Preliminary aircraft design for a midrange reference aircraft taking advanced technologies into account as part of the AVACON project for an entry into service in 2028

S. Woehler and J. Hartmann
German Aerospace Center (DLR), Hamburg, 21129, Germany

E. Prenzel and H. Kwik
Airbus S.A.S., Hamburg, 21129, Germany

Abstract

The main objective of the AVACON project is to evaluate the impact of various technologies and aircraft configurations for an entry into service in 2028 within a consortium of industry partners, research entities and universities. To perform a fair and justifiable comparison with numerous partners the same understanding and level of accuracy of the reference aircraft is inevitable. The focus of this paper will be the design of a common reference aircraft for a 4600nm mission carrying 257 passengers. The elaboration of the top level aircraft requirements for the midrange aircraft will be covered as well as the aircraft characteristics and the design decisions made during the design process to define an agreed baseline for technology and configuration evaluation.

Nomenclature

ARB	=	AVACON Research Baseline
AVACON	=	Advanced Aircraft Concepts
BF	=	Block Fuel
CFRP	=	Carbon Fiber Reinforced Polymer
CPACS	=	Common Parametric Aircraft Configuration Schema
CRM	=	Common Research Model
DLR	=	German Aerospace Center / Deutsches Zentrum für Luft- und Raumfahrt
EIS	=	Entry into Service
GTF	=	Geared Turbo Fan
HLFC	=	Hybrid Laminar Flow Control
HTP	=	Horizontal Tail Plane
ICA	=	Initial Cruise Altitude
ICAO	=	International Civil Aviation Organization
ISA	=	International Standard Atmosphere
L/D	=	Lift over Drag
LuFoV	=	Federal Aeronautical Research Program / Luftfahrtforschungsprogramm V (2018-2022)
MTOW	=	Maximum Take-Off Weight
MWE	=	Maximum Weight Empty
Neo	=	New Engine Option
NMA	=	New Midsize Airplane
OWE	=	Operational Weight Empty
SFC	=	Specific Fuel Consumption
SL	=	Sea level
TLAR	=	Top Level Aircraft Requirements
TOFL	=	Take Off Field Length
UHBR	=	Ultra-High Bypass Ratio Engine
VTP	=	Vertical Tail Plane
v_{app}	=	Approach Speed

1. INTRODUCTION

The constant increase in aircraft passenger demand on a global scale accompanied by limited expandability of airport infrastructure worldwide reveals the demand for a new generation of midrange aircraft. Alongside the potential to increase transport capacity the integration of new technologies is inevitable to improve ecological sustainability and economic efficiency. To reduce the ecological footprint of future aircraft and highlight the potential of the midrange market segment the AVACON project within LuFoV-3 aims at developing innovative aircraft architectures including promising over wing engine integration concepts. The research within AVACON is hereby performed by the DLR together with partners from the industry, research entities and universities.

Experiences from previous projects show that potential benefits of new technologies or configurations have not always been compared to a reference model of the same level of accuracy leading to over- or underestimation of possible impacts. To ensure robustness of the outcome of the overall aircraft design and higher level of fidelity studies a common understanding of technology standards and design principles is needed to ensure comparable outcomes. Therefore the AVACON research baseline was developed in a close collaboration by DLR and AIRBUS as a common reference aircraft to identify potential technology bricks for a future midrange aircraft. The AVACON research baseline (ARB) will be shared in the CPACS [1] data format among all partners involved as a basis for data transfer. It is the common data exchange format for all further trade studies. The AVACON reference aircraft evaluation starts with a Boeing 767-300 design and method calibration, followed by a 2015 state of the art redesign with adapted TLARs and finalized by 2028 technologies application on the AVACON Research Baseline 2028. The AVACON Research Baseline 2028 is a conventional configuration with a mix of technologies that are foreseen as state of the art in 2028. Most techno-bricks that are supposed to be studies within the AVACON project are not applied on the research baseline. Those technologies are a UHBR engine and a high aspect ratio CFRP wing.

