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A Climate-Friendly Future Single-Aisle Airliner for Europe

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Abstract

Various versions of a 174 seated SA-aircraft, commonly named Climatfly, feature distributed hybrid electrical propulsion, with here 44 (+2) electric motors, in a central arrangement and, like present SA-aircraft,with three combustion engines. This leads to energy and power savings of the aircraft of 30-34%, minimum 35% per seat, independent from the fuel, bc the fuel is saved. Regarding global warming and climate-effective emissions, dependent on the specific version and implemented technology, they reach 34 -56 % less* CO_2 emissions, less* H_2O water vapour emissions and at least 30–34% less* NOx emissions. If hydrogen is used, according to the version, the hydrogen need is lowered by more than 76% compared to a conventional kerosene powered ACARE 2000 reference aircraft* changed to full liquid-hydrogen propulsion. The technologies can be applied selectively on a modular platform for future SA-family-aircraft, no matter, which fuel(s) used, as well as adapted to Longe Range aircraft and present existing aircraft, as, at least partly retrofit solutions, for a better climate and world.

1. Introduction

Our planet demands for a healthy climate with less climate-effective CO_2 , H_2O and NOx emissions to protect ourselves and our kids as inhabitants.
Out there are around 40 000 commercial airliners and much more to come in the future. Every day and night they deliver emissions to the earth's atmosphere, on a significant scale. Especially CO_2 and NO_X emissions, contribute to climate effects by global warming.
Every kilo fuel in terms of conventional kerosene burnt leads to 3,415 kg CO_2 emissions.

The global need for a climate-friendly future airliner has been still unanswered.

Designing seriously a real environmentally friendly and therefore - at the same time fuel and therefore cost-effective airliner - from a perspective of aircraft design is much more difficult than present politicians think, but much more easier than aircraft manufacturers managers, would think.

Efforts are welcome, however present shown ZERO aircraft would not work in terms of zero emissions [1,with h-link]. In this terms Zero emission only works on paper, picture and renderings, spread by unaware media, and accepted by unaware clients, hopefully not by unaware scientists.

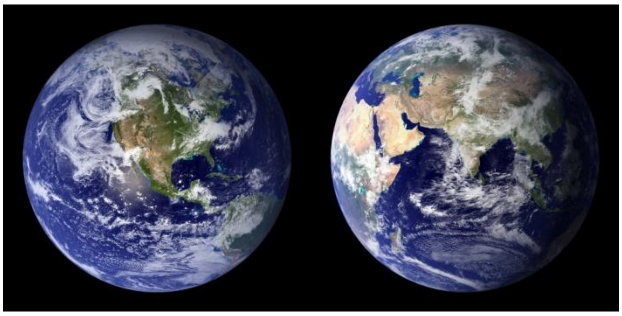

Figure 1: "Our" planet host approx. 6-7 milliards inhabitants and 40000 commercial airliners, which fly for them, (many of them SA-airliners)

Under experts it is known hat present zero emission aircraft, shown, are not zero emission aircraft. In total climate effective emission effects of these shown aircraft would account for approximately 50 % of the climate effects of present aircraft with old technology. That would make these aircrafts SIX ZERO aircraft, or FOUR ZERO aircraft at best. [1,with h-link]
Under certain experts is known, that some of the present shown ZERO emission aircraft, although they are shown by really fantastic renderings, raise at least technical doubts or serious design questions, leading to the question, if they are completely serious meant, as future implications [1,with h-link].

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The subject is serious enough to be re-thought, in terms of aircraft concepts, as well as, in terms of availability of aviation fuel. This to do, is our common responsibly.

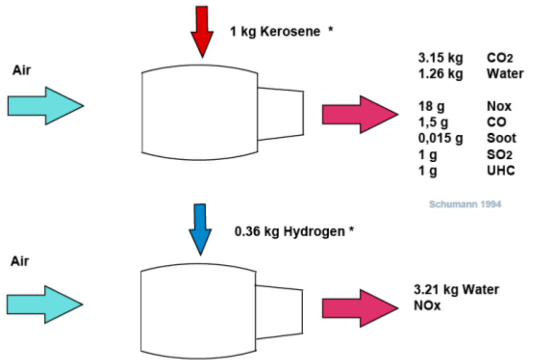

Figure 2

Hydrogen can help to lower climate effects by approximately 50%, for non-propeller airliner. Non propeller-airliner means airliners with pressurized cabins at turbofan flight altitudes and speeds.

A competitive effect, up to - 70% less climate impact, can be reached - by, just flying lower in altitude, with and by the present airliners of old and conventional kerosene technology, meaning by a simple operation adjustment [1,with h-link].

In real, flying lower by altitude, with the present airliners of old and conventional kerosene technology would have immediately a climate-effective positive effect, A hydrogen partly propelled research airliner, which was the Russian TU, was already operated in early years, leading to the Cryoplane project, where in that times the German Airbus Division took part in [1,with h-link]
.
Waiting for full hydrogen-powered non-propeller airliners will take long in time, supposing around 20 further years from now (20222) – this, for non-propeller airliners in commercial operation. This will last until the year 2042. The reason is easy, because designing seriously a new airliner takes 7 – 8 years for an airliner of conventional proven technology. Building the manufacturing sites and streets, flight and operation testing and certification, as well as entering mass production (ramp up) accounts for at least 5 more years. On top comes the delay in time, recent airliner programs show on a regular basis (e.g. Dreamliner, 737MAX, 777X etc.), which accounts for at least a couple of additional years, for conventional and proven technology. It is improbable, that not for new technologies, these years will lower in number.

20 further years from now, until the year 2042, with nearly no relevant positive climate-effects at all, to wait for the full hydrogen powered, non-propeller airliners, would result in a positive climate-effect of around 0, in word ZERO. The number ZERO however, as a number, is a poor result, in this relation. It is questionable, if we can afford that as humankind.

Asking our future childs and generations would maybe result in a clear answer.

For a better world, in real, flying lower by altitude, with the present airliners of old and conventional kerosene technology would have a climate-effective positive effect immediately and over this 20 years span, which is a lot of times greater than ZERO . The described impact would be in reality even much higher than ZERO, because ten-thousands of additional conventional aircraft are expected to enter in service in this time period.

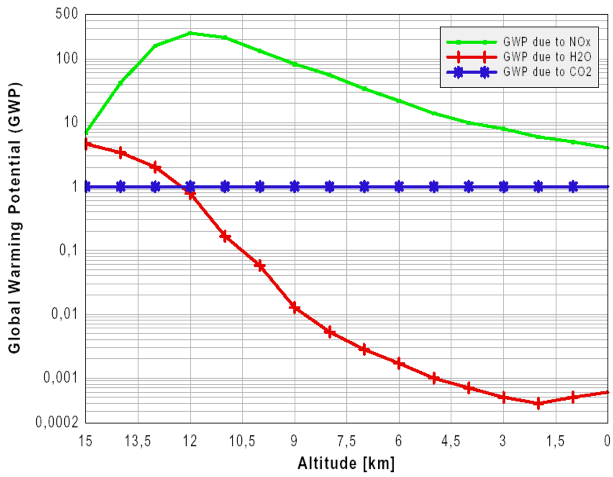

Figure 3: Due to impact on climate, cruising flight altitude is chosen to be 11000m, illustration, source: Airbus Internal Info

As a second major point the availability of aviation fuel has to be clearly discussed, because without fuel, only sailplanes fly.
It could be, that there is enough fuel in terms of hydrogen - from amount to fly - for the couple of full hydrogen propelled non-propeller airliner, which could physically exist in 20 years from now, in that future time, and for the propeller airliners on hydrogen.
It is very questionable, if there is on top, enough fuel in terms of hydrogen left, to feed airliners in Europe on a broad basis, so that they can provide a network over Europe.

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Generation of hydrogen, especially liquid hydrogen - by liquidation is very energy-demanding. At least today is not clear, where all this primary energy should come from. On top it is not clear, where it should come from as a CO_2 neutral source and production.

Hydrogen also needs a complete infrastructure regarding generation and distribution to airports and aircraft. At least today is not clear, where this complete infrastructure should come from, especially, if nobody feels responsible for that. Probably it will not appear out of the nothing, although some recent improvement has come to the media.

Because of these described reasons and under clear mental consideration, regarding the future and in the scope of this paper, it will be expected, that hydrogen in the foreseeable future is still in the ramp-up process- regarding broad availability in airports and aviation, and as a consequence is not available for complete 100% feeding of Future Single Aisle Series Aircraft, which will appear, probably also in future, in very high numbers of operating aircraft - thus with a high fuel demand.

A majority of the world's airliners are single-aisle airliners (SA), worldwide, meaning at the same time huge proportions in worldwide emissions.

This paper delivers impulses and inputs for future single-aisle airliner families. This happens on a concept basis within the possible scope of this paper. It provides several independent solution which can be applied single or in combination on smart modular platforms, no matter, which fuel types will later be chosen or used. Thereby it puts emphasis on lowering the overall energy thus power demand of this aircraft, as saved energy does not need fuel at all, no matter which type of fuel, -nor it shows emissions. Several technology showed, can be transferred also to long range aircraft as well to old aircraft, already existing and presently flying, as in-operation, retrofit solutions.

It reflects the current state of research, which is incomplete, but daily improving, without a guarantee, but with a clear appeal to all airlines in this world, to clearly check, with skilled own engineers, which technology is possible in real and to demand for this technology, and new aircraft, for own and common well being, as well as for the worlds's climate.

For doing that five generation of SA-aircraft are considered, two of the present and three of the future. The CEO reflects to the state of the art ACARE 2000 reference Aircraft. The NEO should reach 15% less fuel and energy compared to the reference CEO. Regarding the future versions the NEO^2 (Neo Quadrat, or NEO squared) is a slightly better version of the NEO with better efficiency.
The BW Better world reflects a new generation of SA aircraft on a modular platform which is open for different fuels (kerosene, SAF, liquified natural gas LNG, Liquified hydrogen LH_2, multifuel-use and eventually gaseous hydogen GH_2 (e.g. for APU use)). The Genius Pro is an advanced future SA-aircraft with intensive new technology used. Not all generations are shown in the paper bc of time and paper limitation.

CEO	ACARE state of the art 2000, to be later modified as family	Present Gen.
NEO	state of the art 2019	
NEO^2	Modified state of the art 2019	
OS Old School	New generation, with as much as old technology possible, 2027	Gen. Climatefly
BW Better World	New generation 2032	
GP Genius Pro	New generation 2035	
Table 1		

By physics it is known, that less energy for a certain transport task can be reached by: lower weight, better aerodynamics, higher thermodynamic (inner) efficiency and greater propulsive (outer) efficiency. In Favorite would be a best combination of all of them, which results - -in real in a best feasible compromise.

For benchmarking a reference is needed, which will be formed by the following BeforeBus Single-aisle (SA) aircraft family, which has ACARE 2000 state of technology, also comparable to CESAR reference. The core aircraft family member is the B 023, accompanied by a little sister B 913 and a big brother B 123, regarding payload and seating capability. Some data are given by table 2, further and detailed data in geometrics, dimensions and performance can be found in literature.

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CEO	**B 913**	**B 023** core family member	**B 123**
MTOW	75,5 t	78 t	93,5 t
OEW	40,8 t	42,6 t	48,5
Max Payload	17,7 t	19,9 t	25,3
Thrust	98 -120 kN	98 – 120 kN	133 – 147 kN
Seat 2 class typical	140	150	185
Seat Maximum	160	190	230
Length	33,8 m	38,7	44,5
Diameter Fuselage	4,0 m		
Fan Diameter	1,74 m (deferring from CERAS)		
Table 2			

As a side reference a BeforeBus NEO family is used, which has basically the same data like in the table, but a fan diameter of 2,06 m for the high-bypass bought-in engines and bought-in blended winglets. By mainly this two modifications a fuel savings on standard short range missions for the core member B 023 NEO of 15% should be guaranteed. This results that the OWE for each member is roughly 1,8 t heavier and the maximum payload 1,3 t less.

2 Lower weight

With current (not-future) lightweight design for the core member a weight saving of 5,5t can be reached. The weight savings are deducted in detail from a "current state of the art SA-aircraft (design in the 90s) SC 300, meaning from present reality, an aircraft, which can not be ordered anymore.

By implementing a CFRP wing further weight improvement of around 1000 kg can be archived.

12 years ago it was published that a new SA-aircraft design would lead to 10% weight savings in terms of OWE compared to the old, which would lead to 4,2 t in weight savings. So 5,5 t (or 6,5 t with CFRP wing) seems feasible in the future.

Focused on winglets will be in the following section regarding better aerodynamics.

3 Better Aerodynamics

Better Aerodynamic can be reached by advanced winglets.

Better Aerodynamics, measured by the glide ratio L/D directly transfer to better than proportional to fuel savings in cruise flight. For example an increase in L/D of 6% due to better aerodynamics will at least cause 6% lower fuel demand in cruise. An improvement of aerodynamics by 6% would lead in same to an improvement by 6% in range. With the fuel saved in cruise from weight reached range will be even higher than 6% (without considering additional fuel reserves, which have to be taken by law, depended on the range).

Current state of the art winglets reach 6% fuel improvement on standard shortrange missions in real, already with taking into account the additional weight for a pair of advanced winglets here approximately 950 kg.

3.1 Winglets

It is well known to use winglets at the ends of the wings tips, which generate a forward component in force in the direction of flight under local inflow conditions, reducing the drag of the aircraft.
In aerodynamics, it is common and well known to explain the effect of winglets in terms of pressure and pressure distribution. As one of their effects, winglets intentionally constrain pressure equalization at the wingtips, where the air naturally seeks to equalize pressure, due to the pressure difference between the upper and lower surfaces of the wing, which appears, while generating lift. Mainly winglets alter the spanwise pressure distribution to a more favorable and effective distribution. The adaptation of properly designed winglets therefore results in favorably reduced induced drag.

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In aerodynamics, aerodynamic effects can be described in terms of pressure or in terms of velocity according to Bernoulli's theorem. An explanation of the function of winglets based on velocity can be found, for example, in the book “Flugzeugentwurf” from Blaue Reihe by the author Friedrich Müller.

According to the following illustration, the generation of lift on the wing, which causes a pressure difference in the form of overpressure on the lower surface and underpressure on the upper surface, leads to a cross-span velocity component of the wing u, which superimposes with the flight speed v.

