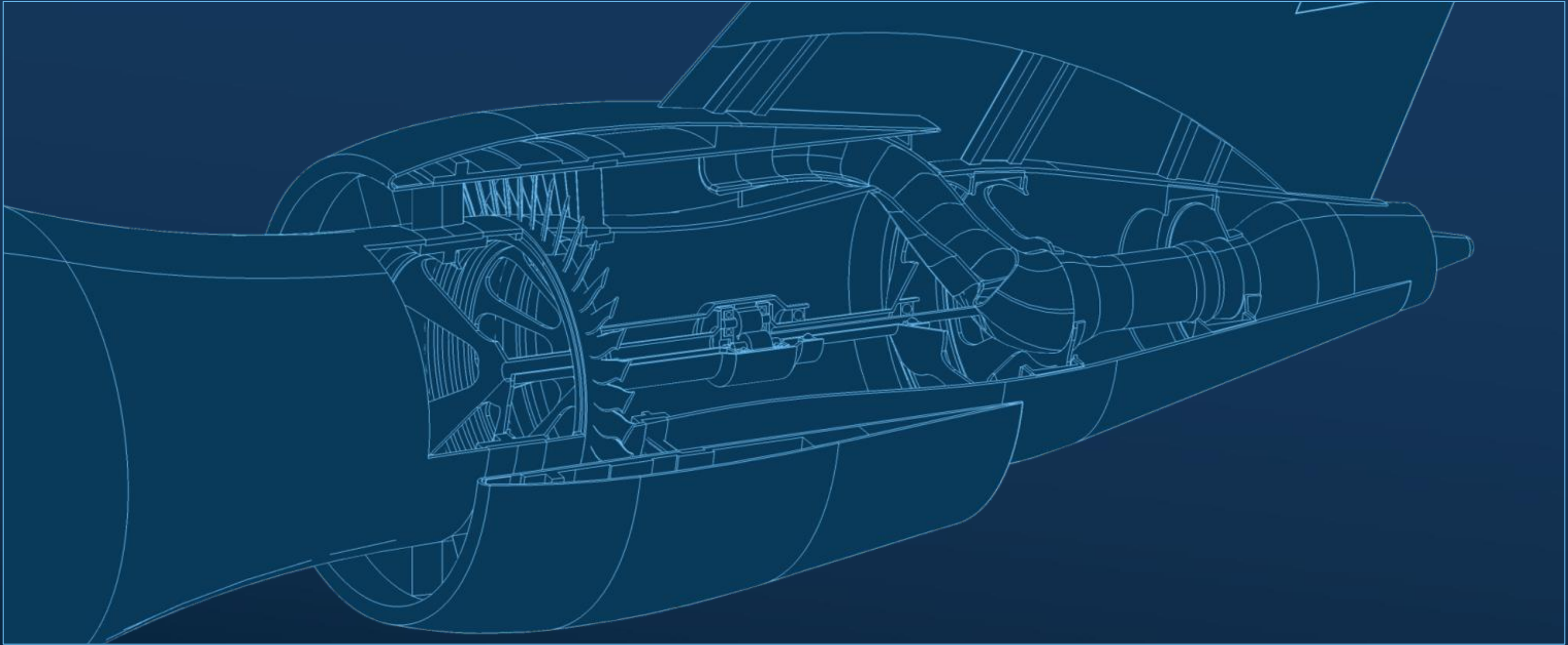
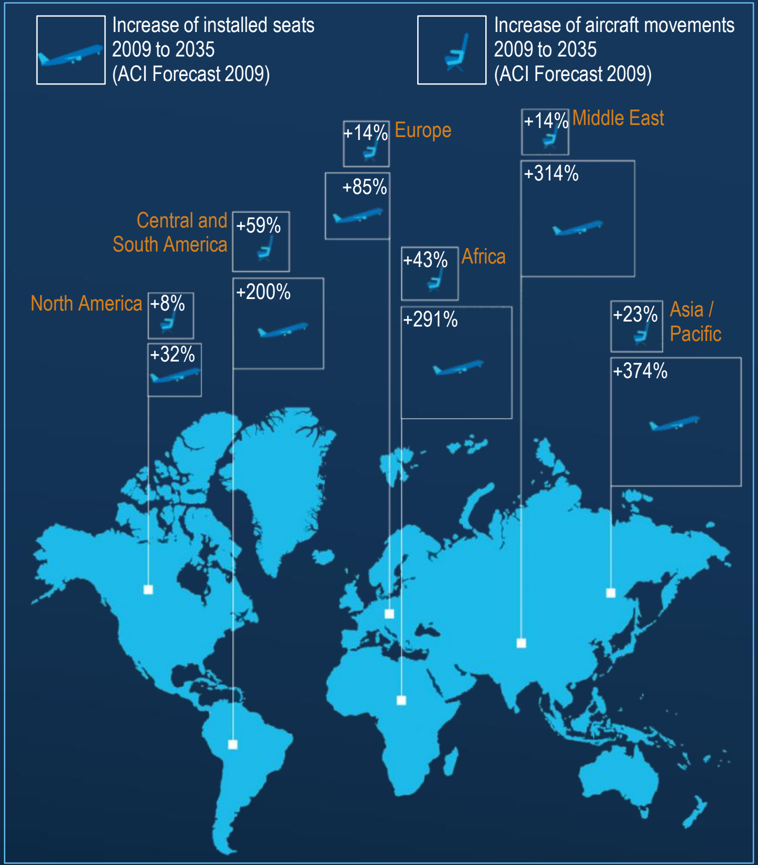
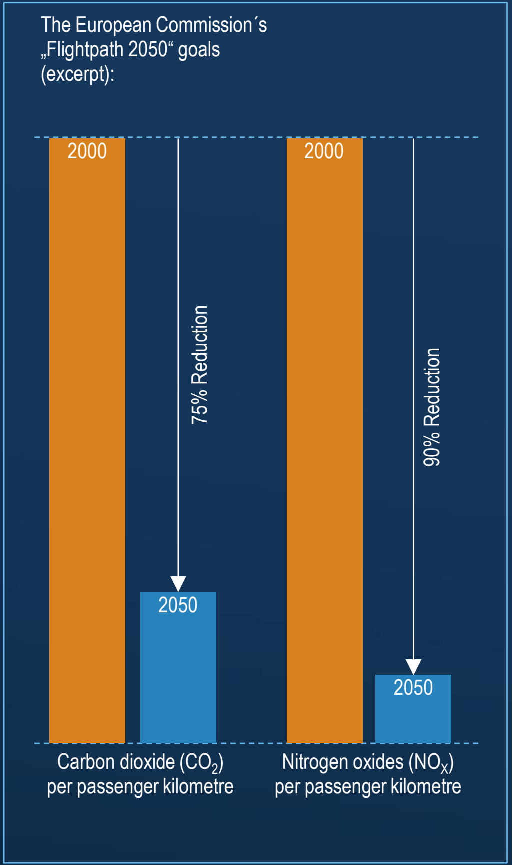
Concept study „Propulsive Fuselage“

Bauhaus Luftfahrt
Neue Wege.







1) Motivation

Global air traffic volumes are forecast to further dramatically increase in the coming decades. Especially in emerging markets like Asia, more and more people will be able to afford travelling by plane. As a consequence, the number of aircraft movements will multiply.

This development even further increases the enormous challenge to make aviation more energy-efficient and ecological. The European Commission's „Flightpath 2050“ goals for example, by the year 2050 demand a reduction of carbon dioxide and nitrogen oxides emissions of no less than 75 respectively 90 percent relative to the year 2000.

In order to meet such ambitious goals despite the substantial growth rates in air traffic, the evolutionary enhancement of aircraft and propulsion systems is not expected to be sufficient.

