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Advanced Hybrid-Electric Propulsion Systems Integrations in Airliners

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Abstract

Hybrid-electrical propulsion showed up to be possible in new architectures for applying additional electrical thrust on demand in engines of airliner, making up hybrid electrical propulsion systems, especially suitable for long range operations. These architectures show both parallel and serial aspects at the same time. If these hybrid-electrical propulsion systems are applied on specially adapted airliners, in a special manner and operation, e.g. used for step climbs, the aircraft can access higher cruising altitudes (both higher initial altitudes ICA and higher maximum cruising altitudes) and travel in more favourable conditions. This leads to significant fuel savings, seen over the mission, especially in long range operations. Electrically driven Flettner-Rotors in this context and in general do not show effective in function of optional propulsors, integrated in the engine, so far. Furthermore further technologies are discussed - these are engine and aircraft related - and are applied on exemplary engines and Single Aisle aircraft (SA-aircraft), and showed up fuel savings up to minus 12,2 % in long range missions. Fuel savings even go up to minus 30,5 % in cruise, if compared to current SA-aircraft on short and medium range missions. In this context of this, at least special long range mission considered, unfortunately it was found out that in the scope of this exemplary long range operation the hybrid-electrical propulsion system has Zero Voltage (0V) - or in other words no hybrid-electrical propulsion systems is needed, as fuel savings appear without.

1. Introduction

It is known, that on this planet earth there is both still need and wish for fuel-efficient aircraft. This planet earth hosts more than 8 milliards human beings and at the same time additionally more than 40 000 airliners. Out of this more than 24 000 are single aisle aircraft. The human-made airliner are made on this planet to serve the humans on this planet in terms of better life and transportation. For the future there will be probably a strong increase in the number of human beings on this planet. On the same time there will be additionally a strong increase in the number of worldwide airliners. Environmental issues are known. Thus they do not need to be explained. Ecological wishes are known. Thus they do not need to be explained. Environmental issues are in line with ecological wishes, which sometimes appears unknown, at least forgotten. Environmentalists and Economists are searching for the (their) right answers, sometimes without talking to each other to much, or even without facing each other. Regarding solutions: Talking about electrical propulsion had been established for airliners up to a capacity of roughly around 90 passengers. For airliner - with more than 90 passengers - talking about electrical propulsion is still (held as) a taboo.

Electrical propulsion can help to enhance the environmental impact in noise, fuel burn and emissions. It can help to boost the financial gains. However on standard single-aisle aircraft, on widebody aircraft, and on widespread turbofan engines- electrical and hybrid-electrical propulsion has not been in sight - so far, and in this context - is still in research state, and held as a taboo. This paper faces some aspects of this challenge.

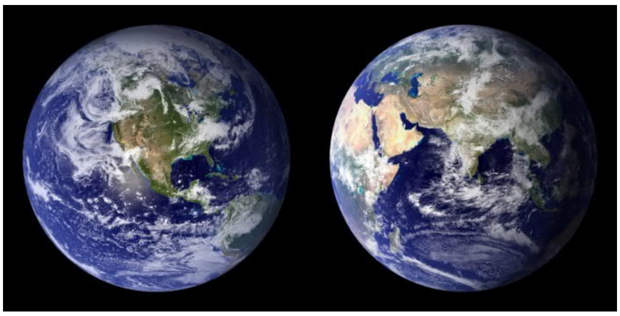

Figure 1: ‘Our’ planet is home for more than 8 milliards human beings, which have so far built more than 40000 commercial airliner, many o. t. in long range operations

Since a practical approach has been the priority, application for fuel efficiency enhancements are applied to exemplary turbofan engines, as well as to exemplary single-aisle aircraft in long range operations.
A first approach and idea was to install electrically

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driven Flettner Rotors as additional optional propulsors in turbofan engines. They are also known under the term magnus rotors. This so far, as an intermediate result, has turned out not to be successful from a perspective of efficiency, but is should not be ruled out for the future completely. Swept back or swept forward magnus rotors or Flettner rotors could be part of solutions, - so far, until now they have not to been examined so.

However on the further course of these researches it came out, that fuel efficiency gains are possible - more or less- on today's existing aircraft, even on long range applications. For that an exemplary mission is examined for a single-aisle aircraft in long range operation, from Paris CDG (Charles de Gaulle) to Washington D.C. IAD (Washington Dulles International Airport). The fuel need could be enhanced by around minus 12,2 Percent for this mission. The fuel savings in cruise flight are even higher and more than 13,5 %. The technology could be also transferred to single-aisle airliners in short- and medium range operation, as well as to widebodies, including 4-engined planes e.g. Airbosses an Airqueens.
It could be found more than one technical solutions and architectures for applying additional electrical thrust on demand in engines of airliner, making up hybrid electrical propulsion systems. At least one solution could be retrofitted to today's existing aircraft and engines, without taking too much effort. These systems found, can't be clearly categorized according to present thoughts and categories. These systems show both parallel and serial aspects at the same time. If these hybrid-electrical propulsion systems are applied on specially adapted airliners, in a special manner and operation, e.g. used for step climbs, on existing aircraft engines, the aircraft can access higher cruising altitudes (both higher initial and higher maximum cruising altitudes) and travel in more favourable conditions. This leads to significant fuel savings, seen over the mission, especially in long range operations.

Furthermore the intended short-time on demand usage of these systems in engine failures could lead to further performance improvements, which especially applies to new designed airliner, if it is taken into account, already from design stage.

In general this paper proposes answers to the following five questions:

I. A Key question of this paper is, how can additional thrust be "in parallel" electrically applied and selectively be added on demand, on the aircraft`s engines. This searches for a flexible and easy engine architecture.

II. Is there a retrofit solution for question 1, for existing or in production engine or aircraft?

III. Which technologies can enhance the efficiency, especially the fuel efficiency, of single-aisle aircraft in long range operations?

IV. Is there a retrofit solution for question 3, for existing or in production engine or aircraft?

V Can these technologies transferred to widebodies and/or aircraft in short and medium operations and/or transfered to different engine architectures?

Interested readers can just continue.
Mainly aircraft-related readers can proceed first to chapter 5, and if, wished can continue with chapter 4, 3 and 2.
Mainly engines-related readers can proceed first to chapter 3, and if, wished can continue with chapters 4, 5 and 2.

Pilots can access any chapter, they wish, dependend on their time/ flight time.
Airlines can proceed first to chapter 5, and if, wished can continue with chapters 3, 4 and 2.

Long time existing aircraft/ engine manufactures should only continue, if they want to change something to positive. Otherwise they should immediately close this issue and deeply hope, that nobody has ever accessed these files.

2. Short status on the research regarding flettner rotors, in use as additional propulsors in turbofan engines

The initial idea, to use Flettner rotors, which are also called magnus rotors, on aircraft engines has the following background.
The fluid flow - in and at aircraft engines - shows high angular inclination, in reference to the flight direction of the aircraft. This shows exemplary figure 3. If in general an aerodynamic profile is placed - in right alignment - in this

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inclined incoming flow, a resulting fluid force can be generated, which has a forward facing, propulsive force component, at least one, which mitigates drag.
Flettner or magnus rotors are rotational aerodynamic profiles. They generate fluid forces in a fluid flow, if they are spinning like cylinders around their axis.
So far they have been mostly in use in wind propulsion for ships and in under water application as stabilizers for ships, to avoid movements of the ton-heavy ships. For that the even small flettner rotors in diameter and span are mounted under water to the ship hulls ,or could be even moved, to additionally stabilize the ship, when not moving.

Flettner or magnus rotors can generate a resulting fluid force, if placed in an aerodynamic incoming flow, which is at least roughly 3,5 times greater than the fluid force of a conventional aerodynamic profile, at same reference area and inflow conditions. Furthermore the force can be regulated (by means of the rotational speed of the rotor), even highly dynamically in time. Therefore it could be used additionally for control, beside for lift generation, thrust generation or generation of manoeuvre forces.

The idea is now, to replace the conventional aerodynamic profiles, sometimes also called stator vanes, by rotating Flettner rotors or rotorfoils (a hybrid, of Flettner rotor with rigid airfoil). This would result in higher forces generated. As forces are partly forward facing, by a force component, this would act as drag mitigating, thus propulsive. By that, the efficiency would be improved. Flettner rotor could be driven by electric motors. This would result in an active stator device or an active electric stator device.

As a stator device the electrically flettner rotors can now be placed in the flow field of a rotor (preferably downstream of the rotor). If the rotor is driven conventionally e.g. by gas turbines, it is easy to make up hybrid electric propulsion systems.
In this relation one aspect regarding Flettner rotors has to be considered. If a spinning Flettner rotor is placed in the aerodynamic flow, a ratio can be formed of the highest ambient speed of the fluid near the rotor (on figure 2 on top of the rotor) compared to the incoming aerodynamic flow, in which the rotor is placed. This ratio is called "speed ratio".

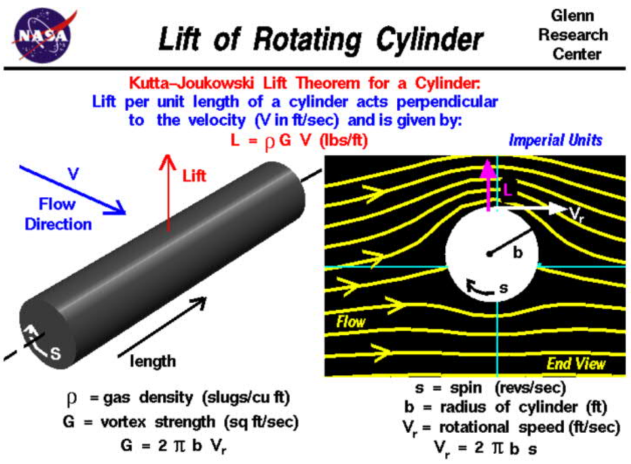

Fig 2: Flettner rotor in flow, NASA, Glen research Center

The higher the speed ratio, the higher the lift coefficient created by the rotor, thus the higher the fluid force, which appears at the rotor or rotor foil. The highest speed ratio, which was thought to be obtained in theory, leads to lift coefficients of 4 times pi ,thus in double digit regimes of the lift coefficient. If a Flettner rotor and a rigid profil have the same reference area, in projection, the generated force at the Rotorfoil can therefore be significantly higher. A known limit for a rigid aerodynamic profile would be 1,4 for the lift coefficient in plain configuration, and maybe around 2,8 in lift coefficient, with leading and trailing devices applied ,e.g. slats and flaps. The limit for the lift coefficient on fletter rotors would be around 12,6. However some researches claimed higher lift coefficients, which were reached.

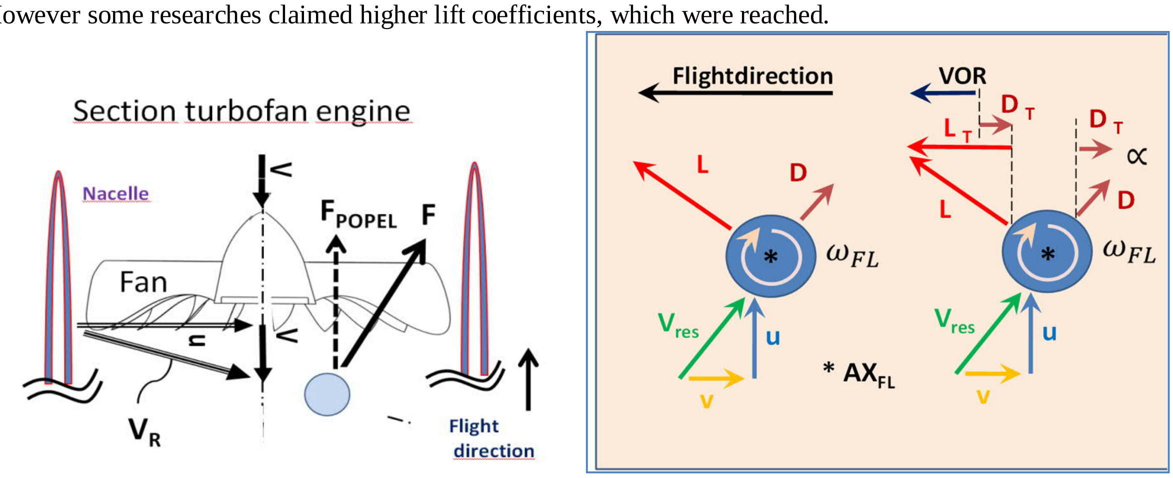

Figure 3: Forward facing Propulsive Force generated by flettners as active (elect.) stator device downstream of a fan

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The limit in history was, that with the technology there could not be reached high rpms in a stable manner.
That is why maximum C_L on rotorfoils is still a little bit unkown.

Which today's electric motors, like brushless motors, and advanced motors it is easily possible to reach rpms of several thousands per minute. With advanced motors, it is even today possible to reach rpms of some 100 000 up to millions in special application, e.g. see research of ETH Zurich, which still holds the world record in rpm of electrical motors, to the authors's knowledge. Second Controlling devices are today present e.g. from model building components (the same applies for advanced electric motors), which allow to control this motors in an easy and cheap way. They were not there in the past. As a consequence significantly higher rpms could be reached on Flettner rotors today with easy means on low weight, which were not there in the past, as technology was still limited, in that time.

Third is the challenge of balancing the rotating cylinders in high rpms, which could not be managed well in the past, at least in high rpms. As a consequence high rpms could not be reached because of strong vibrations present.

Today there are active bearings obtainable, which suppress vibrations, also in very high rpms. This active bearings for example can work with air and/ or by magnetic and electromagnetic means, as active magnetic bearings. They are for example in use in flywheels, which also reach very high rpms. A positive side effect is that this kind of bearings can work more or less frictionless, which additionally helps, to even reach higher rpms.

Basic information on flettner or magnus rotors can be found in the NASA technical paper NACA-TN-209 of rotating cylinders, which is online accessible in the internet via the NASA technical report server. Further detailed research was historically done with wind tunnel experiments, which are still available, in Göttingen in Germany. There are also some recently disclosed paper from US-side about German secret research of this technology around World War II, also in connection with UFOs.

However there is a certain limit in aerodynamic application of Flettner rotors, which comes from aerodynamics. In this research the limit was self set.
In this research the self set limit, was, that the ambient flow near the rotor should not have more speed than M= 0,72, thus means incompressible flow conditions around the rotor are guaranteed.In low incoming aerodynamic speed this does not mean a big barrier, thus high lift coefficients and forces at the rotor can be reached.

However in higher incoming aerodynamic speeds this limits begins to show active, as it lowers the maximum speed ratio of the rotor, which can be set or applied, without reaching Ma=0,72 at the rotor. This has the consequence, that the maximum obtained lift coefficient is limited as well, as well as reached fluid forces are limited on the rotors, if the the rotor is places in a incoming stream of high velocity. This relative high incoming speeds however are present e.g. in turbofan engines, in spite there are location in and at the engines where Ma numbers reaches magnitudes of 0,3 and 0,6 and 0,45. Some of this Ma number only state on the axial velocity, whereby the total velocity counts for the incoming airspeed.

In this relation, so far, it shows, that in turbofan engines, the incoming velocities are too high to reach high forces with significant efficiency gains. More true would be even, that in real, higher forces are obtained at the rotors, even in challenging inflow conditions, but compared to conventional airfoils, it would be more easier, to higher the effective area of conventional rigid airfoils to reach the same (force and/or propulsive effect).

In this context it should be noted/added, that to the author's knowledge there have been no wind tunnel test of Flettner or magnus rotors with relative high incoming velocities, or even in incompressible, transonic or supersonic conditions. How and to what extent Flettner rotors react to compressible flow, i.e. higher Mach numbers, and to what extent they remain functional in this case is currently, to the best of my knowledge, unexplored and therefore unknown. CFD simulations of Flettner rotors are tricky and need evaluations by wind tunnel experiments.