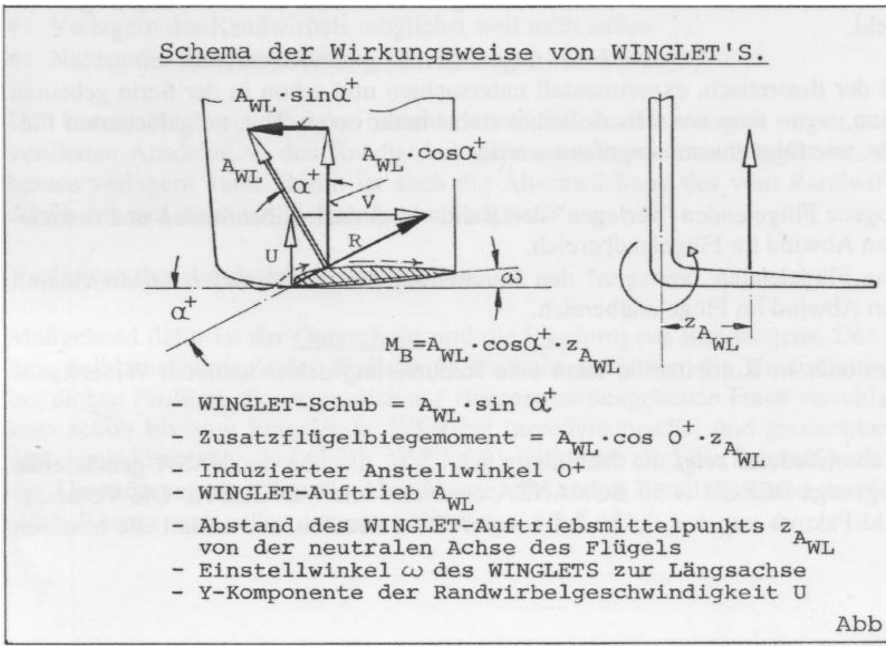

Figure 4: How winglets work: Winglet-Schub = winglet Thrust; Zusatzflügelbiegemoment = additional wing bending moment; induzierter Anstellwinkel = induced angle of attack/incidence; Winglet-Auftrieb = Winglet Lift; next: distance of the center of lift of the winglet from the neutral axis/fibre of the wing, Einstellwinkel... = angle of incidence of the winglet to longitudinal axis; Y component of vortex induced speed u at the tip

This cross-velocity component u is directed outward toward the wing tip on the lower wing surface and in inward direction towards the fuselage on the upper wing surface.
At the same time, of course, the wing in flight encounters the airflow by the velocity of airspeed from the front. Airspeed and crossflow components overlap and form a resulting velocity component V_R on the upper wing surface - as inflow from the outside at the top - and from the inside at the bottom.

Winglets are thus aerodynamically designed and shaped to generate a resultant flow force in a way similar to a mini-wing equipped by airfoils, but as this resultant flow force is inclined forward- meaning in the direction of flight-, it thus contains a force component directed forward in the direction of flight, acting propulsive. Winglets can therefore regarded as static propulsors, mitigating the aircraft drag level in flight.
To generate an aerodynamic flow force - directed forward in the direction of flight -, the winglet must be angularly proper aligned in reference to the incoming airflow. This angular alignment is often named as toe in and toe out. This has to be on the top of the wing to the outside and on the bottom of the wing to the inside.
In summary, winglets, as small airfoils, generate a resultant flow force that contains a forward propulsive component in the direction of flight, leading to a drag-reducing effect on the aircraft. The generation of force is made possible by a local incoming air flow, which is clearly in angle α to the flight direction of the aircraft, meaning in appreciable angle to the direction of flight.

In the light of this insight, the author immediately asked himself:

1.) whether there is also a resultant velocity incoming airflow at other locations of the aircraft in flight, which is clearly in angle to the flight direction of the aircraft, meaning in appreciable angle to the direction of flight.

2.) thus makes the generation of a drag-reducing force in flight by surfaces or fins, seem to be possible.

Question 1 can be clearly answered in the positive. Question 2 seems possible. Although the investigation of this issue is not the subject of this paper, due to its limited volume, only some hints will are given in the following, which originate from the extensive existing investigations of the author.

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For a local thrust effective force generation the aspect ratio of the fins or wings, producing a forward component in force, have to be high, in order to reach a low angle of displacement, of the resulting force, due to induced drag. generated by the fin or wing, in reference to a 90 degree angle, this 90 degree angle, measured to the incoming air flow.

Geometrics 1: A high aspect ratio Λ together with the appropriate angle α of incoming local airflow to the flight direction FD, can enable, the static thrust generations by fins and wings. These are the mandatory first design requirement to be chosen.

A fin, foil or wing in airflow experiences a lift coefficient C_L and a drag coefficient C_D . With help of a symmetric polar C_D can determined by:

$$C_D = C_{D0} + C_{DI} = C_{D0} + \frac{C_L^2}{\pi \Lambda \mathrm{e}} \quad (1)$$

where a glide ratio E can be defined by: $E = \frac{C_L}{C_D}$ (2)

and for most airfoils can be in a first approach regarded as $C_{D0} = 0{,}008$

The incoming air IA flow approaching the fin or wing should be in angle α to the flight direction FD.

The thrust coefficient C_T in flight direction FD can then be expressed by:

$$C_T = C_L \cos\alpha + C_D \sin\alpha = C_L \left(\cos\alpha + \frac{1}{E} sin\alpha\right) \quad (3)$$

Geometrics 2: Whereby the level of force is determined geometrically by the surface area S of the fin or wing.

The flow force in Flight direction is determined by: $F_T = C_T\, q\, S$ (4) $q = \frac{1}{2}\rho V^2$ (5)

Geometrics 3: By 1 and 2 the span b of the wing or fin is determined: $\Lambda = b^2/S$ $b = \sqrt{\Lambda/S}$ (6)

Flight conditions 1: Whereby the level of force is determined additionally by airspeed and flight velocity, like on a normal wing.

$$F_T = C_T\, q\, S \quad (4) \qquad q = \frac{1}{2}\rho V^2 \quad (5)$$

Aerodynamics 1: Whereby the level of force is determined aerodynamically by the the "lift coefficient" C_L. But at least for airliners the applicable lift coefficient is limited by the critical Ma* appearing on the airfoil at high cruising speeds. For airliners in cruise flight near transonic conditions at the wing and winglet is around 0,5 to 0,7, in average C_L=0,6

Aerodynamics 2: If the fin or wing is partly in the boundary layer, the fin or wing can be aerodynamically adapted at least in this spanwise boundary range to the lower velocity and the local airflow incoming constraints due to the boundary layer effects. Secondly a higher lift coefficient can be chosen.

Aerodynamics 3: Choosing at least partly on the fin or wing airfoils with a high negative zero lift angle could eventually at least partly help to substitute a necessary tilt as well as to optimize the fin or wing.

The Fin or wing is placed locally in an environment of airflow of different direction than flight direction. By doing this the fin or wing at same time has an effect on the flow around. This results in the fact that the **applicated** fin or wing must be small in comparison to the body, which distorts the airflow in direction, and which enables the effect of possible static thrust generation.
A main challenge in this design will be to keep the interference drag between fin or wing - and main body small in order not to cancel out the effect of static thrust generation (same as on a winglet design).

A surprise effect is that propulsive force of the fin or wing rises, with flight speed, here for simplicity without considering interference drag.

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This is due to the best lift coefficient can be adjusted by the design of the installation in contrast to the winglet, where the lift coefficient depends first roughly on the lift coefficient of the wing and second alters by angle of attack of the wing, thus flight condition. With winglets at least in initial designs, best values where reached in high C_L levels of the wing, meaning in lower flight speeds e.g. when climbing to cruise altitude or while circling in thermics for sailplanes.

On the other hand the *-lets can be also applied with variable incident angle, meaning e.g. rotatable around an axis e.g. near t/4 of the wing or fin, as rotablets.
The proposed method can be applied potentially on the fuselage as fuselets on the engine as enginlets on the empennage as emplets, and also in the engine as ineginelets, the name regarding to the component the fin or wing is structurally fixed to. It can be also applied on inflows (e.g. appearing in engines, aircondition and cooling) as inflowlets.

Streamlines, especially on swept wings are not straight. The method can be also adapted to the wing as midspanwinglets and to the flap track fairings and as flatrapfairlets. The flap track fairings can be designed (shaped and tilted) to the local airflow according to the same method.

The effect is dependent on the size of the angle of local incoming flow, measured to the direction of flight.
For that fins or wings have to have a low induced drag. Ever lower induced drag can be reaches by equpping the *-lets at the tips by on winglets, making them *-lets^2 (squared) or by installing end plates at one or two of the ends, making them *-lets^e or *-lets^{2e}

An interesting question arises, which minimum angle in flight dircetion is needed for a thrust generation with given geometrics of the fin. Which this “easy” method, as an example for lamda =8 und ca=0,6 is found out by

Readers are encourage to look out when travelling.

Figure 5: the rain protection devices are aligned to local airflow in cruise flight. The present rain protection devices are in angle of 6 degree(left) and 12 degree (right) to the cabin floor level, whereby the cabin floor levels are horizontally aligned in cruise flight. It is really worth to look out for rain protection devices at different aircraft when flying, additionally to the airprobes. The higher right angle is due to the stream angle distortion of the wing by lift generation, which is in the following, here not shown, behind the wing and in the rear of the fuselage, normally a negative angle.

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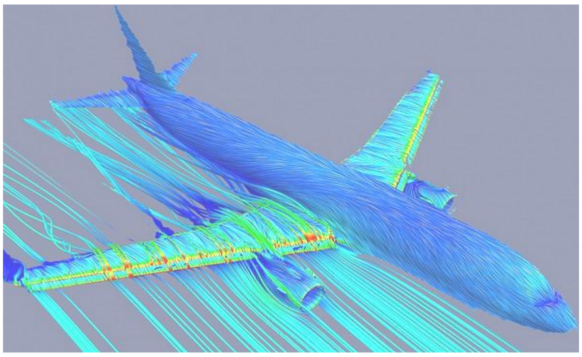

Figure 6: Local airflow, moves as the streamlines, show in, up to significant angle, to flight direction (high lift decives extended), source: DLR with permission from 2018

4 In-Engine-Flowlets

In a deeper consideration an interesting location, which probably one of the highest angle different from flight direction - to appear in flight -, was found, inside the engine, inside the by-pass duct of a turbofan-engine, downstram the fan. In consequence the fin or wings as *-lets where here place as inenginlets, inflowlets, bypasslets and at the same time as *-lets[2e] and finally as rotablets, also enabling apart from thrust generation in flight direction additionally a thrust reverse effect for braking the aircraft by changing the angle of incidence.
They were aligned and tilt –in reference to- to the incoming velocity airflow, -and they are not aligned or tilt-, according to straighten the airstream, leaving the engine.

However they straighten the airstream due to CFD outcomes, so, that it appears not necessary to install additional outlet guide vanes by proper design, which however is additionally possible.

In the following the Engine-Inflowlets should be integrated in a fictive engine of the single-Aisle aircraft, which its named Work Place Gier.

Multiple Engine-Inflowlets are placed in a circular pattern between the hub part, normally containing the primary core duct, and the outer radial casing of the by-pass duct. Their angle of incidence should be capable of being changed by actuators at least collective, e.g. around an axis at the t/4 chord of the fin or wing. Multiple fins could be altered in angle of incidence by a ring, moved by one or more actuators. In that way the fins can be aligned with angle of attack to the direction of the incoming airstream, composed by the rotation of the fan, depended on flight conditions and thrust settings. This angle in operation varies by 20 to 35 degrees.

The angle of a the airstream, leaving the fan, is depended on the forward flight velocity v and the angular rotation speed of the fan ω, more precise, it is mainly depended on the ratio of forward flight speed and angular velocity of the fan ω , which can be also expressed in terms of rpm. As rpm and flight speed V change with thrust settings in reference to different flight conditions, the fins or wing could be adapted in different angles e.g. for different phases of flight moveable.

For take-off run and initial climb, if no derated take-off is chosen, fan runs at highest rpm at relative low forward flight speeds, generating a very low angle alpha downstream the fans, where the fins are now aligned to the incoming airstream from the fan, generating additional thrust for take-off.

For cruise, the permanent allowed thrust level is significantly lower, as for take-off, generating an angle downstream the fan, which is medium, the fins or wings are moved into a right alignment for generating a certain proportion of thrust. This can allow to lower the rpm of the fan or the thrust setting of the engine, allowing altogether lower fuel consumption. This results first in a preferably lower TSFC, and as a second consequence -in a variable TSFC due to fin or wing position. Actuated fins as Multiple Engine- Inflowlets should be connected to dual-channel FADEC, as well as, to the autopilot, FMGS and further avionics. In a certain embodiment they are connect to flight control systems, allowing for example active yaw control in flight by two or more side engines, as well as lift independent air braking.

As a consequence in future - effective empennage areas in surface areas (at least vertical) might be designed less in area, meaning lower drag of the aircraft. This can be done with slight overpowering of overall static Take-off thrust and braking on the healthy side, in engine failures. This to embed is easy bc the following A/C design need remarkable less thrust. Besides for 3 or 4 engine powered airliners climb requirements are lower as for twins.

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At landing the fins or wings could be moved in negative "pitch" for active braking. In another version in control they can close the inlet area in the by-pass duct, causing significantly drag on the engine front, well enough, for braking the aircraft down in the same amount, reached with conventional maximum thrust reserve activation.

They allow to adjust the bypass-duct optimally to the current flight conditions, even in engine failure conditions.

For Future high bypass engines a variable pitch fan rotor was considered for better efficiency. But these rotors are complex and heavy. The installation of these Engine-Inflowlets are much more easier and lightweight. These is because they can be installed on the engine weight-neutral, thus, without contributing to additional weight on the engine or aircraft.

This is because by a rule of thumb half of the weight of the nacelles for turbofan engines comes from the thrust reserve devices (for braking the aircraft on the runway), which are part of the nacelles and included in the nacelles weight. For both CEO engines this makes up 850 kg in total to become free for installation. For nacelles for higher bypass engines at least the same or even more. This works if the thrust reserves takes place in the bypass ducts which is for most modern commercial jet-airliners.

