Investigation of a Novel Turboprop-Driven Aircraft Concept Including Future Technologies

Andreas Johanning and Dieter Scholz

Abstract This paper presents a novel concept for a highly efficient and ecological propeller-driven aircraft. The aircraft has a high wing, T-tail, and two turboprop engines with large propeller diameters decreasing disc loading and therefore increasing propeller efficiency. The aircraft also features a strut-braced wing with natural laminar flow. It is shown that direct operating costs can potentially be reduced by about 17 % while reducing trip fuel mass and therefore CO_2 emissions by about 36 % compared to the reference aircraft Airbus A320.

Keywords Turboprop aircraft · Conceptual aircraft design · Aircraft design optimization · Strut-braced wing · Natural laminar flow

1 Introduction

1.1 Motivation

The protection of the environment gets increased importance in civil aviation (e.g., [1]). Emission reductions can be achieved by reducing fuel consumption because the amount of the major part of emissions is proportional to the amount of burned fuel. Reduced fuel consumption could be achieved by new promising aircraft concepts. The design of these concepts has been one of the tasks of the research project "Airport2030" [2]. This paper presents one of the aircraft concepts designed within the research project. The presented research has been conducted together with the project partner Airbus.

Nowadays, mainly turbofan-driven aircraft is used in the medium range aircraft market. In the future, Turboprop-driven Aircraft (TA) could be an interesting alternative in that market because of their lower fuel consumption. The Thrust

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A. Johanning · D. Scholz (✉)
Department of Automotive and Aeronautical Engineering,
Hamburg University of Applied Sciences, Hamburg, Germany
e-mail: info@profscholz.de

R.P. Bajpai and U. Chandrasekhar (eds.), *Innovative Design and Development Practices in Aerospace and Automotive Engineering*, Lecture Notes in Mechanical Engineering, DOI 10.1007/978-981-10-1771-1_62

Specific Fuel Consumption (TSFC) of TA is 10 … 30 % lower than that of comparable turbojet or turbofan aircraft [3].

However, a disadvantage of TA is that they are usually operated at lower cruise Mach numbers than turbofan aircraft resulting in a lower number of flights in a certain period. Additionally, TA comes along with higher cabin noise levels than turbofan aircraft requiring more soundproofing material and therefore additional mass.

This paper investigates if a novel TA design incorporating the future technologies natural laminar flow (NLF) and strut-braced wing (SBW) could lead to reduced DOC and emissions compared to the medium range aircraft Airbus A320.

1.2 *Concept for the Novel Turboprop Aircraft*

As already stated, TA usually have lower optimum cruise speeds than turbofan aircraft resulting in longer flight times and possibly a lower number of flights per day. The lower number of flights leads to lower productivity and hereby higher seat mile costs. The proposed TA concept counteracts the disadvantage of the lower optimum Mach number by a lower cruise altitude:

By reducing the cruise altitude of the TA compared to that of the turbofan aircraft, the percentage difference between the cruise speeds will become smaller than the percentage difference of the Mach numbers. This fact is illustrated in Fig. 1 showing that an aircraft flying at an altitude of 6140 m at a feasible turboprop cruise Mach number of 0.71 (the cruise Mach number range of the military transporter

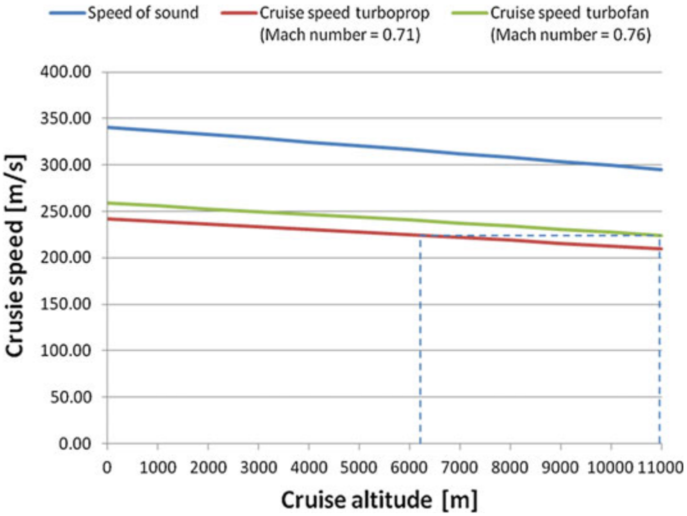


Fig. 1 Reducing the cruise altitude for a given Mach number leads to higher cruise speeds

Airbus A400 M is 0.68 … 0.72 [4]) would have the same cruise speed as an aircraft flying at 11,000 m or above with a cruise Mach number of 0.76.

