Preliminary Design of a Heavy Short- and Medium-Haul Turboprop-Powered Transport Aircraft

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This paper presents the conceptual design of a high-capacity turboprop-driven transport aircraft for short- and medium-range operation. It also depicts the iterative procedure and results of the design process as well as the design methods involved. The aircraft design is based on a market analysis that reveals that the short- and mid-haul markets represent a major fraction of the air transport sector. With two passenger decks and one cargo deck, the turboprop aircraft is intended to operate with a maximum capacity of 420 seats and five tons of cargo over a travel distance of 3,000 km. The design enables operations at airports with underdeveloped infrastructure. Thus, it is especially suitable for fast growing markets in emerging countries. The use of four turboprop engines, each delivering a take-off power of 9.5 MW, enables more energy efficient flight operations on short routes than conventional aircraft types.

Nomenclature

A	=	aspect ratio
ARC	=	aerodrome reference code
b	=	wingspan
D	=	drag
D_{prop}	=	propeller diameter
FAR	=	Federal Aviation Regulations
h	=	altitude
l	=	length
L	=	lift
m	=	mass
$MTOW$	=	maximum take-off weight
P	=	power
S_{ref}	=	reference area
SFC	=	specific fuel consumption
T/O	=	take-off
W	=	weight
W_e	=	empty weight
W_f	=	fuel weight
W_0	=	gross weight / take-off weight

I. Introduction

THE civil aviation sector is experiencing remarkable rates of growth in many regions of the world. It is likely that this development will continue in the next decades. However, in some areas, capacity and regulative constraints are limiting further growth already today. Rising energy costs and the goal to reduce the impact of aviation on the environment present further challenges that the aviation sector has to cope with especially on long term.

New technical solutions are thus required to enable a sustainable future development of the air transport sector. One possible solution is to increase the passenger capacity of short- and mid-range aircraft by operating wide-body aircraft types. Furthermore, an energy efficient propulsion system with low emission characteristics should be used.

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For short-haul aircraft, turboprop engines offer several advantages compared to turbofans once they are operated at lower travel speeds. Besides this, the thrust characteristics of turboprops allow short take-off distances due to a higher thrust at low airspeed.[1] Modern open-rotor concepts also present a promising technology step for short-haul aircraft operation.[2]

This paper presents the preliminary design of a high-capacity turboprop aircraft that is destined for short- and mid-range operation. At first, the most relevant findings of the market analysis that preceded the actual design process are briefly summarized. Then, by analyzing historical aircraft with similar transport mission characteristics, top-level system requirements are determined. Different configurational concepts are examined during the subsequent design process. The impact of alternative positions of system components and shapes of the fuselage on the overall aircraft performance is qualitatively and quantitatively investigated. The final design concept is eventually presented and briefly discussed.

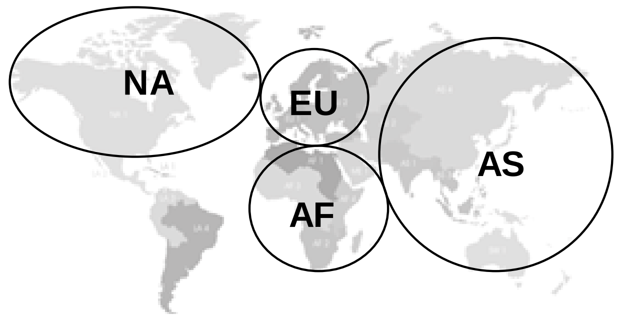

Figure 1. Analyzed world regions. *Map from* [5].

A. Market Analysis

The analysis of the global short- and mid-range air traffic market presented here was based on the market outlooks of Airbus and Boeing.[3,4] The following key findings were determined:

A more or less steady air traffic growth and the replacement of older, less efficient aircraft are driving the demand for new aircraft. In the next 30 years, Asia will become a major market for aircraft sales. Single-aisle aircraft will predominantly operate on regional routes, while twin-aisle configurations will be used for long-haul operations in Oceania. A dominance of Low Cost Carriers (LCCs) is expected on point-to-point routes. LCCs offer less comfort and often use cabin layouts with higher density to reduce operating costs. Especially in Europe, flag carriers will operate wide-body aircraft due to the hub-and-spoke structure of their transport networks. The major part of aircraft sales will be single-aisle aircraft types destined for regional flight operations.

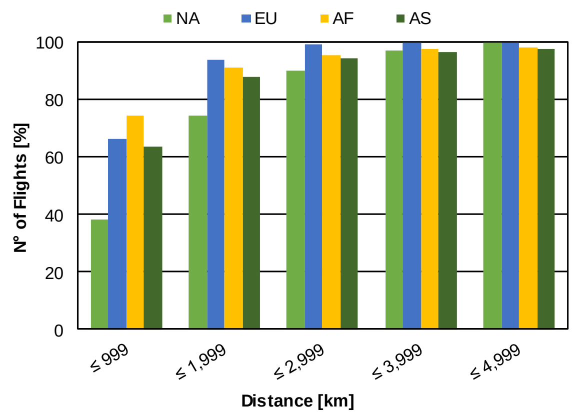

Figure 2. Percentage of flights related to distance served. *Data from* [5].

Besides examining the market outlook publications, OAG data of scheduled flights in June of 2008 were analyzed. The OAG database provides data with regard to the number of flights and transported cargo as a function of distance served.[5] As illustrated in Fig. 1, four world regions were defined for the market analysis: North America (NA), Europe (EU), Africa/Arabia (AF), and Asia/Oceania (AS). Only flights within these regions were considered, i.e., long-range and intercontinental flights were excluded from the analysis. According to Fig. 2, roughly 90% of all flights were operated at distances below 3,000 km in June 2008. Narrow-body aircraft types as the Airbus A320 and the Boeing 737 performed the majority of these flights. In Asia, however, long-range aircraft were operated more frequently on such routes compared to other regions. The average of the transported cargo mass per flight shown in Fig. 3 is more than double in Asia and Africa compared to Europe and North America.

