CONCEPTUAL DESIGN OF A STOL REGIONAL-JET WITH HYBRID PROPULSION SYSTEM

Corin Gologan
Bauhaus Luftfahrt e.V., Garching, Germany

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Abstract

This paper outlines the conceptual design of a fan-in-wing (FIW) short take off and landing (STOL) regional-jet for 50 passengers and a range of 1000 nautical miles with a take off field length (TOFL) of 300m (ground roll).

The approach chosen was to first examine realized lift-fan aircraft and to subsequently derive conclusions for a civil FIW concept. Based on these conclusions parametric design studies for thrust to weight ratio (T_0/W), wing-loading (W/S) and lift-fan thrust were performed in a performance constraint chart to find advantageous combinations that meet the performance requirements. These results were used to design a basic layout including the calculation of component masses. Different hybrid propulsion system concepts for the lift-fans were investigated within this basic configuration. In this context "hybrid" means that the lift-fans are driven by power extracted from the aircraft's main engines and that the lift during take off and landing is produced by the wing and lift-fans. The investigated propulsion systems include mechanical, electrical and pneumatical power transmission and extraction. The concepts were compared in a mission calculation module.

1 Introduction

A predominant problem in the US as well as in Europe is the imminent capacity shortage of major airports. Already today many airports suffer from ongoing excess demand, particularly at peak times. At the same time, traffic demand is assumed to increase significantly worldwide. However, further runway extension of airports is difficult because of residents' resistance and land space availability. Possible solutions are on the one hand the opening up of new small regional airports (regionalization) and on the other hand the extension of the capacity of existing airports through the use of underutilized areas (segmentation). Both solutions require STOL (Short Take Off and Landing) capability for regional aircraft. For this reason, this paper outlines the conceptual design of a STOL regional-jet (hybrid airliner named "HyLiner-R") for 50 passengers and a range of 1000 nautical miles.

2 Examination of Realized Lift-Fan Aircraft

To get an overview about lift-fan aircraft two realized concepts are studied first. For the Lockheed Martin F-35B the calculation of take off field length (TOFL) is performed to understand flight mechanics of lift fan aircraft. The propulsion system of the GE-Ryan XV-5A is examined to get information about pneumatic-driven lift fans.

2.1 Lockheed Martin F-35B

The F-35B is a short take off and vertical landing (STOVL) aircraft. Its propulsion system consists of a main engine and a shaft-driven lift fan that is switched on for additional lift during takeoff and landing. The low pressure turbine of the main engine delivers additional shaft power to drive the lift fan. The main engine has a thrust vectoring nozzle and so it contributes to the lift during take off and landing. Two roll post nozzles enable roll control during low speed and hover. [3]

Fig. 1 shows the authors interpretation of the forces acting during take off and landing/transition.

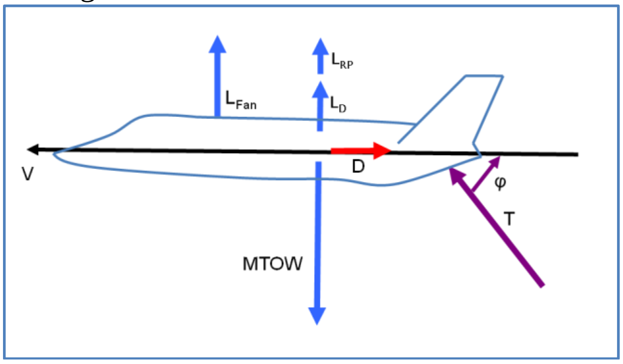

Fig. 1 Forces acting during take off and landing

Tab. 1 shows some basic data of the F-35B taken from [6]:

		JSF F-35B
b	[m]	10.60
S	[m^2]	42.70
MTOW	[kg]	27,216
T_0	[N]	111,000
Lift: fan „on“ mode		
$L_{MainEngine}$= T	[N]	69,837
$L_{RollPost}$	[N]	16,458
L_{Fan}	[N]	88,964

Tab. 1 Basic Data for F-35B

The static thrust T_0 of the main engine is 111,000N. In the "fan on" mode the residual thrust T at the main engine is reduced to 69,837N due to the power offtake for the lift fan and the bleed air offtake for the roll post nozzles. Thus the thrust loss (T_0-T) is 41,163N. The lift of the fan L_{Fan} is 88,964 N and the lift of the roll post nozzles $L_{RollPost}$ is 16,458N, in total (L_{Fan}+$L_{RollPost}$) 105,422 N.

