CONCEPTUAL OPTIMAL DESIGN OF AIRLINERS WITH NOISE CONSTRAINTS

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Abstract. *Noise generated by airplane during the takeoff and landing flight phases is a matter of increasing concern for both aviation and aeronautical industries. Air traffic is steadily increasing and airports are operating close to their capacity limit. Airlines are under high pressure from communities surrounding airports to operate quieter airplanes and/or change their operating procedures. For this reason, quieter airplanes will be welcome by the airlines and comply to the expected traffic growth. From an airplane manufacturer point of view, the reduction of noise generated by airplane to acceptable levels is a very challenging task. It is to be expected that such drastic noise reductions will not be achieved by merely working on mitigating noise sources on the airplane in isolated form. Instead, the interactions of noise sources as well as shielding effects have to be taken into account. Airplane noise becomes a configuration issue and thus has to be considered in the conceptual design phase. Quieter airplanes could be charged with some penalties like performance degradation and higher fuel consumption, in the latter case generating more pollutants. In order to carry out the design for a quieter airplane considering all this aspects, it is useful to incorporate a noise assessment methodology into a multi-disciplinary design and optimization framework. This approach is justified because an airplane should not be designed considering just a few requirements. Field performance, stability and control, operating costs, manufacturing costs, passenger comfort, embedded technology, all this must be simultaneously considered for designing an airliner that airlines need. A Parametric Airliner Noise Prediction Architecture (PANPA) has been developed at Instituto Tecnológico de Aeronáutica (ITA), which is able to predict noise levels generated by an airliner along arbitrary flight trajectories. The related noise levels are estimated for an observer positioned on ground, as required by certification authorities. The module takes into account major airframe and engine noise sources, as well as diverse effects on sound propagation. A multi-disciplinary integrated conceptual airplane design framework, designated AIDMIM, has been in development for some time at ITA. This framework features a modular structure written in MATLAB® language, which allows for manageable incorporation of additional disciplines and analysis methods to the overall design process. PANPA was integrated into AIDMIN and some design tasks with and without noise constraints were carried out.*

Keywords*: Aeroacoustics, airplane design, multi-disciplinary design and optimization*

1. INTRODUCTION

Airplane conceptual design involves many disciplines such as aerodynamics, flight mechanics, performance, weight estimation, ~~aiframe~~airframe-engine integration, manufacturing and operating cost, technology assessment and so on. Over the years, several methodologies have been developed to tackle the problem of designing better airplanes. However, in recent years, with the advent of high speed computers, design methodologies have been implemented in computer programs so as to speed up analyses and more thoroughly test possible configurations. Once they were implemented in computer programs, a natural step was to link them to optimization routines to systematically improve the configuration of the airplanes considering specific objectives such as the empty weight of the airplane, specific range, operating costs and many others.

As computers grew faster, more disciplines were incorporated into the automated design of airplanes: initial structural layout, computational fluid dynamics, aeroelasticity, multiple route analysis. However, a further step was needed, and it considers airplane noise.

Noise caused by airplane during takeoff and landing is a matter of increasing concern for the civil aeronautical industry. Air traffic is steadily increasing and airports are operating close to their capacity limit. Airlines are under high pressure from communities surrounding airports to operate quieter airplanes and/or change their operating procedures. For this reason, quieter airplanes will be welcome by the airlines and comply to the expect traffic growth. From an airplane manufacturer point of view, the reduction of noise generated by airplane to acceptable levels is a very challenging task. It is to be expected that such significant noise reductions will not be achieved by merely working on mitigating noise sources on the airplane in an isolated fashion. Instead, the interactions of noise sources as well as shielding effects have to be taken into account. Airplane noise then becomes a configuration issue and thus has to be considered in the conceptual design phase and suitable methodologies are needed for this purpose.

Because a 1-2 dB difference in aircraft noise is significant, high-fidelity noise prediction is essential, even during conceptual design. In the present model, noise sources such as combustion, turbines, and compressors were considered, even considering that these components are minor contributors to the total aircraft noise signature.

2. HISTORICAL BACKGROUND – AIRPLANE NOISE

The introduction of jet airplanes into airline operations in the beginning of the 1950's was greeted with enthusiasm as it was expected to significantly reduce travelling times between countries and continents. About a decade later the main shortcoming of jet airplanes was causing a commotion with communities living near or beside busy, international airports: airplane noise.

Noise is formally defined as a sound that annoys. And with airplanes it wasn't different: disturbed communities prompted governments to take action against airplane noise, be it by enforcing manufacturers to design quieter airplanes or by reducing and shut down airplane operations close to populated areas.

The first attempt to create a standard for airplane noise evaluation was made at a conference in London, in 1966, which was barely successful. However, three years later, the Federal Aviation Authority in the USA (FAA) issued a Notice of Proposed Rule-Making (NPRM) concerning airplane noise certification (NPRM 69-1). Meanwhile, the International Civil Aviation Organization (ICAO) constituted a committee to investigate and propose regulations concerning airplane noise.

Following NPRM 69-1, the FAA issued in 1971 the first version of the Part 36 of its Federal Aviation Regulations (FAR-36). This first regulation concerning noise defined three locations for noise measurement, as shown in Fig. 1: fly-over, sideline and approach.

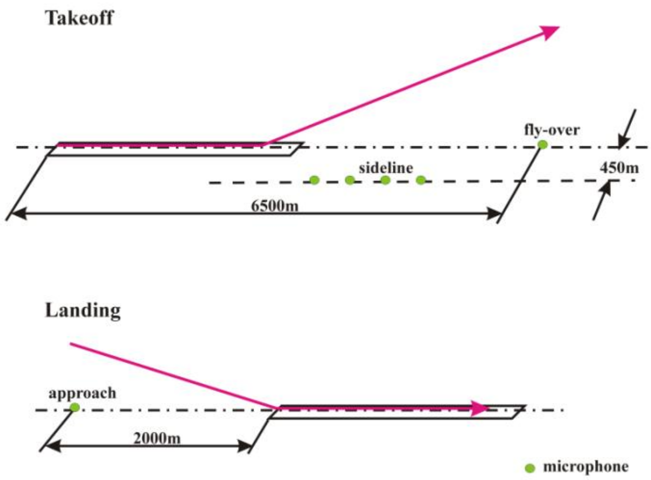

Figure 1. Noise measuring locations for airplane certification

The fly-over measuring location is expected to assess the airplane performance impact on the noise it generates while the sideline noise should address the noise generated by the engine while operating at full throttle. The approaching noise measurement would tackle the noise produced by the airframe. The first version of the FAR-36 set a maximum of 108 EPNdB for noise either at fly-over, sideline or approach, which was about 10EPNdB lower than the noise produced by jet airplanes in operation then. As such noise level was applied to airplanes which were certified and went into operation even before 1969, it forced manufacturers to improve their on-going projects, like Lockheed L-1011 and Douglas DC-10, or even redesign parts of airplanes just certified like the Boeing B-747.