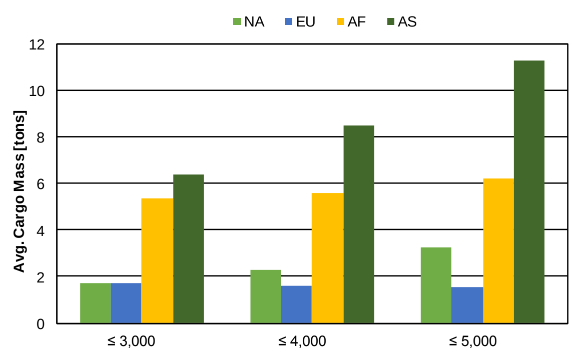

Figure 3. Average of cargo mass transported per flight. *Data from* [5].

B. Existing Turboprop Aircraft and Engines

Information about existing aircraft types that would be able to serve as a basis of comparison for a feasibility study was required prior to the actual aircraft design process. Therefore, data of various historical and current heavy

Figure 4. Relevant heavy turboprop transport aircraft. *Images from [7], antonov.com, and airbusmilitary.com.*

Table 1. Configuration-data of large turboprops. *Data from [6,7].*

Type	**CL-44**	**Tu-114**	**L-188**	**An-10**	**An-70**	**A400M**
PAX	189 - 214	120 - 145	74 - 98	84 - 100	-	-
MTOW [tons]	95.25	187.8	52.67	58.4	130	130
Wing area [m²]	192.8	311	120.77	120	200	221.5
Speed [m/s]	172.2	213.9	180.6	172.2	208	154
Power T/O [kW]	16,848	43,468	11,908	11,760	41,200	32,800
Take-off field length [m]	2,500	2,900	1,500	1,000	600-1,800	1,402
Max. payload [tons]	19.5	21	11	13	47	37

turboprop aircraft types were collected and analyzed. In addition, different powerful turboprop engines were examined in order to identify the technical limits of available thrust and power. Relevant aircraft types are shown in Fig. 4. The corresponding performance data are provided in Table 1.[6,7]

Table 2 summarizes the data of turboprop engines with an equivalent take-off power of more than 10 MW. With 11.025 MW of take-off power, the NK-12 MA is the most powerful turboprop engine that has ever been flown.[1] Experimental engines like the NK-62 and NK-110 reach a maximum power level of more than 15 MW.[8] The D-27 is a modern prop-fan engine with a propeller diameter of 4.5 m.[8]

Table 2. Data and characteristics of relevant turboprop engines. *Data from [8].*

	NK-12M	**NK-12 MA**	**NK-62**	**NK-110**	**D-27**
P_{sl} [kW]	11,025	11,025	unknown	15,883	10,440
M_{cruise} (altitude)	0.68 (at 11 km)	0.56 (at 10 km)	0.75 (at 11 km)	0.75 (at 11 km)	0.7 (at 11 km)
D_{prop} [m]	5.6	6.2	4.7	unknown	4.5
SFC_{Cruise}	58.85 µg/J	58.85 µg/J	13.6 mg/Ns	12.47 mg/Ns	48.44 µg/J

C. Design Requirements and Constraints

The requirements were essentially derived from the findings of the market analysis. In addition, data and performance characteristics of historical aircraft types were taken into account. In this context, we considered the parameters *passenger capacity*, *payload*, *range*, *flight time*, and *take-off/landing distance* as most important among the relevant requirements data.

A passenger capacity of 300 seats was identified as minimum required seat capacity since this would enable the substitution of about two mid-range aircraft units like the Airbus A320 or the Boeing 737 of an airline's fleet. The maximum seat number for the initial concept studies was determined with 500 seats. It is still below the typical configuration of the Boeing 747 Domestic with 568 seats. The mission range was set to 3,000 km as the design transport mission in order to cover 90% of all flights according to the aforementioned market analysis. The cargo mass varies significantly between the different regions and air traffic market sectors. That is why a minimum cargo capacity of 5.0 tons was defined as a compromise. However, ranges of up to 5,000 km and cargo loads of up to 15 tons were considered during the feasibility study.

Turboprop aircraft generally operate at lower cruise speeds compared to turbofan-powered aircraft. According to the data of relevant engines shown in Table 2, some turboprop engines are designed for cruise Mach numbers greater than 0.7. The target cruise speed of the aircraft concept presented here was set to a minimum of 195 m/s of true airspeed, which is a similar value relative to the one of the Antonov An-70. Since open-rotor propulsion systems have already demonstrated promising performance potentials, the cruise speed requirement can be considered as only little ambitious. Thus, it is likely to achieve higher speeds with those propulsion types.

The aircraft dimensions are constrained by the ICAO Aerodrome Reference Code (ARC) and the FAA Airport Index.[9,10] The wing span, gear width, and field length are determined by ARC while the Airport Index restricts the length of the aircraft fuselage. Taking today's wide-body aircraft like the Airbus A350XWB and the Boeing 787 as initial examples, a wingspan of 65 m and a fuselage length of below 60 m seem to be reasonable values for an airliner with a capacity of 350 seats with a high-density seat configuration. However, these aircraft types are categorized as ARC 4E and Airport Index D with a field length of more than 1.8 km. In order to enable aircraft operations from a greater number of airfields, the turboprop aircraft should at least comply with the constraints of ARC category 3D and Airport Index C. Thus, the wingspan was restricted to 52 m, the fuselage length to 48.46 m, and the field length to 1.8 km.