The efficiency factor E is here defined as the ratio of the thrust loss of the main engine to the lift gain of the vertical lift devices:

$$E = (T_0-T)/(L_{Fan}+L_{RollPost}) \qquad (1)$$

For the F-35B E is 0.39, this means that to gain a certain lift only 39% of this gained lift is lost at the main engine. E is later used to couple the lift of lift-fans with the residual thrust and the static thrust of main engines for conceptual design purposes. For a separate lift device, where the thrust of the main engine is not affected by the lift device, E would be zero.

Calculation of TOFL

For the calculation of TOFL (x_{TO}) reference [2] gives the following equation, which can be interpreted as the distance needed to accelerate a weight W to a certain speed:

$$x_{TO}=0.5v_{TO}^2W/(g(T-D-\mu(W-L))) \qquad (2)$$

$(T-D-\mu(W-L))$ is the sum of forces acting in x-direction and has to be evaluated at 70% of take off speed v_{TO}. This is done for the drag D. Here T and the lift L (L_{Fan}+$L_{RollPost}$) are assumed constant during take off. μ is the friction coefficient.

v_{TO} equals the stall speed (v_{ST}) multiplied with a safety factor (1.2 for civil aircraft, here 1.1 is used). v_{ST} results from the forces acting in z-direction (Fig. 1):

$$v_{ST}^2=2(W-L_{Fan}-L_{RollPost}-T\sin\varphi)/(\rho_0\, S\, C_{LMaxTO}) \qquad (3)$$

The zero drag coefficient C_{D0} at take off and the maximum lift coefficient C_{LMaxTO} are calculated with methods from [4] and presented in Tab. 2:

C_{D0}	[-]	0.052
k	[-]	0.15
C_{LmaxTO}	[-]	1.6

Tab. 2 Aerodynamic coefficients

The thrust vector angle φ of the main engine is assumed 55° during short take off based on the available video material. With (2) and (3) the TOFL can be calculated. Fig. 2 shows a trade study for the resulting TOFL for the F-35A and the F-35B against take off weight (TOW).

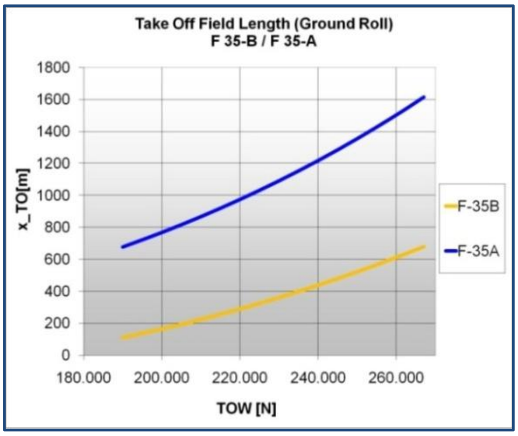

Fig. 2 Calculated Take Off Field Length for JSF

For low TOW the TOFL of the F-35B is about 4 times shorter than for the F-35A. For high TOW it is about 2.3 times shorter. The reason therefore is that for low TOW the ratio of fan and roll post lift to TOW is 55%, for high TOW it is only 39%. No thrust vectoring of the lift-fan is considered during acceleration. A thrust vectoring of 30° already brings a contribution to the accelerating forces of 50% of the lift-fan thrust and thus has a high impact on TOFL. Therefore it will be part of future investigations.

2.2 GE-Ryan XV-5A

The GE-Ryan XV-5A was a vertical take off and landing (VTOL) fan-in-wing aircraft. It had two lift-fans in the wing and one trim fan in the nose. All fans were driven by turbine blades that were installed at the tip of the fans. These tip-turbines were driven by the exhaust of the two main jet-engines which was completely deflected to the tip-turbines during hover. The XV-5A had a variable bypass ratio (BPR) propulsion system, switching from BPR zero in forward flight to high BPR of the lift-fans during take off, landing and transition, thus augmenting the total thrust in these mission segments. Tab. 3 shows available data of the propulsion system taken from [5] and [13]:

T_0	[N]	23,600
L_{Fans}	[N]	71,200
D_{Fan}	[m]	1.5
$W_{Propulsion}$	[kg]	841

Tab. 3 Available data of XV-5A propulsion system

The efficiency factor E - as defined in chapter 2.1 - is for the XV-5A the ratio of T_0 to L_{Fans}, as the total T_0 is lost during hover. Thus E is 0.33.

