

Conceptual Design of a Next Generation Supersonic Airliner for Low Noise and Emissions

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The development of an innovative, medium-range supersonic airliner to meet low drag, low emissions and LTO noise requirements is presented in this paper, including a multi-disciplinary design framework targeting firstly to meet at least the current noise regulations for subsonic aircraft during take-off and landing and secondly to reduce the emission levels. The aircraft is designed to fly 4000 nm at Mach 2.2, carrying 100 passengers. The work contributes to the EU SENECA ((LTO) noiSe and EmissioNs of supErsoniC Aircraft) project, which aims to design different SST (SuperSonic Transport) aircraft platforms to investigate the emissions, the noise and the global environmental impact of supersonic aviation. Results from SENECA can support ICAO in the process of creating future certification requirements as well as form legislation guidelines specifically for the future supersonic commercial aircraft. The technical work includes the assessment of different aircraft-engine configurations, in terms of engine number and positions, on typical flight missions. This enables the evaluation of the baseline layouts that represent the best compromise among payload-range capability, aerodynamic performance, weight and noise. A multi-disciplinary airframe-engine integrated design is carried out in order to pursue a comparative analysis focusing on take-off noise for the different aircraft-engine combination platforms. Lastly, the investigation of the potential use of variable noise reduction systems (VNRS), such as a FADEC controlled thrust reduction during take-off, called Programmed Lapse Rate (PLR) is carried out to study their impact in the mitigation of the resultant noise in the airport environment.

I. Introduction

Extensive scientific research has been conducted in response to the current increase in environmental awareness and revived interest in supersonic travel with the goal of developing a new generation of sustainable supersonic aircraft. The design of a successful, technically, economically, and environmentally viable supersonic transport aircraft is an extraordinary challenge, as history has shown. The difficulties associated with such a design rely on the physics of the problem itself, which leads to conflicting requirements, and the need for increasingly environmentally friendly solutions augments them. Moreover,

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it has been shown [1] that by significantly increasing the Mach number beyond the barrier of Mach 2, the capability of managing and meeting all the requirements becomes even harder.

Only two commercial supersonic aircraft have ever been in service, the Tupolev TU-144 in the Soviet Union and Aérospatiale/BAC Concorde in the western world. Many unsuccessful attempts to develop a supersonic airliner have been made over the years, and concepts have been developed, including the Mach 2.7, 250 passenger Boeing 2707 design in the 1960s, the Mach 2.4, 300 passenger HSCT cancelled in 1999, and the Mach 1.7, 4500 nm and 80 passenger Boom Overture. However, many companies, such as Aerion Supersonic, Boom Supersonic, Lockheed Martin and Northrop Grumman (in collaboration with NASA), made great investment in the design of future supersonic business jets (SSBJ). The smaller size of the SSBJ leads to more surmountable technical challenges to achieve an economic proposition. Additionally, SSBJ could be used as steppingstones for certain technologies assessment to achieve the end goal of an efficient, high-capacity SST aircraft. The three major issues concerning supersonic aircraft are related with emissions, landing and take-off noise and sonic boom.

In the pursuance of the optimal future supersonic commercial aircraft design, an area to be explored is the engine-airframe configurations in respect of number of engines, position, and their integration. The three-engine configuration for commercial transport became popular when in 1964 FAA regulations were modified, allowing trijet aircraft to operate further than a 60-minute flying time of an adequate airport. Nevertheless, in the following years, ETOPS (Extended-range Twin-engine Operational Performance Standards) certification for twin-jet aircraft were introduced due to the increase in engine's reliability, making the aerospace industry abandon the trijet design approach [2]. In the case of the trijet configuration, the major advantage is the ease of its certification at one engine inoperative condition as, in the event of engine failure, 66% of the installed thrust is still available while this value is reduced to 50% of the installed thrust for a twin-engine configuration. Therefore, lower installed take-off thrust for trijet configurations is required, giving as a result a trend of lower thrust to weight ratio for trijet aircraft in comparison with twin-engine aircraft of similar MTOW [3]. Nevertheless, the impact of this thrust reduction and installation of a third engine must be taken into account in terms of fuel burn, structural weight penalties, noise, maintenance, performance, and certification.

Considering that the future generation of supersonic aircraft claims to minimise their operational environmental impact in terms of noise and emissions and the quick phase-out of quad jets in the aviation industry, adding another powerplant seems to go against the goal of sustained supersonic flying. The selection of a four-engine configuration would allow the reduction of each engine size, not only enabling production of these engines to fit inside existing supply chains and manufacturing capabilities, but also the mitigation of the individual engine noise levels while providing redundancy during long range flights. In addition, as stated by Boom Supersonic about their quad jet Overture design [4], by using four engine configurations rather than trijet ones, the design platforms will be able to comply with established manufacturing and maintenance standards while still maintaining weight and temperature within the bounds of currently available technology. Lastly, for mid-size airliners when engines of similar power are installed in quad jets and trijets, the four-engine configuration presents a negative impact in terms of efficiency and costs, however, using four identical engines reduces maintenance costs and eases maintenance procedures.

As part of overcoming the noise challenges in the design of supersonic aircraft, the aircraft planform alongside the engine placement must be studied to allow potential shielding of propulsion noise sources. For sonic boom mitigation and reduction of airport environment noise, the placement of the engines above the wing has remarkable advantages such as, lighter landing gear, reduction of airport noise, decrease in foreign object damage feasibility during take-off, landing and ground operations. Besides, the positioning of the engine above the wing offers a greater shielding of the inlet shock from the pressure signature below the aircraft, resulting in a delay of the N-wave generation [5]. In the case of a trijet configuration, engines mounted on top of the fuselage provide forward-radiating fan noise shielding from observers during take-

off and approach phases [6]. Hence, in the majority of modern transport aircraft, the engines are mounted under the wing for a variety of reasons including safety, ease of maintenance, aerodynamics, structural strength and engine noise perceived in the cabin. Aircraft noise shielding must be assessed in the design of supersonic aircraft configurations since it reduces the overall noise and sonic boom.

Many airports across the world are significantly impacted by aircraft noise. Although these effects are initially categorised as "annoyance," there are more serious health-related implications that have led to a significant amount of academic research. As a result, aviation specialists, engine and airframe manufacturers, airline operators, the general public, and health and occupational services are all focused on the high-profile issue of aircraft noise [7]. For all of these reasons, aircraft noise has been controlled since the 1970s by establishing noise limitations in the form of Standards and Recommended Practices collected in Noise Standards for jet and large propeller aeroplanes (Chapters 2, 3, 4 and 14 of Annex 16 Vol I) developed by the International Civil Aviation Organisation (ICAO) and other organisations over the course of many years [8]. The noise regulations are still under constant review by several groups, in particular the Committee on Aviation Environmental Protection, so they cannot be regarded as closed business.

The standards establish noise restrictions as a direct function of Maximum Take-off Mass so as to determine that heavier aircraft generate higher noise levels, these standards are also dependent on the number of engines. Over the years, new technologies were introduced such as improvements in fuel efficiency, development of engine reduction technologies and new airframe designs which led to enhancements of the aircraft noise performance [8]. Consequently, the ICAO regulations underwent a series of major updates and enforcements called Chapters which included the increase of the noise standards stringency.

Regarding the noise standards for supersonic aircraft, ICAO already set a specific working group named as Supersonic Task Group within the Landing and Take-off (LTO) subgroup which is currently working with industry and research institutes to develop noise standards and recommended practises (SARPs) for the airport environment as a result of the resurgence in commercial supersonic flight interest [9]. The need for these new Standards and Recommended Practices is based on ensuring the social acceptability for the next generation of supersonic aircraft since the Concorde project ignited a contentious discussion about the environmental effects of SST [10]. The high level of ambient noise near the airport environment was particularly one of the Concorde's most controversial and least accepted characteristics. For this reason, including pioneering technologies and flight procedures addressed to reduce noise, especially during take-off operations, is one of the fundamental tenets for the design of low-noise future supersonic aircraft [11]. Until specific requirements for supersonic aircraft are established by the aviation authorities, the common practice in the design of supersonic aircraft will be to target the same noise regulations set for subsonic aeroplanes during take-off.

Certification regulations use the Effective Perceived Noise Level (EPNL) at two reference measurement points for noise certification during take-off, which are illustrated in Fig. 1.

The flyover reference noise measurement point is the one positioned on the extended centre line of the runway at a distance of 6500 m from the start of roll. The lateral full-power reference noise measurement point is located on a line 450 m parallel to the runway centreline and it is determined as the point with the maximum Effective Perceived Noise Level along this side-line.

The maximum available thrust must be maintained until the standard thrust cutback altitude is reached in order to achieve certification. The cutback altitude depends on the number of engines, for an aircraft with two engines it is 300 metres above ground, for three engines it is 260 metres, and for four engines it is 210 metres. Additionally, there are specifications for the calibrated airspeed at take-off, which are defined in relation to the V_2 safe take-off speed according to the aircraft platform. In brief, right after take-off, the speed $V_2 + 10$ knots must be attained, and the speed $V_2 + 20$ knots must not be surpassed during the certification flight.

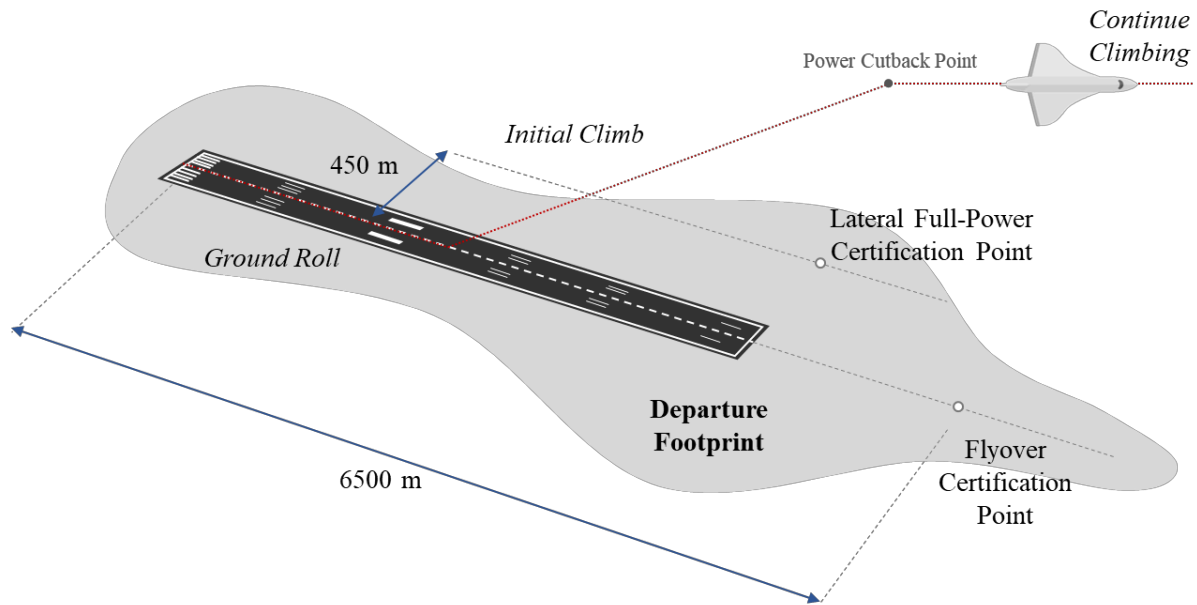


Fig. 1 Reference noise measurement points for noise certification and typical noise footprint.

Due to the engine design requirements of supersonic aircraft for cruise or climb, they have fundamentally excessive available thrust at take-off. To lower the noise levels in the vicinity of airports, particularly the certified noise levels at the reference points, a reduced thrust would be recommended after lift-off. The Programmed Lapse Rate concept (PLR) with automatic thrust variation of the engines controlled by the FADEC (Full Authority Digital Engine Control) makes this suggestion.

The Programmed Lapse Rate technique applied to supersonic platforms means that the propulsion system automatically controls the engines' output thrust by a certain percentage of the maximum thrust after clearing the take-off obstacle height and before the standard take-off cutback. When an aircraft flies around between 800 and 1000 feet above ground level (~245-305 m), side-line noise reaches its peak. However, in the most challenging side-line certification condition, this procedure decreases the noise levels considerably. Importantly, this additional thrust would be usable in an engine-out emergency situation, where the maximum thrust would be automatically restored to the functioning engines.