2. TLAR DERIVATION

In the past the midrange segment in the airline profile was operated by the Boeing 767 aircraft framed by the Boeing 757 and the A321 on the lower side of the market and the Airbus A330 on the upper side. Since the Boeing 767 airframe was phased out of commercial passenger transport aircraft production, Boeing has identified a gap in their product portfolio while especially northern American airlines are looking for a replacement of their aging fleets. The so called “sweet spot” lies at approximately 4600nm and 250 passengers for the middle of the market which can be seen in Figure 1 illustrated by *Aviation Week analysis*.

These characteristics are on par with first details about Boeings NMA aircraft and provide the 4600nm range and 257 passengers as requirements for the midrange studies within AVACON. 257 passengers were chosen for a typical 2 class layout comparable to a typical Boeing 767-300 layout accommodating 261 pax [2]. With a definition of 100kg per pax, including 20kg checked baggage and 5kg carry-on baggage, the design payload results in 25700kg and 30000kg for an all-economy seating layout of 285 pax and 15000kg margin. Additional cargo will not be assessed.

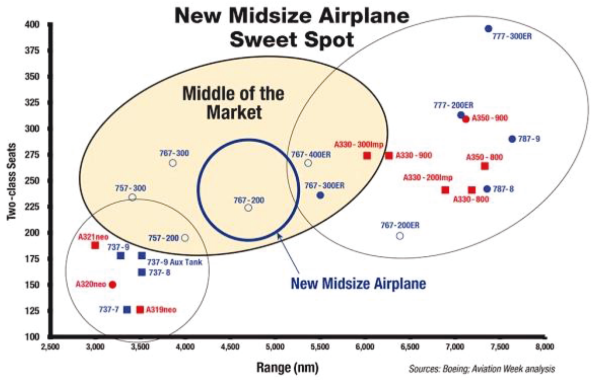

Figure 1 Network of routes of interest within 4600nm

Derived by operational pre-studies a significant marked opportunity can be foreseen for an aircraft capable of starting from runways of 2000m at sea level [3]. The study conducted by Dzikus and Terekhov analyzed the corrected runway length distribution for a midrange market forecast on origin-destination pairs [4]. The plot of the results can be seen in Figure 2 where almost 90% of the predictable passenger demand can be served with a TOFL capability of 2000m. The physical runways where hereby corrected by the airports elevation and reference temperatures to derive the maximum runway length at sea level as a function of passenger demand.

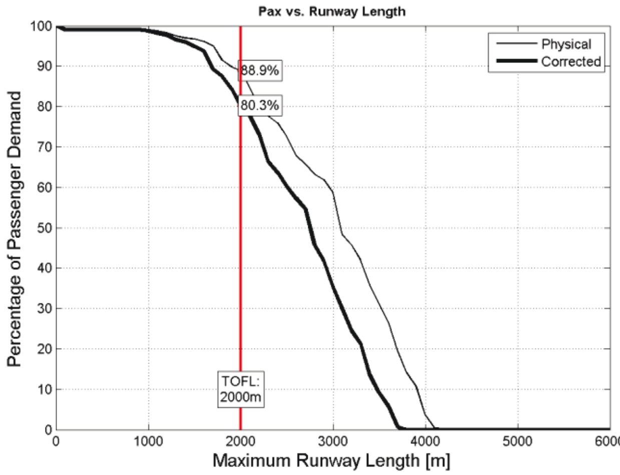

Figure 2 TOFL global availability study

2000m propose a highly sophisticated requirement since the Boeing 767 was operated on runway length of up to 2400m. This could penalize the aircraft due to more thrust needed for take-off then needed in cruise and an unbalance between low-speed and high-speed performance. But with the approach to serve as much airports as possible within the relevant market the aim is to challenge this requirement especially during the engine design phase to study the cost and value of this TLAR.

The cruise Mach number was set to 0.83 for the reference aircraft derived from the current trend to higher Mach numbers in the long range sector. Later during the project a value of speed analysis will be performed based on network and fleet simulations to validate the assumption. In addition to the 2000m TOFL the aircraft shall fulfill the

ICAO aircraft approach category C specification. In particular the speed at threshold v_{APP} must be less than 141 knots. For growth potential the speed at the threshold should be less than 137 knots. To comply with the current Boeing 767 airport operations and the ICAO aerodrome reference code 4D the wing span for gates and taxiways is limiting with 52m at maximum. A summary of all relevant TLARs can be found in Table 1.

