33RD CONGRESS
OF THE INTERNATIONAL COUNCIL
OF THE AERONAUTICAL SCIENCES
STOCKHOLM, SWEDEN, 4-9 SEPTEMBER, 2022

ICAS
2022
SWEDEN

“CONCORDE-NEO”: A BIOFUEL PROPELLED SUPERSONIC COMMERCIAL AIRCRAFT WITH CONCORDE CONFIGURATION

Authors (MSc. Students of Politecnico di Torino):
Borghi Marco, Clinca Giovanni, D’Amico Francesco Antonio, Fornaseri Federico, Versino Emanuela

Politecnico
di Torino

Abstract

Application of the system engineering approach in a conceptual design of a supersonic commercial aircraft with Concorde configuration reducing the environmental impact with the usage of Biofuels. Performance improvements thanks to free flight concept, turbofan architecture, bleedless configuration and more-electric philosophy. Validation of the project with mission simulation (ASTOS).

Keywords: Biofuels and Environmental Impact, Supersonic Flight, Free Flight Concept, System Engineering Approach, MORE&LESS Academy.

1. Introduction

In today’s civil aviation context, there is a growing demand for routes flown faster and with a strong focus on respecting the environment. The distinctive aspect of high-speed transport was already tackled in the last century by aircraft such as the *Aérospatiale-BAC* Concorde and the *Tupolev* Tu-144. However, the last of these aircraft were decomissioned in 2003 due to economic disadvantages for the operating companies and the high environmental impact. Today's technological progress, together with the increasing global regulations to reduce pollution from the aviation industry (around 2% of global CO_2 emissions per year), has led to the need for new studies on this category of aircraft. In December 2019, the European Commission put forth its Green Deal with the objective for decarbonization: net carbon neutrality across all sectors and EU member states by 2050. This and the other regulation imposed have strongly encouraged the aviation sector to a rapid decarbonization.

Combining supersonic flight with emissions’ reduction is one of the biggest challenges airline companies and aircrafts’ manufacturers are facing nowadays.

Starting from this challenge, the authors decided to analyze what this implies, evaluating the feasibility of a supersonic aircraft with a Concorde configuration, but not as troublesome as it was both in terms of environmental impact as well as performance.

The aim of this paper is to be a conceptual design for a new generation of supersonic passenger aircrafts that, starting from the benchmarks of past experiences like that of Concorde, can help today’s engineers in the development of an aircraft that is more economically profitable, better performing and more environmentally friendly than those of the past.

As the reader will see, all the choices made during the development of the project were focused on improving performances in terms of achieving a complete new set of possibilities for an aircraft of this type, both in the area of environmental impact and in increasing the maximum range and the carried payload availability.

Moreover, improved performances would also bring operating costs benefits, which, as mentioned before, had been a weak point for Concorde’s operations and one of the most important causes that made it not widespread as foreseen.

Figure 1: Concorde-NEO rendering

2. Method

Applying the most up-to-date technology of the aerospace sector and the systems engineering to unify them, the following chapters describe the process that has been used for the development, as well as the results obtained to validate the idea.

Starting from the concept outlined in the previous chapter, the development of the project began by defining the requirements to be met.

Once this was done, a first implementation analysis was carried out, which was a turning point for this study: configuration. This, in fact, imposed additional requirements on the project, such as structural dimensioning of the systems. Establishing the configuration allowed to proceed to an iterative phase, mainly focused on the propulsion and propellant system, which proved to be of fundamental importance, as it represents a decisive condition for the correct performance of a mission and, consequently, for the correct power supply of all on-board subsystems.

Once acceptable results were obtained and the mission simulation proved to be satisfactory, development focused on an analysis aimed at verifying the environmental impact of the aircraft.

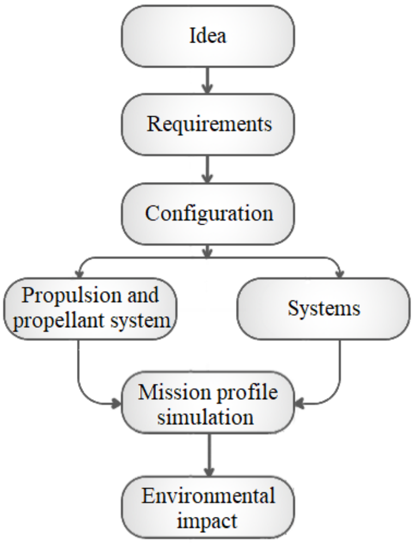

Figure 2: Method

3. Requirements

As reported in Figure 2, the first step that has been made for the development of the project is the definition of the requirements.