As the airplane noise was still considered unacceptable and certification authorities believed there was room for improvement, regulations were reviewed in order to set more strict limits on airplane noise. As a result, a limit of 97.1 EPNdB was set as the maximum allowable noise produced by an airplane. This second step in the legislation, named Stage 2, also introduced the effect of weight in the noise limit, in an attempt to correct a distortion created by the single limit of 108 EPNdB of Stage 1, which was applied to both the Boeing B-747 Jumbo Jet and the Learjet series 20 business jet.

In an attempt to further reduce the noise produced by airplanes, a so-called Stage 3 was created for airplanes certified after October 1977. Although Stage 2 addressed the weight issue on airplane noise, it was then believed that noise levels were still biased as airplanes with similar weights and performances, operating from the same airports, but with different number of engines, were required to meet the same noise levels, i.e., a three-engined DC-10 was allowed to meet the same noise levels of a four-engined Boeing B-747, which forced the B-747, equipped with the same engine model of the DC-10, to have a much quieter airframe. Therefore, as it reduced the maximum allowable noise level, Stage 3 also introduced the number of engines a parameter for airplane noise limits.

More recently, the FAA started requiring what is called the Stage 4 of airplane noise certification. The reference noise levels are the same of Stage 3, but during certification, the airplane must have a minimum margin of 2 EPNdB in each of the measuring conditions and a cumulative margin of 10EPNdB when the three measuring points are considered together.

As the FAA and ICAO urged the design of quieter airplanes, NASA, DLR, AGARD, universities, and manufacturers set out to investigate the sources of airframe and engine noise. In the United States, the combined efforts resulted, in the end of the 1970s, in a set of computer programs used to predict airplane noise while it is still being designed, the ANOPP (Airplane Noise Prediction Program). Although refined methods were later proposed, the methodology used in ANOPP remains valid and forms the base for the assessment of airplane noise during its conceptual design [Antoine, N. and Kroo, I., 2004].

3. METHODOLOGY

The engine of the present methodology is outlined in Fig.2. The AIDMIN package is consisted of two modules: a genetic algorithm able to handle both discrete and continuous variables, called GERETIC; and the remained was named AEROCAL, which is an airliner calculator. AEROCAL was written in Matlab® language and its basic engine, BAERO, is able to estimate airliner weights. Airplane performance, flight mechanics, direct operating cost, and noise signature are some of many outputs provided by AEROCAL.

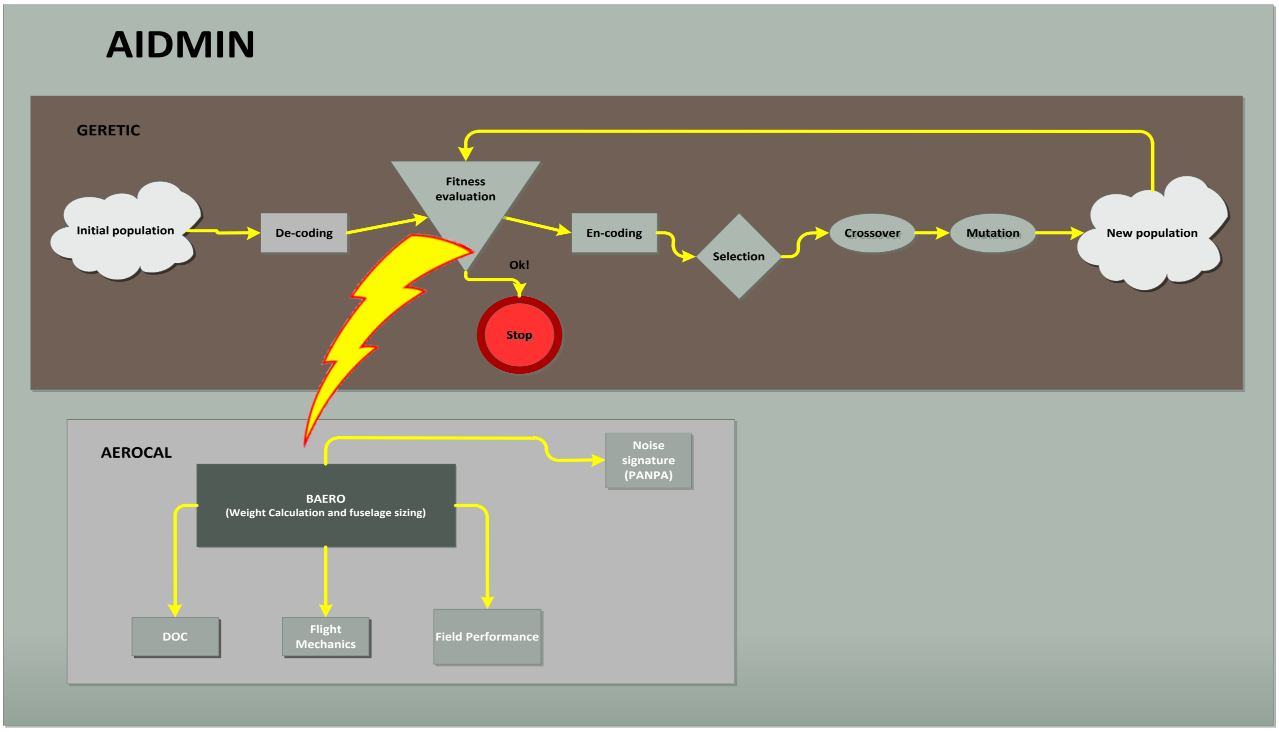

Figure 2 – AIDMIN airliner design and optimization.

3.1 Airliner model

The BAERO module workflow is showed in Fig.3.

In order to evaluate the accuracy of the present methodology for estimating airliner weight a MATLAB® code called BAERO was developed. BAERO features no routine to perform any optimization and utilizes improved Class II weight estimation of structural parts and aircraft systems. It is an airplane configuration calculator.

In order to validate the BAERO calculator, an interactive version nicknamed *Aviao Aeronáutico* was developed (Fig.4).

