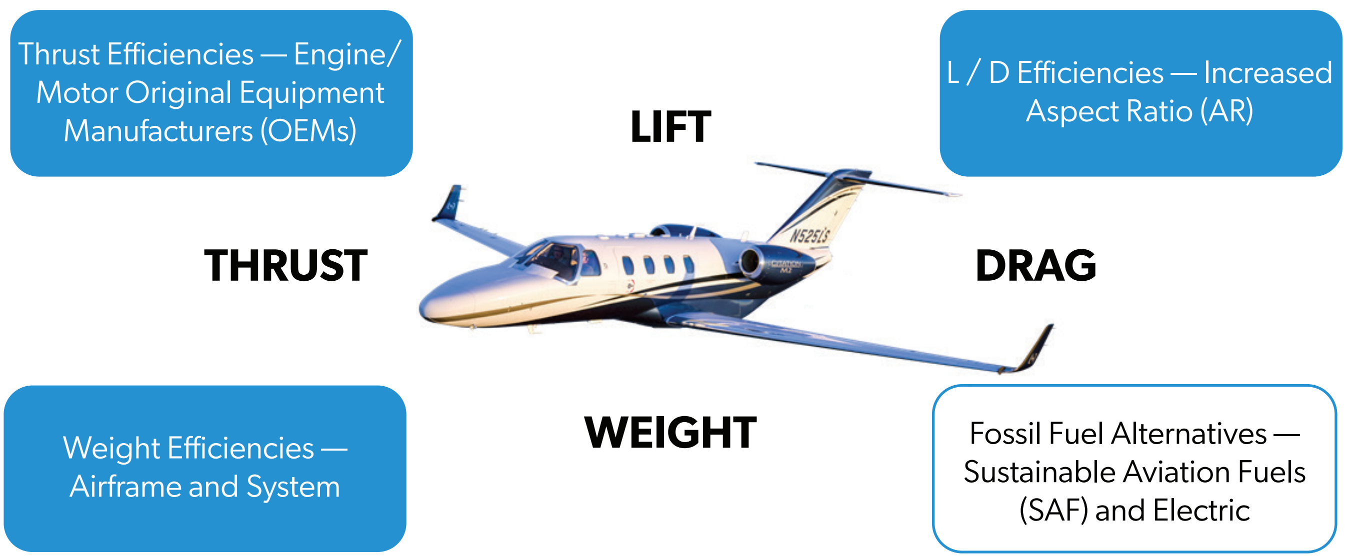

Figure 7. Four Opportunities to tackle the carbon crisis

5 HOW IS THE AVIATION INDUSTRY RESPONDING?

The challenges in making the aviation industry more sustainable are significant. There are many different avenues being explored, and while some are more effective than others, there is no single solution to the problem. To make any kind of significant impact on sustainability a number of these solutions need to be adopted by operators.

5.1 REGULATIONS

The regulators of the aviation industry, like the European Aviation Safety Agency (EASA), have issued regulations or standards for carbon and noise emissions of new aircraft.

> *In 2010, EU and EFTA States agreed to work through the International Civil Aviation Organization (ICAO) to achieve a global annual average fuel efficiency improvement of 2%, and to cap the global net carbon emissions of international aviation at 2020 levels. During 2012, Member States submitted Action Plans to the ICAO for the first time, outlining their respective policies and actions to limit or reduce the impact of aviation on the global climate. Updated and extended State action plans were subsequently provided in 2015 and 2018. (EASA, EEA & Eurocontrol, 2019, p. 27)*

The standard set by ICAO is intended to require aircraft manufacturers to start producing more efficient airplanes. The emissions cap set out by ICAO is highlighted by the thick red bar in the lower half of Figure 8. The top boundary of the graph highlights the forecast CO2 emission levels in 2040 if no action is taken. If operational improvements, such as changes to air traffic control occur, the boundary is reduced by the solid red section. Additionally, the new CO2 standard set out by ICAO would further reduce the boundary by the solid blue section. The new CO2 standard limits the emissions produced by new aircraft type designs as of 2020, as well as current in-production aircraft types from 2023, as described above (EASA, 2019). It demonstrates how regulation can help reduce CO2 emissions; however, Figure 8 makes clear that even with the new efficiency standard, international aviation still has a huge gap between its anticipated emissions and its own environmental goals.

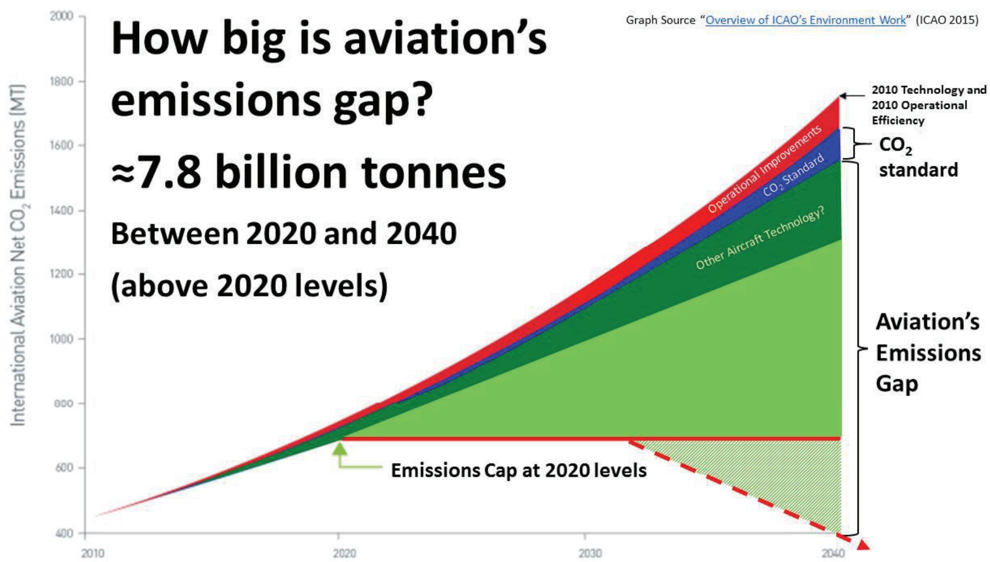

Figure 8. Aviation Emissions Gap; Emissions Cap at 2020 Levels vs. Forecast
Source: (ICAO, 2015)

5.2 OPERATIONAL IMPROVEMENTS

Many of the CO2 reduction techniques emphasise a change to the aircraft design; it is important to note there are also small emission decreases associated with operational improvements. For example, changes to air traffic management (ATM) can make CO2 emission reductions by utilising high altitude flights and route optimality. This is demonstrated with the introduction of Reduced Vertical Separation Minima (RVSM) to Europe in 2002, which introduced 6 flight levels and cut greenhouse gas emissions by 5% above FL290 (ICAO, 2016).