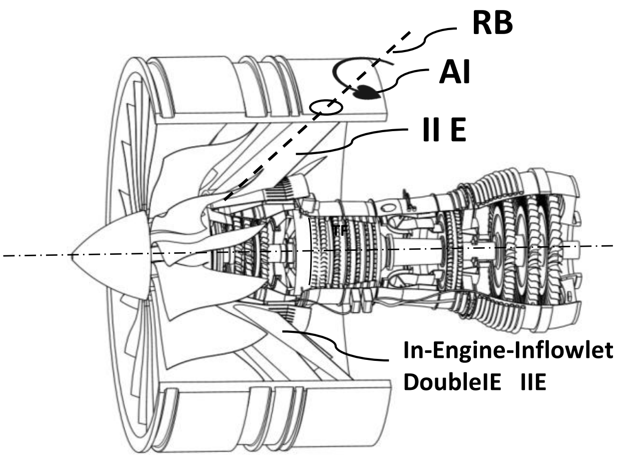

Figure 7

The thrust reserve instead can then happen by the In-Engine-Flowlets, so that no conventional thrust reservers in the nacelles are needed any more.

For the following aircraft designs anyway no thrust reservers are necessary needed in the side engines. It happens just centrally in the rear propulsor. This seems to be a wrong assumption made, for judging the impact of rear propulsors, because with a rear propulsor no thrust reservers are needed any more in the sideboarded engines and two times half of the nacelles weight for twins become available for additional weight for installing in the rear. This is even a lot for long range aircraft.

From safety this seems not to be a point. The A 380 has only two thrust reserve devices only on the inboard engines. If only one thrust reserver ist not operative, the pilots would not apply asymmetrical braking thrust on the runway with only one engine. If a rear propulsor with thrust reserve device fails, it just the same consequence that thrust reserve is not available.

The In-Engine-Flowlets experience different inflow conditions in terms of level of velocity and velocity according to its spanwise radial position. For example the incoming angle α is at In-Engine-Flowlets hubX and on the In-Engine-Flowlets upper end X. That is because the tangential velocity $u = \omega \cdot r$ induced is dependent on radius r of the fan. As a consequence Engine-Inflowlets are by angle of incident, aerodynamically, from geometrics well adapted to the local inflow conditions at the considered cross sections. This leads to spanwise tilt and/ or eventually airfoils to be chosen with different zero-lift angles.

Additionally the can be embodied with swept. This lowers drag of these fins at inflow conditions of higher velocities as well as noise.

It should be now figured of whether and how the Engine- Inflowlets contribute to thrust and efficiency.

To compare the effect of Engine- Inflowlets the basic design in the Work Place Gier should be more closely figured out.

In the engine Work Place Gier there is enough space free available to integrate a plurality of Engine-Inflowlets, even with spatial extension and/or swept back or forward. That is because in this engine there is surprisingly no stator directly downstream the fan integrated, yet, in contrast to other comparable engines of same efficiency and thrust, fan radial extension e. g. a fictive engine Lieb Peak.
This is surprisingly, because a normal stator device directly downstream the fan can, due to various papers, deliver up to 23% additional thrust of fan thrust, at handable noise constraints, which major cruise fuel impact, means savings around 5% in cruise, taking pessure losses, weight and drag into consideration, seems feasible by

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implementing such device, which is presently applied in example engines of same thrust class at even higher fan speeds.

Instead the Work Place Gier features outlet only guide vanes, more or less, in the very end of the bypass outlet duct.

To roughly figuring out a best contribution of outlet guide vanes a simple approach should be used. A common used airfoil can manage incoming air inflow conditions up to an angle of around 12 degree, incoming, without stall, measured with reference to the chord line or the zero lift angle.. By a rule of thumb the angle at the back of the airfoil, when leaving is half of the angle of the airflow coming to the foil, making up 6 degrees. In total this leads to a deviation of the airflow in angle by a maximum of around 18 degrees. This angle is used for the outlet guide vans in a way that the ext flow from the engine is completely straightened.

Taking into consideration the incoming velocity of m/s, in order to avoid not to overcome the critical Ma number of the profile, when the airflow moves around the airfoil, the lift coefficient will be limited to 0,5 to 0,65, like it is approximately the same regarding wing and winglets under cruise conditions in flight.

Some would name these devices a variable Stator. Stator comes from something static, the Engine-inflowlets however move at least by rotation, which states by name and function, that they are non-static.

In aero engines some stators are know, which are in real the static part of fan stages, which together generates a fan pressure ratio. Most of the pressure rise is normally done by the fan, but the stator contributes to a certain considerable share. In this described design the stators normally features a diffusor blading to raise pressure when airflow is moving towards the stator as well as to the rotor.

The engine-inflowlets are however designed to be different, they work with incoming speed and airflow by force generation, like an airfoil on normal wings does for lift, and they do not work by global pressure rise.

The In-Engine-Flowlets however are aligned and tilted to the airflow leaving the fan at an average angle of 34 degree. Therefore they can generate a pretty higher thrust level.

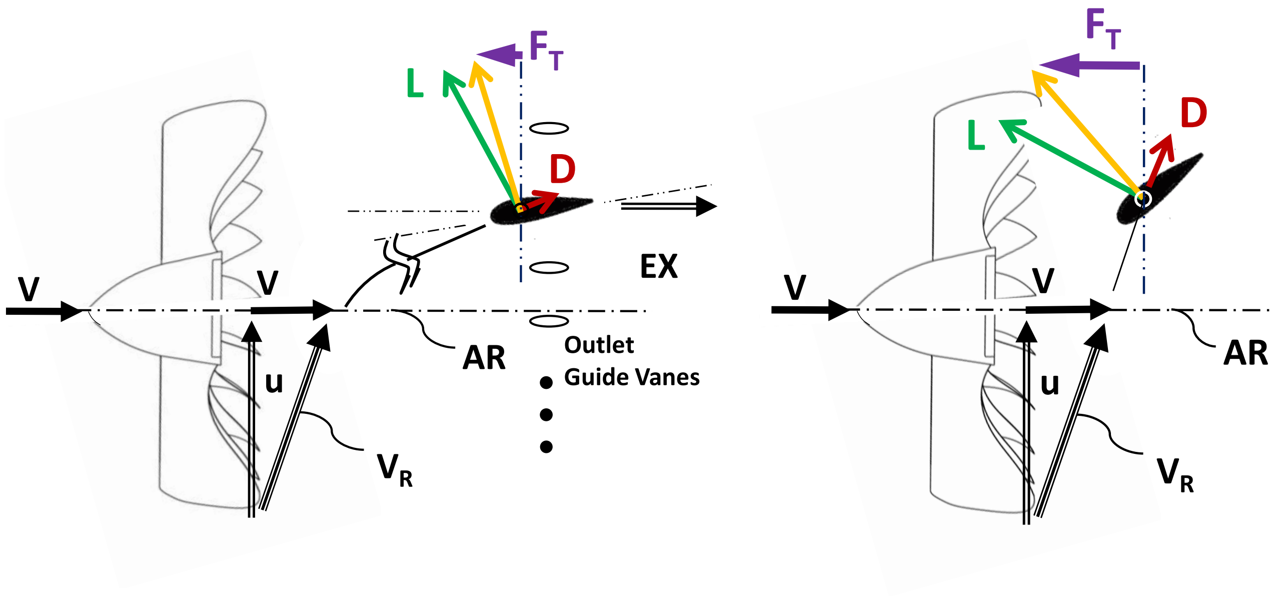

Figure 8: Present solution works not only for turbofan (casing not shown), but also for open rotors

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	Outlet Guide Vanes BP duct	Engine-Inflowlets rotable (adjustable)	factor	
Lift coefficient of element C_L	0,6	0,6	1,0	
Thrust coeffizient C_T reached in flight direction	0,1853	0,472	2,98	
With average angle alpha and alignment strategy	72° (18° measured to profile, 12 ° incoming angle, 6° outflow angle), airflow leaves engine straightened	34,3° airfoil aligned/tilted to incoming flow to reach C_L of 0,6 even with swept considered		
Aspect Ratio capital lambda of Elements	8	5	1,6	
duct height m meaning span b	0,67	0,67		
Number of Elements applied in duct	43	18	1/2,39 with impact on wetted area	
Total wing reference area of elements m^2	2,413	1,616	1/1,49 with impact on wetted area	
Table 3				

As an intermediate result engine-inflowlets, like here, tend to show 2- times higher thrust in cruise - compared to the present outlet guide vanes, presently applied in the bypass duct, already considering the drag of these elements. This refers only to the bypass duct and here the “staticpart” caused thrust, whereas bypass ratio in cruise is assumed to be 7 to 8 for an engine of design bypass-ratio 12.

But from this doubling only half should become effective due to assumed higher pressure losts of the Engine-Inflowlets (however pressure lost can be significantly less, as less wetted are is applied then with outlet guide vanes).

This results in approximately 6,5% more total engine thrust in cruise flight at 11000m due to change to in-Engine Inflowlets with present, thus unchanged fuel flow, means fuel consumption.

However the fuel saving potential appear in different calculation up to 23%, where around 13,5% might be reached in real conditions.

From an energy perspective this at least seems possible, because directly downstream the fan the average u tangential velocity induced by the rotor with at least 183 m/s is at least the same or higher than the axial velocity in the bypass duct of Ma= 0,60 to 0,63. The Engine-Inflowlets are less twisted to the incoming airflow than Outlet Guide Vanes.

This makes up a potential kinetic power, which appears in tangential direction, that can be used for thrust generation of airfoils of:

$$P = \dot{m} \cdot u^2 = \dot{m} \cdot \omega^2 \cdot R^2$$

with $\dot{m}$ in the bypass duct assumed to be at least 195 kg /s and average R = 0,69 m of by-pass duct (total height 0,67m) with rpm of rotors of 263 rad/s an u average 183 m/s leads to a Power P of several MW available.

A main advantage of the Engine-Inflowlets is that they can be rotated and adjusted to flight conditions, like a variable pitch propeller, contributing to remarkable efficiency, while present stator devices in bypass ducts have to be designed to all operation conditions, appearing, compromising an angle range in incoming air flow of 30 to 40 degrees, which makes them not adjustable and therefore inefficient for certain flight stages, like cruise flight.

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5 Thrust Crown

Another interesting location for the adaption of a special embodiment of such a device was found in the rear of turbofan-engines or jet engines in the nozzle areas. In these areas the fluid features an increased energy because of recently having passed the fan, the core engine and the nozzles. So it is being operated like in a windtunnel.

As a second puzzle part: Concorde and fighter jets have rear or forward swept wings to operate in supersonic and transonic flow conditions at high velocities at low drag. Often these wings are composed of delta shaped elements.

Third, if the leading edge has a swept angle greater than around 52-56 degree and the leading edge appears favorably in a sharp shape, this leads to a special mechanism of lift generation by vortices, called non-linear lift generation. As figure shows the lift composes of linear and non-linear lift. This is used for aircraft with delta-shaped wings, when approaching,

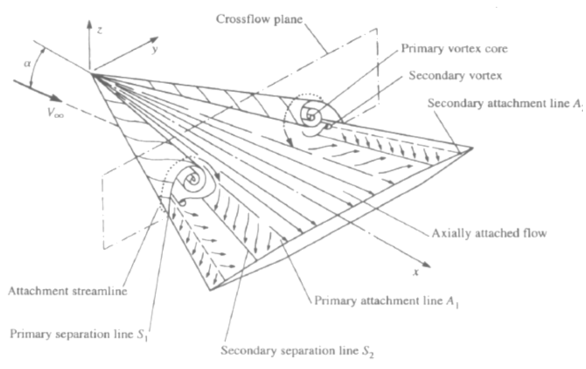

Figure 2.33 Schematic of the subsonic flow over the top of a delta wing at angle of attack. (Courtesy of John Stollery, Cranfield Institute of Technology, England.)

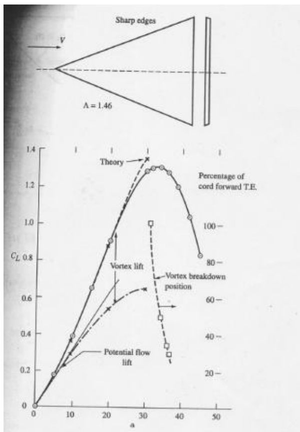

Figure 2.34 Lift coefficient curve for a delta wing in low-speed subsonic flow. (After Hoerner and Borst, Ref. 18.)

Figure 9 a

Fourth at the same time it is know, that for a wing, generating lift, the induced drag, which appears when generating lift, is lowest for a high aspect ratio of the wing. In theories it would disappear if the span and therefore the aspect ratio is infinite high. Forming a closed ring shape causes in theory a wing with infinite span and ratio. In real it leads to wing with high effective aspect ratio, thus a small angular displacement of generated lift force, which contributes to an effective application.

Fifth is to find an area for application, where the local flow field is deviated from angle to the flight direction. In this case it happens, while the vitalized air stream follws more or less the contour of one of the conical shaped nozzles, additionally supported by the Coanda effect. This leads to a conical stream field, in this case with more or less radial symmetry, wherein the thrust crown is now applied in.

In a six step this ring shape device with delta shaped sharp elements, making up a crown, is placed in this conical stream field. According to the idea it generates a force component, forward in flight direction, acting propulsive, taking into account the drag of the crown (profile and induced). This makes up the thrust crow. So far in CFD it has been only calculated incompressible, with repeated hints (also for different nets, different shapes and geometries, different bodies where it is adapted) that is works. I has to be said that the location and shape leads to a variety of parameters like (diameter, chord length, radial distance to bodies, longitudinal distance to bodies, delta angles, angle of incidence and so on) which needs al lot of patience from engineers to make it work. Besides the aspect of thrust generation by an active force component, the following effects in theory become available.

1.) Generation of a forward facing propulsive force component

2.) Vitalization and stabilization of stream fields, especially in or near boundary layers, which from energy would come without device near to detachment or separation. On the other hand with application of the thrust crown shaped for the encircled geometry in a proper way, the fluid follows geometries, energized by the vortices, it would not follow without. This helps e.g. for pressure recovery, combined with a Goldsmith shaped pressure recovery device. Finally this leads to less pressure drag of bodies.

3.) Redirection of airflow in direction, in the described application angular displacement of thrust is corrected by deviating the airflow from conical field in a horizontal more or less parallel flow field. In consequence the thrust is more effective.