Table 3. Quantitative requirements.

PAX	300 - 500
Cargo [tons]	≥ 5
Range [km]	≥ 3,000
ICAO ARC	3D
T/O field length [km]	1.2 - 1.8
Wingspan [m]	< 52
FAA Airport Index	C
Fuselage length	< 159 ft (48.46 m)

The most relevant quantitative requirements are summarized in Table 3. In addition, the following qualitative requirements were taken into account:

- Easy accessibility to the aircraft on the ground with regard to de-/boarding procedures
- Simple manufacturing methods
- Low maintenance costs
- Overall design should account for constructive noise mitigation measures.

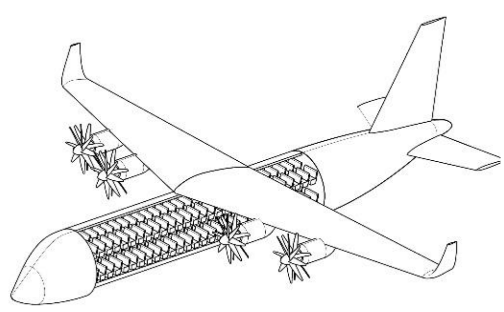

Figure 5. High-wing aircraft concept.

II. Configuration Downselect

An initial top-down and statistics-based approach to aircraft design proved technical feasibility with regard to the fulfillment of the requirements depicted in the above section. Alternative configuration options were analyzed subsequently.

A. Wing Positioning

During the concept study, different wing, engine, empennage, and seating configurations were analyzed. Starting with an initial concept similar to the Antonov An-70, the fuselage length and wing area were determined. Three hundred fifty seats were distributed on two decks. The resulting high-wing configuration shown in Fig. 5 provides several advantages: a big propeller/ground clearance, a short landing gear, and a lower structural weight compared to a low-wing configuration. In addition, the concept also facilitates the installation of large high-lift devices due to the larger ground clearance and small aerodynamic interference phenomena.[11]

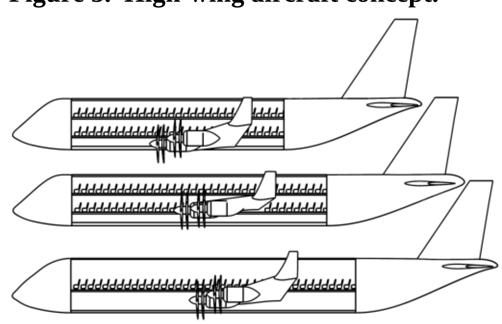

Figure 6. Low-wing concepts. *Two continuous single-aisle decks (top); continuous main passenger-deck, interrupted lower passenger deck (middle); twin-aisle main deck, interrupted cargo deck (bottom).*

A low-wing configuration is used for the majority of today's passenger transport aircraft. The integration of the landing gear into the wing rather than in fuselage-mounted pods can reduce the drag and the overall fuselage weight.[11,12] This is important as for high-capacity transport aircraft, the fuselage is the main driver of the overall aircraft weight. The number as well as the layout of the passenger decks are decisive design parameters with respect to the fuselage length. Fig. 6 displays three alternative fuselage configurations with a capacity of approximately 350 seats. While the two-deck configurations lead to the shortest possible fuselage, there are disadvantages with respect to structural and aerodynamics issues due to the wing-fuselage connection. The interruption of the lower deck enables an installation of the wing near the part of the fuselage with the widest cross-section. This design gets close to a typical mid-wing configuration with the advantage of reduced drag and weight characteristics.[11] The need for a cargo deck, however, leads to a more conventional layout with one passenger deck and a lower cargo deck that is interrupted by the wing box. This design features the longest fuselage. The fuselage length of a low-wing design is less critical in comparison to a high-wing configuration with respect to take-off rotation.

B. Engine Positioning

The propeller/ground clearance is critical for a low-wing configuration with engines mounted below the wing because it necessitates a long (and thus heavy) landing gear. This problem can be mitigated by positioning the engine nacelles above the wing unlike most turbofan nacelles. On the other hand, this results in an increased interference drag. The weight reduction caused by a shorter landing gear is not able to compensate the drag increase, which eventually results in a higher fuel consumption as shown in Fig 7. The D-27 or NK-62 engines have propellers with diameters of less than 5 m. By using these types of engine instead of a modern engine like the TP-400 with a prop diameter 5.3 m,[8] a low-wing configuration and under-wing nacelles become less critical.

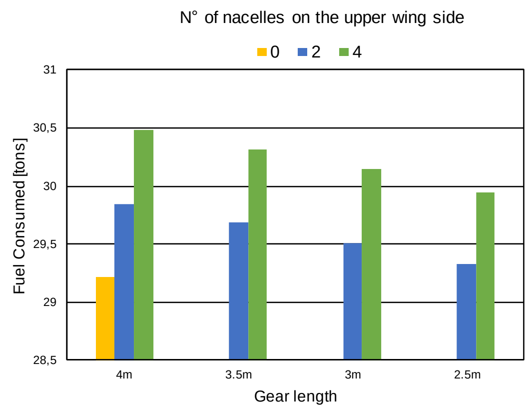

Figure 7. Influence of engine nacelle position on fuel consumption.

In order to reduce propeller-related drag and noise, alternate engine positions were examined (see Fig. 8). At first, a pusher propeller was used in order to reduce drag caused by the propeller wakes. However, one drawback of this option is a potential loss in propeller efficiency and an increase in noise emissions due to the incoming airflow being disturbed by the nacelles and the pylons of the engines.[11] Pylons were used to avoid propeller blockage in the case of the flaps being deployed and diverting the airflow. Yet, the pylons increase the wetted area and the structural weight of the aircraft.