Typical cruising altitudes for subsonic commercial jet transports are between 30,000 and 40,000 ft., although turbojet aircraft can often reach higher altitudes (FAA, 2020). Aircraft operate at such high altitudes because it is more fuel efficient. For a jet plane thrust specific fuel consumption (TSFC), defined as the weight of fuel consumed per unit thrust per unit time, is the measure of engine efficiency (FAA, 2020). TSFC decreases as outside air temperature decreases for constant engine rpm and true airspeed. Since air density is inversely proportional to altitude, higher flight levels are associated with greater fuel economy. As aircraft reach higher altitudes, the amount of excess thrust available for manoeuvring is reduced; therefore, modifications to the airframe are often needed to ensure that movements can be made without stability and controllability being sacrificed at height (FAA, 2020).

As air traffic grows and higher altitude flights are greater utilised, ATM infrastructure needs to be developed. Because of this need, the ICAO and other regulatory bodies have developed the Aviation System Block Upgrades (ASBU) framework. The framework was developed to create a standard approach to technology, procedures, and operational concepts to meet future ATM challenges. It is estimated that this contributed to an increase in fuel savings between 0.69-1.38% in 2018 compared to 2013, which equates to 7.8-15.4Mt of CO2 (ICAO, 2016). A key benefit of operational changes is that they are often quicker to implement than technological improvements. However, it is evident that the small percent of gas emissions they save will not close the emission gap and operational improvements should be used to supplement other CO2 reducing initiatives.

5.3 NEW AIRCRAFT

New aircraft designs utilise the efficiencies described in Figure 7 and other modern technologies; therefore, they are becoming more fuel efficient. It is estimated that the aircraft produced today are approximately 80% more fuel efficient per passenger kilometre than in the 1960s (ICAO, 2016). However, due to the high purchase cost of aircraft they are designed to last 25-30 years; thus, older, less efficient aircraft are still in service, and replacing the current fleet with new and more efficient aircraft will take decades to achieve.

Furthermore, the process is extremely expensive, with the cost of developing new aircraft being widely estimated at $10-12 billion (Ostrower, 2012). In addition, as discussed earlier in this report, the growth in aviation and subsequent increase in emissions has far outweighed the reduction in emissions from the introduction of newer aircraft. Modern aircraft are often built from carbon fibre, and although this provides large weight-saving efficiency benefits, it is currently extremely hard to recycle. In the next 30 years, before these aircraft are retired, better carbon fibre recycling processes are needed.tional improvements should be used to supplement other CO2 reducing initiatives.

5.4 REENGINED AIRCRAFT

The fitting of newer, more efficient engines (combined with other changes such as weight reduction, increased seating capacity and small aerodynamic improvements) to existing airframes has become a popular way for the aircraft manufacturers to offer new products to their customers without the time and cost of developing a clean sheet aircraft.

The combined fuel efficiency gains of these variants are typically mid to low teens on aircraft such as the Boeing 737 MAX (Boeing, n.d.). Except for smaller corporate jets, re-engining aircraft can only be achieved by the original aircraft manufacturer and are not financially viable for retrofit. The redesign process is also expensive and lengthy with Boeing's VP of Business Strategy and Marketing suggesting it would cost $2-3 billion to re-engine the 737 (Ostrower, 2012). Airbus suggests similar figures placing the cost of re-engining the A320 around $1.32 billion (Ostrower, 2012).

5.5 ELECTRIC HYBRID AIRCRAFT

Many electric aircraft are currently in development with manufacturers all over the globe. However, most are currently limited to small passenger air taxis. Figure 9 presents expected time scales for electric air taxis, hybrid-electric aircraft, and battery/fuel cell powered aircraft. At the current rate of development, battery technology will not be able to power a 50-80 seat aircraft until 2035-45 (IATA, 2020). Hybrid-electric technology are an intermediate step to completely electric aircraft; although yet to be fully developed or certified, a 50-100 seat aircraft could be expected to deliver 40-80% reductions in CO2 (IATA, 2020).

In order to truly understand the improvement potential from electric aircraft, the development of battery technology, and understanding of the lifecycle of associated production, needs to be rapidly accelerated

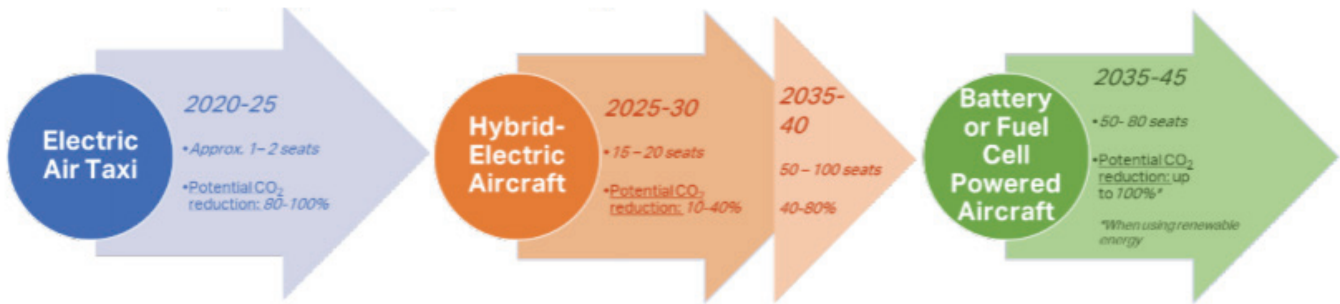

Figure 9. Step-by-step approach for the introduction of electrically powered aircraft
Source: (IATA, 2020)

5.6 SUSTAINABLE FUELS

These can be broken into two main groups: Sustainable Aviation Fuels (SAF) and Biofuels. The difference between them lies in the molecular structure of each; biofuels, like ethanol and biodiesel, are sufficient fuel replacements in some respects. However, they are not pure hydrocarbons, and reaching the required temperature, viscosity, and opacity for aviation-grade fuel is often challenging (Bilal M McDowell Bomani, 2009). There are also disputes on whether creating biofuel such as ethanol from corn requires more fossil energy than produced, as one study suggested that producing ethanol from corn grain required 27% more fossil energy than the biofuel it produced (Bilal M McDowell Bomani, 2009). Furthermore, the amount of land needed to grow corn to turn into ethanol is unfeasible for sustaining the entire aviation industry alongside feeding the global population (Bilal M McDowell Bomani, 2009).

Turning biomass into ethanol using forest and agricultural residue might be a future possibility for reducing costs and increasing scalability. It is estimated that annually, approximately 70-100 billion gallons per year of ethanol could be produced without having to grow any energy crops (e.g., corn); however, this is reliant on improved technology (Bilal M McDowell Bomani, 2009).

SAFs, on the other hand, have an identical molecular make-up to that of ordinary fuel, but have a lower impact on greenhouse gases. Sustainable Aviation Fuel is jet fuel produced synthetically from other hydrocarbon sources without using petroleum. This fuel is produced in a separate plant (not a refinery) and mixed with any Jet A fuel (Tamarack Aerospace Group, 2020).