TLARs	***Unit***	***Boeing 767-300***	***D250-763 2015***	***ARB2028***
Design Range	nm	4000	4600	4600
Std. PAX number (2-class layout)	-	261	257	257
Pax mass	kg	99.23	100	100
Std. passenger payload	kg	25900	25700	25700
Max payload	kg	40900	40900	30000
Cruise Mach number	-	0.80	0.83	0.83
Take-off field length (SL, ISA)	m	2600	2000	< 2000
Approach speed	kt	≤ 141 (Cat. C)	≤ 141 (Cat. C)	≤ 141 (Cat. C)
Wing span limit	m	≤ 52 (4D)	≤ 52 (4D)	≤ 52 (4D)

Table 1 TLAR definition

3. DESIGN PROCESS

The Boeing 767 can be noted as the original midrange aircraft and was chosen as the historical reference aircraft within the AVACON consortium. Furthermore it was agreed, that a conventional configuration will be defined as the research baseline with technologies available in 2028 as EIS. Therefore it was necessary to derive the baselines aircraft as a step by step approach to apply and fully understand the influence of the defined TLARs and technologies. Since some of the techno-bricks for an EIS in 2028 are supposed to be studies within the AVACON project not all were applied on the research baseline. The first preliminary design was derived using handbook methods [5] [6] [7] and later iterated by detail studies.

The baseline's cross section was specifically defined for AVACON by Airbus. It is more flat than the 7-abreast arrangement from the B767 reference to hold LD3-45 standard container instead of standard LD2s in the cargo compartment as seen in Figure 3.

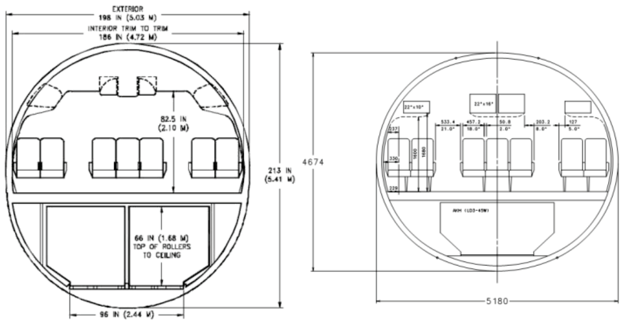

Figure 3 Comparison B767 [2] and ARB 2028 cross-sections

This change represents the reduced need for additional cargo transport in today's airline business. The Fuselage will be a completely new aluminium design with reduced cargo compartment height resulting in less wetted area but the same level of comfort within the cabin. The 7 abreast twin isle approach will be kept with a slightly wider cross-section. The door arrangement is described by two type A doors (2x110pax) and double type III doors (65pax) limiting the all economy seat arrangement to 285pax.

The wing design will be dominated by a high performance design with an aspect ratio of 12.3 and a span limit of 52m. The structure will be made of CFRP with a weight reduction of 5% compared to 2015 state of the art design principles. Aerodynamic characteristics were calibrated from the available Boeing 767 dataset [2] and enhanced by the CRM profiles [8]. HLFC will be considered during a later study.

The tail plane geometry parameters were also derived from the Boeing 767 despite the HTP aspect ratio will be increased to 5.6 according to the increase of the wing aspect ratio. Also the landing gear will be kept similar with a wing mounted main landing gear while the weight is scaled by the influence of the MTOW. Subsequently the design step evaluation is described as following:

Design step evolution for the AVACON Research Baseline 2028:

1. Design and method calibration of the historical reference aircraft: Boeing 767-300
2. Design for adapted payload
3. Design for extended range requirements
4. Design for reduced TOFL requirements and 2015 engine technology
5. Design for the adapted cross section
6. Design for increased Mach number
7. Design for the high aspect ratio wing
8. High-lift & wing planform optimization
9. Integration of 2028 engine technology

4. AVACON RESEARCH BASELINE 2028

The results obtained for external use are validated between Airbus and DLR. The following tables and figures describe the main characteristics of the ARB2028 reference aircraft. Figure 4 gives a rough overview of the conventional configuration of the ARB 2028 geometry. It can be noticed that the fuselage length is roughly the same while the fuselage height was reduced drastically. While having a bypass ratio of 15.6 the turbofans still fit under the wing with the geometry assumptions derived for the nacelle diameter and length.

