An aircraft preliminary design platform for the assessment of advanced engine and aircraft technologies

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Abstract

To gain further insight in the challenges and the possible gains resulting from the adoption of so-called advanced engines and aircraft configurations, a modular aircraft preliminary design platform was developed. This aircraft design and performance evaluation model was built so that different aircraft as well as engine configurations can easily be modeled.

A first section of this paper describes the developed routine. The structure of the program is discussed and the most important modules are briefly covered. The use of the routine is then demonstrated with a wing parametric study for a large long range transport aircraft. The influence of an advancement in technology on the optimum wing is identified too.

1. Introduction

The last decades, a significant amount of research concerning so-called advanced engine configurations like the ultra high bypass ratio (UHBPR) turbofans (ungeared, geared or counter-rotating) or intercooled recuperated gas turbines has been conducted by the world-wide aeronautical community.[5, 11, 12, 19] Even though these configurations are until now not adopted for use on commercial transport aircraft, they hold significant promise for future applications seen the recent boom in aircraft fuel prices and environmental awareness. In the future, these configurations will therefore most likely receive renewed interest.

To gain further insight in the challenges and the possible gains resulting from the application of these advanced engines and aircraft configurations, a modular aircraft preliminary design platform was developed in Matlab. This aircraft design and performance evaluation model was built so that on the one hand the modeling of different baseline aircraft (configurations) and on the other hand the integration of different engine configurations are possible.

The first section of this paper concisely describes the developed routine. The structure of the highly iterative program is shortly elucidated. The most important modules are only briefly covered as more detaild explanations have been published previously.[16] Special attention is given to the input required to set up a design study. The use of the routine is then demonstrated with a wing parametric study for a large long range transport aircraft with 380 passengers and a design range of 7500 nm. An 'aircraft family approach' is adopted where stretched versions are taken into account. The wing area and aspect ratio leading to minimal direct operating costs for the baseline aircraft are identified. The influence of an advancement in technology on the optimum wing design is established too, before conclusions are drawn and further project studies and platform enhancements are identified.

2. The developed aircraft preliminary design platform

The preliminary design of an aircraft is a highly iterative process by nature due to the high level of interaction of the different design modules. In order to flexibly model this process, a modular preliminary design platform was developed in Matlab. The incorporation of modularity makes the routine easier to use and allows a quick and independent adaptation of the various modules to the diverse design studies carried out. For instance, different technology levels for future aircraft and/or engines can be implemented by changing the appropriate individual components or by applying so-called technology factors.

The adopted structure for the preliminary aircraft design model described in this paper is schematically represented on Figure 1. On that figure, only the most important interactions between the different modules are indicated with arrows. As can be seen from the figure, input is required for the mission, the aircraft geometry, the engines and wing position before the design can be attempted. The aerodynamics, performance and mass are consequently calculated as well as the longitudinal position of the center of gravity of the empty aircraft. Finally, the c.g. excursion and the direct operating costs are determined.

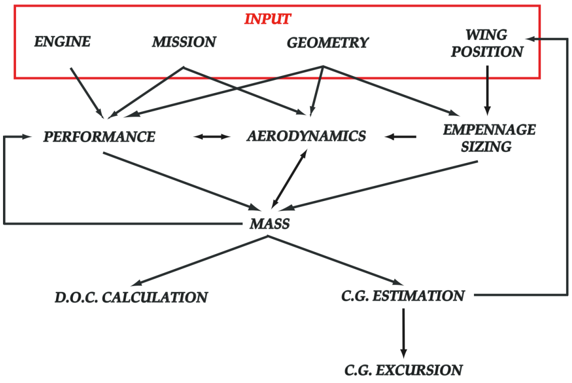


Figure 1: The structure of the developed routine.

For now, the implemented correlations for the different modules are aimed at large long range transport aircraft with high bypass ratio turbofan engines burning different fuels and the routine is set up for a parametric wing study to select the optimum wing design. Thus, the FAR 25 airworthiness regulations with regard to flying qualities and aircraft performance are integrated into the different modules.[21] Below, the most important modules will be briefly reviewed. When applicable, the required input data will be stated too.

2.1 Mission

Besides the airworthiness regulations, aircraft obviously also have to meet operational requirements such as speed, range, payload,... These requirements are entered in the mission module of the developed platform. For the analyses under consideration, a typical mission profile for an international flight is pre-programmed in the routine as this reduces the required user input to a minimum. The implemented mission profile consists of a main mission leg and a reserves mission leg (Fig. 2). The main mission profile is set up to model the actual mission for which the aircraft is designed. The reserves mission is on the other hand added to include the required allowances for taxi, diversion distances and hold times. As these allowances vary with each route to be flown by the aircraft, a standard set of allowances for typical international flights is used to enable a fair comparison between various aircraft.[4] Both the main and the reserves legs are, as shown on Figure 2, further split into several phases to increase the accuracy of the calculations.