SAFs are proven to provide the same performance and safety level as Jet A fuel without affecting jet maintenance needs. In addition, they emit fewer particulates, which reduces cirrus-clouding. SAFs offer a 70-80% reduction in carbon emissions (net life cycle), however current regulations only allow for SAF blends. Thus, we get an average of 60% carbon emission reduction rate (Tamarack Aerospace Group, 2020).

The availability of SAFs is often the rate limiting factor; by 2030, it is estimated that up to 13 million tonnes of SAFs could be available globally. This is equivalent to a savings of 35 million tonnes of CO2 (Sustainable Aviation, 2014). Although sustainable fuel technology is available now in various forms, it will take some time before production can be scaled up to produce meaningful quantities of fuel to supply the aviation industry. Biofuels and SAFs certainly have a role in sustainable aviation, but currently do not present a solution on their own.

5.7 CARBON OFFSETTING

Many airlines have adopted CORSIA – an airline industry carbon reduction and offsetting scheme. CORSIA aims to offset carbon emission increases from 2020 but does not reduce current or future emission levels.

> *"CORSIA is a global scheme which will result in greater levels of CO2 mitigation in international aviation than could be achieved through domestic policy measures. It is forecast that CORSIA will stabilize net CO2 emissions from international aviation at around about 600 million tonnes of CO2.IATA estimates that, without CORSIA, the CO2 footprint of international aviation would increase from 600 million tonnes of CO2 in 2020 to almost 900 million tonnes of CO2 by 2035" (IATA, 2020, para.5).*

The purpose of CORSIA is to act as a tool in reducing overall carbon emissions, but it is not the final solution to aviation's carbon emission production. To achieve net-zero, aviation would require one-third of the entire global carbon removal potential. In terms of mass, Dustin Benton, Policy Director at Green Alliance, as cited by Cranfield University (2019), equates it to growing a forest "the size of Australia, or India" (para. 4) to offset the carbon that aviation emits. Furthermore, the greenhouse gas storing and transport infrastructure currently in place cannot support the scale of offsetting required. Carbon sequestration is also needed by other sectors, such as agriculture, and therefore it is not viable for aviation to use all the UK's natural sequestration ability (Cranfield University, 2019). Although the aviation emissions produced are greater than removal strategies; airlines still must improve the delivery of their carbon offsetting programmes to secure customer uptake and have a measurable impact on CO2 reduction. At this point, offsetting is in the order of a few percent at best

5.8 CARBON SEQUESTRATION

Carbon sequestration is the process of capturing and storing atmospheric carbon dioxide. It is one method of reducing the amount of carbon dioxide in the atmosphere with the goal of reducing global climate change. Professor Neil Harris, Professor of Atmospheric Informatics at Cranfield, stated that "we cannot rely on offsetting schemes alone" (Cranfield University, 2019, para.5). Since many sectors want to use offsetting, carbon offsetting cannot be seen as the cure. Furthermore, carbon sequestration often involves storing the CO2 removed in the soil and therefore, effectiveness is based on how the soil is cared for in the long-term (Cranfield University, 2019). Dr Jacqueline Hannam of Cranfield University stated that "keeping carbon in the soil is a vital part of mitigating climate change – and the degradation of soil means this carbon is being released back into the atmosphere" (Cranfield University, 2019, para.5). Therefore, offsetting schemes are not enough independently, and a cross-industry collaboration is needed to invest and research better energy sources.

5.9 WINGLETS

By far the most popular efficiency improvement has been the addition of winglets like those installed on the B737-800 by Aviation Partners Boeing and Airbus' A320 series sharklet. Winglets are small aerofoils applied vertically to the wing tips and are a positive addition to aircraft as they reduce drag and increase efficiency, as indicated in Figure 10. They work by reducing the aerodynamic drag associated with vortices. Vortices form due to the pressure differentiation between the low-pressure upper wing surface and the high-pressure lower wing surface. At the wing tip, air is free to move from the regions of high pressure to the regions of low pressure forming a circular movement of air which trails from the wing tip (Anderson, 2017). The creation of vortices causes a redistribution of the surface pressure over the wing termed induced drag (Anderson, Introduction to Flight, 2016).

The advantages of winglets are significant; they are retrofittable and therefore can improve today's aircraft, as well as those coming off the production line; they are largely cost effective to implement; and are a 'win, win' as they pay back economically and environmentally.

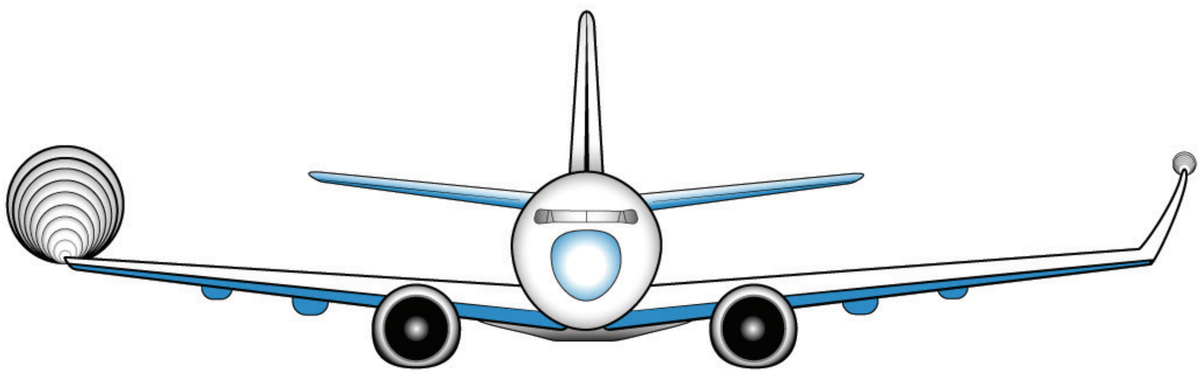

Figure 10. Wingtip Vortices (Left: no winglet—high drag; Right: winglet—low drag)

However, they all suffer from the same paradox. As the winglets alter the spanwise loading to increase efficiency, wing bending stress increases along the wing, as a result. These stresses need to be counteracted in some way. Historically this has meant adding reinforcing structure, which adds weight to the wing. To minimise the additional weight, designers have been forced into a balancing act of reducing winglet efficiency to reduce the amount of reinforcement required. For example, a fully optimised winglet design might be highly efficient; however, the impact of reinforcements required to accommodate the added weight of the winglet results in compromised winglet performance, reducing the benefits to between 4-6% (NASA, 2010). The requirement to add reinforcement significantly increases the grounding time to retrofit winglets, and considering the small benefit, airlines have not widely adopted some winglets as a retrofit option.