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In the nozzle areas behind the turbofan all three effects seem to be effective with priority to 1 and 3. It can applied on a wide variety of bodies, including aircraft fuselages (where in the rear point 2 becomes effective and dominant).

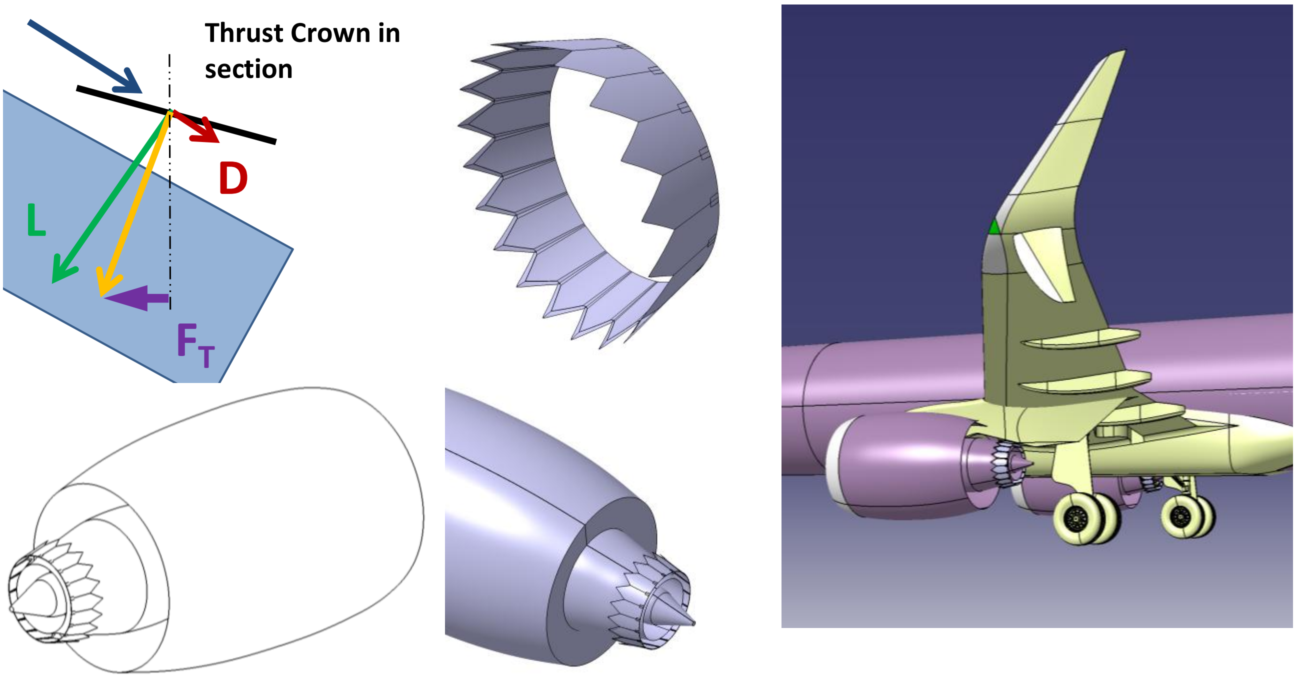

Fig 10: Principle of propulsive Force generation by thrust Crown in section, as first idea of author. A proper shaped Ring in CFD applied in conical flow shows thrust overcoming its own drag. Thrust Crown applied on by-pass nozzle of turbofan engine. However it seems more probable in an explanation, that in special careful chosen designs, pressure fields of bodies might interact in a drag-mitigating way. Effective at take-off - it would enhance climb angle and climb performance, thus enhance noise footprint.

From CFD calculations applied on a Work Place Gier engine geometry up to 2,5% drag reductions on reference aircraft drag level appear so far in non-compressible environments in cruise, which are comparable to winglets in a medium evolution state. In spite of several applications and calculations show repeatedly drag reductions, the effect is not completely proven, but should be implemented in the Climatefly, in a way that drag reduction effect depends on the diameter of the thrust crown.

These devices can be applied to tubular endings of bodies in general e.g. for the rear of fuselages of vehicle and underwater vehicles, for engines and engine gondelas or fairings, for extra fuel tanks and external mountable devices. It might also be integrated on the front part and in the middle parts especially, especially in an area, where the cross section area changes over the length (area rule), like in canopy areas. It appears well, to be specially installed behind propellers, fans, nozzles, where kinetic or overall energy is boosted, but not straight.

6 Thrust Rings

Shortly added should be said, that this application works also with conventional airfoils, where a profile can be applied in a ring-shaped element (ring, circle or ellipsis), or part of that, to mitigate drag. For aircraft with higher cruise speed the devices can be operated as least partly in the boundary layer, even without swept. It can be combined with propellers or a plurality of propellers in a distributed, preferably in an electric manner.
Without propulsors it works for active boundary layer control. In that case in areas where separation would become probable this elements can energize the boundary layer, whereas several rings has to be adapted with distance in series for longer distances or challenging shaped contours. This can additionally help to lower overall drag effective wetted area by designing in a more curved way.
Thrust rings seems so far work more in low speed environments, and more in the rear than in the front. In another application they work for revitalizating the boundary layer (normal orientation - and airfoil upper side

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pointing to body), this works for only a certain distance, until the bodies ends or the next ring is to be applied (serial installation).

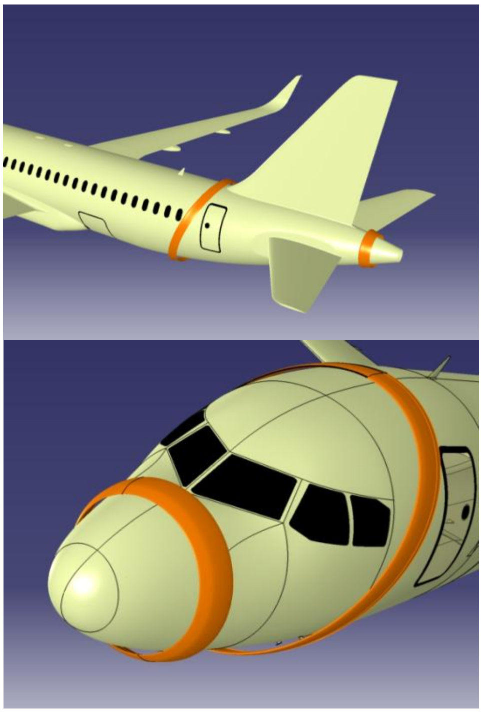

Figure 11: Thrust rings to stabilized boundary layer in the back and the propulsive Radome for retrofits

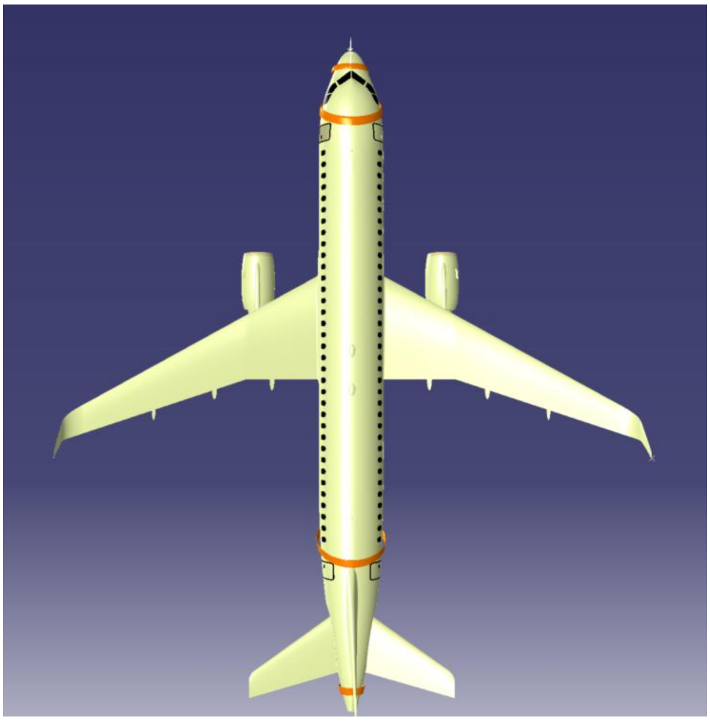

Figure 12: Changing the pressure drag By manipulating the pressure around surfaces by pressure changing bodies and foils.

From timeline after my presentation of this technology on the German aerospace congress in Munich, the technology appeared some years later in commercial operation on “Peter’s build trucks” – from view - modern trucks in the United States, for lowering aerodynamic drag.

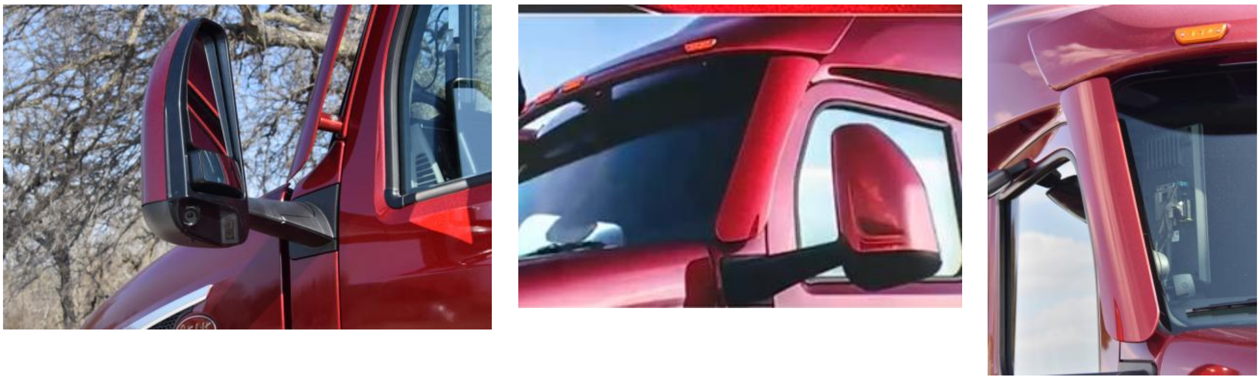

Figure 13: Low-speed-applications

Apart from the static propulsors like winglets and *-lets, rotary propulsors for thrust generation are known.

7 Rotary Propulsors

The principle of flow force generation by an airfoil or wing, - shown previously- ,can also be applied rotationally about an axis of rotation, to produce a resultant flow force, including a force component in the direction of propulsion, commonly referred to as thrust. This device is commonly referred to as a propulsor.

In this process of rotation, the propulsor experiences a resultant aerodynamic inflow velocity in spanwise direction within the respective airfoil section, which is vectorially composed of the airspeed and the velocity component u

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induced by the rotation. This velocity component u depends on the radial distance of the airfoil section from the axis of rotation. This velocity component, shown by the angular velocity ω of the propulsor in the profile section, is lowest in the area of the hub and, according to the relationship $u = \omega \cdot R$, increases linearly with radius R to a maximum value reached at the outer tip of the propulsor blades.

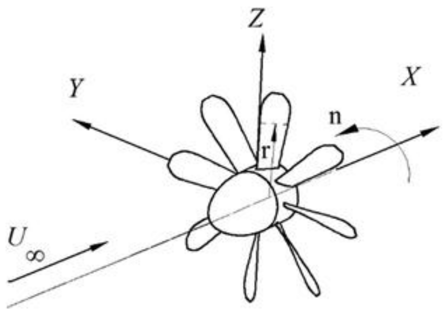

Figure 14: Rotational propulsors are known as propellers, prop fans, and open rotors.

It is important to distinguish fans from propulsors. Fans primarily produce an increase in pressure through their diffuser bladding. The rotation also generates a velocity component u in the fluid in the circumferential direction, commonly known as swirl. In contrast, in the axial direction, the axial velocity often remains nearly the same when flowing through a fan or fan-stator combination. The overpressure achieved by fan stages can be kept contained to the external pressure in a ducted enclosure, and subsequently converted downstream via nozzles into velocity overboost and thus into thrust.
The fan only really works effectively as a propulsor when at least one nozzle is connected downstream. Therefore, fan, shroud (to keep the overpressure contained up to the nozzle) and nozzle are to be seen as a necessary unit for thrust generation, which a propulsor, like described above, as a single piece, does not need, because it can effectively generate thrust solely through rotation in the fluid without additional components.

Thus, fans are not understood by the author to - be propulsors, working on their own - at this point.

This should not be confused with shrouded propulsors, for example. Shrouded propellers do not have diffuser bladings. The differences between fans and propulsors in mode of action are sometimes not well understood in the scientific community. The author had to learn this, too, Similarly, the industry is not equally aware of them, as shown by the term “open fan”, which, according to the above understanding, is simply a propulsor that rotates openly in the fluid and is used as an open rotor. Sometimes new terminology is needed to make old things seem new in marketing

8 Flettner or Magnus Rotor

A Flettner Rotor or Magnus Rotor also generates a transverse lift - or lift according to the definition of lift perpendicular to its aerodynamic incoming flow. In contrast to the lift-generating airfoil this happens by rotating a circular cross-section in the incoming airflow.
Thereby the lift force and respectively the lift coefficient of the Flettner rotor increases with the angular velocity of rotation of the round profile in the aerodynamic incoming flow. By increasing the angular rotation speed, very high, and generally double-digit, lift coefficients are achieved with the Flettner rotor, compared to the rigid profile. One of the first measurements were made in the wind tunnel in AVA Göttingen around the year 1923. The measures are still obtainable.
At that time, it was assumed in theory that the maximum lift coefficient is reached at 4pi and is limited to that. With today's advances in electric drive technology and integration, significantly higher speeds can be achieved on the rotor. Recent measurements and simulations indicate that the lift coefficient is not limited to 4pi, but even higher values can be achieved. Here, the lift coefficient is referred to the projection area of the rotor, similar to the rigid-profile airfoil.
In many measurements, the lift coefficient is referenced to an also non-dimensional Schnellaufzahl λ , here called spin ratio. The spin ratio defines the highest speed at the outer rotor, at the surface at maximum radius, in relation to the reference of the speed in the free aerodynamic incoming flow.
For a spin ratio of 3, the velocity at the outer boundary of the rotor, which is in contact with the fluid, is three times greater than the velocity of the free incoming airflow.

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Similar to the profile, the direction of the ambient fluid mass flow of the rotor is directed when passing the profile under the direction of circulation, directionally from the angle. However, the change of direction is generally higher the stronger circulation compared to a rigid airfoil. The deviation is generally higher than on a rigid profile, at least around 2 times higher in the done implementations. At the same time there is also a drag at the Magnus rotor, by form effect, friction and by induced drag.