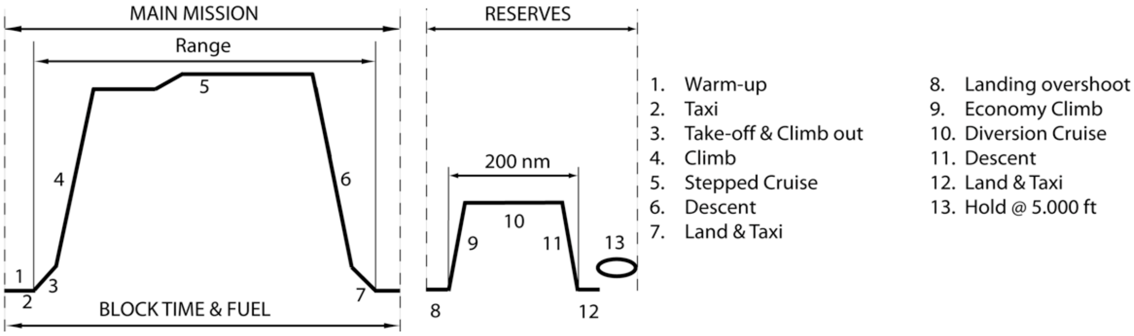


Figure 2: The mission profile for international flights.

For the main mission a stepped climb cruise is included. After all, in order to fly at constant airspeed and constant (optimum) lift-to-drag ratio, the height at which the aircraft flies needs to be increased when fuel is consumed and the aircraft is ideally following a so-called climb-cruise profile. As a continuous climb is not allowed by air traffic control, this optimum cruise profile is in reality approximated with a so-called step climb, where the altitude is increased in steps of 2000 ft (as set by air traffic control). The mission module automatically increases the cruising altitude when the aerodynamic efficiency of the aircraft (L/D) can be improved.[7]

With this pre-programmed mission profile a minimal input is required to set up design calculations. Only the range of the main mission, the initial cruising or top of climb altitude h_{toc} and the cruise Mach number M_{cr} need to be entered. Based on this input, the mission profile is automatically generated as explained before. Even though strictly speaking not really a mission parameter, the number of passengers is entered in this module too.

2.2 Engine

Engine cycle performance data is currently calculated outside the aircraft design platform to allow more flexibility. Like this or a specific engine design and analysis software as Gasturb[22] or Turbomatch[7] can be used or the results from an in-house developed code using EcosimPro™[17] can be incorporated. A so-called rubber engine approach is used where the engine is scaled linearly to achieve the required thrust (see section 2.4). An under-wing podded engine installation is assumed and two or four engines can be chosen. To simulate a design project with a specific engine (type), performance data (mainly thrust, specific fuel consumption and mass flow) needs to be entered for several points in the aircraft envelope. Data is required for the cruise phase at the appropriate Mach number and different altitudes (corresponding to the steps in the cruise phase), for climb and descent calculations and for take-off and landing. The engine weight and size as well as the nacelle drag are calculated based on this input.[2,20]

2.3 Aerodynamics

The aerodynamics module is used to compute the drag and lift of the aircraft in the appropriate flight conditions. As is standard practise, each main component of the aircraft is individually assessed for its contribution to the overall drag and lift of the aircraft.[4] Since a very good resemblance was found with existing aircraft,[7] this method is retained here too and standard correlations based on the flat-lated skin friction coefficient are adopted. Component form factors and interference factors are then applied to obtain the final drag coefficients.[4,16]

In the lift submodule the lift coefficient of the aircraft is determined in function of the aircraft weight, altitude and speed of the considered operational point. The effect of the rate of climb and the deployment of the high-lift devices is accounted for when appropriate. The submodule also incorporates the calculation of the three-dimensional maximum lift capability $(C_{L,max})_{3D}$ in function of the quarter chord sweep angle of the wing $\Lambda_{0.25}$[4]:

$$(C_{L,max})_{3D} = 0.9 F_M \, (C_{L,max})_{2D} \cos \Lambda_{0.25}$$

where the factor F_M models the influence of the Mach number on the wing maximum lift.[14]

2.4 Performance

Several performance conditions and constraints are implemented in the routine to ensure that the designs meet the performance requirements from the mission profile and the airworthiness regulations. Two of these performance requirements are used to ’size’ the rubber engine: the top of climb condition and the one engine inoperative (O.E.I.) FAR25 climb requirements as these are the most critical performance conditions for large long range transport aircraft with four respectively two engines. The engines of large long range transport aircraft are namely usually not sized by take-off and landing limitations due to the fairly relaxed field length requirements.[4] The thrust required for both conditions is compared and the most critical condition is used to size the engines. They are calculated with the following equations:

$$\begin{aligned}
\frac{T_{toc}}{W_{toc} \cdot g} &= \left(\frac{1}{L/D} + \frac{ROC}{V_{cr}}\right) \cdot \left(\frac{1}{N_{eng}}\right) \\
\frac{T_{TO}}{W_{TO} \cdot g} &= \left(\frac{1}{L/D} + CGR\right) \cdot \left(\frac{N_{eng}}{N_{eng} - 1}\right)
\end{aligned}$$

where T is the thrust required, W is the aircraft weight, g the gravitational constant, L/D the lift-to-drag ratio of the aircraft, ROC the rate of climb, V_{cr} the cruise speed, CGR the FAR25 climb gradient and N_{eng} the number of engines. The indices toc and TO indicate the top of climb respectively take-off (O.E.I. FAR25) point.