5.10 INCREASING WING ASPECT RATIO

With the heightened focus on efficiency and sustainability, clean sheet concept designers are increasingly turning their attention to the wing's aspect ratio; (the ratio of its span to its mean chord). Long slender wings, like those of a glider, have a high aspect ratio (high L/D) and therefore high efficiency. This is because the induced drag coefficient is inversely proportional to the aspect ratio (Anderson, 2016). As described above, induced drag is caused by how wing tip vortices alter the flow field and change the pressure distribution in the direction of drag (Anderson, 2016). However, wing designs of this type suffer from a similar conundrum to winglets (as discussed in Para 5.9) in that the longer the wing, the greater the bending moment – this drives the need for stronger wings, which increases their weight.

Boeing and NASA have collaborated to address this problem using a Truss-Braced Wing concept, as shown in Figure 11, designed to be more aerodynamic and fuel-efficient than current designs as part of the Subsonic Ultra Green Aircraft Research (SUGAR) program focusing on innovative aerospace concepts that reduce noise and emissions while enhancing performance (Howard, 2019).

Figure 11. Truss-Braced Wing Concept
Source: (Howard, 2019)

Figure 12. Bombardier CRJ700 high aspect ratio wing concept
Source: (Bombardier, 2017)

Bombardier is also exploring high aspect ratio wings. The illustration shown in Figure 12 shows how their CRJ700 might look with a high aspect ratio wing. Bombardier is also exploring strut-braced wings, and in 2017 published an article explaining how aspect ratio is important for saving fuel (Bombardier, 2017).

5.11 TAMARACK ACTIVE WINGLETS

A proven, trailblazing technology which solves the winglet and wing bending conundrum has been developed by Tamarack Aerospace. The technology dubbed the ‘Active Winglet’ uses the combination of a wing extension to significantly increase aspect ratio with the most optimal winglet to reduce induced drag. Traditionally, the most optimal winglet design is associated with more structural reinforcement, but the Active Winglet negates this requirement. It allows for the most aerodynamically beneficial design, such as a taller or greater degree of angle divergence to be realised with no efficiency degradation.

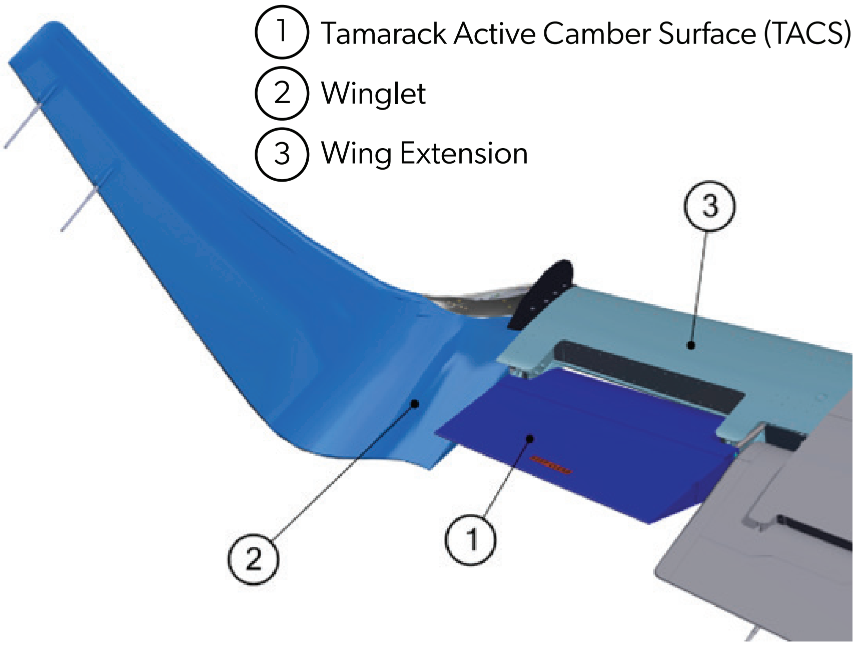

Figure 13. Tamarack Aerospace Active Winglets

It allows the winglet to reap maximum fuel efficiency benefits without subtracting the inefficiencies that occur due to additional structural requirements, as described in section 5.9. This is achieved using load alleviation (at the wing tip) which negates the need for wing structural reinforcement or truss-braces. The load alleviation system uses a ‘g load’ sensor mounted in the aircraft, which sends signals to a spoiler (Figure 13. item 1) which quickly reacts to counteract loads resulting from infrequent, high load conditions (such as a gust or manoeuvre), to momentarily eliminate winglet and extension loads. Refer to section 4.2 for additional details on the operation of Active Winglets. Simplistically, in such conditions the load alleviation system aerodynamically turns off the winglet, rendering it invisible to the wing structure in terms of structural loads.

Airworthiness authorities, such as the FAA or EASA, require that the structure can carry the worst-case flight loads (Design Limit Load); with the addition of a safety factor of at least x1.5 (Ultimate Structural factor of Safety). The purpose of the safety factor is to reduce the probability of a structural failure, this can also be accomplished with the addition of certain systems which relieve loads (Tamarack Aerospace Group, 2016). Existing regulations (EASA CS-25.302) allow a reduced structural factor of safety via a load alleviation system, as long as the probability of a structural failure is extremely improbable (EASA, 2007). Under this regulation, although the safety factor is reduced, the safety of the system is not compromised because the system contributes to the structural safety of the wing. Tamarack's load alleviation system meets this criterion, and the winglet has been designed using this regulation to leverage the benefit for customers (Tamarack Aerospace Group, 2016).

Wing extensions (increasing aircraft span and therefore aspect ratio) alone, increase aircraft efficiency, by an amount even greater than winglets by themselves. By combining the wing extension, denoted "1, (Figure 13. Item 3) and winglet, denoted 1, (Figure 13. item 2) the synergetic efficiency improvement created is an amount larger than the sum of the two efficiencies individually, this can be expressed "1 + 1 = 3". This combination of a fully optimised winglet working in tandem with a wing extension and the lack of structural reinforcement has yielded an impressive 33% reduction in fuel burn on some aircraft types (Tamarack Aerospace Group, 2020).

5.11.1 ACTIVE WINGLETS – BENEFITS SUMMARY

5.11.1.1 SUSTAINABILITY AND FUEL BURN REDUCTION

Eliminating the wing reinforcements and increasing the aspect ratio of the wing yields a fuel burn reduction of up to 33%. Whilst this may be exceptional, most aircraft can expect around 15-20% reduction in fuel burn using Active Winglet technology (Tamarack Aerospace Group, 2020). As discussed in paragraph 5.9, high aspect ratios are a crucial factor in wing efficiency. By increasing the aspect ratio, Active Winglets create efficient glides, climb faster, and require less power, which all contribute to their effectiveness while reducing fuel burn. Reduced fuel carriage, for the same route, can either be used to further reduce emissions and fuel burn (not accounted for in fuel burn figures in this paper), or to maintain the fuel loads and extend the range of the aircraft, making it more versatile for the operator.