On fluid streams at the engines, which are comparative low, the mass stream is not enough to reach high forces. This for example applies to most of the cooling streams of present examined engines.

One effect which is in contrast an argument for the rotors, is that, they are controllable in speed and direction, even highly dynamically in time, nearly in real time, as current electric motors reach very very high accelerations as well as the same time deceleration. This would allow to implement thrust reserve in an easy way e.g. by changing the rotational direction of the rotors. On a standard single-aisle aircraft with two engines - just the thrust reserval means acount for 2 times 800 kg =1600 kg, which would be not needed any more, and the weight free -could be used for an additional electrical propulsion system. Electric in this context means that the Flettner rotors can be driven

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electrically by electrical motors. If the Flettner rotors are integrated in a turbofan engine, it is relatively easy to set up a hybrid electric propulsions systems on airliners.

However, a difference could lie in the interaction of the rigid profiles or rotor profiles **-** or in the interaction of their pressure fields in the form of the overpressure and underpressure fields with neighboring ambient surface contours. Pressure fields in interaction with curved surfaces form directed forces, which can appear negatively as drag or, if skillfully combined in the design, can show up as propulsion in the direction of flight. This has not been investigated further so far, so that no further statement can be made at the moment.

To the present state of research so far, in turbofan engines, the Flettner rotors does not show efficient so far because of the relative high incoming flow velocities present in turbofan engines.

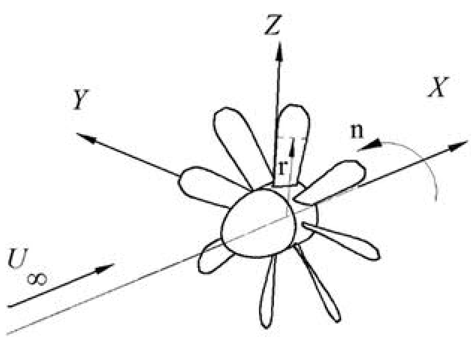
Therefore it is currently proposed- for implementation of Flettner rotors in higher velocities -to examine the following solutions/ additional measures:

- Flettner rotors could be places in certain areas in or at the engine, where incoming fluid velocity speed is moderate to low. To reach that, in the fluid flow there could be applied diffuser means upstream e.g. to slow down the incoming speed. This diffusers can have also suction means to stabilize the aerodynamic flow and to build the diffuser means short in length.

- Flettner rotors could be well adjusted to/twoars the incoming flow, here also including rotational components of incoming flow, by special shape e.g. cone-like. The idea is that, diameter changes over span in an optimal manner.

- Flettner rotors could be well positioned with swept **-** even to higher incoming velocities (preferably inside the by-pass duct of turbofan-engines downstream a fan), like swept is done in rigid airfoils e.g. at the wing and the empennage on the aircraft, or on stator devices with swept wings, inside the turbofan engines. To the authors knowledge there a no examinations or research do far on swept back or swept forward Flettner rotors in fluid flows.

A second possibility would be to have Flettner rotors as propeller blades on a rotor. By that the optimum incoming flow velocity can be adjusted via e.g. the rotational speed of the rotor. A forward facing force component occurs, acting propulsive in suitable incoming flows.



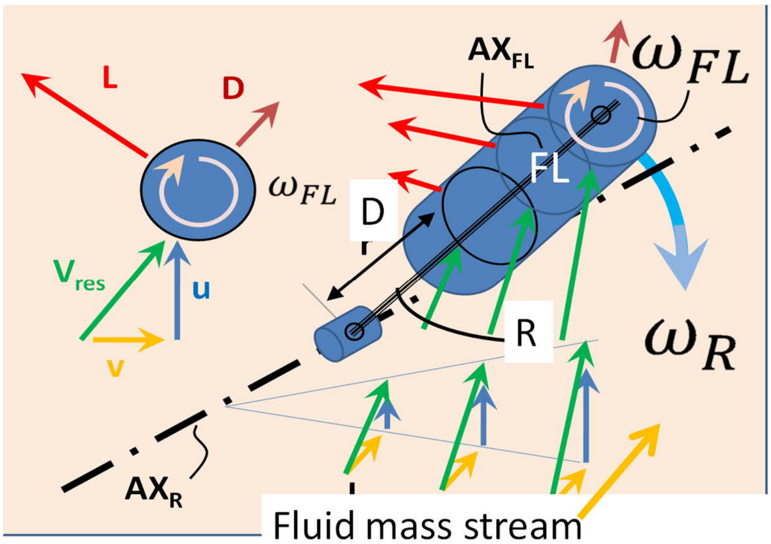


Figure 4 and 5: Flettner rotors, implemented on rotors. They can be electrically driven and controlled. As well they could be placed in a ducted environment, where incoming velocity speed can be controlled, also by means of diffussors

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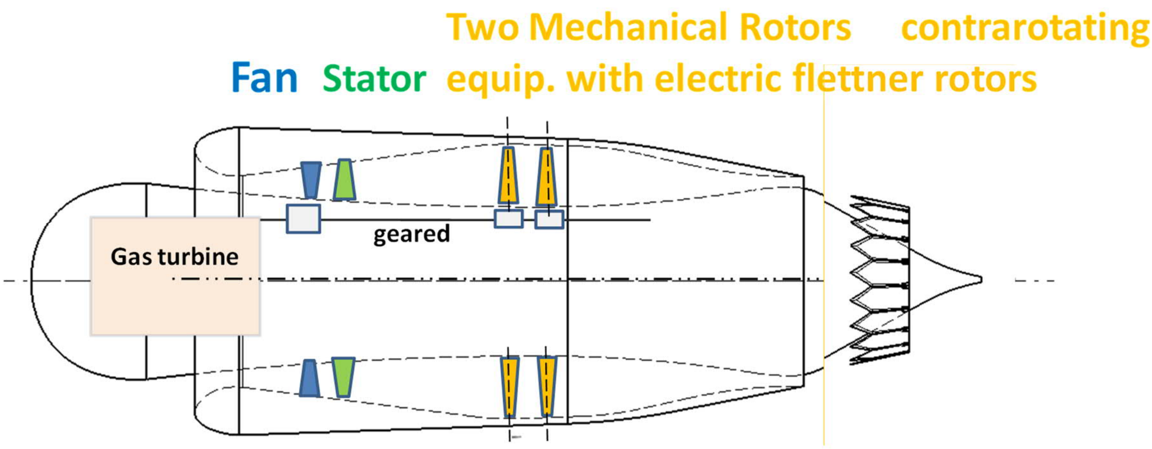

Figure 6: Aircraft engines for higher incoming speeds would need special diffuser means to slow down incoming speed, here two diffusers shown, one open in the inlet area, and one circular over the perimeter, ducted. The fan could be in front or as an aft fan, exemplary engine.

In third the focus for Flettner rotors (magnus rotors) should be turned to more low speed environments, where incoming speed is in the range from 0 to 5 or up to 25 m/s.

In these applications Flettner rotors are very promising, also in terms of efficiency, and energy/power savings.

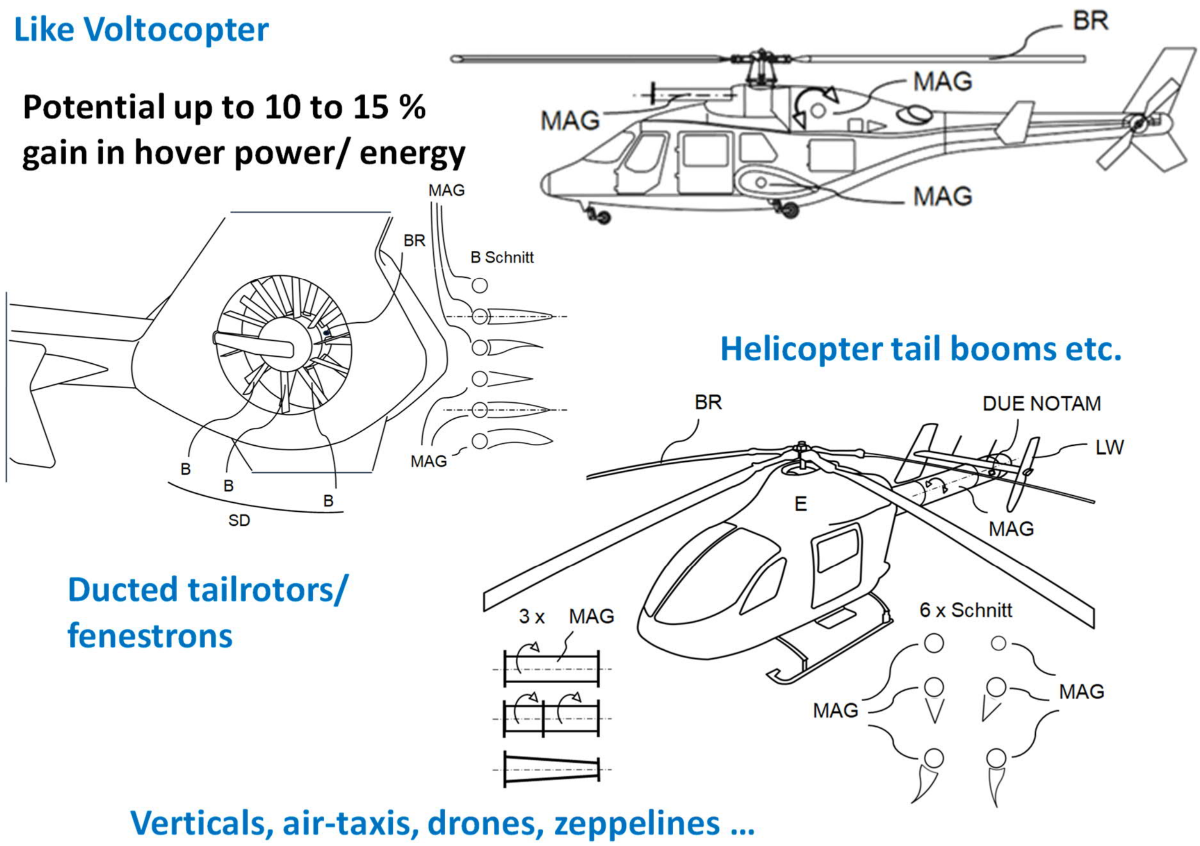

Figure 7: Exemplary applications of magnus rotors in low speed environments could be on air taxis, verticals, helicopters, zeppelins and drones, here shown as active (e.g. electrically driven) stator devices in the flow field of rotors. The idea is also suitable to make up hybrid-electric propulsion systems. Magnus rotors are also called Flettner rotors.

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3. E-Fan

Altogether, an investigation of the integration of Flettner rotors - to this state of research - has shown, that at least in present turbofan engines - so far - no efficiency-increasing effect can be achieved. Applications of Flettner rotors are more suitable to incoming speeds of low velocity, which are present in helicopters, air taxis, verticals, airships, as the previous chapter has shown.

I. A Key question of this paper is thus still unanswered and was, how additional thrust could be "in parallel" electrically applied and selectively be added on demand on the aircraft`s engines. This searches for a flexible and easy engine architecture.

A second question occurred in this context, and is still unanswered, so far, too.

II. Is there a retrofit solution for question 1, for existing or in production engine or aircraft?

So the research continued. In the course of this research, a "conventional" fan was examined in outstanding locations in (turbofan)-engines for integration. As a result it should be now proposed to integrate an E-fan at some outstanding location in the turbofan engine.

3.1 E-Fan in the core stream – Nozzle E-Fan

In the exemplary embodiment shown, a fan, which can be rotated electrically, is introduced in an aircraft engine in the core stream downstream of the last turbine stage and upstream of the nozzle.
By rotating it, it can generate additional propulsion. By the rotation of the fan it generates additional pressure in the fluid in the core stream. This can be converted into additional thrust by/after passing the core nozzle.

The core nozzle could be designed in a, so said, adopted way, that means that its geometry is chosen to be, that the fluid shows the ambient pressure, after having passed the nozzle.

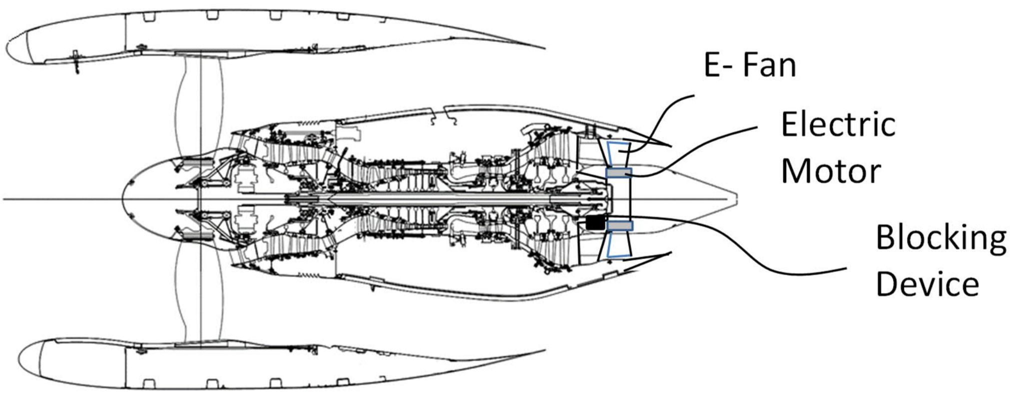

Figure 8: Nozzle E-Fan, integrated in the core stream, upstream the nozzle

In case additional pressure is introduced by the E-Fan upstream of this nozzle, on demand, - after the fluid in the core stream has passed the core nozzle it will have a slightly higher pressure than ambient pressure, which lead to post-expansion of the fluid, after having already past the nozzle. This results in additional thrust.

A second alternative would be to have an adjustable core nozzle which could be adapted e.g. to the pressure being present upstream of the nozzle. This pressure would be higher if the fan is in operation. According to this research this would not be absolutely necessary, but it is an option.

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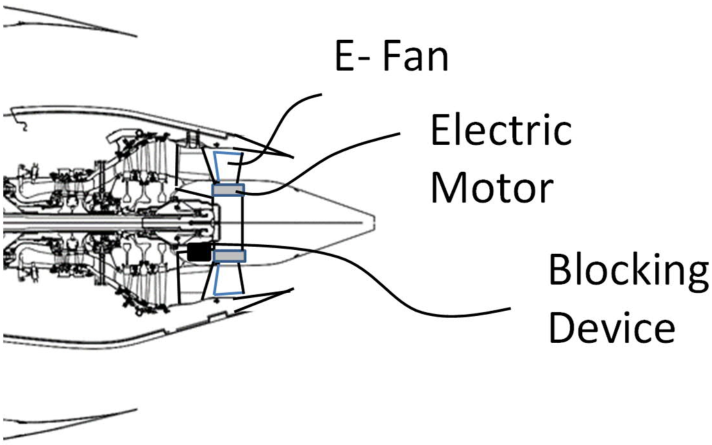

Figure 9 : Detail view of the nozzle E-Fan, - as the conical rear part plug is almost completely empty, there is more than enough room for the integration of electric-motors, furthermore it is placed in flight direction rear of - the mounting or strut connection, which means, that devices can be easily accessed from the behind in operation, if needed, therefore the core E-Fan is in principle been retrofit-able to existing and in production engines and aircraft

One optional characteristic is, that this fan, as a rotor, can be held braked by at least one means (e.g. at least one device). In the braked state, as an option, it can, for example, form and function as a stator device for the upstream turbine, so that the swirl of the upstream turbine can be converted into propulsion and the core stream can in general be straightened.
In a further operating mode, the downstream E-fan can be released from the holding or braking device and can be set in rotation, also by demand, by means of at least one electric motor. Now it is possible that this fan can generate additional propulsion via additional pressure. In doing so, it could also be tuned to the operating state of the upstream turbine by means e.g. of a speed control.
Such an adjustment could, for example, be formed on the basis of - at least on state or parameter (speed, pitch, velocity etc.) of at least the upstream turbine stage. For example, the speed of an upstream turbine stage could be detected for this purpose. Likewise or additionally, a possible adjustment of the fan or its fan blades, e.g. in the pitch angle, could be taken into account.
Such a pitch angle change could, for example, be formed on the basis of the upstream out-flow condition e.g. of the upstream turbine stage. For example, the speed of an upstream turbine stage could be used for this purpose.