After optimization for minimum DOC, the cruise Mach number of the proposed TA and the difference in cruise altitude came out lower than in the previous example but the positive effect stays the same. The later described that optimum TA design has an initial cruise altitude of about 7000 m compared to the initial cruise altitude of the redesigned reference aircraft (introduced in Sect. 1.3) which is around 11,800 m. The optimum cruise Mach number of the TA is 0.51 which is around 33 % lower than the cruise Mach number of the reference aircraft. Due to the described positive effect of a lower cruise altitude, the actual cruise speed of the TA is only 29 % lower than that of the reference aircraft.

A drawback of the reduction of cruise altitude is that aircraft are exposed to higher gust speeds and therefore higher gust load factors. An increased wing loading could counteract that effect and keep gust load factors at the same level [5]. However, the dimensioning requirement of the maximum allowable landing field length leads to a wing loading that is not higher than that of the reference aircraft. As a consequence, the load variation due to gusts of the TA is about 36 % higher than that of the reference aircraft.

An investigation of the importance of several aircraft parameters for the evaluation of an aircraft design in [6] shows that the absolute weighting of the variation of gust loads for the evaluation of an aircraft design is 1.1 %. Due to the low weighting leading to a low importance of that parameter for overall aircraft design, the increase in load variation of the TA has been accepted.

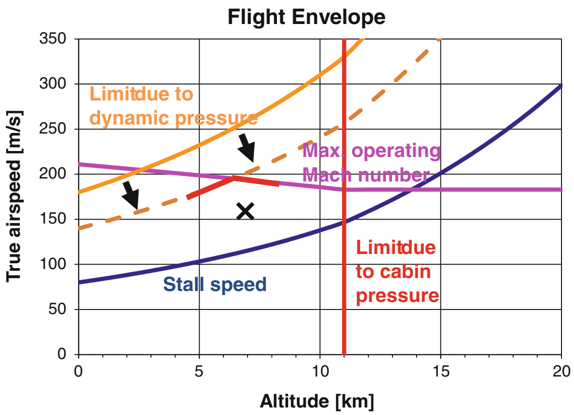
Another effect counteracting the disadvantage of the lower optimum Mach number is the limitation of the indicated air speed below FL 100–250 knots. Due to this limitation, TA does not loose time during about 20 min of flight shortly after take-off and before landing under FL 100. During taxiing, there is no time difference between TA and turbofan aircraft anyway. Due to these two reasons, the block time of the TA on a 755 NM trip (which is used for the DOC calculation and optimization) is only 21 % higher than that of the reference aircraft.

In the flight envelope, the concept of the low-flying TA could be placed close to the intersection of the limit defined by maximum operating Mach number and maximum dynamic pressure (in the so called “speed corner”) [5].

Indeed, due to the lower cruise speed of the TA, the limit due to dynamic pressure could be reduced to a lower equivalent airspeed so that the operating point of the TA lies close to the speed corner (as illustrated in Fig. 2). In comparison to the reference aircraft, the decrease of the limit due to dynamic pressure could potentially lead to a lighter cabin. However, this effect was outside the scope of this paper.

Development costs for the proposed TA could be kept at an acceptable level, as it is a conventional configuration with only an unconventional set of design parameters. It can be integrated easily into the existing aviation system because existing processes for manufacturing and operation of aircraft would not have to be adapted [5].

Fig. 2 Flight envelope of the TA



1.3 Reference Aircraft and Reference Mission

The reference aircraft for evaluating the performance of the TA design is the weight variant WV000 of the Airbus A320−200 with CFM56−5A engines [7]. Key parameters of the selected weight variant are listed in Table 1.