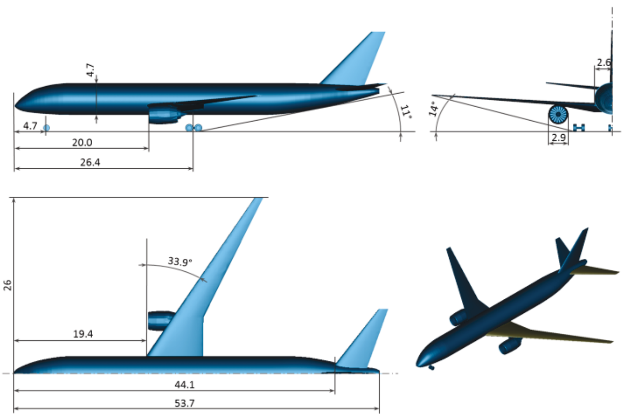

Figure 4 Three view of the ARB 2028

In Table 2 a detailed mass breakdown is given:

Wing	kg	16400
Fuselage	kg	17700
HTP	kg	1600
VTP	kg	1000
Landing Gear	kg	5400
Pylon	kg	1350
Total Structure	kg	**43450**
Systems	kg	8400
Power Units	kg	14000
MWE Evaluation (without Furnishing)	kg	**65850**
Furnishings	kg	6200
Operator Items	kg	9150
OWE	kg	**81200**

Table 2 Mass breakdown ARB 2028

In Figure 5 the lift over drag (L/D) polar for cruise condition at flight level 350 and Mach 0.83 is plotted showing the maximum L/D of 20.6. The lift coefficient in cruise condition is 0.53 and will be flown during the constant climb path detailed in Figure 7 for the design mission.

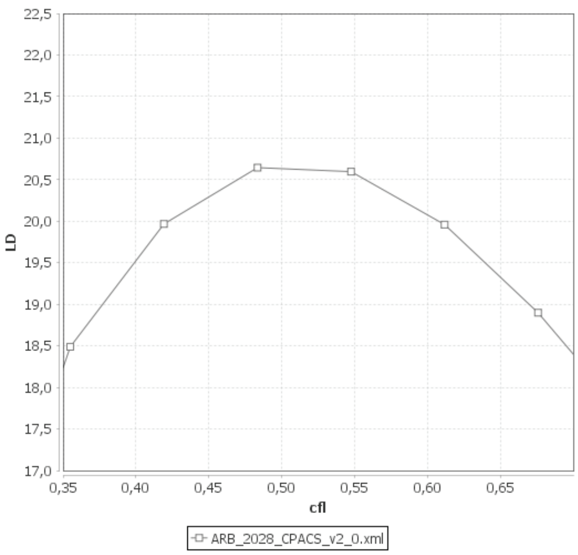

Figure 5 L/D polar at 35000ft and Mach 0.83

The key characteristics of the ARB2028 for the design weights, wing parameters, engine data and flight performance are summarized in Table 3.

Range	nm	4600
Pax (2 class)	-	257
Max. Payload	t	30
Max. Take-off Weight	t	140.0
Max. Landing Weight	t	115.4
Max. Zero Fuel Weight	t	111.2
Basic MWE	t	65.9
OWE Eval.	t	81.2
Wing span	m	52
Wing area	m²	220
Fuel Volume	kl	50.2
Engine type		Generic GTF
Thrust Level	kN	230.8
Fan diameter	m	2.4
Bypass ratio	-	15.6
SFCcruise bucket pt. with Offtakes	Lb/h/lbf	0.475
BF 4600nm	t	29.1
BF 2000nm	t	12.6
Cruise Speed	-	0.83
ICA	ft	35000
Time-to-climb (FL330, ISA)	min	26.2
$c_{L,max\ TO}$	-	2.3
$c_{L,max\ LDG}$	-	2.7
c_L cruise	-	0.53
L/D cruise	-	20.6
TOFL (SL, ISA)	m	2000
v_{APP}	kts	134

Table 3 Key aircraft characteristics ARB 2028

For the MTOW flight mission profile the design range of 4600nm was projected with an alternate distance of 200nm, loiter time of 30 minutes and 3% contingency of the trip fuel in continues climb mode as seen in Figure 6.