The e-fan can also be set up in such a way, that it can rotate in the opposite direction to the upstream out-flow of the turbine stage. This is because the flow leaves the turbine stage with inclination or not in line with flight direction. In this way, up to complete swirl compensation can be achieved. This results in higher efficiency.

In general, for example, an operation of this hybrid-electric propulsion system can be organized, according to flight phases and/or an altitude. For example, the downstream e-fan can also be put into operation only for certain flight stages. For example, it can temporarily provide additional thrust as needed for a climb or especially for a step climb. Because of the limited operating time, the electrical energy storage systems, that may be kept on board, are smaller in capacity and therefore lighter in weight. By this higher flight altitudes can be reached with more effective operation conditions, if the aircraft is adapted to this operation.

Alternatively or additionally it can be power-fed by electrical generators e.g. of the same or another engine. This can happen also temporarily, for example for a step climb, which could be e.g. are around 2000ft climb. A power feeding device could be also an APU.
Alternatively or additionally the E-system can also be used for the take-off roll and/or initial climb.

Another use case, that is interesting - on an only on demand basis -, where electrical energy consumption is manageable due to the limited duration, is an engine failure. In such a case, at least one E-fan of one of the remaining engines can provide additional thrust as needed, e.g., near the ground for a limited period of time, at least to get the aircraft out of a dangerous positions or flight state. Normally the times, in which one engines delivers excessive OEI

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thrust is allowed and limited to around 5 to 10 minutes. For such a small amount of time the electric system can take over. The airplane can be eventually designed more efficiently and adopted to this possibility.

During other flight phases, in which an e-fan is not actively rotating, it can remain braked in the parking position, for example. In this case, however, it can act as a downstream stator device for the turbine. In this case, the stator device can also be designed to be adjustable or tuneable, e.g. for the pitch angle of its blades. This would make up a VIS a variable incident stator.

Shemale A-D062PS	Shemale D-0002PS
Maximum Continous Power 260 KW 0,26 MW	Maximum Continous Power 2000 KW 2 MW
Dimensions Diameter 42 cm x Length 30 cm	Dimensions: Diameter 52 cm x Length 59 cm
Weight 44 kg	Weight 260 kg

Figures 10 and 11 shows exemplary electric engines of a company, which was overtaken by an oiled Retro-company. Eventually purpose to let this technology disappear from the market and from visibility however failed.
Such engines are widely available and have already been copied by several companies, including Chinese manufacturers, which are famous for good prices.

A first orientation regarding weight would be an adjustable multi-bladed pitch-propeller with span of around 75 cm, with braking device. This solution will not result in much additional weight. Above all the electric motor can operate at high rpm and low torque (unlike in the by-pass duct), which further lowers the weight of the electrical motor(s), The electrical motors be therefore lower than 45 kg for 250 kW (1/4 Megawatt per Engine) and can be well integrated in the nozzle with plenty of free space, whereby this space can be also accessible relatively easy without opening the complete engine. That is why a retrofit on existing engines and aircraft seems possible without too much effort, as well as maintenance, if needed.

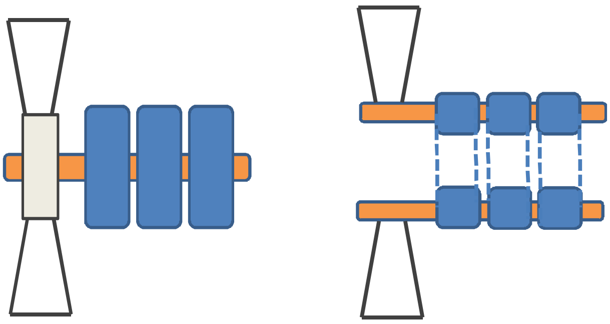

Figure 12: Two possibilities in principal to stack electric motors to add up their power output on same rotational speed on at least one output shaft e.g. for driving a fan, on the left for in-runner electric motors, on the right for out-runner electrical motors mot.

For today's single-aisle engines from volume in this area there would be enough volume to install a maximum of 2 MW electrical engines per turbofan-engine, even in the core aft (plug), which would result in 4 MW on aircraft level. This is just from a volume perspective. Around 8 to 10 MW is needed in cruise flight for a typical SA-aircraft.
However one small Shemale A electric engine (44kg) per turbofan engine in the core duct as core E-Fan would already account for 5% electrical thrust in cruise without emissions and without fuel (if electric engines are fed from batteries). This could be implemented for xample in a Bearbas 123.

For bigger and heavier aircraft, for example Fairbas 330 two Shemale A electric engine (2 x44kg) per turbofan engine in the core duct as core E-Fan would already account for roughly 5% electrical thrust in cruise without emissions and without fuel (if electric engines are fed from batteries).
For Airbosses, for example two Shemale A electric engine (2 x44kg) per turbofan engine in the core duct as core E-Fan would already account for roughly 5% electrical thrust in cruise without emissions and without fuel (if electric

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engines are fed from batteries). From volume and weight there would fit even more of these electric motors, even in the core aft plug of the turbofan engine.
If just one Shemale D electric engine (260kg) is taken for retrofit per turbofan engine of the Airboss it will result, if wanted, in roughly 20% continous electrical E-Thrust in cruise without emissions and without fuel (if electric engines are fed from batteries). This electrical engine fit more than well in the aft core plug of the Airbosses engines. From volume and weight there would fit even more of this electric motors, even in the core aft plug of the turbofan engine.
Furthermore it also fits in the engines of Single-aisle aircraft's engines, even in the aft rear plug.

Aircraft	E-Motor Weight (Total m. weight)	Number and Type of E-Motor on aircraft level	E Motor per turbofan engine	Implementation	Share of continuous Electric Thrust on total cruise thrust as maximum (potentiaally without any emissions and fuel)
Bearbas123	44 kg (88 kg)	2 x Shemale A	1 x Shemale A	Core E-Fan	**5 %** total 0,5 MW
Fairbas 333	44 kg (176 kg)	4 x Shemale A	2 x Shemale A	Core E-Fan	**5 %** total 1,0 MW
Fairbas 953	44 kg (264 kg)	6 x Shemale A	3 x Shemale A	Core E-Fan	**7 %** total 1,6 MW
Airboss	44 kg (352 kg)	8 x Shemale A	2 x Shemale A	Core E-Fan	**10 %** total 2,1 MW
Airboss	260 kg (1044kg)	4 x Shemale D	1 x Shemale D	Core E-Fan	**19 %** total 4,0 MW

Table 7 : Estimated Share of electrical generated E-Thrust of total thrust in cruise with various electric motors configurations on different aircraft. The share is a maximum continuous share, which means it can be steadily applied in cruise, but it is not a must. In real, Electrical E-Thrust can be selectively added on demand, in a range from 0% (none) to the maximum share, which is stated in the last column.

The first idea **-** for an example integration on a typical SA-aircraft was 250 kW per engine, to boost the TOC and the specific excess power on present existing engines, which allows to make step climbs in long range operations (with higher weight and with increased wing area) and fly the mission minimum 2000 ft higher.

1 h operating time is assumed for the electrical E-Fan system on the Single-aisle airliner.

E-Motors on Boars	Implementation	Application	Operating time	Mass Specific weight of battery	Weight of onboard electrical storage
2 x 260 KW 0,52 MW by 2 x Shemale A	Core E-Fan	3 x step climb, each 20 min @ 0,5 m/s, each 2000 ft climb	3 x 20 min = 1 h	300 Wh/kg	2027 kg
2 x 260 KW 0,52 MW by 2 x Shemale A	Core E-Fan	3 x step climb, each 20 min @ 0,5 m/s, each 2000 ft climb	3 x 20 min = 1 h	500 Wh/kg	1217 kg
2 x 260 KW 0,52 MW by 2 x Shemale A	Core E-Fan	6 x Go-Around with initial climb each 10 min	6 x 10 min = 1 h	300 Wh/kg	2027 kg
2 x 260 KW 0,52 MW by 2 x Shemale A	Core E-Fan	6 x Go-Around with initial climb each 10 min	6 x 10 min = 1 h	500 Wh/kg	1217 kg

Table 1: Estimated onboard electrical energy storage weight for different applications for single-aisle aircraft, if electrical motors are completely fed by onboard batteries (which is not a must, as on twin-engines there are three generators on board, on single-aisle 3 x 90 KW = 270 KW). Hereby component efficiency of the Shemale motors of 95% are taken, and another 90% efficiency is assumed for the fan, converting mechanical power into pressure.

Noise would not be a problem, because it is more than well shielded in the core stream and by the core nozzle. The E-fan and its surroundings can be made by temperature resisting materials e.g. metals, metal alloys and/or ceramic composites. One of the advantages of the high temperature is that the Mach number for the incoming flow stream, at the E-Fan present, is relatively low, only around Ma = 0,75 for temperatures around 850 K.

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3.2 E-Fan in the by-pass duct – BE-Fan

Another possibility, which should be now proposed, is to integrate an E-Fan at some outstanding location in the turbofan engine, in the by-pass duct.
In the exemplary embodiment shown, a fan, which can be rotated electrically, is introduced in the bypass engine downstream the fan and upstream of the nozzle.
By rotating it, it can generate additional propulsion. By the rotation of the fan it generates additional pressure in the fluid in the by-pass stream. This can be converted into additional thrust by/after passing the by-pass nozzle.

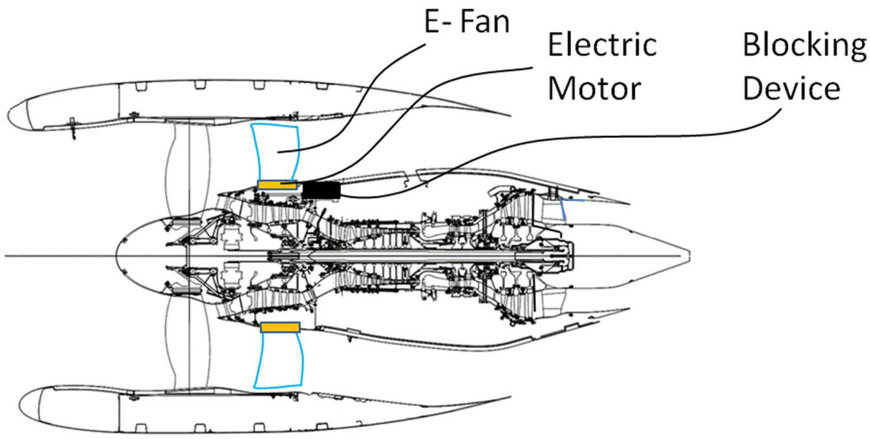

Figure 13: E-Fan integrated in the by-pass duct. This solution allows higher degrees of electrical thrust (degree of hybridization) up to 35% of the by-pass duct thrust, but this of course it leads to higher additional weight regarding installation and electrical storage. But it can be also just used in special flight stages e.g. during climb (out)

The by-pass nozzle could be designed in a, so said adopted way, that means that its geometry is chosen to be, that the fluid has the ambient pressure, after having passed the nozzle.

In case additional pressure is introduced by the E-Fan upstream of this nozzle, on demand, after the fluid in the by-pass stream has passed the nozzle it will have a slightly higher pressure than ambient pressure, which lead to post-expansion of the fluid, after having already past the by-pass nozzle. This results in additional thrust.

A second alternative would be to have an adjustable by-pass nozzle which could be adapted to the pressure being present upstream of the nozzle. This pressure would be higher if the fan is in operation. According to this research this would be rather necessary, because what exits the by-pass nozzle in cruise flight is already near to the speed of sound, and an un-adaptable nozzle would probably not handle this increased mass stream.

One characteristic is that this fan, as a rotor, can be held braked by at least one means (e.g. one device). In the braked state, as an option, it can, for example, form and function as a stator device for the upstream fan, so that the swirl of the upstream fan can be converted into propulsion and the by-pass stream can in general be straightened.

In a further operating mode, the E-fan can be released from the holding or braking device and can be set in rotation, also by demand, by means of at least one electric motor. Now it is possible that this fan can generate additional propulsion via additional pressure. In doing so, it could also be tuned to the operating state of the upstream fan by means e.g. of a speed control.
Such an adjustment could, for example, be formed on the basis of - at least one state or parameter (speed, pitch, velocity etc.) of the upstream fan. For example, the speed of the upstream fan could be detected for this purpose. Likewise or additionally, a possible adjustment of the fan or its fan blades, e.g. in the pitch angle, could be taken into account.
Such a pitch angle change could, for example, be formed on the basis of the upstream out-flow condition e.g. of the upstream fan. For example, the angular speed of the fan could be used for this purpose.

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The E-fan can also be set up in such a way, that it can rotate in the opposite direction to the upstream out-flow of the fan. This is because the flow leaves the fan with heavy angular inclination thus not in line with flight direction. In this way, up to complete swirl compensation can be achieved. This results in higher efficiency. For open propulsors, thus not enclosed propulsors, this results in an increased efficiency of 8% (cruise flight) up to 13% (Take-off).

In general, for example, an operation of this hybrid-electric propulsion system can be organized, according to flight phases and/or an altitude. For example, the downstream e-fan can also be put into operation only for certain flight stages. For example, it can temporarily provide additional thrust as needed for a climb or especially for a step climb.

Alternatively or partly additionally it can be fed by electrical generators e.g. of the same or another engine, or the APU, at least temporarily, at least partly.

Alternatively or additionally the E-system can also abe used for the take-off roll and/or initial climb.

Another use case, that is interesting - on an only on demand basis -, where electrical energy consumption is manageable due to the limited duration, is an engine failure. In such a case, at least one E-fan of one of the remaining engines can provide additional thrust as needed, e.g., near the ground for a limited period of time, at least to get the aircraft out of a dangerous positions or flight state. Normally the times, in which one engines delivers excessive OEI thrust is allowed and limited to around 5 to 10 minutes. For such a small amount of time the electric system can take over. The airplane can be eventually designed more efficiently and adopted to this possibility.

During other flight phases, in which an e-fan is not actively rotating, it can remain braked in the parking position, for example. In this case, however, it can act as a downstream stator device for the fan. In this case, the stator device can also be designed to be adjustable or tuneable, e.g. for the pitch angle of its blades. This would make up a VIS a variable incident stator.

A first orientation regarding weight would be an adjustable multi-bladed pitch-propeller with span extension 2 x 0,5 m from 1 m to 2 m, which means to have a hub diameter of 1m, without having a spinner, but, with braking device(s).

One of the advantages of having E-Fan in by-pass ducts is that they can apply a huge amount of additional E-thrust.
Disadvantage is, that an integration in the by-pass duct will cause more heavy additional weight than in the core stream, integrated as nozzle e-fan.
Another disadvantage is, that the bypass nozzle is already delivering an exit speed near to the speed of sound. So probably an integration of a adjustable by-pass nozzle is needed. These devices are already fully developed for by-pass ducts in turbofan engines and showed in flight test additional fuel savings (apart from an e-fan application) of 1 to 2 % on SA-aircraft.
One advantage is, that the BE-Fan can also possibly be used a thrust reverser, without any other means or deflection devices for reverse thrust. By that, around 800 kg of weight could be saved in each gondola of a SA-Aircraft, because of the removal of the former thrust reserver means, making up a free weight for integration of an E-Fan system of 1600 kg in a 2 engine SA-aircraft.

4. New & Advanced Technologies for single-aisle aircraft in long range operation

The first two questions of the questions - summary in the beginning could be already be answered.

With this in mind there are three further questions left - to be answered. Research is in the following be done to deliver answers.

III. Which technologies can enhance the efficiency, especially the fuel efficiency, of single-aisle aircraft in long range operations?

