CONTRIBUTIONS OF CABIN RELATED AND GROUND OPERATION TECHNOLOGIES TOWARDS FLIGHTPATH 2050

Michael Schmidt, Kay O. Plötner, Clément Pornet, Askin T. Isikveren, Mirko Hornung,
Bauhaus Luftfahrt e.V., Munich, Germany

Abstract

The vision of the European Commission (EC) for 2050 is a 75% reduction in carbon dioxide (CO_2) emissions per passenger kilometer relative to the capabilities of conventional aircraft in 2000. This paper focuses on airframe related contributions to a reduction of CO_2 emissions in terms of structural changes of the cabin and fuselage design. Furthermore, thus far disregarded emissions during the on-block time at the airport are considered and ground operation enhancements are presented to reduce these. For the methodical approach several separate sensitivity analyses were performed to assess the CO_2 impact of cabin and fuselage modifications, in terms of higher passenger density, reduced interior weight or usage of Carbon Fiber Reinforced Plastic (CFRP) for the fuselage structure, on the basis of a narrow-body medium-to-short haul reference aircraft. Moreover, the impact of electric taxiing and reduced on-block Auxiliary Power Unit (APU) running time are investigated. The result of the investigated airframe related technologies is a 6.5% CO_2 emission reduction compared to the reference aircraft and a 6.2% reduction for the ATM and ground operation. However, the reduction potential of the presented strategies is insufficient to reach to target Flightpath 2050 goals solely from the investigated areas. Hence, further studies have to be conducted to improve cabin related designs and ground operation based processes to ensure the fulfillment of the released targets.

ACRONYMS

Al-Li *Aluminium Lithium*
APU *Auxiliary Power Unit*
ATLeRs *Aircraft Top Level Requirements*
ATM *Air Traffic Management*
CFRP *Carbon Fiber Reinforced Plastic*
EC *European Commission*
ECS *Environmental Control System*
EIS *Entry Into Service*
FES *Fixed Energy Systems*
FOD *Foreign Object Damage*
IFE *Inflight Entertainment*
GPU *Ground Power Unit*
GSE *Ground Support Equipment*
MTOW *Maximum Take-Off Weight*
OEW *Operating Empty Weight*
PAX *Passenger*
RPM *Revolutions per Minute*
SET *Single Engine Taxiing*
TSFC *Thrust Specific Fuel Consumption*

1. INTRODUCTION

Aviation today represents 2% of global man made carbon dioxide (CO_2) emissions [1]. Objectives for 2020 of the Advisory Council for Aeronautics Research in Europe (ACARE) target an 80% and 50% reduction in nitrous oxide (NO_x) and CO_2 respectively [2]. The vision of the European Commission (EC) for 2050 is a 75% reduction in CO_2 emissions per passenger kilometer relatively to the capabilities of conventional aircraft of the year 2000. Furthermore, a 90% reduction of NO_x emissions and a 65% perceived noise reduction is targeted. Moreover, aircraft movements on the ground have to be emission-free when taxiing [3]. The total emission reduction is distributed to enhancements of airframe components, the propulsion system and aircraft operations [4]. The scope of the Flightpath 2050 assessment compromises the emission between leaving the parking position at the origin airport (off-block) and the arrival at the position at the final destination (on-block). For a typical narrow-body short haul mission of 500nm (926km), 92% of the CO_2 emissions are generated in-flight, in terms of takeoff, climb, cruise, descent and landing, and the remaining 8% account for the ground maneuvering emissions, as illustrated in FIG 1.

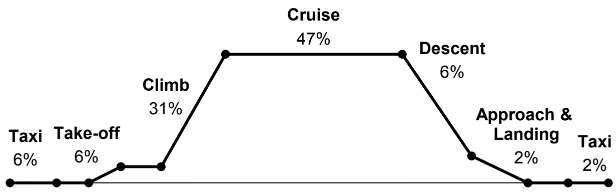

FIG 1 Typical aircraft mission profile with the according CO_2 emission share of the entire mission: reference aircraft, 500nm (926km)

This paper focuses on airframe related contributions to a reduction of CO_2 emissions in terms of cabin and fuselage design changes. Other emissions, for example NO_x, carbon monoxide (CO), hydrocarbon (HC) and particulate matter (PM) are not covered in the scope of this paper. Furthermore, thus far disregarded emissions during the on-block time at the airport are considered and ground operation enhancements are presented to reduce these. Therefore, previous research in the field of emission reduction strategies is reviewed and trade studies are performed. For each study, the reference aircraft is sized with respect to the aircraft top level requirements (ATLeRs) to take sizing cascade effects into account. With the identification of most significant drivers, technology roadmaps could be developed and main research could be focused, which target the Flightpath 2050 goals. Finally, the examined strategies are assessed and summarized.

2. AIRCRAFT RELATED CONTRIBUTIONS

For all sensitivity studies a generic short-to-medium haul narrow-body aircraft is taken as reference. The aircraft is designed for a range of 2760nm (5110km) and accommodates 180 passengers (PAX). The main dimensions can be summarized via the overall length of 37.6m, the overall height of 11.75m and the wing span of 33.9m. The reference aircraft has a Maximum Take-Off Weight (MTOW) of 79000kg, as listed in TAB 1. In the aircraft weight budget, the Operating Empty Weight (OEW) accounts for 55.1% of MTOW. The cylindrical fuselage cross section has an outer diameter of 4.14m and the cabin a total volume is 310m³. The installed two engines provide each a thrust of 120kN at sea level, static conditions. For the case studies, a typical off-design mission of 500nm (926km) is flown 2000 times a year.

TAB 1 Mass breakdown of the short-to-medium haul generic narrow body reference aircraft for design mission of 2760nm

Mass Breakdown		Mass [kg]	MTOW [%]
Structure		**22625**	**28.6**
	Fuselage	8981	11.3
	Others	13644	17.3
Propulsion	Engines	**8370**	**10.6**
Equipment		**8978**	**11.4**
	Cabin Interior	4435	5.6
	Others	4543	5.8
Operational Items		**3580**	**4.5**
OEW		**43553**	**55.1**
	Design Payload	18000	22.8
	Design Fuel	17447	22.1
MTOW		**79000**	**100**

At aircraft level, the strategies to reduce the fuel burn which is directly related to CO_2 emissions are the following:

- Reduce drag and aircraft weight
- Reduce Thrust Specific Fuel Consumption (TSFC)
- Optimize mission profile

Focusing on aircraft related contributions to CO_2 emission reductions during flight, potential cabin weight and cabin energy demand reductions are investigated. Furthermore, the often neglected evolution of the passenger weight, theoretical limits of the passenger packing density and the resulting cross section design are highlighted, before the impact of building the fuselage structure out of composite material, such as Carbon Fiber Reinforced Plastic (CFRP), instead of aluminum alloys is examined.