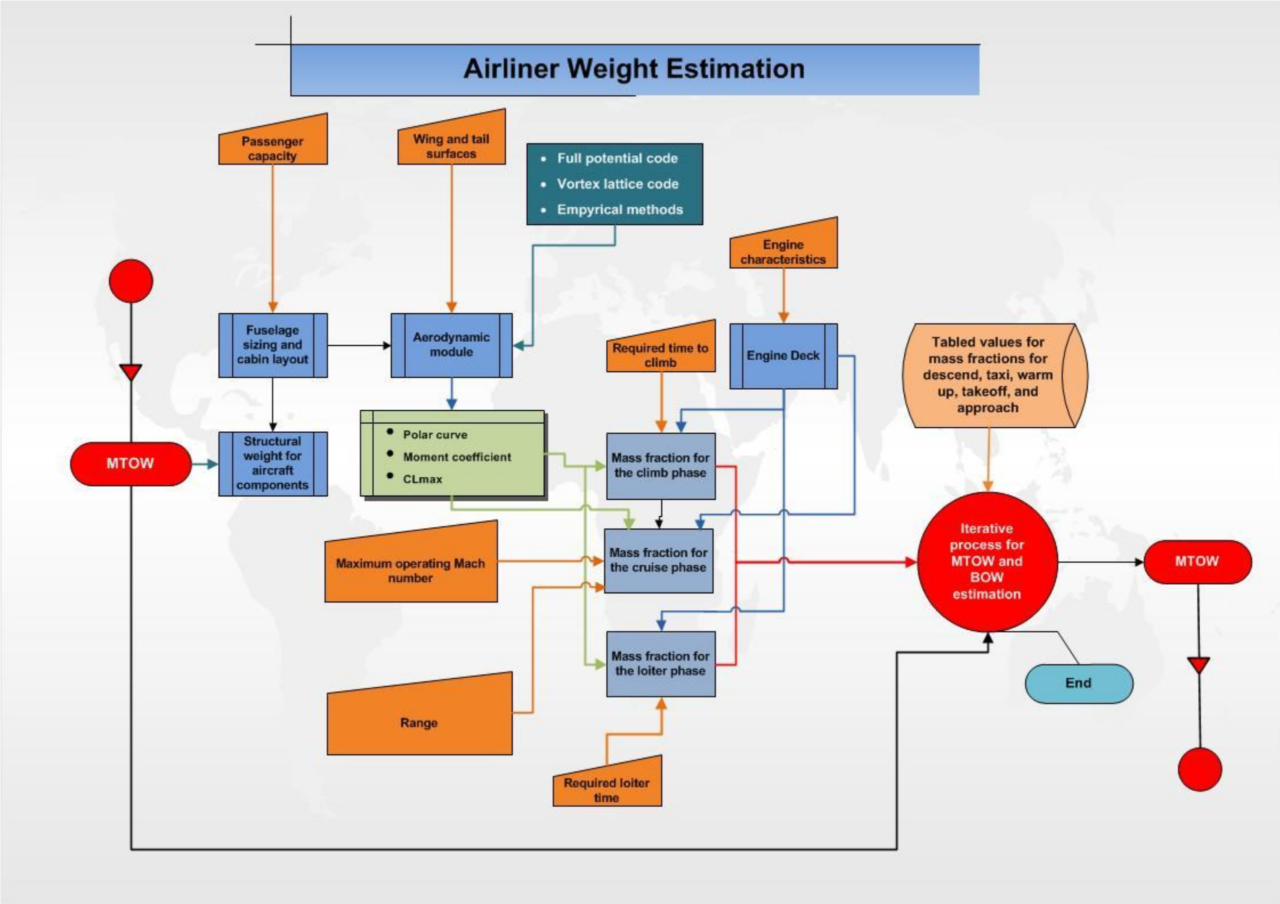

Figure 3 – BAERO workflow.

Four airliners of different categories were employed to validate the BAERO methodology:

- Bombardier CRJ-200LR.
- Fokker 100 with R&R Tay 620 engines (there is a improved version with Tay 650 engines).
- Boeing 737-300 with CFM-56-3B1 engines.
- Boeing 757-200 fitted with two R&R RB511-535E4 engines.

When the overall characteristics of the CRJ-200LR regional jet [Jane's] are inputted into the code, a Maximum Takeoff Weight (MTOW) of 22,439 kg is calculated for this plane (Fig. 4). Indeed, a very small deviation, 2 %, when compared to the actual MTOW of 22,000 kg.

For the Fokker 100 airliner fitted with Rolls&Royce Tay 620 engines, we obtain with BAERO a MTOW of 43,097 kg (Fig. 5), an insignificant difference when compared to the actual figure of 43,090 kg of the standard Fokker 100 [Mattos]. The calculated Operating Empty Weight (OEW) is 24,483 kg, again very close to the actual value of 24,593 kg. Table I summarizes the validation effort undertook for some airliners. Erros for the four airliners studied here are presented in Table II.

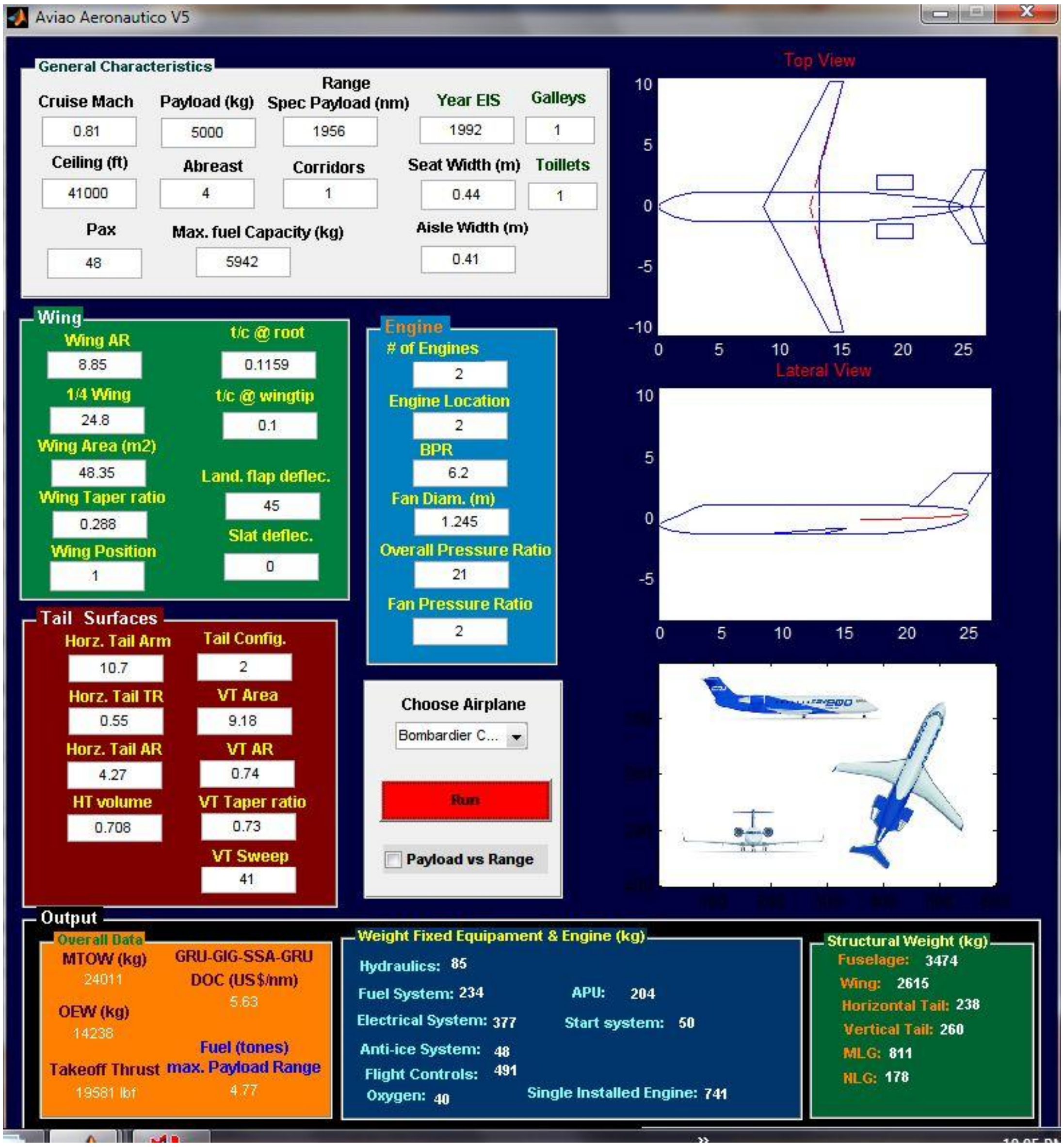

Figure 4 – *Aviao Aeronáutico* main screen showing the calculation performed for the CRJ-200LR regional jet.