Besides these two sizing requirements several additional performance features are calculated and added to the parametric study as constraints for the designs. Despite the large field lengths available, take-off and landing distances are computed as an additional check. The approach speed is determined too as well as the minimum wing size needed to store all the mission fuel. Finally, buffet limits[3,14] are also added as a constraint as shown in the example. Inside these buffet limits, the aircraft can operate smoothly over a range of speed and altitude conditions. Outside the boundary, the aircraft is however subjected to significant separated flow, which results in noticeable shaking of ”buffeting” of the structure and flight controls.

2.5 Direct operating costs

The decisions in the preliminary design phase are very influential on the overall cost of the final aircraft project. Such decisions will affect both the cost of manufacturing and equipping the basic aircraft as well as the subsequent operating cost. Cost estimation methods are therefore essential in the conceptual design phase.

To allow comparisons between different aircraft configurations and to assess the best choice of values for all aircraft parameters, direct operating costs (D.O.C.) are usually estimated in the preliminary project phase and the indirect operating costs are neglected.[4, 13] Here, the D.O.C. are estimated with the method from the Association of European Airlines.[4] D.O.C. are composed of the so-called standing charges, crew, airport, fuel and maintenance costs. The maintenance costs cover both labor and materials as well as an applied burden.[8] Airport costs on the other hand encompass landing fees, navigational charges and ground handling charges while the standing charges comprise the investment related costs. The depreciation, interest and insurance cost of the initial investment (airframe, engines as well as spares) are housed in this category. To calculate these initial investment cost, the so-called study price is used. Here, both airframe and engine study price are determined as the average of the available conventional correlations.[8, 13, 18] Typical examples are included below for the airframe ASP[13] and the engine study price ESP[18]:

$$\begin{aligned} \log_{10} ASP &= 3.3191 + 0.8043 \cdot \log_{10} W_{TO} \\ ESP &= 25842 \cdot T_{TO} + 275334 \end{aligned}$$

For fuel cost calculations, a baseline fuel price of 0.7 US\$ per US gallon is adopted here as typical for international flights.[4]

3. Case study: A long range transport aircraft with 380 passengers

New passenger transport aircraft design studies are normally preceded by an extensive market study to determine the basic design mission for the aircraft. Usually a 'family approach', where possible future stretch and shrink versions are taken into account, is adopted to mitigate the financial risks involved with the decision to start a new design project. As such a market study was not possible within the scope of this project, a large long range transport aircraft family selected for system studies in the EU FP5 Cryoplane project was adopted.[10]

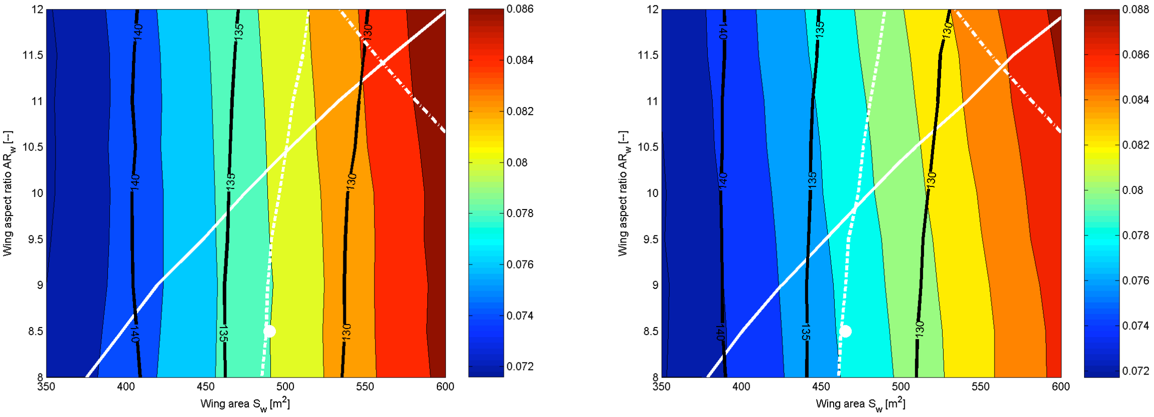
For this case study, an aircraft housing 380 passengers in a three class layout with a design range of 7500 nm at Mach 0.84 was withheld.[10] Two other 'members' of the family are taken in account for the fuselage sizing. In a first step, a 20% stretch version (454 pax) with a design range of 6500 nm is considered. Finally, the structure of the stretched version is further developed to increase the design range back to 7500 nm with 454 passengers.[10] To allow a validation of the created routine, the standards used in the design of the aircraft (seat pitches and width, number of crew,…) were also taken from the EU FP5 Cryoplane study.[9] To keep the length of the stretched version below 80 m, a 3-4-3 seating arrangement is chosen for the economy class, which leads to a fuselage diameter of 6.954 m. The corresponding first and business class seating arrangement are then 2-2-2 and 2-3-2 respectively. The length of the baseline fuselage is 68.48 m, which would allow 550 passengers in a high-density configuration.