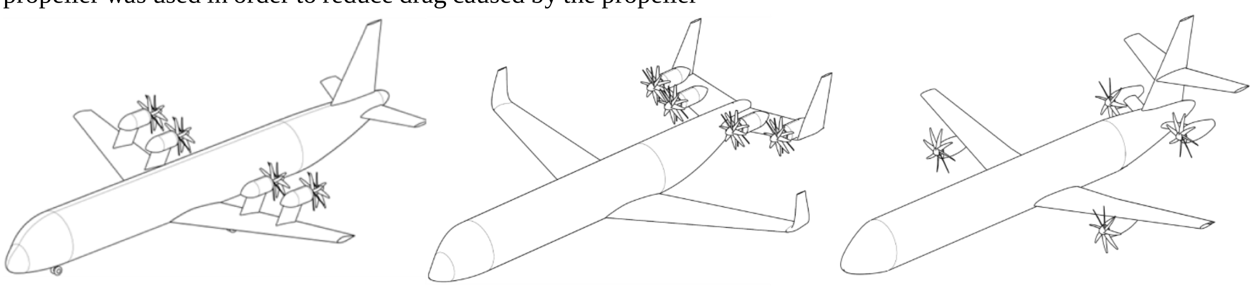

Figure 8. Aircraft configurations with unconventional engine positioning.

Another option was to increase the clearance between the trailing wing edge and the propeller plane by implementing longer engine nacelles. This, however, leads to the negative consequence that the propeller/ground clearance is reduced, which eventually requires a high-wing aircraft configuration to avoid propeller/ground collision especially during take-off rotation.

By positioning the engines at the rear end of the fuselage, the cabin noise was expected to be at a lower level. In addition, the risk of propeller blade-offs during emergency landings would be much lower compared to configurations with under-wing

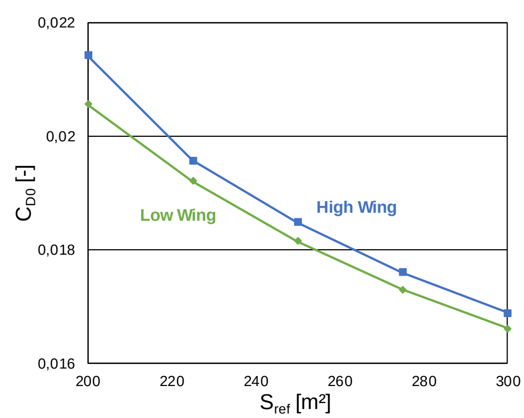

Figure 9. Zero drag coefficient: low wing with conventional tail compared to high wing with T-tail.

nacelles. To avoid the use of additional pylons, the horizontal tail of the aircraft was used for mounting. However, the wing, fuselage, and tail structures became heavier. The resulting CG shift (shift of the center of gravity) makes loading procedures more complicated. On the other hand, greater take-off rotation angles are achievable, allowing a shorter landing gear. The lift distribution over the wing is improved as well. Yet, as with the pusher configuration discussed before, the prop-wash cannot be used for an additional gain of high lift.

The combination of wing-mounted and rear-mounted engines presented an interesting compromise. In this case, the externally blown flaps are partly usable for high lift and the engines are installed far away from the fuselage, which reduces cabin noise. The fuselage is heavier due to the engines being mounted at the rear of the aircraft and the use of additional pylons.

It was eventually found that a conventional configuration with wing-mounted tractor engines had more advantages with respect to weight and high lift compared to the unconventional configurations that had been examined before. The turboprop engine offers the advantage of high thrust at low speed, which results in a reduced take-off field length. The low- or mid-wing configurations were expected to cause less drag than the high-wing design (see Fig. 9).

For a fast flying turboprop that suffers from a loss in thrust with increasing airspeed, a low-wing design is more beneficial because in general, its parasitic drag is less compared to high-wing configurations. By using multiple passenger decks and a separate cargo deck, the number of cutouts was increased, leading to a higher structural weight.[13] However, such a configuration enables a more efficient utilization of the aircraft volume, which results in a reduction of the overall aircraft length. Conventional aircraft configurations also allow the use of less complex design calculation methods.