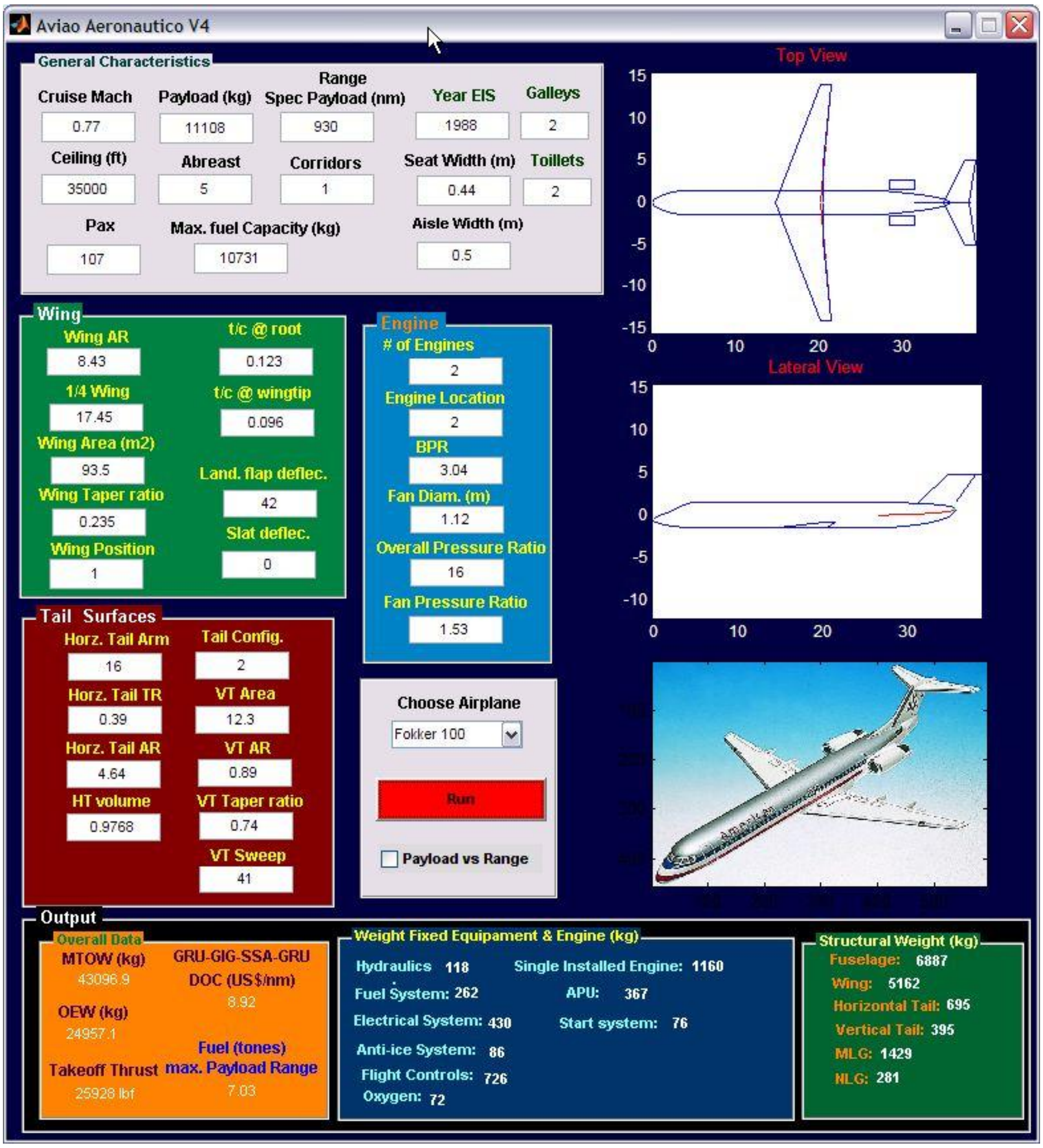

Figure 5 - *Aviao Aeronáutico* main screen showing the calculation performed for the Fokker 100 airliner fitted with Rolls&Royce Tay 620 engines.

Table I – Comparison of actual weight figures with those estimated by *Avião Aeronáutico* (AA) for some existing airliners.

Airplane	MTOW (kg)	OEW (kg)	MTOW (AA) (kg)	OEW (AA) (kg)
Fokker 100 Standard with R&R Tay 620 engines	43,090	24,593	43,097	24,957
Bombardier CRJ-200LR	24,154	13,835	24,011	14,238
Boeing 737-300 with CFM56-3B1 engines	56,473	31,480	55,491	31,121
Boeing 757-200	115,650	62,100	115,501	59,544

Table II – Error in weight estimation by *Aviao Aeronáutico*.

Airplane	MTOW Error (%)	OEW Error (%)
Fokker 100 Standard with R&R Tay 620	0	1.5
Bombardier CRJ-200LR	0.6	2.3
Boeing 737-300 with CFM5-3B1 engines	1.7	1.1
Boeing 757-200 with RB211-535E4	0.12	4.1

3.2 PANPA

Airplane noise is usually divided into two main categories: the noise produced by the airframe and that produced by the engine. The engine noise for its turn is divided according to its origin: fan and compressor noise, engine core noise, turbine noise and jet noise.

Airframe noise consists mainly of flow pressure fluctuations created by the airplane, as it moves through the air, due to the movement itself and gaps, slots, protuberances (such as landing gear, antennas) and cavities (such as the landing gear compartment, when open). In order to model airframe noise, the method proposed in Engineering and Science Data Unit (ESDU) data sheet nr. 90023 was used. In this methodology, the airframe is divided into its main noise generating components (wings, flaps, slats, landing gear, horizontal tail and vertical tail) and the noise of each component is modeled based on data collected and correlated by Fink. The total airframe noise is obtained by logarithmically adding the sound pressure levels obtained for each component. Correlation of the methodology with experimental data indicates an accuracy of ±4dB for airplane takeoff weights in the range of 42,000 kg to 390,000 kg.

Engine fan and compressor noise consists of the noise emitted forward of the engine, through the inlet duct, and that emitted through the fan discharge duct. The noise emitted through the inlet duct is divided into broadband noise, discrete-tone noise and combination-tone noise. The noise emitted through the fan discharge duct is essentially broadband noise and discrete-tone noise. In order to assess the fan and compressor noise, the methodology proposed by NASA was used. Such methodology, later used in ANOPP, was derived from experimental data collected by Dunn & Peart for Boeing, under NASA research contract. This methodology has an accuracy of ±2 dB.

Engine core noise consists of the noise generated by the following sources: the combustion process, the flow around internal obstructions, scrubbing of the duct walls and entropy local fluctuations. In order to assess the engine core noise, the methodology proposed by NASA was used. This methodology, later adopted in ANOPP, was based on experimental data and its accuracy is estimated at ±5 dB.