DisPURSAL

Distributed Propulsion and Ultra-High Bypass Rotor Study at Aircraft Level

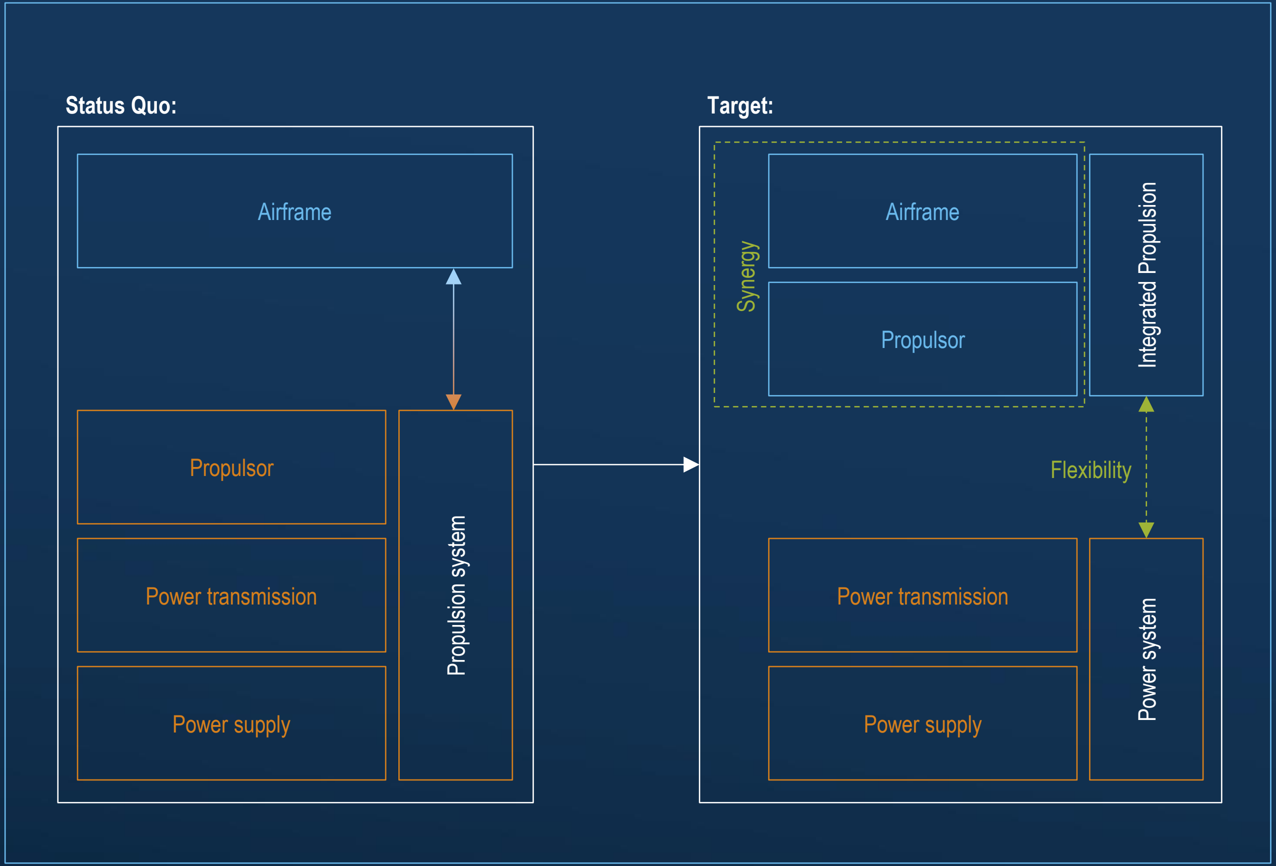
2) The DisPURSAL Project

In view of the more and more difficult enhancement of classic propulsion architectures, a research project called „Distributed Propulsion and Ultra-High Bypass Rotor Study at Aircraft Level“ (DisPURSAL) explores radically-new approaches for future aircraft concepts. The project was launched in February 2013 and is funded by the European Commission in line with its 7th research Framework Programme.

In addition to Bauhaus Luftfahrt as the project coordinator, the international consortium of DisPURSAL and its industrial advisory board consist of well-known players from industry and academia, such as MTU Aero Engines, Airbus Group, the French Office National d'Études et de Recherches Aérospatiales (ONERA), the Russian Central Institute for Aviation Motors (CIAM) and the German Aerospace Center (DLR).

SEVENTH FRAMEWORK PROGRAMME

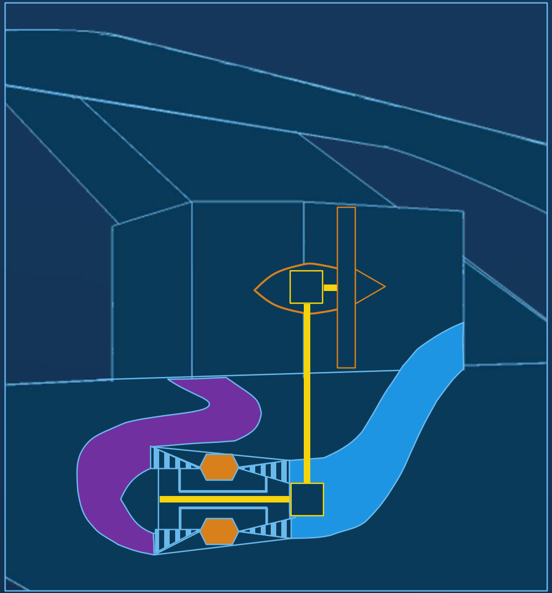
Bauhaus Luftfahrt Neue Wege. | ONERA THE FRENCH AEROSPACE LAB | ЦИАМ | DLR | AIRBUS GROUP | MTU Aero Engines

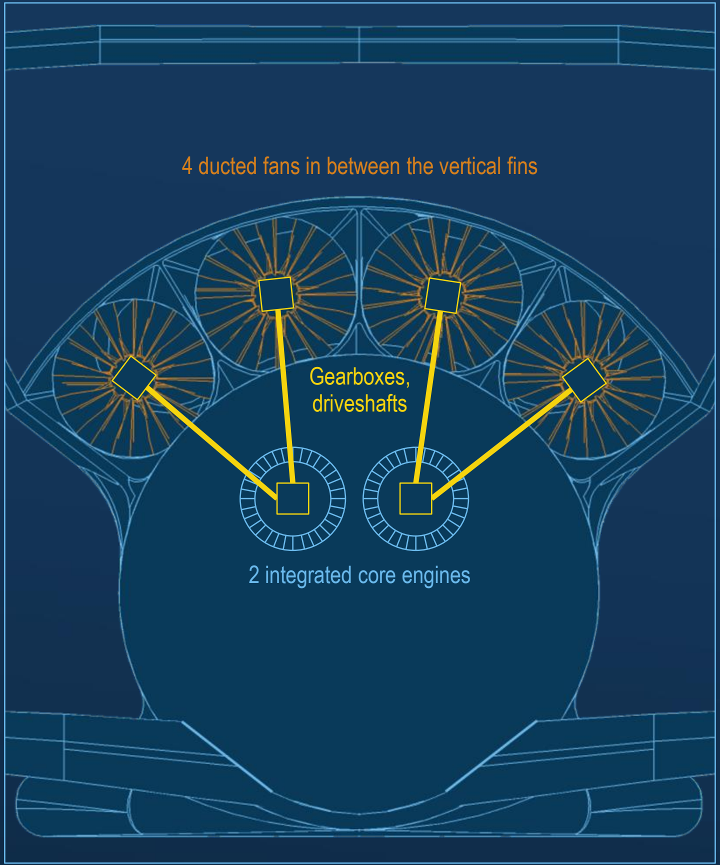


3) „Distributed Propulsion“

The research work conducted in DisPURSAL mainly focuses on breaking with the classical weak coupling of airframe and power plant systems in order to explore synergies from an intelligent integration of propulsive devices along the entire aircraft.

The synergistic effects aimed at, include reduced aerodynamic drag, improved noise shielding, airframe structural relief, as well as potential manoeuvering control power augmentation. The local separation of power generation and thrust production, and, the corresponding increase in aircraft design flexibility is expected to be a key factor in this endeavour. In particular, the distribution of thrust along main components of the airframe, so-called „distributed propulsion“, may facilitate great benefits in this respect.