The proposed TA has the same requirements as the reference aircraft except for a lower cruise Mach number to take account of the speed limitations of TA.

1.4 Literature Review

There has been a lot of research about TA design. In the scope of the literature review of this paper, only few examples can be mentioned:

Xie researched about conceptual TA design in general. However, the research did not have the objective to design a potential candidate for the next medium-range aircraft generation and future technologies like NLF or SBW have not been integrated into the designs either [8].

The “Citizen Friendly Airplane” is the subject of another research project which is based on a TA concept. However, the requirements for that TA drastically differ from those presented here. For instance, short take-off and landing capabilities are

Table 1 Key parameters of the selected A320−200 weight variant from [7]

Parameter	A320
m_{MTO} (kg)	73,500
m_{OE} (kg)	41,244
m_{MPL} (kg)	19,256
R_{MPL} (NM)	1510
n_{PAX} (1-cl HD) (–)	180
M_{CR} (–)	0.76

required. Additionally, no publication describing the design of the citizen friendly airplane could be identified yet [9].

Geraldo et al. also published about the design of a TA. However, their aircraft is designed for 90 passengers so that the requirements again differ from those in this paper [10].

The "Boeing Subsonic Ultra Green Aircraft Research" team evaluated several future aircraft concepts in a NASA research project. Amongst others, a turboprop-driven aircraft with SBW and NLF has been evaluated. However, research mainly concentrated on turbofan engines with very high bypass ratios and on several other future technologies so that TAs only played a minor role [11].

Summarized, the literature review shows that there is an ongoing interest in TA. However, only [11] could be identified also integrating the future technologies NLF and SBW into the design. Additionally, most of the described research approaches have other design requirements and none of them discusses TA as potential candidate for the next generation of medium-range aircraft which represents the motivation for the research presented here.

The outline of the paper is as follows. Section 2 presents the methodology used for the design of the novel TA concept. Section 3 presents the results of the design process and compares the DOC of the TA with the DOC of the reference aircraft. In Sect. 4, the design results are discussed while Sect. 5 concludes the paper.

2 Methods

For the conceptual design of the proposed TA, the tool "Turboprop Optimization in Preliminary Aircraft Design" (PrOPerA) has been used. PrOPerA is a further development of the tool "Optimization in Preliminary Aircraft Design" (OPerA) developed by Niţă [11]. OPerA has been developed for the preliminary design of turbofan aircraft while PrOperA can additionally be used for the preliminary design of turboprop driven aircraft.

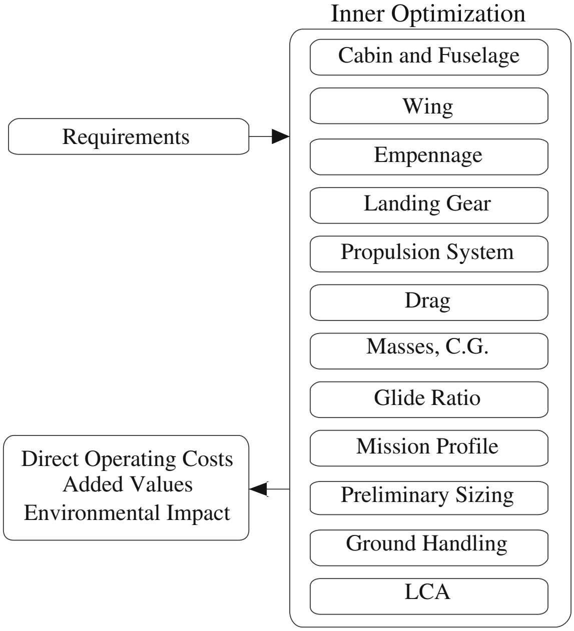
The structure of PrOPerA is illustrated in Fig. 3. In an inner optimization loop, a consistent aircraft is designed based on a set of aircraft parameters and requirements. Thrust-to-weight ratio and wing loading are optimized according to the selected optimization objective.

In an outer optimization loop, all aircraft parameters and requirements can be varied to find an optimum aircraft for the selected optimization objective. The outer optimization is performed using PrOPerA together with the optimization software "Optimus" from "Noesis Solutions."