PLR can be thought of as a Variable Noise Reduction system (VNRS) that automatically reduces engine throttle after take-off after obstacle clearance and before the take-off cutback. Despite PLR not being allowed under the present subsonic noise certification standards, this concept has to be addressed as a noise suppression technique to be potentially implemented in the noise certification at the airport environment for supersonic aircraft. It must be taken into consideration that implementing a PLR profile during the climb-out phase will provide a benefit in side-line noise at the expense of a penalty on the flyover since lower altitudes will be reached when flying over this second noise measurement point [12]. Nevertheless, this penalty can be diminished, and potentially eliminated by employing higher climb-out speeds.

This Programmed Lapse Rate procedure is expected to be applied up to the standard cutback. It should be noted that the requirements to be met in order to perform this standard cutback are as follows. With respect to performance requisites, the cutback thrust level used is based on the required thrust to maintain a climb gradient of 4-percent. In addition, for one engine out conditions, the thrust level must be equal or greater than the required thrust to maintain 3-percent climb gradient until the altitude exceeds 400 ft [13]. With regard to the percentage of maximum thrust applied during the standard cutback, a recommended

reduced rate is determined by the engine manufacturer, being the industry average allowance a maximum of 25% thrust reduction.

Furthermore, reduced thrust profiles lowers the engine internal operating pressure and temperature resulting in a reduction in stress and wear on the engine, lower costs on components and maintenance, longer engine life and higher reliability, all of which improve operating safety and efficiency [14].

An illustration of the variation of thrust during a take-off reference path for noise certifications of subsonic and future supersonic aircraft is represented in the following figure. The PLR technique followed by the standard thrust cutback is applied for the supersonic platform.

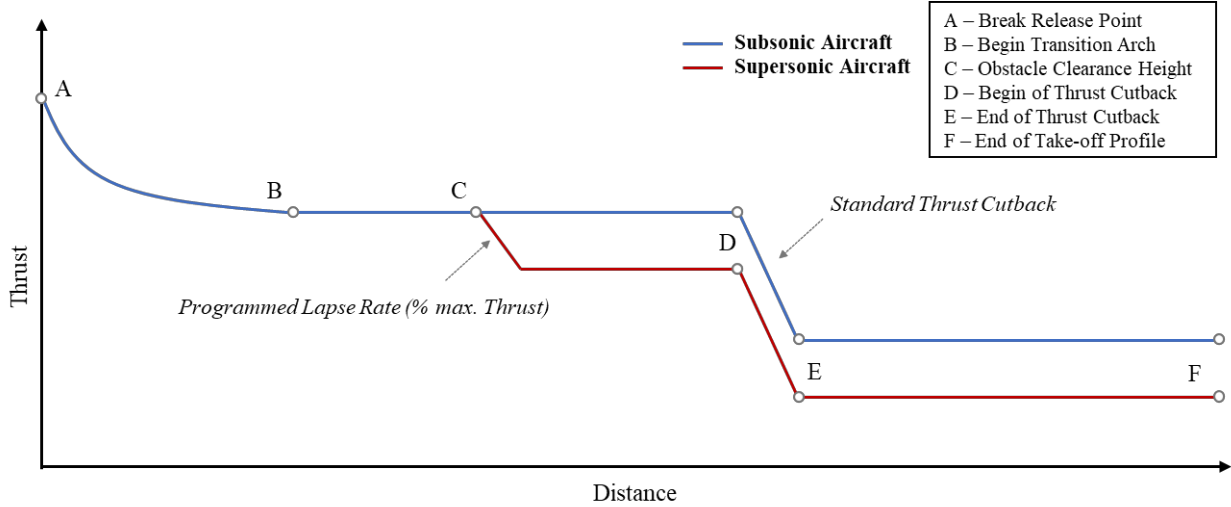


Fig. 2 Variation of thrust for a take-off reference flight path profile of commercial subsonic and future generation supersonic aircraft for noise certification.

Considering the above, the study undertaken in this paper first deals with the definition of multiple aircraft platforms in terms of engine number for a supersonic airliner which cruises at Mach 2.2. Secondly, a simplified take-off noise prediction method, that aims at assessing noise in the vicinity of airports from the beginning of the design process, will be applied to these civil supersonic aircraft. Moving take-off noise analyses to early stages of the design process is crucial to ensure that future supersonic aircraft will comply with low-noise regulations. For this purpose, this research focuses on the implementation of a methodology designed to forecast noise levels generated by different supersonic aircraft platforms during take-off operations. This method will therefore offer guidance for the take-off noise assessment of future supersonic aircraft that are still in the conceptual design stage. A comparative analysis between these aircraft platforms about how the design choices impact on the performance and noise results will be carried out. Lastly, the Programmed Lapse Rate concept will be applied for both platforms as a means to determine its potential advantages in noise reduction.

II. Aircraft Conceptual Design Environment

Multidisciplinary design analysis and optimisation plays a key role in the conceptual design studies of novel aircraft configurations. In order to design the baseline configuration to be used for a Mach 2.2 airframe-engine integrated design exploration and optimization, several steps have been followed and different tools have been implemented. The design process is described in this section, while the implementation of the framework methodologies is described in more detail in Section 3.

A schematic diagram of the design space is shown below, Fig. 3. The framework was created by linking different design modules, and by developing interfaces between external analysis software.

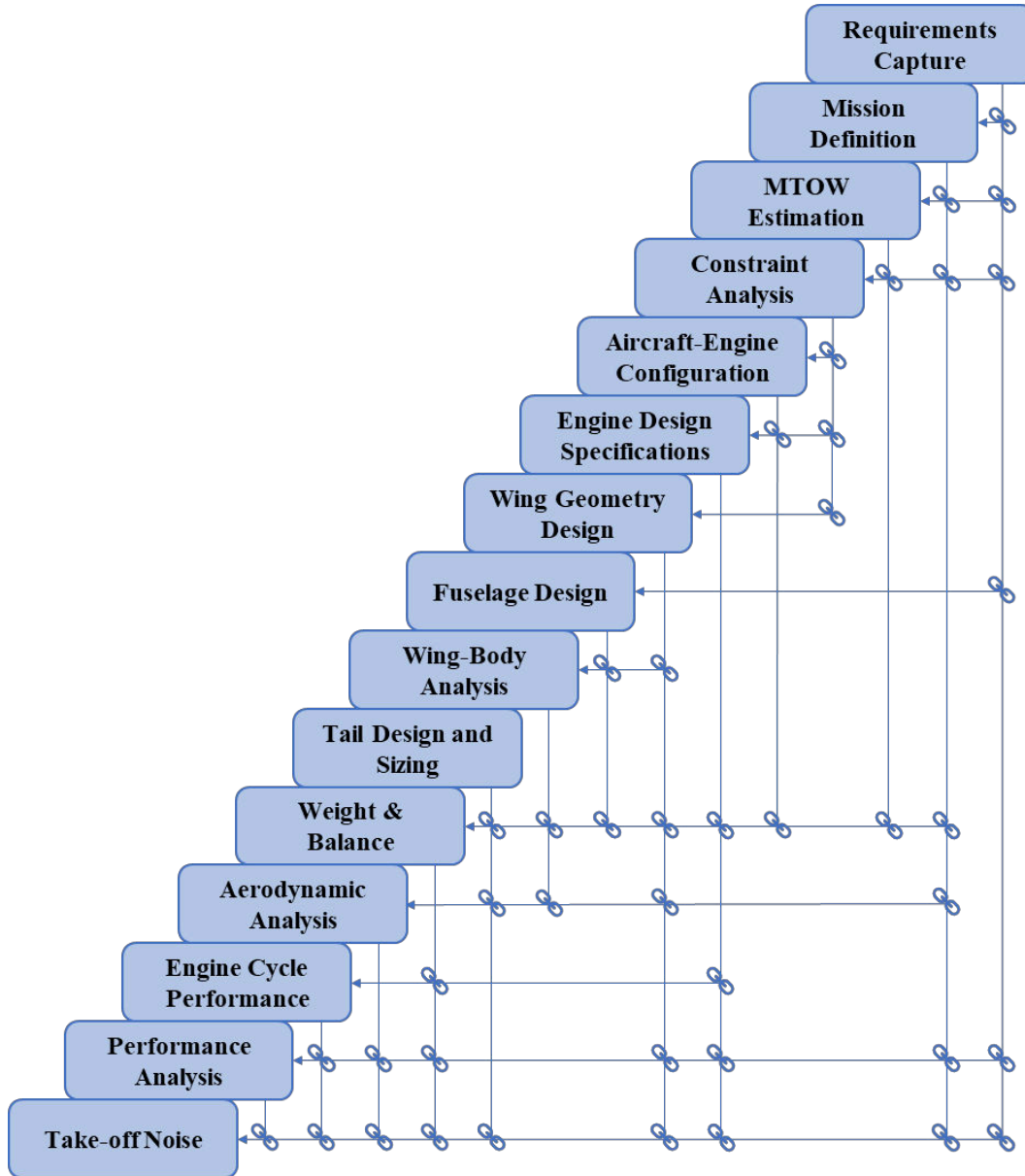


Fig. 3 Supersonic aircraft framework design and data link.

The general design requirements, or TLARs (Top Level Aircraft Requirements), such as range, cruise Mach number and number of passengers, comes from the SENECA project consortium, while other requirements regarding ground performance and environmental impact have been finalized after analyses and review of the major related works. City pairs of interest were analysed to ascertain runway lengths. This led to the setting of a field length requirement (see Table. 1). The routes of interest are illustrated in Fig. 4 as the potential city connections that the future supersonic transport aircraft will operate on.

The maximum cruise altitude was limited between 50000 ft and 60000 ft by both NO_x emissions considerations and cabin decompression limits (FAR-25.841), but it could also be restricted by separation criteria from subsonic traffic.

Concerning emissions and LTO noise requirements, since no specific regulations yet exist for supersonic aircraft, the most recent ICAO requirements that apply for subsonic aircraft has been selected as a reference. Assuming the possibility to fly supersonic overland, it is essential that the sonic boom signature generated by the aircraft be reduced to acceptable levels. Since there is still no agreement neither on what this tolerable level could be nor on which are the best metrics to evaluate boom annoyance, 0.5 psf of overpressure and 70 PLdB have been chosen as sonic boom targets.

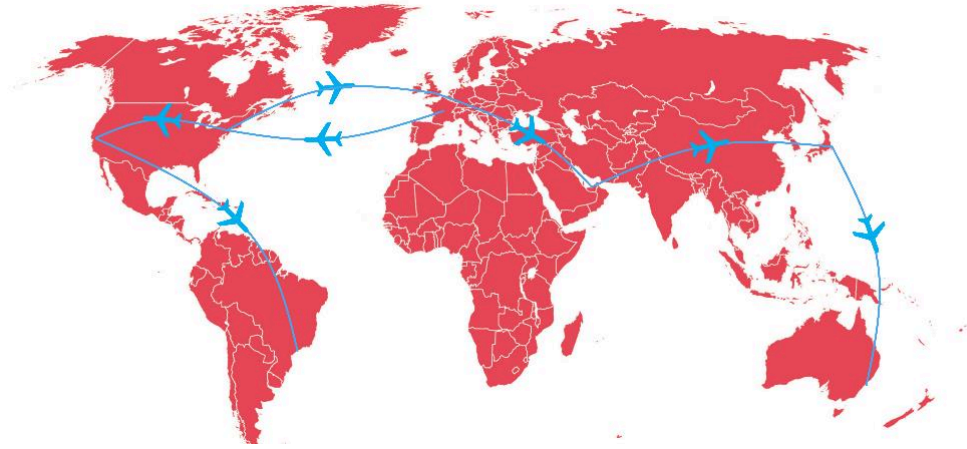


Fig. 4 Routes of interest (~ 4000 nm).

Table. 1 summaries the design requirements captured for the design of the airliner.

Table. 1 Design requirements captured for the supersonic airliner.

Requirement	Value (unit)
Range	4000 nm/ 7408 km
Pax	100
Mach	2.2
Take-Off and Landing Distance	<12000 ft / <3700 m
Max Altitude	50000-60000 ft / 15 -18 km
LTO Noise	ICAO Annex 16 Vol I – Chapter 14
Emissions	ICAO Annex 16 Vol II-III
Sonic Boom	< 0.5 psf & < 70 PLdB

For all the trade studies, a supersonic non-stop mission profile was used to determine the performance of each aircraft configuration. Also, an alternative profile involving subsonic cruise overland has also been taken into consideration, according to SENECA project mission definition.