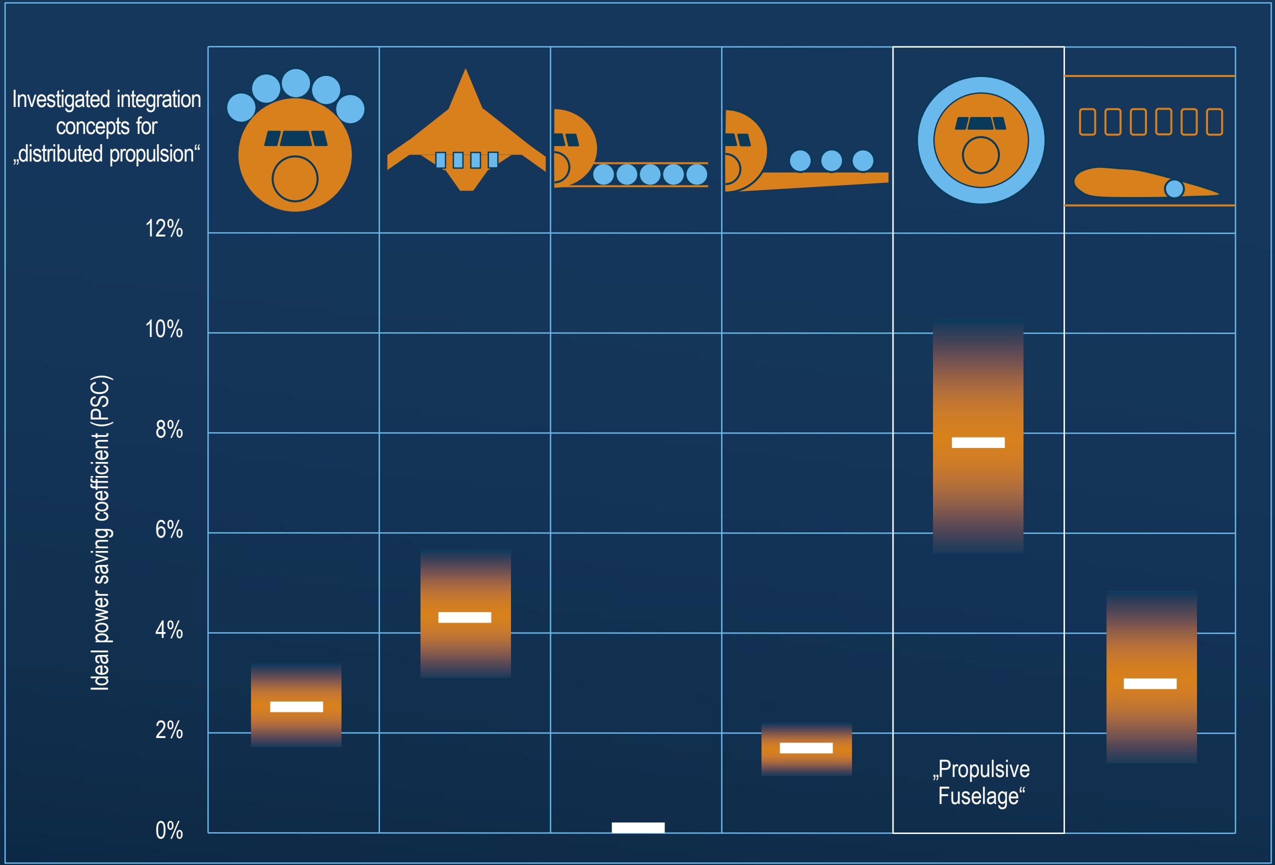


4) Integrated concepts of „distributed propulsion“

In its integrated concept study „Claire Liner“, Bauhaus Luftfahrt and MTU Aero Engines have already presented a promising concept using „distributed propulsion“. Using gearboxes and drive-shafts, each of the two core engines (gas turbines) installed inside the fuselage of this short-to-medium range airliner powers two large ducted fans atop the fuselage.

Since one core engine drives two fans, the so-called bypass-ratio as an indicator for engine propulsive efficiency is greatly enhanced without the usually expected larger fan diameters and corresponding weight and drag penalties.

Moreover, installing the noisy core engines inside the fuselage the Claire Liner would allow for effective noise shielding, significantly reducing the external noise level in comparison to conventional engine architectures.

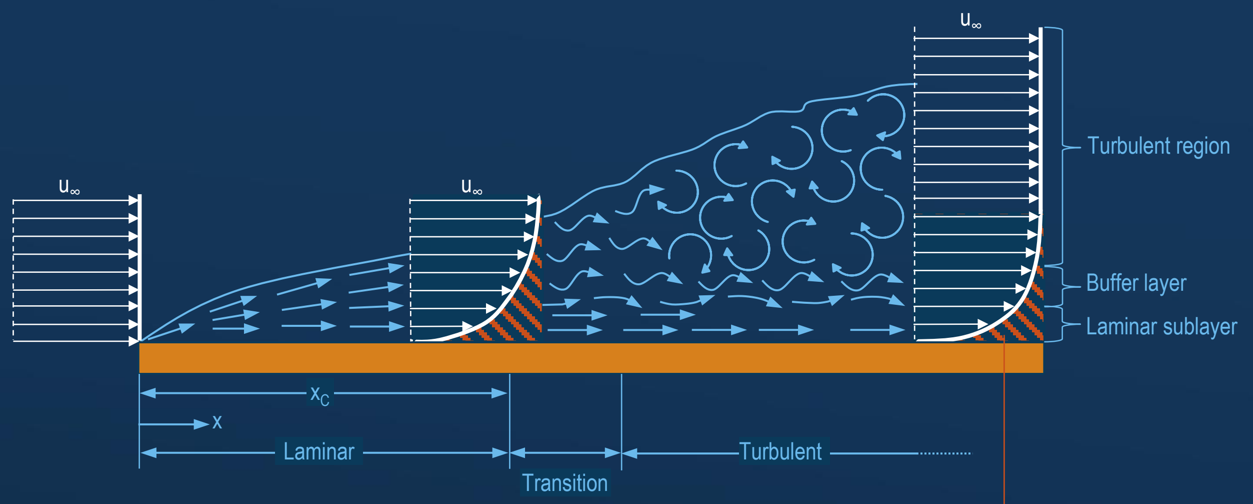


5) More possibilities of „distributed propulsion“

Apart from the Claire Liner, Bauhaus Luftfahrt in recent years investigated numerous additional integration concepts for „distributed propulsion“ architectures in detail. In doing so, researchers place special emphasis on the so-called power saving coefficient (PSC) proposed by Smith as a most important down-selection criterion.

Based on this metric, Bauhaus Luftffahrt is able to estimate to what extent the installed engine power (and hence fuel burn) could be reduced due to synergies between airframe and propulsion system.

Indicating a PSC of up to ten percent, one rather unconventional idea emerged from Bauhaus Luftfahrt's down-selection process as the most promising concept : The so-called „Propulsive Fuselage“:

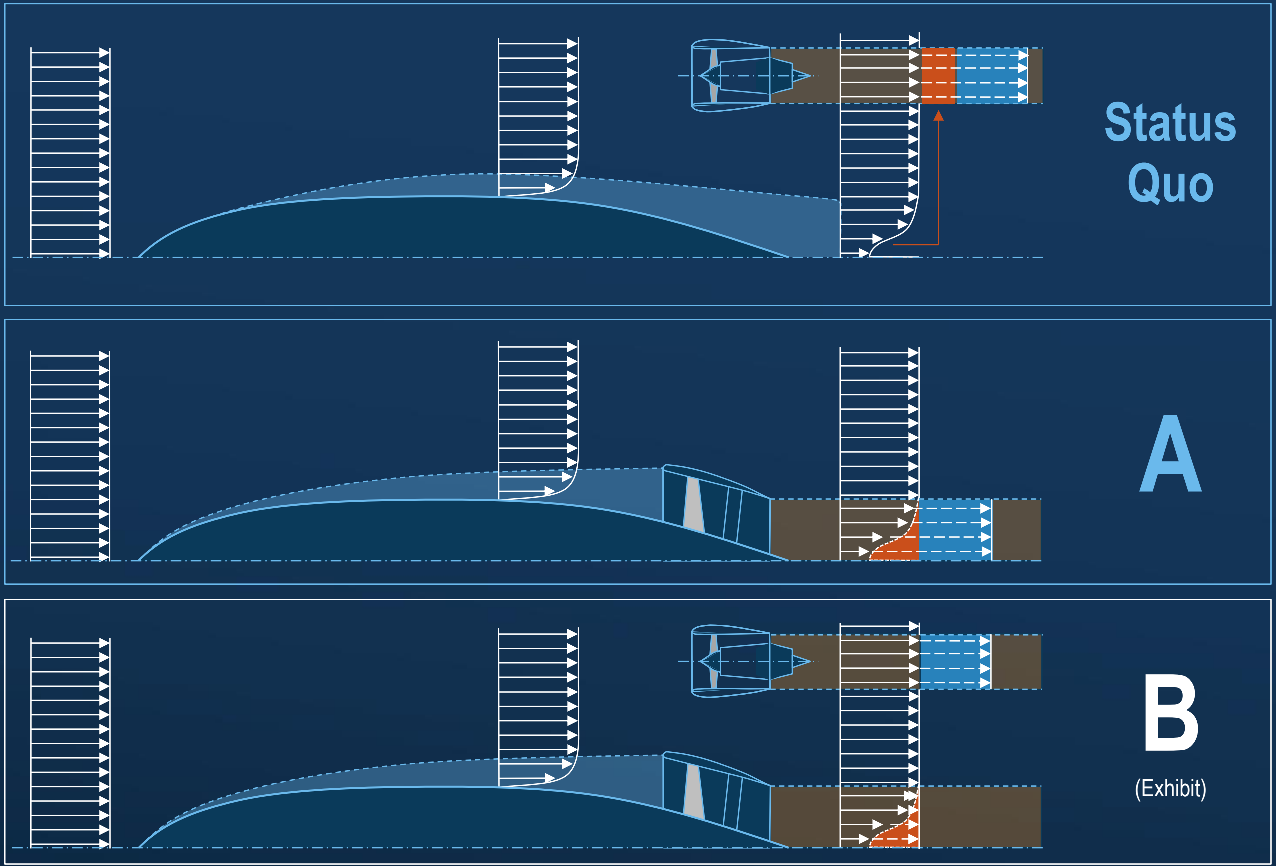


6) Boundary Layer Ingestion

The main reason behind the significant savings potential of the „Propulsive Fuselage“ concept is its distinctive ability to ingest the so-called boundary layer surrounding an aircraft‘s fuselage.

As in every body immersed within a flow of air, interactions between the fuselage surface and air flow layers in close proximity lead to skin friction that affects the velocity gradient in the boundary layer, leading to increased drag.

Ingesting this decelerated boundary layer into a dedicated propulsion system and re-accelerating it to free-stream velocity could potentially eliminate a large percentage of the fuselage drag and significantly improve aircraft efficiency.

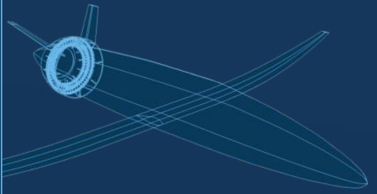


7) Possibilities of Boundary Layer Ingestion

In a conventional podded power plant arrangement (status quo), the external engine has to produce excess thrust (red) in order to compensate for the „velocity gap“ by the fuselage wake. Relative to the classical approach, two possibilities emerge for the utilisation of boundary layer ingestion:

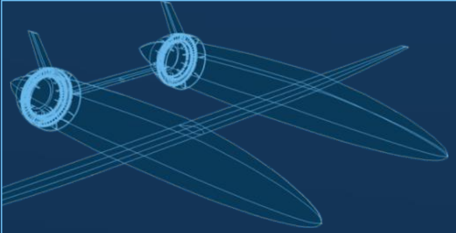
Option A: Propulsive Fuselage as sole thrust source
A fuselage mounted fan re-accelerates the ingested boundary layer back to free-stream velocity, thereby re-filling the “velocity gap” in the aircraft wake (red) while also generating the entire thrust for the aircraft (blue).

Option B: Combination with podded turbofans
A fuselage mounted fan is mainly used to fill the wake (red) while the required residual thrust (blue) is generated by classic turbofan engines in underwing pods. This approach appears to be the most promising and hence formed the basis for the exhibited model.



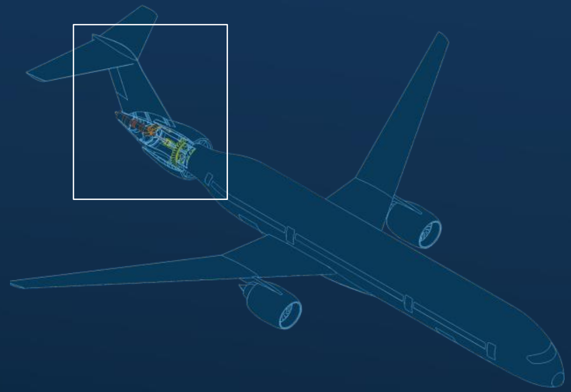
Single fuselage with „fuselage fan“ as sole source of propulsion:

› **No redundancy in the propulsion system**



Twin-fuselage concept utilizing one fan in each fuselage:

› **Plausible solution in order to ensure the required redundancy**



Combination of a „fuselage fan“ with conventional wing-mounted and podded engines :

» **Introducing the propulsive Fuselage as a 21st century twist on the traditional aft-fuselage mounted engine / S-duct or straight-duct approach**

» **Promising solution in order to ensure required redundancy**

» **Conceptual basis for the exhibit**

8) Design aspects at aircraft level

In addition to the effective utilisation of boundary layer ingestion, several design aspects and operational boundaries also have an impact on the definition of a „propulsive fuselage“ concept.

Due to the fact that future aircraft concepts will have to adhere to the same safety standards as state-of-the-art designs, the application of a singular fuselage fan does not represent a plausible solution as it does not allow for the required redundancy in case of an engine failure.

Thus, Bauhaus Luftfahrt for example considered a twin-fuselage solution safeguarding the required redundancy by integrating a fan into each fuselage. However, the combination of a fuselage fan with two conventionally installed engines was considered the most promising solution from both redundancy and design scalability perspectives, also forming the basis for the exhibit which is explained in detail on the following pages.

Views:

Aircraft

Perspective

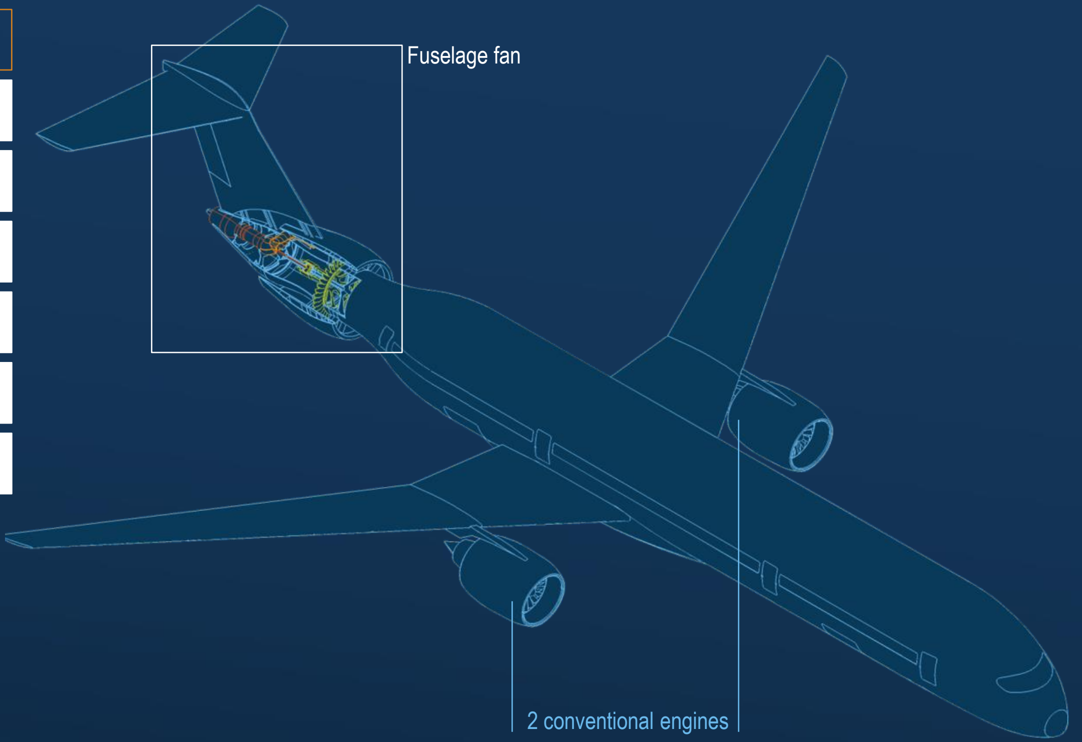
Side view

S-Duct

Core engine

Gear unit

Fuselage fan



9) Details of the exhibit

a) Integration into the aircraft

The rear fan encircles the aft section of the fuselage. From 80 percent of its length onwards, the aft fuselage is tapered as an S-shape towards the fan intake duct, providing for an efficient air inflow. Due to this design feature, the fuselage fan effectively ingests the boundary layer and re-accelerates it to free-stream velocity. In doing so, it accounts for around one quarter of the aircraft overall required thrust, while the conventional podded engines act as the source of all remaining thrust required.

Mainly for aerodynamic and structural integration reasons, a so-called „T-tail“ configuration was chosen for the empennage. The location of the core engine inside the aft-fuselage was tailored to minimise critical systems impacts in case of engine disk burst.

