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Noise, Emissions and Costs trade factors for regional jet platforms using a new software for aircraft preliminary design

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A multidisciplinary analysis approach plays a very important role in the development of future transport aircraft, being able to interconnect all aircraft-related subjects and suppliers. A major issue, which has prevented aircraft manufacturers from implementing efficient and cost-effective design processes, is the loose integration of engine models into iterative aircraft design workflows. The continuous improvement of computer calculation capabilities over years has allowed the growth of a large family of software dedicated to aircraft preliminary design activities concerning also multi-disciplinary analyses, and optimizations.

In this context, a new software for aircraft preliminary design, multi-disciplinary analyses and optimizations named JPAD (Java toolchain of Programs for Aircraft Design) has been developed at the University of Naples Federico II.

The main purpose of this paper is to show the capabilities of the JPAD software applied to typical preliminary design problems. Thus, results of the activities carried out by means of JPAD in the scope of the Work Package 2 (WP2) of the European CleanSky2 project ADORNO will be shown. Those will concern trade factors and response surfaces related to environmental noise, DOC, and pollutant emissions (linked to the design mission block fuel) for a Rear-Mounted engines (RM) reference 2014 aircraft configuration.

I. Nomenclature

A/C	=	Aircraft
AEA	=	Association of European Airliners
APU	=	Auxiliary Power Unit
ATA	=	Air Transport Association of America
ATAG	=	Air Transport Action Group
BRF	=	Body Reference Frame
DAF	=	Design of Aircraft and Flight technologies research group
DOC	=	Direct Operating Costs
DOE	=	Design of Experiment
EPNL	=	Effective Perceived Noise Level
FAA	=	Federal Aviation Administration
FAR	=	Federal Aviation Regulation
GA	=	Genetic Algorithm
GUI	=	Graphical User Interface

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IATA	=	International Air Transport Association
ICAO	=	International Civil Aviation Organization
JPAD	=	Java toolchain of Programs for Aircraft Design
MAC	=	Mean Aerodynamic Chord
MDA	=	Multi-Disciplinary Analysis
MDAO	=	Multi-Disciplinary Analysis and Optimization
MTOW	=	Maximum Take-Off Weight
ODE	=	Ordinary Differential Equation
OEI	=	One Engine Inoperative
OEW	=	Operating Empty Weight
OOP	=	Object-Oriented Programming
PSO	=	Particle Swarm Optimization
RM	=	Rear-Mounted engines
RPK	=	Revenue Passenger Kilometer
TLAR	=	Top-Level Aircraft Requirements
TNAC	=	Transport Aircraft Noise Classification
TOFL	=	Take-Off Field Length
UM	=	Underwing-Mounted engines
UNINA	=	University of Naples Federico II
V_2	=	Take-off safety speed
VeDSC	=	Vertical tail DESign Stability and Control tool

II. Introduction

A major challenge in the transport sector is to make economic growth compatible with sustainability and environmental constraints, while remaining competitive and innovative. In this sense, the Horizon 2020 program will be decisive for delivering the innovations defining this century's fleet and its environmental footprint.

The aeronautical sector, through CleanSky2, will be a critical player in contributing to one of the key Societal Challenge 'smart, green and integrated transport' defined in Horizon 2020. In fact, CleanSky2 (CS2) results will be applicable to 75% of the world fleet needing replacement up to 2050, and CS2 technology will be able to address aviation emissions totaling over 70% of the worldwide civil air fleet according to Clean Sky 2 Joint Technical Program.

The climate change and the increasing lack of resources claim for a clear reduction of the aviation impact on citizens and the environment [1]. In terms of environmental impact, the International Air Transport Association (IATA), the Air Transport Action Group (ATAG) and the Clean Sky 2 Program have defined several targets as driving parameter in the research for new technologies.

As reported by ATAG in [2], in 2008, leaders from across the industry gathered at ATAG's Aviation & Environment Summit to deliver a strategic vision for aviation's sustainable development, signing the Commitment to Action on Climate Change. As part of the commitment, the ATAG board developed a set of environmental goals for the short, medium, and long-term.

These goals were supported and reiterated by the IATA Board and the association's Annual General Meeting. They include:

- An average improvement in fuel efficiency of 1.5% per year from 2009 to 2020.
- A cap on net aviation CO_2 emissions from 2020 (carbon-neutral growth).
- A reduction in net aviation CO_2 emissions of 50% by 2050, relative to 2005 levels.

The Clean Sky 2 Program aims to accelerate the introduction of new technology in the 2025-2035 timeframe. By 2050, 75% of the world's fleet now in service (or on order) will be replaced by aircraft that can deploy Clean Sky2 technologies [3]. High level objectives for Clean Sky 2 can be summarized as follow:

- A reduction in CO_2, NO_X and environmental noise from -20% to -30% in the 2014-2024 timeframe.
- A reduction in CO_2 of -75% by 2050.
- A reduction in NO_X of -90% by 2050.
- A reduction in environmental noise of -60% by 2050.

If one target is to reduce aircraft environmental impact, at the same time world air transport demand will suffer the effects of the recent COVID-19 outbreak in the next years. IATA forecasts highlight a worldwide -48% RPK with respect to 2019 [4].

ICAO market analysis provides two possible recovery scenarios [5]. The first one will be characterized by a V-shaped path during 2020 with a first sign of recovery in late May; while the second one, with a U-shaped path, expects a restart during the third quarter of 2020 or even later. According to ICAO [5], given the originally-planned seat capacity, passenger demand could have increased 72 million for 2020, compared to 2019. However, latest estimates expect the passenger demand to drop from the above baseline by 861 to 1292 million (Scenario 1) and 1108 to 1524 million (Scenario 2). This demand level would be 789 to 1221 million (Scenario 1) and 1036 to 1452 million (Scenario 2) below the 2019 level, with the most substantial demand reduction (in number) expected to be in Europe and Asia/Pacific.

A third very important parameter to be considered in the current aircraft market scenario is related to need by most of the major airlines, especially in the regional aircraft segment from 20 to 150 seats, to replace several hundred heritage airplanes, currently in service around the world, which are now coming to the end of their useful commercial life.

The combination of these factors will result in a very difficult period for aircraft designers who must face ever-more demanding challenges to come up with innovative aircraft configurations or technologies.

Preliminary Aircraft Design can address all these issues defining a new frontier of innovation in terms of configurations and technologies suitable for the ever-increasing need for more green and efficient aircraft with reduced operating costs.

In general, the design, and the related development, of aeronautical products is a complex multidisciplinary process with requirements and constraints on the air transport system as a whole, i.e. the aircraft, and all the individual components to be produced, in particular, the engine. A major issue, which has prevented aircraft manufacturers from implementing efficient and cost-effective design processes, is the loose integration of engine models into iterative aircraft design workflows. This requires on one hand a novel design paradigm accelerating the integration of aircraft and engine models, accounting for design and certification requirements. On the other hand, it requires human-centric methods supporting the analysis of large data-driven scenarios and the decision-making process.

That is the research context of the ADORNO (Aircraft Design and nOise Rating for regional aircraft) project which complies with the European Union topic JTI-CS2-CfP07-ENG-02-07 (Aircraft design and noise assessment for a regional application) as part of the Clean Sky 2 program for Horizon 2020. The project topic leader is the German engine manufacturer MTU Aero Engines, while the University of Naples Federico II (UNINA) is the project coordinator. The main objective of the ADORNO project is to provide aircraft requirements (e.g. thrusts, offtakes, etc.) as well as trade factors for specific fuel consumption, engine drag and engine weight on fuel burn for both a year 2014 reference aircraft models and a CS2 target aircraft models with entry into service expected for 2025 or later. In addition, an aircraft noise tool will be developed and integrated in an aircraft design chain [6].

The interaction between aircraft designers and engine manufacturer is a key point in the design process of a new aircraft platform. To make this interaction more efficient both in terms of time and costs is the key enabler to deliver innovative and constantly evolving aircraft products. Thus, another aim of the ADORNO project is to reduce design times by coupling, since the very beginning of the preliminary design process, a multi-disciplinary aircraft analysis approach with a dedicated set of engine trade factors. Those will allow the designer to easily modify engine parameters and characteristics according to the aircraft needs as well as to estimate effects of these modifications at aircraft level.

A multidisciplinary analysis (MDA) approach plays a very important role in the development of future transport aircraft, being able to interconnect all the aircraft-related subjects and suppliers.

The continuous improvement of computer calculation capabilities over years has allowed the growth of a large family of software dedicated to aircraft preliminary design activities concerning also multi-disciplinary analyses, and optimizations [7][8][9][10][11][12][13][14]. A key feature that most of this software provide, is the possibility to parametrically define both aircraft components and complete aircraft configuration leading to a very fast and intuitive definition process of a generic aircraft model. With software and computer hardware currently available in aerospace industry, the design process has become very effective and employs, a very sophisticated and highly optimized chain of calculation tools. Furthermore, because of the relevance of aircraft performance, operative costs, environmental noise, and emissions levels in the commercial success of a transport aircraft, a modern preliminary design software must be developed aiming at a multidisciplinary approach [15].

The members of the DAF (Design of Aircraft and Flight technologies) research group of the Department of Industrial Engineering of the University of Naples Federico II have been users of most of the abovementioned software, and they have reached a mature vision of which features one must expect from a modern Multi-Disciplinary Analysis and Optimization (MDAO) software for aircraft design.

This vision has driven the development of JPAD (Java toolchain of Programs for Aircraft Design) as a modular software, gathering all the lessons learned in the last few decades of tool development for aircraft design [15][16][17][18][19].

The JPAD software is currently developed, promoted, and soon commercialized by SmartUp Engineering, an Italian innovative startup, and academic spin-off of the University of Naples Federico II, funded by professors, young researchers, and PhD of the DAF research group.

The main purpose of this paper is to show the capabilities of the JPAD software applied to typical preliminary design problems. Thus, results of the activities carried out by means of JPAD in the scope of the Work Package 2 (WP2) of the ADORNO project will be shown. Those will concern trade factors and response surfaces related to environmental noise, DOC, and pollutant emissions (linked to the design mission block fuel) for a RM reference 2014 turbofan aircraft configuration.

The following sections will firstly provide an overview of the JPAD software, as well as a brief description of the implemented methodologies. Then, starting from the definition of a set of TLAR, the generation of two UM and RM baseline aircraft models will be presented. Finally, the complete MDA process carried out for each configuration will be described showing its results in terms of response surfaces and trade factors.

III. Software and methodologies

JPAD is a Java framework developed in-house at the University of Naples Federico II by the DAF research group allowing to perform multi-disciplinary analyses and optimizations of civil transport aircraft. It is the result of the efforts of the DAF group during several years of involvement in European research projects, which have allowed to gather a solid experience in aircraft design techniques and in the development of novel methodologies supporting the design process [20][21][22][23][24][25][26].