The mission profile targeted is divided into the following flight phases: taxing stage, take-off, initial subsonic climb; which can include a constant altitude subsonic acceleration mid climb; constant altitude transonic acceleration at an appropriate altitude is followed in order to reach the supersonic flight regime and after this, a supersonic climb. Next, the cruise segment can be classified as two types: climbing cruise or cruise at constant altitude. The initial cruise altitude is the optimal altitude at which the cruise Mach number is reached after performing a supersonic climb. A climbing cruise would be carried out maintaining

constant cruise Mach number, up to the maximum cruise altitude selected which is constrained as mentioned before by both NOx emissions and cabin decompression limits. A constant altitude cruise would be performed at the maximum cruise altitude from the beginning if the optimal altitude at which the cruise Mach number is achieved is that same maximum altitude. Lastly, a descent and deceleration phase, followed by the landing is considered.

The alternative mission involving subsonic cruise includes a subsonic cruise at optimal altitude overland, follow by a transonic acceleration, supersonic climb to reach the optimal supersonic cruise altitude and a supersonic cruise overwater. The fuel reserves are based on a missed approach and a flight to an alternate airport 200 nm away, followed by 20 minutes loiter at 15000 ft and a landing at the alternate airport. The mission profiles described are shown in Fig. 5.

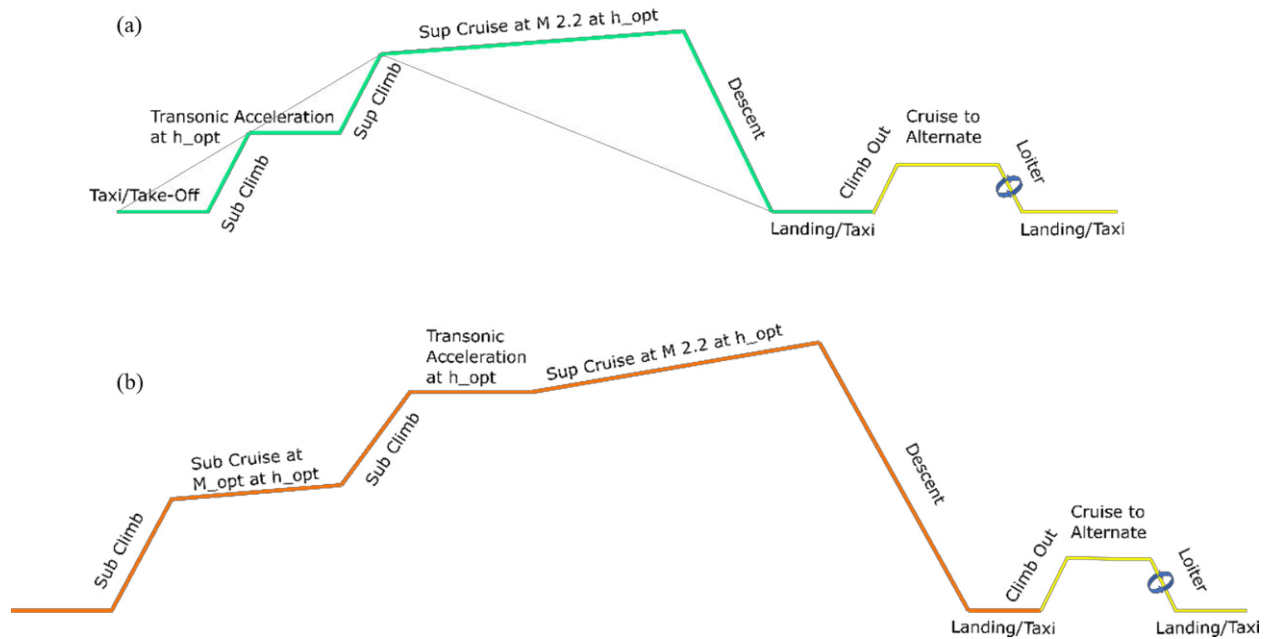


Fig. 5 Supersonic Non-Stop Mission Profile (a) and alternative mission profile including subsonic cruise overland (b).

III. Design Methodology

Designing innovative efficient aircraft platforms requires complex process that combines different analytical disciplines such as aerodynamics, structures, performance, and propulsion. Aircraft design can be divided into three major phases: conceptual, preliminary, and detailed. The conceptual design is crucial in the pursuance of a representative outcome. Requirements in terms of mission capabilities, including payload-range are set as an initial approach to start developing the conceptual design. Then this design is subjected to analytical calculations and the results obtained are used to optimise the model in future studies, which leads to a continuous modification of the design that contributes to the identification of the optimal design layout and nominal operating conditions.

This project pursues the development of a conceptual design methodology to model the next generation of supersonic transport aircraft. In this section, the methodologies and software implemented in the design framework are presented.

First, the **Maximum Take-off Weight Estimation**, is accomplished by the fuel-fraction method, a method for the preliminary weight estimation for a given mission specifications [15], [16], [17]. According to this methodology, an estimation of the weight of fuel needed can be obtained by the product of all the weight ratios (or fuel fractions) $W_{\text{final}}/W_{\text{initial}}$ of each phase in which the mission can be broken down, and then expressed in terms of the unknown MTOW. The phases' fuel fraction can be directly calculated by using Breguet equations, in case of cruise and loiter, but for the most part of the mission, it usually comes from statistics collected for similar existing airplanes [15].

Next, **Constraint Analysis** has been performed by implementing analytical equations. The conceptual design process of an aircraft commences with a constraint analysis to ensure all the performance requirements will be met. A constraint analysis simply translates the vehicle's performance requirements into functional relationships between thrust loading (T/W) and wing loading (W/S). The final outputs of this analysis, also counting on the estimation of the MTOW, are the wing area and the sea-level static thrust which will define the **Engine Design Specifications** for each **Aircraft-Engine Configuration**, by inputting the number of engines. For the supersonic airliner, the design should be sized for: take-off, landing, climb, supersonic cruise and transonic acceleration. The result is a carpet plot that defines the suitable design space in terms of T/W and W/S.

Once the initial requirements have been established, as discussed in the previous section and the constraint analysis has been performed, the airframe design is achieved as follows. Leading, **Wing Geometry**, once the wing area has been obtained, the geometry of the wing should be modelled. The objective of this module is to initially size the airframe configuration, to achieve this, Raymer's initial sizing methodology has been implemented [17]. Planform parameters such as aspect ratio, taper ratio, sweep angles and dihedral angles are selected in such a way the wing could ensure the generation of the required lift in all the flight phases while minimising drag. The wing design module also includes aerofoils selection and high-lift devices sizing. The resultant wing geometry is then analysed aerodynamically both at high and low speed flight regimes in the aerodynamics module. Last, the wing geometry has been modelled by using the AirCADia Environment [18]. As for the **Fuselage Design**, empirical methods and statistics from similar aircraft are used to achieve the fuselage design through implementation.

The last design module related to the airframe geometry is the **Tail Design and Sizing**, the method used to determine the initial estimation of the horizontal and vertical tails dimensions is called the "tail volume coefficient" model. For this approach, the tail moment arms, and tail volume coefficients must be estimated in order to obtain the first iteration of the tails area parameter. Note that the moment arm is typically calculated as the distance from the wing quarter-chord to the tail quarter-chord and it is usually given as a percentage of the fuselage length. The tail arm of an aeroplane with wing-mounted engines is roughly 50–55 percent of the fuselage length. The tail arm is roughly 45–50% of the fuselage length for engines that are positioned aft. Regarding the volume coefficients values, typical values for tail volume coefficients are provided for different types of aircraft based on historical data.

This methodology will offer an initial estimation of the tails sizing so as to compute the mass and centre of gravity assessment. Once the balance estimation is done; the tail parameters will be determined from the stability and control requirements. The tail geometry has been also modelled in AirCADia[18].

For the **Weight and Balance** module, three different methodologies will be implemented to calculate the mass breakdown: Raymer's Aircraft Statistical Weights method [17], Roskam's Class II Method for Estimating Component Weight [15], and Cranfield University Aerospace Vehicle Design Aircraft Mass Prediction method based on Howe's Mass Prediction method [19]. It is convenient to use several different methods to calculate the weight of each component since making an average of them will come of more representative results. The three methodologies mentioned above have a statistical basis, that is based on an enormous historical database. Equations based upon advanced regression analysis will be applied, providing a detailed estimation of the major component groups' weights. The equations of the three methodologies implemented in this module can be found in Raymer's Chapter 15: Weights - Aircraft

Statistical Weights Method [17], Roskam's Part V: Component Weight Estimation – Class II Method [15] and Cranfield University Aerospace Vehicle Design Aircraft Mass Prediction method [19]. As new technologies are introduced in aircraft design, it becomes necessary to include a correction factor adjustment since the equations presented by the methodologies mentioned above are not suitable for every aircraft configuration. Then, the final component weights will be the result of the statistical equations calculations multiply by a series of correction factors.

Finally, the mass breakdown was also computed in NASA tool FLOPS (Flight Optimization Systems), since its built-in weight estimation module is known to be of high fidelity as a substantial amount of effort went into its development by the Aeronautics Systems Analysis Branch at NASA Langley Research Centre [20]. The FLOPS weights module predicts the weight of each element in a group weight statement using statistical and empirical equations. This will allow the cross-checking of the results and hence will increase drastically the reliability of the results.

Concerning the *Aerodynamic Analysis*, for the lifting surfaces a routine has been implemented to export the tessellation of the geometry modelled in AirCADia to a PANAIR geometry input file format. PANAIR [21] (panel aerodynamics) is a computer program developed to predict inviscid subsonic and supersonic flows about an arbitrary configuration by means of a higher order panel method. PANAIR has been used to calculate wing and tail lift and induced drag coefficients. Parasite drag and wave drag have been calculated by using the Form Factor method [22] and the supersonic area rule [23]. Wing-body configuration aerodynamic analyses are also carried out by using PANAIR. In addition, the aerodynamic analysis results have been validated by means of analytical equations which provide a range of parameters' values, in terms of lift coefficient, drag coefficient and aerodynamic efficiency. This battery of values is calculated depending on the angle of attack for subsonic flight regime and a set of values depending on the Mach number for supersonic flight regime, thus providing an aerodynamic study of the design for numerous flight configurations. The methodology implemented to pursue the aim of this validation is the one presented in "Introduction to Aeronautics: A Design Perspective" by Steven A. Brandt [24].

Regarding *Engine Cycle Performance* and *Mission Performance Analysis*, both the vehicle performance and the engine cycle performance are analysed using the NASA tool FLOPS (Flight Optimization Systems) [20]. For rapid conceptual aircraft design and advanced technology impact analyses, FLOPS was developed. It is a multidisciplinary system of computer programs for conceptual and preliminary design which includes weight estimation, aerodynamics estimation, engine cycle analysis, scaling and interpolation of propulsion data, detailed mission performance analysis, take-off and landing performance analysis, noise footprint estimation, and cost analysis. It is extensively used as a starting point and common factor in studies of aircraft design. FLOPS is effective for both new aircraft design development and modifications to current aircraft. Karl Geiselhart [25] developed the engine cycle analysis module, which is based on the QNEP programme [26], a modified version of NEPCOMP [27] and its successors. The engine cycle definition includes thrust and fuel flow data for multiple Mach-altitude conditions. This methodology can be applied for turbojets, turboprops, mixed flow turbofans, separate flow turbofans, and turbine bypass engines.

The engine deck obtained as output of the engine cycle analysis module is implemented in the propulsion data scaling and interpolation module [28]. This FLOPS propulsion design space fills any missing data and scales the engine data to the desired thrust using linear or nonlinear scaling equations. Any propulsion information required by the mission performance module, or the take-off and landing module is then provided.

As for the mission performance module, the derived weights, aerodynamics, and propulsion system data are used to determine the performance outcome. The optimum climb profiles are predicted with respect to energy considerations while the cruise phase may be performed at the optimal altitude and Mach number while satisfying the selected optimisation requirement such as maximum range or endurance or to minimize NOx emissions [28]. Descent may be flown at the optimum lift-drag ratio. For take-off and landing profiles

computation, the following parameters are obtained all-engine take-off field length, the balanced field length including one-engine-out take-off and aborted take-off, and the landing field length. Detailed take-off and climb out profiles can be generated in the mission performance module so as to be afterwards used in the noise footprint module to predict the noise levels at the certification locations.