2.3 Conclusions for a Civil Fan-in-Wing Aircraft with Hybrid Propulsion System

Both concepts (F-35B and XV-5A) augment their lift during take off and landing by driving lift-fan(s) with extracted power from the main engine. This augments the bypass ratio of the propulsion system. A higher bypass ratio always means more thrust for a given power. Although the main engine thrust is reduced, the sum of the residual main engine thrust and the additional lift/thrust of the lift-fan(s) is higher than the static thrust of the main engine. E describes the coupling of the lift of lift-fans with the residual thrust and the static thrust of the main engines. The F-35B has an E of 0.39; the XV-5A had an E of 0.33. For the following chapter it is assumed that E=0.33 can be achieved with a civil hybrid lift-fan concept.

3 Parametric Design Studies

When designing an aircraft the engineer has to ensure, that the aircraft meets the performance requirements for each mission segment. Typical segments for civil transport aircraft are take off, climb with one engine inoperative (OEI), cruise and landing. Therefore T_0/W is calculated as a function of W/S for each mission segment and plotted in a performance constrain chart (PCC). This PCC shows all the parameter combinations that meet the performance requirements. Subsequently a suitable design point - a combination of T_0/W and W/S which fulfils all requirements - can be selected.

For the aircraft type investigated here having lift-fans, the standard methods for the performance calculation had to be adapted. The reason therefore is that the static thrust of the main engine is reduced during take off, climb and landing due to power off take. Only the residual thrust is available. For the calculation of take off, climb and landing performance the residual thrust and the lift of the fan are needed, but for civil aircraft the static thrust to weight ratio is the main describing parameter. Formula (1) can be modified to generate a correlation of static thrust, residual thrust and fan-lift (roll post lift is not considered for this civil concept as conventional flight control devices are available):

$$T=T_0-EL_{Fan} \qquad (4)$$

This chapter first presents how the standard mission segment performance methods were extended using this correlation and the final PCC of the HyLiner concept.

3.1 Take Off

TOFL is calculated with (2), stall speed with (3). (4) is inserted into (2) and (3) to describe the correlation between residual thrust, fan-lift and static thrust. This correlation can now be solved for T_0/W as a function of W/S and plotted within the PCC.

3.2 Climb OEI (2nd Segment)

The thrust to weight ratio needed to perform a certain climb rate is derived from the forces acting in x-direction (drag and thrust). It is climb rate plus the ratio of drag to weight. For an aircraft with thrust vectoring at the main engine only the cosine-component of the thrust can be used for climb:

$$T\cos\varphi/W = D/W + \frac{\dot{H}}{v} \qquad (5)$$

For OEI conditions this term has to be multiplied with *(N-1)/N*. D has to be evaluated at 1.2 times the stall speed (again calculated with (3)), the required climb rate is 0.024 [7]. The weight in the drag to weight ratio is substituted by the forces in z-direction (Fig. 1):

$$W = L_D + L_{Fan} + T\sin\varphi \qquad (6)$$

With

$$L_D = 0.5\,\rho\,v_{TO}^2\,S\,C_{LMaxTO} \qquad (7)$$

Again (4) is inserted into (5) and (6) to model the correlation between residual thrust, fan-lift and static thrust.
These correlations can now be solved for T_0/W which is not a function of W/S. Climb performance is only a function of thrust and aerodynamic efficiency and thus a horizontal line in the PCC.

3.3 Climb to Cruise Altitude

For the climb to cruise altitude performance requirement (5) is modified, as the lift-fans in this segment are not operating and the thrust is not vectored. W in this segment equals the dynamic lift, the residual thrust is decreasing with increasing altitude ($T=T_0\,\rho_{Cruise}/\rho_0$ [2]):

$$T_0/W = \rho_0/\rho_{Cruise}(D/L + \frac{\dot{H}}{v}) \qquad (8)$$

The required climb rate for this segment is 0.011 [7].