According to and proven by measurements, stationary or, even better, rotating end plates help to lower this resistance significantly. Wind tunnel measurements confirm the calculations that, in addition to the lift coefficient, the drag coefficient of Flettner rotors is higher than that of the airfoil. This results in a low glide ratio E compared to an airfoil of at best approximately 3.0 for the rotor alone. As is the case with the wing with a rigid airfoil, a large aspect ratio generally improves the glide ratio by lower induced drag. In addition it is possible to further improve the glide ratio of a Flettner rotor by equipping it with some kind of airfoil covering in the wake, something like a profile casing, making the rotor a rotorfoil.

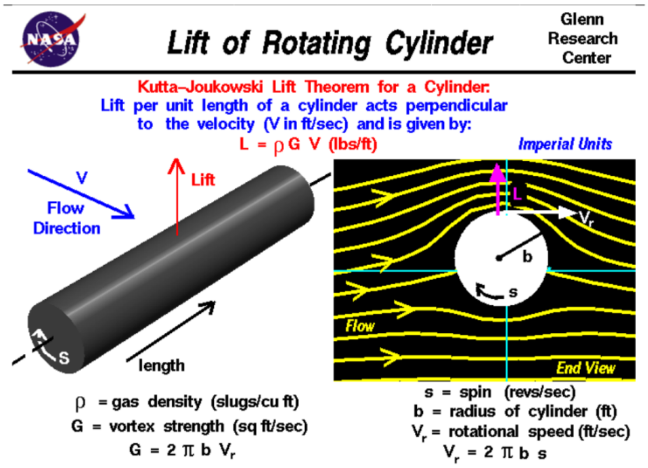

Fig 15.: Flettner rotor in flow, NASA, Glen research Center

The picture shows such a Flettner rotor modified with profile coverings as a complete unit with an aspect ratio of 1:5, which was aerodynamically measured in the wind tunnel.
The wind tunnel tests were carried at Airbus out in the low-speed wind tunnel at Airbus in Bremen. Diagrams 1 and 2 show the lift and drag coefficients recorded by Airbus engineers as a function of the Schnellaufzahl λ, denoted here as spin ratio, shown on the y-axis.

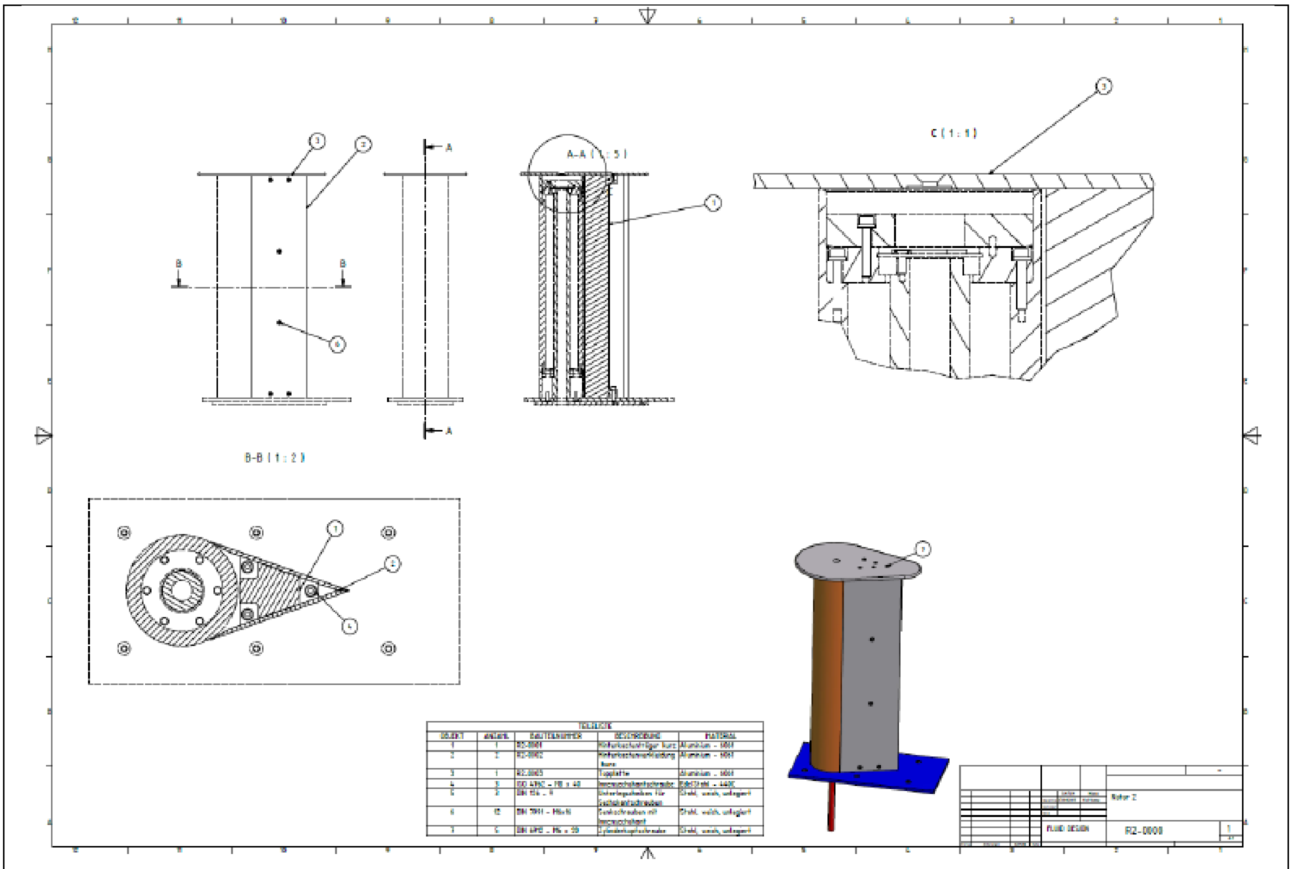

Fig 16: Flettner Rotor with profile casing of aspect ratio 5, which was measured in the Airbus wind tunnel

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This measurement also confirms the high lift coefficients, and an improved glide ratio by higher aspect ratio (also a rotorfoil with aspect ratio 10 was measured due to modular design of the test body), and an improved glide ratio by rotor casings, as shown above, which by the way a rotable around the Flettner rotor axis, for adapting to different incoming flow angles. The measurements here must have been carried out at an inflow velocity in the range of about 12 m/s.

Figure 17: Modular test assembly for rotors and rotorfoils of two different aspect ratio

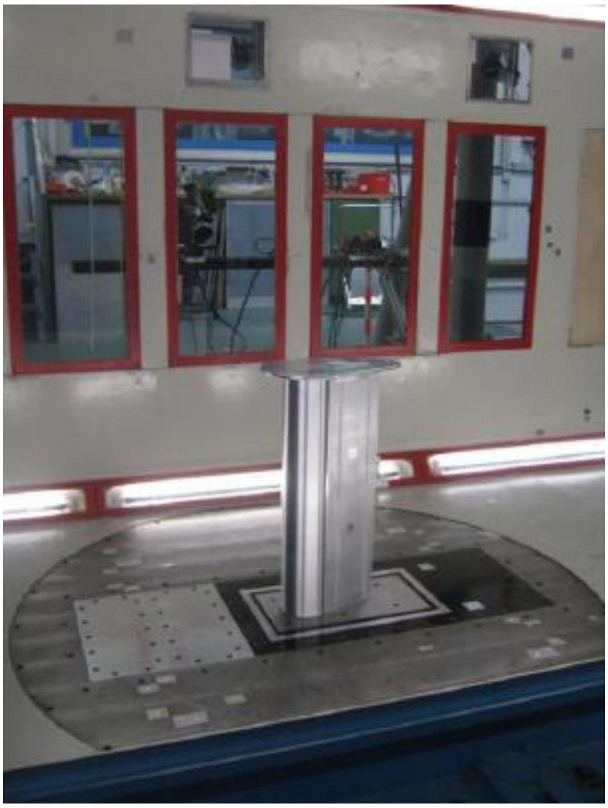

Figure 18: Aspect ratio 5 rotor foil with endplates in the windtunnel.

As investigated in the Airbus low-speed wind tunnel, the Flettner rotors are supplemented by initially symmetrical profile fairings to improve the glide ratio. In this application, the fairings are aligned in correspondence with the local incident flow in the respective radial section of the profile, which results in a geometric twist that is known in a similar comparable form from conventional propellers.

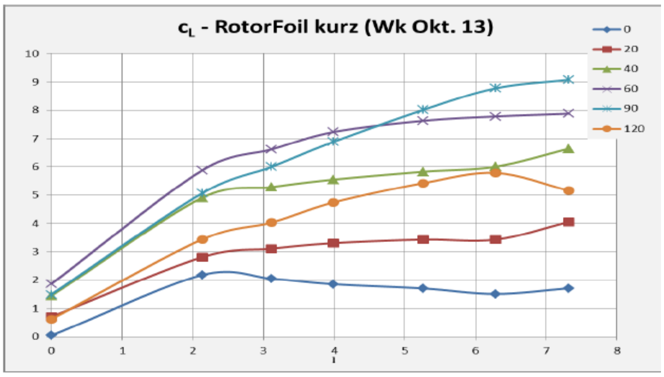

Fig. 19: Lift coefficient CL on y-axis depending in the Schnelllaufzahl λ for a Flettner Rotor of aspect ratio Λ=5 under different angles (colour). Here 90° is most important.

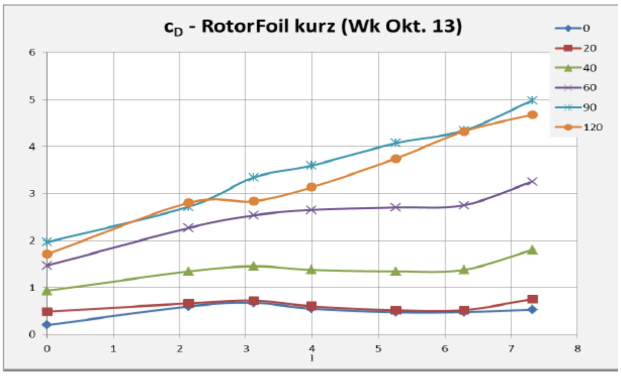

Fig.20: Drag coefficient CD depending in the Schnelllaufzahl λ for a Flettner Rotor of aspect ratio Λ=5 under different angles (colour). Here 90° is most important.

By combing both the illustrations the glide ratio can be figured out, depending on the lift coefficient.

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9 Deduction of a new propulsion-engine with hybrid-electric capability

In the course, a new drive and propulsion concept will be derived here by the author, which features hybrid-electric capability.

In a first step flettner rotors are installed on a main rotors as propeller blades. So Flettner rotors (MA) are arranged on a main rotor (R), which can be rotated at a distance (D) from an axis of rotation (RA) of the main rotor (R) about this axis of rotation (RA), under power absorption. In addition, the Flettner rotors (FL) can each rotate about their own axis (AF).

By that it is formed a double rotating Propulsor DRP. For each Flettner Rotor the following velocity income situation appears to be effective.

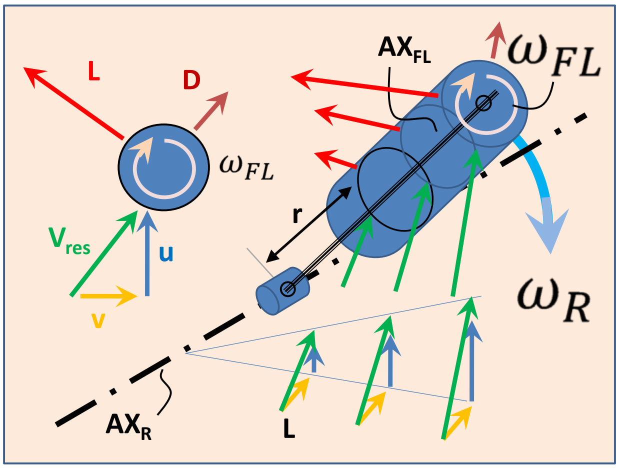

Figure 21: In principle: a rotated rotating Flettner rotor experiences the following velocities and forces of the double rotating system, forming a DRP, double rotating propulsor. Drag for clarity is only shown in the most outer section, equal diameter of Flettner assumed

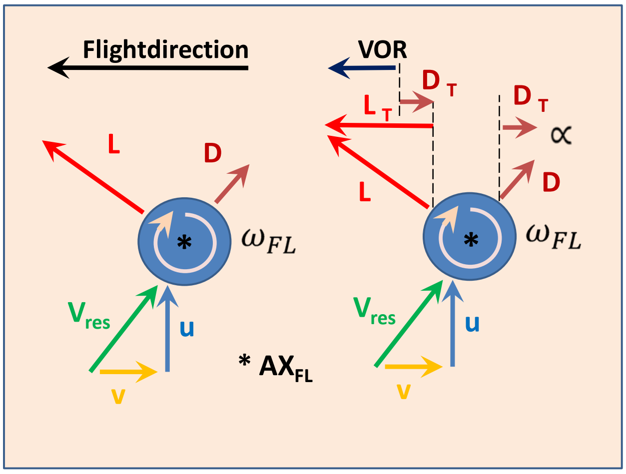

Figure 22: Velocities and forces in the profile section of a flettner rotor, resulting in a propulsive Force VOR in flight direction. The flettner moves down in this illustration (by rotation of the main rotor)

By velocities also forces in circumferial direction appear, which are directed as drag against rotation, which means that the main rotor has to overcome a drag moment.