In PrOPerA, each TA is designed together with an optimum propeller according to the particular requirements of the aircraft using the method proposed by Adkins and Liebeck [12].

Important engine parameters are calculated using empirical equations derived from the turboprop engine database of Roux [13].

Fig. 3 Structure of PrOPerA



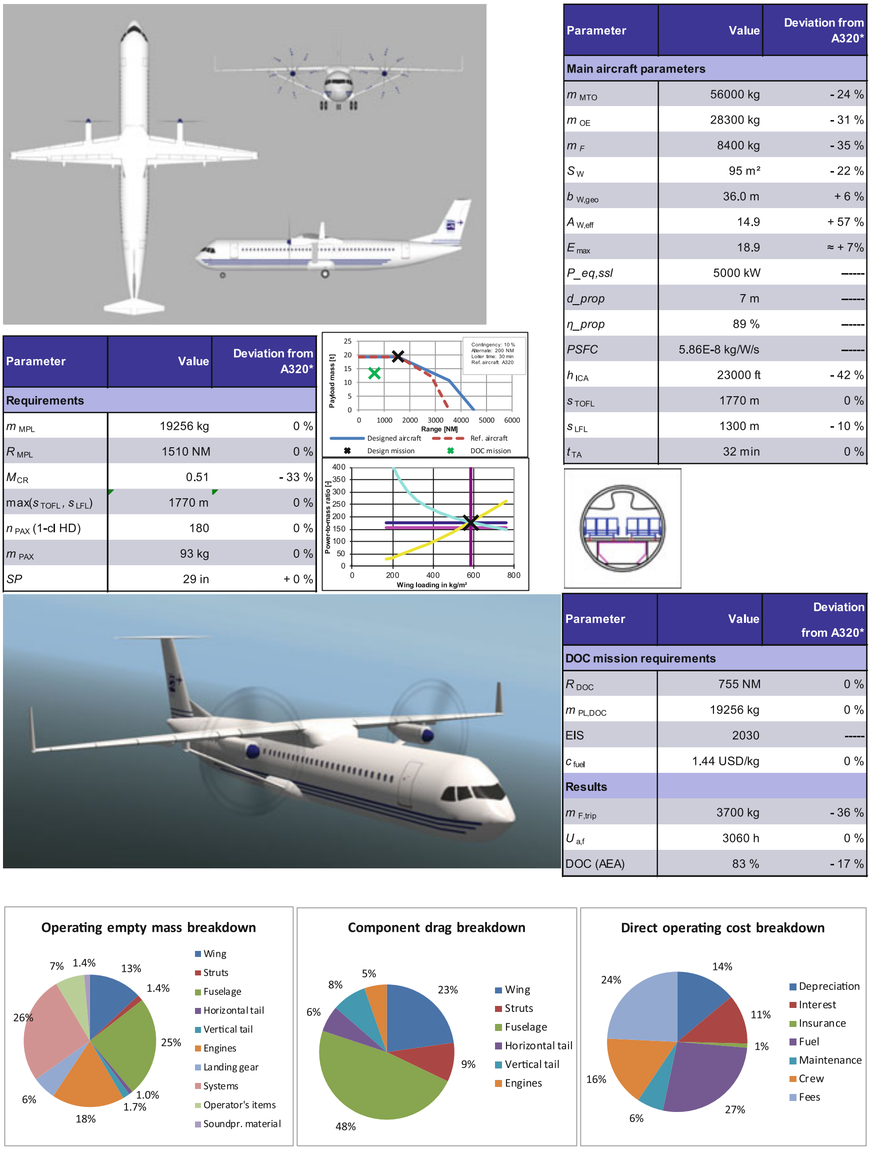
To consider the drawbacks of high propeller diameters with regard to landing gear length and mass, the landing gear is sized according to the requirements from tail strike angle, bank angle clearance, engine ground clearance, and longitudinal, as well as lateral tip stability [5].

The calculation of the power-to-weight ratio and wing loading due to take-off and landing field length requirements and the assumption for the maximum lift coefficients at take-off and landing are based on a statistical analysis of existing TA [5].