C. Cabin Layout and Fuselage Cross-Section

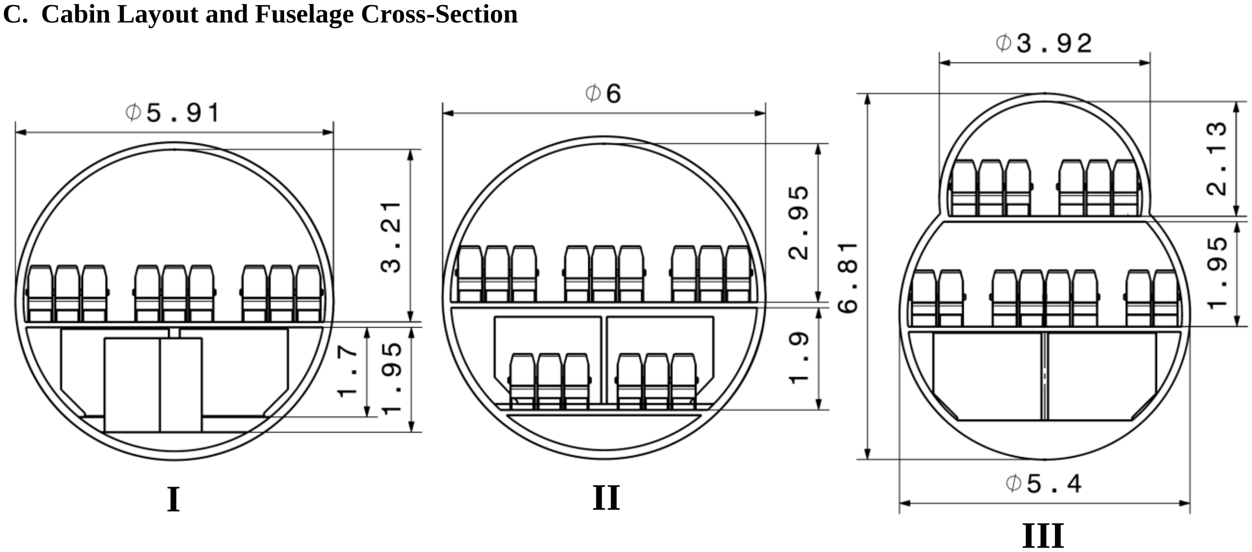

Figure 10. Fuselage Variants I, II, and III. *All dimensions given in [m].*

During the design process, three alternative fuselage variants were examined (Fig. 10). In order to fit the cabin equipment, the following assumptions were made: passenger seats have a width of 0.51 m and a height of 1.04 m. The aisle width is 0.46 m. Lavatories have a square cross-section with 1.05 m of side length. Variant I is equipped with one passenger deck. The lower deck is divided into a cargo section with a ceiling height of 1.7 m and an area destined for galley and lavatory accommodation with a ceiling height of 1.95 m. This is possible because of the requirement of only five tons of cargo mass. LD3 containers are stored in the cargo area near the wing box. Lavatories are installed in the passenger area in front of and behind the cargo load. Stairs connect both decks. Variant II is equipped with seats in a twin-aisle configuration on the main deck and a single aisle on the lower deck. Only the front part of the lower deck is used for passenger transport. Galleys and lavatories are distributed on the upper and lower decks. The more efficient use of volume enables a reduced fuselage length. Variant III has a double-bubble cross-section with two passenger decks and one cargo deck. This type offers the highest potential to shorten the fuselage. However, it is also the most complex one from a structural point of view.

Table 4. Wetted areas and weights of cross-section Variants.

	Area [m²]	Mass [tons]
Variant I	934	22.0
Variant II	828	20.1
Variant III	825	19.8

In Table 4, the wetted areas and fuselage weights of all fuselage variants are compared. All variants are designed for a pressure altitude of 10 km. By using a circular cross-section, Variant II offers a reduction of the wetted area of 11% compared to Variant I. Variant III possesses the same benefit but has a larger usable volume. On the other hand, the accessibility of the upper deck is more difficult. Due to the small size of the upper deck, only Type I emergency exits can be installed to avoid structural disadvantages.[12,14]

Although Variant III has the biggest number of cutouts, it is nearly as heavy as Variant II. Both Variants are significantly lighter than Variant I. For the weight estimation of Variant II, a continuous cargo floor was assumed that increases the weight, but allows substituting the seats with containers. There are significant advantages of using Variant III because of the large usable volume and a reduced surface area.

Fig. 11 depicts the influence of the cruise altitude on the fuselage mass. By lowering the design cruise altitude from 10 km to 6 km, weight can be reduced by 13%. There are further advantages of operating at a lower cruise altitude. Due to a lower Mach number (to achieve the same cruise speed), the propeller efficiency can be increased. A smaller loss of power due to higher air densities at lower altitudes leads to less installed engine power required (reference: mean sea level), and therefore a lower overall take-off weight.

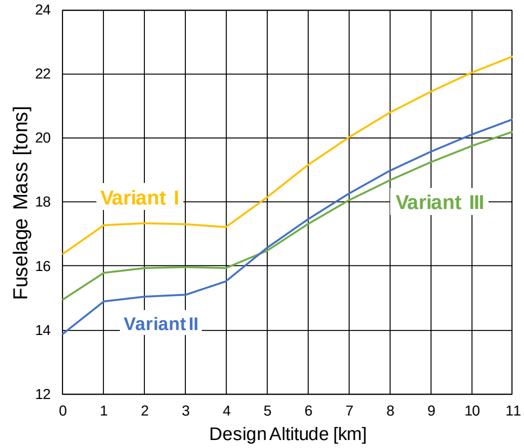

Figure 11. Interrelation between cruise altitude and fuselage mass for the different fuselage variants (Fig. 10).

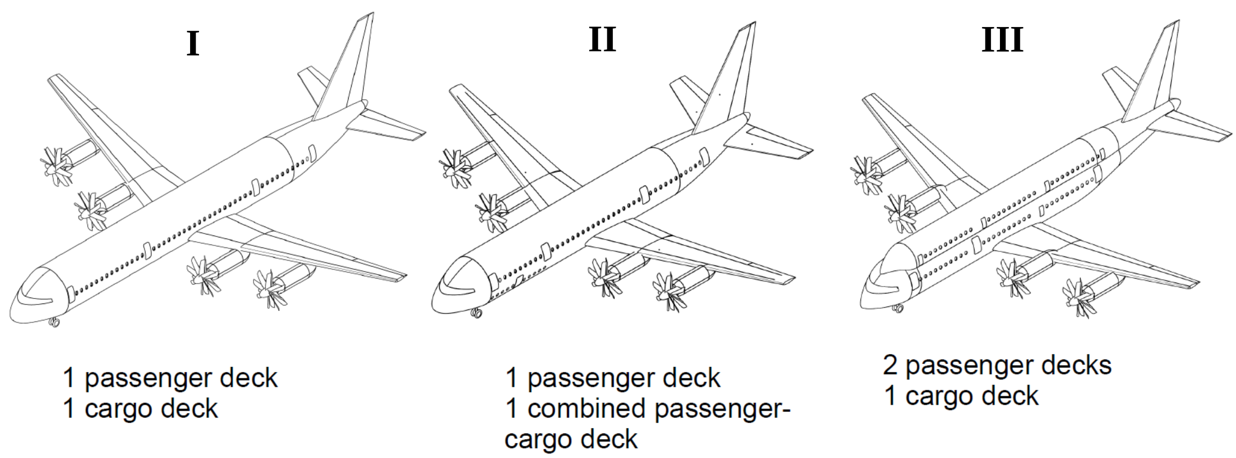

Figure 12. Design Variants I, II, and III with the associated Fuselage Variants I, II, and III. *Not to scale.*

