The Environmental Impact And Resource Cost Of The Aviation Landing Process.

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1. Introduction

Fuel conservation is a significant concern of every airline. During landing and take-off cycle phase (LTO), up to 950 m, the specific fuel consumption is significantly higher than it is for cruising. So, any improvement on this stage of the flight will allow fuel saving.

To ensure a good braking effect for the aircraft, several systems and strategies are used to deaccelerate. Aircraft are equipped with thrust reversers, brake discs and flaps.

In this report, the environmental and cost repercussions of a new brake disc cooling system are analysed. The proposed cooling technology will reduce the rotating disc average temperature and this will have several consequences, that will be analysed in this report:

- Brake cooling can be done during the braking period and on the runway prior to full stop and reaching the terminal.
- Reverse thrust, a high fuel demanding system, is not necessary to stop the aircraft, as excessive brake energy can be avoided and brake can be used more when decelerating.
- Significant amount of time can be saved on the ground as no external cooling is needed, so the period between landing and take-off can be reduced.
- Resources used for the aircraft brake cooling (time and manpower) will be eliminated.

The new developed technology has not been tested yet, so the elimination of reverse thrust may be less than 100%. So in this report three reverse thrust mitigation scenarios are considered: 100%, 50% and 25%. All the calculations have been made for the 100% reduction scenario and the results are presented in section 2 and 3, while the results for the three considerations are presented in section 4.

2. Fuel saved in reverse thrust

A thrust reverser system is designed for the use on ground only. With full reverse thrust, fuel flow can reach 3,200kg/h, a value similar to take-off thrust configuration (Trincheiras, 2016). Considering that normally an aircraft stops in 30 seconds, this means that the fuel consumption operating 100% in reverse thrust can be of **26.67 kg of fuel per aircraft and landing**.

This value is very similar to those obtained by Unique for the case of Zurich Airport (Unique, 2005). They evaluated 10 different aircrafts landing in Zurich Airport. The duration from touch down to end of roll out was between 44.2 seconds and 49.5 seconds, while the duration of thrust reverser deployment during roll out was between 28.4 seconds and 34.7 seconds. The fuel consumed by Thrust reversers by aircraft was between 12.7 kg and 40.5 kg.

The average price of a barrel of jet fuel in 2018 was $86 per barrel (IATA, 2019), which is 0.67 $/kg. The price of jet fuel fluctuates a lot. For example the average 2020 price is $46.3 per barrel, 0.36 $/kg (IATA, 2020a). Because the 2020 reflects the COVID-19 situation, we use the average value of 2018 to make calculations in this report. So, the **cost on fuel used in reverse thrust** per aircraft when landing is **$17.94** (£13.81).

So, the new developed cooling technology may avoid the need of using reverse thrust, which means that each aircraft may save 26.67 kg of fuel per landing. This saving supposes also a saving on the cost, £13.81 per landing, and on environmental impacts.

In the following table the environmental savings of avoiding 26.67 kg of jet fuel are presented.

Table 1 Environmental impacts saved per aircraft and landing by avoiding reverse thrust.