The final TA design presented in Sect. 3 is the result of an optimization for minimum DOC. To optimize the aircraft for minimum DOC, an evolutionary algorithm with a population size of 35 and 60 generations is used. For all DOC calculations, the DOC method proposed by the Association of European Airlines [14] is used. The designs have been evaluated for an entry into service in 2030 when the next generation of medium range aircraft might be introduced. For that year, an inflation-adjusted fuel price of 1.44 USD/kg has been assumed based on a forecast presented in [15]. The reference aircraft has been evaluated with the same fuel price to have a fair comparison in the year 2030.

For the integration of the future technology “Natural Laminar Flow” (NLF), a Reynolds number for the transition from laminar to turbulent flow is calculated depending on the sweep angle of the leading edge of the wing to determine the wing fraction with laminar flow. An upper limit of 50 % laminar flow is set. It is assumed that there are no negative side effects from using a laminar flow wing profile.

For the integration of the future technology “Strut Braced Wing (SBW),” the strut chord has been set to 30 % of the wing mean aerodynamic chord according to a statistical evaluation of strut-braced wing aircraft. The strut is attached to the wing at 50 % of the wing span (illustrated in Fig. 4). The variation of the wing mass



Parameter	Value	Deviation from A320*
Requirements		
m_{MPL}	19256 kg	0 %
R_{MPL}	1510 NM	0 %
M_{CR}	0.51	- 33 %
max(s_{TOFL}, s_{LFL})	1770 m	0 %
n_{PAX} (1-cl HD)	180	0 %
m_{PAX}	93 kg	0 %
SP	29 in	+ 0 %

Parameter	Value	Deviation from A320*
Main aircraft parameters		
m_{MTO}	56000 kg	- 24 %
m_{OE}	28300 kg	- 31 %
m_F	8400 kg	- 35 %
S_W	95 m²	- 22 %
$b_{W,geo}$	36.0 m	+ 6 %
$A_{W,eff}$	14.9	+ 57 %
E_{max}	18.9	≈ + 7%
P_eq,ssl	5000 kW	-----
d_prop	7 m	-----
η_prop	89 %	-----
$PSFC$	5.86E-8 kg/W/s	-----
h_{ICA}	23000 ft	- 42 %
s_{TOFL}	1770 m	0 %
s_{LFL}	1300 m	- 10 %
t_{TA}	32 min	0 %

Parameter	Value	Deviation from A320*
DOC mission requirements		
R_{DOC}	755 NM	0 %
$m_{PL,DOC}$	19256 kg	0 %
EIS	2030	-----
c_{fuel}	1.44 USD/kg	0 %
Results		
$m_{F,trip}$	3700 kg	- 36 %
$U_{a,f}$	3060 h	0 %
DOC (AEA)	83 %	- 17 %

Fig. 4 TA design results

reduction depending on the position of the strut connection point is derived from [16]. The maximum wing mass reduction is set to 30 % as suggested by Torenbeek [17]. Only high wing configurations have been considered.

3 Results

In this section, the results of the TA design will be described. First, single design parameters have been varied to better understand the design decisions of the optimizer and to analyze their influence on the design. In the following first subsection, some of these single parameter variations will be presented. In the second subsection, the optimization results of different optimized aircraft configurations will be compared to each other and a configuration will be selected. In the third subsection, the final TA design is presented.

3.1 Single Parameter Variations

For several design parameters, the single parameter variations showed that there was no need to consider them in the following design optimization because minimum DOC was always found at the lower or upper border:

The optimum wing taper ratio λ for minimum DOC has always been at the lower border. The advantage of a lighter wing at lower λ always overcompensated the disadvantage of a sometimes lower glide ratio due to a not optimum lift distribution over the wing. Later, during optimization, λ has therefore been set to 0.2 because this is the suggested minimum allowable λ according to [18].

For minimum DOC, the take-off field length and the maximum lift coefficient at take-off always went to the upper border because this offered minimum power-to-weight ratio P/W which is off course advantageous for the aircraft design. The maximum lift coefficient for landing also always went to the upper border because this offered maximum wing loading which is also advantageous for the design. These parameters have been set to the values of the reference aircraft to enable a fair comparison.