Three different aircraft configurations were developed based on the presented fuselage variants (Fig. 12). They were designed for a transport capacity of 400 passengers and five tons of cargo and a flight mission of 3,000 km at 180 m/s of true airspeed during cruise flight. The relatively low cruise speed is defined in order to lower the required power to reasonable values (i.e., below 12 MW per engine). The conservative, simple engine model leads to an overestimation of the required engine power (in comparison to existing configurations). For Design I and Design II, conventional nacelle positions under the wing were chosen to improve the lift distribution over the wing. For Design III, the inner nacelles were raised and the landing gear shortened. Although the reduction of the landing gear weight does not fully compensate the drag increase, the improved accessibility on the ground is the predominant advantage of this concept.

The analysis results and aircraft data are summarized in Table 5. Design I is the heaviest one with the highest take-off power required. However, it possesses the best L/D-value due to a higher aspect ratio that was determined to make the design more

Table 5. Key data of Design Variants I, II, and III.

Design	I	II	III
l [m]	57.5	51	51
b [m]	55.6	53.2	52.2
S_{ref} [m²]	260	260	250
A	12	11	11
h_{cruise} [km]	9	8	8
W_0 [kg]	163,500	161,400	158,200
W_e [kg]	86,600	84,800	81,600
W_f [kg]	26,900	26,600	26,700
Oswald factor	0.7486	0.7496	0.7208
$P_{SL_{eng}}$ [kW]	11.900	10.500	10.700
L/D_{cruise}	18.8	18.7	18

competitive towards the others. Design III is the lightest and has the lowest L/D-value due to the inboard nacelles that disturb parts of the top-wing airflow. The required mission fuel specific to each configuration varies by 1.2% at maximum. Design III possesses the most complicated physical structure, but offers the highest potential to be able to comply with the constraints of ARC category 3D and Airport Index C.

III. Final Design and Sizing

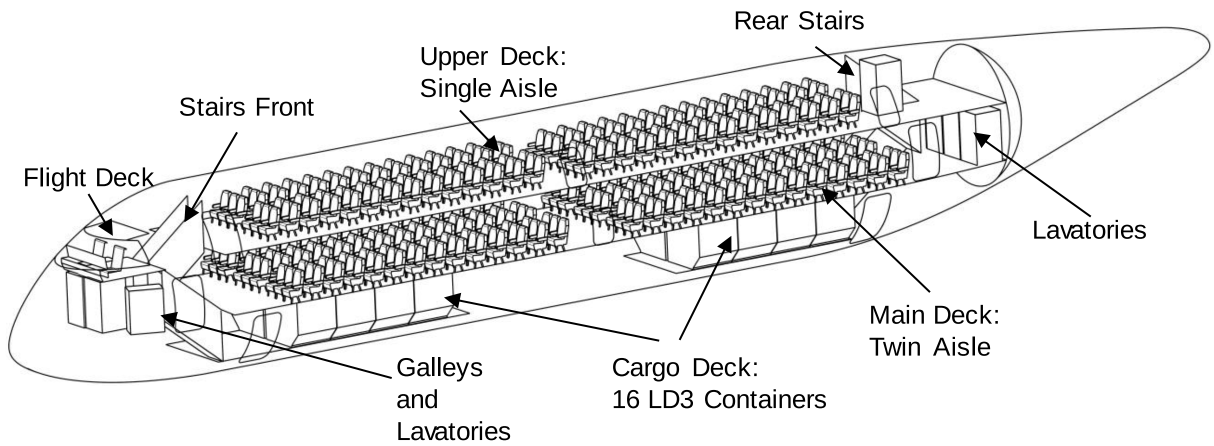

Figure 13. Final design: interior design.

A. Overview

The final configuration was based on Design III with three decks (Fig. 13). The main deck was widened to fit nine seats abreast, which allows a shortening of the fuselage to 47.7 m of length. The inboard engine nacelles were installed on the top of the wing. The wingspan reaches 51.65 m. Thus, the constraints of ARC category 3D and Airport Index C are met. The tail volume coefficients were reduced due to the high stability of Design III. On the cargo-deck level, four doors of Type A are installed. They allow a boarding with integrated gangways, which makes the aircraft more independent from airport infrastructure.

B. Wing and Engine Sizing

During the design process, the wingspan that is constrained by ARC category 3D was set to 51.65 m while the reference area was varied. Fig. 14 shows that a small reference area is preferable in terms of fuel consumption during cruise flight. However, the weight estimation method used here may underestimate the weight for a wing with very high aspect ratio for which a higher fuel consumption was expected.[10] For the definition of the wing reference area, the balanced field length and the FAR field length were restricted to 1.8 km. As a compromise, a wing area of 250 m² and engines with an equivalent take-off power of 9.5 MW were determined. This power level allows the use of the D-27 prop-fan engine.

A Mach-sensitive engine model was used for the calculations of the final design. Compared to Design III, the cruise speed was raised by 15 m/s to 195 m/s. The specific fuel consumption was initially based on the D-27 engine data and then increased by 5% to account for installation losses, resulting in 5.1×10^{-8} kg/J.