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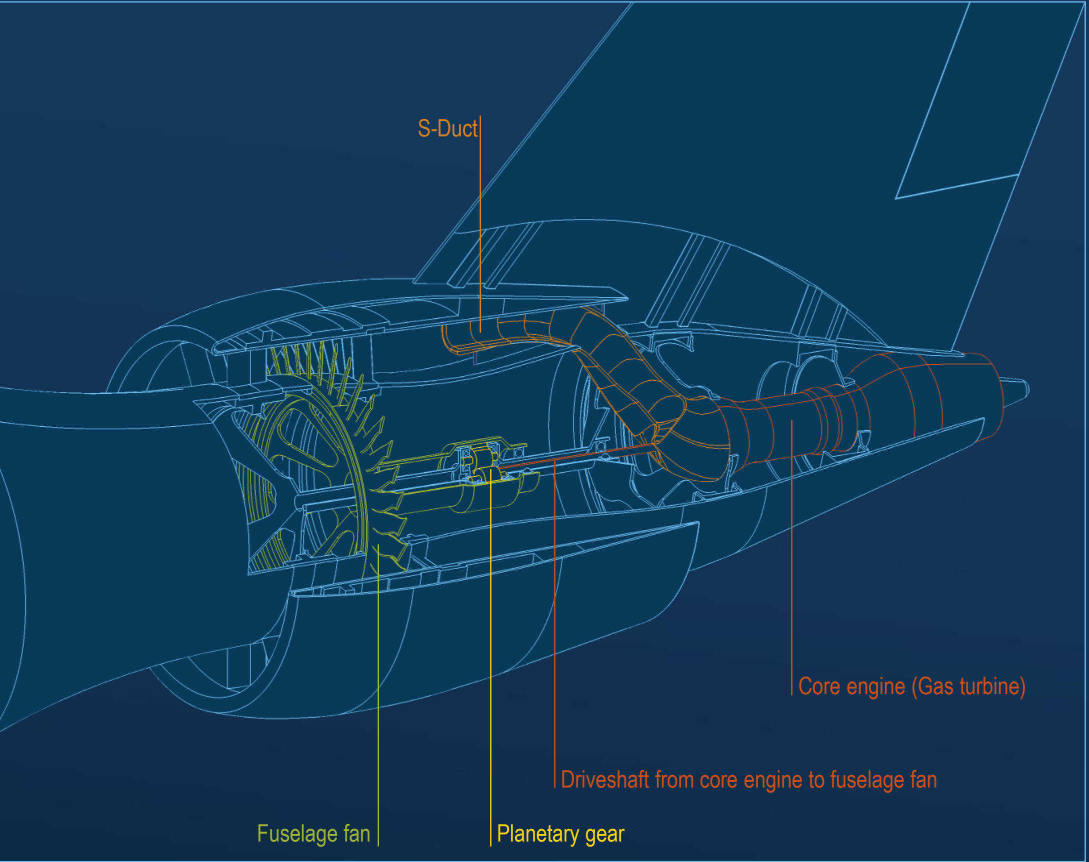


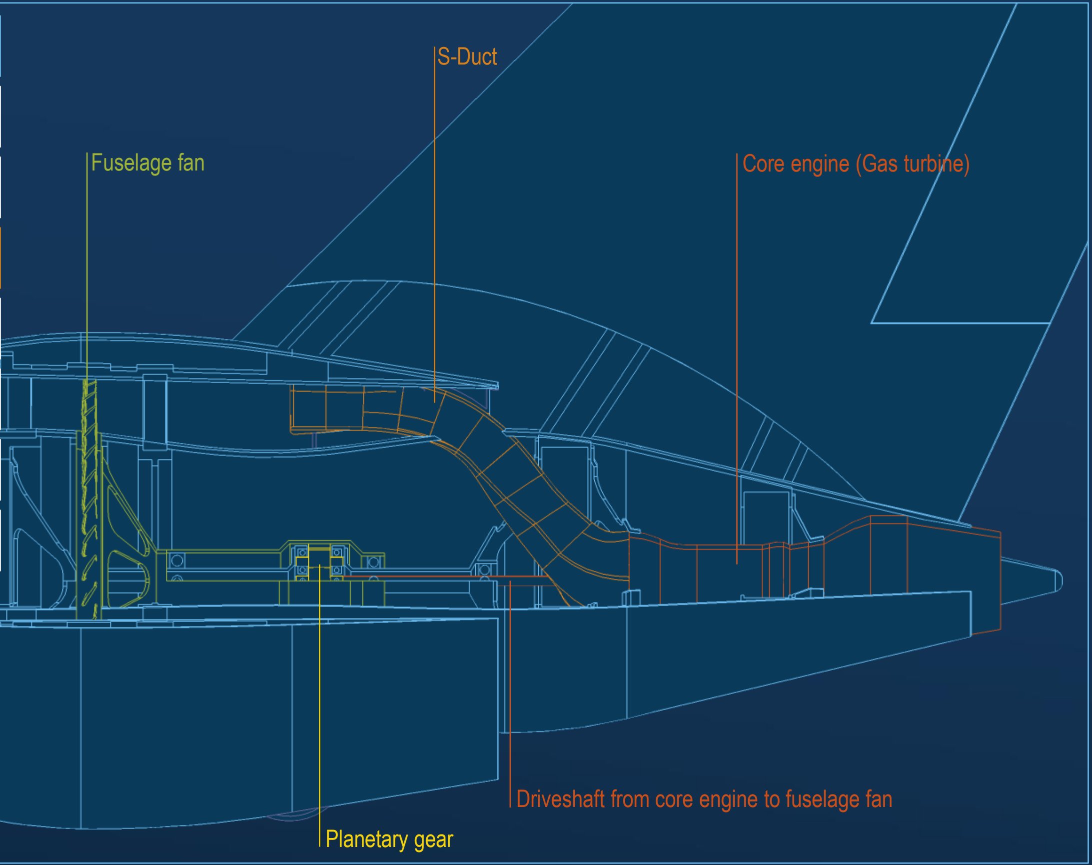
9) Details of the exhibit

b) Overview of key components

The exhibit displays all system components with particular importance to the „Propulsive Fuselage“ concept functionality.

A small percentage of the air ingested by the fan enters the so-called S-duct in the tailfin root. The S-duct geometry guides the air into the core engine mounted at the most aft region of the fuselage. Therein, the air is compressed, mixed with fuel, ignited in the combustion chamber and expanded in the turbine, which finally rotates the drive-shaft.

The high speed of the drive-shaft is reduced by a ratio of 5:1 through a planetary gear system. Hence, the fuselage fan rotates at its optimum speed, effectively providing for boundary layer ingestion and fuselage drag reduction.



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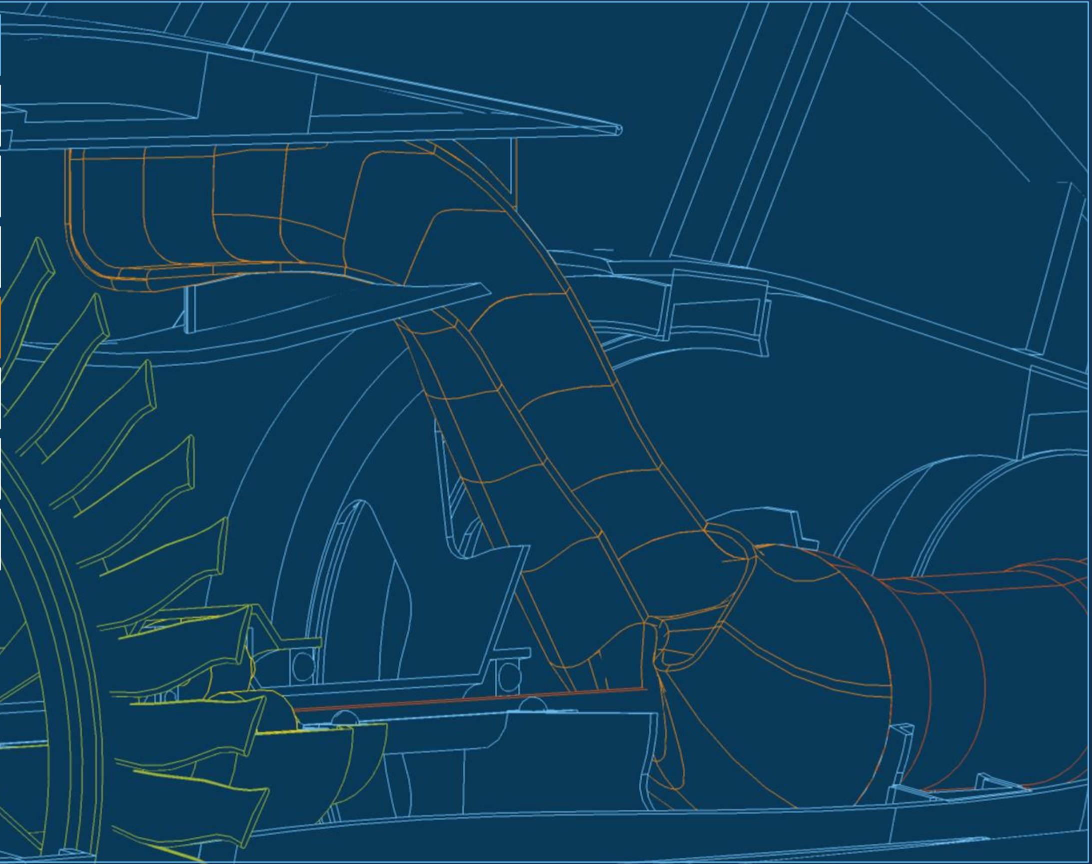