As expected, the cabin parameters seat pitch, seat width and aisle width always went to their lower border so that there was no need to include them in the later optimization either. For this reason, the cabin parameters have also been set to the values of the reference aircraft.

The following seven design parameters did not show such a definite trend and have therefore been included in the design optimization:

Cruise Mach number M_{CR}, propeller diameter d_{prop}, wing sweep at 25 % chord φ_{25}, effective wing aspect ratio $A_{\mathrm{W,eff}}$, wing thickness ratio t/c, landing field length s_{LFL}, and ratio of maximum landing mass to maximum take-off mass $m_{\mathrm{ML}}/m_{\mathrm{MTO}}$. In the next paragraphs, the main advantages and disadvantages identified during the single parameter variations will shortly be discussed for a better understanding of the design results

- The higher M_{CR}, the higher the number of flights and therefore transported payload in a certain timeframe lowering the DOC. But a higher M_{CR} also requires a higher P/W and at high M_{CR}, the propeller efficiency starts to decline impairing the DOC. During the common variation of all design parameters, an optimum compromise was found at an M_{CR} of about 0.51.
- The higher d_{prop}, the higher the propeller efficiency decreasing required fuel mass and improving DOC. But high d_{prop} also requires high landing gear length and therefore mass to ensure sufficient propeller ground clearance. An optimum compromise was found at a d_{prop} of about 7 m.
- The lower φ_{25}, the lower the wing mass. For aircraft flying at high Mach numbers, increasing φ_{25} helps to reduce wave drag. However, the optimum M_{CR} of the TA is relatively low so that wave drag does not play an important role. Nevertheless, a certain φ_{25} together with the fixed taper ratio of 0.2 leads to an optimum lift distribution over the wing. An optimum compromise was found at a φ_{25} of about 6°.
- The higher A, the higher the glide ratio leading to lower fuel consumption. But the higher A, the higher the wing mass increasing fuel consumption and impairing the DOC. An optimum compromise was found at an A of about 14.9.
- The higher t/c, the lower the wing mass. But the higher t/c, the lower the critical Mach number of the wing and therefore the higher the wave drag at a certain Mach number. Due to the low optimum Mach number of the TA, the optimum t/c was expected to be a bit higher than that of the reference aircraft. During the common variation of all design parameters, this expectation has been fulfilled because an optimum compromise was found at a t/c of about 0.13.

3.2 *Choosing the Optimum TA Configuration*

After an isolated variation of these parameters, all parameters have been varied together until a parameter combination with minimum DOC has been found. To be able to compare different design configurations to each other and to identify the best TA configuration, different TA configurations have been optimized separately:

TA with two or four engines, conventional tail or T-tail and low wing or high wing have been designed. Altogether this leads to eight possible TA configurations.

Table 2 contains an overview about the design results. The DOC of different TA configurations are compared to the DOC of the reference aircraft. A TA with a high-wing, T-tail, and two engines offers the highest DOC improvements. The DOC of this aircraft are 13.6 % lower than those of the reference aircraft.

Future technologies have been integrated in the design and their potential has been quantified to further increase the possible DOC savings.

Table 2 Comparison of the DOC of different TA configurations with the DOC of the reference aircraft

Smart turboprop	Number of engines			
	2	4	2	4
	T-tail		Conventional tail	
High wing (%)	−13.6	−11.4	−13.3	−11.1
Low wing (%)	−12.4	−11.5	−12.9	−11.1

In a first step, the future technology “Natural Laminar Flow” (NLF) has been integrated into the design. Table 3 compares the DOC of the TA with NLF to those of the reference aircraft. The results show that the integration of NLF offers additional DOC improvements of 2.6 … 3.5 % points depending on the chosen configuration.

In a second step, a strut-braced wing (SBW) has been integrated into the design. Table 4 presents the DOC improvements compared to the reference aircraft. The results show that the integration of a SBW offers additional DOC improvements of 0.4 … 0.9 % points.

Finally, the technologies NLF and SBW have together been integrated in the TA design. Table 5 shows that together, both technologies lead to an improvement of 2.9 … 3.5 % points compared to the TA without future technologies. Altogether, the optimum TA offers a possible saving of 17.1 % compared to the DOC of the reference aircraft.