The last module, part of the design space, is *Take-Off Noise Estimation*, take-off noise assessment will be carried out in the noise calculations part of the software FLOPS [20]. All the noise sources will be included in the overall take-off noise evaluation, each source contribution will be computed following different models according to the individual component. The noise sources included are jet noise, fan/compressor noise, combustor noise, turbine noise and airframe noise which includes the contribution to the overall noise coming from the flaps, slats, wing, horizontal tail, vertical tail, nose landing gear and main landing gear. For the jet noise, the empirical Stone 2 jet-noise prediction method [29] is implemented as it is the closest to agreeing with existing flight data. For the fan/compressor noise contribution, the fan noise prediction method is based on the empirical formulation of fan data derived by Gliebe [30]. As for the turbine noise, the prediction method adopted is based on the method recommended by Krejsa and Valerino [31]. For the burner noise, the method implemented was developed by the SAE ARP876 [32]. The airframe noise prediction model is based on Fink's method [33]. With the aim of carrying out an engine noise shielding assessment during early design stages, a simple method is applied (Maekawa method) which predicts noise shielding effects based on wing-fuselage planform and engine locations [34].

IV. Aircraft Platforms Definition

The conceptual design process of an aircraft typically commences with a constraint analysis to ensure all the performance requirements will be met. After computing a first estimation of the maximum take-off weight by the means of empirical methods, the outputs of the constraint analysis will be the sea-level static thrust and the wing area. The design point selected remains the same for all the airframe-engine configurations and it is shown in blue in Fig. 6 and results such total thrust, thrust per engine, thrust to weight ratio and wing area are presented in Table. 2.

As reference the Concorde design point has been also included in the graph. The production airliner Concorde was propelled by four Olympus 593 engines and together produced 677000 N/152200 lbs. Its maximum take-off weight equals to 185065 kg/408000 lbs. As it is shown in the following figure, the Concorde design point is found at 0.372 thrust to weight ratio and 530 kg/m² or 106 psf wing loading.

Table. 2 Maximum Take-Off Weight, Sea-Level Static Thrust and Wing Area.

Parameter	Value
MTOW	156492 kg / 345000 lb
Total Thrust	667794 N / 150120 lbf
Thrust per Engine (Twinjet)	333897 N / 75000 lbf
Thrust per Engine (Trijet)	222598 N / 50000 lbf
Thrust per Engine (Quad jet)	166948 N / 37500 lbf
Wing Area	267.38 m ² / 2878 ft ²
Wing Loading	585.6 kg/m ² / 120 psf
Thrust to Weight Ratio (T/W)	0.435

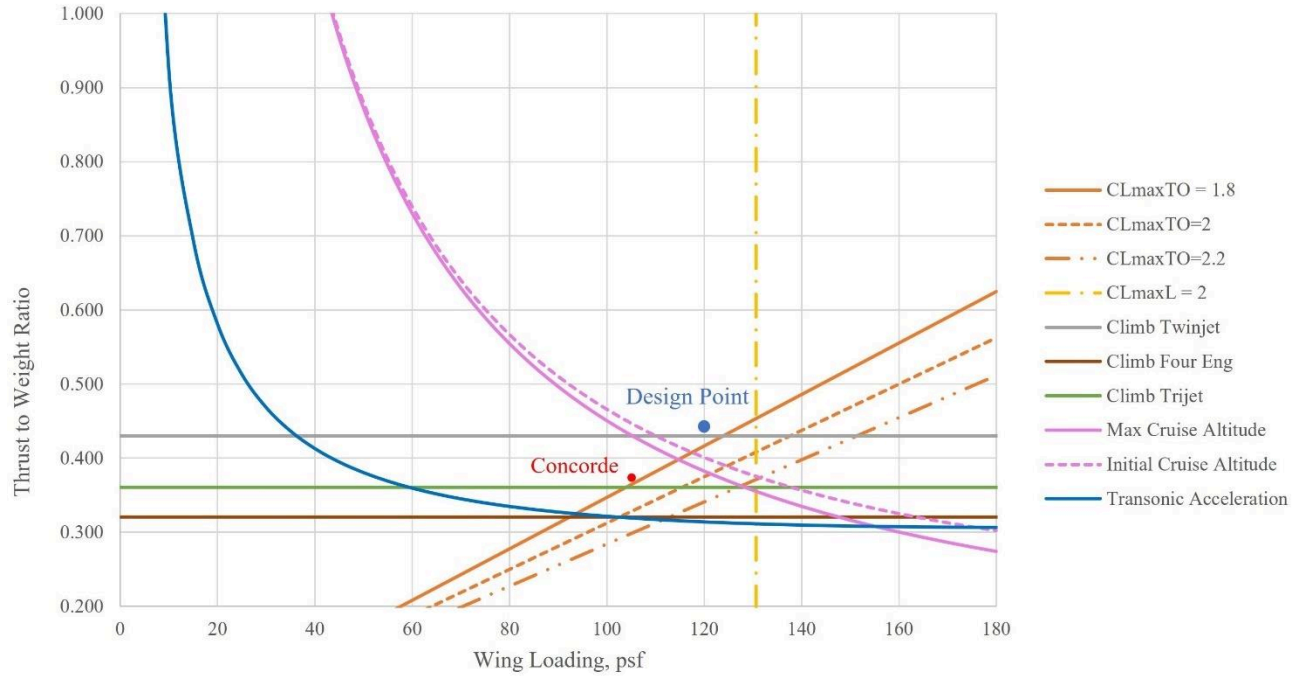


Fig. 6 Constraint analysis for the different supersonic airliner configurations.

Results for the twinjet, trijet and quad jet configuration, have been obtained and analysed. The twinjet platform presents concerns in terms of engine sizing, as the design requirement to reach 50000 ft altitude at cruise Mach 2.2 demands a greater thrust per engine than the usual in transport aircraft. Therefore, the manufacturing and cost efficiency limitations makes the twinjet configuration a non-suitable platform for this application. Even if an engine that generates the thrust need would be designed, the weight will exceed the engine mass expectations for the corresponding designed airframe and the 4000 nm range required will not be met. Once the wing area has been obtained, the wing geometry has been modelled in AirCADia [18], the wing planform model can be seen in Fig. 7, aerofoils have been selected and a first aerodynamic analysis has been performed for assumed cruise conditions as it the most demanding flight phase.

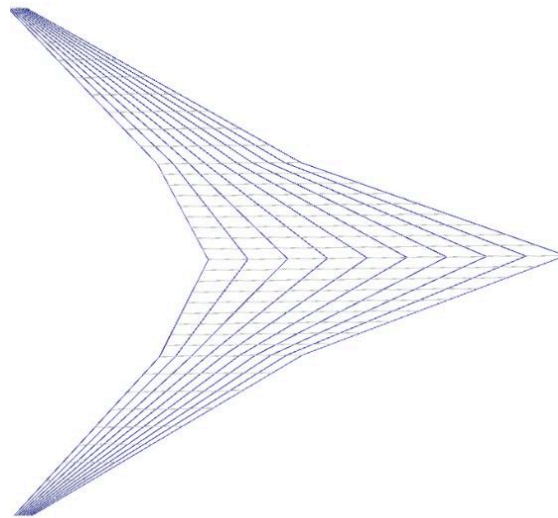


Fig. 7 Wing planform geometry modelled in AirCADia environment.

Results from PANAIR analysis are shown in Fig. 8, along with the C_L target value calculated from an estimate of average weight in cruise. As it can be seen, the wing is able to achieve the target lift coefficient with low incidence angle (3 degrees), with low drag generation and with nearly maximum aerodynamic efficiency. The drag polar has been built by adding wave and parasitic drag to the lift induced drag obtained from a PANAIR calculation [21].

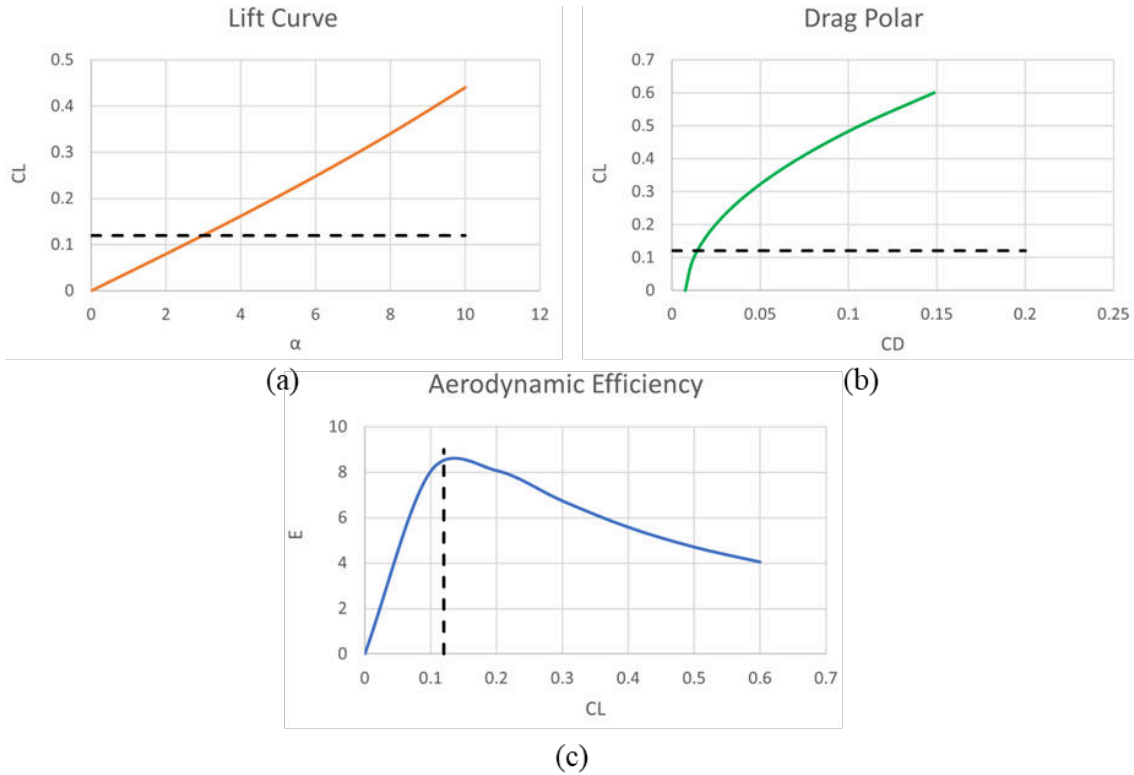


Fig. 8 Wing Lift (a), Drag (b) and Efficiency (c) during cruise condition.

The definition of the supersonic airliner platforms conceptual design for the trijet and the quad jet configurations are presented below in terms of airframe geometrical data. This comprises a simplified surface CAD model and main dimensions, shown in Table. 3. The following information presented herein provides a first iteration of the vehicle configuration, subject to change in future stages of the preliminary and detailed design of the aircraft platforms. It must be noted that the nacelles have been sketched only as a reference as a detailed design of the nacelle geometry has not been carried out at this point.

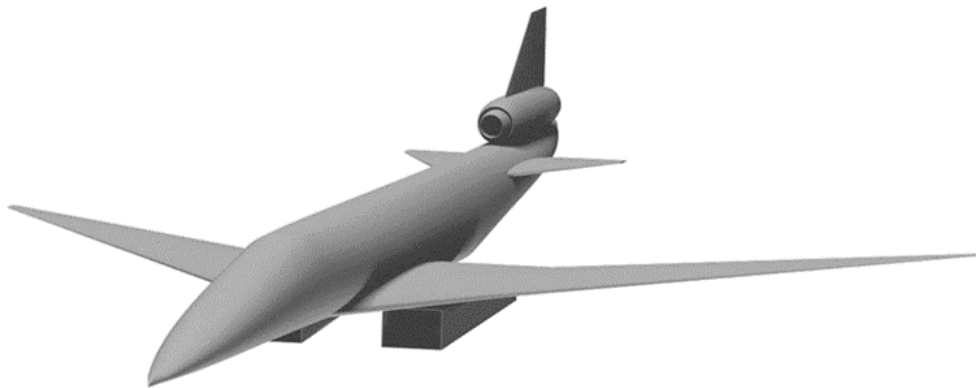


Fig. 9 Perspective view of the M2.2 Airliner Platform: trijet configuration.



Fig. 10 Perspective view of the M2.2 Airliner Platform: four engine configuration.

The technical data related to the M2.2 airliner airframe geometry is displayed in the following table.

Table. 3 Reference airframe dimensions from M2.2 Airliner.