IV. Is there a retrofit solution for question 3, for existing or in production engine or aircraft?

V Can these technologies transferred to widebodies and/or aircraft in short and medium operations and/or transfered to different engine architectures?

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4.1 Conical Thrust Displacement and Corrections

With regards to engines, my investigations furthermore revealed, that it is possible to improve efficiency and, in particular the fuel efficiency, especially in the field of thrust generation.

It is well known, that in general a thrust displacement lowers the efficiency of the operation. The thrust vector is then not aligned antiparallel with the direction of aircraft motion (flight direction), and instead has a displacement in form of a displacement angle (in the figure shown as alpha).
In aircraft design it is text book knowledge to take only the cos-part of the thrust vector of the displaced exit velocity V_{EI} into consideration, if there is a thrust displacement angle present. A component of the thrust vector therefore dissipates and does not become full effective in terms of propulsive efficiency.

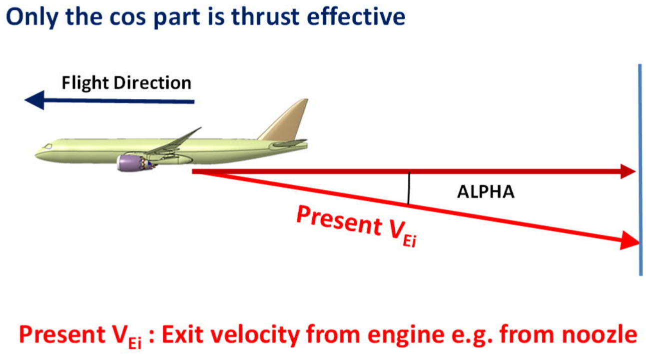

Figure 14 : Only the cos-part regarding the angle alpha of - the thrust vector, formed by exit velocity V_{EI} - becomes thrust effective (effect exaggerated for clarity)

A closer look at the exemplary bypass engine, as just one representative of engines and turbofan engines, reveals that a conical thrust displacement is present in the bypass core as well as in the core flow.

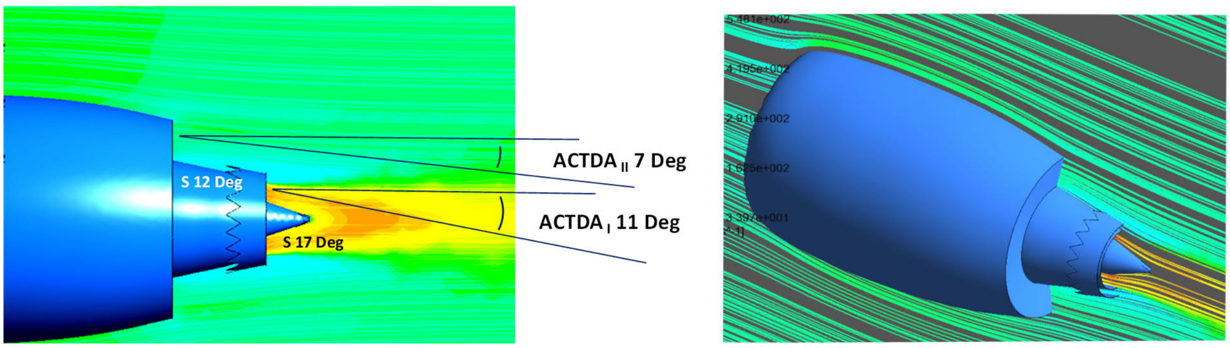

Figure 15 : Average Conical Thrust Displacement Angle (ACTDA) in the core and in the bypass stream and slope angle of the contour (S) at an exemplary engine in cruise flight, the streamlines when leaving the engine parts by exit speed VEI are not in line with the flight direction, thus they are angular 3 D displaced

For this phenomenon, so far, which is apparently unaware, there is still no term/naming for this form of thrust displacement. Therefore it is should be called conical thrust displacement.

Force is physically defined as a change in momentum. A singular change of momentum, respectively a single force, can have the influence on a body, that it changes its velocity, or its direction, or both. A singular change of momentum, present as a single force, can have the influence on a fluid or a fluid mass flow, that it changes its velocity, or its direction, or both.
In this context consider an airfoil in stationary cruise flight, like it is normally illustrated. As is it known, this airfoil experiences a lift force while being exposed to the fluid flow stream. Together with drag, which also becomes effective, a resulting force like is effective and directed upwards and slightly to the right.

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According to the principle actio equals reactio, the fluid mass flow experiences an equal and opposite force in decelerating manner downward. However the mass flow of the air is, regarding its amount and mass, is very high. This results in, that a certain part out of this amount of cumulated mass flow, experiences just a relatively low change in direction or velocity or both.
This principle should now to be applied to the correction of the conical thrust displacement. This should be initially done in the core flow. According to Figure 16, a ring-like wing is designed, here in a ring-shaped closed manner, which is exposed to the conically displaced fluid mass flow in the bypass stream. The flow hits the ring shaped wing along its circumference, generating lift and drag, in form of a resulting fluid flow force.

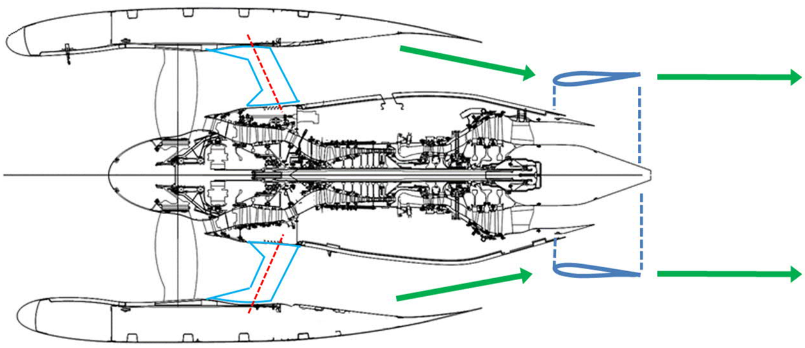

Figure 16: Correction of the conical thrust displacement by a ring-shaped wing (named Thrust Crown, TC), exemplary shown in the bypass-duct. The TC deviates/corrects the exit velocity in/to flight direction. The ring (TC) acts like a teeth-retainer for the engine

The direction of the resulting fluid force can be influenced, depending on the geometry of the ring together with the present conical thrust displacement. So it can be also possible, that the resulting fluid force of the ring is slightly directed in flight direction. In this case the force forms a component in the direction of flight of the aircraft. This force acts propulsive and has a drag-weakening or propulsive effect on the aircraft.

For a resulting force with forward facing component the requirement is:

$\arctan \frac{D}{L} < ACTDA$ or $\arctan \frac{C_D}{C_L} < ACTDA$ whereby lift and drag coefficients refer to the ring-shaped wing **(1)**

That means, that the ring-shaped-wing must be designed according to, that its glide ratio 1/E have to be better than 1/E = 1/5,14 = C_D/C_L= D/L for the core stream with ACTDA = 11 ° present and 1/E = 1/8,14 = C_D/C_L= D/L for the bypass stream with ACTDA = 7 ° present. This however appears to be feasible.

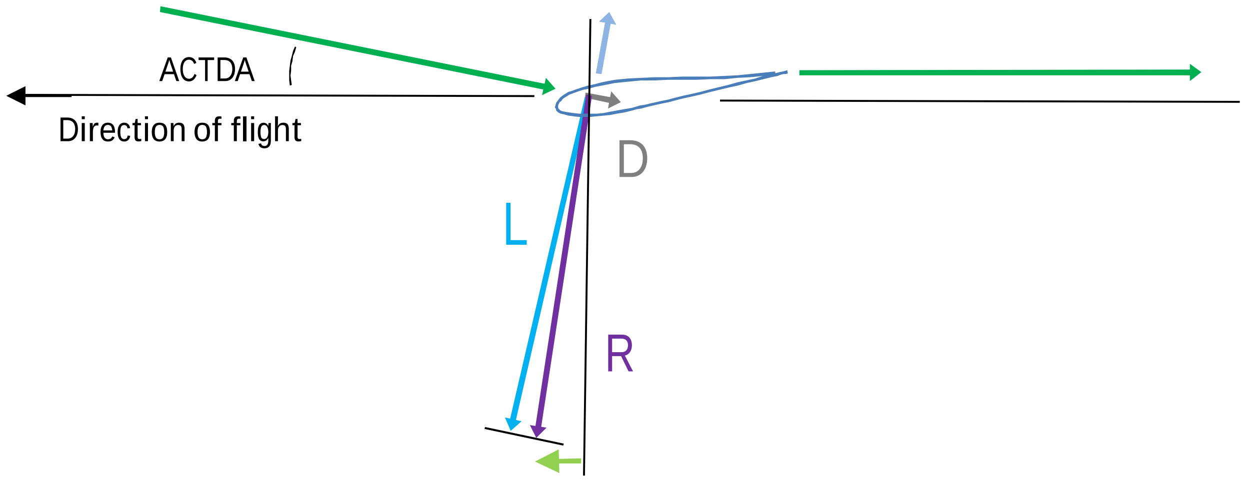

Figure 17: By this arrangement a resulting fluid force at the ring-shaped wing is generated, which is tilted to the front .in flight direction, thus having a propulsive - or drag weakening force on the aircraft, like a winglet

The direction of the resulting fluid force can be slightly different generated, according to the geometry of the ring together with the present conical thrust displacement. So it can be also possible, that the resulting fluid force of the

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ring is perpendicular to the flight direction. In this case there is no impulse exchange of fluid and ring in flight direction, which means in other words, there is no force neither on ring or fluid in flight direction.
But there is a force perpendicular to flight direction, which corrects the radial flow component of the exit velocity speed, preferably in such a way, that the exit velocity is deviated exactly in antiparallel flight direction. This means, that conical thrust displacement is completely corrected. By that thrust is maximized.

For a resulting force with no impulse exchange in flight direction, the requirement is:

$\arctan \frac{D}{L} = ACTDA$ or $\arctan \frac{C_D}{C_L} = ACTDA$ whereby lift and drag coefficients refer to the ring-shaped wing **(2)**

That means, that the ring-shaped-wing must be designed according to, that its glide ratio 1/E is around $1/E = 1/5{,}14 = C_D/C_L = D/L$ for the core stream with ACTDA = 11 ° present and $1/E = 1/8{,}14 = C_D/C_L = D/L$ for the bypass stream with ACTDA = 7 ° present.

In the following it should be assumed, that the resulting fluid force on the ring shaped wing acts perpendicular to the flight direction, like it was recently explained, and like Figure 18 below shows.

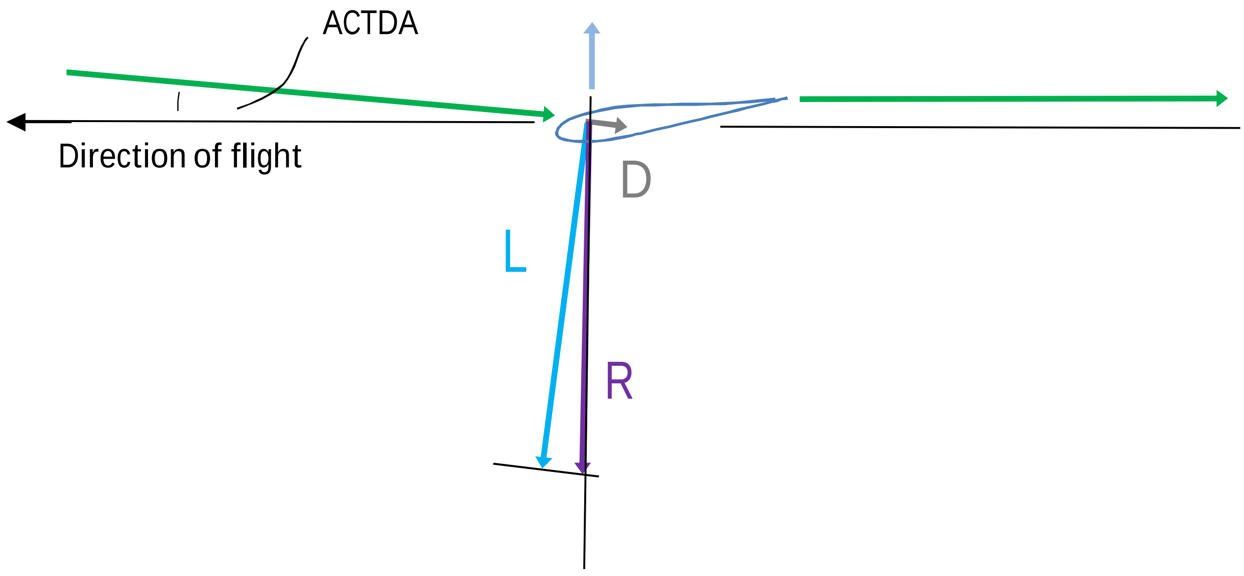

Figure 18: By this arrangement a resulting fluid force at the ring-shaped wing is generated, which is perpendicular to the flight direction, thus having no force effect in flight direction, neither on the ring, nor on the fluid. That means, that no impulse change happens in flight direction. The change in impulse happens in radial flow direction, perpendicular to the flight direction, being effective as a angular correction of the exit velocity, which is thereby aligned in antiparallel flight direction, to maximize thrust.

In the following it should be assumed, that the resulting fluid force on the ring shaped wing acts perpendicular to the flight direction, like it was recently explained and like above Figure 18 shows.

That means, that no impulse change happens in flight direction. The change in impulse happens in radial flow direction, perpendicular to the flight direction, being effective as a angular correction of the exit velocity, which is thereby aligned in antiparallel flight direction, to maximize thrust. In radial direction, there appears a fore on the ring (action). According to the principle of actio = reactio the, direction of the fluid mass flow is changed (reaction happens on the fluid mass stream), and thus by this action the conical thrust deposition can be corrected. As a result, the thrust vector in the specific stream along the conical circumference is corrected and oriented antiparallel to the direction of flight. In this manner the thrust vector is most effective and propulsive. This effect can also be expressed in form that the thrust vector is rotated (aligned) in flight direction as figures 14 an figure 16 show.

The effect can be calculated in the following:

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The thrust for a Jet-engine in steady-state cruise flight can be determined by:

$$F = \dot{m} \cdot (V_{EI} - V_{CRU}) \qquad \textbf{(3)}$$

The total thrust is composed of m thrust in core stream I and thrust in bypass stream II:

$$F = F_I + F_{II} \qquad \textbf{(4)}$$

The velocities entering and exiting the engine are known:

Stream	Core Stream I	By-Pass Stream II
Cruise velocity v_{CRU}	v_{CRU} 230 m/s Ma 0,78	v_{CRU} 230 m/s
Exit velocity v_{Ei}	v_{EI} 450 m/s	v_{EII} 288 m/s
Mass flow m_i	m_I not needed to be known in value	m_{II} not needed to be known in value

Table 1: Characteristic velocities, needed for the calculation of the effects of the exemplary thrust crowns TCs

First, the mean or average conical thrust displacement angles (ACTDA) in the different streams of the engine are determined individually for the core stream and for the by-pass stream. This can be done by measurement (e.g. by visualization; by PIV particle image velocity) or from CFD.

By determining this angle - a help can be found in the angle of the downslope contour e.g. of the nozzle. It shows that this is the most extreme angle, which can happen, and happens to the flow only directly near to this nozzle slope. Far away from here the free stream is aligned in flight direction. So the average conical thrust displacement angle ACTDA is somewhere between these extreme angular alignments.

So normally a typical average conical thrust displacement angle from amount/magnitude is somewhere between the following extremes: slope angle of neighbouring contour (maximum displacement) and the other extreme flight direction 0° displacement). For first estimation - it can be as a rough estimate taken half of the downslope contour angle.

As a next step, the outflow velocities of the two flows are determined e.g. for cruise flight. These should actually already be known, because with help of them thrust of the engine could be calculated. They are taken from table 1.