2.1. Cabin Weight

The cabin of an aircraft is referred to as a space that is pressurized and environmentally controlled, equipped with cabin monuments, equipment and furniture and where the passengers are seated. The layout of an exemplary short haul narrow-body cabin is illustrated in FIG 2. In the forward area, one lavatory (L), a small galley (G) and two cabin attendant seats (A) are integrated. The center part of the fuselage is characterized by 180 economy class seats with a seat pitch of 29in (0.737m). The aft fuselage houses two additional lavatories, a galley and two cabin attendant seats. In terms of the cabin weight budget, the aircraft cabin consists mainly of passenger seats which account for over 50% of the total cabin weight. Further cabin parts are lavatories and potable water systems, galleys containing food containers and trolleys, floor covering, stowage housing, overhead bins, wardrobes and emergency equipment for flight and cabin crew. At aircraft level, the cabin equipment accounts for around 11% of the total OEW of the reference aircraft.

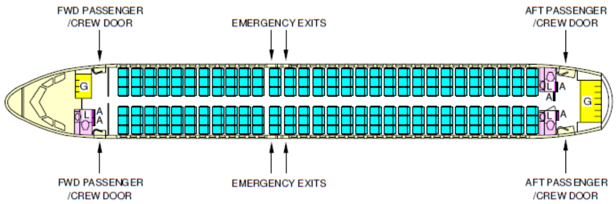

FIG 2 Cabin layout of a short haul narrow-body for a typical one-class version with a six abreast and 180 PAX in total [5]

As the passenger seats are the biggest lever to reduce the total cabin weight, recent research focused on light-weight seats [6]. However, current regulations limit the degrees of freedom of even lighter seats. The EASA Certification Specification (CS-25.561 and CS-25.562) state for emergency landings with dynamic conditions that a passenger seat have to sustain load of 16g fwd and 14g down [7]. Hence, a large effort is required to achieve radical advancements. Another lever would be to reduce the current level of service, in terms of galley and lavatories, and to install more seats. In a case study, a possible cabin weight decrease of 10% is assumed for 2050 taking new materials and technology improvements into account. This reduction corresponds to a 1.5% OEW reduction. The sensitivity of the CO_2 emissions as a function of the cabin interior mass reduction is depicted in FIG 3. To achieve emission savings of 1%, it is required to lighten the cabin gross weight by 10.2%. The above mentioned feasible 10% reduction will lead to 0.96% CO_2 savings compared to the reference aircraft.

On the contrary, current trends show that especially business class seats are getting heavier by reason of more electrical components used for Inflight Entertainment (IFE) and seat adjustability. In the context of a more electric cabin, it will be a challenge to maintain or even improve the current level of component weights.

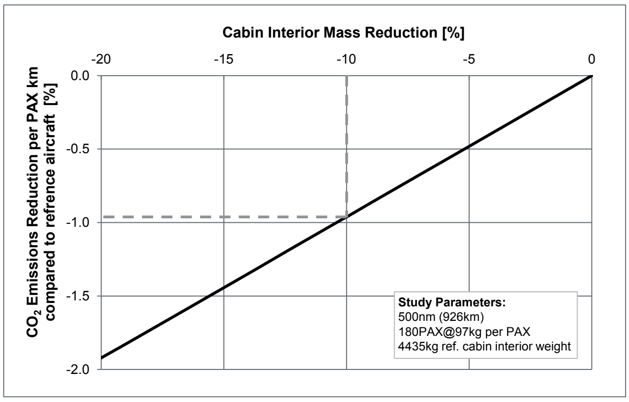

FIG 3 Sensitivity study of the influence of a cabin interior mass reduction on CO_2 emission per PAX km

2.2. Passenger Influence

One aspect that cannot be influenced by the aircraft integrators or airlines are the passengers themselves. In terms of payload, the average body weight of the passengers is a significant aspect the aviation industry has to deal with. An average American man was in 2010 18% heavier and a woman 19% heavier compared to 1960 [8,9]. Moreover, the worldwide obesity has nearly doubled since 1980 [10]. If the current global trends continue, the obesity rate of the world population will be a major issue in 2050. However, the ratio of male and female air travelers also changes. More women are using flights for business trips and therefore the trend of heavier average passengers might be abated [11]. Another aspect is the increase of the average passenger height over the past years [12]. Taller passengers need more space to experience the same level of comfort as smaller passengers. This change of the human body results in an increased demand for individual space, which can be answered by airlines with wider seats and increased leg-room. In contrast, aircraft operators try to maximize their yields with a higher packing density of passengers, which results in reduced comfort, such as low cost carrier are already doing today.

In the following FIG 4, a sensitivity study of the influence of an increased human body weight and the effect on CO_2 emissions was performed.

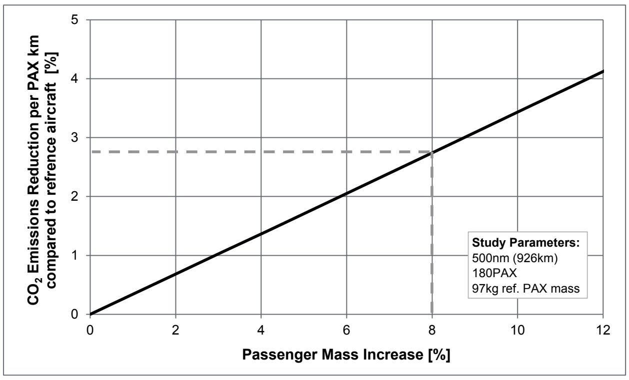

FIG 4 Sensitivity study of the influence of a passenger mass increase on CO_2 emission per PAX km

According to EASA EU-OPS (1.620, Subpart J – Mass and Balance), an average standard passenger accounts for 97kg including his carry-on and checked-in luggage [13]. Based on a survey, [8] promotes an adjustment of the current regulation value. The recommended mass for adult passengers is 88kg and 17kg for check-in luggage which adds up to 105kg. The suggested ratio of male and female is 70/30 [8]. With regard to the above mentioned trends, an 8% increase of the average passenger weight can be assumed for 2050. This weight increase of the 180 passengers would lead to 2.8% higher CO_2 emissions, as illustrated in FIG 4.