The Concorde-NEO, which would be a supersonic aircraft for commercial operations, would have three High-Level Requirements:

- Cruise Mach number $M = 2$;
- Reducing environmental impact;
- Concorde configuration.

Maintaining the same configuration and cruising speed would therefore results in an aircraft strongly inspired by the original Concorde which, in the meantime, consider all the measures taken by regulators to reduce aviation's environmental impact. In order to fulfil this task, it has been decided to use biofuels as propellant for the aircraft.

Further requirements that have been listed for the project were:

- MTOW < 200 tons;
- Range 7200-9000 km;
- Thrust 140kN – 170kN
  (dry – wet conditions).

All these values come from the actual performance of the Concorde, with appropriate changes made to the range of the MTOW and the distance traveled, for which the increase with respect to the original values has been implemented in order to achieve the performance improvement envisaged in the previous paragraphs, allowing thus to operate on a greater number of routes, improving the offer and opening up new economic possibilities.

As for the number of passengers, it has been imposed that the Concorde-NEO would have been able to travel the same amount of the Anglo-French aircraft: 120. This is the result of the choice to keep the original configuration of the aircraft, keeping its dimensions unchanged and, therefore, not having any space available to accommodate a higher number of passengers. passengers.

3.1. Biofuels

Biofuels, which are fuels produced by natural sources (mainly vegetables) with chemical-physical characteristics like Jet A-1 kerosene, are gaining place in everyday use on airplanes. However, they are currently used as blenders (nowadays, biofuels usage represents the 2-3% of all the fuel burnt in the aviation industry), not as primary fuels; nevertheless, in 2022 flight tests 100% powered by biofuels have already taken place[1]. This chemical-physical affinity of biofuels with kerosene fuels is fundamental to

---

[1] https://www.airbus.com/en/newsroom/press-releases/2022-03-first-a380-powered-by-100-sustainable-aviation-fuel-takes-to-the https://www.atr-aircraft.com/presspost/atr-successfully-performs-test-flights-with-100-saf-in-one-engine/

allow an immediate introduction in the aeronautical industry; in this way, in fact, there would be no need to modify any plant onboard aircrafts to be able to use biofuels. For this reason, these kinds of fuels are also defined as *Drop-in Fuels*. Thus, biofuels do not impose the necessity of retrofitting the aircraft, which is not always an economical advantage.

As far as combustion is concerned, the amount of CO_2 produced per kilogram of biofuel burned is identical to that of kerosene-based fuels. However, the environmental benefit of biofuels is realized considering the whole life cycle, where the CO_2 emitted during combustion is reabsorbed by the crops used to produce them. Looking at the graph in Figure 3, which shows the estimated trend of carbon dioxide emissions considering the foreseen increase in the number of flights in future years, it is possible to see what the expected emissions reduction thanks to such fuels is. It is then clear that the introduction of new types of fuel in the short term is a necessary condition for achieving the objectives set for the reduction of polluting emissions.

Further benefits regarding the usage of biofuels concern the absence of Sulphur oxides created during combustion and independence from the price of oil. However, biofuels also incorporate some disadvantages, including the absence of aromatic components that lead to accelerated wear out of the propellant system’s seals and turbines, as well as a higher incidence of bacterial cultures inside tanks. Both aspects should not be overlooked as they introduce a whole new range of issues that infect both combustor and turbine components. As for the disadvantages, they could result in early wear out of the components, thus rescheduling all their operative lives. The usage of Biofuels is therefore a fundamental part of the desire to make the Concorde-NEO decidedly less polluting than Concorde, backing this choice up even using lower consumption thrusters than the Olympus 593, as will be analyzed later. However, biofuels even introduce a thorny ethical issue: the feasibility and sustainability of using vegetable crops to produce fuels. As an alternative to "classic" crops, studies have been done on the use of algae.

All these things considered, it can be quite clear that biofuels could represent the only one transitional technology that can immediately guarantee a lower aviation environmental impact while developing alternative propulsion solutions (hydrogen, electric propulsion).

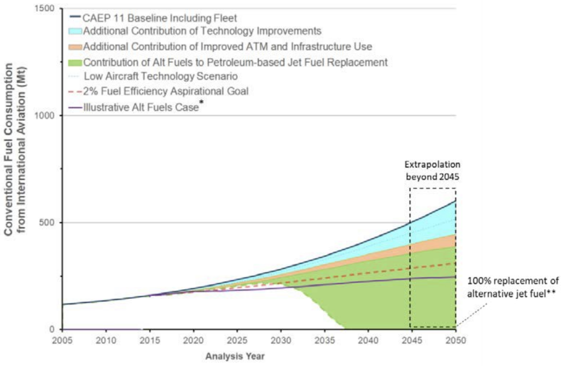

Figure 3: Carbon dioxide emissions forecast[2]

3.1.1. Concorde-NEO’s Biofuel

The biofuel chosen for the Concorde-NEO is the one produced with the SIP method, whose main characteristics are shown in Table 1, and even compared with those of the traditional kerosene fuel (Jet A-1).