Nowadays the preliminary design phase of an aircraft has become very challenging due to increasingly demanding requirements. The goal of first design stages is to search for the configuration that best fits all the requirements among the results of a great number of multi-disciplinary analyses. This task must be accomplished as fast as possible and, preferably, with a certain grade of accuracy. JPAD has been designed meeting all these requirements, relying on semi-empirical methods which allow a fast estimate of all the most significant aircraft quantities and performance. A comprehensive study of the methods available in literature has been firstly carried out, followed by a period of testing against experimental data, to select the most accurate ones or to perform a merge between different available approaches. In addition, several in-house developed methods [20][22] have also been implemented in the JPAD framework, providing a significant advantage with respect to most of the current competitors in the aircraft design software scenario. Particular attention has been paid for aerodynamics and performance estimation methodologies, for which the classical semi-empirical approaches have been complemented (or in some cases even substituted) with more refined and higher fidelity techniques [27][28], such as vortex lattice method and simulation-based approaches.

The JPAD framework has been organized as an interconnected ecosystem of software modules, each one dedicated to a specific task. The root of the JPAD framework is the *jpad-core* module, which allows to manage the aircraft parameterization and the performing of all available analyses. On top of that, several other modules provide other important features (Fig. 1).

- *jpad-cad* – This module oversees the automatic CAD modelling, based on the aircraft parameterization provided and managed by the *jpad-core* module [19].
- *jpad-commander* – The dedicated Graphical User Interface (GUI) of the JPAD framework. Completely written using JavaFX along with the support of Gluon Scene Builder, this powerful tool allows users to easily define a JPAD-parametrized aircraft model, to generate its CAD model, to run a prescribed set of analyses, and to visualize results.
- *jpad-doe* – This module is in charge to perform sensitivity studies, as well as full-factorial design of experiments (DOE), by managing changes to geometrical and/or analysis-related design parameters, thus generating a population of aircraft to be analyzed. It makes use of the *jpad-core* module to perform a set of multi-disciplinary analyses for each aircraft included in the population. The output of the *jpad-doe* module is a response surface, which is suitable for both built-in optimizations and external optimization tools.
- *jpad-initializer* – Starting from a set of user-defined top-level aircraft requirements (TLAR) and a reduced amount of information regarding the aircraft category, its general layout and engine platform, the *jpad-initializer* allows to easily generate a baseline A/C to be used, for example, to perform sensitivity studies. The *jpad-initializer* relies on a statistical database. Throughout the years, those have been enriched by the DAF research group by gathering data from several renowned aircraft design textbooks, aircraft manufacturers, and online available material.

- *jpad-optimizer* – This standalone module can be used to perform single-objective as well as multi-objective optimizations by means of the state of the art in terms metaheuristic optimization algorithms based on computational intelligence, like Genetic Algorithms (GA) and Particle Swarm Optimization (PSO).
- *jpad-report* – Conceived for fast and efficient output visualization, this module allows to automatically generate a complete aircraft report mixing text, figures and tables, both in Microsoft Word and PDF file formats.

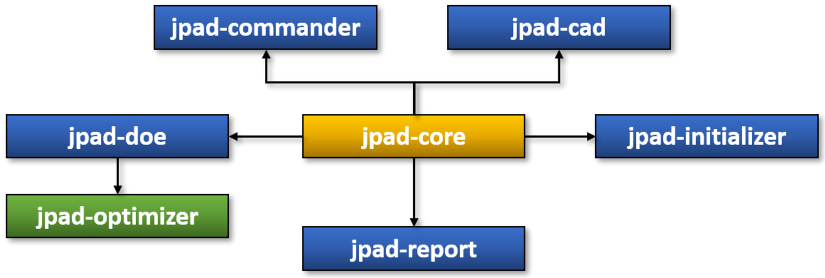

Fig. 1 JPAD modules hierarchy.

The following subsections provide a more detailed description of the JPAD modules which have been directly involved in this work.

A. The core of the JPAD framework

The *core* module of JPAD manages both the aircraft parameterization and the analyses managers related to the seven embedded disciplines: weights, balance and ground stability, aerodynamics and static stability, performance, pollutant emissions, environmental noise, and costs (Fig. 2). Input both for the geometry and for the analyses, in the format of XML files, have been organized forming a hierarchical structure, following a pattern similar to the one adopted for the classes. With regards to the aircraft geometry, for example, the main aircraft file (*aircraft.xml*) collects all the components positions with respect to the Body Reference Frame (BRF) along with the related XML file name (i.e., *fuselage.xml*, *wing.xml*, etc.). These, in turn, contain all the geometrical data related to that specific component.

To enhance the framework flexibility, the core has been conceived to allow both a complete analysis loop, involving all the disciplines shown in Fig. 2, and standalone use of any of its analysis modules. Since the obvious interconnections between the core disciplines, in the last case the user must directly provide all the necessary input for the analysis to be carried out.

In case the user wants to perform a complete multi-disciplinary analysis cycle, a preliminary iterative loop on mission fuel mass is performed. In this case a first weights estimation is carried out, along with a balance analysis to determine the center of gravity excursion. For each considered center of gravity position (e.g., max forward, max afterward, and operative), the aerodynamic and stability module estimates trimmed drag polar curves and lift curves for the take-off, climb, cruise, and landing conditions. Then the performance module uses the results coming from the aerodynamics and static stability analysis to perform a detailed simulation of the mission profile, estimating a new amount of fuel needed to cover the mission. Thus, an iterative process is carried out until the first estimated fuel mass is equal to the one calculated by the mission profile analysis. In addition, during this first preliminary analysis phase, users can require the aircraft also to match specific performance requirements in terms of target take-off field length, maximum cruise Mach number, and minimum cruise service ceiling. In case one of the above-mentioned requirements has not been fulfilled, the engines static thrust is automatically increased. As a result, all dimensional thrusts (i.e., at different power settings and flight conditions) provided by the non-dimensional engine deck, on which the JPAD performance analysis module is based, are scaled as well.

It is important to highlight that, to account for the snow-ball effect provided by an increased value of the engine static thrust, JPAD calculates new values for the engine dry mass, the engine overall length, and main nacelle dimensions, for each updated aircraft, using a dedicated statistical database developed by the DAF research group. In this way, effects of the engine update process influence all the disciplines involved in the analysis cycle.

Once the preliminary iterative loop has converged, the JPAD library reads from the XML input file all the analysis of which the user wants to see the results and invokes only their analysis modules. An overview of JPAD complete analysis cycle is provided in Fig. 3.

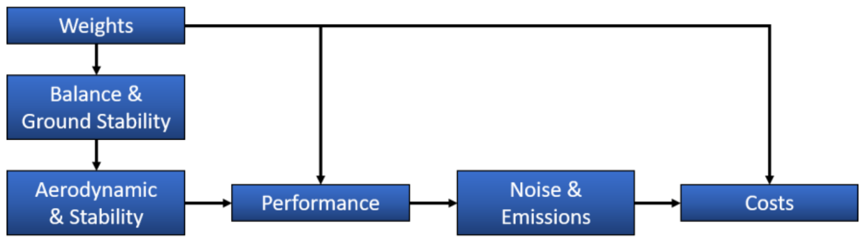

Fig. 2 JPAD core analyses dependencies.

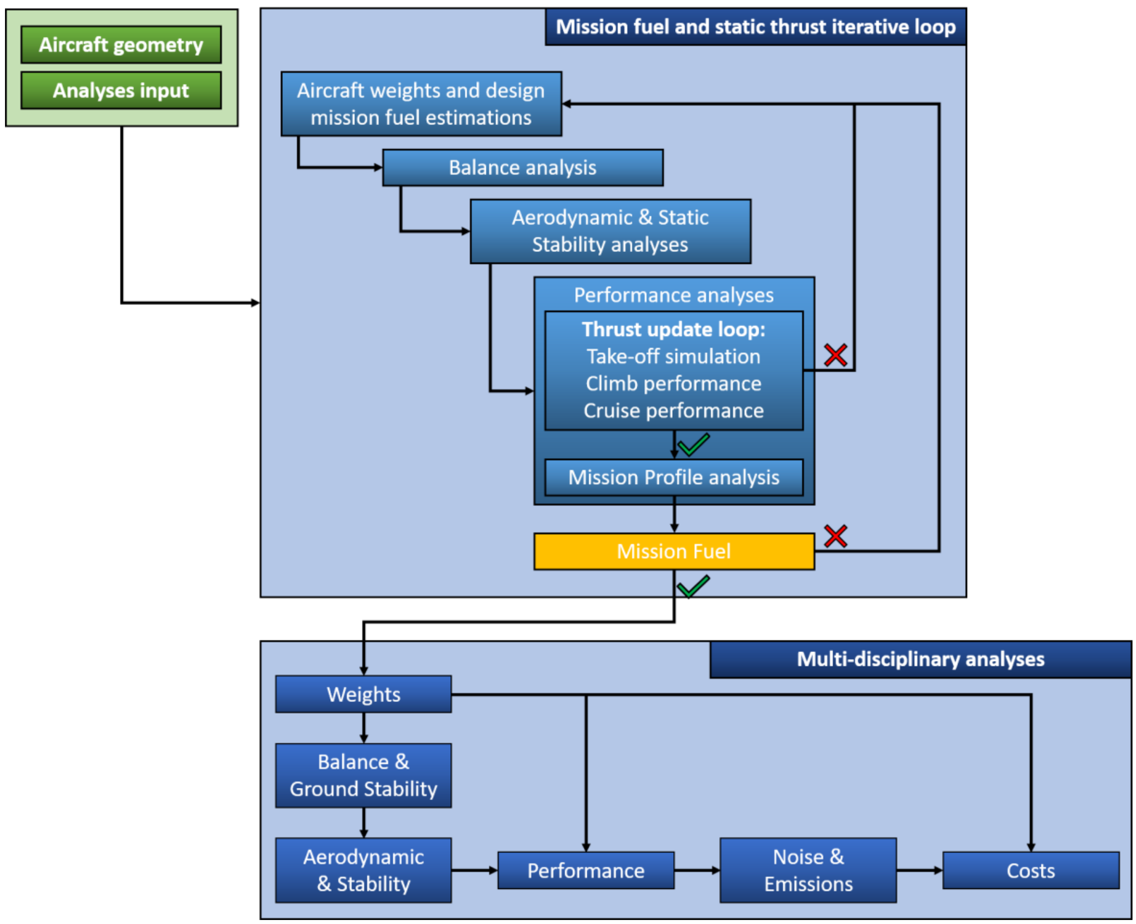

Fig. 3 JPAD complete analysis loop.

The following listing provide a brief overview of the analysis modules implemented by *jpad-core*.

- **Weights analysis** – This module is in charge of performing a Class-II estimation in order to assess all main aircraft weights data starting from a detailed mass breakdown of all its components. Each component mass is calculated using several semiempirical equations retrieved from the literature [29][30][31][32][33][34][35]. The user is allowed to choose, for each aircraft component, whether to use a specific calculation method or a mean value provided by the application of all the available methods. In addition, the weights analysis manager also provides the user with the possibility to manually calibrate each component weight by means of a dedicated set of calibration factors, in order to simulate technological trends.
- **Balance and Ground Stability analyses –** The balance module allows to calculate: the aircraft center of gravity position at different weight conditions (e.g., operating empty, max zero fuel, max take-off, etc.); the center of gravity of each component; the boarding diagram; the max forward, the max afterward and the operative center of gravity positions; aircraft inertia moments and inertia products. With regards to inertia

calculation, a semiempirical approach, based on formulas proposed in [29][30], has been implemented. The module can also take into account for main systems groups centers of gravity positions like APU, anti-icing systems, control surfaces, etc. Those can either be manually assign by the user or estimated by means of an automatic procedure based on statistical on-board systems typical positions. In addition, the balance module also performs several ground stability and ground operability checks, to ensure that the aircraft configuration provides for: a safe rotation during take-off and landing; enough engine ground clearance; aircraft stability and operability during touchdown at taxiing phases; enough 180 degrees turning radius.