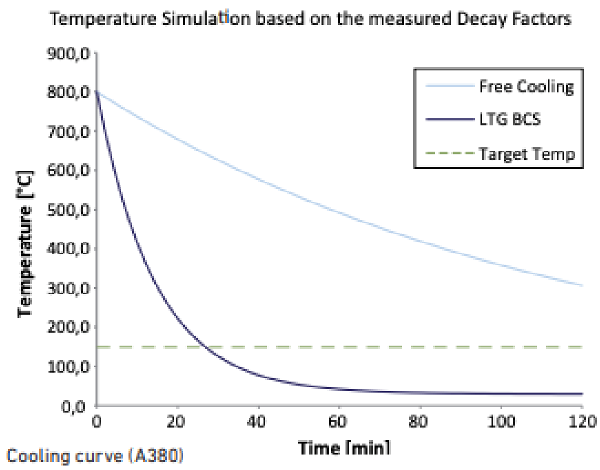
Environmental impact category	Units per aircraft and landing	Environmental impact avoided from fuel saving
Climate change	kg CO_2 eq	98.42
Stratospheric ozone depletion	Kg CFC11 eq	3.28E-05
Ionizing radiation	kBq Co-60 eq	0.74
Ozone formation, human health	kg NOx eq	0.43
Fine particulate matter formation	kg $PM_{2.5}$ eq	9.08E-02
Ozone formation, terrestrial ecosystems	kg NOx eq	4.35E-01
Terrestrial acidification	kg SO_2 eq	2.83E-01
Freshwater eutrophication	kg P eq	2.37E-04
Terrestrial ecotoxicity	kg 1.4-DBC e	79.17
Freshwater ecotoxicity	kg 1.4-DBC e	3.16E-02
Marine ecotoxicity	kg 1.4-DBC e	0.12
Human carcinogenic toxicity	kg 1.4-DBC e	0.32
Human non-carcinogenic toxicity	kg 1.4-DBC e	1.95
Land use	m^2a crop eq	0.16
Mineral resources scarcity	kg Cu eq	2.48E-02
Fossil resource scarcity	kg oil eq	32.84
Water consumption	m^3	0.16
Cumulative energy demand	MJ	1,431

3. External brake cooling system resources and time saving

Currently, once the aircraft has landed, it cannot initiate another flight immediately. Some ground operations are required, being one of them the brake cooling.

In brakes the kinetic energy is converted into heat and even after stop is completed the temperature continues to rise. In the following graph the cooling curve of brake is shown by time, comparing the cooling process without intervention and the cooling process using the Brake Cooling System Type BCS 315 from the manufacturer LTG (LTG Incorporated, 2016), and the target temperature that will allow the aircraft to fly again.

Figure 1 Temperature Simulation based on the measured Decay Factors of the Brake Cooling System Type BCS 315. Source: LTG Incorporated, 2016



The new developed cooling technology will require only 5 minutes to get the target safety temperature, while brakes now in use require at least 30 minutes to cool using portable cooling fans, and one person per brake.

So, reducing the cooling period once landed, represents:

- a saving on time of 25 minutes, that can be used to initiate another flight and that could be translated also into parking costs savings, and
- 25 minutes of work labour per brake saved.

A. PARKING COSTS SAVING

Airlines have to face airports' charges, for the use of the infrastructure and services. Several European conditions of use including airport charges have been analysed in order to determine the cost saving that could come from the 25 minutes saving. As some charges depend on the MTOW (Maximum take-off weight), an average weight has been considered of 172 tonnes per aircraft (average of 6 different aircrafts).

Table 2 Parking charges in different European airports.

Airport	Condition	Average parking cost per minute and aircraft (£)
Heathrow, UK	Wide Bodied Aircraft: There is no charge for the first 90 minutes. Charge per 15 minutes or part thereof after the free period is: £61.13 Narrow Bodied Aircraft: There is no charge for the first 30 minutes. Charge per 15 minutes or part thereof after the free period is: £25.47	4.08
Luton, UK	Charge per tonne, per minute based on aircraft MTOW: First 15 minutes from time of landing, free of charge After free period £0.037/minute/tonne	6.36
Madrid, Spain	0.136884 € per quarter hour or part thereof and tonne (aircraft MTOW)	1.41
Girona, Spain	0.071892 € per quarter hour or part thereof and tonne (aircraft MTOW)	0.74
Paris Vatry, France	Traffic area: 0.20 € per hour and tonne (MTOW) Distant area: 0.10 € per hour and tonne (MTOW) The duration of parking is deducted for every aircraft between the time of landing and take-off time	0.39

Based on these data, we have obtained an average parking cost, without considering the free of charge period after landing: £2.60/minute.

With the proposed new cooling technology, 25 minutes may be saved, which means a **saving on parking costs of £64.91** per aircraft and landing.