	Density [kg/m³]	*Calorific power [MJ]*	*Flash point [°C]*	*Freezing temp. [°C]*
SIP[3]	773	44	>100	-47
Jet A-1	775	43,15	38	-47

Table 1: SIP biofuel characteristics vs Jet A-1

From Table 1 it is possible to notice that the biofuel selected has chemical-physical characteristics very close to those of Jet A-1.

A very important fact is the calorific value, which for the SIP biofuel is even higher than that of Jet

---

https://www.ge.com/news/reports/united-flies-worlds-first-passenger-flight-on-100-sustainable-aviation-fuel-supplying-one

[2] Source image: https://www.icao.int/environmental-protection/Documents/ICAO-ENV-Report2019-F1-WEB%20(1).pdf

[3]

A-1, and this is a very advantageous point: being higher means more fuel efficiency, and thus a lower environmental impact.

Also, the density has a very similar value for the two types of fuel, which means that there is no need for any expedient in the architecture of the propellant system to store the fuel like it would have been using the LH2 for example.

Eventually, another point absolutely in favor of the selected biofuel compared to the Jet-A1 is the flashpoint. Being the Concorde-NEO a supersonic aircraft as per requirement, having a higher flash introduce less technical issues in the thermal protection to avoid fuel management problems due to surfaces' heating by external flow friction. Concorde relied heavily on this system to keep the fuel in an acceptable temperature range despite the Mach 2.0 cruising speed.

4. Analysis

As far as the analysis carried out for the conceptual design of the Concorde-NEO are concerned, as already indicated in Figure 2, they can be divided into 3 main areas:

- propulsive and propellant system analysis.
- configuration analysis;
- subsystems analysis.

Further detailed analyzes that have been carried out, although not iteratively like the previous ones, are those based on the mission profile, on the aerodynamic model and on the emission indices of the aircraft.

However, before focusing on all these, it has been undertaken a previous analysis in order to have those conceptual design parameters from which to make all subsequent reasoning: the matching chart analysis (*Roskam method*).

According to the wing loading (W/S) and the thrust-to-weight ratio (T/W), this chart represents all the performance requirements that the aircraft must meet in the various phases of flight. Thus, it has been possible to identify which was the dimensional condition and then, obtaining the main design parameters, to proceed with all subsequent more detailed analysis. The matching chart's results are reported in Figure 4. Furthermore, this wing loading and thrust-to-weight ratio imply that the characteristics of the Concorde-NEO are those reported in Table 2.

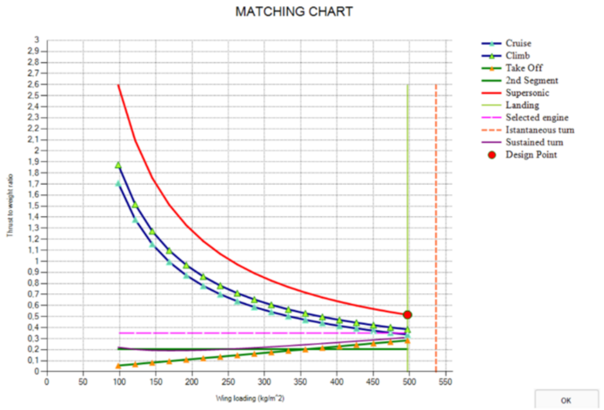

Figure 4: Matching chart

	Concorde	***Concorde - NEO***
MTOW [kg]	185070	176849
OEW [kg]	78700	79460
Fuel [kg]	95000	82189
Payload [kg]	13380	15200

Table 2: Concorde vs Concorde-NEO characteristics comparison

These results are referred to the case of having set a cruise requirement which is 8500 km of range rather than 7000 km as the Concorde. Even having more than 1000 km range over that of Concorde, both the MTOW and fuel weight values for the Concorde-NEO are lower than that for the Anglo-French aircraft thanks to a reduction in fuel consumption that have been assumed for the propulsion system and that will be analyzed later. Furthermore, it has even been supposed an increase of around 1000kg in payload capacity.

All these first results already show an improvement in aircraft's performance compared to that of Concorde.

4.1. Propulsion system

Regarding the propulsion system of the Concorde-NEO, the choice has been made in such a way as to try to satisfy two conditions deriving from the requirements:

- a front section like that of the Olympus 593, which comes from the configuration's requirement;
- strong reduction in specific fuel consumption (SFC) compared to that of the Concorde, resulting from the requirement to have a lower environmental impact.