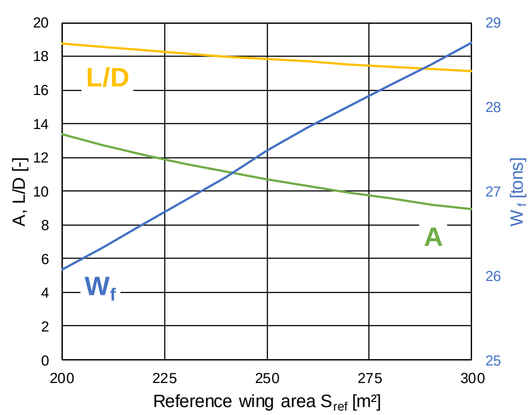

Figure 14. Dependency of aspect ratio (A), L/D ratio, and fuel consumption (W_f) on the wing reference area.

C. Key Features

The final design shown in Fig. 15 is a conventional low-wing aircraft with wing-mounted tractor engines. This configuration supports a reduction of noise emissions due to an undisturbed inflow. The externally blown flaps support high lift generation. Positioning the wing close to the widest fuselage section provides a sufficient connection area without a large, drag-increasing fairing. However, further structural analysis will be required to proof this design. The

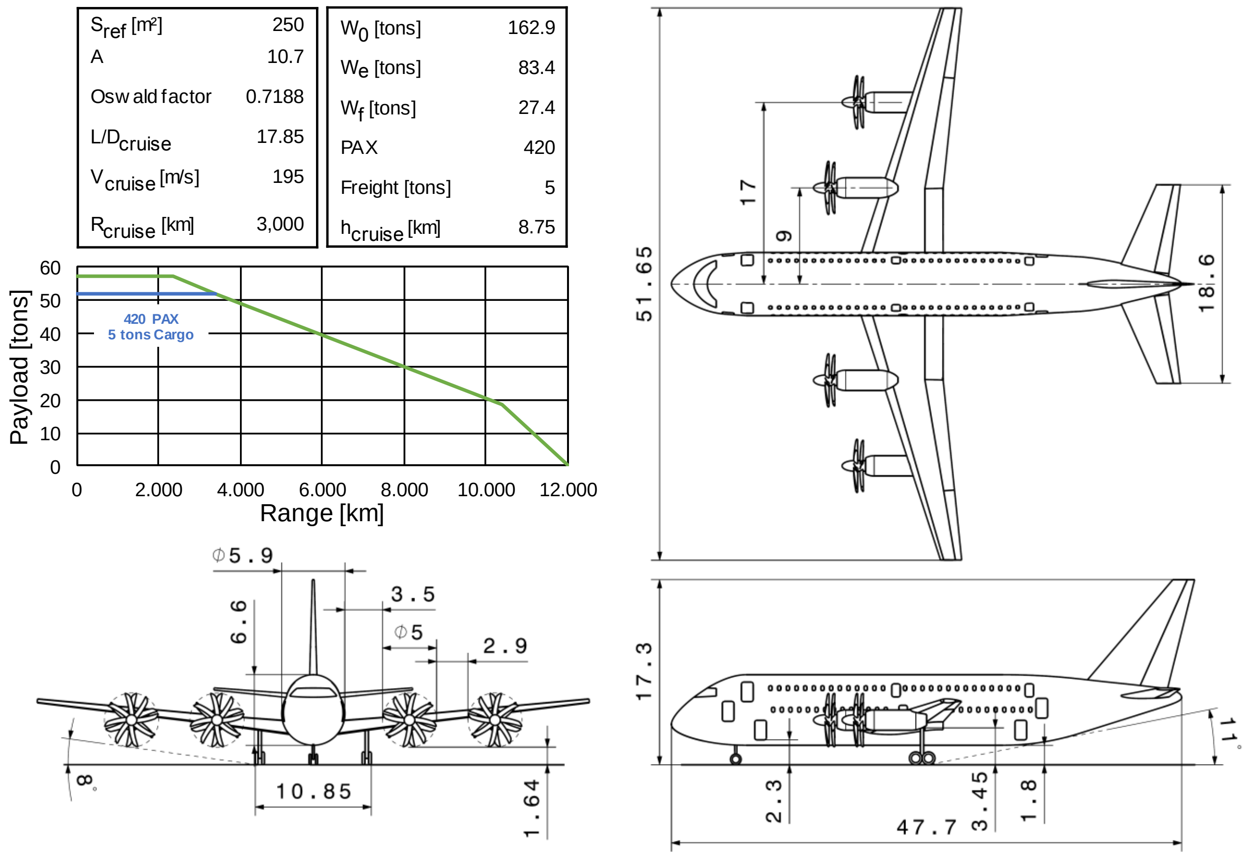

Figure 15. Heavy turboprop aircraft concept: final design.

conventional, horizontal tail possesses a dihedral of 5° and thus supports a reduction of the influence of the prop-wash. The available power of 9.5 MW per engine is slightly lower compared to the D-27 engine. The propeller diameter is set to 5 m and thus exceeds the D-27 propeller by 0.5 m. This provides sufficient reserve space in case a propeller with a larger diameter is used for future concepts (recall that the TP-400 propeller has a diameter of 5.3 m).

Table 6. Fuel consumption per 100 PAX-km for typical regional load factors. *Load factor data from* [16].