Dimensions	Value (m)
Wingspan	31.4
Horizontal Tail Span	7.3
Vertical Tail Span	6
Fuselage Width	3.3
Fuselage Length	58.9
Wing Longitudinal Apex Position	19.8
Horizontal Tail Longitudinal Apex Position	45
Vertical Tail Longitudinal Apex Position	49
Wing Vertical Apex Position	0.3
Horizontal Tail Vertical Apex Position	2.6
Vertical Tail Vertical Apex Position	4.3

V. Mass Breakdown, Engine Cycle Performance and Mission Performance Results

This chapter reports the conceptual design results in terms of weights, aerodynamics, propulsion data, mission definition and mission thrust profile. In respect of the mass breakdown, a comparison between the results obtained through Raymer's [17], Roskam's [15] and Howe's [19] empirical methods and the outputs calculated by FLOPS has been carried out, finally the mass breakdown results selected are the ones obtained through FLOPS as the other three methodologies offer overestimated and inaccurate values due to the lack of reference supersonic commercial aircraft. Table. 4 shows the mass breakdown of the major components and airframe systems computed by FLOPS [28] with which the design analysis is continued. The gross (ramp) weight was specified as 345000 lb (156489.24 kg). Empirical computational models (based on NASA FLOPS) were employed for estimating the mass breakdown.

Table. 4 Mass breakdown for the Trijet Configuration and the Four Engine Configuration.

Components	Trijet Configuration		Four Engine Configuration	
	Mass [kg]	Percentage [%]	Mass [kg]	Percentage [%]
Wing	15802.24	10.1	15802.24	10.1
Horizontal Tail	730.74	0.47	730.74	0.47
Vertical Tail	728.02	0.47	728.02	0.47
Fuselage	10097.41	6.45	10097.41	6.45
Landing Gear	5885.81	3.76	5885.81	3.76
Structures Total	33244.21	21.24	33244.21	21.24
Engines	12370.81	7.91	12370.81	7.91
Thrust Reversers	0	0	0.00	0
Misc. Systems	0	0	0.00	0
Fuel System	762.03	0.49	862.73	0.55
Propulsion Total	13132.85	8.39	13233.09	8.46
Surface Controls	2014.86	1.29	2014.86	1.29
Auxiliary Power Unit	402.79	0.26	402.79	0.26
Instruments	492.15	0.31	505.76	0.32
Hydraulics System	957.08	0.61	965.70	0.62
Electrical System	1285.03	0.82	1567.16	1
Avionics	743.89	0.48	743.89	0.48
Furnishings and Equipment	6538.98	4.18	6538.98	4.18
Environmental Control system	1849.75	1.18	1849.75	1.18
Anti-Icing and De-icing System	161.48	0.1	168.74	0.11
Systems and Equipment Total	14446.45	9.23	14757.62	9.43
Empty Weight	60823.51	38.87	61234.92	39.13
Flight Crew and Baggage	204.12	0.13	204.12	0.13
Cabin Crew and Baggage	210.92	0.13	210.92	0.13
Unusable Fuel	404.60	0.26	439.98	0.28
Engine Oil	126.55	0.08	139.71	0.09
Passenger Services	673.13	0.43	673.13	0.43
Cargo Containers	396.89	0.25	396.89	0.25
Operating Empty Weight	62839.27	40.16	63300.12	40.45
Passengers (99)	7409.43	4.73	7409.43	4.73
Passengers Baggage	1975.85	1.26	1975.85	1.26
Cargo	0.00	0	0.00	0
Zero Fuel Weight	72224.55	46.15	72685.40	46.45
Mission Fuel	84264.69	53.85	83803.84	53.55
Gross (Ramp) Weight	156489.24	100	156489.24	100

As shown in the table above, the structural total weight is identical for both configuration since the airframe design remains the same. Regarding the propulsion system mass breakdown, the engine mass does not vary given that the total thrust is fixed for both configurations as the engine mass estimation is directly

proportional to the required installed thrust, following the empirical methods applied. The systems and equipment total weight is slightly higher for the quad jet configuration due to the extra engine. Lastly, to meet the selected design point requirements for both configurations, the required gross ramp weight is equal. Consequently, there will be a difference in the mission fuel which will impact in the total range achieved in both cases as it will be shown in the mission results below.

Fig. 11 presents the high-speed drag polar for different Mach numbers (at altitude = 50000 ft). The method employed for computing the complete drag polar is based on NASA FLOPS, which is a mid-fidelity empirical drag estimation method. The conclusion for the aerodynamic outcome represented in the graphs below is that both configurations offer similar aerodynamic performance, as it was expected considering that the only differences in drag contribution come from the contrasting engine layouts. For the three-engine configuration, the maximum aerodynamic efficiency during cruise at 50000 ft altitude and Mach 2.2 is 7.04 for a lift coefficient of 0.14, this point corresponds to the top of climb or start of the cruise segment. In the case of the four-engine design, under the same conditions, the maximum lift to drag ratio is 6.9 for a lift coefficient of 0.135 which it is also attained at the top of climb point or start of cruise.

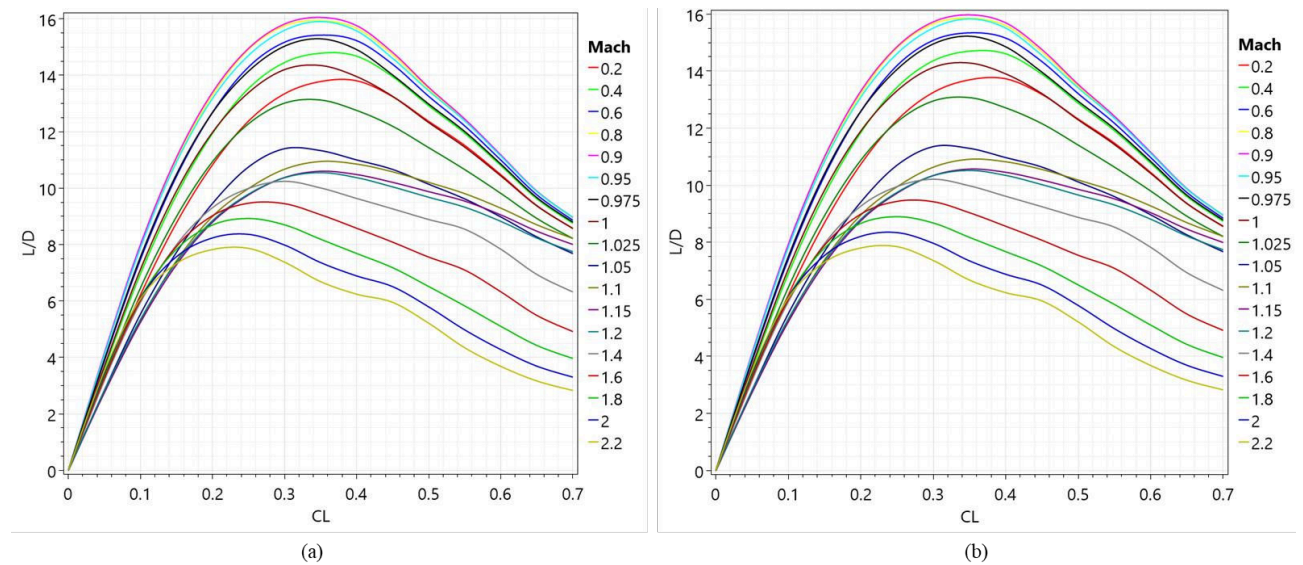


Fig. 11 High speed drag polar (lift over drag ratio vs lift coefficient) for trijet configuration (a) and for quad jet configuration (b).

Fig. 12 and Fig. 13 illustrate the variations of thrust with respect to Mach number and altitude, respectively, where the y axis refers to thrust per engine. The engine cycle performance deck was obtained through FLOPS. No remarkable differences must be stated regarding the engine performance apart from the difference in thrust per engine for each configuration. As the total thrust remains constant for both platforms design alternatives, the thrust per engine decreases with the number of engines.

The engine architecture selected for both configurations is a mixed flow turbofan. For a supersonic aircraft design the selection of the engine type must be made taking into consideration the top-level requirements, especially environmental limitations. In order to minimise the noise emitted by the engine while complying with desired features such as fuel and cost efficiencies, a mixed-flow turbofan offers the best compromise.

As previously mentioned, the engine deck for both configurations has been computed by using FLOPS. This software has the capability to use oxides of nitrogen (NOx) emissions evaluation in the conceptual and preliminary design stage. The mission performance module alongside the engine cycle performance ensure the compliance of the engine design with ICAO Annex 16 Vol II-III [35], [36].

In the assessment module of mission performance, the cruise profiles have been optimised not only to minimise fuel but also to minimise NOx emissions. Then, the engine cycle analysis module has been upgraded to provide the required emissions index.

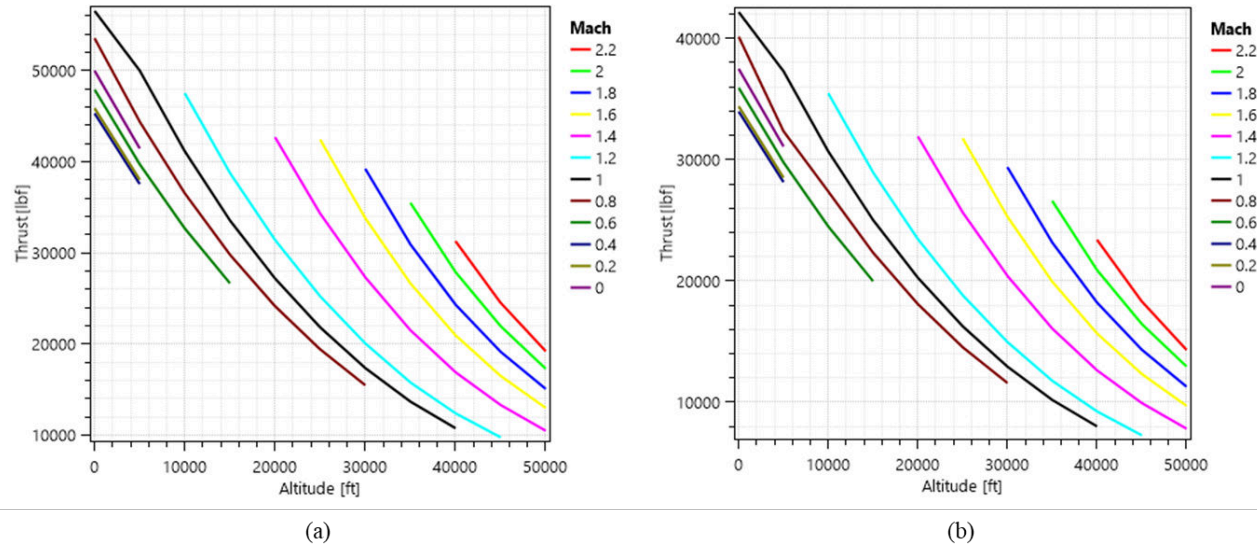


Fig. 12 Variation of thrust with respect to Mach number for trijet configuration (a) and quad jet configuration (b).

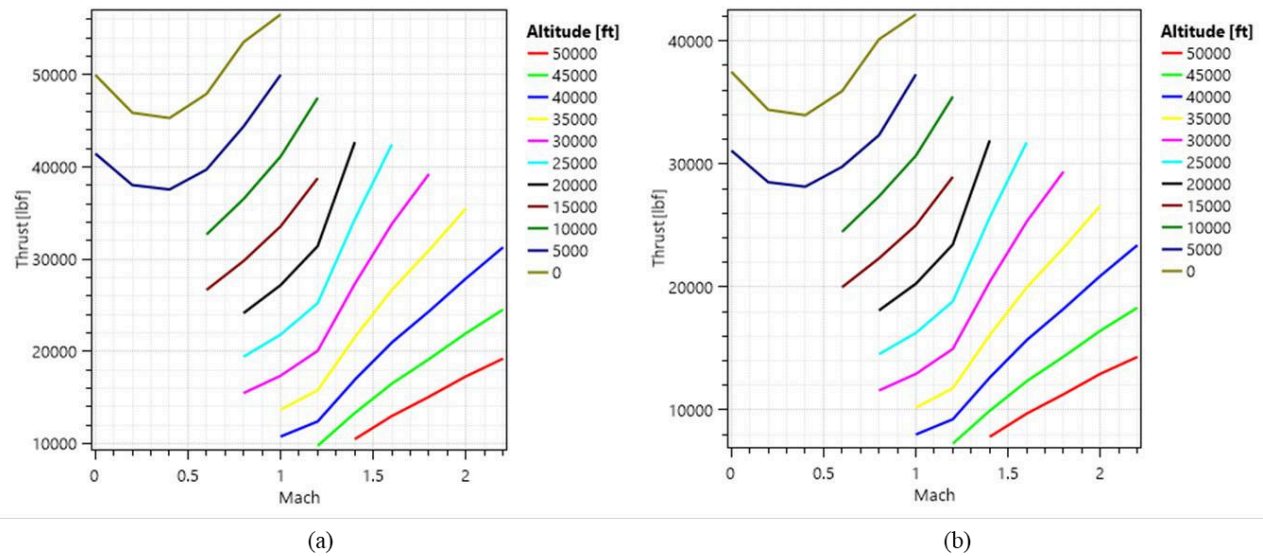


Fig. 13 Variation of thrust with respect to altitude for trijet configuration (a) and quad jet configuration (b).