Trying to match these two requirements with those of thrust levels, the choice fell on an engine with low BPR turbofan architecture and afterburner. However, since to date there is no engine on the market that fully respects all the requirements, it was then opted for the choice of the one that came closest to the fulfillment of all these, then going to scale it so that it fully meets all requirements. The engine chosen is the F-135 of Pratt & Whitney that has been scaled as shown in the Table 3.

Concorde-NEO engine	
Thrust without AB	155 kN
Thrust with AB	170 kN
Diameter	1.21 m
SFC	0.75 (1.5 AB on) lb/lbf·h

Table 3: Concorde-NEO engine characteristics

As far as the SFC values are concerned, they have been calculated using formulas available in literature [1]. Having a reduction to 0.75 for the SFC in dry condition, it means an improvement of 22% in fuel efficiency with reference to Concorde.

4.1.1. Thrust model

A clarification must be made on the thrust value calculated in dry conditions. It is 15 kN higher than the initial requirement of 140 kN. This value is due to the fact that the engine was iteratively rescaled to verify if its performance was sufficient for the mission through the simulation that will be seen later. In order to perform this simulation, a thrust model that would consider the variation of thrust both at altitude and Mach variation has been assumed.

The model used is

$$T = T_{sl} * \varphi * \psi * \chi * k \tag{1}$$

where, knowing the value of the thrust at sea level (T_{sl}), it takes into account how it varies by considering, besides the throttle (φ), also the altitude (ψ) and the flight speed (χ). In addition, as in the case of the Anglo-French aircraft, it has been assumed that the engine intake (k) would play a key role in the generation of thrust, and thus in the maintenance of the supersonic regime during cruise, through the dynamic compression of the airflow due to oblique shocks.

Having made this clarification, from the simulation of the mission with ASTOS software (analyzed later on) it was seen that the thrust required at sea-level had to be at least 155 kN. This result is absolutely conservative because Concorde, which weighed more, had 140 kN at sea level; and this is the reason why this result has been considered valid, because it does not overestimate, but at most underestimates, the engine performance.

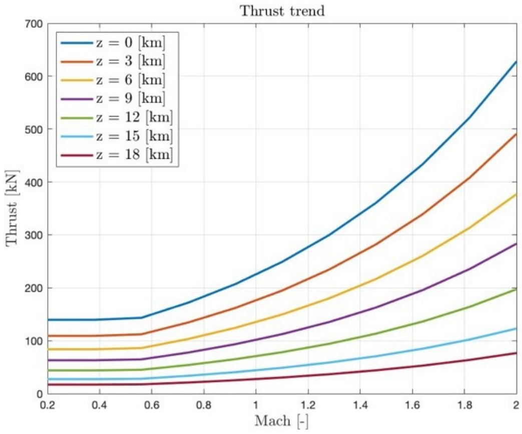

Figure 5: Thrust model

Moreover, further considerations have been made about the thrust model developed:

- the trend is only reasonable when the two parameters (Mach and altitude) are combined;
- the thrust was linearized as possible, or at least it has been tried to avoid as much singularities and discontinuities as possible such as the sharp bend shown for Mach ~ 0.6, to avoid extreme oscillations in ASTOS;
- before Mach 0.5 the effect of the intake compression was considered constant

and equal to 1 since, from what has been found in literature, it makes an important contribution for Mach greater than 1 but still has an effect at lower Mach, negligible when it becomes very low.

4.2. Configuration

The configuration of the aircraft has been slightly modified, keeping in mind that it should have been inspired to the Concorde one according to the requirements.

Starting from the results obtained from the matching chart (Figure 4) and others various aircraft parameters derived from them, the variation in the design point from that of the Concorde resulted in a slight change in the geometric dimensions of the aircraft. This led to a variation of two parameters that characterize the configuration of an aircraft: the τ coefficient and the Kuchemann's parameter k_w.

These parameters are strictly related to aircraft volume and planform surface: acting to reduce the wing surface of $385\ [m^2]$ of the Concorde by 7% and at the same time increasing the thrust planned of $140\ [kN]$ by 10% to maintain the flight capability, it is possible to obtain a reduction in both τ and k_w.

Specifically, lower value of τ results with a higher slenderness configuration and therefore higher aerodynamic efficiency, with a value of 8.9 for the Concorde-NEO compared to 8.5 for the Concorde. In addition, the reduction of k_w is also relevant as it leads to a configuration closer to the best theoretical estimations as shown by the blue curve in Figure 6.