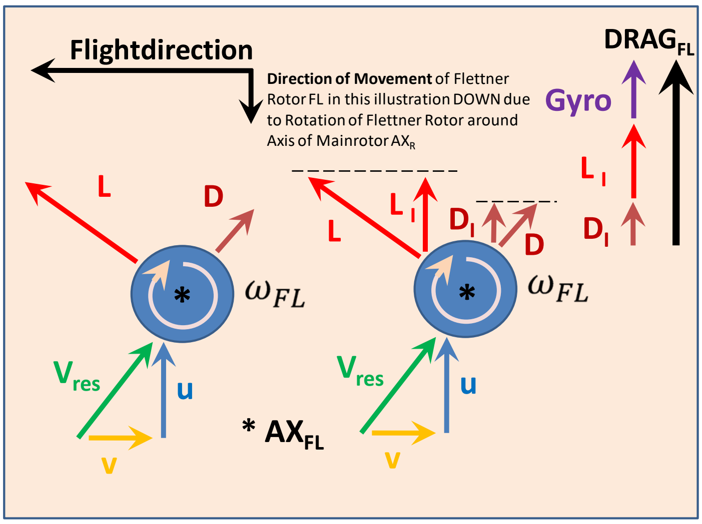

Figure 23 Velocities and forces in the profile section of a flettner rotor, resulting in a drag moment to be overcome by main rotor

A first main rotor compromises 2 Flettner rotors with each a span of 0,4 m and aspect ratio 1:5, like it was measured in the wind tunnel.
As a thought experiment it will be operated exemplarily at a suitable all-electrically operated UL aircraft F2E at 33 m/s cruising speed instead of the normal propeller as an example study. The hub, the spinner diameter with around 0,6 m will be quite huge.

The Thrust, calculated by this two rotor "bladed" DRP is 473 N at a flight velocity of 33 m/s.
The power needed to produce this thrust by spinning this DRP can be calculated according to the following section.

This makes up a propulsive efficiency around

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12%, which is quite poor, compared to propeller propulsors, which an efficiency in this implementation of around 67-78%.

From the Zeppelin NT (NT for “Neue Technologie- Technology”) it is known that it reaches by stern propulsion (propeller at the very back) a propulsive efficiency, which is greater than 1.0.
This comes from - that thrust generation is done in a lower velocity compared to the flight velocity, because the propeller operates in the boundary layer of the hull, which is significantly slowed down.

For ship designers is quite normal to calculate and to design propulsors in the rear, which have a propulsive efficiency, well greater than one. It comes from the same effect, whereby ship length can be even larger than airship lengths. The effect is quite larger in ship design.

CRISP was an experimental engine at MTU in Germany, where within a gondola two counter-rotating propulsors produce thrust at a horizontal speed (generated by the gondola) which was below cruising flight speed. It reached at that time a high efficiency. In this application to counter-rotating propulsors are operated in a velocity lower than flight speed.

10 Rear Propulsors

Rear propulsors are also known in aviation. Aircraft with a central engine are known. Well-known examples are the Boeing 727, the Lockheed Tristar, the DC 10 and, “more recently”, the MD 11. In these aircraft, the central engine is located in the center of the fuselage or in the vertical stabilizer.

11 Tail propulsors with boundary layer insertion

Aft thrusters are also known, e.g. from the Boeing Sugar project, which are arranged on the tail of the fuselage or in the wake of the aircraft fuselage and can also be operated electrically in some cases.
These aft thrusters also suck in part of the fuselage boundary layer, thus providing drag savings by wake filling.

Tail propulsors are also known. In addition to tail propulsors with propellers, ducted versions are also known. Some of these are designed in a radial manner around the fuselage tail in such a way, that they can suck in at least part of the boundary layer. This results in fuel savings, since thrust generation can generally take place at reduced speed, in this case with the aid of the slowly moving boundary layer, which is significantly slowed down by speed, relative to the airspeed of the aircraft. This fuel savings are up to 36% compared to ACARE 2000 like aircraft (Bauhaus Luftfahrt Jahresberichte).

12 Distributed Propulsion

Distributed Propulsion is known to enhance efficiency, especially in electric propulsion, widly by the scientific communiyt.

13 Electric Engines’ weight

The output specific weight of electric engines is known to be normally much better for high rpm then for high torque. This insight is considered for the electric aerodynamic propulsion part within the design process, and leads to an overall electric engine weight (without considering the torque motors of the E-Wheel-Drive+2) of less than 100 kg for 44 engines, which might be surprising for aerospace research members, but not for the model-building flight models community, which has been flying full electric powered aircraft since at least 3 decades with high innovation (outrunner, brushless etc.).
The present considered engines run at 30 000 rpm which seems to be currently a well compromise in view of possible rotor burst, to keep it contained or shielded. However even higher rpms are feasible up to 100 000 rpm or even a lot higher, including electric engine control (ETH Zürich + ATE electric propulsion).

14 PropulsionArchitecture

A double-rotating Propulsor DRP is applied in a duct of a rear propulsor, whereby the rear propulsor sucks in boundary layer airflow at the aft of the aircraft fuselage at already low entry speed, here of about 103 m/s in cruise.

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The DRP is placed downstream a diffusor device after the fan. The DRP experiences relatively low horizontal air speed incoming of 33 m/s like the ultra light aircraft from before, which leads to achievable speed ratios (Schnellaufzahl of 3 to 4), that results in high lift coefficient, high thrust coefficients, which areeffective in flight direction and high values of thrust being generated.
The flettner rotors are driven by electric motors. The DRP should have in this case 22 rotating flettners as blades. That makes up 22 electric motors to rotate the flettners in a distributed electric propulsion concept per main rotor.

The contarotaing rotor CDRP

Due to LTH section propellers contra-rotating propellers reach depended on design and operation phase an increased higher efficieny with 8-12% increase over a single rotated propulsor. This is due to the flow field, caused ba the first rotor, the downstream rotors rotates in.

It was found out that the second main rotor produces 15% more thrust, in the flow field of the first main rotor, an when rotated slightly higher rpm of 1200 rpm (e.g. by different gear ratios). The potential for increase seems even higher. It needs slightly increased power for that.

The main rotors, which hosts the flettner is geared and driven by a combustion gas turbine. The gas turbine has at least one free power turbine, which can power the main rotors, as well as a electrical generator, driving the flettner rotor in a serial tuboelectric manner. Both can happen e.g. by rotor brakes selectively. That means that the gas turbine can be also used as an APU substitute, without any propulsors moving. This is e.g. known as a “Hotel Mode” of the commuter airplane ATR, which doesn’t have a separate APU, but is autarkic by using the right engine in an APU mode without propulsors moving.

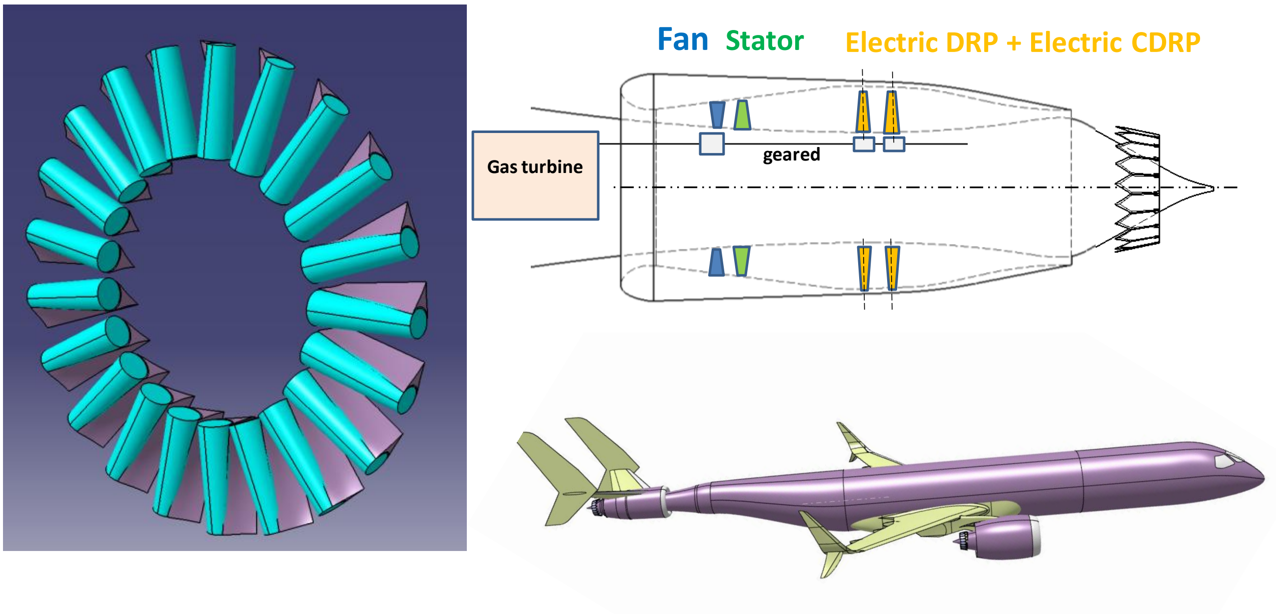

Figure 24: : The violet parts could be rotated too in a fashion of a variable pitch propeller

By this the aircraft stays like with three combustion engines, like the reference aircraft before. The only change happens is that it can be used additionally for driving the rear propulsor, if needed, in the frame of a hybrid electric propulsion concept. Another change can be made according to the version, that this combustion motor can be run on multiple fuels, meaning hydrogen (LH2 or GH2), natural gas (LNG or GNL), convention kerosene and of course SAF. For the better world version , also for LH2 and kerosene in one architecture, selctively.

Taxi can be thus made weather by the rear hybrid electric propulsor or by electric nose wheel taxi, fed by the 300 kW generator at the rear. In general the electric generator in the rear can fed the electric consumers in normal cases (with fallback possibility), so that less offtakes are needed on the main engines, which can slightly improve efficiency. If the rear turbine is fed with hydrogen, it is locally CO_2 emission free.

The propulsion system should be now calculated in the following.

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15 Calculation of the hybrid-electric propulsion system

For the calculation each Flettner rotor is divided into 6 panels of equal size. At the DRP (Double Rotating Propulsor) the following inflow situations result in the individual panels. The following applies in detail to the columns:

The Span of one Flettner Rotor is chosen to be 0,4m.

The Flettner Rotor rotates regarding its radial geometric middle 0,2 m, at a distance of 0,6 m from the Rotation axis A_{XR} of the rotor. The Hub radius is therefore 0,4 m, the hub diameter thus 0,8m at the Flettner Rotor position.

C1	C 2	C 3	C 4	C 5	**C 6**	**C 7**	C 8	C 9	**C 10**
Panel number	Radial middle of panel in m	R from Axis in m +0,4m	u in m/s $u = \omega \cdot R$	v_{RES} in m/s $(C4^2+D0^2)^{0,5}$ D0 = 33 m/s² for cruise	λ_{MAX} speed ratio Grenzschnell	Diameter for Flettner Rotor chosen at radial middle of panel in m	Surface in m² projection area of panel C8 = 1/6 x D 5 x C7	C_L in panel from Fig. X	Lift in N lifting Force in panel
P 1	0,033	0,433	49,92	60,02	2,98	0,114	0,0076	**6,00**	50,014
P 2	0,100	0,500	57,60	66,55	2,59	0,110	0,0073	**5,57**	54,944
P 3	0,167	0,567	65,28	73,29	2,26	0,105	0,0070	**5,17**	59,443
P 4	0,233	0,633	72,95	80,21	1,98	0,101	0,0067	**4,80**	63,414
P 5	0,300	0,700	80,63	87,25	1,74	0,096	0,0064	**4,47**	66,791
P 6	0,367	0,767	88,31	94,39	1,53	0,092	0,0061	**4,18**	69,533
arithmtr average	0,2	0,6		76,95	2,18	0,101		**4,65**	
Sum P 1-6							0,0412		364,139
									Table 4 und up and down

More columns of this table follows:

C 11	**C 12**	C 13	**C 14**	C 15	**C 16**	**C 17**	**C 18**
Panel number	Angle α in degree	C_W from Fig 8	D drag in N	E = C9/C13 local glide ratio in panel	VOR in N propulsive force in flight direction	D II in N Force acting against Rotation	Moment in Nm due to aero drag of Flettners
P 1	33,73	3,265	27,216	1,84	26,479	50,408	21,844
P 2	30,06	3,066	30,264	1,82	32,394	53,715	26,858
P 3	27,05	2,886	33,208	1,79	37,838	56,609	32,078
P 4	24,56	2,730	36,045	1,76	42,699	59,139	37,454
P 5	22,46	2,597	38,775	1,72	46,912	61,350	42,945
P 6	20,68	2,486	41,388	1,68	50,438	63,276	48,511
arithmtr average	26,42	2,675		1,75			
Sum P1-6			206,896		236,760	344,497	209,691

The calculated values are for one Flettner Rotor. The main rotor should be operated in cruise at 1100 U/min, thus 18,34 U/s and $\omega = 115{,}19\ rad/s$

The power needed to rotate the main rotor with just one rotor Flettner rotor to overcome the moment of 209,69 Nm from column C 18 is determined by:

$$P_{MAINROTOR} = M_{MAINR} \cdot \omega_{MAINR} = 24{,}07kW$$

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The Rotor should consist of 22 of these Flettner Rotors. The rotors are designed to have not more then Ma=0,7 around them, by the critical spin ratio (Schnellaufzahl).

The rotation of the flettner rotors by the main rotor leads to gyroscopic effects on the main rotor, which a result that an additional moment on the rotor due to gyro effects has to be overcomed, which can be figured out by:

Gyroscopic effects have to be considered according to the following illustration and table:

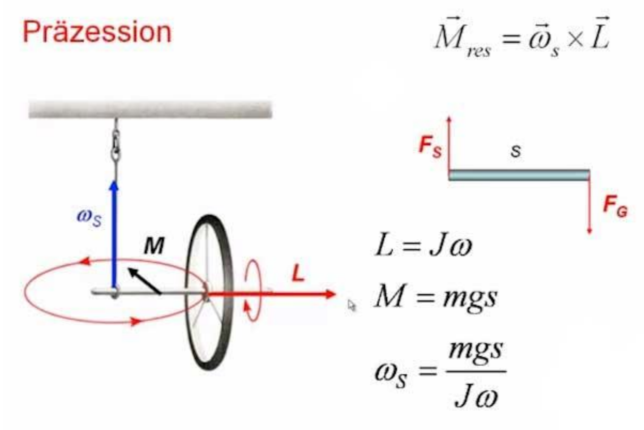

Figure 25

Doubles Rotation leads to an additional Moment M to be compensated. Not gravity force is taken, but aerodynamic flettner force. Gravity forces compensate on each side of the rotor, but let to gyroscopic moments twisting the rotor, also in one additional dimension by aero forces, which are finally taken by the bearings.