B. WORK LABOUR COST SAVING

Considering a passenger aircraft of 8 wheels, it is assumed that 4 workers spend 30 minutes each of them to cool the braking system. So, with the new developed technology, potentially 25 minutes per worker may be saved.

Ground handling companies worldwide employees 135,000 people (IATA, 2020b). Each year 20,000 new employees are incorporate to these companies and they suppose a cost of $200 million USD, including training costs ($50 million USD).

In order to calculate the labour cost, the UK minimum wage is considered, £8.72 per hour.

The cost work labour to cool the braking system of an aircraft during 30 minutes is £4.36 per employee, so reducing the cooling time 25 minutes causes a **saving of £14.53 per aircraft and landing**, considering 4 workers.

4. Different reverse thrust consideration

Even though the initial study indicates that the reverse thrust could be reduced 100%, in this section two conservative scenarios are considered:

- The new developed technology implies a thrust mitigation of 50%
- The new developed technology implies a thrust mitigation of 25%

Even if the reverse thrust is reduced 50% or 25%, the labour and parking cost saving is the same as 100% reduction scenario. So only fuel and the related environmental impact would be reduced.

Table 3 Carbon emissions, fuel and costs savings by avoiding reverse thrust 100%, 50% and 25%, per aircraft and landing.

Consequences of reverse thrust reduction	Units per aircraft and landing	100% reverse thrust reduction	50% reverse thrust reduction	25% reverse thrust reduction
Fuel saving	kg	26.67	13.33	6.67
	£	13.81	6.91	3.45
Climate change – carbon emissions saving	kg CO_2 eq	98.42	49.21	24.61
Parking costs saving	£	64.91	64.91	64.91
Work labour cost saving	£	14.53	14.53	14.53

In 2019, 38.9 million flights were performed by the global airline industry (Statista, 2020). So in the following table the annual potential savings of reverse thrust reduction are presented, for the three scenarios considered.

Table 4 Carbon emissions, fuel and costs savings by avoiding reverse thrust 100%, 50% and 25%, per year.

Consequences of reverse thrust reduction	Units per annual air movements worldwide	100% reverse thrust reduction	50% reverse thrust reduction	25% reverse thrust reduction
Fuel saving	tonnes	1,037,333	518,667	259,333
	£	537,389,315	268,694,658	134,347,329
Climate change – carbon emissions saving	tonnes CO_2 eq	3,828,634	1,914,317	957,159
Parking costs saving	£	2,524,944,421	2,524,944,421	2,524,944,421
Work labour cost saving	£	565,346,667	565,346,667	565,346,667

5. Conclusions

The new developed brake cooling technology avoids the need of reverse thrust when stopping the aircraft. As the technology has not been tested yet, different mitigation considerations have been made, 100%, 50% and 25% reverse thrust reduction.

Reducing reverse thrust has several consequences, like reducing fuel consumption when landing, which means a reduction on costs and carbon emissions and other environmental impacts, and reducing the need of external cooling once landed, which is translated into labour work and parking cost savings.

For landing, an aircraft can save between 6.67 and 26.67 kg of jet fuel if reverse thrust is 25% or completely avoided. It implies a reduction on costs of at least £3.45 and maximum £13.81. In terms of carbon emissions, the 98.42 kg CO_2 eq would not be emitted.

As the cooling process saves time on external brake cooling, £64.91 can be saved on parking costs and £14.53 on labour costs.

If we consider that 100% reverse thrust is eliminated, on each landing, an aircraft can save £93.26, £86.35 if it is reduced 50% and £82.90 if reduced 25%.

On global annual terms, based on the number of flights of year 2019, reducing 100% reverse thrust means saving £3,628 million. If it is reduced 50%, the saving would be £3,359 million and £3,225 million if reduced 25%.