2.3. Cross Section Design and Passenger Packing Density

Typical aircraft cross sections can be subdivided into single aisle, twin aisle and double deck configurations; however, the seat abreast varies for each category, as illustrated in FIG 5. Single-aisle aircraft have typically a six abreast and are used for short-to-medium haul operations, such as the reference aircraft with a maximum range of 2760nm (5110km). Comparing recent aircraft programs, the trend shows an increasing cross section size to allow a larger seats abreast or more spacious cabins (cf. TAB 2). The Russian program MS-21 with an estimated Entry Into Service (EIS) 2017 has a 8.7% larger fuselage diameter than the B737 and 4.3% larger than the A320.

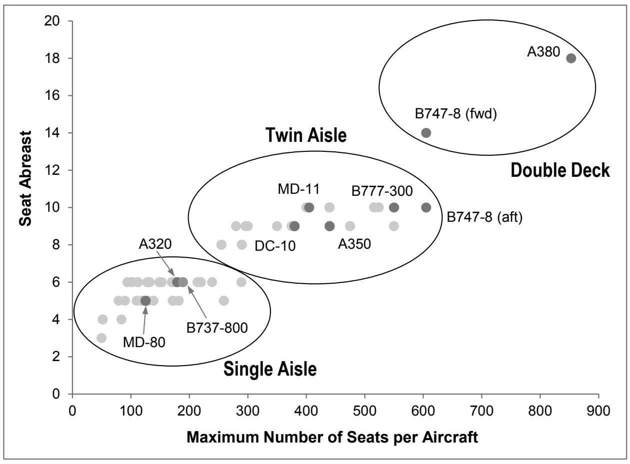

FIG 5 Clustering of cross section layouts according to seat abreast and maximum number of passenger per aircraft

TAB 2 Evolution of the inner fuselage diameter for selected narrow-body and wide-body aircraft

	Aircraft Type	EIS	Abreast	Width [m]	Width Delta [%]
Narrow-Body	B707	1958	6	3.56	**-3.8**
	B727	1964	6	3.28	**-11.4**
	B737	1968	6	3.55	**-4.1**
	MD-80	1980	5	3.14	**-15.1**
	A320	**1988**	**6**	**3.70**	**Ref.**
	MS-21	2017	6	3.86	**+4.3**
Wide-Body	DC-10	1971	9	5.54	+17
	B767	**1982**	**7**	**4.72**	**Ref.**
	MD-11	1990	10	5.71	**+21**
	A330	1994	8	5.28	**+12**
	B777	1995	10	5.87	**+24**
	B787	2011	9	5.49	**+13**
	A350	2014	10	5.61	**+19**

Focusing on the fuselage, a wider cross section implies an increased wetted area for a fixed seats abreast and a higher structural mass of the fuselage. This leads to higher fuel consumption during flight resulting in higher CO_2 emissions.

As depicted in FIG 6 (overleaf), an 8% wider cross section, which would follow the historic trend for narrow-body aircraft taking the A320 as a reference, leads to 1.8% more CO_2 emissions. However, a cross section enlargement should always be accompanied with an increased passenger number to reduce the emission per passenger. Taking current cabin designs into account, the number seats per row and hence the total number of passengers per aircraft is a discrete problem. Anyhow, before the fuselage diameter should be varied; the theoretical passenger limit of the reference fuselage is examined in the following.

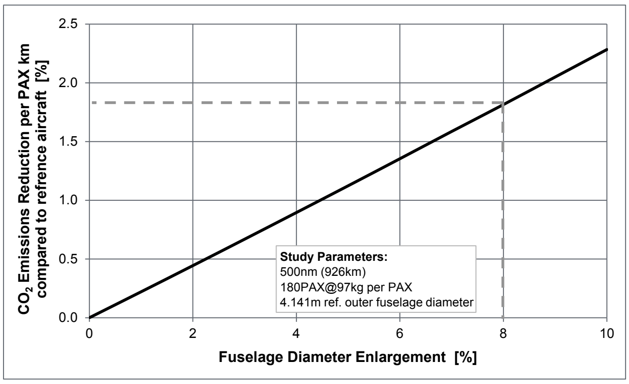

FIG 6 Sensitivity study of the influence of a fuselage diameter enlargement on CO_2 emission per PAX km

Assuming the volume of an average human body is 0.075m³ and for IATA standard size cabin baggage the volume is 0.063m³ [14]. Taking the total cabin volume of 310m³ without any cabin interior, such as seats, lavatories or galleys, the maximum number passengers fitting into the cabin would be 2244 (cf. TAB 3) with a packing density of 7.25PAX/m³. This value is the theoretical limit of passengers without any equipment or space between them. If passengers are seen as small boxes with a volume of 0.33m³, the total number reduces to 947 and accordingly 3.06PAX/m³. Taking a comfort zone of 0.5m (1st zone in TAB 3) before and behind each passenger into account, the number reduces to 239 (0.77PAX/m³) respectively to 137 (0.44PAX/m³) with 1.0m comfort zone (2nd zone in TAB 3). Compared to the current seat density of 0.58PAX/m³, there is still room for improvement.

TAB 3 Theoretical passenger number limit of the reference cabin and cargo compartment volume

Case Study	PAX Cabin	Equivalent PAX in Cargo Comp.	PAX Total	Packing Density [PAX/m³]
Reference	180	0	180	0.58
Theoretical	2244	395	2639	7.25
Box	947	167	1114	3.06
1st Zone	239	42	282	0.77
2nd Zone	137	24	161	0.44

A recent study, revealed a concept to use the freight compartment for accommodating passengers as well [15]. With additional seats in the under floor compartment, the maximum number of passengers for the five case studies can be once more increased (cf. TAB 3). However, the ceiling height of the cargo compartments of the reference aircraft is with 1.24m too less, to allow passengers movement with ease.

The 1st zone density with 0.77PAX/m³ seems a reasonable goal for 2050. Subtracting the thus far neglected volume for the cabin monument; a 10% enhancement could be feasible. In comparison to the 180 installed seats in the current version of the reference aircraft, a room use enhancement of 10% (198 PAX) would lead to 6% CO_2 reduction considering also maximal structural loads, as illustrated in FIG 7. The higher total number of passenger seats can be realized due to reduced galley and lavatory space combined with a decreased seat pitch. Compared to prior identified strategies, the passenger packing density enhancement represents great potential in reducing CO_2 emission, since they are measured on a passenger kilometer basis.