A reduction in fuel burn directly equates to a reduction in emissions and therefore the CO2 and other harmful substances produced. The amount of CO2 emissions reduced by Active Winglets is presented in the case study in Section 5.12. The significant emission reductions resulting from Active Winglets has the potential to make a serious and realistic impact on ICAO's sustainability goals. As the technology is retrofittable (paragraph 5.11.1.5) and applicable to all aircraft (paragraph 5.11.1.6) the potential reduction in C02 emissions across the global fleet is significant.

5.11.1.2 NOISE REDUCTIONS

In addition to reducing harmful emissions, the use of Active Winglets has the potential to assist in noise reduction. Active winglets can assist in a faster climb and greater climb angle, which can decrease the effective perceived noise levels on the ground. Many airports and their surrounding areas have noise limits, and it is a requirement of operators to comply with these noise levels. To abide by these limits airports often have required Noise Abatement Department Procedures (NAPD). This could involve a faster climb to reduce noise to aircraft within a closer vicinity (NADP1) or a more gradual climb to reduce noise in an area further away (NADP2). Active winglets can play a role in helping aircraft reach the required altitudes in time to meet these noise requirements without having to sacrifice payload.

5.11.1.3 PERFORMANCE BENEFITS

The reduced structural safety factor, as detailed in section 5.11, is applicable to the entire wing. This provides opportunity for increased Maximum Take Off Weight (MTOW), which is limited by the structural load, therefore increasing the versatility and profitability of the aircraft through the payload it can carry. Alternatively, new wing designs in the future could utilise the reduced structural load requirements for wings with Active Winglets and create lighter more efficient wings.

The load alleviation system can be tuned to increased fatigue life by detecting winglet-specific loads and wing-loading of the aircraft. This has the potential to increase its longevity and hull value, which is more sustainable than scrapping and replacing the current fleet with newly built aircraft. Since the Active Winglet system alleviates loads above prescribed g-force limits, it can result in a smoother more comfortable ride for passengers during turbulence.

The greater L/D ratio achieved from having an increased aspect ratio due to the Tamarack Winglet System, equates to lower stall speeds which mean lower landing speeds which reduces wheel and brake wear and allows operation from shorter runways. Other take-off performance benefits from a greater L/D ratio, include the ability to take-off from high-altitude airports and during higher ambient temperatures without having to reduce payload. Furthermore, the improved L/D qualities, allows aircraft with Tamarack Winglets installed to operate at higher altitudes (above 40000 ft), which can further reduce fuel burn and harmful emissions produced. Finally, de-rated take-offs are possible which decreases wear on the engines, increasing their life and hence their value. Taking off with reduced thrust also has the potential of decreasing noise and emissions for people within the vicinity of the airport, which can have significant health and environmental benefits.

5.11.1.4 FAST TO MARKET

The innovative Active Winglet technology developed by Tamarack Aerospace is proven and available now, by 2020 over 100 aircraft had already been fitted. Furthermore, the Active Winglet is certified by the European Aviation Safety Agency (EASA), Federal Aviation Authority (FAA) and other regulators as a Supplementary Type Certificates (STC) for the Cessna Citation Jet family. As a roadmap to certification has been established and because wing reinforcement is not required; the design, development and certification timescales for each new candidate aircraft is rapid at 12-18 months.

5.11.1.5 RETROFITTABLE

Active Winglets are effectively a 'bolt on' wingtip solution and therefore much simpler to retrofit to existing aircraft. They are designed to be independent of the aircraft's flight controls and systems, other than electrical power being provided from the aft electrical junction box. Figure 14 highlights the simplicity of their addition. The wing extension, containing the TACS, and the winglet are installed to the wingtip. The TACs moves up and down to alleviate loads using information from Tamarack's Control Unit (ACU), which is installed under the cabin in the centre of the aircraft using wires running through the "Bulkhead Pass-Through Connector". Next to the ACU is an Annunciator Line Replaceable Unit, which powers and manages the lighted Inop Button on the instrument panel in the cockpit. The Inop button allows pre-flight system testing and notification of any defects. This design greatly reduces the certification and time to retrofit because structural reinforcement in the wing is no longer required. The hangar time required to fit them is reduced to a few hundred manhours vs. a few thousand manhours for previous winglet types. Ground time and manhours are a significant cost incurrence for airlines and therefore this is a significant benefit of Tamarack's Active Winglet.

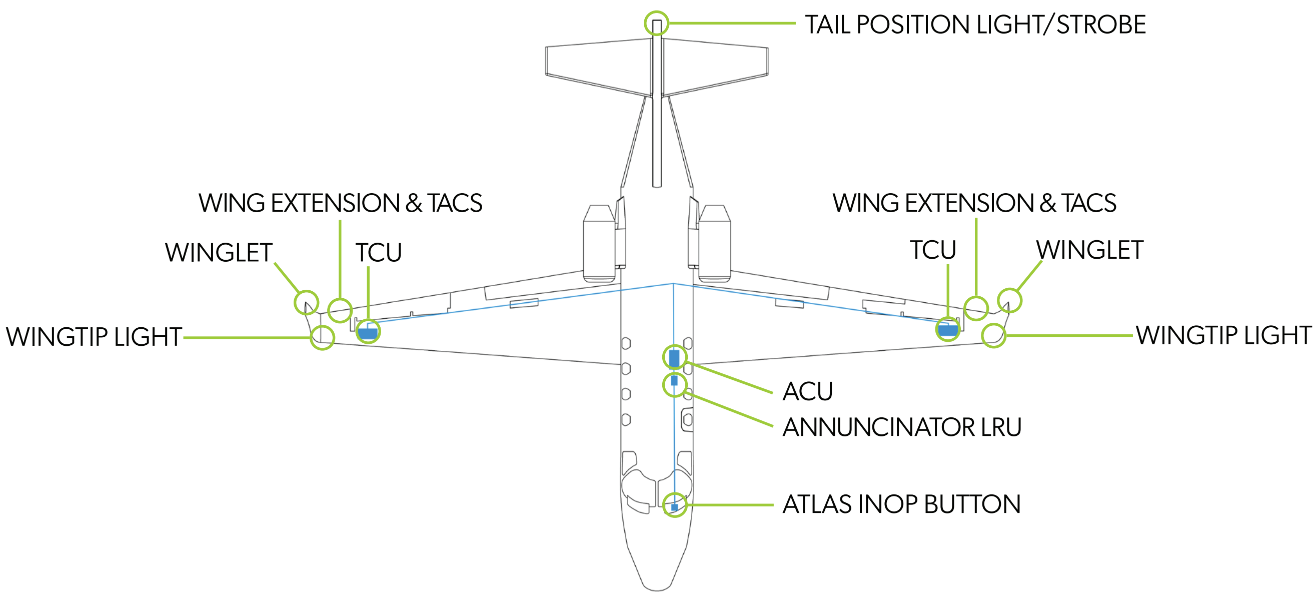

Figure 14. Tamarack Aerospace Active Winglets Installation

5.11.1.6 APPLICABLE TO ALL AIRCRAFT

Most aircraft types fitted with Active Winglets will benefit from substantial fuel burn reduction, fatigue life increases and performance benefits, including those previously thought to be poor candidates for winglets due to marginal or negative results with traditional winglet designs. Tamarack has carried out extensive (verified) computer modelling on multiple wide and narrowbody aircraft types such as A320, 737, A340, King Air 90 & 350, Dash-8 and on military platforms like the C130 Hercules. All these aircraft showed extensive, double digit, reductions in fuel burn (and hence CO2 emissions) ranging from 14 to 20%. Even the latest fuel-efficient aircraft such as the Airbus A320 NEO and 737 Max displayed a substantial reduction of circa 14% from the addition of Active Winglets, as highlighted in Section 5.11.2.