Below, a wing parametric study to identify the optimum wing area and aspect ratio will be executed for the identified aircraft (family). Typical constraints on the design space will be covered in detail in this section. As twin engine configurations are only possible with an ETOPS (extended twin engine operations) certificate, four engines were considered in a first step and a comparison is made with a twin engine configuration. After all, one could gather the required flight hours to prove the reliability of the new engine configurations (as required to obtain the ETOPS certification) on routes where ETOPS is not required. In a second subsection, the influence of the assumed fuel price on the wing design point and the resulting direct operating costs is investigated. For the reported designs, a turbofan engine with a BPR of 8.4 is used,[15] similar to the GE90 engine used on the B777. The gas turbine performance data is determined with Gasturb10.[22]

3.1 Wing parametric study

The wing area and aspect ratio have a significant impact on the aerodynamic efficiency of the aircraft in the cruise phase as well as on the take-off weight of the aircraft. As such they also have a strong influence on the amount of fuel needed for long range missions and thus on the D.O.C. too. Therefore, wing parametric studies are widely used in the preliminary design phase to fix the 'baseline' design of the aircraft.[4] Here, the wing area S_w and aspect ratio AR_w that result in the lowest cost per passenger per seat mile will be withheld as the baseline wing for the studied aircraft.

Figure 3 shows the direct operating costs per seat mile of this investigation for the wings under consideration. Besides the direct operating costs, several performance and geometric constraints are added to the plot. Obviously, the minimum possible wing size needs to be able to store all the fuel required for the mission and the reserves. This fuel volume constraint is shown with a white solid line on the figure.



(a) 4 engines

(b) 2 engines

Figure 3: The direct operating costs per passenger per seat mile (1990 technology) [$/pax/nm].

As buffeting of the wing can be severe enough to cause minor structural damage and can be associated with abnormal aerodynamic stability and control characteristics, some margin to the so-called buffet onset point, which occurs at high lift coefficients and/or high speeds, is taken into account in the preliminary design phase.[3,14] The minimum wing area to comply with this buffet margin is indicated with a dashed white line on the figure.

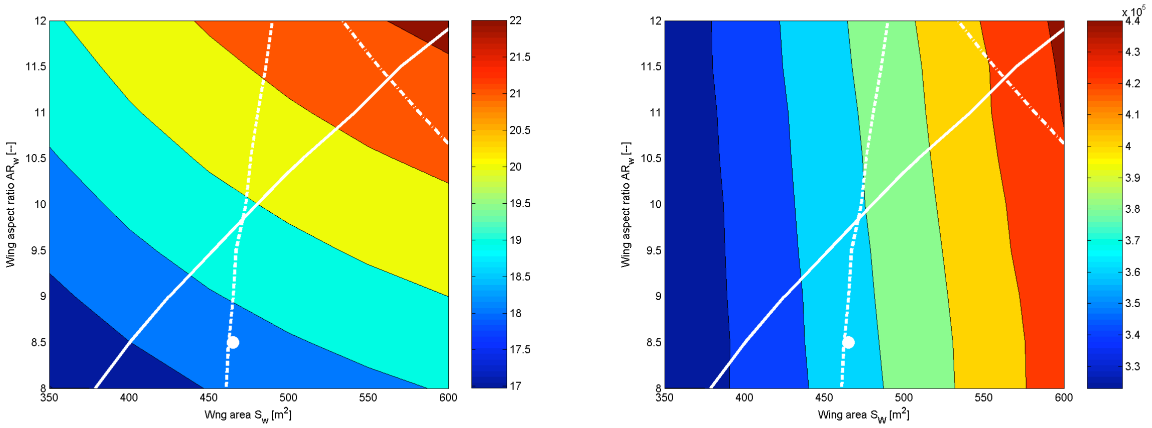
Besides these constraints, black contour lines are also given for the approach speed of the aircraft. In order not to complicate the traffic control near the airport, approach speeds of different aircraft of the same type should namely be close to each other. Furthermore, as the required landing distance is roughly proportional to the approach speed squared, the approach speed should be limited to ensure that the required landing distance is shorter than the available airport runway length. For the aircraft type under consideration, the allowable approach speed is typically limited to 140 KEAS.[9] The same limit is adopted in this study.