- **Aerodynamics and Static Stability** – The JPAD aerodynamics module estimates all the aerodynamic characteristics concerning lift, drag and moment coefficients, at four different operating conditions (take-off, climb, cruise and landing), both for the complete aircraft and for each airframe component (wing, tails, fuselage and nacelles). Furthermore, the stability module provides useful data regarding longitudinal and lateral-directional static stability of the whole aircraft, taking also into account non-linear effects (i.e., pendular stability, non-linear downwash gradient, etc.). Each analysis is carried out using one, or a mix, of the following approaches: a) low-fidelity, e.g., semi-empirical equations from literature; b) medium-fidelity, e.g., vortex lattice method for lifting surface loading, corrected for non-linear effects; c) high-fidelity surrogate models developed by UNINA DAF group [20][36][37]. With regards to lifting surfaces, the starting point is the definition of all airfoil characteristics. Currently JPAD provides users with three different options: a) to manually assign each aerodynamic parameter required to model the lift curve, the drag polar and the pitching moment curve of a generic airfoil; b) to assign an external set of curves to generated, for example, by means of higher fidelity tools; c) select a NACA airfoil from a dedicated internal database, based on the book from Abbott and Von Doenhoff [38]. One of the main features of the JPAD aerodynamic module consists in implementing an improved methodology for lift estimation, which overcomes some of the issues of classical vortex methods. The vortex-lattice method implemented in JPAD modifies the load distribution obtained by using the NASA-Blackwell approach [39], taking into account actual airfoil lift characteristics and extending results up to the stall [27]. An improved methodology for high-lift devices has been also implemented, which accounts for the presence of flaps and slats by using the flapped airfoil aerodynamic characteristics where needed, replacing the clean wing geometry parameters with the flapped ones. More information concerning these approaches can be found in [27].
- **Performance** – The performance module of JPAD has been completely developed using a simulation-based approach for each mission phase. It has been divided in several sub-modules to allow the user to perform a single performance analysis (e.g., a detailed take-off or landing simulation), a complete mission profile analysis, or a combination of them. In the overall *jpad-core* dependency map (Fig. 2), the performance module requires some weight data, as well as trimmed aerodynamic drag polar curves and lift cures for every flight condition. The performance module also requires a non-dimensional engine deck for each engine installed on the aircraft. This must contain all necessary information regarding engine characteristics in terms of thrusts, fuel consumption and emissions indexes, for every flight condition and rating. The performance module allows to carry out the following simulations: take-off, landing, take-off certification noise trajectories, landing certification noise trajectories, climb, cruise, descent. In addition, it allows to perform a complete mission profile analysis, as well as to generate both the payload-range and the V-n diagrams. With regards to take-off, landing and certification noise trajectories simulations, an appropriate set of Ordinary Differential Equations (ODE) has been implemented to handle aircraft equations of motion, as reported in [28]. In addition, especially for the take-off phase, several fundamental simulation variables, such as maximum allowed rotation angle or minimum control speeds, are monitored, in order to ensure the absence of tail strike, as well as to provide for a rotation speed in line with the FAR regulations. In particular, the calculation of the minimum control speed is carried out by means of the Vertical tail DESign Stability and Control tool (VeDSC) [37], embedded inside the core of the JPAD software. Output coming from the noise trajectories analysis allows also to perform an environmental noise assessment with respect to all certification measurement points (Approach, Flyover, Lateral) prescribed by FAR-36 [40]. Concerning the take-off noise trajectory simulation, two different airplane trajectories are produced: one relative to a 100% take-off thrust simulation, and another one with a thrust cutback at a specific altitude prescribed by FAR-36 [40].
- **Emissions** – The JPAD emissions tool provides the user with the possibility to estimate pollutant emissions at mission level. The estimation procedure is tightly linked with the output of the mission analysis module, from which it retrieves fuel consumption for each flight phase. These data are then used to assess each pollutant emission using emission indexes provided by the engine deck (the same used for performance assessment). The following species are considered by the emission tool: NO_x, CO, HC, Soot, CO_2, SO_x, H_2O.

- **Noise** – Concerning the noise analysis, a module for the environmental aircraft noise estimation has been developed by professors and researchers of the UNINA noise and vibration research group. The latter, named ATTILA [6], has been interfaced with the JPAD software. ATTILA allows to evaluate aircraft EPNL values, along with other noise metrics, at all three certification points prescribed by ICAO regulation: Approach, Flyover and Lateral. Both airframe and engines contribution are considered to assess overall aircraft noise levels. The procedure, described in [41], is used to estimate airframe noise, while the methodology reported in [42] has been used to generate a set of noise engine decks to be used within the calculation tool. Starting from these datasets, ATTILA estimates engine noise contribution using a Doppler shift to consider the noise source motion, as well as taking into account for the actual radial distance from the receiver to evaluate propagation attenuation. Linear interpolation is used to assess engine noise for both polar emission angle and engine throttle setting values that are not directly covered by the deck. In order to increase results reliability, several additional effects have been modeled inside the ATTILA tool, such as atmospheric attenuation, ground reflection and lateral attenuation. The implemented methodologies refers to [43][44][45].
- **Costs** – The last analysis module of JPAD is the one in charge of estimating Direct Operating Costs (DOC). The estimation of the DOC breakdown concerns flight operations and considers the following items: capital costs (depreciation, interest, insurance), crew costs (flight and cabin), fuel cost, charges (landing, navigation, ground handling, environmental noise, emissions), direct maintenance (airframe and engine). To estimate those cost items, the methodologies defined by the Association of European Airliners (AEA) [46] for capital, fuel, charges (landing, navigation and ground handling) and crew costs have been implemented, while the method proposed by the Air Transport Association of America (ATA) [47] has been used for direct maintenance costs estimation. A more detailed description of JPAD costs module can be found in [48].

B. JPAD initializer
JPAD provides users with a module dedicated to the aircraft parametric model initialization. The *jpad-initializer* module allows to generate the baseline A/C from which a parametric study, a multidisciplinary investigation or a sensitivity analysis can be carried out. The main input to the tool consists in a set of top-level aircraft requirements (e.g., number of passengers, design range, cruise Mach number, take-off field length, landing field length), and basic requests in terms of aircraft category (e.g., general aviation, commuter, business jet, regional jet, regional turboprop, medium-haul jet, long-haul jet) and configuration (e.g., low wing, high wing, conventional tail, T-tail, wing-mounted engines, rear-mounted engines). Starting from this limited set of information, the module performs an aircraft statistical pre-design by employing its own database of aircraft statistics, relative to aircraft geometry, weights, and aerodynamics.

The *initializer* basically operates in three steps, that have been summarized in Fig. 4.

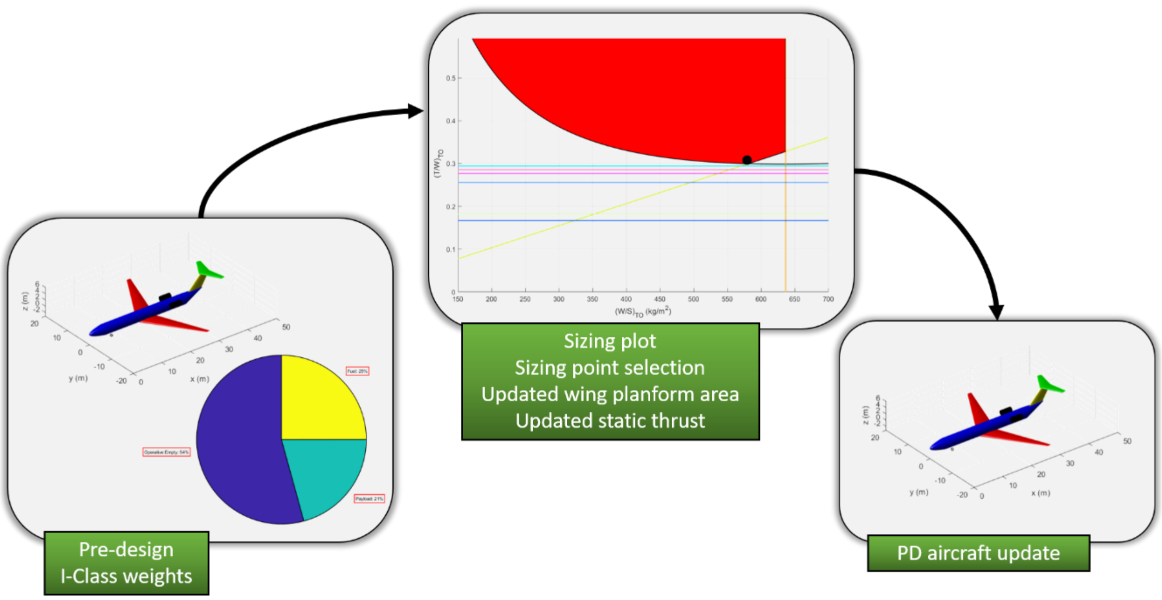

Fig. 4 JPAD initializer complete workflow.

The first step defines the geometry of the novel aircraft configuration. A Class-I weight estimation is also carried out during this phase using the fuel fraction method for the mission fuel estimation, as well as in-house prepared statistical laws to link the maximum take-off weight (MTOW) to operating empty weight (OEW).

The outcomes of this first pre-design phase are used in order to perform the sizing of the newly created aircraft configuration, ensuring it does not only meet range and endurance objectives, but it also fulfills performance targets fixed by the TLARs in terms of take-off field length, landing field length, climb rate, and cruise speed.

Once the sizing activities have been performed and the sizing point has been selected (manually by the user or through one of the available strategies aimed at selecting the most convenient design point), updated values concerning the overall aircraft static thrust and the wing area are calculated. Finally, the pre-design module updates all components geometries, which parameters depends directly either on the wing planform surface or on the engines static thrust.

C. JPAD module for sensitivity studies

The *jpad-doe* module enables the users to perform parametric studies and full factorial DOE. This module is the starting point of the Multi-Disciplinary Analysis and Optimization (MDAO) workflow implemented inside JPAD. To carry out such a task, the *jpad-doe* module relies on all the features implemented inside the *jpad-core*. Thus, the *jpad-doe* module can be seen as a more general analysis manager, allowing users to easily analyze a large number of different aircraft models.

It allows to have access to all possible input variables needed to define both the aircraft parametric model and main analysis input parameters (e.g., calibration factors to simulate technological trends), giving the possibility to specify which ones have to be changed and within which range of values. The final number of aircraft models generated by a *jpad-doe* analysis is equal to the total number of possible combinations between all the design parameters, together with their arrays of values, in a full factorial combination.