The simplified design mission for the Mach 2.2 Airliner is shown in Fig. 14 Design mission for M2.2 Airliner. The mission analysis was performed for cruise Mach number of 2.2. The mission profile implemented is comprised of the following flight phases: taxiing, take-off, initial climb (including a thrust reduction to cutback power), followed by a constant altitude subsonic acceleration mid subsonic climb, final subsonic climb, constant altitude transonic acceleration, supersonic climb and finally cruise at 50000 ft (constant altitude) and Mach 2.2, to finish with the descent and landing. Both subsonic and transonic acceleration occur at the applicable altitude to ensure that the climb profile is optimised by meeting the condition of minimum time to climb with the aim of reaching the supersonic regime and its corresponding altitude in the shortest amount of time.

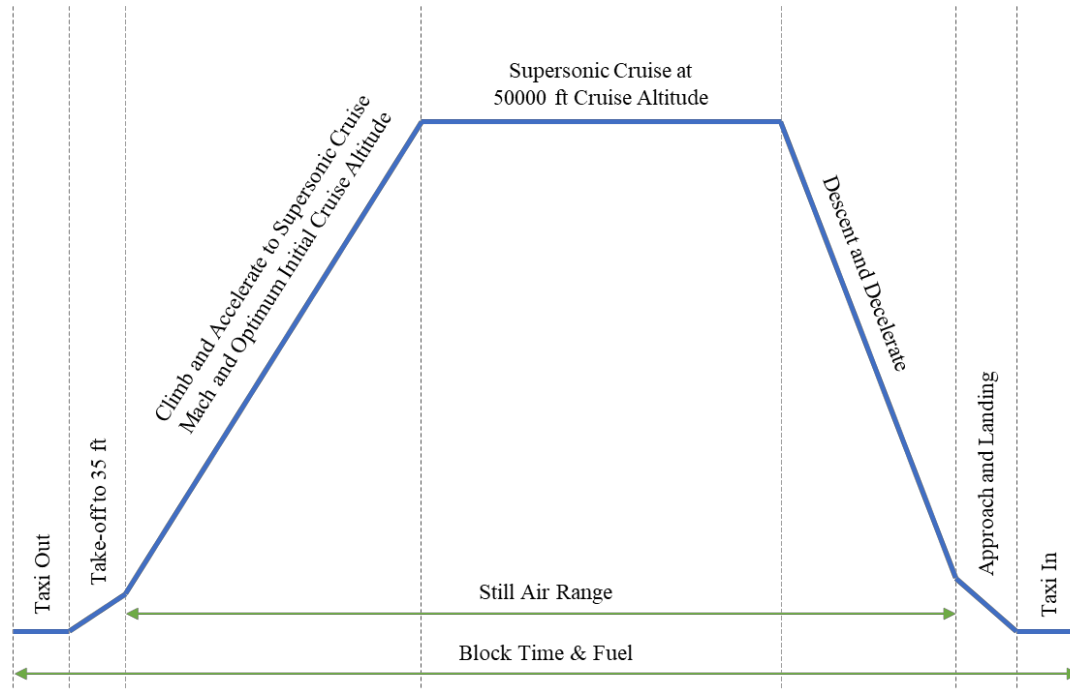


Fig. 14 Design mission for M2.2 Airliner.

By comparing the mission performance results obtained for each configuration, the following conclusions must be highlighted for the three mission key parameters: block time, mission fuel and range.

The block time to complete the mission is the same for both cases taking a total of 3 hrs 58 min. In the quad jet design, the extra engine increases the empty weight due to the miscellaneous systems and components necessary to operate the fourth engine. As a consequence of the maximum take-off weight for both aircraft being a fixed parameter in order to maintain the same design point, in the four-engine configuration there is a lesser allowance for fuel weight. For the trijet the consumed fuel is a total of 84264.7 kg while for the quad jet is 83803.8 kg. This fuel penalty impacts on the achievable range totalling 4044.6 nautical miles for the trijet and 3992.4 nm for the quad jet.

Fig. 15 presents the thrust profile of the three main segments (climb, cruise, and descent), which contains performance results at the discrete points of the complete mission. These thrust profiles will be the ones implemented in the noise calculations where results are shown in the following section. The thrust profiles for the tri and quad jet configurations are very similar, as expected, since the same mission profile is a requirement to be met by both configurations. A difference is apparent in the transonic acceleration phase where the required total thrust is lower for the quad jet configuration at the initial and final point of this acceleration.

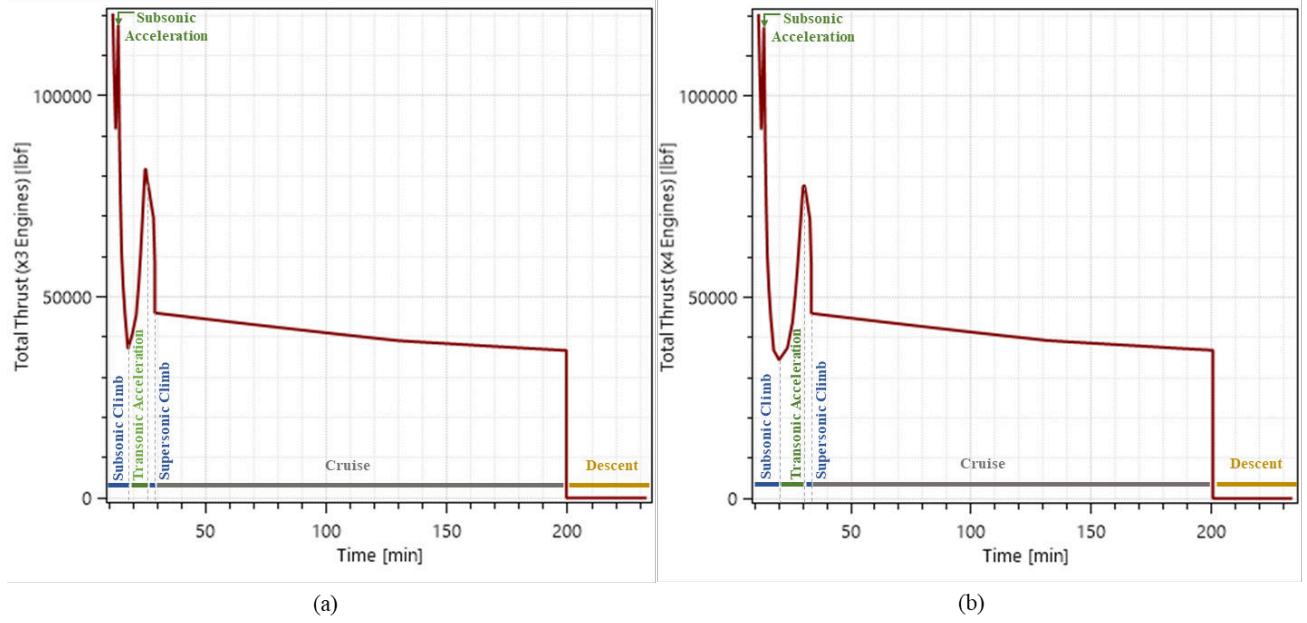


Fig. 15 Mission thrust profile (climb, cruise, and descent segments) for trijet configuration (a) and quad jet configuration (b).

VI. Noise Footprint Estimation Results

A. Noise Assessment Introduction

Aircraft have two main noise sources: engine and airframe. Engine noise is composed of the noise generated by its different components such as jet, compressor, combustor, and turbine. It should be noted that the increase of the by-pass ratio of contemporary turbo fan engines has led to a reduction of the noise levels [37]. On the other hand, airframe noise is a combination of the noise mainly coming from the landing gear and high lift devices. Noise levels emitted by the wing, horizontal tail and vertical tail can be also included. Due to unstable aerodynamic phenomena like vortex recirculation, free shear layer vortex flow reattachment, and tone noise caused by edge scattering, high lift devices are significantly involved in noise generation mechanisms [38].

In this chapter, all the noise sources are included in the overall take-off noise prediction, each source contribution is computed following different models according to the individual elements as previously mentioned in the methodology chapter. The overall noise as well as the individual noise contributions of each source are calculated at the two reference noise measurements point during take-off: flyover and side-line. These results are illustrated in the spider charts given in Fig. 16 and Fig. 17 for each aircraft configuration, which allows the pursuance of the comparative analysis.

To evaluate the loudness or annoyance of any level of noise on the human hearing system, a noise metric must be selected. Different aviation organisations, countries, and airports use a variety of noise measurements metrics [39]. Effective perceived noise in decibels (EPNdB) is a measurement of human annoyance to aircraft noise, which has unique spectral properties and a persistent soundscape. It takes into account how people react to the spectral structure, intensity, tonal content, and duration of aircraft noise [40]. Effective Perceived Noise Level (EPNL) are regarded as annoyance-based [41]. EPNL has been found to be more reliable for the assessment of heavy jet-powered aircraft noise because annoyance-based metrics are more sensitive to the spectral shape and tone content of the sound [42]. Therefore, the EPNL metric is used for the present noise assessment as it is the one implemented for noise certification of commercial airplanes.

B. Comparative Analysis between Trijet and Quad Jet Configurations

The predicted EPNL for the individual noise components at standard departure (jet, fan, combustor, turbine and airframe) of each airframe-engine configuration is depicted in Fig. 16.

The following difference in noise source ranking can be identified for both aircraft platforms. Jet noise is the dominant source for the two noise certification reference points in both cases. The noise generated by each source is of similar magnitude for both platforms. At the flyover location, the noise contributions ranking from highest to lowest is jet, airframe, combustor, turbine and fan. The side-line point ranking from highest to lowest is jet, combustor, airframe, turbine and fan. A reduction in jet noise influence can be seen during flyover due to the standard reduced thrust setting (thrust cutback) and the resulting reduction in jet exhaust velocity.

As a consequence of designing the aircraft to be suitable for supersonic cruise flight, the wing area and aerofoil forms vary considerably when compared to subsonic aircraft designs. The most common difference is the implementation of the delta wing shape, which deteriorates the aircraft performance during low-speed regimes. In conjunction with this, the use of slim supersonic aerofoils furthermore decreases the aircraft capabilities during subsonic phases. This type of aerofoil also makes the installation of the high lift devices more complex. All these factors result in adverse impacts on the airframe take-off noise which is significantly higher for this supersonic design than for a typical subsonic wing platform.

It should be noted that the engine number parameter barely impacts on the noise levels since the total thrust remains the same and the airframe design used for both configurations is identical. Despite the fact that the engines for the quad jet platform are of smaller size as the thrust per engine is lower, the extra engine offsets the improvement in noise levels per engine. The difference in the fan noise level between the two configurations has to be raised for further investigation with the SENECA partners who will be designing in detail the engine geometry as part of a further aircraft design iteration.