To ensure compatibility with the available airport runway lengths for typical international flights, the take-off and landing distances are monitored too. However, as long range transport aircraft are considered here, the required take-off and landing distances are much lower than the typically available field length (around 5000-6000 ft compared to 10000 ft[9]). They are therefore omitted from Figure 3. to increase the readability of the figure.

Nonetheless constraints are still imposed by the airport. The aircraft dimensions namely have to remain within the so-called 80 by 80 by 80 box to be compatible with the standard international airports (Category F). Aircraft transgressing this 80 m limit (length and wingspan) could namely not park at existing gates. The wing span thus has to be limited to 80 m even though some margin could be achieved by applying folding wing tips. As the latter however increases the wing weight, the design space is limited here to wing spans below 80 m. This limit is indicated with a white dash dot line on Figure 3.

Figure 4 shows two other performance-related aircraft characteristics. The left hand side of the figure shows the maximum lift-to-drag ratio during the cruise phase. The right hand side of the figure on the other hand gives the maximum take-off weight of the aircraft. A comparison between this figure and the direct operating costs of Figure 3 shows that the higher aerodynamic cruise efficiency of the aircraft with a high wing area and aspect ratio is more than counterbalanced by the increased structural weight, which is mainly due to an increased wing weight. This effect is mainly due to the allowance of the stepped cruise. Every aircraft of the parametric study namely flies close to its own optimum altitude during the complete cruise phase. When a constant cruise altitude is imposed, on the contrary, the D.O.C. curves change completely.[16] Some aircraft (with the 'correct' combination of S_w and AR_w) are now namely flying close to their optimum cruising altitude while others are flying at an altitude that is far away from their respective optimum.

The design point for the wing is chosen based on all previously mentioned reflections and constraints. The combination of S_w and AR_w that leads to the smallest D.O.C. without violating any of the considered constraints is chosen as the baseline wing. The design point is indicated with a white dot on Figures 3 and 4. Some characteristics of the resulting aircraft using two respectively 4 engines are given in Table 1. As can be seen from the table, adopting 2 engines instead of 4 reduces the D.O.C. by approximately 2 % for the envisaged mission, which means huge savings over the lifetime of the aircraft.



(a) $(L/D)_{max}$

(b) W_{TO}

Figure 4: The lift-to-drag ratio and the take-off gross weight for the twin engine configuration (1990 technology).

Table 1: Wing design points for aircraft with 2 and 4 engines (1990 technology).

	2 engines	**4 engines**	**diff. [%]**
S_w [m^2]	465	490	5.4
AR_w [$--$]	8.5	8.5	–
W_{TO} [kg]	362852	382014	5.3
W_{OE} [kg]	139955	146359	4.6
W_L [kg]	173605	187342	7.9
W_F [kg]	193702	199460	3.0
D.O.C. [US$ ¢/pax/nm]	7.78	7.94	2.1

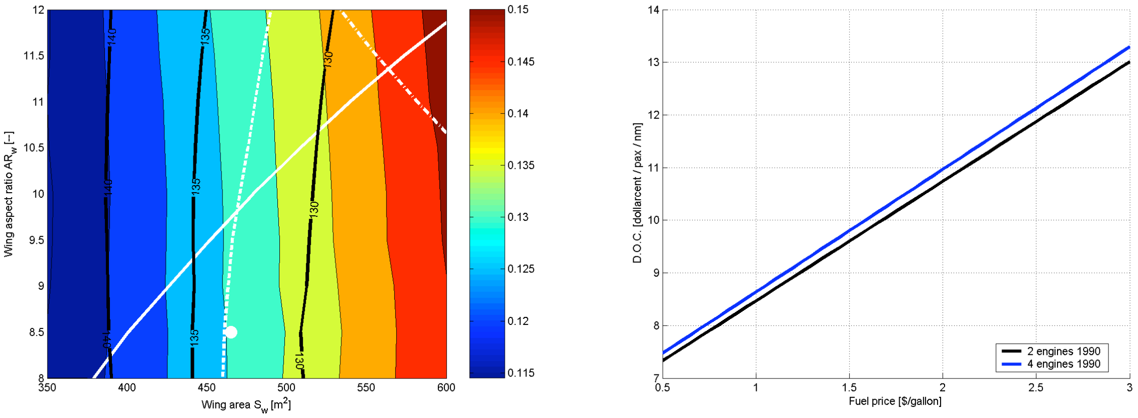
3.2 Influence of the fuel price on the direct operating costs

Next to depreciation, the fuel cost represents in general the most significant cost parameter in the design.[4] Obviously, the relative importance of fuel is even bigger for the large long range transport aircraft envisaged in this paper seen the large quantity of fuel embarked for this type of mission. Once the aircraft characteristics are known, the cost of fuel is relatively easy to estimate providing the fuel price can be accurately predicted. However, seen the variability of the fuel price over time in the past, it is hard to confidently predict the fuel price in the future. Seen the growing attention towards the importance of greenhouse gases and the possible creation of CO_2-taxes this could entail, this prediction will become even harder. The influence of the fuel price on the optimum wing design and on the direct operating costs is therefore assessed.