5.11.1.7 SCALABLE

Tamarack's technology is proven, certified and can be applied to most aircraft types. Currently, Tamarack winglets can be installed and serviced in locations across the United States and in the United Kingdom. Furthermore, there are many companies (design houses) with the right capabilities with which Tamarack can partner or licence the technology, and production can be scaled up using existing manufacturing infrastructure. Hence, accelerated adoption on multiple aircraft types can greatly reduce carbon emissions and fuel burn.

5.11.1.8 ECONOMICALLY VIABLE

Crucially Active Winglets are a 'win-win' for customers financially as well as for carbon emissions reduction. With significant fuel burn reduction plus an increase in fatigue life and payload, airlines will be able to receive a 100% return on investment (ROI) in a very short space of time (1-2 years). Airlines can also carry less fuel or increase range to open longer routes on smaller more efficient types.

5.11.2 NARROW-BODY CARBON EMISSIONS CASE STUDY

Tamarack has conducted a case study, applying Active Winglets to narrow-bodied commercial aircraft as they are the highest contributor of carbon emissions (43%, as described in Section 4) compared to other classes of aircraft. They are also excellent candidates for Active Winglets, with the case study finding reductions in fuel burn of up to 20% when fitted to the 737-800 and 14% for the A320 CEO, A320 NEO and 737 Max.

The case study utilised data from the Airbus Global Market Forecast and Boeing Commercial Market Outlook reports in terms of expected narrowbody fleet growth between 2020 and 2040 (Boeing, 2020; Airbus, 2019). It then derived global CO2 emissions reductions from computer modelling, predicting the fuel burn reduction for an aircraft fleet fitted with Active Winglets using data obtained from Massachusetts Institute of Technology (MIT) Airline Data Project (MIT, 2020). The fuel burn reduction was converted and expressed in terms of CO2 (Jardine, 2009). These models have been validated against the 100+ aircraft for which Active Winglets have already been certified and fitted, and the thousands of hours of 'real world' data that has been gathered.

The results of the narrowbody study are highlighted on Figure 15, demonstrating a significant reduction in emissions across the global fleet, reaching 14% CO2 emissions reduction per annum at full embodiment. To ensure the relevance of the model, it considers a reserved embodiment plan, reflective of known timescales for regulatory approval of Active Winglets, availability of maintenance facilities, and active aircraft downtime. Furthermore, it assumes an annual retrofit rate of 10% of the operating global aircraft fleet, starting in 2023, with a production line cut-in in the year 2024.

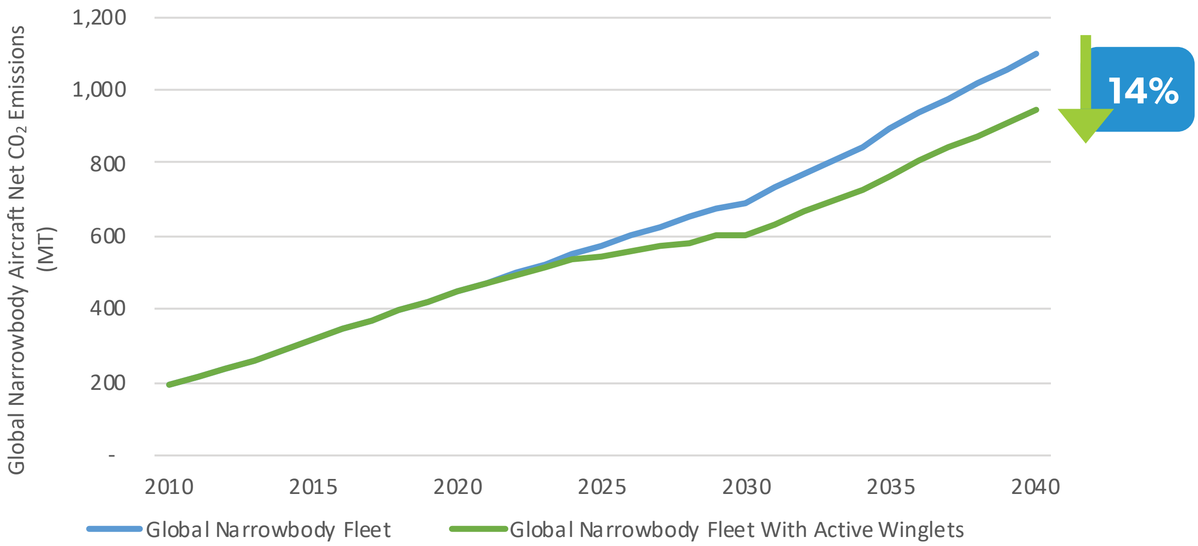

Figure 15. Global Narrowbody Emissions reductions with a staggered embodiment of Tamarack Active Winglets

When considered in the context of ICAO's own emissions forecasting (Figure 8), the model predicts that embodiment of Active Winglets on the narrowbody fleet alone, could reduce CO2 emissions by 1.6 billion tonnes between 2023 and 2040. This represents 20% of the total 7.8 billion tonnes emissions gap and has the potential to make an enormous contribution to meeting ICAO's emission goals. Figure 16 demonstrates the direct reduction resulting from Active Winglets relative to the emissions gap determined by ICAO (ICAO, 2015). Naturally if Tamarack Active Winglets were applied more extensively across the existing global fleet of civil and military platforms the total emissions reduction would be much higher.