Calculation of additional Power needed due to gyroscopic effects - to rotate the Mainrotor, which contains one or n Flettner-Rotors		
Averaged Outer Radius in m	0,05	E0 = D3
Inner Radius in m	0,047	E1
Wall thickness in mm	3,0	E2 = E0 –E1
Span of Flettner Radius	0,40	E3 = D5
Volume in m^3	0,000366	E4
Density material kg/m3	1450 kg/m^3	E5 Aramid
Mass of main rotating part of Rotor kg	0,530	E6 = E4 x E5
Moment of inertia J in kg x m^2	0,0013256	E7 = E6 x $E0^2$
Omega w rad/s	3141	E8 = D12
level arm in m	0,60	E9 = E3 + 0,4 m
Moment in Nm	142,06	**E10 =E9 x Sum C 16**
Additional Power due to Gyroscopic effects ONE Flettner Rotor in kW	16,364 kW	E11 = E10 x E8
Additional Power due to Gyroscopic effects 22 or n Flettner Rotor in kW	360,00 kW or 16,364 kW x n	E12 = 22 x E11 or E12 = n x E11
Table 5		

The propulsion efficiency can later be obtained for a flight speed of 240 m/s. This results in 1,045% which is 4,5 P% higher than 100%. like it appears in ship design and on the Zeppelin NT for the stern propulsion.

The Propulsion efficieny, calculated for a speed of 33m/s, in which the force generated is around 10% and pretty poor, but if it is bookeeped to the flight speed of 240 m/s it becomes of course higher. The efficiency gain therefore comes from generating thrust at lower velocities. The inside propulsion efficiency should be referred to the speed, the propulsion is generated in. But what is the speed? It is not just the horizontal speeed of 33m/s bc of double rotation. The velocity has to be superimposed and averaged on the rotors which results in around 180 m/s.

For the outside energy demand, of ourse, it must be refered to the outside flight speed of 240 m/s. So most of the efficiency comes from generating thrust at much more lower velocity like flight speed of 240 m/s. This also works for contrarotating propulsors, like MTU CRISP (Counter Rotating Integrated Shrouded Prop Fan)shows. Here 2 contrarotating propulsion devices generate thrust also in lower flight speeds than the outside, bc the horizontal speed for the propulsor is lowered by the gondola.

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Calculation of power to spin flettners.

V incoming horizontal airspeed	33,00	D0
Ro density at Flettner Rotors kg/m^3	0,618	D1
cf	0,006	D2
Averaged Outer Radius in m	0,05	D3
Perimeter in m	0,314	D4
Span of Flettner Radius	0,4 m	D5
Wetted area in m^2	0,1257	D6 = D4 x D 5
Averaged Schnellaufzahl	2,18	D7 from C6
Highest speed at Flettner Rotor m/s	223,24	D8 = D7 x D0
Staudruck in N/m^2	15400	D9 = 0,5 x D1 x $D8^2$
Peremetric al drag (only outer)	11,61 N	D10
Peremetrical Moment	0,5806 Nm	D11
Omega in rad/s	3141	D12
Equals rpm of	30 000	D13
Power to spin ONE Flettner Rotor in kW	1,824 kW	D14 = D11 x D12
Power to spin 22 or n Flettner Rotor in kW	39,533 kW or 39,533 kW x n	D15 = 22 x D14 or D15 = n x D14
Table 6		

16 Fan power demand

The total overall pressure in the free stream at cruise flight 240 m/s in 11000m of is 33 070 Pa.
The total overall pressure, when entering the rear propulsor inlet is already decreased to drag, losses and boundary effects 26 868 Pa.
The air streams enters the rear propulsor at 103 m/s due to the effective boundary layer speed.

The total overall pressure loss in the ducting is due to CfD (Spalart Almaras) due to the duct around 6.5%.

Additional pressure losses have to be considered for the stator and for the 2 main rotors.
The pressure losses, accumulated for the air going through the duct are, are calculated in a first approach to be in total 35%. Hereby pressure losses of the diffusor are included. However it is possible to withdraw some air at interesting position of the diffusor for better efficiency (suction and controll). By that boundary layers can be held stable. This air has a favourable high pressure and thus can be used for feeding at least partly the combustion engines and/ or the different airconditioning zones/packs or directly feeding the cabin, where power for compression can be used efficiently.

This pressure losses have to be compensated by the fan.

This can happen in a way to give the airstream with a proper designed nozzle, exactly the flight speed of 240 m/s when exiting the system. However if the exit speed is chosen less from value, not considering the outer surface nacelle drag, this leads to thrust for any exit speed greater than 103 m/s (the entering speed in the propulsor). This would result in a lower power demand and needed pressure ratio for the fan.

The drag of the nacelle and stretch of fuselage (complete due to shape, wetted area, compressible effects) is in cruise calculated 1450 N, which can be supposingly lowered by optimized design.

For the fan/stator a pressure ratio of 1,7 is chosen, for a mass stream of air, going through the propulsor in cruise flight, of 13,41 kg/s. Air streasmes moving to SA - engine have around 200 - 250 kg/s.

The rear propulsor thrust (without nacelle drag) in cruise is about 1838 N.
With considering nacelle drag it is around 500 N.

The rear propulsors is designed for hosting the DRP and for compensating additional drag of the rear propulsors with

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works here as housing for the additional DRCP.
It generates some thrust to allow for even higher weights, flight altitudes and for TOC demand.

However the rear propulsor can be designed differently and be scaled up for higer air flows by radially extending the inlet height and therefore inlet area.

From here on in the paper, because limited time available, contributions are given for experts, which can make it fit together, if wanted, only basic information, without much explanation, author wishes to explain more in detail in another occasion, what is already fitted together, but not documented so far, Thank You!

17 Overall power demand of rear propulsor

Tornado 5 D Rear Engine Power needed Cruise @ 11 000 m ISA		
Hybrid electric DRP main rotor	531,4 kW	@1100 rpm
Hybrid electric CRDRP main rotor	483,6 kW	@1200 rpm
Fan	550,0 kW	
44 Flettner rotors @ 30000 rpm	80,0 kW	probably less
Gyro-Power main rotor 1	720,0 kW	
Gyro-Power main rotor 2	549,6 kW	
	2914,6 kW	for Liaison 804 T with 5MW power at MSL
Table 7		

This values are for 83% Turboelectric transmission efficiency (line 4) and 1,5% losses in mechanical transmission for both main rotors (already considered in the values stated for lines 1,2) . Fan efficiency is taken as 90% (line 3).

18 Overall thrust generation

Tornado 5 D Rear Engine Thrust Contributions in Cruise @ 11 000 m ISA	
Thrust by hybrid electric RDRP + CRDRP (rotor 1 + c-rotor 2)	5209N + 7290N = 12499 N
Thrust by coventional combustion part without considering offtakes	1837 N
Rear nacelle and stretch (additional drag 1450 N) is already book kept in overall aircraft L/D	
Sum : Overall Thrust of hybrid electric engine in Cruise Conditions	14336 N
PTSF of turbine	0,177 kg/h/kW
Cruise Power demand by hybrid-electric engine	2914,6 kW
Fuel needed in conventional kerosene or SAF/h	516 kg /h
reference aircraft Fuel needed /h for all thrust of reference aircraft/h	2500kg/h for 38119 N (68 t)
reference aircraft Fuel needed /h for thrust contribution of Tornado 5D (37,7% at 71 t cruise weight)	940 kg/h for 14366 N
Fuels Savings of 5 D Rear Tornado to reference aircraft for thrust contribution	45,1 % (-424 kg)
Table 8	

If outer rear nacelle drag and stretch of aircraft cabin (cannot be distinguished here, therefore taken as one value) is book kept under the rear engine, which makes sense for the first part mentioned, net thrust is 12886 N and savings in cruise flight drop to 362 kg and 38,5 % compared to the reference aircraft.
Calculation is done by normal way of bookkeeping at aircraft manufacturers, meaning nacelles outer drag book kept to aircraft L/D and engines inner drag to engine (as nacelle is responsibility of a/c manufacturer). All drag is considered anyway, it is just a question of bookkepping.

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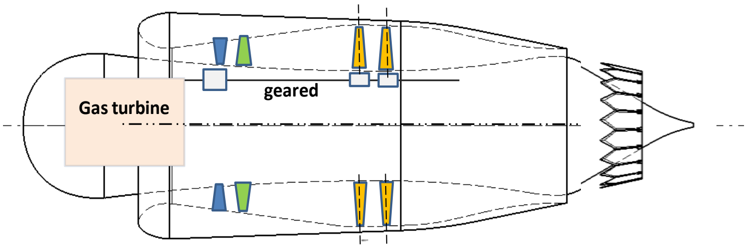
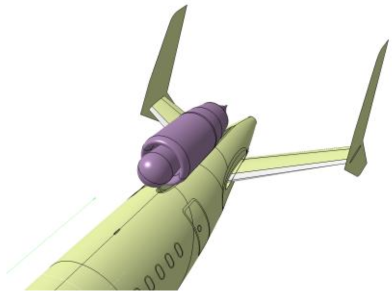
19 Single

The described DRCRPD has been integrated to the ducted rear (last - D) of the engine as Tornado 5 D. In another embodiement this technology can be integrated in a nacelle, forming an own aircraft engine, used partly in operation to contribute or substitute thrust, at least partly (part-time job). By that idea develops Tornado 5 D Single, which can feature, not shown in this illustration, a Thrust Crown at the rear, too.

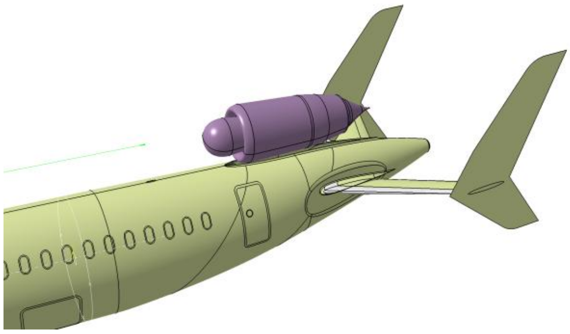
Of course Tornado 5 D Single can be additionally used as Stereo for twin engine or multi-Engine configurations. At 4 engines Aircraft it can alternatively substitute 2 of 4 engines with eventually lowering the MTOW for same thrust to weight ratio of the aircraft, thus for same Take-off and Climb performance.



2,6 m diameter version of Single for 2 DRCRP, ready to be mounted on pylon



Interface of Vertical Stabilizer used for attaching Single as a retrofit for enhancing fuel efficiency on CEOs as well as retrofitted new THS empennage



APU is removed, Single can be used as APU substitute bc of included turbine

Can be run additionally on hydrogen with tank(s) in unpressurized area, integrated tank e.g. in the middle part

20 Future

In future DRP and CDRP can be paired with turbofan or jet engines, partly or fuel. Just showing one example, formed by a core Sport ACE engine and a at least partly circumferring FRRPD or FRCRPD technology with own ducts(s). It can have in future one or two common shared fans. The present shown example "Tornado 5 D Sport Core" has a maximum diameter of 2,6 m, and can therefore substitute present SA-engines. The core can be alternatively fed by hydrogen.

On aircraft of lower speed or at least partly in the boundary layer it can be applied as DRPO or DRCRPO with last – O for Open Rotor.

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21 Weight Contributions

Base OWE	42600 kg - 6500kg (weight savings with CFRP wing) = 36100 kg	
Rear Engine Tornado 5 D	3000kg	
Hydrogen Module	N x 500 kg	Only if applied, one containing 186 kg LH2, reserves in fuel and volumes, loadable in rear cargo areas, to substitute kerosene on rear and/or front propulsor
Front Engine Pinochio 5 D	2550 kg	
One Thrust Crown	120 kg	
Additional Weight due to H-Empenage	235 kg	
Stretch to final length 44m (cabin stretched by 4,4m) + 24 PAX	Already in OWE calculations	
Winglets additionally down	220 kg	If applied additionallyto blended winglets
Advanced Winglets up and down	950 kg	If retrofitted
The weight for the Better World aircraft will more or less being the same, but can host 24 passenger more.		

Blue is optional

For Better World version OWE with Winglets up and down, 3 Thrust Crowns, Rear Propulsor and 4 Modules full of LH2 to run rear propulsor on LH2 without CO_2 will be OWE = 42645 kg, thus around weight neutral to CEO.

But Ready to host 24 more Passengers (+2400 kg) with luggage in standard configuration (equipped). So initial cruising weight for a 700 nm mission would be with the fuel savings of the rear propulsor/h of 425 kg/h around 68 t, the weight in initial cruise for the reference aircraft 68 000kg + 2000 kg = 70 000 kg, means 2 t more for the people.

2000 kg more weight from 68 000kg means according to the performance manual of the reference aircraft and that flight altitude 2,4%morefuel needed /h, which have to be deducted from the calculated fuel savings in flight for the overall aircraft. Actually it will be less to be deducted bc of the savings. On the other hand the fuel per seat enhances by the seats available by the factor 174/150 =1,16. This results in fuel savings in cruise for the Better World aircraft of more than 37,2 % per seat. Besides the 2,4 % more fuel can be overcompensated by taxi boot on the ground, which leads to 3-4% less fuel for the mission.

22 Aerodynamic Contributions – Changes to be applied in L/D in cruise of aircraft (best 17,5)

Nacelle with high bypass (present NEO technology)	+2,4% to CEO	0% to NEO
Nacelle and Integration of Rear Engine Tornado 5 D as well as fuselage stretch	+1450 N Drag	
Thrust Crone at aft fuselage with pressure recovery – minus 1000 N already bookkept in fuselage stretch		(?) without stretch
Change to H-Empennage	+1,5 % to CEO	
Boundary Layer Ingestion of rear Engine	- 0,0 % to -3,0 % better	
Advanced Winglets to up and down	- 6,0 % to CEO	+2,0 % to NEO
The L/D in cruise will be more or less being in result unchanged and around 17,5 for the Better World aircraft		

Cabin stretch leads to 24 more PAX in standard configuration, thus 174 PAX (cabin enlongered by 4,4 m).