Therefore, since the objective of the Concorde-NEO project was to obtain an aircraft with the configuration of the Concorde lowering its environmental impact, even this slight change in the size of the aircraft compared to the original one is functional to meet the requirement.

Moreover, the configuration has been analyzed not only from the point of view of aerospace performance, but also in terms of passenger comfort. In fact, by foreseeing the use of modern seats with a more optimized design compared to those on board the Concorde, a clear improvement has also been foreseen in terms of flight quality standards for passengers by managing to increase the seat pitch about 7 cm for each seat in the cabin. This also addresses one of the main problems faced by passengers today: the reduced living space between seats, which is mainly dictated by the commercial requirements of the aircraft.

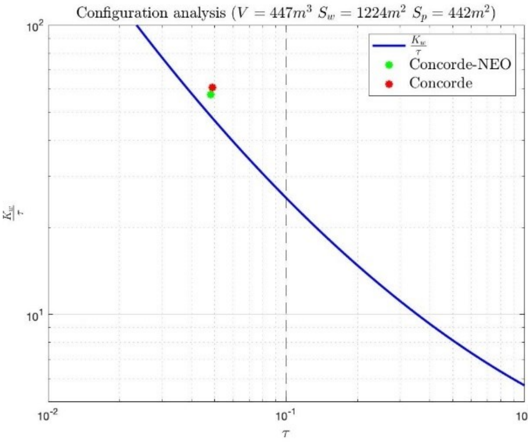

Figure 6: Configuration analysis

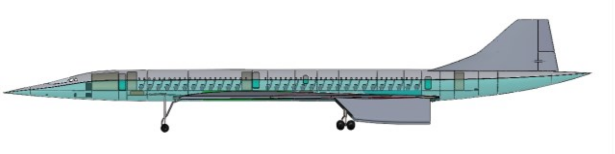

Figure 7: Internal layout

	Concorde	*Concorde - NEO*
Seat pitch	0,86 m	0,93 m
Seat width	0,43 m	0,43 m
Central aisle	0,83 m	0,83 m
Payload	13380 kg	15200 kg

Table 4: Internal configuration comparison

4.3. Aircraft subsystems

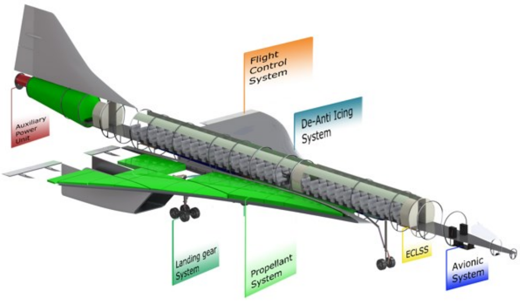

Figure 8: Subsystems scheme

In order to reduce the environmental impact not only through the reduction of emissions, even reduce the consumption of the aircraft is helpful. Electric generation is a fundamental aspect of Concorde-NEO's design.

A bleedless architecture was indeed introduced when sizing the power generation systems, in pursuit of the More-Electric Aircraft philosophy to reduce fuel consumption and the weight of the integrated systems, removing the pneumatic one and relative air bleed from the compressor stages, thus improving propulsive efficiency, and enhancing the performance of the engine.

The absence of the pneumatic system therefore leads to higher power demands on the remaining generator systems, especially the electric one. Nevertheless, the request for higher electric power implies higher voltage to generate power as it leads to having lower current. This is a positive aspect for an aircraft, helping it to have lower losses on the line and a lighter system. However, the use of a higher voltage has not only advantages, for example it requires better standards of insulation.

A primary generation in 230 $V\ AC$ variable frequency was chosen, but also converters have been provided to supply a 28 $V\ DC$ bus and a 115 $V\ AC$ 400 Hz bus. The generation in variable frequency allows powering users that were allocated on the pneumatic system too: the anti-ice and the de-ice systems.

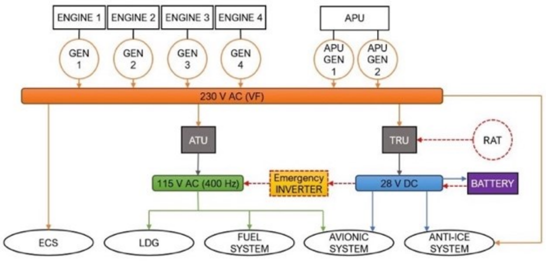

Figure 9: Electrical System - logic scheme

Given the advantages of using electrical power distribution, the braking function of the main landing gear has also been associated with this power generating system. In particular, the usage of EHA (Electro-Hydraulic Actuators) was foreseen. This choice was made in order to have both a more selective and proper control, as well as greater safety and reliability in landing phase when the hydraulic system is usually overloaded by other systems.