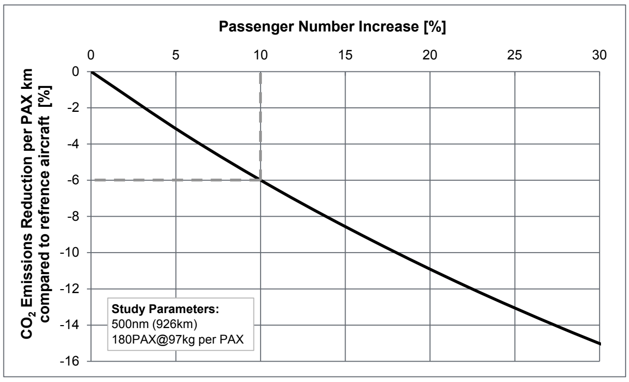

FIG 7 Sensitivity study of the influence of the number of passengers on CO_2 emission per PAX km

2.4. Fuselage Weight

An aircraft fuselage is its main part and holds the payload in terms of crew, passenger and cargo. Conventional fuselage structures are built of aluminum alloy frames and longerons covered by a skin. In recent aircraft programs, such as the A350XWB or B787, the share of composite material of the total structure rose up to over 50% and as a technical innovation for civil aircraft also the fuselage is built of composite material [16,17]. Composite material, such as CFRP, is a matrix material made of polymers containing carbon fiber reinforcements. The key characteristics of this composite material are a high strength-to-weight ratio and very good rigidity. However, also disadvantages for the CFRP use exist. The composite material is sensitive to lateral impact damage, which may occur during ground handling operations, and therefore, enhancements have to be considered in areas where interactions between aircraft and ground support equipment occur. The so called 3rd generation aluminum lithium (Al-Li) alloys promise both the required impact protection, such as lightning and bird strikes, in a CFRP airframe and reduced density compared to current aluminum alloys [18]. In the following FIG 8, a sensitivity study of the influence of a reduced fuselage weight and the effect on CO_2 emissions was performed.

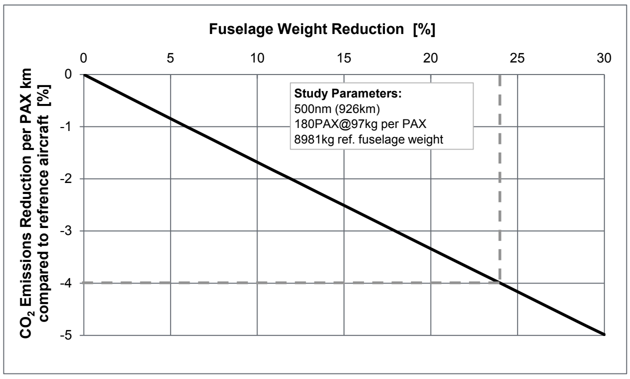

FIG 8 Sensitivity study of the influence of a fuselage weight reduction on CO_2 emission per PAX km

Due to the lower density of CFPR in comparison to aluminum alloys, a substitution of all aluminum parts in the fuselage is aspired. The total fuselage structure mass of the reference aircraft can be reduced by 24% using CFRP [19]. However, this reduction accounts for only 5% reduction of the OWE. The major advantages of the use of these composites in aircraft lie in its material-specific properties. As shown in FIG 8, the reduction of the fuselage weight leads to 4.0% of CO_2 savings.

2.5. Cabin Energy Consumption

Another option to decrease the fuel burn of an aircraft is to reduce the required power to accelerate and lift-off the aircraft. Since the power of the engine is used to supply the cabin with energy, a reduction of the cabin energy consumption will lead to less fuel burn. The major energy consumers in the cabin are the cabin equipment, evacuation equipment, lights, galley equipment, cargo door actuator, lavatory heater and waste water master heater. Regarding the average required mean power of the total energy consumption of the aircraft, the cabin accounts for around 25%, as listed in TAB 4. The main customer of the subsystems is the Environmental Control System (ECS) with approximately 62%.

TAB 4 Power demand of the generic reference aircraft subsystems averaged over each flight phase [20]

Subsystem	Mean Power [kW]	%
Cabin	82.3	25.3
ECS	202.6	62.3
Various	40.3	12.4
Total	325.2	100.0

The cabin demand is taken into account as pneumatic and mechanical power off-take during the sizing of the engines. The impact of the cabin energy demand is marginal, as depicted in FIG 9. A possible 10% reduction of cabin energy leads to 0.16% CO_2 savings. This reduction could be feasible due to technology improvements, such as LED lights.

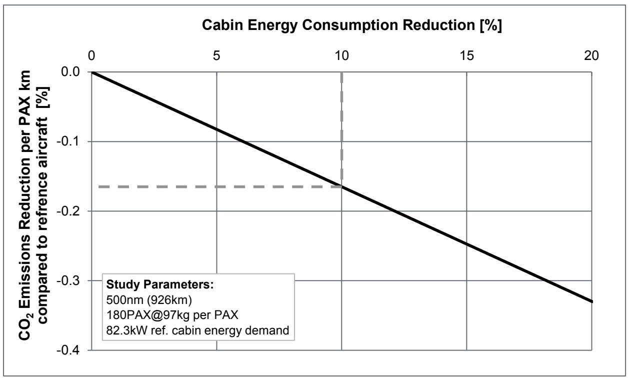

FIG 9 Sensitivity study of the influence of a cabin energy consumption reduction on CO_2 emission per PAX km

As already stated before, recent trends towards a more electric cabin show that the power demand for IFE or electrical seat adjustability is likely to be increased in the future. Hence, the necessity of these enhancements has to be balanced for short-to-medium haul flights.

3. AIRPORT AND OPERATION RELATED CONTRIBUTIONS

This section deals with emissions at the airport, especially during taxi as well as on-block emission. Furthermore, emissions caused by inefficient air traffic management are examined. At an airport, not only the air traffic is a source for CO_2 emission - ground handling vehicles, the road traffic as well as the energy production causes emissions, as illustrated in FIG 10.