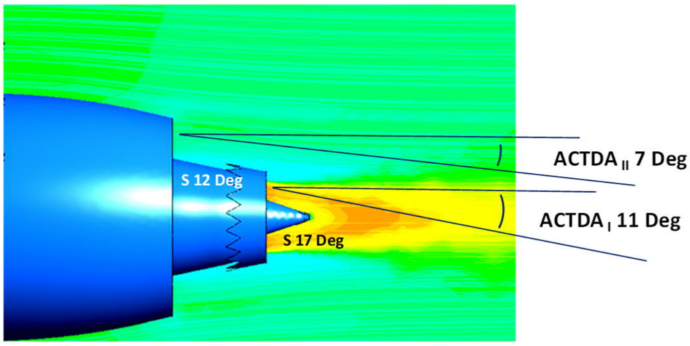

Figure 19 : Average Conical Thrust Displacement Angle (ACTDA) in the core and in the bypass stream and slope angle of the contour (S) at an exemplary engine in cruise flight, the streamlines when leaving the engine parts by exit speed VEI are not in line with the flight direction, thus they are angular 3 D displaced

Average conic thrust displacement angle, present in core stream $\qquad ACTDA_I = 7°$
Average conic thrust displacement angle, present in by-pass stream: $\qquad ACTADA_{II} = 11°$

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The full potential of correction of the conic thrust displacement angle can be calculated as follows:

Full potential means that the thrust average thrust displacement angle ATDA is corrected completely.

Assumption: the Average conic thrust displacement angle is completely corrected. As the average thrust displacement angle ATDA is a mean angle (as an average) it means - in deep- that the flow is not completely straightened, but in average it is straightened.

The potential is created for the core stream and for the auxiliary stream, separately:

The correction of the $ACTDA_I$ in the core stream should be corrected by 11 °

The correction of the $ACTDA_{II}$ in the by-pass stream should be corrected by 7 °

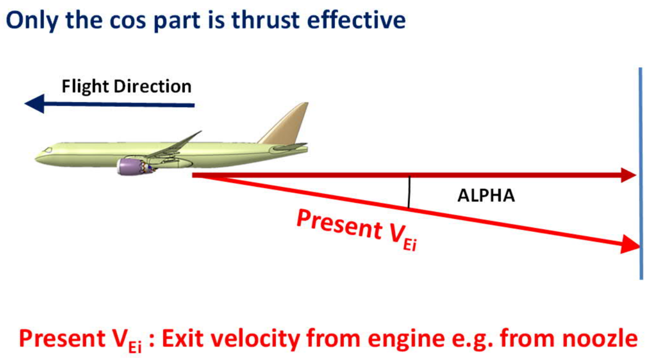

Figure 20 Only the cos-part of the thrust vector with exit velocity becomes thrust effective (effect exaggerated for clarity)

State of the art is that only the cos-Part of the displaced exit velocity V_{EI} becomes thrust effective for efficiency.

State of the art core stream:

$$V_{EI\ BFORE\ EFFECTIVE} = V_{EI} \cdot cos\ (ATDA_I) = 441{,}73 \text{ m/s} \qquad \textbf{(5)}$$

State of the art by-pass stream:

$$V_{EII\ BFORE\ EFFECTIVE} = V_{EII} \cdot cos\ (ATDA_{II}) = 285{,}85 \text{ m/s} \qquad \textbf{(6)}$$

A full correction of the Average Thrust Displacement angle with the help of thrust crowns means, that the exit velocity V_{EI} becomes completely effective.

With thrust displacement angle fully corrected, the exit velocity in antiparallel flight direction, effective, in the core stream duct is:

$$V_{EI\ MOFIFICATED} = V_{EI} = 288 \text{ m/s} \qquad \textbf{(7)}$$

With thrust displacement angle fully corrected, the exit velocity in antiparallel flight direction, effective, in the by-pass stream duct is:

$$V_{EII\ MOFIFICATED} = V_{EII} = 450 \text{ m/s} \qquad \textbf{(8)}$$

The Thrust effective in flight direction, being generated in the core duct with modification is therefore:

$$F = \dot{m}_I \cdot (V_{EI} - V_{CRU}) \qquad \textbf{(9)}$$

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The Thrust effective in flight direction,being generated in the bypass duct with modification is therefore:

$$F = \dot{m}_{II} \cdot (V_{EII} - V_{CRU}) \qquad \textbf{(10)}$$

The ratio of thrust effectively being generated with modification/
to the thrust before without modification before is therefore for the core duct is:

$$\frac{F_{I\ MOFIFCATION}}{F_{I\ BEFORE}} = \frac{\dot{m}_I \cdot (V_{EI} - V_{CRU})}{\dot{m}_I \cdot (V_{EI} \cdot cos\,(ACTDA_I) - V_{CRU})} = \frac{(V_{EI} - V_{CRU})}{(V_{EI} \cdot cos\,(ACTDA_I) - V_{CRU})} = 1{,}0391 \qquad \textbf{(11)}$$

The thrust gain in the core duct is therefore:

$$TGTC_I\,[\%] = 3{,}91\% \qquad \textbf{(12)}$$

The ratio of thrust effectively being generated with modification/
to the thrust before without modification before is therefore for the by-pass duct:

$$\frac{F_{II\ MOFIFCATION}}{F_{II\ BEFORE}} = \frac{\dot{m}_{II} \cdot (V_{EII} - V_{CRU})}{\dot{m}_{II} \cdot (V_{EII} \cdot \cos(ACTDA_{II}) - V_{CRU})} = \frac{(V_{EII} - V_{CRU})}{(V_{EII} \cdot \cos\,(ACTDA_{II}) - V_{CRU})} = 1{,}0384 \qquad \textbf{(13)}$$

The thrust gain in the by-pass duct is therefore:

$$TGTC_{II}\,[\%] = 3{,}84\% \qquad \textbf{(14)}$$

The thrust Gain of the turbofan engine effectively being generated with modification/
to thrust before without modification is therefore

$$\frac{F_{\ MOFIFCATION}}{F_{\ BEFORE}} = \frac{BYPR_{\ CRU} \cdot (V_{EII} - V_{CRU}) + (V_{EI} - V_{CRU})}{BYPR_{\ CRU} \cdot (V_{EII} \cdot \cos\,(ACTDA_{II}) - V_{CRU}) + (V_{EI} \cos\,(ACTDA_I) - V_{CRU})} = 1{,}0386 \qquad \textbf{(15)}$$

The thrust gain for the overall engine with Thrust crown in both ducts (core and by-pass) is IN IDEAL CONDITIONS AS FULL POTENTIAL is therefore:

$$TGTC_{OVERALL\ \ IDEAL}\,[\%] = 3{,}86\% \qquad \textbf{(16)}$$

In real application component efficiencies have to be added, - for both streams they are chosen to be 78%:

Trust gain estimated under real conditions:

$$TGTC_{OVERALL\ \ REAL} = \frac{\eta_{TC\,I} \cdot TGTC_I\,[\%] + \eta_{TC\,II} \cdot BYPR_{\ CRU} \cdot TGTC_{II}\,[\%]}{BYPR_{\ CRU} + 1} = 3{,}00\% \qquad \textbf{(17)}$$

Fuel consumption is proportional to thrust for small thrust changes being effective. Therefore fuel gain under real conditions can be estimated:

$$Fuel\ Gain\ TCs = \frac{\eta_{TC\,I} \cdot 3{,}91\% + \eta_{TC\,II} \cdot BYPR_{\ CRU} \cdot 3{,}84\%}{BYPR_{\ CRU} + 1} = 3{,}00\% \qquad \textbf{(18)}$$

$BYPR_{CRU}$ ist the by-pass ratio for the engine in cruise flight, which is assumed to be 8:1 in cruise for a maximum by-pass ratio of the engine of 12:1.

This rectification by thrust crowns has the effect of increased efficiency. With the same fuel more thrust is generated. This thrust increase could be used for 1.) higher payload - means higher weight and/or 2.) for accessing higher cruising altitudes at same weight. Especially in the beginning of long range cruise, when the aircraft is still very heavy and cannot climb to higher cruising altitude this effect can show up to be very fuel saving. As a result a higher initial climb altitude ICA can be established, as well as an higher cruise altitude in general.

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In another application less thrust could be applied - means to be set, which the effect, that according to better efficiency, - even with lower thrust setting - more thrust is effectively be present in flight. This means directly less fuel consumption.

The ring vane realizes the function of a thrust rectifier. It can show up very precious in efficiency and cost.
That is why it should be named Thrust Crown TC.
The Thrust Crown can be applied in the core stream, as well as in the bypass stream, and in combination.
Due to the higher Mach in the by-pass stream in the by-pass stream it must be shaped in an adjusted shape, regarding geometry, e.g. with wing swept.

In the score stream, even there is very high (exhaust) velocity present, around 450 m/s, due to the high temperature, the incoming flow for the thrust cone shows only a Mach number of Ma = 0,76.

This means, that in theory no swept is necessary in the core stream. Instead the thrust cones have to be designed temperature resistant (like other parts of the engines e.g. nozzles). This can happen by metals, metals alloys or with the help of ceramic composites, which can further contribute to a lightweight design.

Devices like a thrust crown (TC) can in general also be used to correct a thrust displacement and/or used for pitch moment influence and enhancement. For examples on old SA-aircraft , which were equipped with more up-to-date turbofan engines challenges appeared by pitch up moments due to the new and larger gondolas (Bearbas 023 and DoIng 373 Fax).

Applied on the exemplary engine for single-aisle aircraft a combination of core Thrust Crown and by-pass Thrust Crown, - King and Prince ;-) – should mean an additional weight of 380 kg per engine. This weight comes from, if the full volume of the thrust crown is made of titan. This additional weight of 720 kg is in the same order like blended winglets (+680 kg) on these types of aircraft. A further lightweight design in optimization appears possible. The weight saving potential could be around -50 %.

On 4-engine planes, like the Airbosses and/ or Airqueens, four Thrust Crowns can be applied “four” long-houl. This could be offered Princes as the Crown Package for Retrofits.
In a first approach the additional weight is proportional to the perimeter of the wing shaped vanes. The same applies to the expected efficiency gain - or effect being present -, which depends on the perimeter of the crown, too.

For design it has to be taken into account that the lift slope of - a ring shaped or closed wing - is different to the one of a planar wing. Furthermore it has to be taken into account that the lift slope of a ring shaped with swept is different to the one without swept.

A very rough but so far confirmed estimate is, that core crown and side crown (by-pass) contribute to additional thrust in the same extent. This is because in the by-pass duct the perimeter outside is large, but velocity is relatively small. In the inside (core) duct however the velocity is significantly higher, but the perimeter is small.

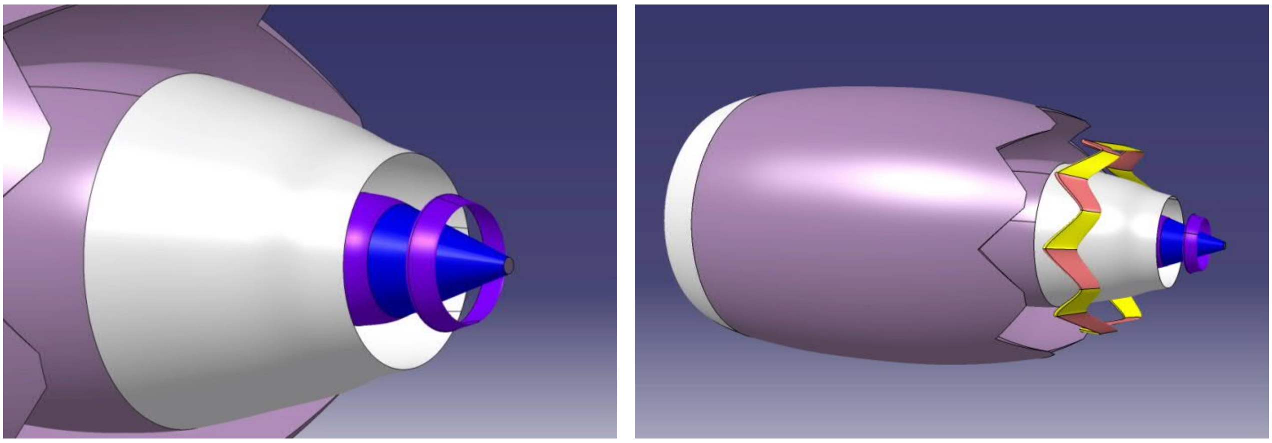

Figure 21: Exemplary embodiments of Thrust Crowns in the core duct (left) an in the by-pass duct (right). In the by-pass duct the ring-shaped wing has to be designed with swept.

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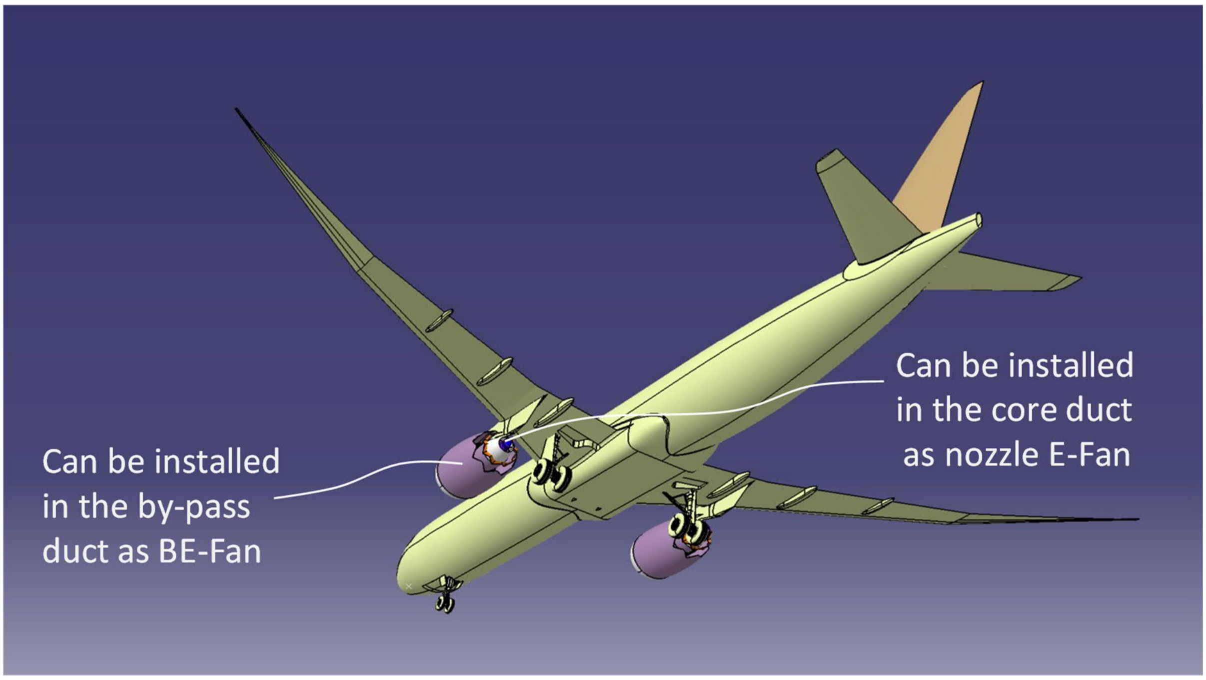

Figure 22: Possibilities to install E-Fan and/or Thrust Crowns in the engines of an aircraft. Core E-Fan and Thrust Crowns in general can be retrofitted to existing/ in production engines an aircraft, also including wide body aircraft