9) Details of the exhibit

c) The „S-duct“

The S-shaped duct system starts right behind the fuselage fan and guides a small part of the ingested air from the bypass duct towards the core engine mounted towards the rear of the fuselage.

The so-called bypass ratio hence describes the amount of air routed around the core engine by the fuselage fan (bypass) relative to the amount of air that is compressed, ignited and expanded in the gas turbine. With a bypass ratio of 18:1 the configuration on display surpasses state-of-the-art engines architectures by a significant margin.

In its general shape, the S-duct moreover resembles similarities to inlet duct designs of modern turboprop engines.

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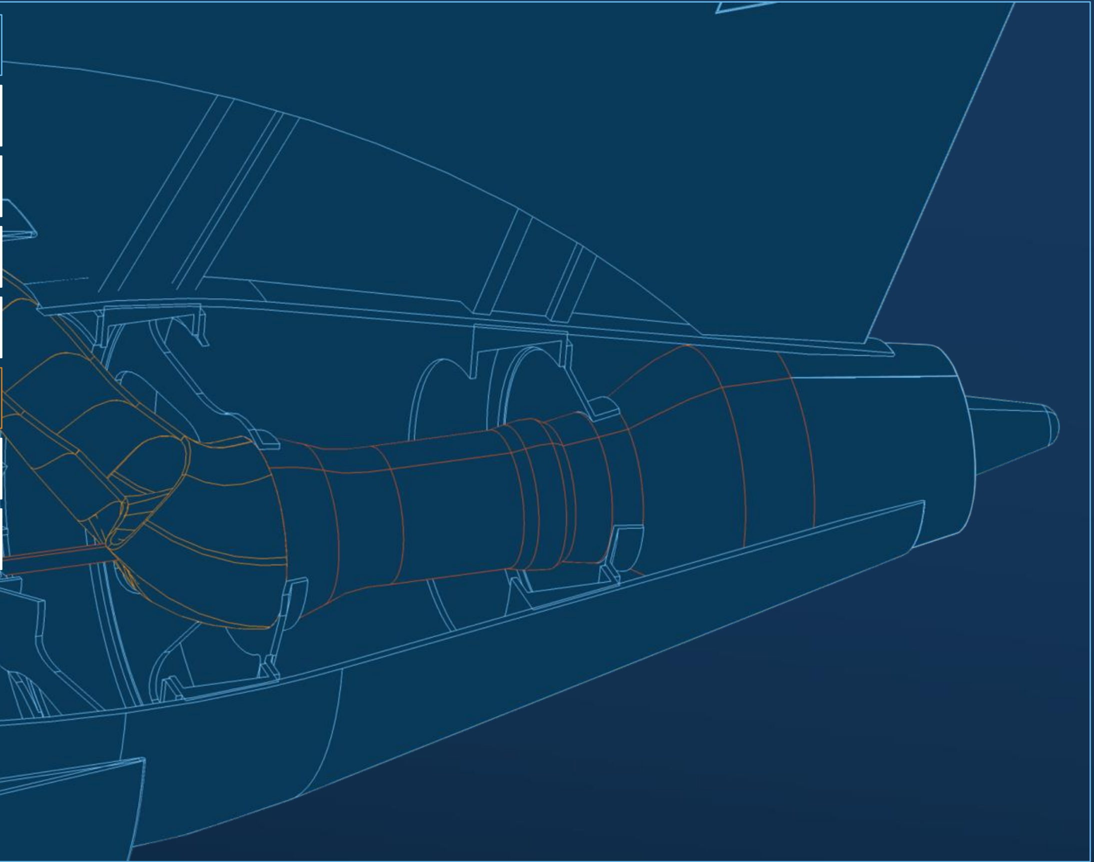


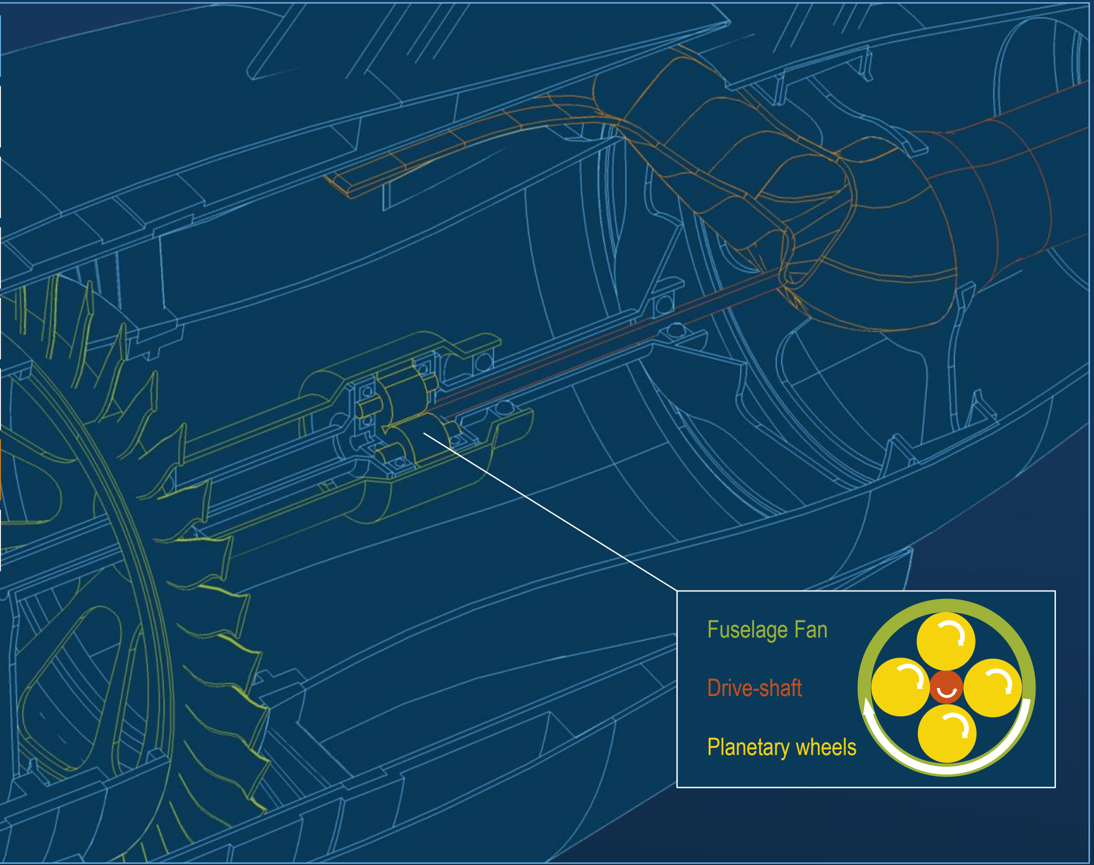
9) Details of the exhibit

d) The core engine (Gas turbine)

Fed with air through the „S-duct", the core engine mounted in the very rear of the fuselage generates the power required to drive the fuselage fan. For reasons of commonality, identical core engine part numbers between conventional underwing power plants and the fuselage fan were emphasised.

The highly efficient core engine architecture is facilitated by a high-speed low-pressure turbine and a very high overall pressure ratio. Moreover, as expected for future „More / All-Electric Aircraft", the on-board systems architecture eliminates the need for bleed air extraction from the engines.