To ensure the feasibility of each generated aircraft model, several consistency checks are performed. These consist in a series of geometrical checks used to assess that there are no overlapped or floating components. For example, the module is capable to inspect lifting surfaces and to check whether their positioning with respect to the fuselage is not consistent (i.e., lifting surfaces are not attached to the fuselage).

In addition to feasibility checks, the *jpad-doe* module allows the user to assign one or more geometry update strategies, to be used to generate an aircraft population from a baseline A/C. These update strategies mainly concern the geometry of the fuselage, the planform shape of the lifting surfaces, and the positioning of the tail surfaces. Furthermore, concerning horizontal and vertical tail planes, users can choose whether or not to scale (and eventually move) their surfaces to keep the volumetric ratios equal to one coming from the baseline A/C model. If the planform surface scaling process provides for an unfeasible tail positioning (e.g., the tail plane is no more attached to the fuselage), the latter is also moved as shown in the iterative loop represented in Fig. 5.

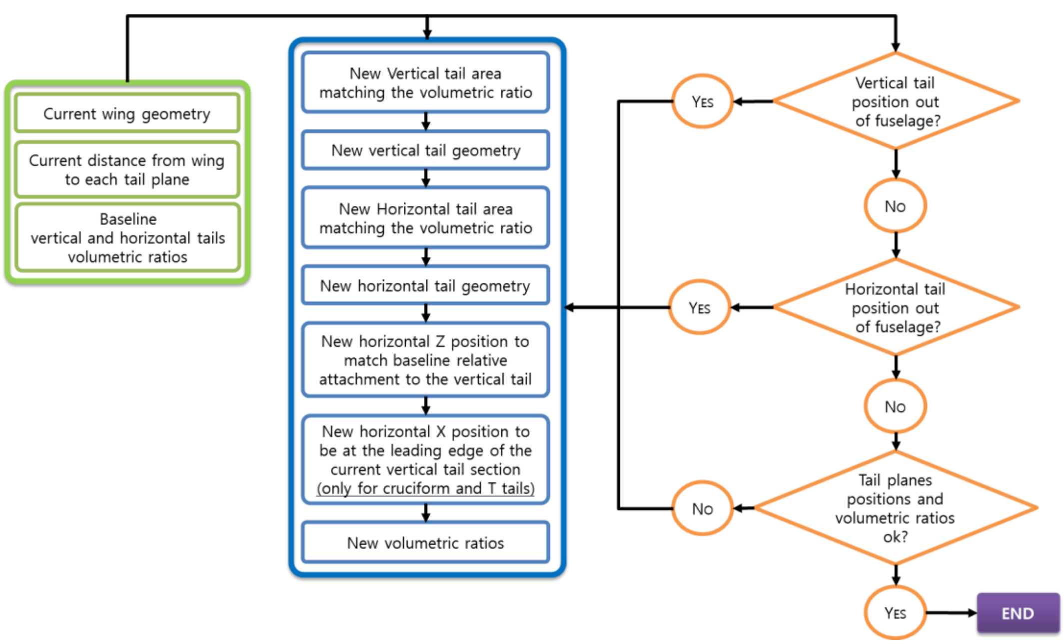

Fig. 5 Tail planes geometries and positions update loop implemented inside the JPAD DOE module.

Once the population has been generated, each aircraft is analyzed by means of a combination of the *jpad-core* modules. At the end of each analysis cycle, the software stores all output variables that the user has decided to monitor in an external dataset, defining in this way a cloud of solution points (one per aircraft), from which all possible response surface can be generated.

An example of complete workflow involving all the three main analysis modules which have been described so far has been reported in Fig. 6.

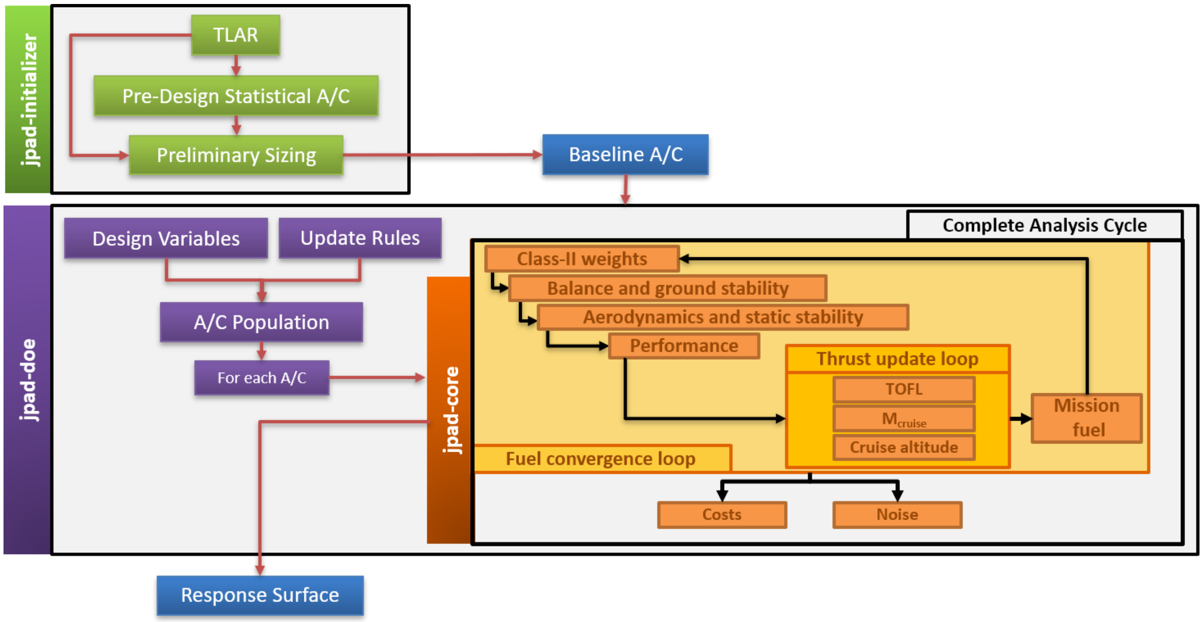

Fig. 6 Example of JPAD analysis workflow involving the *initializer*, the *core*, and the *doe* modules.

IV. TLAR definition and generation of the baseline aircraft model

The set of TLAR related to the Airbus A220-300 has been selected as starting point for the design activities related to the second work package of the ADORNO project. The latter has been used to carry out the statistical pre-design of the reference 2014 RM configuration which will be discussed in this paper. The assumed set of TLAR is reported in Table 1.

Table 1 Set of top-level aircraft requirements used to design the reference 2014 RM aircraft configurations in the framework of the ADORNO project.

Description	Value	Unit
Design passengers	140	
Design range	3100	nmi
Landing field length	1509	m
Take-off field length	1890	m
Cruise Mach number	0.78	
Cruise altitude	37000	ft
Alternate range	200	nmi
Alternate Mach number	0.65	
Alternate altitude	20000	ft
Holding duration	30	min
Holding Mach number	0.55	

The statistical pre-design process has been carried by means of the methodology described in section III.B. Several calibration factors, made available in the initializer input file, have been employed, in order to obtain slightly higher values for certain design parameters, like the wing aspect ratio, with respect to the ones directly provided by embedded statistics. This, to simulate technological trends and to obtain values at least comparable to the ones related to the most recent flying aircraft with the same configuration and with a similar set of TLAR. In particular, the MD-87 has been selected as the reference platform in terms of aspect ratio with a value of 9.61 instead of the statistically-estimated value of 8.5.

Results in terms of sizing limitations calculated by the *jpad-initializer* module are shown in Fig. 7, where the available design space and the selected design point for the RM configuration have been highlighted.

The selection of the design point has been driven both by sizing limitations and by the overall static thrust value. In fact, having the UNINA engine performance deck been validated by MTU for an engine similar to the Pratt&Whitney PW1524G in terms of thrust, fuel consumption and emissions trends, only small variations of the reference static thrust around the original value agreed with the MTU (equal to 103.6kN) were available in order for the engine dataset to still be considered reliable.

Some of the main characteristics of the statistically-defined baseline RM A/C model generated by the *jpad-initializer* module are reported in Table 2. In addition, Fig. 8 provides a representation of its CAD model automatically-generated by the *jpad-cad* module.

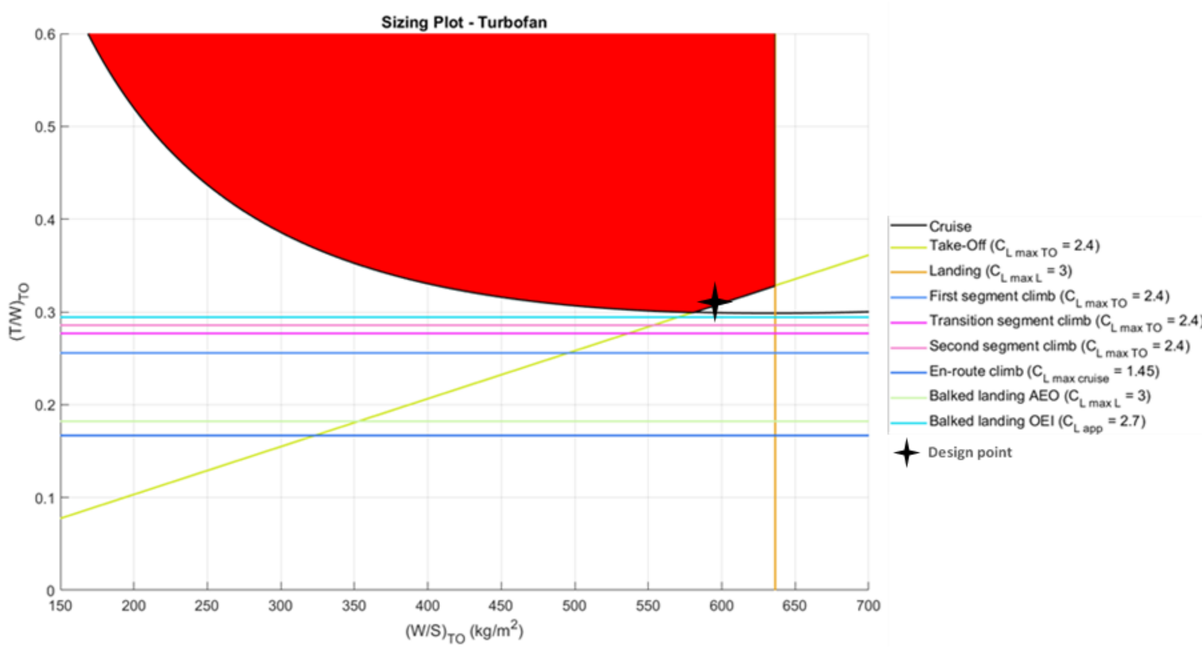

Fig. 7 Sizing limitations, available design space and design point selection for the RM configuration.