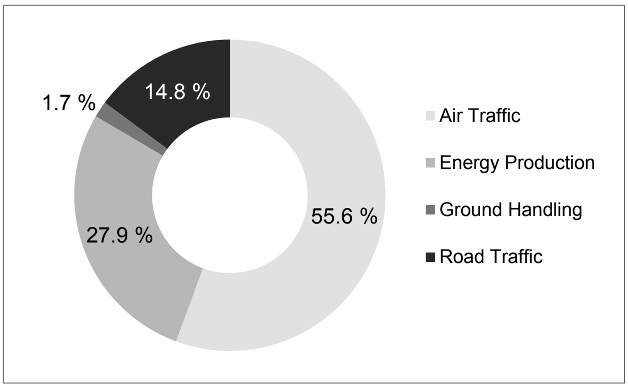

FIG 10 Share of the CO_2 emissions contributes: air traffic, energy production, ground handling and road traffic at Munich Airport [21]

The emissions related to air traffic are the major part with up to 55.6% and can be clustered into engine and Auxiliary Power Unit (APU) emission during normal operation and in emissions for occasional engine tests. The second largest part account for the energy production of the airport via combined heat and power plant at 27.9%. Another emission source at the airport is the road traffic with airside ground traffic, which includes ferrying passengers form the gate to the aircraft and vice versa, parking and landside traffic which adds up to 14.8%. The ground handling account for 1.7% and compromises the Ground Support Equipment (GSE), Ground Power Unit (GPU), anti-icing and fueling.

3.1. On-Block Emissions

In the following, the focus is on emission occurring during the on-block time of an aircraft at the gate or remote positions. When the aircraft approaches a parking position, the APU is running to provide power for electrical, pneumatic and hydraulic systems as well as for air-conditioning. The downside is the fuel consumption of 1.75 kg/min for the APU of the reference aircraft [22]. Hence, electrical ground power by either ground-based generators or main power supplies from airport are used to substitute the APU running time and furthermore cut their maintenance cost, since these systems run more efficiently. A typical distribution of APU and Fixed Energy Systems (FES) or GPU usage is illustrated in FIG 11 (overleaf). Noticeable is the longer use of the APU at remote positions due to often late arrival or even unavailability of the GPU. According to [23], a 85% reduction of the APU is feasible even today.

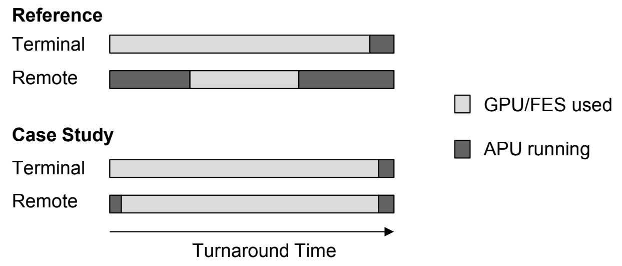

FIG 11 Distribution of APU and FES or GPU usage at terminal and remote position for a turnaround time of 60min

In a case study, the potential of the APU substitution of the reference aircraft was examined. Emissions generated by GSE besides FES or GPU are not covered in the scope of this study. With an average turnaround time of 60min and a 50/50% distribution of remote and terminal positions the effects were calculated. The increased use of the GPU raises their emissions; however, a total reduction of 65% of the on-block emissions can be achieved, as depicted in FIG 12. Since the on-block emissions account for only 1.6% of the total emissions emitted during one flight cycle, the impact on a mission level is with 0.6% rather small. Recent research focused on changing the energy source for APU from kerosene to fuel cells, since the APU has low efficiency of around 20% and less at part load conditions. The goal of implementing fuel cells is to avoid the inefficient operation phases and hence, further decrease the emission [24].

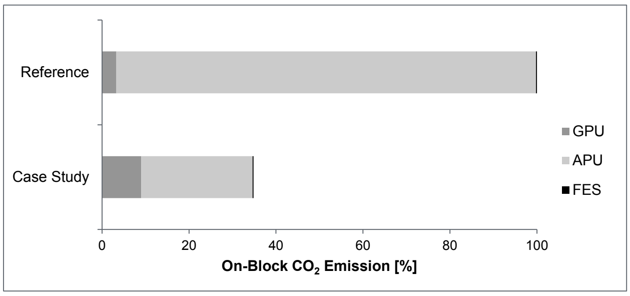

FIG 12 CO_2 emission sensitivity of the investigated case study show a significant APU emission reduction compared to the reference

3.2. Turnaround Time

During the turnaround process, not only the ingress and egress of passengers, but also the loading and unloading of freight and/or luggage are taking place. Furthermore, the aircraft is replenished with fuel, water and lavatory chemical (if applicable), the catering is loaded and the cabin is cleaned. The push-back of the aircraft is the closing process of the turnaround. In the majority of cases, a turnaround for a short haul flight takes 20-60min and 60-120min for long haul flights.

In the following, the effects of a turnaround time reduction are investigated. Focusing of an average stage length of 500nm (926km), the effect on the aircraft utilization is depicted in FIG 13. A reduction of the turnaround time from 40min to 30min increases the annual aircraft utilization by about 8%. This would enable a carrier to reduce the number of aircraft and to distribute fixed ownership costs over higher number of trips [25].

In a case study, the impact of the turnaround time reduction on CO_2 emissions was analyzed. A reference airline utilizes each aircraft for 2000 annual trips with an average stage length of 500nm (926km). In the case study, the airline manages to reduce the average turnaround time from 40min to 30min. The impact on CO_2 level due to reduced on-block ground emissions concerning shorter usage of the GPU or FES is marginal and accounts for 0.21% for the ground handling process and 0.001% for an entire mission. This is why the time during the usage of GPU or FES is reduced, and not the APU running time, which produces most of the emissions. In the investigated case study, the APU is still needed for the engine start. However, the turnaround time reduction could result in a higher aircraft utilization which leads to reduced cost of ownership.