Region	Load Factor [%]	l/100PAXkm
Africa	70.0	3.88
Asia/Oceania	78.1	3.45
Europe	80.7	3.36
Latin America	77.5	3.50
Middle East	78.5	3.46
North America	84.0	3.23

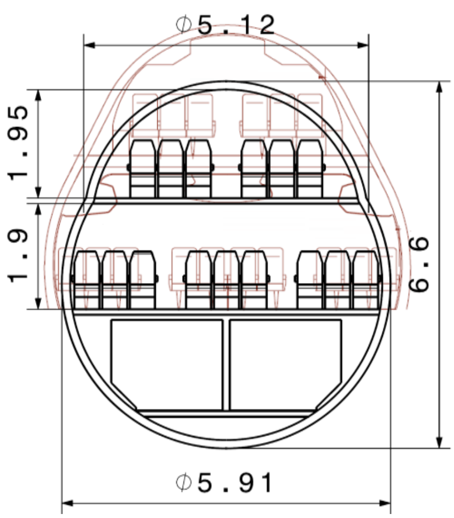

Figure 16. Comparison of cross-sections: Boeing 747 (red) vs. final design (black).

The fuselage displayed in Fig. 16 features a double-bubble cross-section with two passenger decks and one cargo deck. Four doors on the lower deck can be used for de-/boarding procedures without the need for external gangways. For ordinary boarding procedures, doors of type A are installed on the main and the upper deck. Stairs are used to connect the decks at the front and the rear part of the cabin (Fig. 13). The high density of cutouts at the front and the rear of the fuselage may lead to a further weight increase that was accounted for in the final design by diminishing weight-decreasing effects due to the use of composite materials.

The analysis shows that for the final design, the optimum initial cruise altitude is 8.75 km with 195 m/s of true airspeed. This is equal to a cruise Mach number of 0.64 that is significantly smaller compared to conventional turbofan-powered aircraft. A maximum L/D ratio of 17.8 can be reached under these conditions. The take-off weight is 163 tons, and the required fuel is 27.4 tons for the design mission. These values are higher compared to the previous design concepts. However, the transport capacity was increased by 20 additional seats and the cruise speed was raised by 15 m/s. For the aerodynamic analysis, the component-based build-up method was used.[11] It was found that the zero-lift drag coefficient is equal to 0.0195. The maximum lift coefficient slightly exceeds a value of 3.1 by using double-slotted flaps and prop-wash at full thrust with all engines operative.

The resulting fuel consumption per 100 PAX-km is 2.72 liters with a load factor of 100%. By using a typical load factor of 80%, 3.4 liters per 100 PAX-km are achieved. In the case of the German air transport fleet, this value presents an efficiency improvement of 11% at minimum.[15] In Table 6, more fuel consumption-related data for typical regional load factors are provided.[16]

IV. Conclusion

Figure 17. Heavy turboprop aircraft concept: exterior and interior design.

The heavy turboprop-powered aircraft concept presented in this paper (Fig. 17) is able to carry over 400 passengers and five tons of cargo on short- and medium-haul routes more energy efficiently than currently operating conventional aircraft types. It requires a field length of less than 1.8 km. Compared to the Boeing 747 Domestic (Fig. 18), the turboprop aircraft is able to operate from airports with a lower ARC. However, its passenger capacity is roughly 30% smaller. In comparison to the Airbus A320 with ARC category 4C, category 3D is achieved (Fig. 18).[17] Thus, the turboprop aircraft is not able to substitute the A320/737-fleet entirely. Nevertheless, the passenger capacity per flight operation can be more than doubled relative to an A320/737 flight.

For the design-related calculations, common handbook methods were applied. In addition, contemporary engine data were used to derive a realistic engine model. It is obvious that more sophisticated methods are necessary in order to confirm the presented turboprop aircraft concept.

Several aspects of the final aircraft design require further investigation. One is the weight and structure of the fuselage because of its unconventional double-bubble cross-section. Another aspect is the turnaround-time at the airport because the aircraft features a cabin with two passenger decks. Furthermore, the wing with its high aspect ratio has to be analyzed in more detail. The use of additional doors at the cargo deck is questionable. In this context, it is interesting to check whether the weight penalty due to the cutouts can be economically compensated by additional flights to airports with inferior

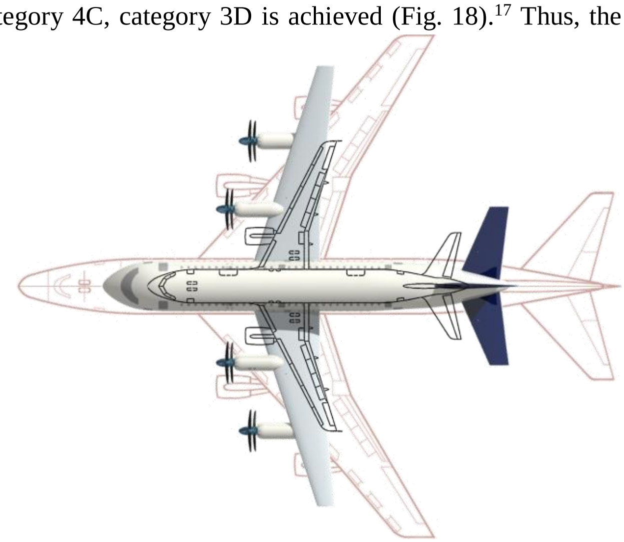

Figure 18. Top-view comparison: Airbus A320 (black), Boeing 747 Domestic (red), and final design of turboprop aircraft (grey-blue).

infrastructure. Further improvements of the wing design are feasible by using a curved shape that provides sufficient propeller/ground clearance with under-wing engine nacelles.

One of the most critical aspects of the aircraft concept presented here is the use of propeller engines that may lead to higher noise emission levels compared to turbofan aircraft. Although new propeller designs may drastically reduce noise emissions compared to earlier technologies, further investigations on that matter are needed. Yet, the steady growth of the global air traffic volume in the face of rising energy costs is likely to make high-capacity turboprop aircraft like the concept presented here more attractive and may consequently open up new markets for aircraft manufacturers and operators.

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