Table 3 Comparison of the DOC of different TA configurations (including the technology NLF) with the DOC of the reference aircraft

Smart turboprop + NLF	Number of engines			
	2	4	2	4
	T-tail		Conventional tail	
High wing (%)	−16.2	−14.1	−15.9	−13.7
Low wing (%)	−15.9	−14.2	−15.3	−13.7

Table 4 Comparison of the DOC of different TA configurations (including the technology SBW) with the DOC of the reference aircraft

Smart turboprop + SBW	Number of engines			
	2	4	2	4
	T-tail		Conventional tail	
High wing (%)	−14.3	−11.8	−14.1	−11.7
Low wing	–	–	–	–

Table 5 Comparison of the DOC of different TA configurations (including the technologies NLF and SBW) with the DOC of the reference aircraft

Smart turboprop + NLF + SBW	Number of engines			
	2	4	2	4
	T-tail		Conventional tail	
High wing (%)	−17.1	−14.3	−16.6	−14.1
Low wing	–	–	–	–

3.3 Description of the Optimum TA Design

The final TA configuration with minimum DOC is a strut-braced high-wing with NLF, T-tail, two engines, and a propeller diameter of 7 m. On a mission range of 755 NM, this aircraft could offer fuel mass savings of about 36 % compared to an A320. The CO_2 emissions would therefore also be reduced by about 36 %. DOC could be lowered by about 17 % compared to the reference aircraft.

A simplified analysis of the DOC of the A320neo using OPerA showed that the DOC of the A320neo are about 4 % lower than the DOC of the A320. Comparing the DOC of the previously described TA to the DOC of the A320neo therefore still leads to a potential DOC reduction of about 13 %.

The final aircraft design is illustrated in Fig. 4. The figure shows key parameters of the design and a comparison to the values of the reference aircraft A320. The values for the A320 are taken from a redesign of the reference aircraft in PrOPerA.

Additionally, the figure contains the matching chart, payload range diagram, cabin layout, and pie charts of the operating empty mass, the component drag and the DOC of the TA.

The ground handling and the ability to derive an aircraft family are two important requirements for every new aircraft concept. The conventional design layout of the TA allows to keep the ground handling processes very similar to those of the reference aircraft and allows a conventional derivation of an aircraft family [5].

4 Discussion

Compared to [5], some design parameters changed. These changes will be discussed in the next paragraphs.

Cruise Mach Number

In [5], a cruise Mach number of 0.71 was favored for the TA design. Now, the optimum Mach number went down to 0.51.

This is mainly due to the reason that real aircraft drag polar data in [19] allowed to improve the calibration for the calculation of the drag polar of the TA leading to an increase of the required P/W at a certain Mach number which led to a lower optimum Mach number for minimum DOC.

Number of Engines

In [5], a TA configuration with four engines was preferred. Now minimum DOC are reached with two engines. When four engines were preferred, the requirement coming from the second segment was the dimensioning requirement for P/W. As the second segment requirement has to be fulfilled with one engine inoperative, four engines are advantageous in comparison with two engines. The main reason for the change of the optimum number of engines again comes from the increase of required P/W due to an improved calibration of the drag polar calculation. Now the required cruise Mach number is the dimensioning requirement for P/W so that the advantage of four engines for the second segment requirement has no influence on the design anymore.

Cruise Altitude

The design results confirm that the Cruise Altitude (CA) of the chosen TA configuration is lower (about 40 %) than the CA of the A320.

The cruise altitude for horizontal flight can be found by setting lift equals weight, solving for ρ and after that solving for the cruise altitude:

$$C_L \cdot \frac{\rho}{2} \cdot v^2 \cdot S_W = m \cdot g \tag{1}$$

finally leads to:

$$h_{\mathrm{CA}} = \frac{1 - \left(\frac{2 \cdot g}{C_L \cdot \rho_0 \cdot v^2} \cdot \frac{m}{S_W}\right)^{\frac{1}{4.25588}}}{k_a} \tag{2}$$