Shifting the focus to the Hydraulic System it must be highlighted that, unlike Concorde, although the number of circuits is the same, these three are used in a different way. In the original Concorde configuration only two out of three hydraulic lines (the blue and the green one) were in actual use, while the third circuit, called "standby circuit" (the yellow one), was used only during emergencies.

In the Concorde-NEO project it was chosen to activate the three circuits simultaneously, in order to reduce the workload on each line, while maintaining safety redundancy.

The distribution of users for each circuit is described below, followed by the representation of the system:

- Blue circuit: outer elevons, inner elevons, upper rudder, main landing gear retraction, front landing gear retraction and steering;
- Green circuit: outer elevons, middle elevons, upper and lower rudder, main landing gear retraction;
- Yellow circuit: middle elevons, inner elevons, lower rudder, slats, nose landing gear retraction.

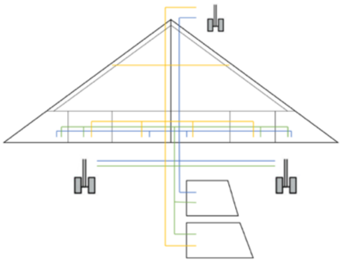

Figure 10: Hydraulic system - lines

As for the Avionic System from an operative point of view, the analysis and execution of the mission are characterized by high-tech on-board avionics.

The idea underlying the design of the system is the Free Flight Concept, where the pilots are responsible for the separation assurance of the aircraft instead of the air traffic controller.

Navigation, communication and mission data are provided via a 'glass cockpit' interface. This technology allows pilots to visualize flight parameters and information in digital format on LCD displays, replacing mechanical indicators with a few screens on which to display the information required to improve attention and concentration. On-board HUDs also provide increased safety during landing and take-off.

A further improvement of the avionics system and flight management is due to the integration of ADS-B technology which manages automatic, GNSS-dependent, broadcast information transmission. This system can provide a faster and more accurate data update rate with a wide coverage and, forecasting appropriate future developments, it can guarantee the possibility of decentralized air traffic control with an autonomous control of the separation from other aircraft.

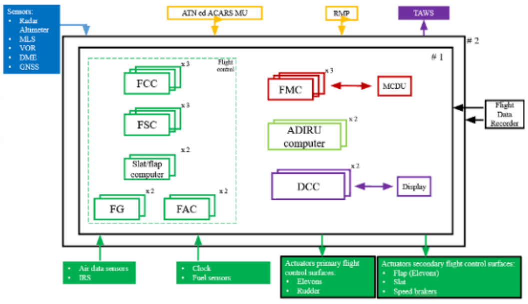

Figure 11: Avionic system - logic scheme

4.4. Mission profile

In order to compute the mission simulation to analyze whether the performance has been reached or not, it has been necessary to first focus on the mission profile.

The one hypothesized is depicted in Figure 12 and **Errore. L'origine riferimento non è stata trovata.**.

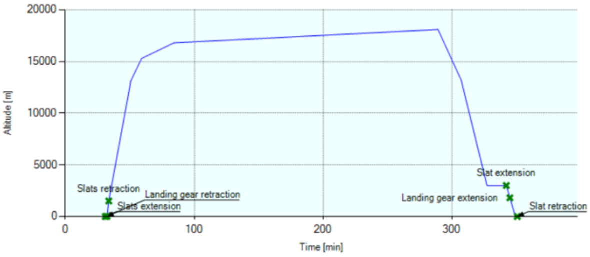

Figure 12: Mission profile

The data of each phase of the mission profile come from the Eurocontrol platform concerning the flight profile of the original Concorde, with a proper change in terms of cruise phase time and distance in order to reach a total range of the mission of 8500 km, and to be sure to fly over continental areas in subsonic regime both during climb and approach.

Phase	Duration [min]	Initial altitude [m]	Final altitude [m]	Average speed [m/s]
Take off	1,4	0	11	71
Initial Climb	1,3	11	1500	129
Subsonic Climb	15,5	1500	12000	219
Sonic Transition	1,5	12000	13100	295
Supersonic Climb	8,5	13100	15300	401
Climb to Cruise	25	15300	16800	533
Cruise	205	16800	18100	591
Supersonic Descent	18	18100	13200	470
Subsonic Descent	20	13200	3000	221
Loiter	20	3000	3000	150
Approach	7	3000	15	159
Landing	1,5	15	0	57

Table 5: Mission profile (data)

4.5. Aerodynamic analysis

In addition to the analysis of the thrust model, it has also been assumed an aerodynamic model for ASOTS’s simulation. That is the one derived from the Aerodynamic Data of Space Vehicles [2], which shows typical trends for aerodynamic coefficients for certain types of aircraft.