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Annex. Impact categories description

Environmental impact category	Unit	Description
Climate change	kg CO_2 eq	An increased atmospheric concentration of greenhouse gases will increase the radiative forcing capacity leading to an increase in the global mean temperature (°C). Increased temperature ultimately results in damage to human health and ecosystems.
Stratospheric ozone depletion	Kg CFC11 eq	Emissions of Ozone Depleting Substances ultimately lead to damage to human health because of the resultant increase in UVB radiation. Chemicals that deplete ozone are relatively persistent and have chlorine or bromine groups in their molecules that interact with ozone (mainly) in the stratosphere. This increased radiation negatively affects human health, thus increasing the incidence of skin cancer and cataracts.
Ionizing radiation	kBq Co-60 eq	Anthropogenic emissions of radionuclides are generated in the nuclear fuel cycle (mining, processing and waste disposal), as well as during other human activities, such as the burning of coal and the extraction of phosphate rock. Exposure to the ionizing radiation caused by these radionuclides can lead to damaged DNA molecules and thus affect human health.
Ozone formation, human health	kg NOx eq	Ozone is not directly emitted into the atmosphere, but it is formed as a result of photochemical reactions of NOx and Non Methane Volatile Organic Compounds (NMVOCs). This formation process is more intense in summer. Ozone is a health hazard to humans because it can inflame airways and damage lungs.
Fine particulate matter formation	kg $PM_{2.5}$ eq	Air pollution that causes primary and secondary aerosols in the atmosphere can have a substantial negative impact on human health, affecting the upper part of the airways and lungs when inhaled.
Ozone formation, terrestrial ecosystems	kg NOx eq	Ozone is not directly emitted into the atmosphere, but it is formed as a result of photochemical reactions of NOx and Non Methane Volatile Organic Compounds (NMVOCs). Ozone can have a negative impact on vegetation, including a reduction of growth and seed production, an acceleration of leaf senescence and a reduced ability to withstand stressors.
Terrestrial acidification	kg SO_2 eq	Atmospheric deposition of inorganic substances, such as sulphates, nitrates and phosphates, cause a change in acidity in the soil. This change in acidity can affect the plant species living in the soil, causing them to disappear
Freshwater eutrophication	kg P eq	Freshwater eutrophication occurs due to the discharge of nutrients into soil or into freshwater bodies and the subsequent rise in nutrient levels, i.e. phosphorus and nitrogen. Environmental impacts related to freshwater eutrophication are numerous. They follow a sequence of ecological impacts offset by increasing nutrient emissions into fresh water, thereby increasing nutrient uptake by autotrophic organisms such as cyanobacteria and algae, and heterotrophic species such as fish and invertebrates. This ultimately leads to relative loss of species.
Terrestrial ecotoxicity	kg 1.4-DBC e	Human toxicity and ecotoxicity accounts for the environmental persistence (fate), accumulation in the human food chain (exposure), and toxicity (effect) of a chemical. This can result in affected species and disease incidences, leading finally to damage to ecosystems and human health.
Freshwater ecotoxicity	kg 1.4-DBC e	
Marine ecotoxicity	kg 1.4-DBC e	
Human carcinogenic toxicity	kg 1.4-DBC e	
Human non-carcinogenic toxicity	kg 1.4-DBC e	
Land use	m^2a crop eq	Land use includes the direct, local impact of land use on terrestrial species via change of land cover and the actual use of the new land. Change of land cover directly affects the original habitat and the original species composition accordingly.
Mineral resources scarcity	kg Cu eq	Assessment of consumption of natural resources (distinguished in two indicators depending on whether the resources are energy or non-energy) including a weighting of these resources according to their scarcity and the speed of their exploitation. The more the resource is considered as scarce and exploited, the more the value of the indicator increases and the more the product contributes to the depletion of resources.
Fossil resource scarcity	kg oil eq	

Water consumption	m^3	Water consumption is the use of water in such a way that the water is evaporated, incorporated into products, transferred to other watersheds or disposed into the sea. Water that has been consumed is thus not available anymore in the watershed of origin for humans nor for ecosystems
Cumulative energy demand	MJ	The Cumulative Energy Demand represents the direct and indirect energy use throughout the life cycle, including the energy consumed during the extraction, manufacturing and disposal of the raw and auxiliary materials.