The exhaust nozzle of the core engine is designed and integrated at the very aft of the fuselage in order to minimise fuselage base drag.



9) Details of the exhibit

e) The fuselage fan gear system

The planetary gear unit reduces the high speed of the low-pressure turbine to an optimum level for the large fuselage fan.

The turbine‘s drive-shaft acts as the center gear (the „sun“), while four planetary wheels drive a lightweight ring gear (the fuselage fan).

The reduction gear ratio of 5:1 between drive-end and output-end of the fuselage fan is slightly higher than that of the wing-mounted engines also designed as geared turbofans.

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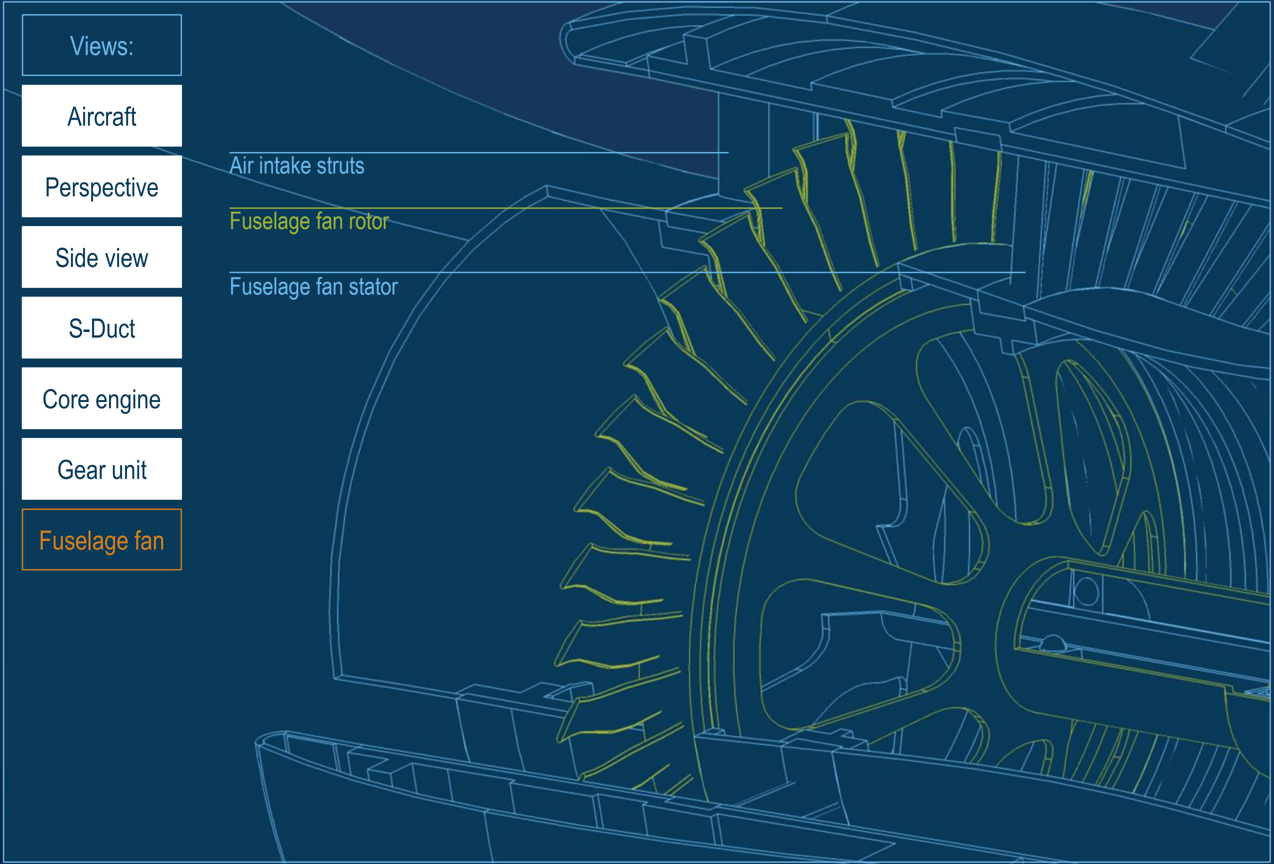
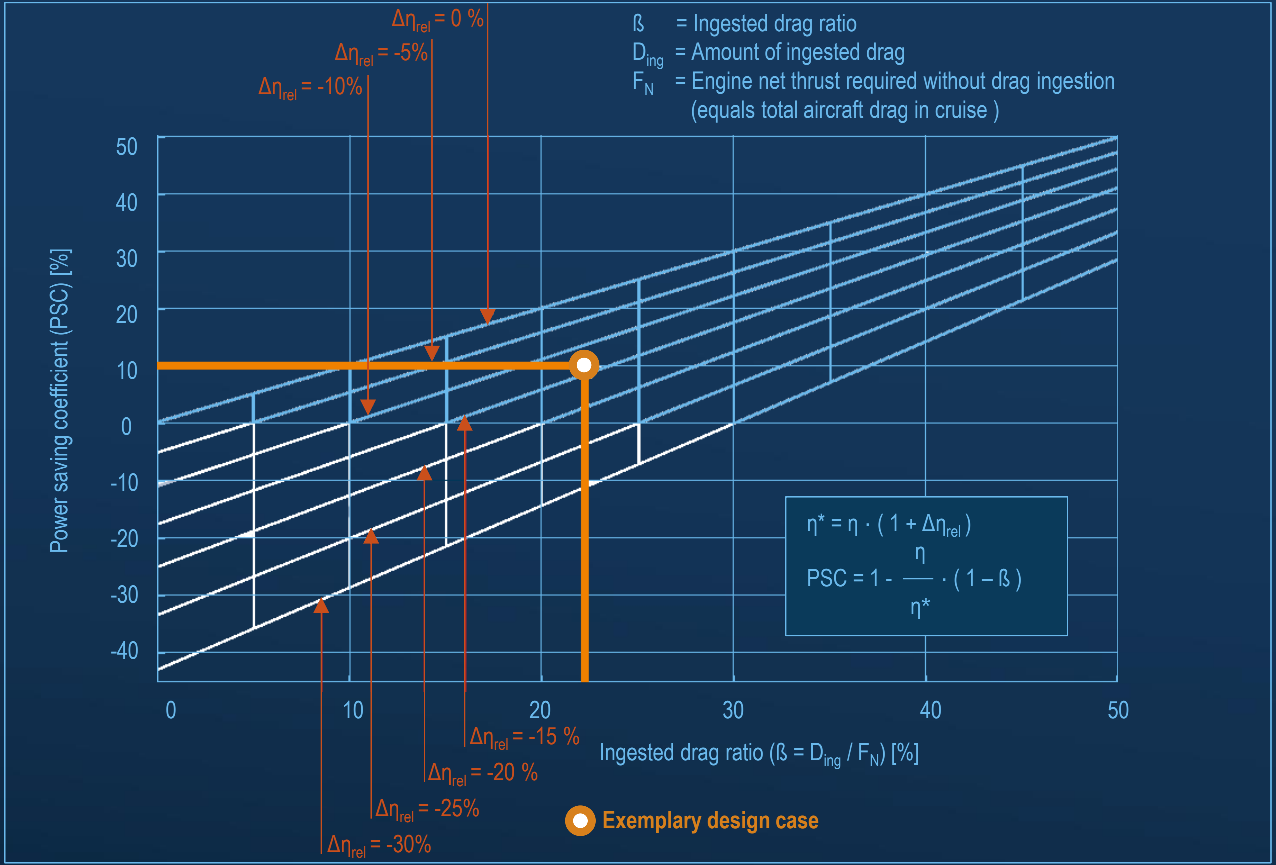


9) Details of the exhibit

f) The Fuselage Fan

The exhibit features a fuselage fan which is mainly designed to fill the „velocity gap“ and eliminate aircraft wake drag. Hence, the fan itself is specially designed, both aerodynamically and structurally, to effectively operate in these unconventional flow conditions.

The fuselage fan is designed as a single-rotating fan with a diameter of approximately four meters. Despite its large size, it is required to provide a modest amount of the aircraft overall thrust requirements. The struts mounted within the air intake duct, which measures a height of approximately 0.5 meters, also significantly contribute to the vertical tail structural integrity.