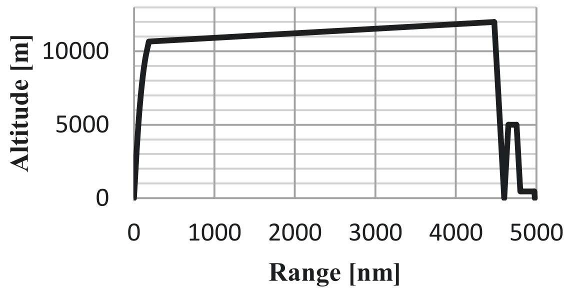

Figure 6 MTOW mission flight profile

The design mission is marked in red in payload range diagram in Figure 7 showing the maximal possible fairy range and the 3850nm range for the maximum payload mission.

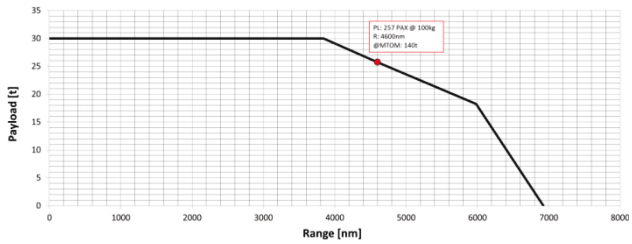

Figure 7 Payload-Range Diagram ARB 2028

5. CONCLUSION

The AVACON Research Baseline represents a highly mature preliminary aircraft design for an EIS 2028 midrange aircraft. Both Airbus and DLR conducted numerous iterations leading to a detailed design that serves as the reference aircraft for various technology and configurational studies to come. The technologies applied were integrated iteratively to understand and evaluate their impact within the consortium. The next revision will feature a more detailed engine and advanced system architectures for on the board systems. Publishing the AVACON research baseline will serve future studies in this market segments by offering reliable assumptions and an elaborated set of TLARs.

References

[1] Nagel, B., Böhnke, D., Gollnick, V., Schmollgruber, P., Rizzi, A., La Rocca, G., Alsonso, J.J., “Communication in Aircraft Design: Can we establish a Common Language?”, 28th International Congress of the Aeronautical Sciences, Brisbane, Australia, 2012.

[2] Boeing Commercial Airplanes,”767 Airplane Characteristics for Airport Planning”, May 2011.

[3] Dzikus, N., Terekov, Gollnick, V., Hartmann, J., “Market-driven Derivation of Field Performance Requirements for Conceptual Aircraft Design” *AIAA-2018-3499*, AIAA AVIATION Forum, Atlanta, 2018.

[4] Ghosh, R., Klker, K., Terekhov, I., “Future Passenger Air Traffic Modelling: A theoretical Concept to integrate Quality of Travel, Cost of Travel and Capacity Constraints”, 19th World Conference of the Air Transport Research Society (ATRS), Singapur, 2-4 July 2015.

[5] Torenbeek, E., “Synthesis of Subsonic Airplane Design”, Delft, 1984.

[6] Raymer, D.P., “ Aircraft Design: A Conceptual Approach”, *AIAA Education Series*, 4th ed., Washington DC, 2006

[7] Rosskam,, J., “ Airplane Design”, Part 1-7, Kansas, 1985.

[8] Vassberg, J.C., DeHaan, M.A., Rivers, S.M., Wahls, R.A., “Development of a *Common Research Model* for Applied CFD Validation Studies”, *AIAA-2008-6919,* 26th AIAA Applied Aerodynamics Conference Honolulu, Hawaii, 2008.