In the wing studies of the previous section the fuel price was set at 70 US dollarcent per US gallon. This value was taken as typical for international flights.[4] As crude oil prices and thus also kerosene prices have however boomed recently and the value taken was typical for the year 2000, the fuel price per gallon has been varied between 0.5 and 3.0 $ per gallon to see the influence of this price rise on the wing design point. The result of this analysis is represented on Figure 5. The left hand side of the figure shows the resulting direct operating cost for a fuel price of 3 $ per gallon. A comparison with Figure 3(b), shows that the shape of the D.O.C. curves and thus also the wing design point have not significantly been influenced by the fuelprice. Only the absolute level of the direct operating cost is affected by the increasing fuel price, as shown on Figure 5(b). The fuel cost rises from 20.5% of the total D.O.C. for a price of 0.7 $ / gallon to about 52.5 % for a price of 3.0 $ / gallon.

4. Influence of an advancement in technology level

The correlations used to determine the different aircraft characteristics are mainly empirical and are thus based on existing aircraft. However, as technology improves over time, using the existing correlations as they are is not possible for projections in the future. In preliminary design studies for future aircraft projects, technology factors are typically applied for the most important aircraft and engine characteristics to take these advancements in technology into account.[8,9]



(a) D.O.C. for a fuelprice of 3 $ / gallon

(b) Variation of D.O.C. with fuelprice

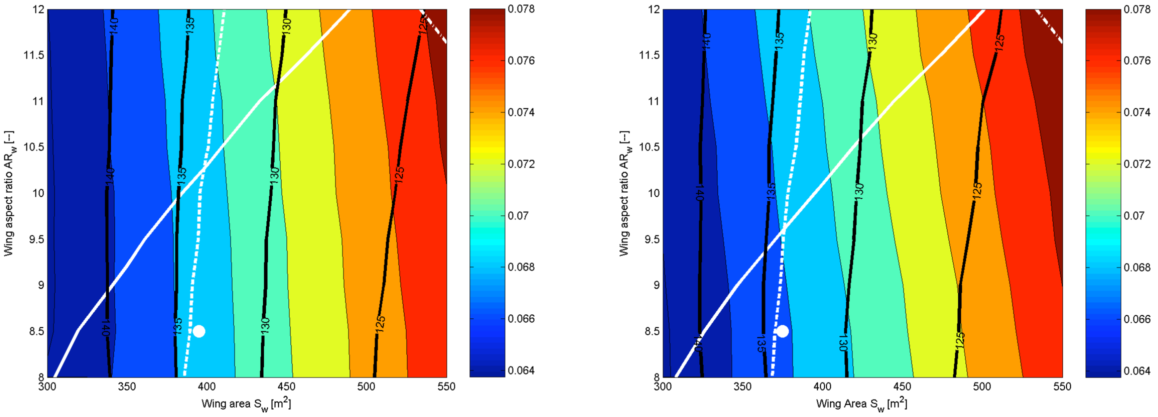
Figure 5: Influence of the fuel price on the direct operating costs (2 engines, 1990 technology).

Despite the fact that the correlations available in the open literature are based on aircraft that entered into service several years and sometimes even decades ago, most of them were already tailored to some more advanced technology level. When this was not already done by the authors of the different correlations, the appropriate factors were applied to the individual correlations in the routine. As such, the results of the correlations can be considered representative for a 1990 in service standard aircraft, as is shown by a comparison of the obtained results with the results from the similar EU FP5 Cryoplane study.[1,6]

However, to make a realistic assessment for future advanced engine and aircraft configurations, additional factors need to be applied to the appropriate aircraft characteristics. The following improvements (compared to the 1990 in service standard) are applied to yield a 2010 design standard[9]:

- Aerodynamics: L/D 4 % better
- Mass: W_E 7.5 % better
- Engines: sfc 10 % better

As a first check of the implications of this advancement in technology level, a wing parametric study similar to the one in section 3.1 was set up for the new technology level. The results of this parametric study are graphically represented on Figure 6 for 2 as well as 4 engines. As can be seen from that figure, the D.O.C. per passenger per seat mile are lower than for the 1990 in service standard. From the figure, it is also clear that the minimum wing area needed to store all the fuel is reduced due to the lower fuel and take-off weight. The range of wing loadings (W/S) at take-off for both technology levels is therefore very similar (680-900 kg/m^2). The characteristics of the airplanes chosen as the baseline configurations for the new technology level can be found in Table 2.