The mechanisms of noise generation for a turbine are comparable to those of a fan and a compressor and, therefore, divided into two types: discrete tone noise and broadband noise. NASA methodology was adopted to assess the turbine noise in PANPA. It is based on experimental data and has an estimated accuracy of ±5 dB for the tone noise and ±9 dB for the broadband noise.

Jet noise originates from the shearing of layers of air at different temperatures, the hot one from the engine core and the cold one from the outside air. Modeling of the jet noise indicates that it is proportional to V^8, in which V is the gas exhaust speed. For PANPA implementation, the jet noise was estimated based on the methodology developed by NASA, which has an accuracy of ±3 dB when compared to experimental data.

After selecting an appropriate calculation method for each airplane noise source, they were all integrated to form PANPA following the recommendations set forth by Schmid and Amado & Mattos. The main function of PANPA would receive inputs from the airplane design methods, generate airplane flight-paths and then compute the noise for each of the measuring points required by the FAA. Such inputs consist of airplane geometry (areas, spans, lengths), aerodynamic coefficients (lift, drag), weights (Maximum Takeoff Weight – MTOW, Maximum Landing Weight – MLW) and engine data (geometry, aerothermodynamic properties, thrust, shaft speed).

PANPA was calibrated in a two-step approach. In the first step, the noise values of each component were calculated and compared to the results obtained by the Java Applet developed by Schmid and placed in his website. Differences were on the order of ±2 dB. In the second step, the overall result was compared to actual certification figures for civil airplanes, as published by FAA on its website. Differences were on the order of ±8 dB.

Once PANPA was calibrated and linked to AIDMIN, suitable criteria for noise constraints in airplane preliminary design had to be derived. Considering the individual and combined accuracies of the adopted noise methodologies and the results of the calibration tests, it was decided, in an initial approach, that conceptual airplanes with noise levels above the original 108EPNdB would be classified as unfit by the genetic algorithm. Thus they would be discarded and prevented from going into the next generation in the optimization process, as shown in Fig.2.

4. ANALYSIS OF RESULTS

In order to test the coupling of PANPA with AIDMIN, a small, short-range commercial airliner design was considered. Such airliner should be capable of carrying 70 passengers at up to 41000ft and achieve a speed of Mach 0.82. As a further set of constraints, the resulting airplane should be able to fly the following routes:

- Rio de Janeiro to São Paulo (GIG-CGH);
- São Paulo to Rio de Janeiro (CGH-GIG);
- Rio de Janeiro to Salvador (GIG-SSA).

The parameters listed in table III below were considered for the airplane design and optimization:

Parameter	Type	Unit	Optimization Range	
			Minimum	Maximum
wing area	continuous value	m²	40.0	250.0
wing aspect ratio	continuous value	-	-	-
wing tapper ratio	continuous value	-	0.25	1.00
wing sweep	continuous value	deg	18.0	-
thickness to chord ratio at wing root	continuous value	%	9.0	16.5
thickness to chord ratio at wing tip	continuous value	%	9.0	14.5
vertical tail area	continuous value	%	10.0	22.0%
horizontal tail tapper ratio	continuous value	-	0.3	0.8
horizontal tail sweep	continuous value	deg	-	-
horizontal tail arm	continuous value	m	-	-
engine fan diameter	continuous value	m	0.75	2.40
engine overall pressure ratio	continuous value	-	6.0	32.0
engine fan pressure ratio	continuous value	-	1.2	2.0
engine by-pass ratio	continuous value	-	2.0	7.0
engine position (underwing or at the rear-fuselage)	discrete value	-	-	-
engine number	discrete value	-	2	4
number of seats abreast	discrete value	-	2	6
wing position (low, high)	discrete value	-	-	-
horizontal tail position (low, high)	discrete value	-	-	-

Table III. Design optimization parameters

For the AIDMIN/PANPA validation, two runs of the Genetic Algorithm were performed: the first with 10 individuals in the population and the second, with 20. As the amount of processing time is large with each noise assessment lasting roughly 20 minutes, only 5 generations were considered for both cases. Mutation rate was set at 10%, with 5% of the genes being mutated. Sexual reproduction and entropy selection were considered for the formation of the next generation. The two sets of conditions were applied to the optimization process with and without noise constraints and the results were then compared.

As a further refinement in the validation of AIDMIN/PANPA, in which the optimization process works with airplane noise constraints, two other runs were performed. In the first one, the robustness of the methodology was tested by lowering the noise level limit to 106EPNdB while keeping the population with 20 individuals, for 5 generations. In the second run, the number of generations was increased to 10 while keeping the population with 20 individuals and the original 108EPNdB noise level limit.

4.1. Optimization without noise constraints

The optimization of the airplane while in the conceptual design phase, not considering the noise constraints, led to the results shown in Table IV.

Parameter	Unit	Optimization Results	
		10 individuals	20 individuals
wing area	m²	86.7	88.5
wing aspect ratio	-	8.75	8.42
wing tapper ratio	-	0.256	0.259
wing sweep	deg	22.7	22.1
thickness to chord ratio at wing root	%	11.6	10.8
thickness to chord ratio at wing tip	%	9.0	9.0
vertical tail area	m²	9.26	8.85
horizontal tail tapper ratio	-	0.362	0.328
horizontal tail sweep	deg	26.7	26.1
horizontal tail arm	m	13.74	13.47
engine fan diameter	m	1.29	1.28
engine overall pressure ratio	-	23.5	26.7
engine fan pressure ratio	-	1.9	2.0
engine by-pass ratio	-	4.2	3.3
engine position (underwing or at the rear-fuselage)	-	rear-fuselage	underwing
engine number	-	2	2
number of seats abreast	-	5	5
wing position (low, high)	-	low	low
horizontal tail position (low, high)	-	high	low
fly-over noise (takeoff)	EPNdB	100.8	100.2
sideline noise (takeoff)	EPNdB	113.2	113.1
approach noise	EPNdB	96.0	95.9
maximum takeoff mass	kg	33704	33908
operating empty mass	kg	20319	20119

Table IV. Optimization results without noise constraints

Figures 6 and 7 show the optimized airplane configuration obtained, without noise constraints, for 10 and 20 individuals, respectively. Figures 8 and 9 show the evolution of the objective function (minimization of operating empty weight) for 10 and 20 individuals, respectively, considering the weight of the best individual in the first generation as a reference.