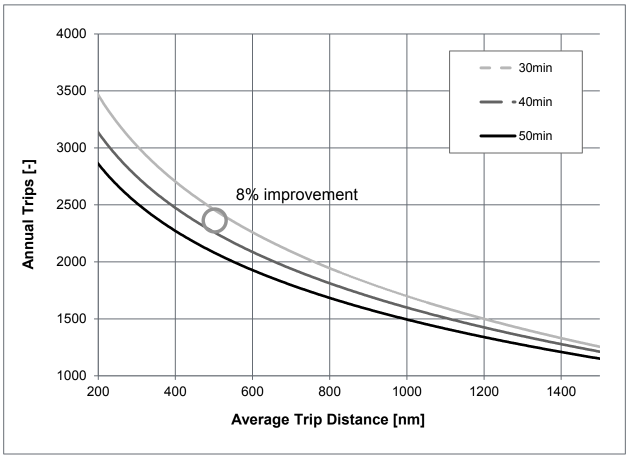

FIG 13 Effects of a potential turnaround time reduction depending on the average trip distance and the aircraft utilization in terms of flights per year, adopted from [25]

3.3. Taxiing

After leaving the parking position, the aircraft is taxiing to runway for take-off. This taxi-out phase lasts for an average of 15min in 2012 in the USA, whereupon, 5min are related to delays [26,27]. The taxi-in phase after landing is much shorter with an average duration of 7min. Based on US data, 93% of flights left the ground within 30min of gate departure in 2007 and compared to previous years this percentage is declining.

During the taxiing, the engines are running to accelerate the aircraft. In the following, the three strategies: Single Engine Taxiing (SET); dispatch towing; and, electric taxiing, are examined to reduce the running time of the engines and thus the emissions. Since the engines must be warmed up prior to departure and have to cool down after landing, for a period that ranges from 2-5 min depending on the engine type, the presented operational strategies are not applicable for the whole taxiing procedure. Based on this, the case studies focus on the longer taxi-out phase and the taxi-in is not considered.

3.3.1. Single Engine Taxiing

As most of the commercial transport aircraft are equipped with two or more engines, one option to reduce the emissions during the taxiing is the single engine taxiing, where only one engine and the APU are used to move the aircraft to or from the runway. This has been in use by airlines for several years now to reduce the fuel burn. As stated by [28], this allows the engines to operate more efficiently, in terms of higher RPM, and thus results in lower fuel burn, HC and CO emissions. However, conditions such as icing, rain or slush on taxiways disallow taxiing on a reduced number of engines [29].

3.3.2. Dispatch Towing

Another strategy to reduce the emissions during taxiing is operational tow-out. In the majority of cases, the aircraft needs a push-back to leave the parking position at the gate or remote stands. The towing tug leaves the aircraft after the engines have started and is maneuvering to the taxiway and thereafter to the runway. In the case of dispatch towing, a high speed tug is used to tug the aircraft until the runway is reached. Not until then, the engines are started around five minutes prior to take-off. During the towing procedure, the APU is running, the engines are switched off and the power required to tow the aircraft to the runway is generated by tugs. The optimum would be, if the tug could subsequently tow an aircraft from the runway to the terminal to reduce empty trips; however, this aspect is disregarded in the following calculations. As a result, the aircraft emissions are reduced, but tug emissions are introduced. Moreover, the aircraft could be powered by the tug and the APU can also be shut down until the engines have to be started. A downside are the loads imported on the nose landing gear, which will have an impact to structural sizing.

3.3.3. Electric Taxiing

Recent research revealed demonstrators of taxiing the aircraft with help of electric power [30]. Therefore, electric motors are installed into the nose or main landing gear and allow the aircraft a forward and backward maneuvering on the airfield. Hence, the usually required push back by a tug to leave the parking position will be obsolete. The motors are either powered by the APU or by a separate fuel cell. The additional weight for the installed motors adds up to 400kg for the reference aircraft. In the case study, an APU powered electric solution is investigated as presented by [30]. A positive effect of shutdown engines during taxiing are reduced Foreign Object Damage (FOD) due to the pull of engine suction [29].

3.3.4. Taxiing Procedure Results

In the following, the results of the case studies are presented. Taking a taxi-out time of 15min as the reference, the three investigated taxi procedures: SET; dispatch towing and, electric taxiing are compared to each other.

Introducing SET, the produced emissions can be reduced by 21.8% using SET for 15min taxiing procedure, as depicted in FIG 14. For total mission, this emission reduction accounts for 1.2% (see FIG 15).

Dispatch towing promises higher CO_2 savings with up to 63.6% during the 15min taxi-out, as shown in FIG 14, and 3.5% for the entire mission (see FIG 15). Admittedly, from the operational tow-outs the NO_x emissions increase by 75% due to the usage of diesel tugs. With the application of electric driven tugs, this drawback can be eliminated. However, new high speed tugs are required, since the current tugs are too slow and interfere with other ground traffic.

Launching electric taxiing in operation including cascade effect of the identified weight, the taxi-out emission could be reduced by 55.1% (see FIG 14) and for the entire mission the savings account for 3% compared to conventional taxiing with engines running at idle, as illustrated in FIG 15. Furthermore, the required time for the push back can be reduced due to eliminating the disconnecting time of the tug. A recent study performed by Airbus, shows similar results with potential CO_2 saving of 4% for a total taxi-in and out time of 22min, less 5min for engine warm up and 3min for engine cool down, when the two engines are running [30].

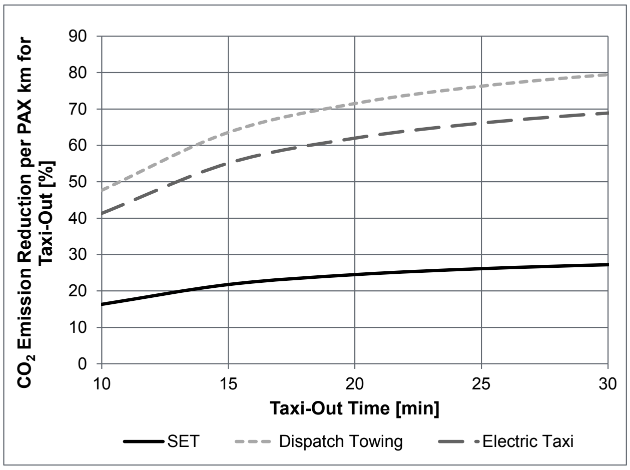

FIG 14 Taxi-out emission reduction for the three investigated strategies: SET, dispatch towing and electric taxiing

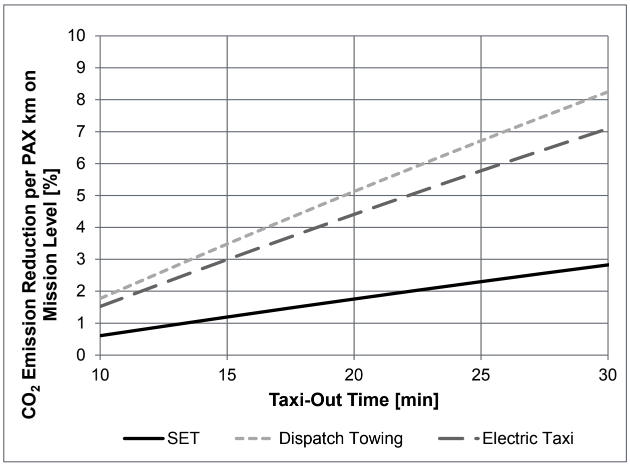

FIG 15 Mission-based CO_2 emission reduction potential for: SET, dispatch towing and electric taxiing

As stated before, during a typical short haul mission of 500nm (926km) the taxi emissions add up to 6% of the total emissions. Hence, strategies, such as dispatch towing or electric taxiing, provide a great potential to reduce emission apart from in-flight savings.