3.4 Cruise

The thrust to weight ratio required to satisfy cruise requirements is derived from the equilibrium of forces in x- and z- direction for cruise conditions (T=D and W=L).

$$T_0/W = (0.5\rho_{Cruise}\,v_{Cruise}^2 C_{D0}\,S/W + 2k/(\rho_{Cruise}\,v_{Cruise}^2)W/S)\,\rho_0/\rho_{Cruise} \qquad (9)$$

3.5 Landing

For the calculation of landing field length (LFL) [2] gives following equation:

$$x_L = 0.5\,v_L^2\,MLW\,/\,(g\,(D+\mu(MLW-L)) \qquad (10)$$

Again, (decelerating) forces acting in x-direction *(D+μ(W-L))* have to be evaluated at 70% of the landing speed [2]. Landing speed is calculated with (3) and multiplied with 1.3 (reserve factor for landing [7]). With the lift-fan operating LFL results:

$$x_L = 1.69(MLW-L_{Fan})MLW\,/\,(\rho S\,CL_{MaxL}\,g\,(D+\mu(MLW-L_{Fan})) \qquad (11)$$

With MLW being 85% of MTOW this equation can be solved for T_0/W.

3.6 Aerodynamic Coefficients

For the calculation of the aerodynamic coefficients initial values were taken from the Bombardier CRJ200 [8] with a slightly reduced MTOW (due to less range and composite materials, see Tab. 4).

S	[m²]	48,35
b	[m]	21,21
MTOW	[kg]	22.000

Tab. 4 Values for calculation of aerodynamic coefficients

Based on these data the aerodynamic coefficients were calculated with methods of [4] respectively taken from this reference for the category “transport jets” (Tab. 5):

$\Delta C_{D0Flaps}$	[-]	0.02
$\Delta C_{D0LandingGear}$	[-]	0.02
e	[-]	0.80
AR	[-]	9.30
k	[-]	0.0428
S_{wet}	[m^2]	328
$C_{D0Clean}$	[-]	0.0211
$C_{DOFlaps}$	[-]	0.0411
$C_{D0Flaps+LandingGear}$	[-]	0.0611

Tab. 5 Aerodynamic coefficients

3.6 Parametric Constraint Chart

Parametric studies were done for TOFL and LFL of 300m modifying the fan-lift and the maximum lift coefficients. One PCC is shown in Fig. 3 for the parameter setting of Tab. 6.

L_{Fan}	[N]	120,000
C_{LmaxS}	[-]	2.2
C_{LmaxL}	[-]	2.2
E	[-]	0.33
N	[-]	2
φ	[°]	0
μ_{TO}	[-]	0.03
μ_L	[-]	0.3
M_{Cruise}	[-]	0.74

Tab. 6 Final parameter setting

The following design point was selected: W/S of 3600N/m^2 and T_0/W of 0.5. Take off (green line) and climb "2nd segment" (red line) requirements are dominating. The required T_0/W for "climb to cruise" (blue) and "cruise" (black) - both conventional segments - is 0.3 and in the range of conventional regional jets.
A small thrust vector angle of 15° at take off already modifies the take off requirement significant, for W/S a value of 4.800 N/m^2 could be selected, where the landing constraint (yellow) would be reached. But to include thrust vectoring knowledge about the position of the lift fan is needed to calculate the pitching moment. Thus for the selection of the first design point thrust vectoring is not considered. The installation of three engines or vectoring of the lift-fan thrust could reduce the "2nd segment" requirement.

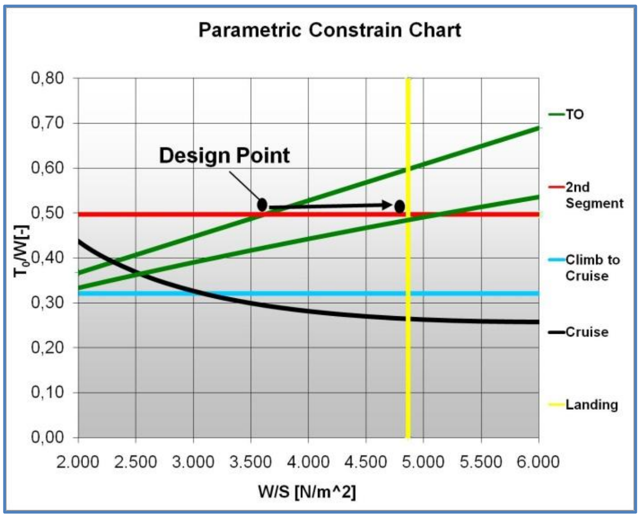

Fig. 3 PCC for HyLiner-R

4 Basic Configuration

Based on the selected design point the basic configuration was calculated, including fuselage, wing and tail geometric parameters, main engine size and component masses.