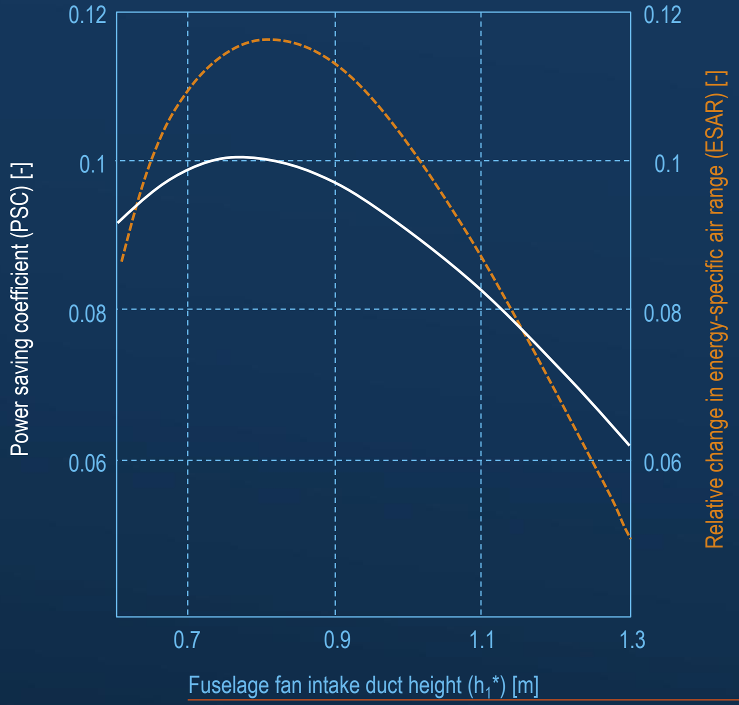
9) Savings potential

a) Possible reduction of installed power

On the one hand, the savings potential of a „Propulsive Fuselage“ can be characterised as follows: The higher the ingested drag ratio, the less installed power (and hence energy consumption) is required for the aircraft.

On the other hand, the low impulse of the ingested boundary layer and the complex channeling of air towards the core engine may significantly reduce the efficiency within the propulsion system.

However, taking both effects into account, the overall drag reduction achieved through the „Propulsive Fuselage“ outweighs the internal propulsion system losses by far. In the displayed example, an ingested drag ratio in between 20 and 25 percent reduces the propulsion system efficiency by roundabout 15 percent, but the power saving coefficient on the overall aircraft level still accounts to approximately ten percent.



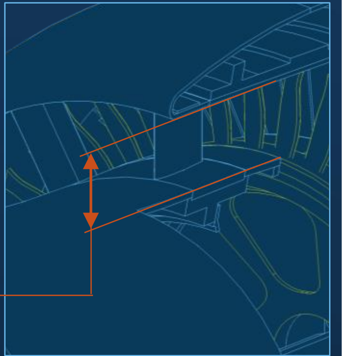
Study settings:

Altitude 35,000 feet
ISA standard atmosphere
Airspeed: Mach 0.8

Baseline aircraft
Maximum take-off weight: 217 tons
Fuselage length: 65 metres
Air intake at 80 percent of fuselage length

Results relative to reference propulsion system
(Geared turbofan, bypass ratio 18)

Generic pre-study:
Results valid for a configuration in which a fuselage fan acts as the sole source of propulsion



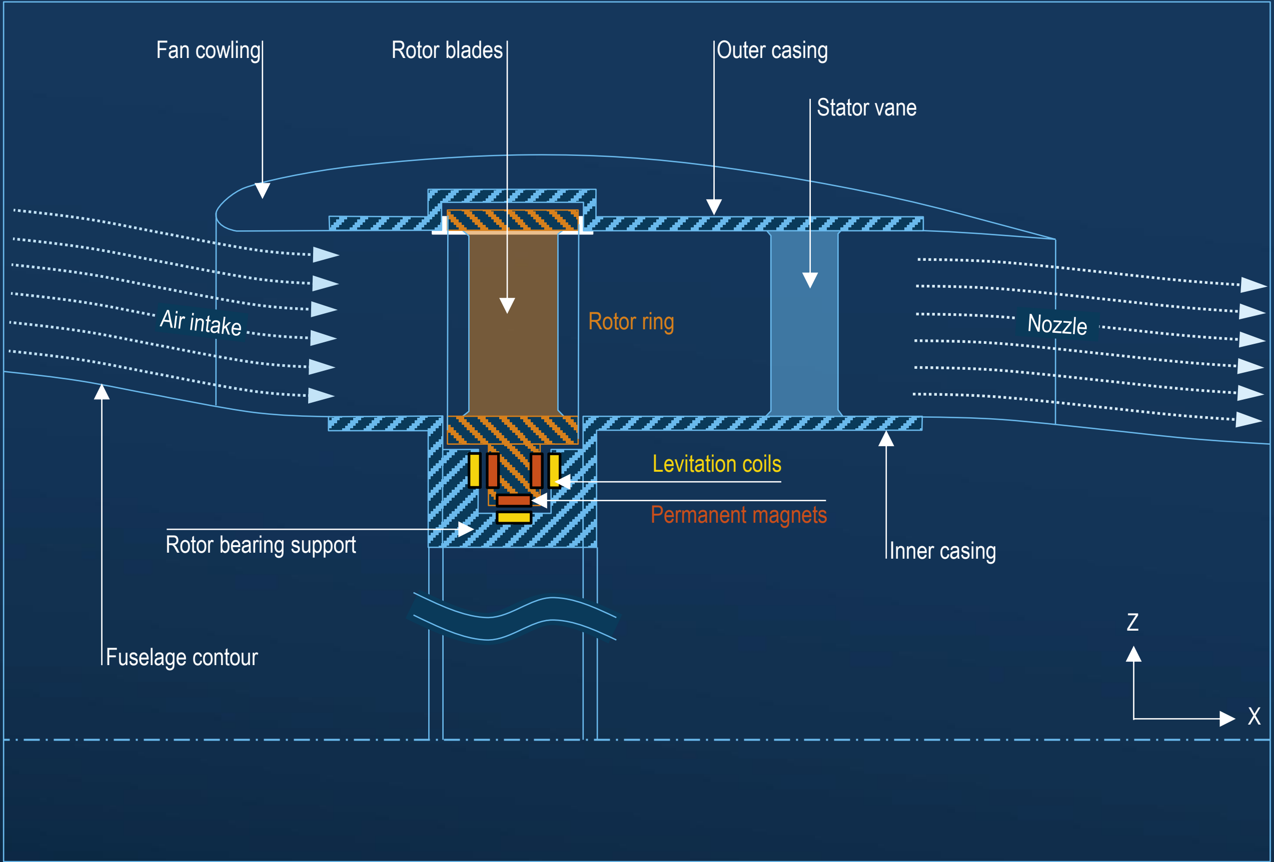
10) Savings potential

b) Impact on flight performance

When integrated on the aircraft, geometric constraints such as the required ground clearance during take-off rotation and landing, the additional weight and drag of larger fan designs further limit the fan diameter for optimum vehicular efficiency.

The energy-specific air range (ESAR) is a convenient figure-of-merit for the energy efficiency of the aircraft, taking into account, the power plant efficiency, as well as weight and drag characteristics of the overall vehicle.

In case all thrust demand of a typical wide-body transport aircraft would have to be provided by a single fuselage fan, the ESAR-optimum intake duct height may be found at approximately 0.8 metres.



11) Outlook / Perspectives for e-Aviation

Although the „Propulsive Fuselage“ promises significant savings potential in combination with conventional gas turbines, researchers at Bauhaus Luftfahrt expect even more interesting perspectives from the exploitation of alternative energy sources for such propulsion systems.

Most of all, a possible advent of electro-mobility in commercial aviation is expected to open up many new possiblities for this engine architecture, as both hybrid and fully-electric approaches would provide aircraft designers with numerous additional degrees-of-freedom in the integration of the propulsive devices.

As one promising simple and elegant idea, researchers at Bauhaus Luftfahrt envision a fuselage fan which is rotated by magnetic levitation („MagLev“) technology. In this approach the fuselage fan would be powered from on-board sources of electrical energy.

11) Conclusion

The synergy combination of propulsion system and aircraft structure to form a „Propulsive Fuselage“ which effectively ingests the boundary layer is considered a promising pathway towards a significant increase in overall efficiency of future aircraft.

The DisPURSAL project will continue to explore this type of propulsion system until early 2015. However, together with MTU Aero Engines and other partners, Bauhaus Luftfahrt will carry on with its activities in the field of both distributed propulsion and „Propulsive Fuselage“ technology even beyond the project‘s funding period in order to assess the possibilities and potentials of this approach in higher levels of detail.