Going deeper in the analysis, even if the Concorde-NEO does not fits into CAV’s category, their aerodynamic data have been used anyway as long as they represent an excellent solution for a Mach 2.0 aircraft with Concorde configuration.

4.6. Environmental impact indexes

To evaluate Concorde-NEO’s environmental impact, it has first been necessary to identify the engine emission index (EI) for each pollutant. As already seen, the thrusters installed onboard the Concorde-NEO do not exist yet but have been identified by scaling up an existing engine with characteristics that satisfy the project requirements. However, since it is an engine used in the military sector, the values of CO, HC and NO_x emission indexes are not available in literature.

It was therefore decided to scale the emission indexes of a third engine with performances like those of the F135 (the reference engine from which the one installed onboard the Concorde-NEO was derived). The reference propeller selected from the ICAO Aircraft Engine Emissions Databank [3] is the PW1127GA-JM. It has been chosen because its thrust values at sea level and frontal section are similar to those of the F135.

Before proceeding, it is important to underline that all values, both emission indexes and fuel flow, that have been rescaled are referred to the case of the Concorde-NEO engine with the afterburner on (except for the "Idle/Taxi" phase) as prescribed by the regulations.

Using biofuels, a variation in terms of emission indexes of CO, HC and NO_x is considered, while those of O_2, H_2O and SO_x remain unchanged. Specifically for the SIP biofuel, the variation in terms of emission indexes compared to that of Jet A1 fuelled thrusters are shown in Table 6.

	ΔEI_{CO}	ΔEI_{HC}	ΔEI_{NO_x}
SIP	-10%	-10%	+10%

Table 6: Emission index variation due to biofuel

These values of percentage variation of emission indexes were chosen according to literature [4].

Interpolating the emission indexes with the corresponding fuel flow values, the trends shown in **Errore. L'origine riferimento non è stata trovata.** are obtained.

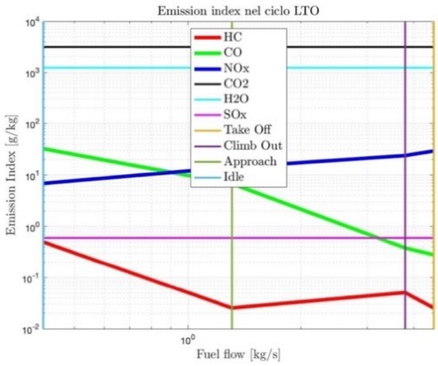

Figure 13: Emission indexes variation with fuel flow

From Figure 13 it is clear that, as CO_2, H_2O and SO_x emissions indexes are constant, those of CO, HC and NO_x have a great variation as the fuel flow changes. When less thrust is required, which means lower fuel flow, there is a predominance of CO due to lower turbine temperatures and longer flow residence times. On the contrary, when greater thrust is required, there is a prevalence of NO_x due to higher temperatures in the turbine and lower residence times. Regarding HCs, their trend is macroscopically decreasing as the thrust required increases.

5. Results

As results, hereafter are analyzed:

- the mission simulation analysis, in order to demonstrate its feasibility and thus an improvement in aircraft performance with reference to that of Concorde as per requirement;
- the environmental impact analysis, to demonstrate how environmentally friendly the Concorde-NEO would be.

5.1. Mission simulation

ASTOS software was used to analyze the mission profile of the aircraft, and thus demonstrate the increase in performance over those of Concorde.

Once defined the environment in which the mission is modelled as a WGS84 system, a geodetic coordinate system based on a reference ellipsoid which is used to define the flattening factor and the gravitational parameter in order to determine the shape of the Earth itself and the acceleration of gravity, the atmosphere model which has been selected is the US Standard 76 model.

Using the thrust model previously described, the fuel flow has been trivially calculated as:

$$\dot{m_f} = T * SFC \left[\frac{kg}{h}\right] \tag{2}$$

The following table shows the average throttle values for each phase, which will also be used later for the environmental impact analysis.

In addition to the engines data, the previously analyzed aerodynamic model and the geometrical size of the wing surface are entered in the software. Eventually, the aircraft is defined with its respective masses of payload, fuel and even the empty one.

Subsonic Climb	85%
Transonic Transition	100 % + AB
Climb-to-Cruise	60%
Cruise	50%
Descend-to-Approach	20%

Table 7: Engine throttle in mission simulation

As for the simulation method, the software's default settings for numerical integrations are maintained, manually thickening them only in the most delicate phases with higher oscillations, related to the abrupt variation of lift. The trends of thrust and total angle of attack in the mission profile are shown in Figure 14 and Figure 15.