4.1 Fuselage

The fuselage geometry was taken from the reference configuration (4 abreast cabin layout). Fuselage length is 23.5m and the diameter is 2.8m, thus the wetted area is approximately 150m^2.

4.2 Wing

The wing area results from the initial MTOW and W/S as 60m^2. A high aspect ratio of 12 is selected for cruise efficiency. Sweep angle is calculated as 13.3° for M_{Cruise}=0.74 at 37.000ft, taper ratio is 0.3 (taken from [4]).

4.3 Tail

Stabilizer is designed for a horizontal tail volume coefficient of 1.0 (according to [1]) with an aspect ratio of 6 (half of the wing aspect ratio). The fin is designed for a vertical tail volume coefficient of 0.09 according to [1]. Thus the stabilizer reference area is 14.7m^2 and the fin reference area is 14.5m^2.

4.4 Engine

For the basic configuration a two engine layout was chosen. T_0/W of 0.5 means a static thrust of 54kN for each engine. With a bypass ratio of 4.5 the dry weight of one engine is 966kg and the diameter 1.32m calculated according to [1].

4.6 Three View

Fig. 4 shows the three view of the basic configuration.

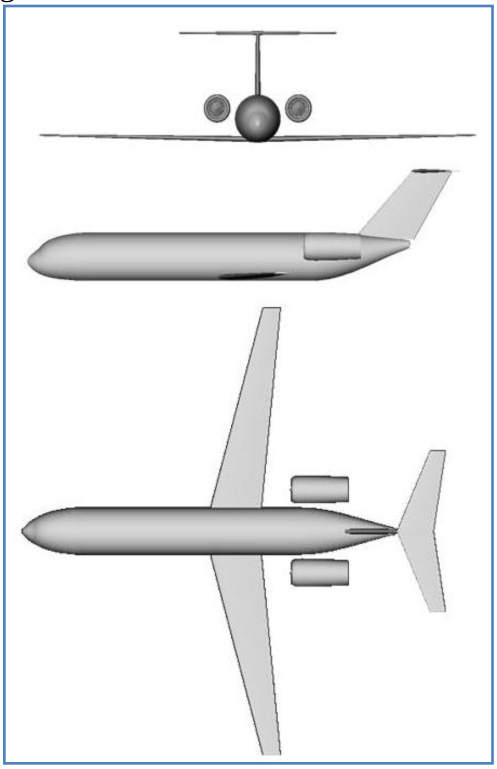

Fig. 4 Three view of basic configuration

4.5 Mass Breakdown

The configuration mass breakdown (Tab. 7) was calculated with the "approximate empty weight buildup" method and adapted by "fudge factors" [1] due to application of composite materials.

Fuselage	[kg]	3,240
Wing	[kg]	2,499
Stabilizer	[kg]	330
Fin	[kg]	325
Installed Engines	[kg]	2,465
Landing Gear	[kg]	899
"All Else"	[kg]	3,740
OWE_{Basic}	[kg]	13,498

Tab. 7 Mass breakdown of basic configuration

Compared to the OWE of CRJ200 (13.835kg) this is in good accordance. The higher weight of the installed engines is compensated by the application of composite materials. This basic OWE has to be completed by the calculation of the weights of the propulsion system for the lift-fans and the weight of the lift-fans.

5 FIW Configurations

Based on this basic layout, different configurations with hybrid propulsion systems for lift-fans were developed using a morphological matrix.
Three of the resulting concepts are presented in this paper. All of them have four lift-fans integrated into the wing, two on each side. To enable the integration of a wing-box the fan diameter is set to 2m (Fig. 5). The lift-fan weight is calculated with the "GD-method" from [10] for a four-blade fan and is a function of thrust and power.

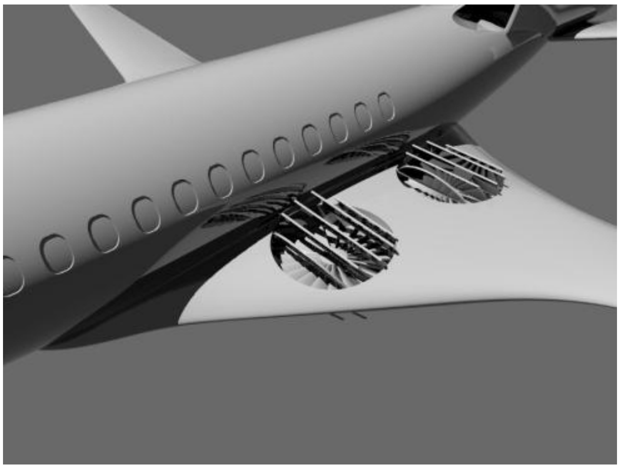

Fig. 5 Lift-fan integration

The first concept has electrical-driven lift-fans, the second one shaft-driven lift-fans and the third one tip-turbine-driven lift-fans. The principal aspects of these concepts is first presented in this chapter including an evaluation of their specific weights. Then the propulsion system is evaluated to quantify power offtake performance of the main engine. With this available power the lift-fan thrust is calculated. Finally the results of the mission calculation are presented.