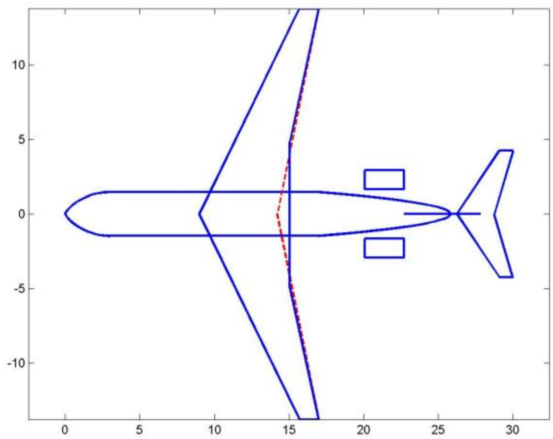

Figure 6. Airplane configuration after optimization with 10 individuals, *without* noise constraints

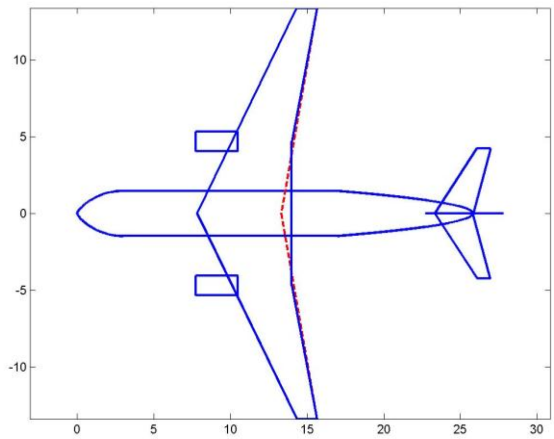

Figure 7. Airplane configuration after optimization with 20 individuals, *without* noise constraints

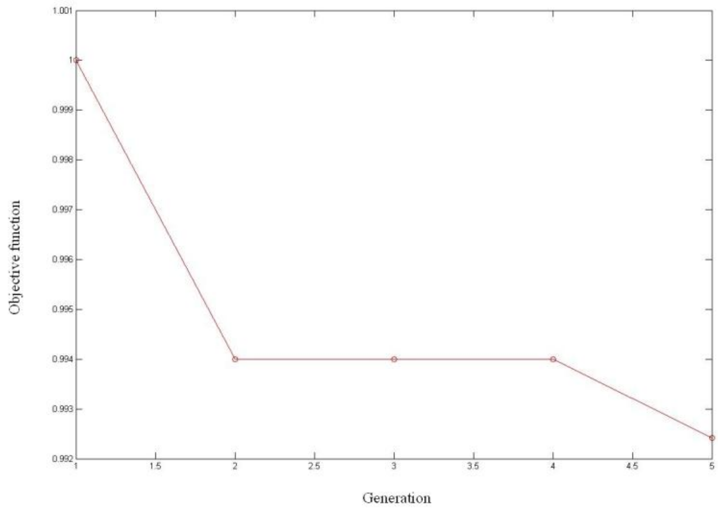

Figure 8. Objective function evolution, optimization with 10 individuals, *without* noise constraints

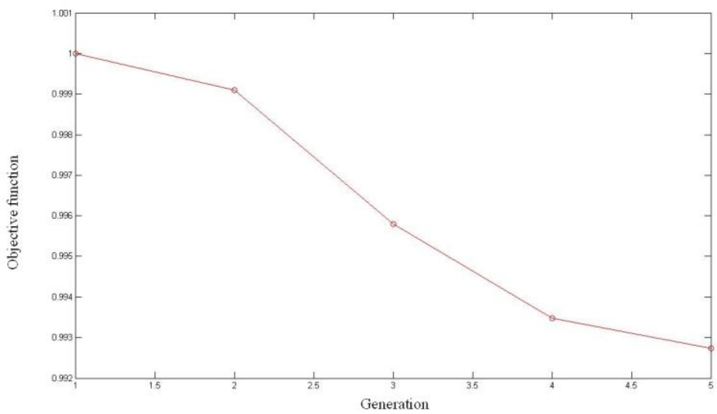

Figure 9. Objective function evolution, optimization with 20 individuals, *without* noise constraints

4.2. Optimization with noise constraints

The optimization undertaken for the airliner considering noise constraints led to the results shown in Table V. This data was obtained in an optimization with 5 generations and the noise limit of 108EPNdB.

Parameter	Unit	Optimization Results	
		10 individuals	20 individuals
wing area	m²	93.5	89.6
wing aspect ratio	-	9.23	8.20
wing tapper ratio	-	0.270	0.250
wing sweep	deg	25.2	24.9
thickness to chord ratio at wing root	%	10.6	11.1
thickness to chord ratio at wing tip	%	9.8	9.3
vertical tail area	m²	10.30	8.96
horizontal tail tapper ratio	-	0.341	0.332
horizontal tail sweep	deg	29.2	28.9
horizontal tail arm	m	13.15	13.60
engine fan diameter	m	2.29	1.840
engine overall pressure ratio	-	23.8	19.7
engine fan pressure ratio	-	1.6	1.9
engine by-pass ratio	-	6.8	6.3
engine location	-	fuselage @ rear	fuselage @ rear
engine number	-	2	2
number of seats abreast	-	5	5
wing position (low, high)	-	low	low
horizontal tail position (low, high)	-	high	high
fly-over noise (takeoff)	EPNdB	96.9	97.2
sideline noise (takeoff)	EPNdB	101.9	106.3
approach noise	EPNdB	97.5	96.2
maximum takeoff mass	kg	43525	36113
operating empty mass	kg	28419	21201

Table V. Optimization results with noise constraints

Figures 10 and 11 show the optimized airplane configuration obtained, without noise constraints, for 10 and 20 individuals, respectively. Figures 12 and 13 shows the evolution of the objective function (minimization of operating empty weight) for 10 and 20 individuals, respectively, considering the weight of the best individual in the first generation as a reference.

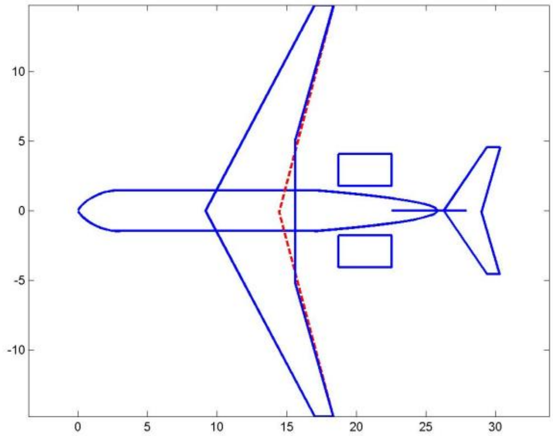

Figure 10. Airplane configuration after optimization with 10 individuals, *with* noise constraints

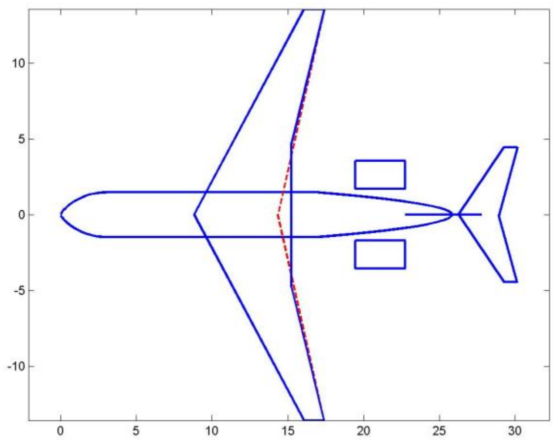

Figure 11. Airplane configuration after optimization with 20 individuals, *with* noise constraints