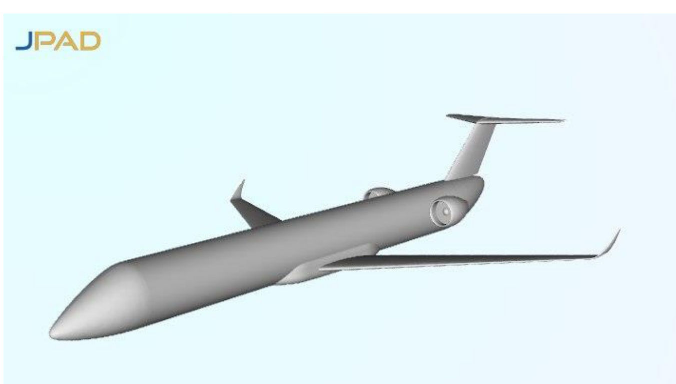

Fig. 8 CAD model of the baseline RM A/C generated by JPAD initializer.

Table 2 Main characteristics of the baseline RM A/C model.

Description	Value	Unit
Wing loading	597	kg/m^2
Thrust loading	0.310	
Max take-off weight	70968	kg
Static thrust (per engine)	107.98	kN
Wing area	118.9	m^2
Wing AR	9.61	
Wingspan	33.81	m
Wing MAC	4.01	m
Horizontal tail area	28.32	m^2
Horizontal tail AR	4.29	
Horizontal tail span	11.02	m
Horizontal tail MAC	2.72	m
Vertical tail Area	17.06	m^2
Vertical tail AR	1.12	
Vertical tail span	4.38	m
Vertical tail MAC	3.95	m
Fuselage length	38.7	m
Fuselage max diameter	3.7	m

V. Response surface and trade factors generation

Starting from the baseline aircraft models defined in the previous section, a complete MDA process has been carried out to investigate the effect of some of the main aircraft geometrical design parameters on mission-related output objectives linked to CO_2 and NO_X emissions, the environmental noise and the DOC.

The complete sensitivity analysis has been carried out by means of the JPAD software which has been already presented in previous sections of this paper. In particular, the workflow described in Fig. 6 has been adopted to perform the overall design space investigation.

Being the reference dimensionless performance engine deck already been approved by MTU in the context of the WP2 of the ADORNO project, the latter has not been considered to change inside the MDA cycle. However, according to the possibility to modify the reference static thrust of each engine to match some given TLAR during the iterative loop reported in Fig. 3, the maximum allowed static thrust variation has been set at a value of ±3% with respect to the baseline value. The latter equal to 107.98kN for the RM configuration under investigation. In this way the need for a new engine deck has been avoided.

In terms of design variables used to generate the initial aircraft population for the parametric study, main wing geometrical parameters have been selected together with the wing and engines longitudinal positions. It must be noted that the fuselage has not been modified at all in this process to keep the same number of passengers and the same seat abreast assumed in the set of TLAR reported in Table 1.

Parallel to the definition of the set of design variables, a dedicated list of geometry update rules has been generated to feed the DOE module of the JPAD software as reported below.

- Each lifting surface planform geometry has been modified by assigning each panel chords as well as the overall span.
- Lifting surfaces chords have been scaled using the ratio between the current and the baseline lifting surface planform areas.
- Wing fuel tank dimensions have been updated according to the ratio between the current and the baseline lifting surface planform areas.
- Aircraft control surfaces and high-lift devices areas have been scaled according to new lifting surfaces planform areas.
- Constant landing gears leg lengths have been considered.

- Horizontal and vertical tail planes planform geometries and positions have been updated assuming constant values of volumetric ratios and aspect ratios. Their values have been calculated from the baseline aircraft model. Each tail plane geometry update process has been carried out using the iterative loop shown in Fig. 5.
- In case of static thrust variation, engine length and dry mass, as well as nacelle maximum diameter, have been updated using a dedicated statistical database developed by UNINA and implemented inside the JPAD software. This accepts as input data the static thrust and the BPR (assumed as a constant parameter) to estimate the abovementioned engine/nacelle parameters.
- Having an engine performance dataset designed for a modern high by-pass ratio turbofan engine similar to the PW1524g, the reference BPR has been kept constant for each aircraft inside the generated population.

In terms of static thrust update strategy inside the iterative loop of the MDA cycle shown in Fig. 3, a first attempt has been made aiming at matching both the take-off field length and the cruise Mach number reported in the set of TLAR. Then, a second attempt has been made also adding the cruise service ceiling to the set of target values within the process (see Fig. 27). The latter assumed as the altitude at which the aircraft has a residual rate of climb in cruise condition of 100 ft/min.

However, due to very similar results, the first strategy has been selected to reduce the amount of computational time needed to carry out the complete design space investigation. A visual representation of the selected static thrust update process is shown in Fig. 9.

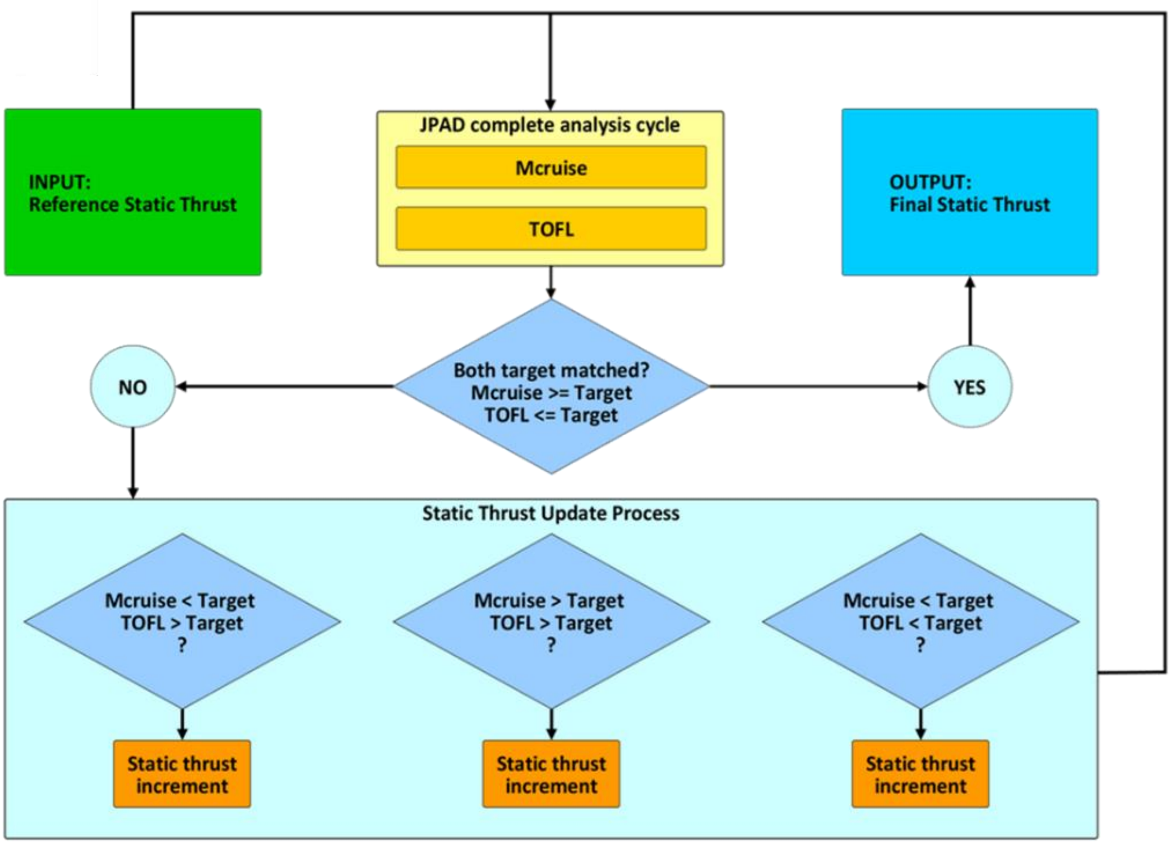

Fig. 9 Selected static thrust update strategy for the MDA cycle of the JPAD software.

To fully understand the interconnection existing between the main geometrical variables used to define a generic aircraft parametric model inside JPAD, Table 3 reports a list of the design variables selected for the DOE process as well as the set of all the dependent variables involved in the aircraft update process. It must be notes that the set of dependent variables is also related to the abovementioned set of geometry update rules.

Table 3 Summary of the independent design variables and dependent aircraft parameters

Design variables	MDA cycle related variables	Dependent variables
Wing area	Engines static thrusts	Wingspan
Wing aspect ratio		Wing fuel tank volume
Wing leading edge sweep angle		Wing high-lift devices areas
Wing apex longitudinal position		Wing control surfaces areas
Engines and nacelles positions		Tail planes control surfaces areas
		Main landing gears positions
		Engines and nacelles dimensions (according to the current value of the static thrust)
		Engines dry masses (according to the current value of the static thrust)

The exploration of the design space has been carried out by means of a full factorial Design of Experiments (DOE) approach. This expects to analyze each single aircraft model coming from the combination of all design variables values to define a response surface. Thus, the higher the number of values for each design parameter, the more precise the final response surface will be. However, this approach would surely result in a huge amount of computational time required to perform all the analyses.

To optimize both the analysis time and the accuracy of the response surface, avoiding the need for a large number of analysis, a preliminary sensitivity study has been carried out for each design variable to evaluate its effect on the baseline A/C model. The obtained set of trend curves has been used to assess the best variation range of each design variables aiming at achieving the best trade-off between response surface accuracy and computational time.

Once the values range of each design variable has been assessed, the best number of elements of the values array has been selected considering the variation sensitivity of main aircraft output parameters (weights, aerodynamics, performance, DOC, noise) with respect to the design variable under investigation. The lower this effect, the larger the step of the variable values array.

It must be noted that, due to the impossibility to install both engines ahead of the rear-cabin bulkhead, a maximum engines forward position equal to -2% of the baseline model has been considered. In addition, due to a detrimental effect on the longitudinal static stability highlighted by the preliminary sensitivity analysis for a large afterward engines installation, a maximum afterward position equal to +2% of the baseline model has been considered as well. A summary of the final DOE setup is provided in Table 4.

Table 4 Setup of the DOE concerning the reference 2014 RM aircraft configuration.

Design variables	Boundaries and number of elements	Baseline values
Wing area (m^2)	From -2.9% to +10.0% with 5 values	118
Wing aspect ratio	From -1.14% to +24.8% with 5 values	9.61
Wing sweep angle at leading edge (deg)	From -10.6% to +10.7% with 3 values	29.8
Wing longitudinal position (m)	From -3.25% to +6.0% with 3 values	16.33
Engines longitudinal position (m)	From -2.0% to +2.0% with 3 values	28.5
Total number of analyzed aircraft = 675		

Output of the full factorial DOE have been the following aircraft parameters:

- Block fuel.
- Environmental noise in terms of cumulative EPNL.
- Total DOC.

The selection of the block fuel as one of the three monitored output of the DOE is mainly linked to the tight relationship between this parameter and the amount of pollutant emissions produced. In fact, the latter are calculated by the JPAD software as the product of the fuel burn, for each mission phase, times the emission index of that specie (if available) retrieved from the engine performance deck. Furthermore, it must be noted that the estimation of the cumulative EPNL for each aircraft configuration has been carried out using the UNINA ATTILA tool, developed in the context of the ADORNO project and interfaced with JPAD, as previously discussed.