5.1 Electrical-Driven (ED) Lift-Fan (LF)

Fig. 6 Electrical-driven lift-fan configuration

The main engines have thrust vectoring (for additional control during low speed flight) and are partly integrated into the aft-fuselage (Fig. 6). This enables power offtake from the high/low pressure spool and the integration of electrical generators in front of the engines (mechanical offtake combined with electrical power transmission). The lift-fans are driven by electrical motors that receive their energy from the generators. The system weight is based on an electrical generator for aeronautical application that is in development at IPS. It has a power of 1MW and a weight of 200kg [11]. As this system consists of a generator and a motor a specific weight of 400kg/MW was assumed. Advantages of the electrical system are the geometrical variability of the propulsion system arrangement and simple cross linking of the fans.

5.2 Shaft-Driven (SD) Lift-Fan

The shaft-driven lift-fan concept has the same configuration as the electric driven one except of the high wing arrangement. Fig. 7 shows the principle arrangement of the configuration. The low pressure spool is lengthened to drive the lift-fans like in the F-35B. Cross linking of the two shafts is provided. The shaft system weight is calculated in a very conservative way. The maximum expected power offtake of one engine is 4MW. Typical low pressure spool speed is 6000/min, thus the resulting torque is 6400Nm. The resulting stress of a shaft with an outer diameter of 12cm and an inner diameter of 11cm is 128MPa, which is far under the maximum stress of standard low pressure spool materials. A typical density of such materials is 6kg/l (titan), thus the resulting weight per meter is 10.8kg. The needed shaft length is 28m including the shafts for the cross linking. Thus the resulting shaft weight for 4MW (8MW total) offtake is 302kg, with linear interpolation the specific weight is 38kg/MW.

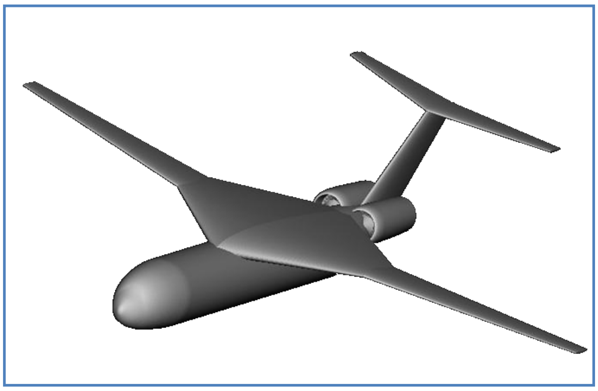

Fig. 7 Shaft-driven lift-fan principal arrangement

5.3 Tip-Turbine-Driven (TTD) Lift-Fan

This concept has lift-fans that are driven by tip-turbines. Bleed air is extracted out of the high pressure compressor. Energy is added in an additional burner before the air expands in the tip-turbine. For this propulsion system the engines are positioned on the wings to keep the ducts short (Fig. 8), but a position of the main engines at the aft fuselage is also applicable.

Fig. 8 Tip-turbine driven lift-fan configuration

As no data for tip-turbine weights were available following consideration was done: A turbo-prop engine in the 2MW class has an approximate specific weight of 210kg/MW [12]. The same value results from a calculation with methods of [1]. It was assumed that the weight of the turbine is one fourth of the total weight.

Thus a specific weight of 52kg/MW was chosen for the tip-turbine.

5.4 Propulsion System Performance

A 54kN turbo-fan engine with BPR 4.5 was modeled with the gas turbine performance tool “GasTurb” [14]. The specific fuel consumption without power offtake is 1.9e-5kg/Ns. Three power offtake possibilities were analyzed. (i) high pressure (HP) spool, (ii) low pressure (LP) spool and (iii) bleed air offtake. The residual thrust of the main engines is plotted against the bleed air power offtake respectively shaft power offtake in Fig. 9. The bleed air power - which is the power that is provided to the tip-turbine - was calculated for a tip-turbine burner exit temperature of 1600K and a tip-turbine pressure ratio of 4 (one stage, expansion to ambient pressure).