3.4. Air Traffic Management

After the take-off, the aircraft usually tries to reach its destination the shortest and fastest possible way. However, during peak times the airspace above Europe is often congested. Hence, the distance and actual flight time between origin and destination scales up with detours.

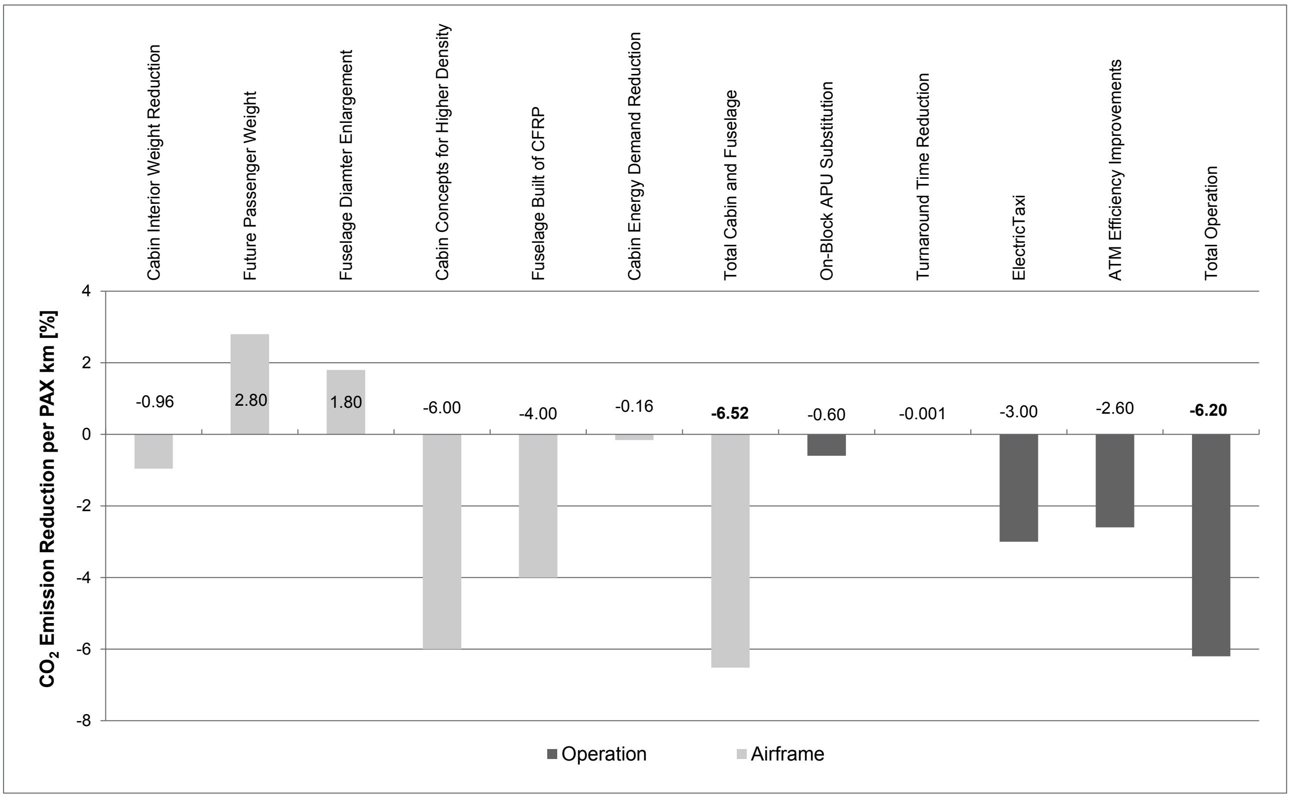

FIG 16 Result summary of the presented strategies to reduce CO_2 emission clustered into airframe and operation related

The current Air Traffic Management (ATM) system is a highly optimized system despite interdependencies with safety, capacity and weather constraints. The future demand will out ship the capacity in near to midterm [27]. Today's efficiency varies between 92-94%, as listed in TAB 5. The aspirational goal of 95-98% should be reached by 2050. However, collaboration by all stakeholders is required to accelerate efficiency improvements to reach the forecasted goals.

TAB 5 Air traffic management efficiency forecasted until 2050 and impact on additional fuel burn and time [31]

Year	Efficiency [%]	Stage Length [nm]	Fuel Burn [%]	Time [%]
Base	**100**	**500**	**ref**	**ref**
2005	92-94	538	+5.3	+5.0
2025	94-95	529	+4.1	+3.8
2050	95-98	518	+2.5	+2.4

The efficiency improvements of the ATM for 2050 account for 2.6% taking year 2005 as a baseline. Hence, the fuel burn and respectively the CO_2 emissions can be assumed to be 2.6% lower, compared to the aspired 3% by the EC [4,32]. The improvements have to be done in the terminal area, where holdings and taxi queues cause congestion, especially if the airports are running at the capacity limit. Furthermore, the horizontal separation in terms of flights plan should cover en route efficiencies and vertical separation should cover climb and descent improvements.

4. SUMMARY OF FINDINGS

This paper presents various strategies to reduce CO_2 emissions focusing first on aircraft related contributions, such as weight reduction of the cabin interior and the fuselage. Significant possible savings could be achieved by increasing the passenger packing density inside of the cabin. Furthermore, the often neglected evolution of the passenger weight is taken into account. The second part deals with airport and ground operation related to CO_2 reduction strategies. The priorities of the investigations are set on taxi emissions and on-block emissions. Additionally, the effects of an aspired turnaround time reduction and the ATM efficiency are examined.