with

$$K_a = 0.022558\,\mathrm{km}^{-1}$$

$$\rho_0 = 1.225\,\frac{\mathrm{kg}}{\mathrm{m}^3}$$

$$g = 9.81\,\frac{\mathrm{m}}{\mathrm{s}^2}$$

The only variables in this equation influencing the cruise altitude are C_{L}, v, and m/S_{W}. v is squared and therefore has a dominating influence on cruise altitude. The lower v, the lower h_{CA}. m/S_{W} and C_{L} of TA and reference aircraft are similar and therefore do not lead to a significant change of h_{CA}. The cruise speed v of the TA is 29 % lower than that of the reference aircraft leading to a 40 % reduction of cruise altitude. The parameters C_{L}, v, and m/S_{W} have been optimized for minimum DOC. The resulting h_{CA} is therefore also a result of the optimization process and represents the optimum h_{CA} for the TA.

The main reason that the optimizer choses a low M_{CR} (and therefore low v) is the resulting low P/W. The resulting lower h_{CA} leading to a higher v is a positive side effect but not the main reason for the low M_{CR}.

In summary, the proposed TA concept flies at lower altitudes but due to a different reason than initially expected.

In [5], the difference in cruise altitude of TA and reference aircraft was lower. This is simply due to the fact that the optimum M_{CR} and therefore also v were higher leading to a higher cruise altitude of the TA.

5 Summary and Conclusion

In comparison to the reference aircraft Airbus A320, the proposed turboprop-driven aircraft concept potentially reduces fuel consumption and CO_2 emissions by about 36 %. DOC can potentially be reduced by about 17 % on a DOC mission range of 755 NM. The improvements mainly come from the lower fuel consumption of turboprop engines compared to turbofan engines, the increased aspect ratio leading to a high glide ratio and the big propeller diameters leading to high propeller efficiency, all together causing additional positive snowball effects. Drawbacks are the 21 % increase in block time due to the lower cruise speed and additional mass due to the higher landing gear lengths caused by high propeller diameters and additional required soundproofing material due to the engine noise.

Acknowledgments The authors acknowledge the financial support of the German Federal Ministry of Education and Research (BMBF) which made this work possible. The authors would like to thank Axel Dengler and colleagues from Airbus for interesting discussions and the exchange of ideas. This paper is based on the publication *Novel Low-Flying Propeller-Driven Aircraft Concept For Reduced Direct Operating Costs And Emissions* [5]. In [5], a preliminary version of the design concept has been investigated. Here, the final design results are being presented.

Appendix

Notation

A	Aspect ratio
$A_{\mathrm{W,eff}}$	Effective aspect ratio of the wing
$b_{\mathrm{W,geo}}$	Geometrical span
c_{fuel}	Fuel cost
C_{L}	Lift coefficient
d_{prop}	Propeller diameter
DOC	Direct Operating Costs
$E_{\max}$	Maximum glide ratio
EIS	Entry into service
G	Standard gravity
h_{CA}	Cruise altitude
h_{ICA}	Initial cruise altitude
k_{a}	Constant
m_{F}	Fuel mass
M_{CR}	Cruise Mach number
M	Mass
m_{F}	Fuel mass
$m_{\mathrm{F,trip}}$	Fuel mass for the DOC range
m_{MPL}	Maximum payload mass

m_{MTO}	Maximum take-off mass
m_{OE}	Operating empty mass
m_{PAX}	Passenger mass
$m_{\mathrm{PL,DOC}}$	Payload mass for the DOC calculation
n_{PAX}	(1-cl HD) Number of passengers in a one-class high density layout
$P_{\mathrm{eq,ssl}}$	Equivalent take-off power at static sea level
PSFC	Power-specific fuel consumption
P/W	Power-to-weight ratio
R_{DOC}	Range for the DOC calculation
R_{MPL}	Maximum range (with maximum payload
s_{TOFL}	Take-off field length
s_{LFL}	Landing field length
SP	Seat pitch
S_{W}	Wing area
t_{TA}	Turnaround time
t/c	Thickness ratio
$U_{\mathrm{a,f}}$	Utilization
V	Speed
η_{prop}	Propeller efficiency
λ	Taper ratio
ρ	Air density
ρ_0	Air density at sea-level of the International Standard Atmosphere
φ_{25}	Sweep angle at 25 % chord

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