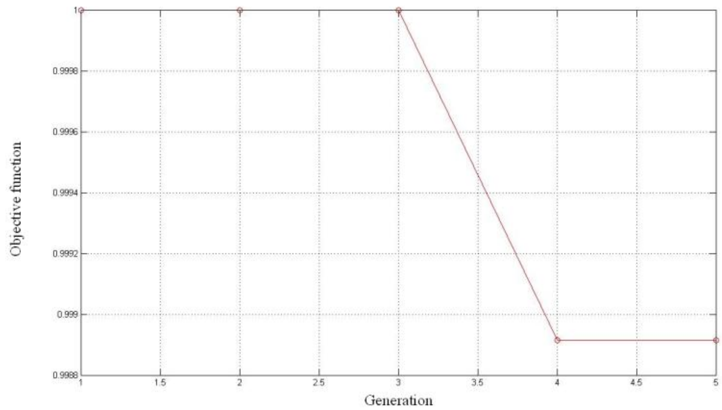

Figure 12. Objective function evolution, optimization with 10 individuals, *with* noise constraints

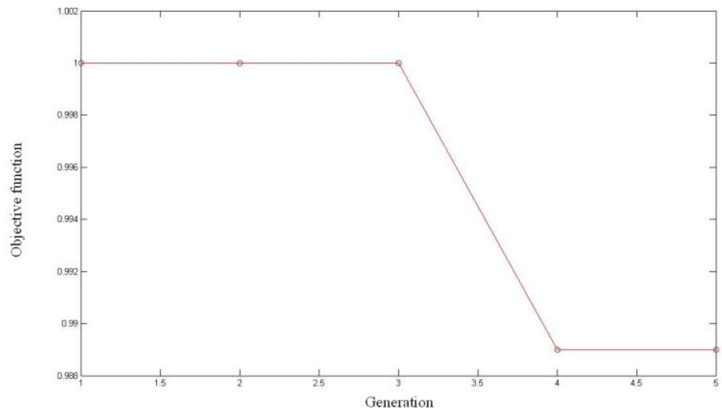

Figure 13. Objective function evolution, optimization with 20 individuals, *with* noise constraints

The comparison of the results listed in tables IV and V indicates that the inclusion of the noise assessment in the conceptual design phase led to several design parameters to change. These changes are discussed in detail in the following paragraphs.

Although insulation and design techniques have evolved significantly during the last decades, engines remain a major noise source of airliners. By including the noise constraints in the design process, the optimization algorithm is forced to search for a better combination of engine and airframe characteristics. Considering, for example, the case of 10 individuals in the design population, it can be seen that both the engine fan by-pass ratio and the wing area are increased noise constraints are included. These changes result in a reduction in both the takeoff noise level (by improving rate of climb after takeoff and by reducing the takeoff run and the takeoff speeds) and in the approach noise level (by lowering the approach speed). However, this benefit on noise levels has the draw-back of an increase in takeoff weight, due to a heavier wing, and a larger fan, for a roughly similar overall pressure ratio, which means a heavier engine.

The increase in the number of individuals in each generation had the expected effect of increasing the diversity of the population and the number of valid design solutions. In the case of the optimization without noise constraints, the increased number of individuals improved the solution, resulting in a lower empty weight. With noise constraints, the benefit is even more evident both in terms of empty and maximum takeoff weights, although the noise levels are higher. Nevertheless, they still fulfill the determined criterion of 108 EPNdB.

Regarding the optimization algorithm, it may also be observed that the convergence is faster *without* the noise constraints, i.e., for the same number of generations, a larger reduction in empty weight is obtained when noise constraints are not considered. Hence the inclusion of noise constraints demands more generations, with consequently more computing time, in order to obtain better results. This new demand also leads to the need of better tuning of the optimization parameters (number of individuals and generations, mutation and cross-over rates).

Finally, it is worth comparing the results thus far obtained with airplane which actually made it into commercial operation. Taking for instance the case of design optimization with 20 individuals considering noise constraints, the airplane configuration resembles that of a Bombardier CRJ-700. Table VI shows a comparison of key parameters for the two airplanes.

Parameter	**Unit**	**Airplane data**	
		CRJ700	**Optimized, 20 ind.**
wing area	m²	70.6	89.6
wing aspect ratio	-	7.64	8.20
engine fan diameter	m	1.174	1.840
engine overall pressure ratio	-	28.5	19.7
engine by-pass ratio	-	5.0	6.3
engine position (underwing or at the rear-fuselage)	-	rear-fuselage	rear-fuselage
engine number	-	2	2
number of seats abreast	-	4	5
wing position (low, high)	-	low	low
horizontal tail position (low, high)	-	high	high
fly-over noise (takeoff)	EPNdB	82.1	97.2
sideline noise (takeoff)	EPNdB	89.5	106.3
approach noise	EPNdB	92.6	96.2
maximum takeoff mass	kg	32361	36113
operating empty mass	kg	19349	21201

Table VI. Optimized x actual airplane key parameters

A glance at table VI indicates the way the optimization algorithm took in order to improve the airplane design: a larger wing and an engine with a larger fan and a lower overall pressure ratio. Although the operating empty weight is 9.6% higher than the CRJ-700, it can be viewed as a direct consequence of noise constraints, which for their turn also affect the calculated noise levels. On the other hand, the differences in noise levels are significant, mainly due to the cumulated uncertainties of the calculation methods used for both the airframe and engine components' noise, which, as mentioned before, is estimated as being as high as 9dB for some components. Besides, the airplane manufacturers may also use other correction techniques such as nacelle insulation which are not addressed by the adopted noise models. Better tuning of optimization parameters coupled with more precise noise assessment methods are likely to promote further improvements in the quality of the results, both in terms of weight and noise. Nevertheless, the results thus far obtained are considered a suitable initial approach to noise assessment in the conceptual design of airplanes.

Regarding the additional tests to the methodology, their results are presented in the following paragraphs. In the first of the tests, the maximum acceptable noise level was lowered to 106EPNdB. The results of this optimization is presented in Table VII and figs. 14 and 15.

Parameter	Unit	Optimization Results 20 individuals, 5 generations	
		108EPNdB limit	**106EPNdB limit**
wing area	m²	89.6	99.9
wing aspect ratio	-	8.20	8.24
wing tapper ratio	-	0.250	0.278
wing sweep	deg	24.9	23.3
thickness to chord ratio at wing root	%	11.1	9.76
thickness to chord ratio at wing tip	%	9.3	9.3
vertical tail area	m²	8.96	9.99
horizontal tail tapper ratio	-	0.332	0.333
horizontal tail sweep	deg	28.9	27.3
horizontal tail arm	m	13.60	15.47
engine fan diameter	m	1.840	1.940
engine overall pressure ratio	-	19.7	31.9
engine fan pressure ratio	-	1.9	2.0
engine by-pass ratio	-	6.3	3.8
engine location	-	fuselage @ rear	underwing
engine number	-	2	2
number of seats abreast	-	5	5
wing position (low, high)	-	low	low
horizontal tail position (low, high)	-	high	low
fly-over noise (takeoff)	EPNdB	97.2	97.6
sideline noise (takeoff)	EPNdB	106.3	105.5
approach noise	EPNdB	96.2	96.9
maximum takeoff mass	kg	36113	43910
operating empty mass	kg	21201	28557