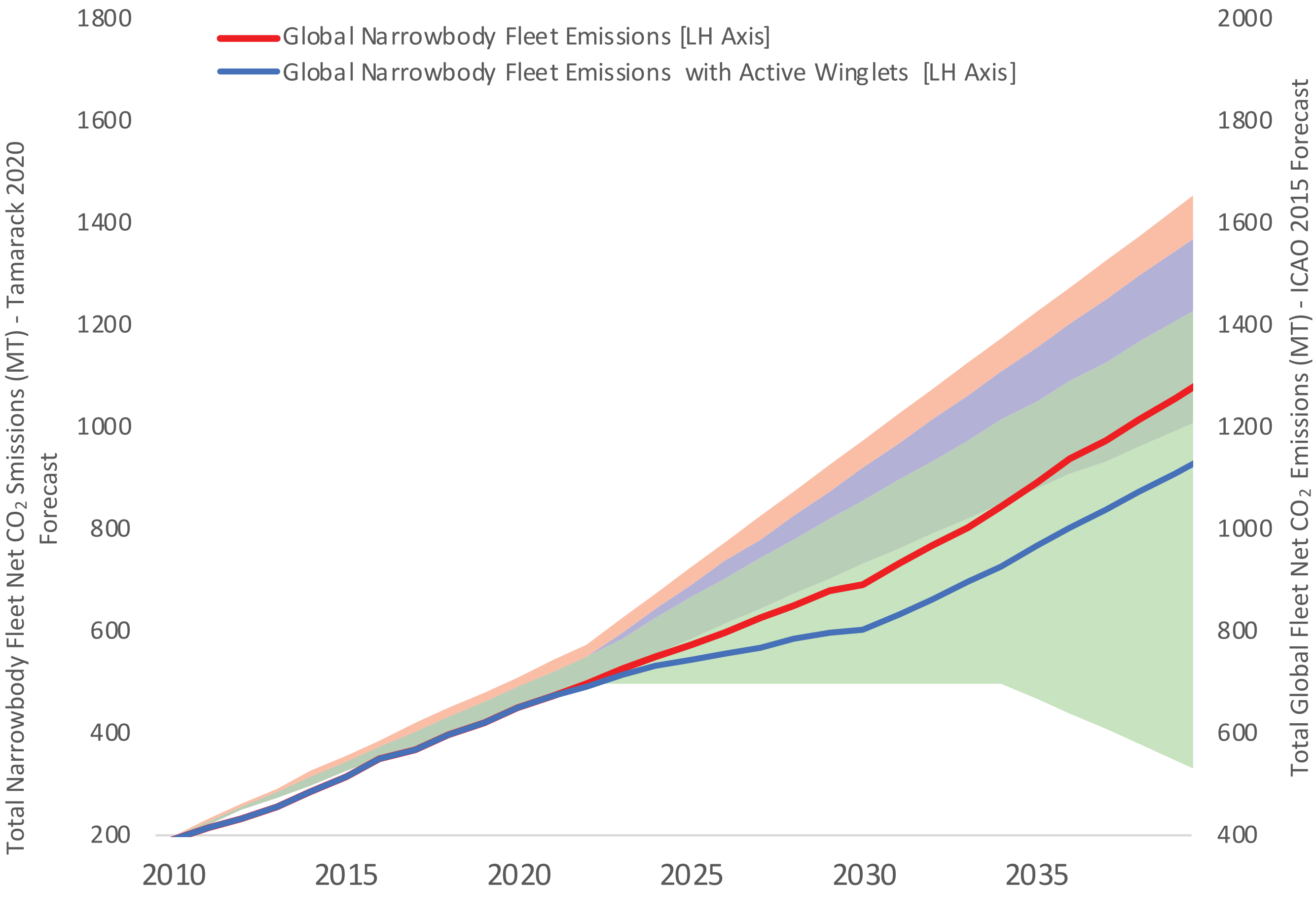

Figure 16. Impact of Active Winglets Installed on Global Narrowbody Fleet on ICAO CO2 Emissions Gap

6 AIRLINE SUSTAINABILITY

Airlines are utilising a combination of measures discussed in Section 5 to reduce their emissions. A study conducted by Professor Susanne Becken of Griffith University, in collaboration with Amadeus, assessed airline uptake of emission reducing initiatives (Green Air Online, 2020, as cited from Amadeaus, 2019). The analysis, presented in Figure 17, highlighted 22 different categories of action being taken by leading international airlines as a function of their embodiment. The categories are grouped into aircraft efficiency, flight operations, offsetting, governance, and alternative fuels, all of which are discussed in detail in Section 5. Other than fleet renewal, the majority of the most widely utilised initiatives are options which could be incorporated relatively quickly, retrofittable and do not affect the certification of the aircraft. Unfortunately, the initiatives in Figure 17 often do not have the scale of impact needed to greatly reduce CO2 emissions in the next decade. A key finding of the report expresses the multitude of carbon saving initiatives but emphasises that most of them result individually in relatively small reductions of 0.1-0.3% of annual fuel use – compared with overall emissions (Green Air Online, 2020, as cited from Amadeaus, 2019). In conjunction with each other, the initiatives can have an impact on emissions, but to compensate for the growth in air transport these measures would have to be implemented year on year. A retrofittable solution with high CO2 reductions, that is available now is essential to reduce aviation's role in climate change; of the initiatives highlighted in Section 5 and Figure 17, Active Winglets stand out as a solution to both.

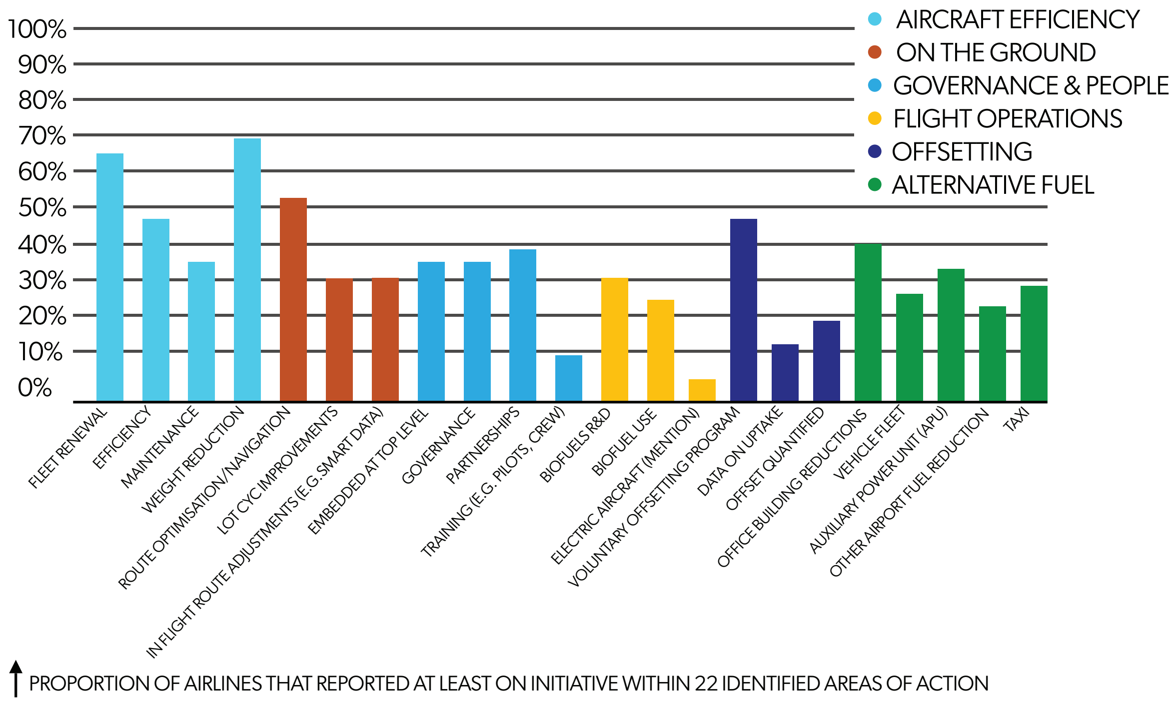

Figure 17. – Sustainability Projects Embodied by Airlines by Type and Business Areapt
Source: (Green Air Online, 2020, as cited from Amadeaus,2019))