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23 Engine Contributions Sideboard engines

Engine with highbypass (present NEO technology)	18% to CEO	0 % to NEO
Pairing of present technology PEAK + GIER for high inner and outer efficiency at the same time at 2,06 m fan diameter and at greatest weight of both	3% to CEO	3% to CEO
Higher BPR due to Redesign of 2,06 m Fan to 25% less thrust from rear propulsor implementation	3,5% to CEO	3,5% to CEO
In - Enginelets in Bypassduct	6,5% to CEO	6,5% to CEO
Thrust Crones around engines nozzles	2,5 % to CEO	2,5 % to CEO
Total Improvement in TSFC up to	**33,5% to CEO**	
Additionally: Taxing by boot (Mission fuel savings)	-3%	-3% to CEO

Tornado 5 D Rear Engine Weights	
Encircling Nacelle	+345 kg Aramid
Central Hub part with Goldschmith Shaped end	+230 kg
Rear Thrust Crown	+120 kg
Remove of APU from Reference Aircraft	- 150 kg
Engine with free Power turbine and APU capability Liaison 804 T	+505 kg
Fan and Stator to move airstream through the duct	+125 kg
Recuperative means for enhancing PTSF of engine to cruise 0,177 kg/h/kW	+700 kg [1]
Power transmission means (shafts, gears)	+ 80 kg
Rotating Flettner shapes, wound aramid fiber reinforced	2 x 22 x 0,55 kg = 24,2 kg
Aerodynamic Flettners Profile Casings CFRP	2 x 22 x 2,3 kg = 96,6 kg
Electric Motors 42 x 1,82 KW = 80 kW with actuation and mounting	2 x 22 x 2,3 kg = 96,6 kg
Electric Controllers	2 x 22 x 0,2 kg = 8,8 kg
Electric Generator 300 kW	70 kg
End Plates, Bearings, support of Flettner Rotors	2 x 22 x 3,6 kg = 151, 2 kg
Main Rotor for rotating Flettners	2 x 103 kg = 206 kg
Additional Shielding Devices /Aramid, Ceramic Composites)	+ 360 kg
	2969 kg
there of part of hybrid electric engine section,	+ 663 kg + 4/5 x additional c-engine weight = 663 kg + (505+700-150) kg = 663 kg + 844 kg = 1507 kg

Shielding can be at least partly done by nacelle. In that total weight of nacelle is + 360 kg, thus up to 1005 kg.

5600 kW combustion engine D x 0,69 m x 1,46m, with 2740 KW available at 11 000 m, like in GE-38-5B (MPC 75), however more because, air is taken from diffuser downstream fan (lower density height*, active air control to stabilize air, when moving through the diffuser) and partly or as mixture from pressurized cabin (eventually pe-cooled by outside air, so energy for compression is saved, which could mean that the engine could be sized eventually smaller.

Shielding of DRPs against uncontained engine failure is uncritical, bc present fans with much more weight radially outward, and much more mass, and much more rpm up to 3500 rpm, are managed to keep contained, presently by regulation as requirement for certification, present state of technology, with fibre reinforced casings.

Shielding of flettners: There are light weight wearable vest known, for shielding of policewomen and war men against shootings and projectiles with 250 kN impact capability, to keep contained, made with/of fibre and ceramic reinforced plastics. This lightweight technology can be used for that in nacelles and fuselage. There are even higher impact categories available. In worst the flettner breaks into just 2 pieces half of 0,5 kg means 0,25 kg to be applied on centrifugal acceleration. Present HP rotors are certified up to 24 000 rpm, 30 000 rpm on the flettners or even higher should be feasible.

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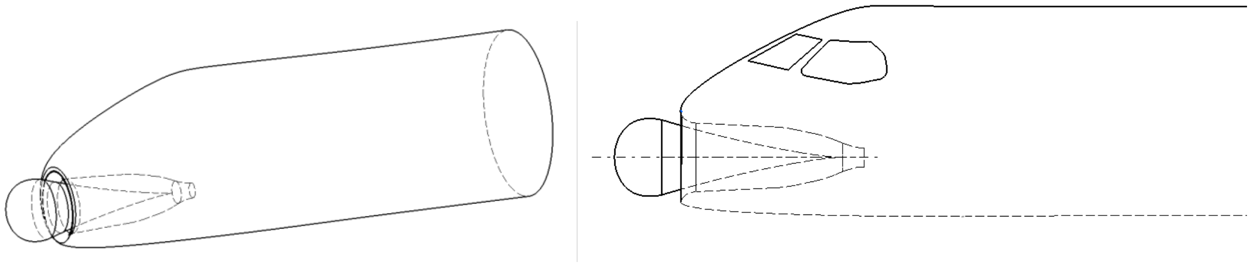
* Would be roughly as to operate the engine at 6700 m or lower, which is already the rating for that type of engine.

Where 22% (663 kg) comes from the electric contribution and around half of overall weight of the rear propulsor (3000 kg) comes from the turbo-hybrid electric part.

Empennage featured no common THS, but variable moveable leading edge devices, with altering camber (preferably in a smooth way), like a more advanced droop nose device, moveable together with at least one stage of rear edge deflection devices (elevators) to change overal cambering and profile geometry of horizontal empennage for trim and control.

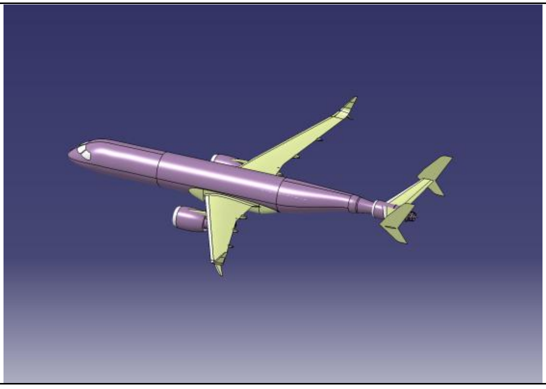
Tornado 5 D Rear Engine Maximum Thrust Contributions at take-off an initial climb @ MSL ISA without considering available power limit by installed gasturbine(about 5600 kW)	
Thrust by hybrid electric DRP + CDRP roughly	17387 + 24333 = 41720 N
Thrust by coventional combustion part with considering offtakes	6132 N
Rear gondela is already bookkepped in overal aircraft L/D	
Overall Thrust in take-off and initial climb	47 852 N

Tornado 5 D Single (ready to be mounted on pylons) change in weights compared to Tornado 5 D Rear from table before	
Central Font Hub, birds strike approved	+ 90 kg
Non Removal of APU from Reference Aircraft	+150 kg
	3209 kg



Genius Pro can additionally feature a Pinochio Propulsor, in the nose cone the weather radar can be implemented, no additional nacelles drag, ready to host DRP and CRDP, intake air used for bleed, air conditioning, and /or out on slotted nozzles on propulsive fins, on the right fin side to strengthen circulation and therefore propulsive force.

24 Pictures of better World Version



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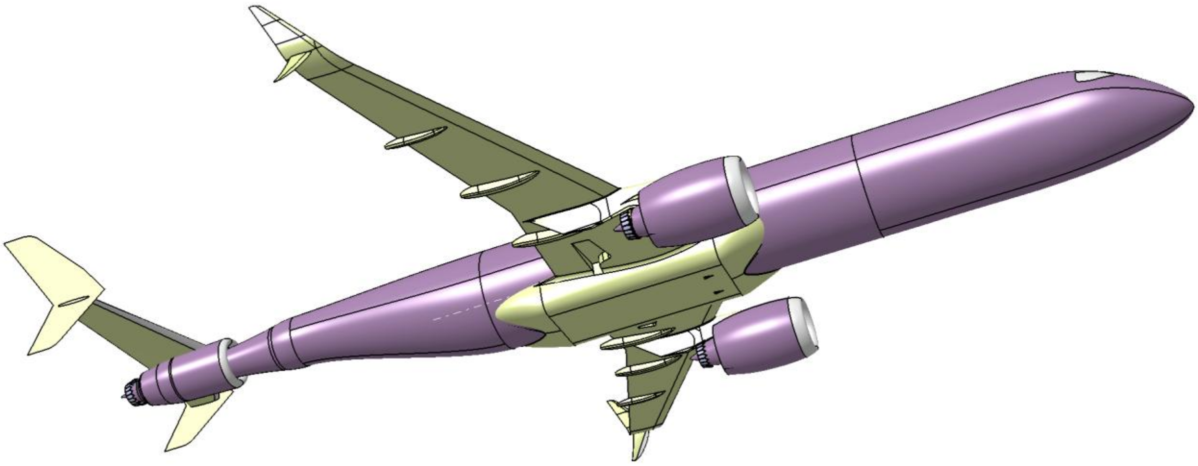

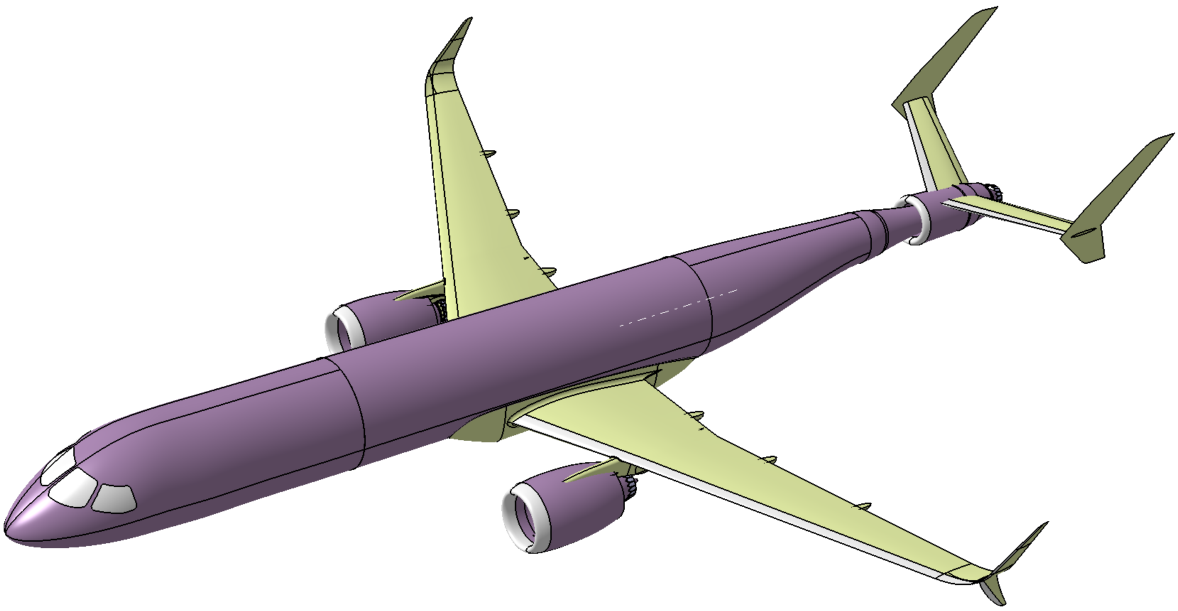

25 Ducted or Open rotor propulsion

For those, who tend more to Open Rotor Propulsion, there is a now further improved open rotor version of a 150 seated SA-aircraft, with fuel savings to CEO on typical short range missions of now more than 40%, with basic old literature to be found on [3,with h-link] and [4,with h-link].

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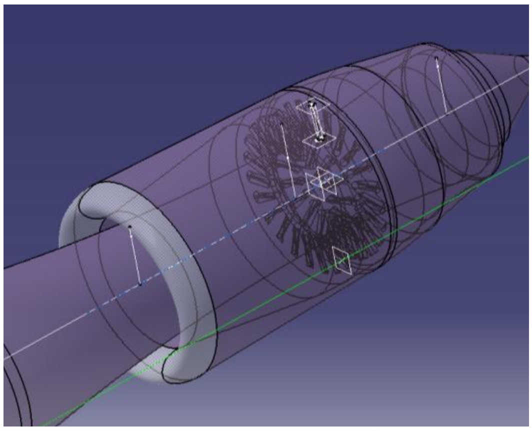

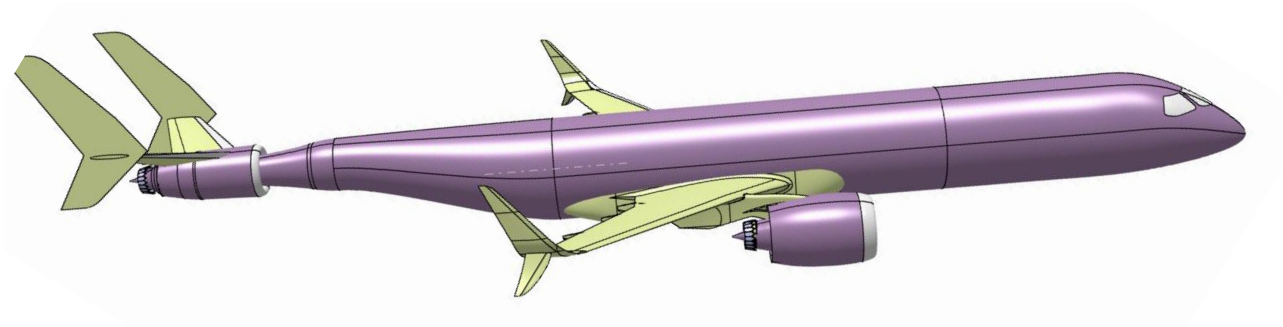

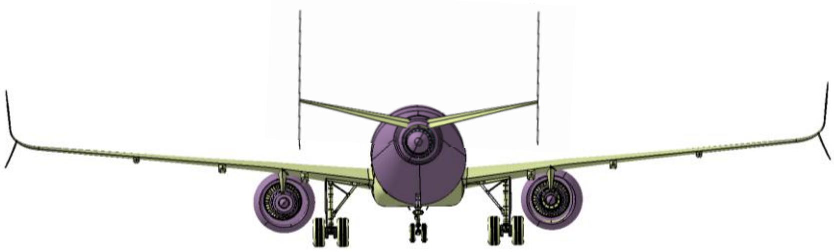

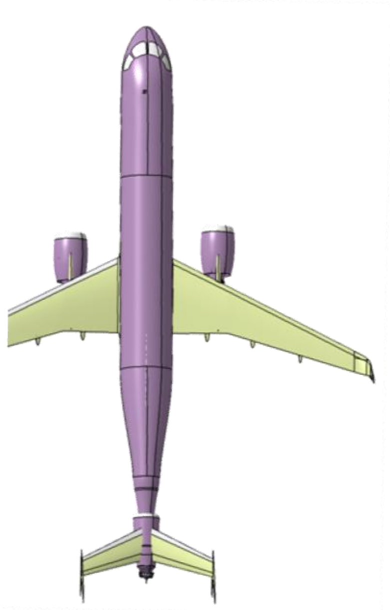

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