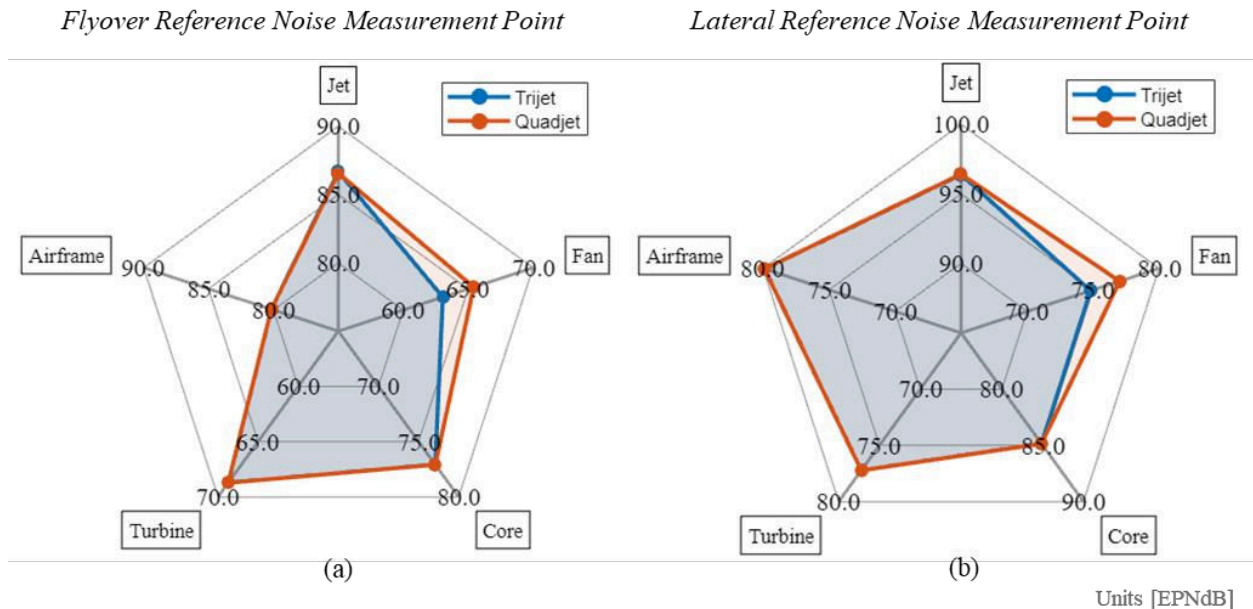


Fig. 16 Predicted EPNL at flyover measurement point (a) and at lateral measurement point (b) for the individual noise components of trijet and quad jet configuration.

The estimated EPNL values for the overall noise at the two certification locations are represented in Fig. 17 alongside the mission performance results in terms of range and block fuel for both aircraft design configurations for comparative purposes.

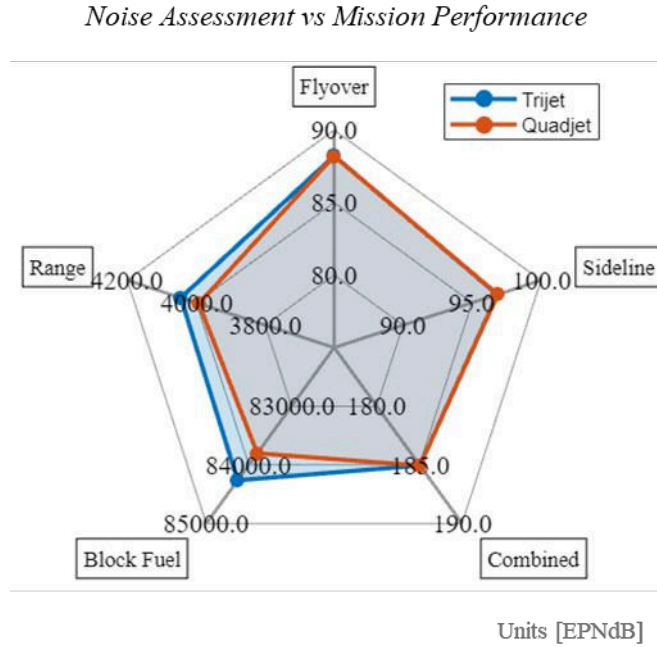


Fig. 17 Overall noise assessment at the departure measurement points vs mission performance.

The predicted EPNL values for the overall noise are now contrasted with the noise restrictions that have been established at each certification point in accordance with ICAO Annex 16's Noise Chapters [8] and the proposed FAA regulations [43], as shown in Table. 5 for the trijet and quad jet configuration.

Certification Point	Trijet Configuration					Units
	Predicted EPNL	FAR 36 Limits	ICAO Chapter 3 Limit	ICAO Chapter 4 Limit	ICAO Chapter 14 Limit	
Flyover	88.2	98.8	98.8	98.8	97.8	EPNdB
Lateral Full Power	96.8	99.5	99.6	99.6	98.6	EPNdB

Certification Point	Quad Jet Configuration					Units
	Predicted EPNL	FAR 36 Limits	ICAO Chapter 3 Limit	ICAO Chapter 4 Limit	ICAO Chapter 14 Limit	
Flyover	88.2	100.8	100.8	100.8	99.8	EPNdB
Lateral Full Power	96.9	99.5	99.6	99.6	98.6	EPNdB

Table. 5 Simulated noise levels at departure certification measurement points for trijet and quad jet configuration. Limits of individual measurement points from ICAO Annex 16 and FAA FAR 36.

At the departure certification points, the defined noise limitations of FAA and ICAO are not exceeded by any of the configurations. Regarding the ICAO regulations, Chapter 3 was introduced in 1977 and established new noise limits at each of the measurement points. The Chapter 4 became applicable in 2006 and it maintains the Chapter 3 limitations at the different certification points. While the latest standard, Chapter 14, released in 2013, requires at least 1 EPNdB margin at each measurement point in comparison to the Chapter 3 limits [8]. At the flyover reference noise location, the trijet configuration overall noise is 10.6 EPNdB lower than the constraint in accordance with the FAA and 9.6 EPNdB lower than the ICAO regulations while the quad jet configuration noise emitted is 12.6 EPNdB lower with respect to the FAA limits and 11.6 EPNdB lower when compared to the ICAO limitations. The beneficial margin in the noise predictions at this certification point in comparison with the limits dictated by the regulations is due to the implementation of the standard thrust cutback during take-off. At the lateral full power point, the trijet configuration overall noise is 2.7 EPNdB lower than the constraint in accordance with the FAA and 1.8 EPNdB lower than the ICAO regulations while the quad jet configuration noise emitted is 2.6 EPNdB lower with respect to the FAA limits and 1.7 EPNdB lower when compared to the ICAO limitations.

The results show compliance with the noise regulation requirements from both authorities, Chapter 14 qualification for ICAO and the limitations defined in Part 26 from FAA. Therefore, this leads to the conclusion that supersonic transport aircraft can meet the noise standards currently set for subsonic aircraft. Further work in this regard could include comparisons to Concorde noise levels and regulations and experimental noise data from subsonic airliners of similar maximum take-off weight.

C. Application of Programmed Lapse Rate to Departure

Lastly, overall noise levels have been assessed for both configurations when programmed lapse rate procedures are used during take-off. The PLR technique has been simulated for different altitudes of initiation: 50 ft, 200 ft and 400 ft and different reduction of thrust percentages: 90% and 80% of the maximum thrust; with the aim of creating a database to analyse the impact of this promising method on the noise levels of the future generation of commercial supersonic aircraft.

First, the departure profile has been defined. Maximum thrust is maintained up to the PLR initiation altitude at which the thrust is reduced to a certain percentage of the maximum thrust. Next, the aircraft climbs at this reduced thrust until the standard thrust cutback point is reached which has been located at an altitude of 1500 ft so as to ensure that the industry average allowance of twenty-five percent thrust reduction is achieved before going over the flyover noise reference point.

In Table. 6, the results for the noise assessment for PLR profiles are presented in comparison with the overall noise results obtained for the original take-off profile. In addition, these results have been illustrated in Fig. 18.

<i>Trijet Configuration</i>							
Programmed Lapse Rate Procedure Noise Assessment for Different Initiation Altitudes [EPNdB]							
Certification Point	Original Take-off Profile Results	90 % max. Thrust			80 % max. Thrust		
		50 ft	200 ft	400 ft	50 ft	200 ft	400 ft
Flyover	88.2	88.9	88.8	88.7	89.7	89.5	89.2
Lateral Full Power	96.8	95.5	95.5	96	93.8	95.3	96
Combined	185	184.4	184.3	184.7	183.5	184.8	185.2

<i>Quad Jet Configuration</i>							
Programmed Lapse Rate Procedure Noise Assessment for Different Initiation Altitudes [EPNdB]							
Certification Point	Original Take-off Profile Results	90 % max. Thrust			80 % max. Thrust		
		50 ft	200 ft	400 ft	50 ft	200 ft	400 ft
Flyover	88.21	88.9	88.8	88.7	89.8	89.5	89.2
Lateral Full Power	96.86	95.5	95.8	96.3	94	95.6	96.2
Combined	185	184.4	184.6	184.9	183.8	185	185.5

Table. 6 Programmed Lapse Rate Procedure noise assessment results for each combination of initiation altitude and thrust reduction percentage at the departure certification points for the trijet and the quad jet configuration.

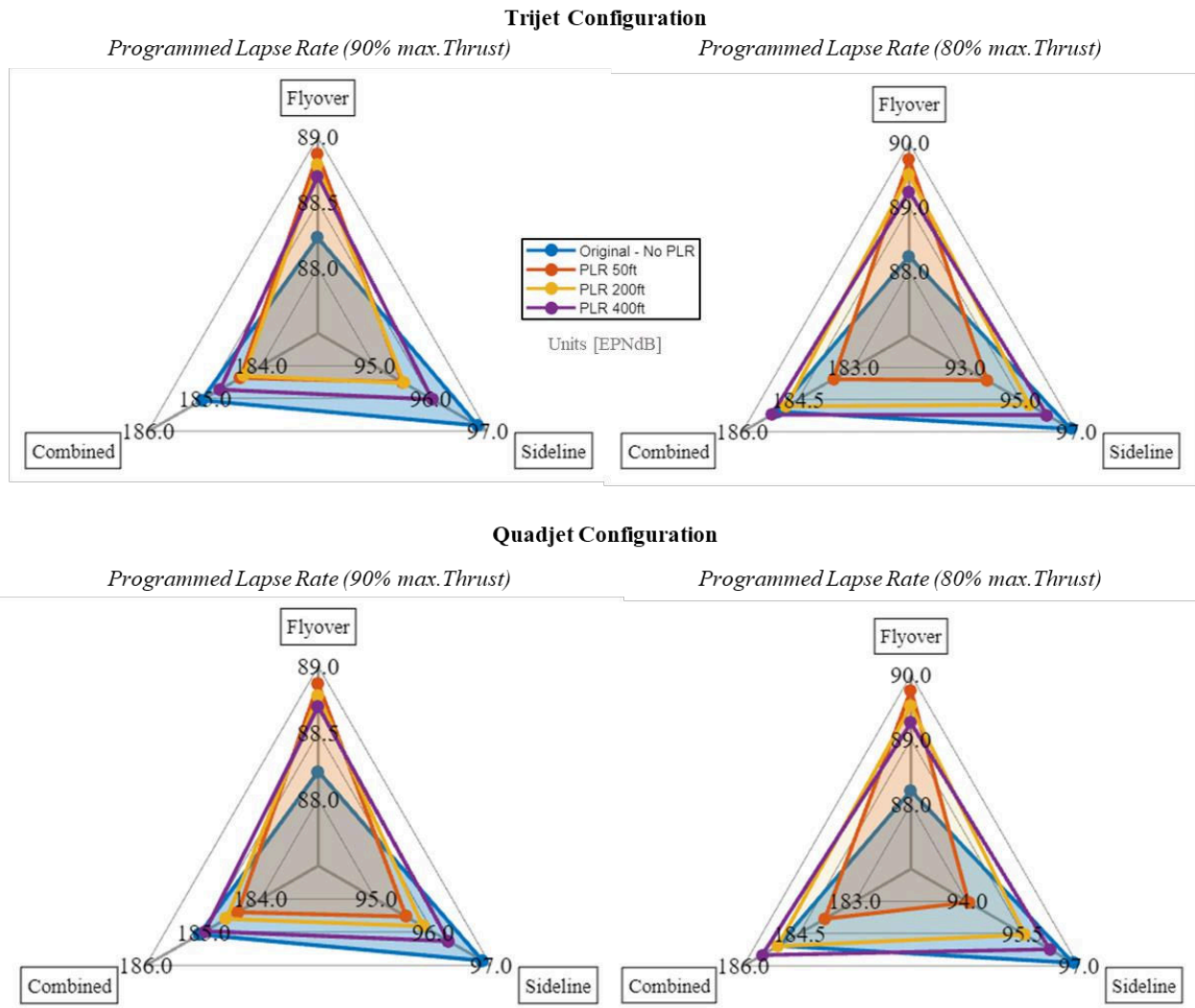


Fig. 18 Programmed Lapse Rate Procedure noise assessment results for each combination of initiation altitude and thrust reduction percentage at the side-line and flyover certification points for the trijet and the quad jet configuration.