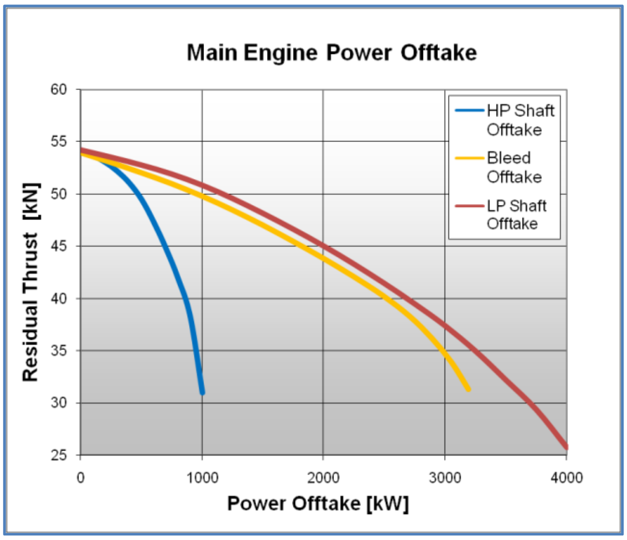

Fig. 9 Residual thrust over power offtake

The engine is capable to deliver more LP-spool shaft-power than bleed-power. The bleed-air offtake is limited at 3.2MW. At this point the thermodynamic cycle cannot be retained stable anymore. For the LP mechanical offtake this limit is at 4MW. HP shaft offtake has severe negative effects on the thermodynamic process. The offtake is limited at the relatively low offtake of 1MW with a thrust reduction of about 40% and is therefore not suitable for power offtake for high lift devices.

Fig. 10 shows the thrust of one lift-fan with a diameter of 2 m over the available power, calculated according to [9] with a fan efficiency of 0.85.

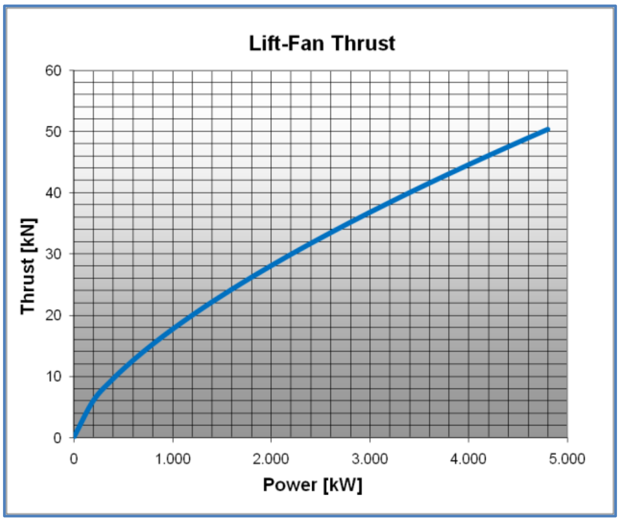

Fig. 10 Lift-fan thrust over available power

With Fig. 9 and Fig. 10 the residual thrust and the lift-fan thrust can be calculated for any power offtake value. The corresponding weight of the fan and the lift-fan propulsion system is calculated based on the documented specific weights and added to OWE_{Basic}. Thus the take-off and landing performance according to chapter 3 can be calculated.

At this point the assumption for E that was made for the parametric design studies can be checked. For one engine at a mechanical offtake of 2MW the residual thrust is 45kN (thrust loss is 9kN). Two fans with 2m diameter (1MW each) generate 36kN of thrust. Thus E is 0.25 which is even better that the assumed E. For the shaft offtake and 3MW E is 0.37 and somewhat higher than the value assumed in chapter 3. The total fan-lift for 3MW offtake is 92kN and lower than the fan-lift assumed in chapter 3. Thus the resulting TFL and LFL will be longer than 300m. 4MW offtake is not considered due to the high thrust loss of over 50%.

5.5 Results

The documented methodology was implemented in a matlab program that includes a mission calculation module (fuel fraction method). Calculations were performed for 2MW and 3MW power offtake for each concept.