A summary of the presented strategies to reduce CO_2 emissions is depicted in FIG 16. The total potential of CO_2 emissions coming from the airframe related investigated strategies add up to 6.52% and for the ATM and ground operation is of 6.2%. Building the fuselage with CFRP, as it is already state of the art for recent long range wide-body aircraft, accounts for a 4% reduction; increasing the packing density of the passengers amounts for a 6% CO_2 emission reduction; both are big levers for possible savings. Focusing on operational aspects, new taxi procedures, such as electric taxiing, promise a 3% emission reduction and provide opportunities to contribute strongly to the Flightpath 2050 as well. Unfortunately, an increased average passenger weight is causing a higher fuel burn and 2.8% more CO_2 emissions.

5. OUTLOOK

With the identification of most significant drivers, technology roadmaps can be developed to focus on main research to fulfill the requirements of Flightpath 2050. Unfortunately, the promised savings of presented strategies are insufficient. According to [4,32], the goal for airframe related CO_2 emission savings account for 25% and for operational improvements 7%. Hence the identification of further technologies is required to achieve the challenging Flightpath 2050 goals. In this study, single improvements have been investigated and their isolated benefit is described. A further step will be the integration and combination of the presented strategies to see the combinational effect at aircraft level.

6. REFERENCES

[1] Air Transport Action Group (ATAG), *The right flightpath to reduce aviation emissions*. *UNFCCC Climate Talks*. Durban, South Africa, 2010

[2] Advisory Council for Aeronautical Research in Europe (ACARE), *European Aeronautics: A Vision for 2020*, 2001

[3] European Comission, *Flightpath 2050 Europe's Vision for Aviation - Report of the High Level Group on Aviation Research*, Luxembourg, 2011

[4] Advisory Council for Aviation Research and Innovation in Europe (ACARE), *Strategic Research & Innovation Agenda (SRIA) - Volume 1*, Brussels, 2012

[5] Airbus, *A320 - Airport and Maintenance Planning*, 2005

[6] James, A., *Peoples Choice*, Aircraft Interiors International, June 2009, pp. 46–58, 2009

[7] European Aviation Safety Agency (EASA), *Certification Specifications for Large Aeroplanes CS-25*, 2009

[8] NEA, *Survey on standard weights of passengers and baggage*, Zoetermeer, 2009

[9] U.S. Department of Health and Human Services, *Anthropometric Reference Data for Children and Adults: United States, 2007–2010*, 2012

[10] World Health Organization (WHO), *Obesity and overweight*, http://www.who.int/mediacentre/factsheets/fs311/en/index.html, last updated: 01.07.2013

[11] Easen, N., *Business travel gets a female touch*, http://www.bbc.com/travel/blog/20130213-business-travel-gets-a-female-touch, last updated: 01.07.2013

[12] Strässle, A., *Holländischer Weitblick*, http://www.nzz.ch/aktuell/startseite/hollaendischer-weitblick-1.549440#, 2007, last updated: 01.07.2013

[13] European Comission, *Comission Regulation (EC) No 859/2008*, 2008

[14] International Air Transport Association (IATA), *Checking in a bag*, http://www.iata.org/whatwedo/passenger/baggage/Pages/check-bag.aspx, last updated: 07.07.2013

[15] Bundesverband der Deutschen Luft- und Raumfahrtindustrie e.V. (BDLI), *IMAGINE...*, http://bdli.de/index.php?option=com_content&view=article&id=2622, last updated: 01.08.2013

[16] EADS, *Airbus A350 XWB*, http://www.eads.com/eads/int/en/our-company/What-we-do/Airbus/A350.html, last updated: 01.08.2013

[17] Hale, J., *Boeing 787 from the Ground Up*, Boeing Aero Magazine, QTR_04, 2006

[18] Ostrower, J., *Alcoa unveils 3rd generation aluminium lithium alloys and technologies, http://www.flightglobal.com/news/articles/alcoa-unveils-3rd-generation-aluminium-lithium-alloys-and-technologies-357829/, last updated: 01.08.2013*

[19] Achternbosch, M., Bräutigam, K.-R., Kupsch, C., Reßler, B., Sardemann, G., *Analyse der Umweltauswirkungen bei der Herstellung , dem Einsatz und der Entsorgung von CFK- bzw. Aluminiumrumpfkomponenten*, Karlsruhe, 2003

[20] Xia, X., *Dynamic Power Distribution Management for All Electric Aircraft*, Master Thesis, Cranfield University, 2011

[21] Gaffal, R.-M., *Modell zur nachhaltigen Schadstoffreduktion an Flughäfen*, Dissertation, Technische Universität München, 2010

[22] Unique (Flughafen Zürich AG), *Aircraft APU Emissions at Zurich Airport*, Zurich, 2005

[23] Air Transport Action Group (ATAG), *Beginner's Guide to Aviation Efficiency*, 2010

[24] Kallo, J., Renouard-Vallet, G., Saballus, M., Schmithals, G., Schirmer, J., Friedrich, K.A., *Fuel Cell System Development and Testing for Aircraft Applications Fuel Cell System Development and Testing for Aircraft Applications*. *18th World Hydrogen Energy Conference 2010 - WHEC 2010*. pp. 435–444, 2010

[25] Mirza, M., *Economic Impact of Airplane turn-times*, Boeing Aero Magazine, QTR_04, 2008

[26] Bureau of Transportation Statistics (BTS), *Special Report - Sitting on the Runway: Current Aircraft Taxi Times Now Exceed Pre-9/11 Experience*, 2008

[27] Boeing, CANSO, *Accelerating Air Traffic Management Efficiency: A Call to Industry*, 2012

[28] Kumar, V., Sherry, L., Thompson, T., *Analysis of Emissions Inventory for Single-Engine Taxi-Out Operations*. *International Conference on Research in Air Transportation (ICRAT-2008)*. pp. 1–6. Fairfax, 2008

[29] Wollenheit, R., Mühlhausen, T., *Operational and Evironmental Assessment of the Electric Taxi Based on Fast-Time Simulation*. *TRB 92nd Annual Meeting*. Washington, 2013

[30] Yann, N., *eTaxi - Taxiing aircraft with engines stopped*, Airbus Technical Magazine - FAST 51, pp. 2–10, 2013

[31] Stollery, P., *ATM Global Environment Efficiency Goals for 2050*, 2008

[32] Baier, H., *Morphing Enabling Technologies for Propulsion System Nacelles (MorphElle)*, FP7-AAT-2012-RTD-L0, Proposal No. 341509, European Commission Directorate General for Research and Innovation, 14 March 2013