Applying PLR procedures has reduced the combined noise levels in every initiation altitude-reduction percentage combination apart from the 20% thrust reduction at 400 ft. For both configurations for which the combined overall noise has increased by 0.2 EPNdB for the trijet configuration and by 0.5 EPNdB for the quad jet configuration which leads to the conclusion that the PLR procedure for a 20% reduction in thrust at 400 ft initiation altitude is does not offer any advantages.

By analysing the results, it can be stated that following PLR profiles can be beneficial for the lateral full-power noise reference point levels. As it was expected, the noise prediction results indicate that this procedure lowers the side-line noise levels at the expense of slightly increasing the noise level at the flyover reference point since this technique results in a lower altitude over this certification point.

However, for example, in the cases of PLR initiation altitude 50 ft for any of the thrust reduction percentages, it is shown that the increase in the flyover noise level is lower than the increase in the side-line noise output. Therefore, this yields a reduction in the overall combined noise results. The lower the altitude at which the PLR technique is activated, the more beneficial is for the side-line noise outcome while more detrimental for the flyover measurement point.

Despite of potential disadvantages in terms of flyover noise, the PLR method is a useful option to reduce the take-off noise of the future generation of supersonic transport aircraft.

The take-off thrust profiles considering a PLR initiation altitude of 50 ft and different reduction percentages alongside the profile when PLR procedure was not applied is depicted in Fig. 19 for the trijet configuration and in Fig. 20 for the quad jet design.

For each configuration, the total thrust during the programmed lapse rate profile is represented against the horizontal distance, showing the locations at which, the PLR is initiated and the point where the standard thrust cutback is applied. The flyover thrust reduction has to effective before reaching the 6500 m or 21400 ft in horizontal distance as it is where the flyover reference noise measurement point is positioned as per dictated by the certification regulations.

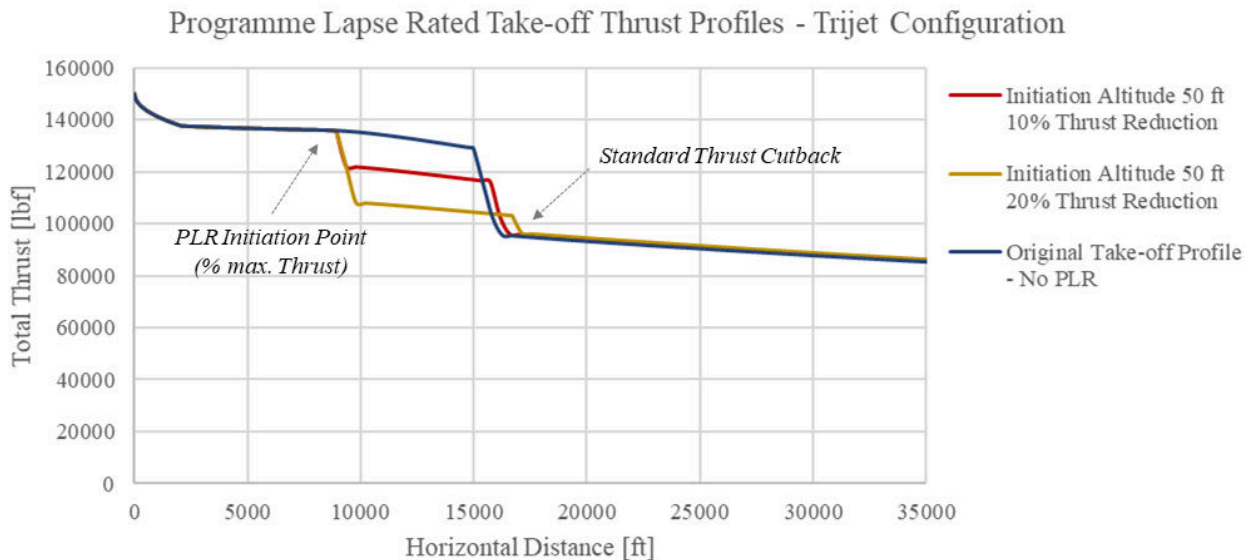


Fig. 19 Programmed Lapse Rate take-off profile total thrust vs horizontal distance for a PLR initiation altitude of 50 ft and different thrust reduction percentages for trijet configuration.

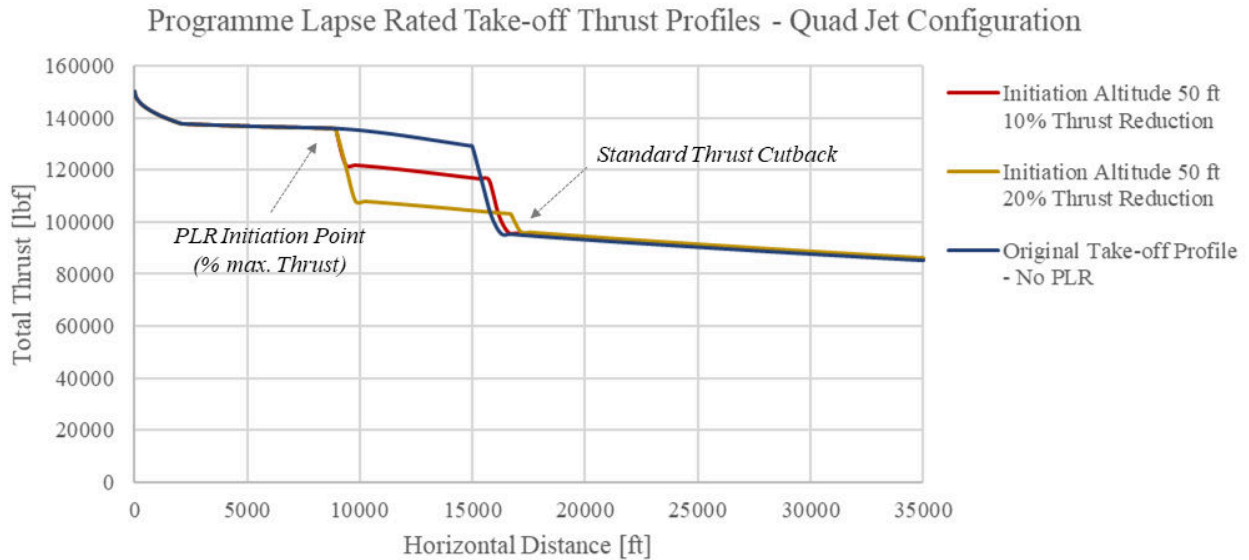


Fig. 20 Programmed Lapse Rate take-off profile total thrust vs horizontal distance for a PLR initiation altitude of 50 ft and different thrust reduction percentages for quad jet configuration.

Which once again proves that there is no significant difference between the results in terms of mission performance capabilities for both configurations.

Fig. 21 shows the impact that the thrust reduction percentage has on the overall noise results for a specific PLR initiation altitude of 50 ft. From the results, it can be determined that the higher the thrust reduction, the more beneficial is for the side-line noise while more detrimental for the flyover noise level.

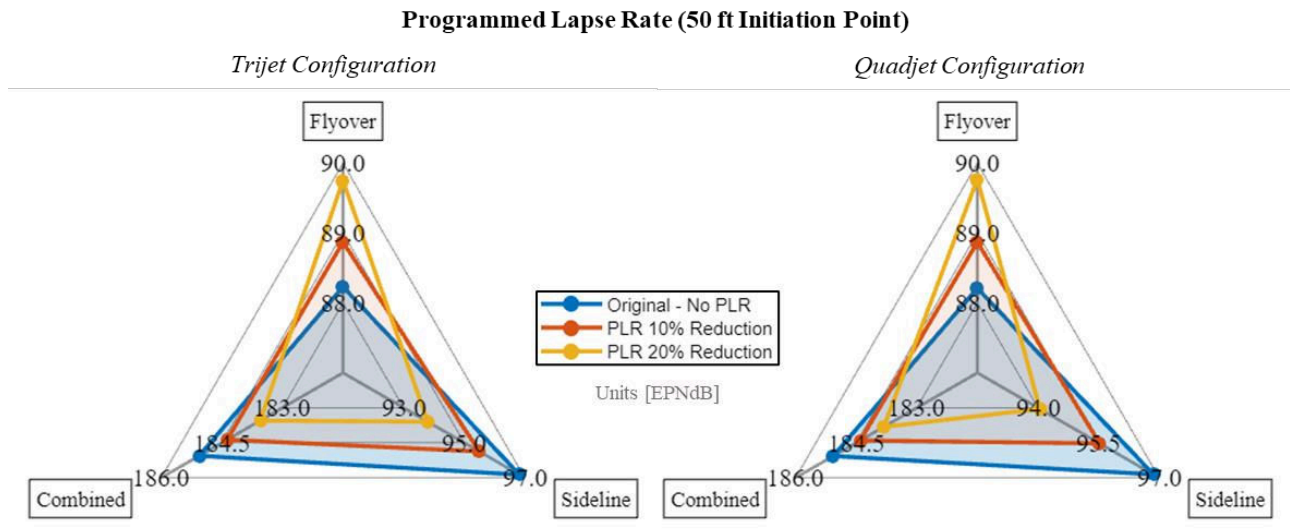


Fig. 21 Programmed Lapse Rate Procedure noise assessment results at an initiation altitude of 50 ft for different thrust reduction percentages at the side-line and flyover certification points for the trijet and the quad jet configuration.

VII. Conclusion

This paper presents the development of a framework for conceptual design of supersonic transport aircraft. Various Cranfield University in-house and freely available tools (e.g., AirCADia, FLOPS, PANAIR, etc.) are connected to setup a low-to-medium fidelity computational workflow with different multidisciplinary analysis modules such as structures, aerodynamics, propulsion, mission, stability, noise, emissions, etc. The framework is employed to develop the platform specification for a next generation 100-seater supersonic airliner with cruising Mach number of 2.2, for an EU Horizon 2020 research project named SENECA “(LTO) noiSe and EmissioNs of supErsoniC Aircraft”.

First, the top-level aircraft requirements are specified, including performance requirements and environmental requirements (NO_x emissions, flyover/side-line noise). Following this, a constraint analysis is conducted to determine the required wing-loading and thrust-to-weight ratio in order to define different aircraft configurations in terms of bi-/tri/quad-engine powerplant arrangements.

Once the supersonic aircraft platforms are defined, the developed conceptual design framework is implemented for each configuration, obtaining results such as technical geometry data, reference surface model, mass breakdown, engine cycle performance, mission performance and noise footprint prediction at the three certification measurement points defined by ICAO along standard departure. Moving take-off noise analyses to early stages of the design process is one of the goals of this paper, in order to ensure that future supersonic aircraft will comply with low-noise regulations. Lastly, the feasibility of applying noise reduction techniques such as Programmed Lapse Rate profiles has been investigated so as to study its impact in the mitigation of the noise level in the vicinity of the airport and potentially to ease the noise certification of the next generation of supersonic transport aircraft.

The outcome of this research activity led to several useful considerations in the field of supersonic aircraft design as well as take-off noise prediction. For this mission application, cruising at 50000 ft altitude and Mach number of 2.2, it has been proven that a twin engine configuration is non-suitable due to engine sizing concerns which impacts negatively in the manufacturing and cost efficiency. On the other hand, both trijet and quad jet configurations are consistent designs that meet the top-level aircraft requirements while being compliant with the current noise standards set for subsonic transport aircraft by ICAO and FAA as it has been reported in this paper.

Finally, programmed lapse rate procedure has been considered. This method automatically reduces the engine throttle during take-off after obstacle clearance and before the take-off standard thrust cutback with the objective of reducing the peak side-line noise. Results show that it provides a benefit in lateral full-power noise at the expense of a penalty on the flyover noise reference point. The PLR technique has been implemented for different combinations of initiation altitudes and thrust reduction percentages for both trijet and quad jet configurations. The results show that a compromise can be found between the initiation altitude and the thrust reduction percentage in order to maximise the side-line noise levels suppression while not impacting excessively the flyover noise output.

An additional factor to be considered in future work is the investigation of the PLR procedure with variation of the climb out speed during the take-off. The purpose of this is to reduce flyover noise by reach higher altitudes at the flyover reference noise measurement point. Despite PLR not being allowed under the present subsonic noise certification standards, this concept has to be addressed as a noise reduction technique to be potentially implemented in the noise certification at the airport environment for supersonic aircraft.

Future work will involve consideration of aircraft performance assessment for missions with 3D trajectories to determine the impact of routes with over-land and over-water flights. Detailed engine cycle performance and noise assessments using high fidelity methods will be used to further validate and improve the early-stage aircraft design methods reported here. High fidelity engine models will inform emissions and cost analyses.

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