(a) 4 engines

(b) 2 engines

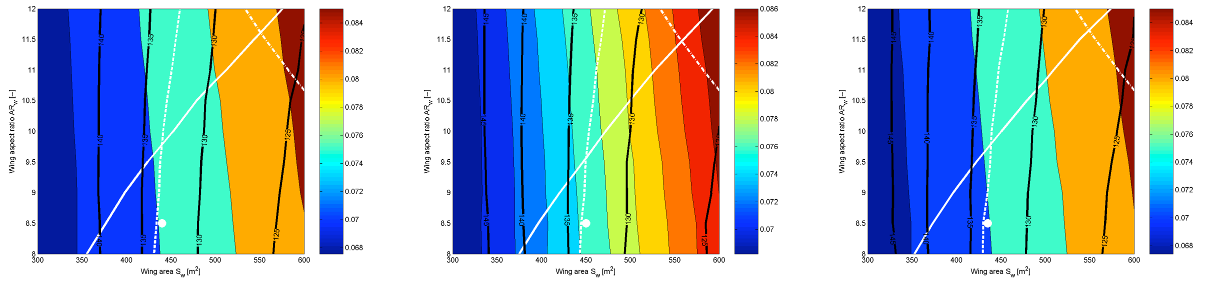
Figure 6: The direct operating costs per seat mile (2010 technology) [$/pax/nm].

Table 2: Characteristics of the baseline aircraft for the 2010 technology level.

	2 engines	**4 engines**	**diff. [%]**
S_w $[m^2]$	375	395	5.3
AR_w $[--]$	8.5	8.5	–
W_{TO} $[kg]$	291639	306818	5.2
W_{OE} $[kg]$	109690	121201	10.9
W_L $[kg]$	149611	161385	7.9
W_F $[kg]$	145753	149422	2.5
D.O.C. [US$ ¢/pax/nm]	6.75	6.85	1.5

A comparison between Tables 1 and 2, shows that the take-off weight for the twin engined aircraft is reduced by about 24.4 % due to the improvement in technology while the fuel weight is 32.9 % lower. This results in a fuel saving of 47.9 tons and reduces the direct operating costs from 7.78 to 6.75 dollarcent per passenger per seat mile for the twin engine baseline aircraft. The advancement in technology thus leads to a reduction of the D.O.C. of 15.3 %. The difference between the aircraft with 2 and 4 engines is however slightly reduced.

In a second step, the relative importance of the different changes in technology is assessed by changing the individual technology factors independently. Each factor (aerodynamics, mass and fuel consumption) is changed to reflect a 5 % improvement in the appropriate technology and the optimum wing design is identified for each change in technology. Even though it is realized that it will be harder to get a 5% improvement in aerodynamics due to the maturity of the technology than for instance a 5% improvement in mass, this approach allows to classify the different technologies relative to each other, which indicates where the biggest gain in operating cost can be obtained. The results of the investigation for aircraft with two engines are shown on Figure 7. Table 3 compares the design point for the different cases.



(a) aerodynamics (b) weight (c) s.f.c.

Figure 7: Influence of the different technology factors on the D.O.C. (2 engines) [$/pax/nm].

Table 3: Characteristics of the baseline aircraft for the different technology factors (2 engines).

	1990	**aerodyn**	**diff. [%]**	**mass**	**diff. [%]**	**s.f.c.**	**diff. [%]**
S_w $[m^2]$	465	440	5.7	450	3.3	435	6.9
AR_w $[--]$	8.5	8.5	–	8.5	–	8.5	–
W_{TO} $[kg]$	362852	342342	6.0	352127	3.0	339488	6.9
W_{OE} $[kg]$	139955	128143	9.2	124790	12.2	127573	9.7
W_L $[kg]$	173605	168583	3.0	165226	5.0	168022	3.3
W_F $[kg]$	193702	178005	8.8	191142	1.3	175720	10.2
D.O.C. [US$ ¢/pax/nm]	7.78	7.49	3.9	7.61	2.2	7.45	4.4

The table clearly shows that both the aerodynamics and the specific fuel consumption have a much bigger influence on the direct operating costs as could be expected. After all, both factors have a direct impact on the fuel needed for the mission which constitutes a big part of the direct operating costs. The influence of an improvement of the mass on the D.O.C. of the aircraft is only about half of that of the other two technologies as it only plays an indirect role on the fuel consumed during the mission. Nonetheless, as indicated previously, it will be much easier to get an improvement in mass (for instance, due to the adoption of composites) than in aerodynamics or specific fuel consumption. As aerodynamics is the most mature field of the considered technologies, a significant improvement will be hard to obtain (except by the adoption of a new configuration such as the blended wing body). This explains the focuss on the development of new engine cycles, which is less costly than the development (and certification) of a completely new aircraft configuration. All in all, as shown in Table 3, the specific fuel consumption has the biggest influence on the direct operating costs.