Charts from Fig. 10 to Fig. 12 show 2D trade factors of the three selected output parameters as a percentage of the baseline values. Firstly, the wing area and the wing aspect ratio have been assumed as independent variables at fixed baseline values of wing sweep at leading edge, wing longitudinal position and engines position. Then, the wing sweep angle and the wing position have been set as independent parameters considering fixed baseline values of the other variables. It must be noted that the effects provided by engines positions on the three output parameters has not been shown. This due to the very limited influence of this variables caused by the allowed variation range. The effect of this design variable has been mainly related to the reduction of the center of gravity excursion of the aircraft, with a beneficial effect on aerodynamics and longitudinal static stability with forwarder engines positions.

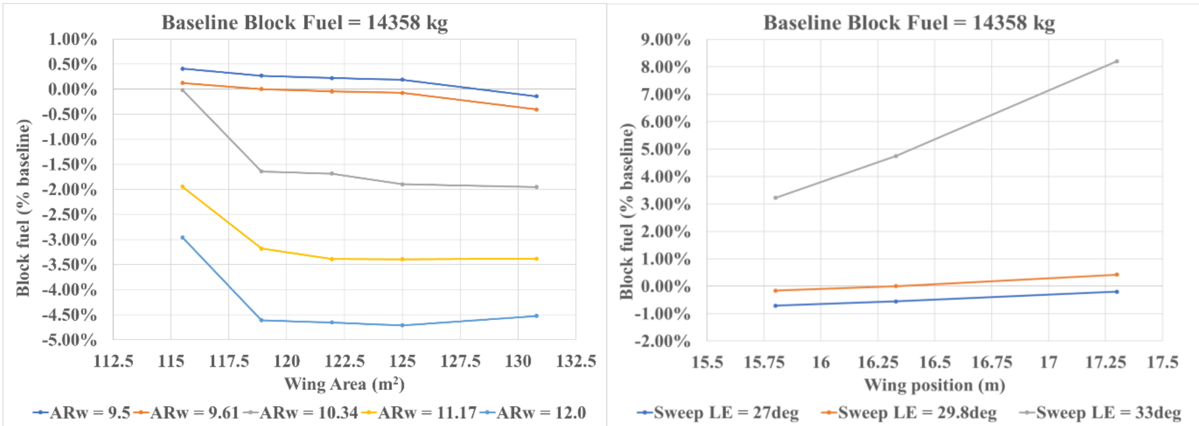

Fig. 10 Block fuel trade factors without feasibility constraints.

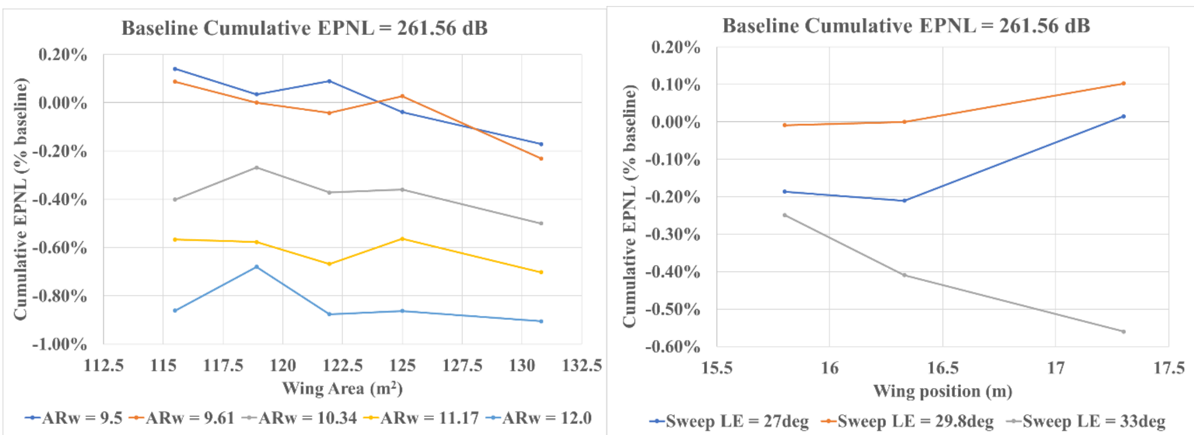

Fig. 11 Cumulative EPNL trade factors without feasibility constraints.

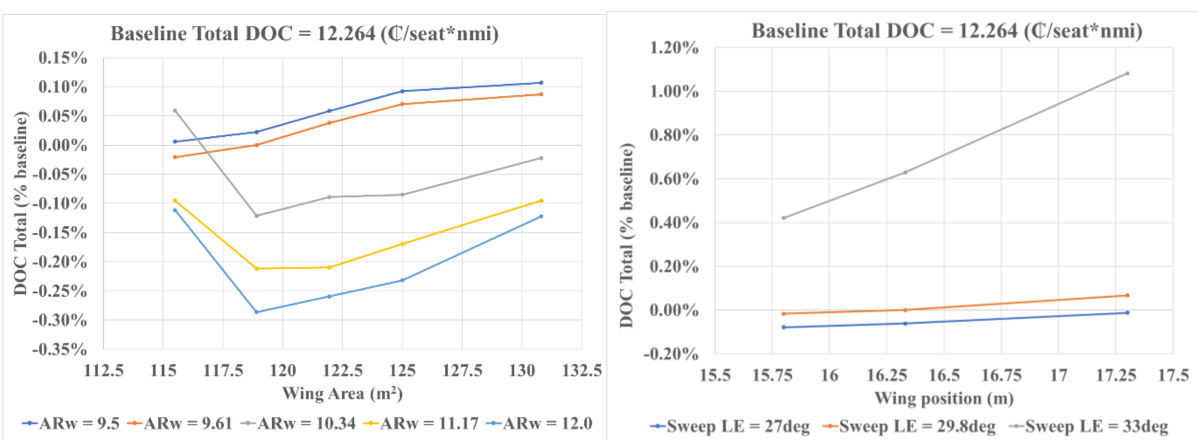

Fig. 12 Total DOC trade factors without feasibility constraints.

For sake of clarity, it must be noted that all the shown trade factors do not include the effect of any constraints. Those should be addressed to the feasibility of each aircraft configuration under investigation, providing limitations to the output design space.

Thus, a configuration has been marked as feasible if all the following checks returned positive result. Effects of the selected constraints have been shown in the updated trade factors charts reported from Fig. 13 to Fig. 15.

- The wingspan is below the limit of 36m prescribed by ICAO Annex 14 for aircraft category C [49].
- Each engine static thrust variation is below 3%. This to allow the use of the same performance engine deck for each A/C model.
- The design mission fuel mass is lower than max fuel mass storable in the wing fuel tank.
- All ground stability and ground operation checks must pass:
    - Possibility to rotate the aircraft during take-off and landing phases at a given rotation angle.
    - Engines clearance from ground is in line with the minimum limitations from FAR regulations.
    - The maximum bank angle during ground operation is lower than the maximum turning bank angle.
    - The minimum sideways turnover angle is lower than the maximum value of 63° [50].
    - The turning radius is lower than the maximum allowed value prescribed by FAA [51].
    - Landing gears positions complies with limit values calculated as suggested by Torenbeek in [30].
- The static stability margin at the most aft center of gravity position provides for aircraft longitudinal stability.
- No tail strike during the take-off simulation.
- No tail or nose strike during landing simulation
- The minimum take-off safety speed (V_2) during OEI take-off is at least 1.13 times the take-off stall speed.
- The initial cruise service ceiling is above the cruise altitude of 37000ft (which has been prescribed by TLAR).
- The number of passengers allowed for the design mission is equal to the design passengers number.
- The climb speed for both full-power and cutback take-off noise trajectories is inside the range of V_2+10kts and V_2+20kts, as prescribed by FAR-36 regulation [40].

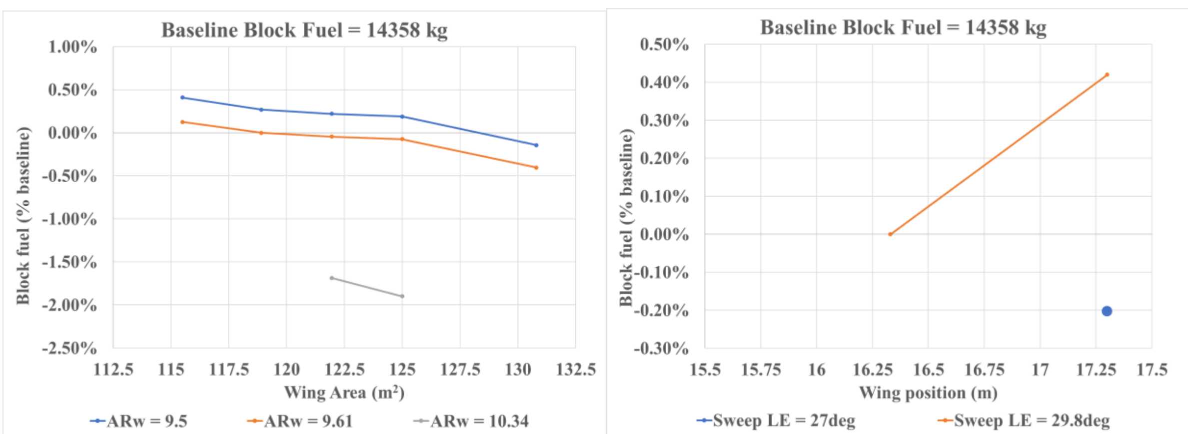

Fig. 13 Block fuel trade factors with feasibility constraints.

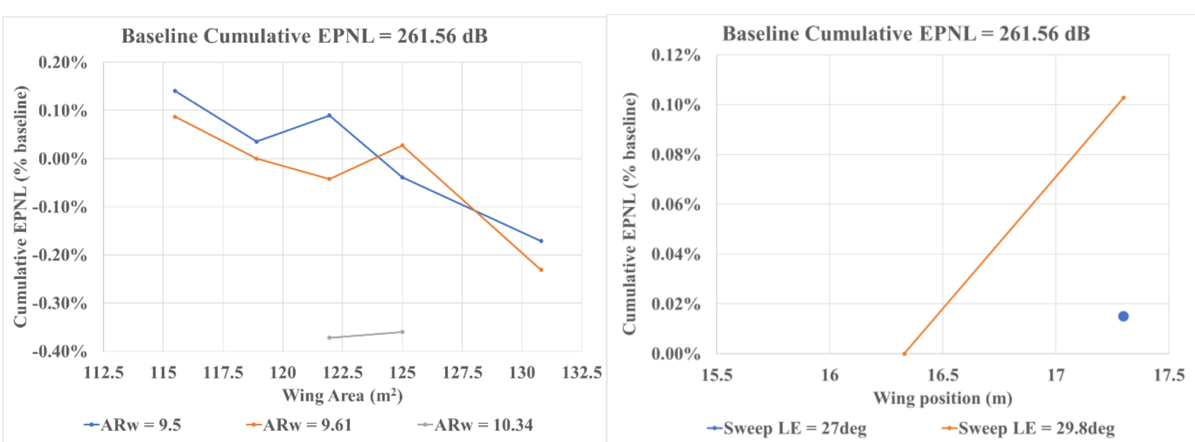

Fig. 14 Cumulative EPNL trade factors with feasibility constraints.