Table VII. Optimization results with noise constraints set at 106EPNdB

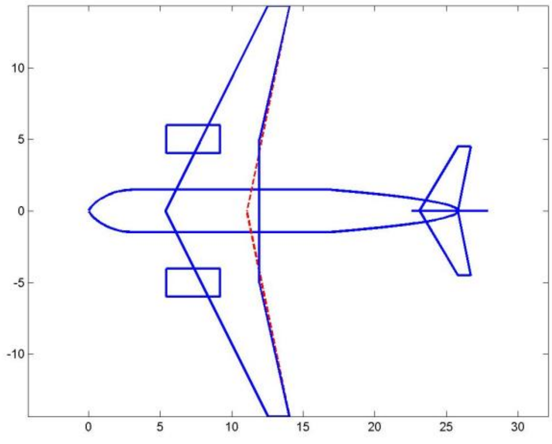

Figure 14. Airplane configuration after optimization with 20 individuals, with noise constraints set at 106EPNdB

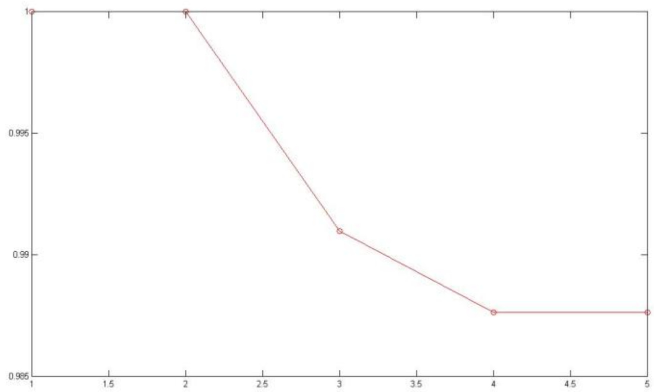

Figure 15. Objective function evolution, optimization with 20 individuals, with noise constraints set at 106EPNdB

An analysis of the data presented in table VII indicates that the when the acceptable noise level limit was lowered to 106EPNdB the optimization algorithm had difficulties to converge within only 5 generations. The airplane configuration is similar to the one obtained for the airplane without noise constraints and the airplane weights are substantially higher than for the 108EPNdB limit constraint. Therefore, it may be necessary to increase the number of generations considered and investigate the effects of the other optimization algorithm settings (crossover and mutation rates, selection method) in order to obtain a lower empty weight.

The results of the second additional run of the optimization process with noise constraints are shown in table VIII and figs. 16 and 17. In this additional run, the noise level limit was set at 108EPNdB and the number of generations was increased to 10.

Parameter	Unit	Optimization Results 20 individuals, 108EPNdB limit	
		5 generations	10 generations
wing area	m²	89.6	94.9
wing aspect ratio	-	8.20	9.12
wing tapper ratio	-	0.250	0.274
wing sweep	deg	24.9	23.4
thickness to chord ratio at wing root	%	11.1	11.7
thickness to chord ratio at wing tip	%	9.3	9.0
vertical tail area	m²	8.96	10.41
horizontal tail tapper ratio	-	0.332	0.346
horizontal tail sweep	deg	28.9	27.4
horizontal tail arm	m	13.60	13.96
engine fan diameter	m	1.840	1.78
engine overall pressure ratio	-	19.7	24.9
engine fan pressure ratio	-	1.9	1.4
engine by-pass ratio	-	6.3	5.1
engine location	-	fuselage @ rear	underwing
engine number	-	2	2
number of seats abreast	-	5	5
wing position (low, high)	-	low	low
horizontal tail position (low, high)	-	high	low
fly-over noise (takeoff)	EPNdB	97.2	97.7
sideline noise (takeoff)	EPNdB	106.3	107.0
approach noise	EPNdB	96.2	96.7
maximum takeoff mass	kg	36113	40166
operating empty mass	kg	21201	24204

Table VIII. Optimization results with noise constraints, 10 generations

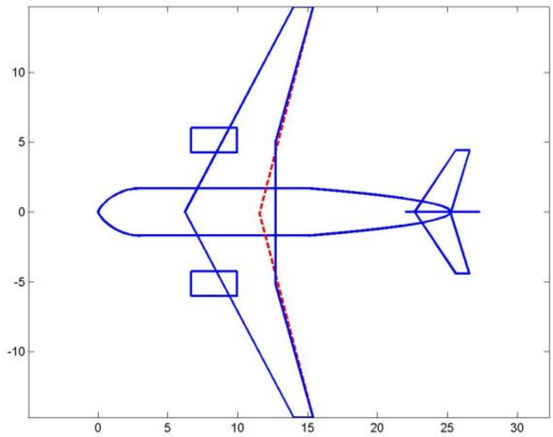

Figure 16. Airplane configuration after optimization with 20 individuals, 10 generations

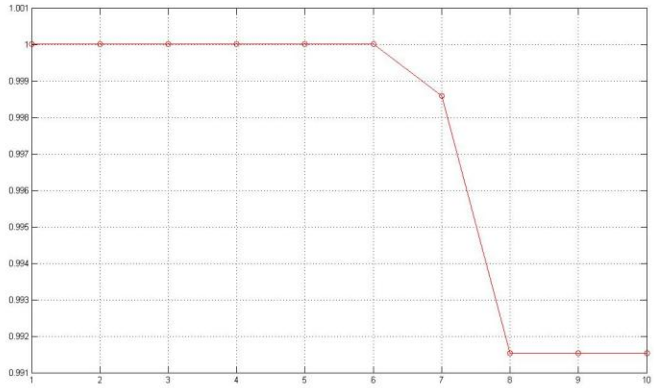

Figure 17. Objective function evolution, optimization with 20 individuals, 10 generations

An analysis of the data presented in table VIII reinforces the need for a fine tune in the optimization algorithm settings. Altough the number of generations was increased, apparently the algorithm got stuck in a local minimum point and tried to optimize that airplane configuration with poor results in terms of airplane empty weight and reductions in the objective function. Nevertheless, it can be seen that the algorithm is correctly grasping the key parameters leading to a low noise level: the engine by-pass ratio and the wing area were set at a high value. Increasing the former usually leads to a low sideline noise value while increasing the latter reduces the landing speeds and the approach noise.

5. CONCLUDING REMARKS

It was observed that the noise assessment methodology of PANPA worked properly with the conceptual design optimization already implemented in AIDMIN. Although more than 30 years old, the methods compiled into PANPA proved to be adequate for airplane conceptual design. This methodology set correct trends for airplane design parameters regarding noise, with differences between configurations being properly addressed. However, its accuracy is limited considering the errors of each method; in the extreme case when all the errors are added together, the accuracy may be very poor when preliminary design results are compared with those of the final certified airplane.

As the constraint of 108EPNdB is quite simple and relaxed for current certification standards, more updated and refined methodologies for noise assessment must be investigated for use in PANPA / AIDMIN so that Stage 3/4 noise constraints may be investigated for use in the preliminary design of airplanes.

On the other hand, as the major draw-back observed with the use of the current PANPA methods was the computational time, which more than doubled, simpler or more empirical methods must also be investigated.

Furthermore, the use of the parallelization features of more recent versions of Matlab® must be explored in order to reduce computational times and then perform a more thoroughly optimization of airplane design.

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