5. Conclusions & Future Work

An easily adaptable, flexible and modular aircraft preliminary design platform that allows a modeling of both different aircraft configurations as well as advanced engine technologies has been developed. The platform is capable of predicting aerodynamic, performance and mass characteristics of the different aircraft of the project study as well as calculating the direct operating costs and c.g.-excursion of the aircraft. Future aircraft technology levels can easily be implemented through technology improvement factors and advanced engines can be simulated by changing the thrust and sfc data of the engine as well as its mass. The correlations used for the individual components can furthermore easily be modified due to the modular structure of the developed routine. A case study for a large long range transport aircraft has shown the flexibility of the program. Aircraft with 2 and 4 engines are compared and the influence of the fuel price and an improvement in technology has been assessed.

In a next step, advanced cycles for high bypass ratio turbofan engines (intercooled-recuperated) will be modeled and their influence on the key aircraft characteristics will be investigated. Special attention will be paid to the integration of the engine under the wing. After this, the appropriate modules will be adapted to allow the simulation of hydrogen-fueled aircraft as well as so-called unconventional aircraft configurations like the twin fuselage aircraft. An extra module will be added to calculate the environmental impact of the aircraft (both pollutant emissions and noise).

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References

[1] Astaburuaga M.F. and van Holten Th., Conventional Aircraft Description - Long Range Aircraft. Cryoplane - Liquid Hydrogen fuelled aircraft - system analysis, TTR 2.1.3, 2001.

[2] Gerend R.P. and Roundhill J.P., Correlation of gas turbine engine weights and dimensions. AIAA 1970-669, San Diego, California , June, 1970.

[3] Howe D., Aircraft Conceptual Design Synthesis.Professional Engineering Publishing Limited, 2000.

[4] Jenkinson L.R., Simpkin P. and Rhodes D., Civil Jet aircraft design. AIAA Education Series, 1999.

[5] Kowe J.C. and Wynosky T.A., Energy Efficient Engine Program - Advanced Turbofan Nacelle Definition Study. NASA-CR-174942, 1985.

[6] Krijnen J., Astaburuaga M.F. and van Holten Th., Conventional Aircraft Description - Long Range Aircraft. Cryoplane - Liquid Hydrogen fuelled aircraft - system analysis, TTR D9 (partial), 2001.

[7] Laskaridis P. and Pilidis P., An Integrated Engine - Aircraft Performance Platform for Assessing New Technologies in Aeronautics. International Symposium on Air Breathing Engines, ISABE-2005-1165, Munich, 2005.

[8] Liebeck R.H. et al., Advanced subsonic Airplane Design & Economic Studies. NASA-CR-195443, 1995.

[9] Oelkers W. and Schulz H.G., Design Standards for Long Range Commercial Transports. Cryoplane - Liquid Hydrogen fuelled aircraft - system analysis, TTR 2.2.5S, 2000.

[10] Oelkers W. and Schulz H.G., Aircraft Categories and Selected Families. Cryoplane - Liquid Hydrogen fuelled aircraft - system analysis, TTR 2.2.9, 2000.

[11] Owens R.E., Hasel K.L. and Mapes D.E., Ultra High Bypass Turbofan Technologies for the Twenty-First Century. AIAA-1990-2397, Orlando, Florida, 1990.

[12] Peacock N.J.and Sadler J.H.R., Advanced Propulsion Systems for Large Subsonic Transports. AIAA-1989-2477, Monterey, California, 1989.

[13] Roskam J., Airplane Design Part VIII: Airplane Cost Estimation: Design, Development, Manufacturing and Operating. DARcorporation, 1989.

[14] Schaufele R.D., The Elements of Aircraft Preliminary Design. Aries Publications, 2000.

[15] Verstraete D., Hendrick P., Pilidis P. and Ramsden K., Hydrogen as an (aero) gas turbine fuel. ISABE-2005-1212, Munich, Germany, 2005.

[16] Verstraete D. and Hendrick P., An aircraft preliminary design platform for the assessment of advanced engine configurations. National congress on theoretical and applied mechanics, Mons, Belgium, 2006.

[17] Verstraete D. and Hendrick P., Development and validation of a modular gas turbine engine performance model for the assessment of advanced engine technologies. ISABE-2007-1330, Beijing, China, 2007.

[18] Volders M. and Slingerland R., Environmental harm minimization during cruise flight for long range preliminary aircraft design. AIAA 2003-6803, Denver, Colorado, 2003.

[19] Whellens M.W., Singh R. Pilidis P. and Taguchi H., Genetic algorithm based optimization of intercooled recuperated turbofans. AIAA-2003-1210, Reno, USA, 2003.

[20] Cranfield University Short Courses., Propulsion System Performance and Integration. Cranfield, January - February , 2007.

[21] Federal Aviation Authorities, The World Wide Web, `http://www1.airweb.faa.gov/Regulatory_and_Guidance_Library/rgFAR.nsf/MainFrame?OpenFrameSet`.

[22] GasTurb, The World Wide Web, `http://www.gasturb.de`.