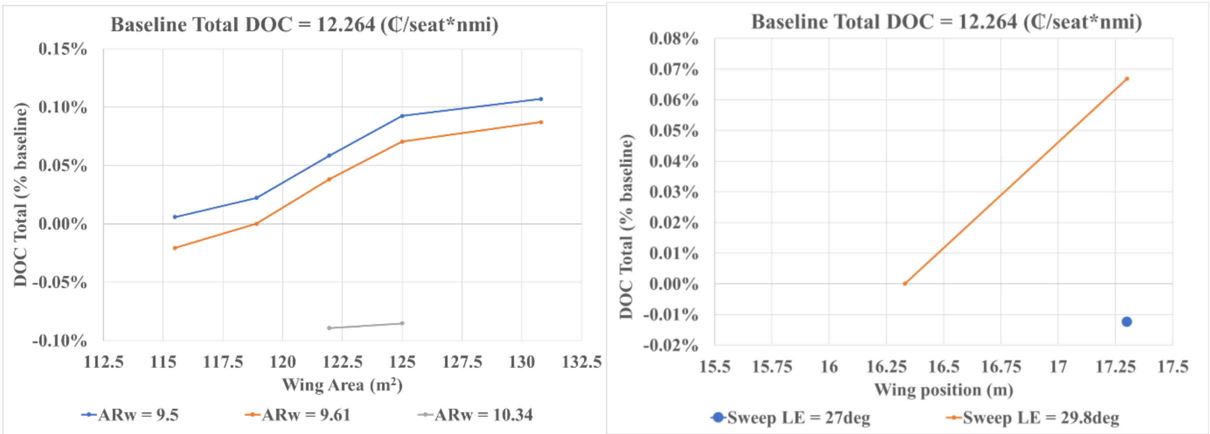

Fig. 15 Total DOC trade factors with feasibility constraints.

The limiting effect of the selected set of constraints can be better observed from the 2D response surface charts reported from Fig. 16 to Fig. 18, where two groups of feasible constrained solutions have been highlighted.

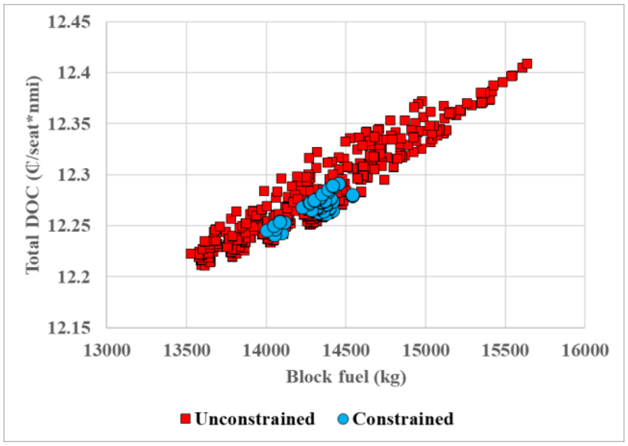

Fig. 16 Comparison between unconstrained and constrained feasible solutions in terms of block fuel and total DOC.

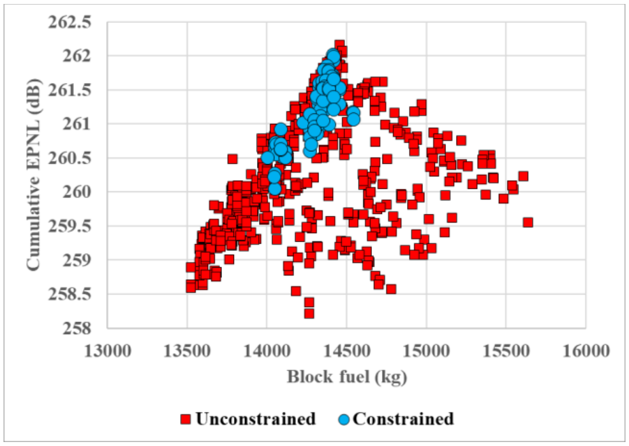

Fig. 17 Comparison between unconstrained and constrained feasible solutions in terms of cumulative EPNL and block fuel.

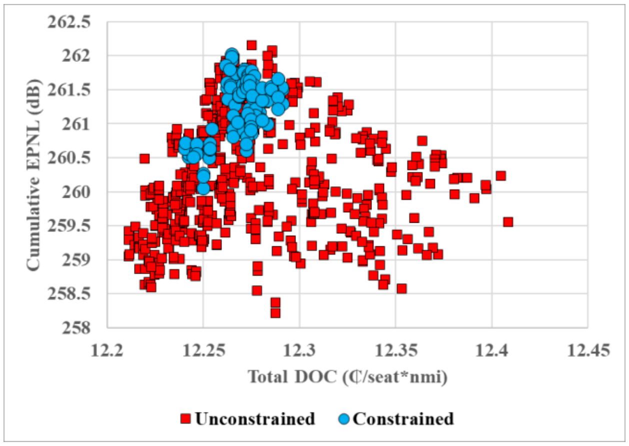

Fig. 18 Comparison between unconstrained and constrained feasible solutions in terms of cumulative EPNL and total DOC.

Considering the unconstrained set of calculated points, trade factors from Fig. 10 to Fig. 12 highlights the following possible improvements.

- A possible design block fuel reduction up to 4.7% of the baseline value (-646.11kg) using the highest available wing aspect ratio and a wing area of 125m^2.
- A maximum cumulative EPNL reduction equal to -0.91% of the baseline value (-2.38dB) with maximum considered values of both wing area and wing aspect ratio. A lower reduction (-0.56% equal to -1.46dB) has been achieved considering maximum values of both the wing leading edge sweep angle and the wing position.
- A reduction in total DOC up to -0.29% of the baseline value assuming a wing area equal to the baseline value of 118.91m^2, as well as a wing aspect ratio of 12. It must be noted that, considering the total DOC expressed in $/flight, a reduction -0.29% with respect to the baseline value provides for a saving of 162.4$ for each flight. In addition, using the equation proposed by Kundu in [52] for the estimation of the aircraft utilization parameter, a value of 3505 block hours per year has been reached. Thus, using the calculated value of 430 min of block time for the design mission range of 3100nmi, a reduction of –22.66$ per block hour can be achieved, leading to an annual total DOC reduction equal to -79408$.
- A very small effect of both the wing leading edge sweep angle and the wing position on the design mission block fuel, with a maximum reduction up to -0.7% of the baseline value (-100.5kg) in case of minimum considered values of both these two design variables. A similar effect, although with a much lower magnitude, can be observed considering the total DOC, where a maximum reduction of -0.08% of the baseline value can be achieved (-21962$ per year).

However, due to the effects of the selected set of constraints, those improvements have been reduced as shown in the trade factors charts from Fig. 13 to Fig. 15. The following limitation can be observed.

- The initial block fuel reduction of -4.7% with respect to the baseline value has been reduced down to -1.9% (-272.8kg) due to the impossibility to adopt wing aspect ratios higher than 10.34. A similar effect can be also observed concerning the total DOC with a maximum allowed reduction of -0.09%. The latter, in terms of annual saving per aircraft, leads to a reduction of -24728$.
- The small block fuel and total DOC reductions related to the wing leading edge sweep angle and to the wing position have been further reduced making this effect almost neglectable.
- A limiting effect similar to the one observed for the block fuel has been obtained for the cumulative EPNL as well. In fact, considering the case of independent values of both the wing area and the wing aspect ratio, the initial maximum reduction of -2.38dB has been lowered down to -0.37% of the baseline value (-0.97 dB). The latter related to the maximum allowed aspect ratio of 10.34 and a wing area equal to 121.95m^2.
- The effect of both the wing sweep angle at leading edge and the wing position has been also reduced making the baseline configuration the best one with no possible improvements.

Since all trade factors charts have not included the effect related to the engines position, the latter, as previously described, has mainly influenced the center of gravity excursion and the longitudinal static stability margin.

Best values of this parameter can be found between the max forward position and the baseline position, providing for a less limiting effect of the static stability margin constraint.

VI. Conclusions

This paper has described the main features of the JPAD software, with major focus on its multi-disciplinary analysis workflow and its interconnection with the DOE module. Furthermore, to show the software capability to support the investigation of typical preliminary design problems, the latter has been used within the framework of the ADORNO project to carry out preliminary activities related to the design of the reference 2014 RM aircraft configuration. In particular, the setup of the full factorial DOE used to analyze the design space has been described, providing also some details in terms of both aircraft geometries and engines static thrusts update strategies.

Results in terms of trade factors concerning the design mission block fuel (tightly linked to the amount of pollutant emissions), the environmental noise, and the total DOC have been shown, highlighting possible improvements with respect to a statistically-defined baseline aircraft model similar to the MD-87.

It must be noted that the reported trade factors provide only for an initial understanding of the possible objective parameters improvements. In fact, the use of only two design variables as independent parameters, at fixed baseline values of all the others, allows only to see each variable direct effect, ignoring possible improvements coming from their cross-correlation. However, this is out of the scope of this paper which aim is to show JPAD capabilities with respect to this kind of investigations.

To distinguish between feasible and unfeasible aircraft configurations, a dedicated set of constraints has been generated considering both the chosen set of TLAR as well as other aircraft consistency checks.

Effects related to this set of constraints have been shown in terms of limitations concerning the abovementioned trade factors, as well as in terms of 2D response surfaces.

Form the analysis of the constrained 2D response surfaces, two groups of feasible solutions have been highlighted. The smallest one has shown better results, in terms of all three selected objectives, than the biggest one. Thus, the research of optima aircraft configurations should be focused on this region of the design space.

Although very limited, this small region has highlighted opposite objectives behaviors. Furthermore, due to the small number of points related to this group of solutions, a more detailed investigation aiming at searching for the best set of optima aircraft configurations should be carried out.

Starting from these considerations, future works, concerning the use of JPAD in the framework on the ADORNO project, will be addressed to the description of a complete MDAO process aimed at defining both the final UM and the RM reference 2014 aircraft platforms in the context of the design activities related to the second work package.

In conclusion, this work has highlighted the possibility to use the JPAD software as a useful tool for preliminary design activities and research projects, allowing for the analysis of complex design spaces using a detailed multi-disciplinary workflow.

Acknowledgments

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European Commission

Clean Sky 2 JOINT UNDERTAKING

References

[1] Nicolosi, F., Corcione, S., Trifari V., Della Vecchia, P., and De Marco A., "Design Guidelines for High Capacity Innovative Regional Turboprop Aircraft", *AIAA Scitech 2019 Forum*, San Diego, California, 2019, doi: 10.2514/6.2019-0256.

[2] Air Transport Action Group, "Climate change", *ATAG*, 2020, URL: https://www.atag.org/our-activities/climate-change.html [retrieved 8 May 2020].