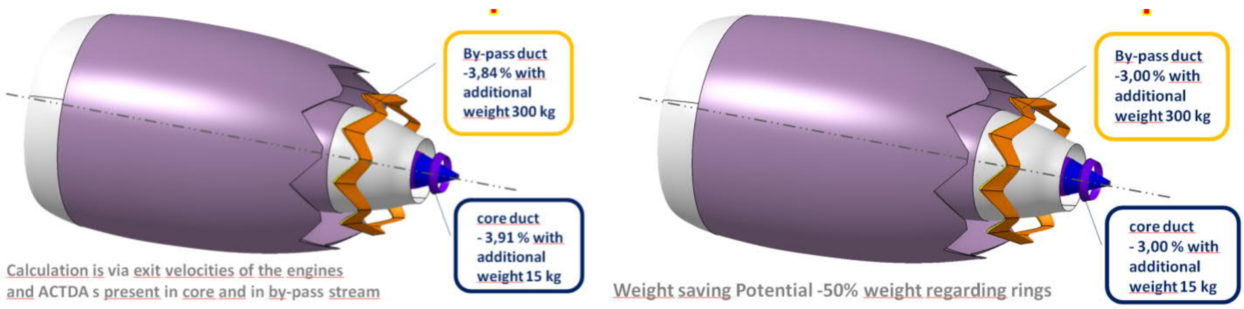

Figure 23: Fuel saving potential for thrust generation under ideal conditions (left) and under estimated real conditions (right) for thrust generated in the core/ and in the bypass stream. The total potential under real conditiodn can be figured out with help of the thrust ratio in cruise between core and bypass stream, and is for an SA-aircraft exemplary engine set of two engines 3% fuel savings for the aircraft in cruise flight, with components efficiency of thrust crowns, estimated, beeing 78%

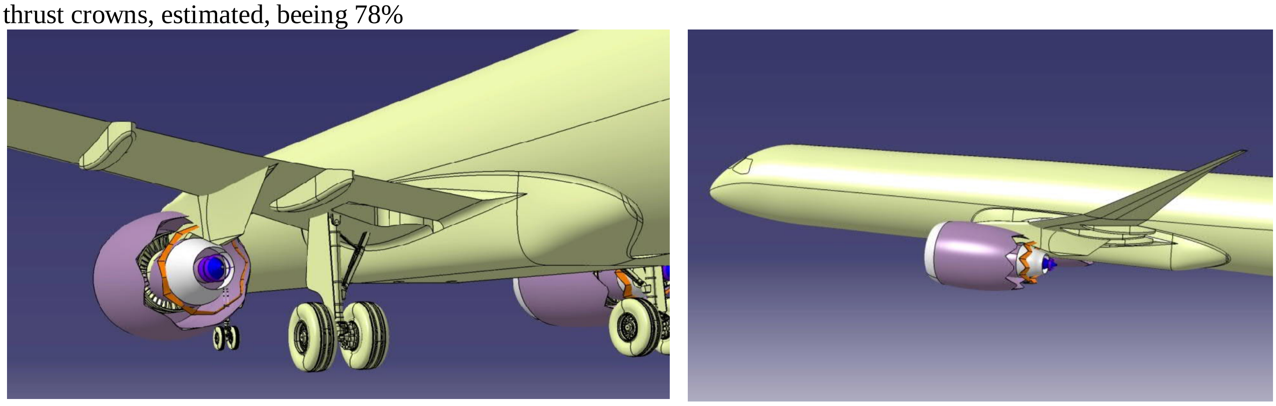

Figure 24 : The thrust crowns (TC) can be fixed to the pylon, as well as additionally to the struts, which links the nacelle to the core engines (here not shown). This applies specifically to the TC in the by-pass are. In the core stream the TC can be fixed to at least one of the nozzle components, preferably to the core engine nozzle e.g. by struts.

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5. Long Range Single-aisle-Airliner Mission with Implemented Technologies

As already indicated in the paper, in the following, some of the multiple-fuel-saving technologies should be implemented on a Single-aisle-Airliner for a Long Range Mission.
Recently, existing aircraft, which were designed 35 to 45 years ago as short-range aircraft (family), are now in use for long-range missions. These operations are characterized by long ranges, long flight times, a large required amount of fuel and therefore a large takeoff weight.

5.1 Long-Range Mission

This Long-Range Mission, exemplary flown, for the Single-aisle-Airliner has a great circle distance of around 3870 nm and is representative for a typical transatlantic mission. The airliner takes-off in Paris CDG with final destination Washington D.C. Dulles International Airport IAD. The flight time duration is about 8,5 to 9 hours. Speed chosen is long range cruising speed of Ma 0,78. Take-off weight for this mission will be 85 300 kg, which is medium for this aircraft.
The fuel reserves on board will be additional 3 tons. Alternate airport, in case of distortion is Ronald Reagan Washington National Airport DCA in the City Center. Figure 25 shows a map of the flight track, with chosen ETOPS time is 180 minutes.

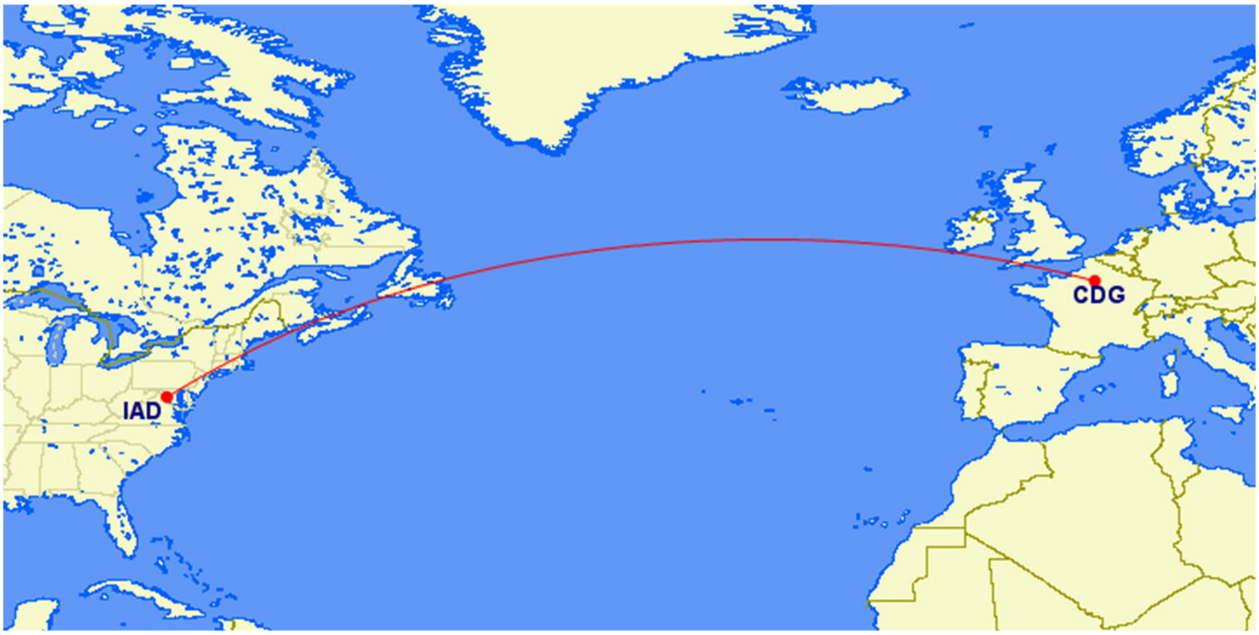

Figure 25: The long range mission from Paris to Washington has a distance of 3870 nm and takes 8,5 to 9 houres

5.2 Aircraft Bearbas 123 XXLR

The aircraft, which flies this mission, is newly designed by the author, but originates from typically existing Single-Aisle-Airliner, however this aircraft is modified which some new and interesting technology. The name of this aircraft will be Bearbas 123 XXLR. The name could be also written as Bearbas 123 X^2 LR. OEW is estimated to be 51 000 kg with just 124 seats and less stewardess needed, and already including new fuel saving turbofan engines with higher weight. The weight in real would even be lighter. The technologies on board of this aircraft are described in chapter 5.5. Further details can be seen in table 5.

This new aircraft version will origin more or less from two reference aircraft. These two reference aircraft will be described in the following.

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5.3 Reference Aircraft Bearbas 123 and Bearbas 123 LRX

The first Reference Aircraft will be the longest and heaviest of a four-member aircraft family of Single-Aisle-Airliner, made for short and medium range domestic flights. Its name should be Bearbas 123. It is the core version, from everything originates from. OEW is estimated to be around 48 000 kg. This reference aircraft features conventional turbofan engines of maximum bypass ratio 5-6. This reference aircraft shows the technology level of the year 2000 and is therefore ACARE 2000 conform. Further details can be seen in table 5.

The second Reference Aircraft, **-** which is used in this paper, originates from the core version, from the first reference aircraft. It is a modified version for intercontinental Single-Aisle Long Range Operations. Therefore the name should be Bearbas 123 LRX. This can be roughly translated as:
Better **E**fficient **A**erodynamic **R**etro **Bas**ed Airliner **123 L**ong **R**ange **Limited**. The additional term X states, that it is modified with more modern technologies, to enable this long range-operation in general, but that the Long Range is still limited in Range. OEW is estimated to be 51 100 kg with maximum seating in just one class of 244 passengers and all the stewardesses needed. Further details can be seen in table 5.

Major changes of this second Reference Aircraft Bearbas 123 LRX, compared to the root aircraft Bearbas 123 are:

- Installation of additional fixed fuselage fuel tanks for fuel amounts to enable long range and intercontinental missions.

- Two bought-in, more fuel-saving, turbofan engines

- Increase in wing span from 34,1 m to 35,8 m, which leads to roughly 2 m^2 more wing area and an increased wing aspect ratio of 10,0 compared to a former wing aspect ratio of 9,5 of the Bearbas 123.

- Bought-in blended fishlets at the wing-tips, which each stretches to a height of approximately 2,5 m, which mainly enhance lift-dependend induced drag in flight, This leads to typical fuel mission fuel savings of roughly - 4 % Additional weight, already included in OEW is around + 680 kg.

5.4 Specialities to be considered when today's Single-aisle-Airliner go on Long Range missions

The aircraft were core- designed 35 to 45 years ago. The aircraft is designed and laid out for clear short and medium range and missions. The maximum flight altitude is therefore low and limited. For the Bearbus 123 core version ceiling is around 39800 ft. For other family member the ceiling can be made higher as an option for retrofit or while manufacturing. The maximum flight altitude is designed for short-range missions. In short range missions it is not that important to fly in higher altitudes.

Figure 26: Typical cars and buses of the 70s and 80s, when the core design of most of today's single-aisle airliner took place, which has been 35 to 45 years ago. Some of the airliners got a modified wing, new cockpit displays, and/or LED-lighting in the cabin. Bought in turbofan engines and bought- in winglets could be added.

The wing area is designed as a compromise between 4 family members and therefore rather small for the largest and heaviest family member. Therefore, the wing area for this stretched aircraft **-** as the largest family member of a short and medium range aircraft **-** is comparatively small.

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But for long range applications, where a lot of fuel weight has to be carried for a long flight time and high flying weights have to be lifted up, the wing area is extremely small and rather “too small”.

This is a second and main reason why the supporting wing area is very small. Due to the high takeoff and flight weights on long range missions, the wing weight loading is extremely large.

A comparison with a DoIng 575- 200 W shows this especially. This DoIng is additionally partly designed for long range missions. The maximum takeoff weight is the same for the Bearbas 123 LRX and for the DoIng 757-200 W at around 100 t MTOW.
Nevertheless, the wing area of the DoIng 575-200 W is designed to be almost +42 % larger, at same maximum take-off weight. This has a dramatic impact on flight performance in long-range missions for the aircraft with the comparatively smaller wing area. Besides the thrust installed on the DoIng 575 is much more (factor 1,22) at same MTOW.

Despite its high weight, the DoIng can climb to comparatively high altitudes after takeoff thanks to its large wing area, i.e. to high initial cruise altitudes (ICA). At high Initial Cruise Altitudes, the aircraft can be operated very efficiently, means very fuel-efficiently, in cruise flight with its engines.
The Bearbas 123 LRX, on the other hand, with its small wing area, can only climb to very low ICA and begin cruise flights on longrange missions with the weight close to takeoff weight. Only step by step - via step climbs - it can climb to higher cruise altitudes, but for a long time of the mission, this flight altitudes are much more lower than the flight altitudes of the DoIng 575-200 W.
The maximum cruising altitude is also greater for the DoIng at 43000 ft than for the Bearbus 123 LRX (39800 ft).

For each wing loading or cruise C_L, there is an optimum cruise altitude - at which to fly at a given speed - for optimum fuel consumption. The lower the wing loading, the higher the optimum cruising altitude.
If possible, a high altitude is chosen to improve efficiency, especially fuel efficiency.
Increasing the wing area can be in general done by:

- Enlargement or extension of the attached trailing edge flaps, e.g. in depth or chordlength, Bearbas 123. The disadvantage of this is, that in reality the wing area can only be increased to a very limited extent.
- New wing
- Modified wing tip devices, with more span and/or depth, which increase the wing area in normal projection along the z-axis of the aircraft.
- Folding wing at the ends
- Rotating wings at the ends

5.5 New Technologies of the SA-Aircraft Bearbas 123 XXLR

The new version will be based on the Bearbas 123 LRX and will have following known technologies installed:

- Installation of additional fixed fuselage fuel tanks for fuel amounts to enable long range and intercontinental missions.
- Two bought-in, more fuel-saving, turbofan engines (will be considered with additional weight but not with fuel savings due to the engines – the fuel savings of the engine have to be added on top later)
- a just single-slotted flap at the trailing edge of its wings

The new Bearbas 123 XXLR will have additionally furthermore the following modifications/ changes made, respectively the following technologies installed:

- 4 TC Thrust Crowns installed, in the core and in the by-pass ducts in the exit-area of both engines
- “Removal” of the fishlets and span enlargement to 41,1 m, here in a shape, similar to raked wingtips. This modification leads to an increased wing area of 135,5m^2. This is an increase in wing area of +10%, compared to the former wing area of 128m^2. This modification leads to an increased wing aspect ratio of 12,47. This is an increase of +25% compared to the former wing ratio of the long-range version with wing aspect ratio 10,0. As can be seen in table 5, the new span

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of 41,1 m equals the span of the DoIng 575-200 W, for where airports worldwide are adjusted for, in handling.

- As the previous described wing changes would demand to cut the original wing of the reference aircraft - on a more inner and inbord spanwise position – compared to, when winglets or wingtips are installed, as aconsequemce, a new wing should be designed, which ist aerodynamically optimized. This includes an optimal spanwise lift distribution for supporting a low induced drag at relative high C_L of the aircraft, which occur in cruise flight at higher weights in long range operation with much fuel onboard. By this it will further enhance the Oswald factor e, to raise from former 0,69 to now 0,78, which reflects the optimized lift distribution quality along the wing. Furthermore the wing (outside the fuselage) will be realized in weight-saving CFRP Carbon Fiber Reinforced Plastics, as it is common and known from long-range widebody aircraft.
- A system, which can lower the inside cabin pressure in cruise selectively dependend on altitude of the aircraft. By that it can fly higher than present ceiling e.g. 39800 ft , here 41800 ft. The maximum differential pressure (what structurally counts) is than not exceeded in higher cruising altitudes. Instead the inside cabin pressure can be reduced. This does not touch the comfort level because normal inside cabin pressure is normally 8000 ft, on Bearbas private jets version the pressure is increased to 6400 ft (with cycle number lowered), on Bearbas XLR it is already increased (the pressure) to 6000ft in FL 330, like on Streamliner and on Fairbus X53, both 6000 ft, while on Fairbus 330 ONE it is increased to 7000ft. That means, that the Bearbas XXLR can fly in 41 800 ft even with higher inside cabin pressure than root Bearbas 321, thus higher comfort level, while Cabin differential pressure is not exceeded. Inside Cabin pressure would be slightly lower for this Bearbas 321 XXLR in 41 800 ft compared to the 6000ft pressure for Bearbas XLR in 33 000 ft, but in spite the comfort level (and pressure) inside is higher in the ceiling Altitude of 41 800 ft for Bearbas 321 XXLR than in most of all aircraft worldwide.