	SDLF	EDLF	TTDLF
MTOW [kg]	22,199	23,891	22,267
W_{Fans} [kg]	348	348	348
$W_{Propulsion}$ [kg]	152	1.600	210
OWE [kg]	14,148	15,446	14,056
W_{Fuel} [kg]	3,196	3,445	3,211
L_{Fan} [N]	70,800	70,800	70,800
x_{TO} [m]	350	424	362
x_L [m]	523	572	525
T_0/W	0.49	0.46	0.49

Tab. 8 Results for 2MW offtake

	SDLF	EDLF	TTDLF
MTOW [kg]	22,440	24,978	22,541
W_{Fans} [kg]	480	480	480
$W_{Propulsion}$ [kg]	228	2,400	315
OWE [kg]	14,280	16.378	14,293
W_{Fuel} [kg]	3,231	3,600	3,248
L_{Fan} [N]	92,000	92,000	92,000
x_{TO} [m]	372	511	406
x_L [m]	488	565	491
T_0/W	0.49	0.44	0.49

Tab. 9 Results for 3MW offtake

The MTOWs are in good accordance with the initial value assumed in chapter 3 for the SD and the TTD concepts. The ED concept is heavier than the initial value, which comes from the heavy propulsion system (1,600kg for 2MW and 2,400kg for 3MW). Hence TOFL and LFL is the longest of all concepts and the fuel burn the highest. The value for MTOW and thus the other values would even be higher after a recalculation with the new initial MTOW. An advantage of the electrical system is the simple cross linking of the fans. This concept has a potential for future applications as weights of electrical generators and motors are continuously decreasing.

The weight of the fans of all concepts is 348kg for 2MW and 480kg for 3MW, they generate 70.800N (2MW) respectively 92.000N (3MW) of vertical thrust. Propulsion system weights of the SD and TTD concepts are similar and thus fuel consumption and take off and landing performance.

The weight of the TTDLF (fan plus propulsion system) for 2MW offtake (70,800N fan-lift) is 558kg, compared to the weight of the XV-5A propulsion system (which had the same lift) it is 35% lower. This is a good accordance as about 50 years of progress in material research have passed since the XV-5A development and as the disc-loading of the HyLiner fans is lower. An advantage of the TTD concept is the simple cross-linking of fans, a disadvantage is the need of additional burners.

The SD concept is slightly better compared to the TTD concept due to the higher residual thrust of the main engine and the lower specific weight of the propulsion system. Take off field length is 350m for 2MW (372m for 3MW); landing field length is 523m (488m). The higher take off field length for higher offtake results from the lower residual thrust that is available during acceleration. The lower landing field length for the higher offtake results from the higher fan-lift. In addition to the best performance results an advantage of this concept is the best offtake performance without the need of additional burner installation. A disadvantage is the limited variability in the arrangement of the fans and engines.

7 Conclusion and Outlook

This paper documents the conceptual design of a FIW STOL regional-jet for 50 passengers with hybrid propulsion system. Two realized military concepts (XV-5A and F-35B) were first examined to define the efficiency factor E that describes the coupling of static thrust, residual thrust of the main engine and lift-fan vertical thrust. With E the standard flight mechanic equations were extended to perform parametric design studies for T_0/W and W/S for a civil FIW aircraft. Based on these studies, a basic layout and lift-fan integration was designed including component mass calculation.

Three power offtake possibilities were simulated with “GasTurb” for a 54kN turbofan engine: (i) high pressure spool offtake, (ii) low pressure spool offtake and (iii) bleed air offtake with the result that low pressure spool power offtake is the most efficient way with a residual thrust of 45kN at 2MW and 37kN at 3MW offtake. Bleed offtake is close to this if an additional burner is added to the tip-turbine. LP-spool offtake has shown not to be a suitable power offtake option. Based on these results three concepts were compared: (i) an electrical driven lift-fan concept, (ii) a shaft-driven lift-fan concept and (iii) a tip-turbine-driven concept. The shaft-driven lift-fan concept has the lowest take off (372m) and landing field length (488m) and mission fuel burn due to the lowest specific weight of the propulsion system and the highest residual thrust.

Further investigations have to be performed in the field of the extension of the flight mechanic equations, e.g. to include thrust vectoring of lift-fans during acceleration and climb and the calculation of pitching moment. Furthermore wind tunnel experiments and CFD calculations have to be conducted to understand the complex flow field of the investigated fan arrangements. These FIW concepts will be compared to conventional concepts and STOL concepts with flow control devices.

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