[3] European Commission, "Clean Sky 2 Joint Undertaking Development Plan", 2017, URL: https://www.cleansky.eu/sites/default/files/inline-files/51.%20CS2DP%20December%202017.pdf [retrieved 8 May 2020].

[4] Pearce, B., "COVID-19 Updated Impact Assessment", *International Air Transport Association* (*IATA) Economics*, 2020, URL: https://www.iata.org/en/iata-repository/publications/economic-reports/covid-fourth-impact-assessment/ [retrieved 8 May 2020].

[5] Air Transport Bureau, "Effects of Novel Coronavirus (COVID-19) on Civil Aviation: Economic Impact Analysis," *ICAO*, 2020, URL: https://www.icao.int/sustainability/Documents/COVID-19/ICAO_Coronavirus_Econ_Impact.pdf [retrieved 8 May 2020].

[6] Casale C., Polito T., Trifari V., Di Stasio M., Della Vecchia P., Nicolosi F., and Marulo F., "Implementation of a Noise Prediction Software for Civil Aircraft Applications", *XXV International Congress of the Italian Association of Aeronautics and Astronautics, AIDAA*, Rome, Italy, 2019.

[7] TXT Group, “Pacelab APD”, 2019, URL: https://www.txtgroup.com/markets/solutions/pacelab-apd/ [retrieved 8 May 2020].
[8] Stanford Aerospace Design Lab, “SUAVE”, 2019, URL: https://suave.stanford.edu/ [retrieved 8 May 2020].
[9] University of Manchester, “FLIGHT”, 2019, URL: http://www.flight.mace.manchester.ac.uk/ [retrieved 8 May 2020].
[10] CFS Engineering, “CEASIOM”, 2019, URL: https://www.ceasiom.com/wp/ [retrieved 8 May 2020].
[11] Lysiss Ltd, “Piano”, 2014, URL: https://www.lissys.uk/ [retrieved 8 May 2020].
[12] Optimal Aircraft Design, “ADS – Aircraft Design Software”, 2016, URL: http://www.pca2000.com/en/index.php [retrieved 8 May 2020].
[13] DARCorporation, “AAA – Advanced Aircraft Analysis”, 2019, URL: https://www.darcorp.com/advanced-aircraft-analysis-software/ [retrieved 8 May 2020].
[14] Raymer, D., “RDS-win aircraft design software”, 2019, URL: http://www.aircraftdesign.com/rds.shtml [retrieved 8 May 2020].
[15] Trifari, V., Ruocco, M., Cusati, V., Nicolosi, F., and De Marco, A., “Multi-disciplinary analysis and optimization Java tool for aircraft design,” *ICAS 31st Congress of the International Council of the Aeronautical Sciences*, Belo Horizonte, Brazil, 2018, ISBN: 9783932182884.
[16] Nicolosi, F., De Marco, A., Attanasio, L., and Della Vecchia, P., “Development of a Java-based framework for aircraft preliminary design and optimization,*” AIAA Journal of Aerospace Information Systems*, Vol. 13, No. 16, 2016, pp. 234-242, doi: https://doi.org/10.2514/1.I010404.
[17] Trifari, V., Ruocco, M., Cusati, V., Nicolosi, F., and De Marco, A. “Java Framework for Parametric Aircraft Design – Ground Performance”. *Aircraft Engineering and Aerospace Technology (AEAT)*, Vol. 89, No. 4, 2017, pp. 599–608, doi: http://dx.doi.org/10.1108/AEAT-11-2016-0209.
[18] De Marco, A., Cusati, V., Trifari, V., Ruocco, M., Nicolosi, F. and Della Vecchia, P., “A Java Toolchain of Programs for Aircraft Design”, *Proceedings of the 6th CEAS Air and Space Conference*, Bucharest, Romania, 2017, ISBN: 978-973-0-25597-3.
[19] De Marco, A., Di Stasio, M., Della Vecchia, P., Trifari, V., and Nicolosi, F. “Automatic modeling of aircraft external geometries for preliminary design workflows”. *Aerospace Science and Technology*, Vol. 8, 2020. doi: 10.1016/j.ast.2019.105667.
[20] Nicolosi, F., Della Vecchia, P., Ciliberti, D., and Cusati, V., “Fuselage Aerodynamic Prediction Methods”, *Aerospace Science and Technology*, Elsevier, Vol. 55, Aug. 2016, pp. 332-343, ISSN: 1270-9638, doi: 10.1016/j.ast.2016.06.012.
[21] Nicolosi, F., Ciliberti, D., Della Vecchia, P., Corcione, S., and Cusati, V., “A comprehensive review of vertical tail design”, *Aircraft Engineering and Aerospace Technology*, Emerald, Vol. 89, Issue 4, 2017, pp. 547-557, ISSN: 0002-2667, doi: 10.1108/AEAT-11-2016-0213.
[22] Ciliberti, D., Della Vecchia, P., Nicolosi, F., De Marco, A., “Aircraft directional stability and vertical tail design: a review of semi-empirical methods”, *Progress in Aerospace Sciences*, Vol. 55, Nov. 2017, pp. 140-172, ISSN: 0376-0421, doi: 10.1016/j.paerosci.2017.11.001.
[23] Nicolosi, F., Ciliberti, D., and Della Vecchia, P, “Aerodynamic Design Guidelines of Aircraft Dorsal Fin”, *34th AIAA Applied Aerodynamics Conference*, AIAA Aviation 2016, June 2016, Washington.
[24] Nicolosi, F., Della Vecchia, P., Corcione, S. “Design and Aerodynamic Analysis of a Twin-engine Commuter Aircraft, ” *Aerospace Science and Technology (Elsevier) AESCTE*, Vol. 40, Jan. 2015, pp. 1-16, ISSN 1270-9638, doi: 10.1016/j.ast.2014.10.008.
[25] Nicolosi, F., Della Vecchia, P., Ciliberti, D. “Aerodynamic interference issues in aircraft directional control, ” *ASCE's Journal of Aerospace Engineering*, Vol. 28, N. 1, January 2015, ISSN 0893-1321, doi: 10.1061/(ASCE)AS.1943-5525.0000379.
[26] Nicolosi F., Corcione S., Della Vecchia P., “Commuter Aircraft Aerodynamic Design: Wind-Tunnel tests and CFD Analysis”, *29th ICAS (International Council for Aeronautics and Astronautics) Conference*, St. Petersburg (Russia), 07-12 September 2014, pp. 1-13, Proceedings ISBN: 3-932182-80-4.
[27] Ruocco, M., “High-lift and stability issues for innovative transport aircraft configurations in aerodynamic design”, PhD Thesis, Department of Industrial Engineering, University of Naples Federico II, Naples, Italy, Apr. 2020
[28] Trifari, V., “Development of a Multi-Disciplinary Analysis and Optimization framework and applications for innovative efficient regional aircraft”, PhD Thesis, Department of Industrial Engineering, University of Naples Federico II, Naples, Italy, Apr. 2020
[29] Sforza, P., “*Commercial Airplane Design Principles*” Elsevier, 2014, ISBN: 9780124199538.
[30] Torenbeek, E., “*Synthesis of subsonic airplane design: an introduction to the preliminary design of subsonic general aviation and transport aircraft, with emphasis on layout, aerodynamic design, propulsion and performance*”, Springer Netherlands, 1982, ISBN: 978-94-017-3202-4, doi: 10.1007/978-94-017-3202-4.
[31] Carichner, G., and Nicolai, L., “*Fundamentals of Aircraft and Airship Design*”, AIAA Education Series, AIAA, 2013, ISBN: 978-1-60086-751-4, doi: 10.2514/4.867538.
[32] Raymer, D., “*Aircraft Design: A Conceptual Approach*”, 5th ed., AIAA Education Series, AIAA, 2012, ISBN: 978-1600869112, doi: 10.2514/4.869112.
[33] Sadraey, M., “*Aircraft Design: A Systems Engineering Approach*”, John Wiley & Sons Inc, 2012, ISBN: 978-1-119-95340-1.
[34] Howe, D., “*Aircraft conceptual design synthesis*”, John Wiley & Sons Inc., 2000, ISBN: 978-1-860-58301-8.

[35] Torenbeek, E., "*Advanced Aircraft Design: Conceptual Design, Analysis and Optimization of Subsonic Civil Airplanes*", John Wiley & Sons Inc, 2013, ISBN: 978-1-118-56811-8.
[36] Nicolosi, F., Ciliberti, D., Della Vecchia, P., and Corcione, S., "Wind tunnel testing of a generic regional turboprop aircraft modular model and development of improved design guidelines", *AIAA Aviation and Aeronautics Forum and Exposition*, 2018.
[37] Della Vecchia, P., Nicolosi, F., and Ciliberti, D., "Aircraft directional stability prediction method by CFD", *33rd AIAA Applied Aerodynamic Conference*, 2015.
[38] Abbott, I.H., and Von Doenhoff, A.E., "*Theory of Wing Sections*", Dover Publications, 1959, ISBN: 9780486605869.
[39] Blackwell, J.A. Jr, "A finite-step method for calculation of theoretical load distributions for arbitrary lifting-surface arrangements at subsonic speeds", NASA Technical Note, D-5335, 1969, URL: https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/19690021959.pdf.
[40] Federal Aviation Administration (FAA), "Noise Levels for Transport Category and Jet Airplanes Under § 36.103", FAR Appendix B to Part 36, Section B36.7.
[41] ESDU, "Airframe noise prediction", Item No. 90023, ESDU International plc, London, UK, Nov. 1990.
[42] ESDU, "Prediction of noise generated by fans and compressors in turbojet and turbofan engines", Item No. 98008, ESDU International plc, London, UK, Apr. 1998.
[43] ESDU, "Evaluation of the attenuation of sound by a uniform atmosphere", Item No. 78002, ESDU International plc, London, UK, Apr. 1998.
[44] ESDU, "The correction of measured noise spectra for the effects of ground reflection", Item No. 94035, ESDU International plc, London, UK, Dec, 1995.
[45] ESDU, "Estimation of lateral attenuation of air-to-ground jet or turbofan noise in one-third octave bands", ESDU International plc, London, UK, Nov. 1993.
[46] Association of European Airliners, "AEA Requirements", 1989.
[47] Air Transport Association of America, "Standard Method of Estimating Comparative Direct Operating Costs of Turbine Powered Transport Airliners", ATA, 1967.
[48] Cusati, V., "Design activities for innovative turboprop aircraft with minimum economic and environmental impact", PhD Thesis, Department of Industrial Engineering, University of Naples Federico II, Naples, Italy.
[49] International Civil Aircraft Organization (ICAO), "Aerodromes Design and Operations", *ICAO Annex 14 Aerodromes Volume I*, 8th edition, 2018.
[50] Currey, N.S., "*Aircraft landing gear design: principles and practices*", AIAA Education Series, AIAA, 1988, ISBN: 978-0930403416.
[51] Horonjeff, R., McKelvey, F.X, "*Planning and Design of Airports*", McGraw-Hill Education, 1994, ISBN: 978-0071446419.
[52] Kundu, A.K., "*Aircraft design*", Cambridge University Press, 2010, ISBN: 9780511844652. doi: 10.1017/CBO9780511844652.