The new SA-Aircraft version Bearbas 123 XXLR will however not be equipped with an additional hybrid-electric propulsion systems, as it was previously being thought. The former idea was, to install two E-Fans, one in each turbofan engine in the core exit duct, to apply additional thrust, just in short time, and on demand, only for step-climbs to higher, thus increased flight altitudes, to fly there locally under more favourable fuel-saving conditions. From an aircraft perspective the idea behind is, to guarantee the same amount of required or wished Specific Excess Power SEP, even in higher cruise altitudes, where could be flown up in enhances fuel saving conditions, for efficient long range operations. The idea behind was to higher the TOC Top of climb - for the existing engines - for long-range operations at higher weight and with extended wing area. Normally an extended wing area means more aerodynamic drag. Therfore the installed cruise thrust on same TOC has to be increaed in parallel. For higher TOC it has to be increased even higher. But it was found out, in this research at this aircraft, that due to the wing extension by raked wingtips, wing area could be increased and at the same time lift dependend induced drag could be significantly lowered, which leads to lower overal aerodynamic drag in cruise flight, even lower in higher altitude. That is why no thrust increase showed in this case to be necessary at all, even with higher weight and in heigher altitude. That is why no hybrid electric propulsion system was installed in this exemplary aircraft.

However on different aircraft it could be differnt, so, that hybrid electric propulsions systems make sense.

Weight deltas due to modifications and fuel needed in TOW for components	Weight delta	remark
CFRP-Wings outside fuselage without wing tip extension (spanwise)	Change in weight due to material and new design -1600 kg	16% lighter due to wing made on CFRP
Wing tip extension to 41,1m	+ 900 kg	Made in CFRP, remark: fishlets with bended span extension around + 5 m showed + 680 kg
4 Thrust Crowns with mountings	+ 680 kg	Potential to save half of the weight
Furthermore fuel saved in mission, not to be taken on board	-1580 kg	Iterative calculation with programme
Final weight delta mission in TOW	Around – 1600 kg less	

Table 2: Weight deltas of the Bearbus 123 XXLR for TOW due to modifications and fuel saved - compared to the two reference aircraft

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For the Bearbas 123 XXLR, in this case, the wing area is increased and extended by raked wingtips. Unlike winglets, which lower the drag of the aircraft but do not increase the wing area, raked wingtips do. They therefore increase the wing area and reduce the induced drag of the airplane via an increased aspect ratio of the airfoil and via an improved lift distribution along the span.
So in the closer research and examination it has come out, that the special describes geometrical wing adaptions lead not just to 10% more lift, to lift the long-range aircraft in higher cruise altitudes at high long range weights, but at the same time, by these modifications, the aerodynamic drag is significantly enhanced to lower values, which influences the overall drag of the aircraft in cruise in such favourable a way, that even with the previous and installed engines, enough thrust could be provided, to operate there in high altitudes of low densities. So as a result no additional thrust is needed and therefore, at least in this special present case and mission, no additional electric E-fan as hybrid-electric attribute propulsion system is needed. This could be different in other mission or aircraft (including widebodies) or various combinations of both of them.
For the Bearbas 123 XXLR, in this case, the wing area is increased and extended by raked wingtips. Unlike winglets, which lower the drag of the aircraft but do not increase the wing area, raked wingtips do. They therefore increase the wing area and reduce the induced drag of the airplane via an increased aspect ratio of the airfoil and via an improved lift distribution along the span.

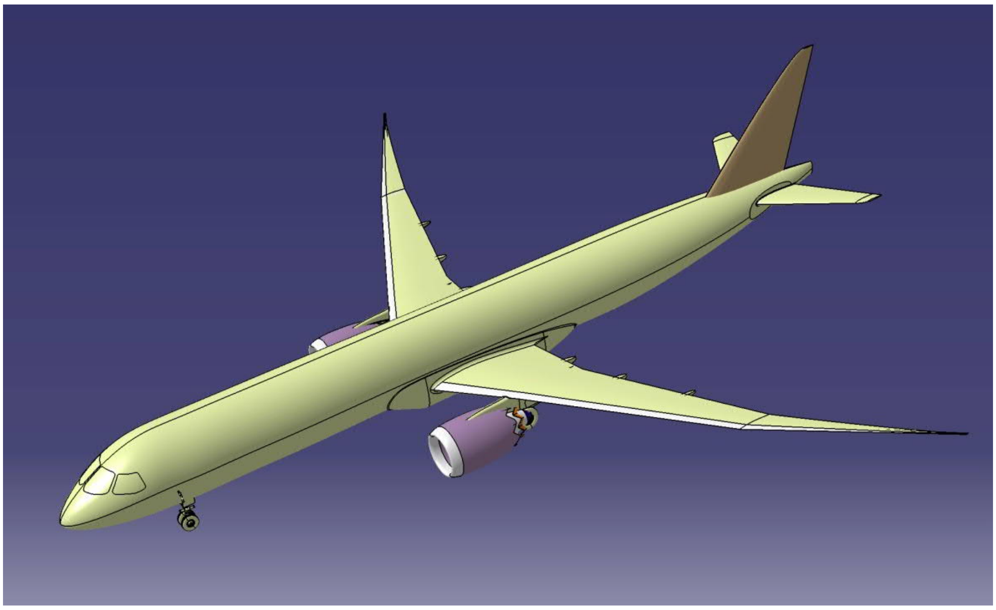

Figure 27: Bearbas 123 XXLR features wing area increase by wing tip devices in “raked wing tip manner” by +10 % whereby they at the same time lower significantly induced drag, thus generating lower overall drag in cruise flight, wherby the increased wing area enables higher cruising altitudes with lower fuel burn

5.6 “Approach” for calculation of this this Long Range Mission

The calculation is done in/for cruise flight. For better representing this certain mission a point is picked, where the different aircraft versions have already been 4,1 h in cruise flight and around 4,5 h airborne in the air. In this point the Bearbus XXLR has already consumed about -10 300 kg of kerosene (climb to initial and maximum cruising altitude took 3300 kg fuel), 7250 kg fuel is left for the ongoing flight and additionally 3 tons of reserve. The weight in flight at this point is very close to 75 000 kg.

Table 3: Payload on board of this exemplary log range mission from Paris to Washington, representative for present offered Single-aisle flights, e.g. from London to New York

Payload, kg	PAX	Weight per Pax	Weight
Eco	90	115	10350
Business Suites	24	150	3600
Cargo			2700
Total			16650

With these insights of this point in cruise mission, the performance can be estimated for the complete mission. In points later in time as the present point in time and space, examined as a representative of the mission, the aircraft

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will be lighter, therefore flying on a more advanteous lift coefficient C_L, which means less lift-dependend drag. For the rest of the mission the aircraft will be therefore even more fuel-efficient. The descend happens normally -gliding with the engines in idle. It takes about 30 to 40 minutes. Because of idle the fuel consumption is neglectable in the light of and compared to a 8,5 to 9h mission. Same is valid for the approach phase regarding time with less than 10 minutes.
For all the flight before the chosen point of monitoring, the aircraft is heavier and consumes more fuel, because of higher weight (due to unconsumed fuel), thus higher lift coefficient and increased lift-dependend drag.

For the flight stages in cruise flight before and after the monitored point in space and time, it is assumed that they compensate each other in best manner. That is why the monitoring – point is even before the middle of the mission in time and range. Climb and lift-up to cruising altitude takes a litte more than 30 minutes and is considered by a fuel amount of 3300 kg. As a result the point in time and space is representative for the cruise flight and cruise flight mission and allows to give estimates for the fuel consumption from take of to landing.

The take- off in Paris happen at TOW of 85 300 kg. On board there are 90 Pax in economy and 24 Pax in individual business suites. These is a representative configuration, like it is flown in typically advanced Single-aisle aircraft in transatlantic missions, like Jet Clue, or on shorter routes like London New-York and Paris New York. The majority of the passengers should be originating from the destination. That is why a slightly higher mass is calculated for their bodies plus luggage. On asian missions the weight of the luggage could be significantly lighter, except flights originating or with destination to/out of India.
Besides there is some cargo on board. This should be spare parts on rush for (turbofan engines of) present single-aisle airliners, which should be distributed by a spare part center nearby Washington D.C in Virginia.

Because of the relative low number of passengers less steward(esses) are needed, which means less weight in terms of OEW. However the OEW was not adapted, which hints, that in real even less fuel could be needed. The whole calculation furthermore contain some more conservative points and assumptions, where eventually increased fuel savings appear possible.

New Span in m	41,10
Delta Wing Area m2	12,66
Ratio Wing Area	1,10
New Wing Area m2	135,26
New Wing Aspect Ratio	12,49
Ratio Aspect Ratio old to new	1,32

Table 4: New Wing parameters of the Bearbas 123 XXLR compared to the root version Bearbas 123. Wing aspect ratio it increased by a factor of 1,32.

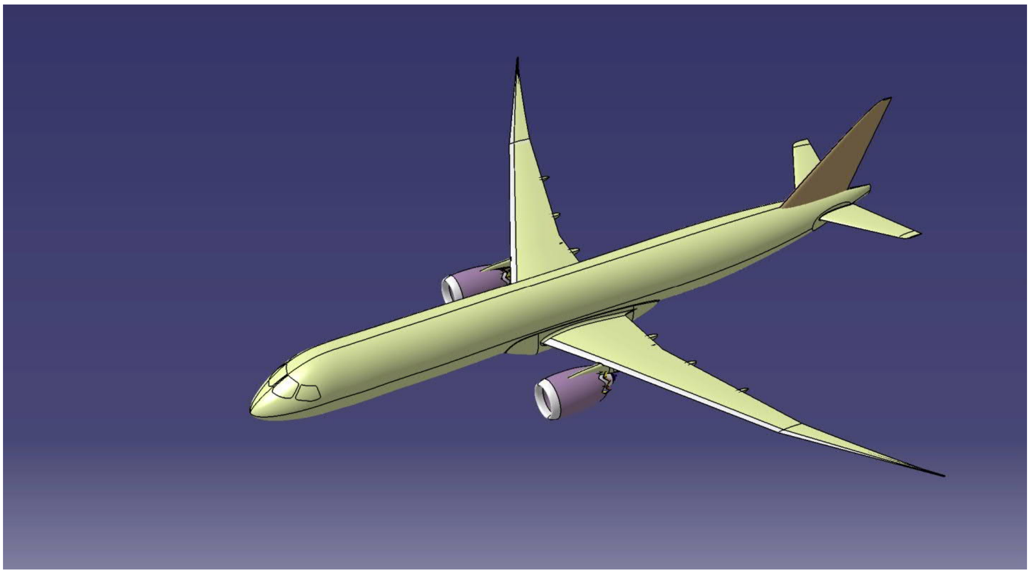

Figure 28: Bearbas 123 XXLR with modified wing ans Thrust Crowns at engines

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	DoIng 575-200 W	Bearbas 123	Bearbas 123 LRX	Bearbas 123 XXL
Maximunm Take-Off Weight tons	99,8	93,5	101,0	101,0
Factor to stear the cruise flight weight to comparable values	0,752	0,802	0,743	0,743
Cruise weight in tons	75,0	75,0	75,0	75,0
Wing Area in m2	181,3	122,6	128,0	135,5
CA 39800 ft with density 0,304471	0,505	0,746	0,715	0,676
CA 40800 ft with density 0,290183	0,555	0,820	0,786	0,743
Maximum Wing Loading kg/m2	550,6	762,6	789,1	745,6
Wing Loading kg/m2	414,0	611,6	586,3	553,6
Range of order in nm	3915,0	3200,0	4697	around 5496
Maximum cruising altitude ft	43000,0	39800,0	39800,0	41800,0
Span in m	41,1	34,1	35,8	41,1
Wing Aspect Ratio	9,320	9,485	10,013	12,470
Zero Drag Coefficient	0,017	0,027	0,027	0,027
k for cruise clean configuration	0,049	0,035	0,031	0,024
Induced Drag Coefficient 39800 ft with density 0,304471	0,012	0,020	0,016	0,011
Induced Drag Coefficient 41800 ft with density 0,2777	0,015	0,024	0,019	0,013
Ma	0,78			
a in m/s	294,63			
V Cruise m/s	229,81			
Dynamic Pressure N/m2 39800 ft with density 0,304471	8039,79			
Dynamic Pressure N/m2 41800 ft with density 0,2777	7314,39			
Zero Drag N 39800 ft with density 0,304471	25123,8	26597,5	27769,0	29387,4
Zero Drag N 41800 ft with density 0,2777	22857,0			26736,0
Induced Drag N 39800 ft with density 0,304471	18086,6	19255,7	16446,7	11880,4
Induced Drag N 41800 ft with density 0,2777	19880,3			13058,6
Overall Drag N 39800 ft with density 0,304471	43210,4	45853,3	44215,8	41267,9
Overall Drag N 41800 ft with density 0,2777	42737,3			39794,6

Table 5: In Cruise aerodynamic flight performance as an estimate, values have been rounded, not all digits shown

The table is focused on aerodynamics without engine effects. Engine effects have to be added on top, e.g. the equipment with fuel saving (geared) turbofan engines, for example ONEs (which will be done later for comparison with Bearbas 123 root), which presently reach up to 15% less fuel on missions. In cruise flight it could be even more. In the future it might be even more. However weight decrease is already considered with advanced engines installed.

Same applies to the effect of the installation of thrust crowns. They have not been considered in this table and the effects of thrust crowns have to eadded later on top (which is done in the following).

Important: In the table for Bearbas 123 LRX the k factor is influenced to reach **-** 4% fuel savings on aircraft level due to the installation of fishlets.

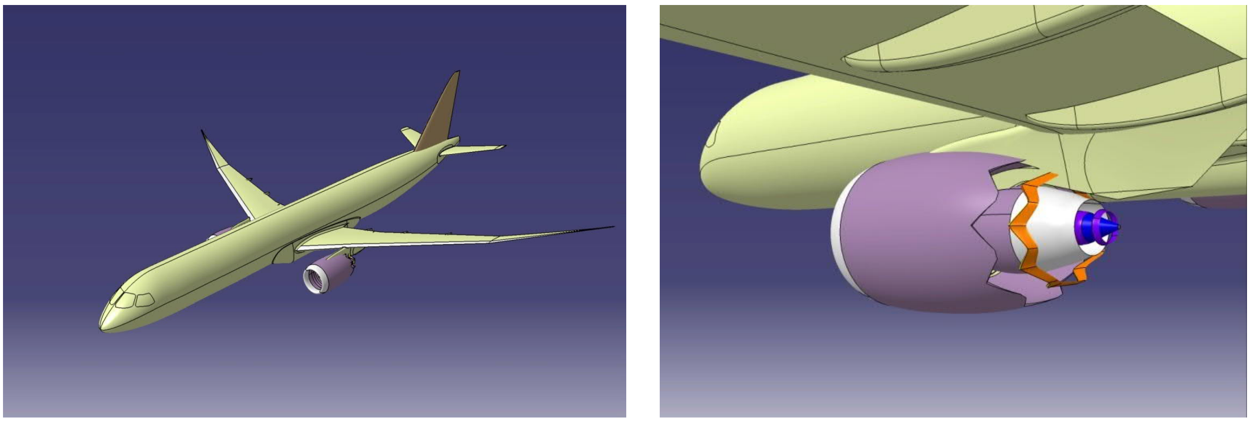

Figure 2 , 30: Bearbas 123 XXLR with modified wing in raked-tiü manner and Thrust Crowns installed at engines

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5.7 Results of the new version Bearbus XXLR on this Long Range Mission

The Bearbus XXLR in this mission with its moderate take-off weight can directly climb to its maximum ceiling of 41800 ft. The maximum ceiling is increased, compared to the reference aircraft, which has 39800 ft as maximum ceiling (some of its smaller and lighter family members could be modified to at least 40000ft).
No further steps climbs are needed until the end of the cruise flight for the Bearbus XXLR on the mission from Paris to Wahington, as it can directly climb in this mission to the modified maximum cruising altitude.