Future technological advances are also integral to reducing carbon emissions as discussed in Section 5. However, the time to certification is long and the benefits may not be obtained for at least another 10 years plus. Since the carbon emissions crisis is happening now, both immediate and long-term solutions need to be utilised. Figure 18 is a high-level matrix summarising the sustainability initiatives and their effectiveness in tackling sustainability problems today as found in Section 5 of this paper. Their time to implementation and their effect on emissions is qualitatively shown in the matrix. The matrix is colour coded based on the most effective solution that is already on the market today and the most cost effective option.

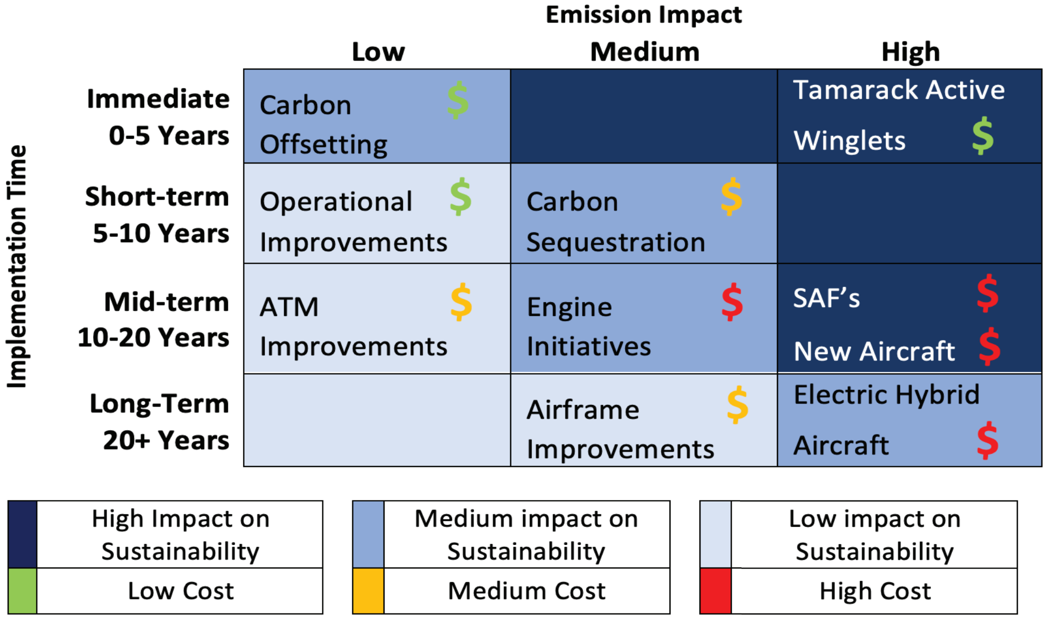

Figure 18. Carbon reducing initiatives in relation to: time to implementation, effectiveness & cost

The trade association for the world's airlines, the International Air Transport Association (IATA), has a goal to reduce net aviation CO2 emissions by 50% before 2050, relative to 2005 levels; some airlines have gone further to pledge being carbon neutral by 2050 (IATA, 2020). They aim to reach this target through the commitment of all stake-holders to follow a four-pillar strategy. This is based on improving technology, introducing more efficient aircraft operations, making infrastructure improvements, and introducing a single global market-based measure to fill the remaining emissions gap (IATA, 2020). Airlines are intent on increasing their sustainability practices, for a range of social, economic, and legal reasons. As with other industries there is a moral responsibility to ensure that a global effort is made to reduce carbon emissions but also a responsibility to passengers who are becoming more con-scious about doing their part to reduce CO2. A shift in passenger attitudes towards sustainability is starting to drive change within the aviation industry; however, a greater awareness of the impact of travel and greater transparency from airlines on their sustainability practices are needed to ensure that passengers can make informed choices. The initiatives introduced by even the most sustainable airlines are still small and far from reaching IATA's 2050 carbon pledge. Sustainably conscious airlines, which are intent on having a meaningful impact in reducing CO2 emissions, are in desperate need of affordable, retrofittable technology such as Tamarack's Active winglets to achieve their net zero goals whilst increasing their fleet size.

7 CONCLUSION

The coronavirus pandemic has shrunk the world fleet because of airlines going out of business and older, less efficient aircraft being retired early. From 2020 onwards, this will unquestionably deliver reduced CO2 emissions lower than previously projected. However, this is not the solution to aviation's carbon emission challenges. Although passenger numbers dropped by 2690 million (60%) in 2020 compared to 2019, passenger numbers are predicted to recover to 2019 levels within the next 3-5 years (ICAO, 2021). Furthermore, in 2020 compared to 2019, approximately USD 370 billion of gross passenger operating revenues of airlines were lost (ICAO, 2021). This unprecedented event could present a major opportunity for operators to reset their thinking on emissions targets and implement sustainable practices in every aspect of their new, reshaped organisations.

Aircraft are reliant on fossil fuels and with no clear path or timeframe to a zero-emission alternative, ICAO predict a large gap in the emissions targets set for the period of 2020 to 2040. There are several steps that aircraft operators can put in place to significantly reduce emissions which is discussed throughout Section 5. The science and market demands are dictating that we need to act now. Technology such as Sustainable Aviation Fuels face significant scalability obstacles, carbon sequestration and offsetting would be required on a vast scale to have a significant impact and the introduction of newer, more fuel-efficient aircraft which emit less CO2, will not be sufficient on its own to offset the growth in the number of air transport movements. Of the options outlined, Tamarack's Active Winglet technology stands out as an exciting prospect because it can reduce the emissions gap by over 1.6 billion tonnes (-20%), it is available now and is scalable. If retrofitted across a wide range of civil and military fleets the total global reduction in emissions would be much greater than that calculated in the study. The technology is economically viable, paying the investment back in a short period and can have a significant benefit for the existing as well as future fleets of aircraft. Conservative estimates on narrow bodied aircraft, demonstrate that Tamarack's Active Winglets can reduce fuel burn by 14-20%, providing significant cost savings and having a meaningful impact on aviation's carbon crisis.

As availability of Sustainable Aviation Fuels increases and technology advances, the aviation sector will see substantial reductions in carbon emissions until zero emissions aircraft can be developed. However, where a near-term solution is needed, fitting Active Winglets would be a significant step forward for operators looking to obtain carbon neutral operations, particularly when combined with a host of other sustainable initiatives.

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