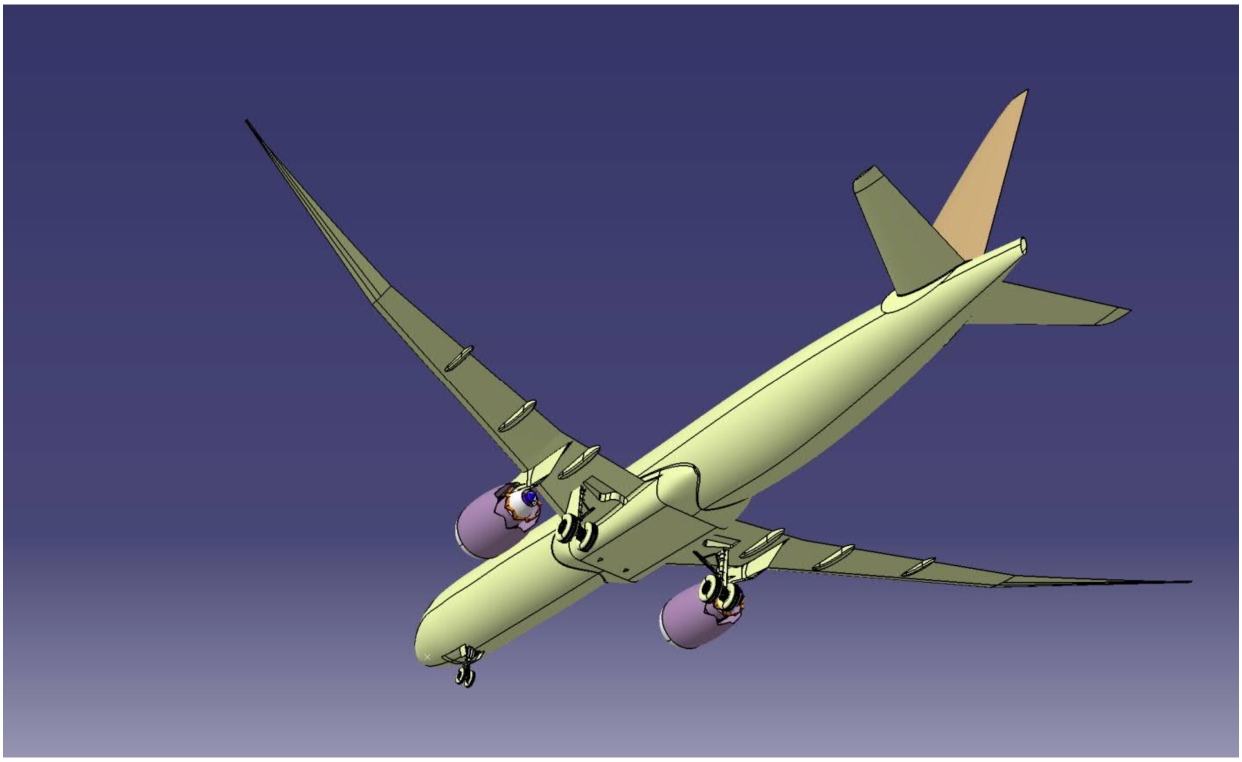

Figure 31: By the increased wing area it gets possible to climb in higher intitial and maximum cruising altitudes with less air density and lower drag, thus more fuel efficiency

Regarding climb performance the Bearbus XXLR can climb with 99 tons flight weight directly to a cruising altitude of 39800ft. Reference aircraft are told to manage to lift up 90 tons directly on 39800 ft.

The Bearbus XXLR can lift up 90 tons directly to the ceiling of 41800 ft.

Regarding cruise performance the following results can be stated:

On same cruise altitude of 39800 ft:

On same altitude the new wings with 10% increased wing area and significantly increased wing aspect ratio on the Bearbus XXLR, featuring a span of 41,1 m like the DoIng 575-200 W first leads to 6,8% less fuel consumption per hour on this mission, compared to the Bearbus LRX with fishlets.

Compared to root plane Bearbas 123(without major wing tip devices) it is 10% less fuel needed, only because of that.

Fuel savings of Bearbus XXLR due to new shaped wing in raked-wing tips manner on same cruise flight altitude in cruise flight	Compared to Bearbus 123 LRX (including fishlets)	Compared to Bearbus 123 (Root)
	- 6,8%	-10,0 %

Table 6: Fuel savings of Bearbus XXLR due to new shaped wing in raked-wing tips manner on same cruise flight altitude in cruise flight compared to reference airplanes

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The new extended wing on the Bearbus XXLR, shaped in raked wing tip manner, more and less being straight present in the wing plane in projection, increases the wing area by +10% unless like the fishlets on the reference plane, which are horizontally bended up, thus they do not significantly increase the wing area.
As a result the Bearbus XXLR on same flight weight can fly with this increased wing area higher, namely on an altitude higher, which is 10% less in air desity (for same speed and Ma, whereby Ma depend on altitude and above 11 km temperature and therefore Ma number is constant). In higher altitudes flights in more fuel saving conditions can be made.

Regarding the ceiling of the aircraft the Bearbus XXLR can fly minimum 2000 ft higher.

This flying in high altitude -because of the increased wing area - accounts for additional more - 3,6 % better fuel performance. The Bearbus XXLR flies then in 41800 ft compared to the reference airplanes which manages 39800 ft on maximum. The Bearbus XXLR flies this whole mission in cruise in 41800 ft. It can directly climb to this altitude.
As the change in air density happens exponentially in altitude, on lower flying altitudes around FL 230 and 250 this means around 2700 ft higher flight altitude, possible with the Bearbas 123 XXLR.
Altogether the flight altitude, including the initial flight altitude ICA, on the whole mission can be minimum 2000 ft higher with the new version, the Bearbus XXLR.

Fuel savings of Bearbus XXLR due to increased wing area with effect of higher cruising altitude possible, enabled by the wing tip extension, here for cruise flight	Compared to Bearbus 123 LRX (including fishlets)	Compared to Bearbus 123 (Root)
	- 3,6 %P	- 3,6 %P

Table 7: Fuel savings of Bearbus XXLR with effect of higher cruising altitude, due to new shaped wing in raked-wing tips manner, they enable, for cruise flight - %P percentive points

As on long range mission the 36 m span box for aircraft handling on the ground does not play a big role in air for cruise flight. Ground handling of a Doing 575-200 W plane with 41,1 m is worldwide common, including most smaller airport with that runway capability for LR operations As a consequence span was increased to the Doing 575-200 W span of 41,1 m. In other words Paris Charles de Gaulle and Washington Dulles International airport can both handle a plane with DoIng 575 W span, as well as many other airports worldwide, namely most.

For long range cruise the 36 m wing span limit it not the factor, but for fuel savings in mission- more-than-dominant cruise flight the increased span is the factor, which plays a major role.

As is explained the aircraft will be equipped with 4 TC Thrust Crown in core and in by-pass ducts of each of the both engines. This gives another 3% less fuel savings in cruise flight, which can be added on top.

Fuel savings in cruise of Bearbus XXLR due to TC Thrust Crowns in core and by-pass streams of engines	Compared to Bearbus 123 LRX (including fishlets)	Compared to Bearbus 123 (Root)
	- 3,0 %P	- 3,0 %P

Table 8: Fuel savings of the Bearbus XXLR due to TC Thrust Crowns in core and by-pass streams of engines, compared to reference airplanes - thrust crown effects

The fuel savings of the past tables can be added for the total fuel savings in cruise flight of:

Overall Fuel savings of Bearbus XXLR due to new wing installed and four TC retrofitted on engines, in cruise flight	Compared to Bearbus 123 LRX (including fishlets)	Compared to Bearbus 123 (Root)
	- 6,8% - 3,6%P - 3,0%P	- 10,0% - 3,6%P - 3,0%P
Additional effects of more fuel saving (geared) turbofan engines in cruise flight Pure engine effects	None, as both the Bearbus XXLR and the Bearbus LRX have these engines installed – thus no difference to each other	- 15%P
Total fuel savings for cruise flight	**- 13,4 %**	**- 31,6 %**

Table 9: Final Fuel savings of the new version Bearbus XXLR in cruise, compared to reference airplanes

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So far the fuel savings for cruise flight have been calculated.

Even more interesting are the total fuel mission savings in the Long Range mission from Paris to Washington. Estimated fuel savings for the Long Range Mission

The final fuel savings for the mission can be calculated like in the following:

The fuel saving due to higher aspect ratio is effective in aerodynamics during the whole time of the mission.
The fuel savings due to the thrust crown are effective the whole time of the mission (including climb), except descend, as thrust is then in idle. Descend time is half an hour.
The fuel saving due to higher wing area is effective the whole time of cruise flight. Cruise flight time is 7,5 hours. Total flight times is about 8,5 to 9h.

	Compared to Bearbus 123 LRX (including fishlets)	Compared to Bearbus 123 (Root)
Fuel savings of Bearbus XXLR due to new shaped wing in raked-wing tips manner on same cruise flight altitude for the mission	- 6,8 % effective all over the mission	- 10,0% effective all over the mission
Fuel savings of Bearbus XXLR due to new shaped wing in raked-wing tips manner and with effect of higher cruising altitude, they enable, here for mission	- 3,6 % multiplied by 7,5h/8,5h	- 3,6 % multiplied by 7,5/8,5
Fuel savings in mission of Bearbus XXLR due to TC Thrust Crowns in core and by-pass streams	-3,0 %P multiplied by 8,0h/8,5h	-3,0 %P multiplied by 8,0/8,5
Additional Effects of more modern (geared) turbofan engines installed	None, as both the Bearbus XXLR and the Bearbus LRX have these engines installed – thus no difference to each other	- 15%P effective all over the mission
Overall Long Range Mission Estimate on global fuel Savings for mission fuel used in flight of Bearbus XXLR	**- 12,2 %**	**- 30,5 %**

Table 10: Final Estimated Fuel savings of fuel used of the new version Bearbus XXLR for the long range mission from Paris to Washington, compared to reference airplanes (it is assumed that the core version can fly this mission)

These values, could be even better. Not all positive snow ball effects have been (so far) considered. One additional reason is:

Flying below roughly 11 km altitude is very fuel-expensive, an altitude sensitive, because temperature gradient with altitude is around - 6,5 degree per 1 km height, while above 11 km temperature is stable, thus Ma number, too. The Bearbus XXLR can fly 2700 ft higher in this regimes, it can climb faster. Fuel savings are even higher in this altitude regimes. Besides effect of thrust crown during climb might be also positively higher than in cruise flight.

Besides, some positive side effects, take-off length is better due to higher wing area. Climb angle and Climb performance, including OEI, is better due to higher wing area and better glide ratio. This lowers noise footprint during take-off and initial climb. Landing field length is better due to higher wing area, at least, if traffic situations allow to approach with lower speed (smaller than 140 kts), which could be possible at many smaller airports.

Finally it should be said that airlines should actively demand for these technologies, otherwise they would not come. Therefore they should gain skilled engineers to boost their fleet efficiency- independently working and calculating, apart from manufacturers. It can be also possible to make own Supplementary Type Certificates for their own fleets. In this context they should not rely on engine and aircraft manufacturer, because experience has shown, that they sell their decade-old technologies for further decades, without any significant improvement, apart from their income in money, they forgot about their responsibility.

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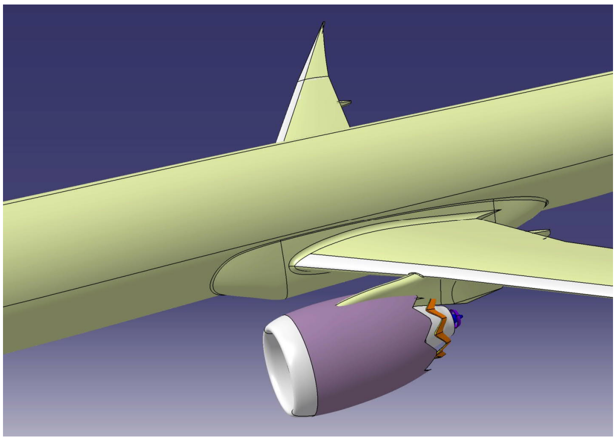

Figure 32: " More modern (geared) turbofan engines are in place on Bearbas 123 XXLR and on reference aircraft Bearbas 123 LRX

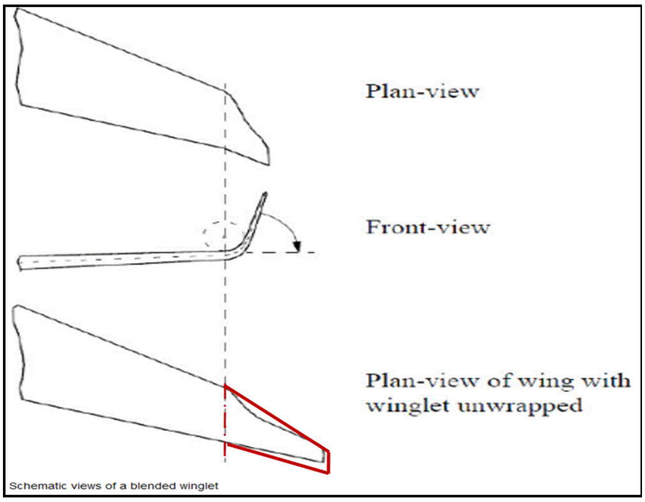

Figure 33: Span extension in a "raked-wing tip" manner leads to a significantly enlarged wing area in contrast to winglets, which are bended up, whereby first helps to boost significantly long range (fuel) performance

Second it is amended, that regarding cars, a long time, it was thought, also by professionals, that electric drive is only possible on smaller and lighter car, due to battery weight – e.g. lighter than plying Polo.
Now situation has changed, turned out to be different in reality, due to experience. There are huge and heavy cars (SUV and SUV+), which are sometimes called E-tanks, which can take a lot off battery weight.
Regarding airliners these thought can help. Now it is thought, electric and hybrid-electric propulsion only works on light and small planes. But flying with widebodies, which offers high payload and volume, can be the chance/ the clue.
In Japan there is high demand in passenger numbers for domestic flights, which mostly takes place in widebodies, on shorter routes, e.g. Air Queen and Triple Heaven, for domestic flights. Why not fly this short flights electric or hybrid electric with many passengers on widebodies.
The engine architecture, described in this paper, like E-fan, can now allow this, especially to add electric thrust to a well chosen and flexible extent, even depending/varying on certain flight stages. For people interested - the attention should be drawn to these hybrid electric Airbus A340-600, which appeared in this diploma thesis as technically possible and can be modified to short and medium range with the help of the engine architecture, described above, please see the following reference for further information – for well thought combination with this paper.

Third, a short summary is to be found in the beginning of the paper.

References

[1] Performance assessment of a hybrid electric-powered long-range commercial, Bachelor thesis 01 Jan 2012, English, KTH Stockholm and TU Munich, Zöld, Thomas, [Link looks strange but works] *https://www.diva-portal.org/smash/get/diva2:612190/FULLTEXT01.pdf*

Illustrations of this paper show an exemplary Single Aisle aircraft version with extended span up to nearly 52 m, which is the limit of the next box IV with span limit 171 ft (category for ground handling of aircraft). For this version fuel savings are even higher and according to first calculations are in the order of 25 % compared to the reference aircraft Bearbas 123 XLR in cruise.
This leads to the hint that a DoIng 575 (200/300) ONE aircraft with new CFRP wings with increased span and area (e.g. in raked wing tip manner) and thrust crowns installed, would probably deliver a competitive fuel performance with very high fuel savings, even with existing engines.

Bearbases 123 with extended span in 'raked-wing-tip manner' will boost fuel performance, as shown in this research.

This present paper has been written with 100% percentage climate-neutral electric power from wind turbines, with electricity of neutral colour.