There are inevitable oscillations in the initial climb phase, due to:

- thrust, which passes from the situation of afterburners on to off with a gradual reduction of the throttle and, in order not to strain the engine too much, it is decided to keep it at around 85%.
- angle of attack is decreased to avoid keeping it too high, for the comfort of the passengers.

These oscillations settle down after the transition phase to supersonic, when the throttle and angle of attack begin to stabilize. A final consideration is related to the angle of attack in the cruise phase: supposing that the wing is set at around 4°, the angle of attack settles at around 2°. This angle is not constant, like the thrust profile, due to the lightening of the aircraft.

In Figure 16 and Figure 17 there are Mach and flight altitude’s trends during the mission profile. As can be seen, apart from the oscillations mentioned above, the mission profile can be considered sufficiently reliable.

Moreover, from Figure 16 Mach 1.0 is reached after about 1000 flight seconds, which means being over 200 km away from the departure airport. This means that, according to current regulations, Concorde-NEO (which would then have a sonic boom very close to the Concorde one having a very similar configuration) will not be able to fly to continental airports, unless flying in the subsonic regime which would not be a good idea. It will be able to fly to all the coastal airports, and even more inner ones like London and Paris as Concorde already did.

In Figure 18 it is reported the plot of the fuel consumption of the aircraft along with the entire mission profile. As in the event of a missed approach, the aircraft would then have a reserve fuel of slightly less than 20 tons (about 20% of the total one) for making a second landing attempt or even a deviation on a secondary airport.

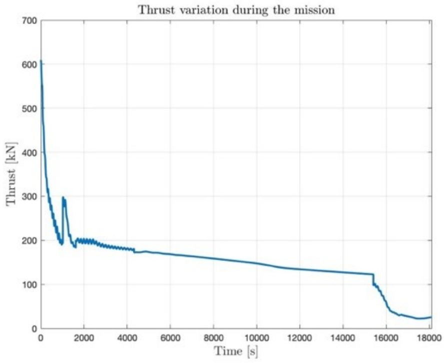

Figure 14: Thrust over mission profile

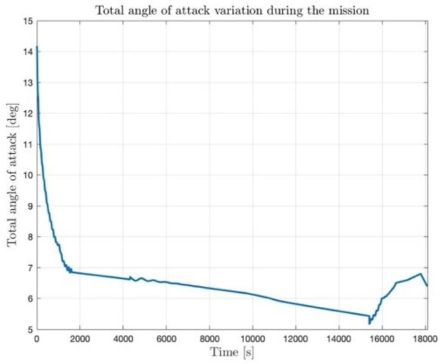

Figure 15: Angle of attack over mission profile

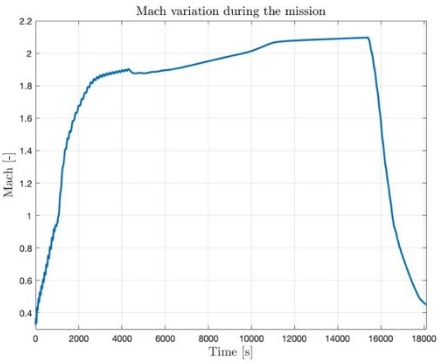

Figure 16: Mach over mission profile

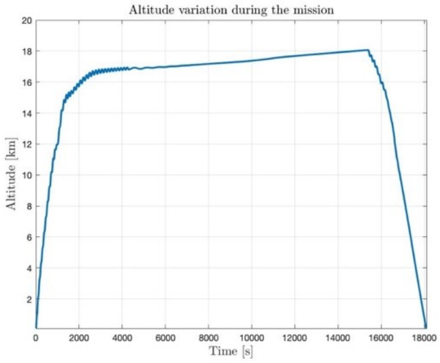

Figure 17: Flight altitude over mission profile

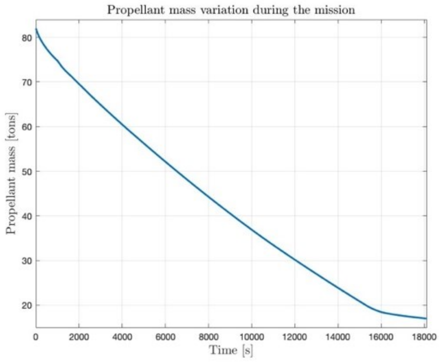

Figure 18: Fuel mass over mission profile

In the end, with ASTOS simulation software it has been demonstrated the fact that Concorde-NEO would be an aircraft with a much lower environmental impact engine than that of Concorde due to 22% lower SFC, but in the meantime capable of much higher performance both in terms of carried payload and range.

5.1.1. City pairs

In Figure 19 it is represented a mission profile example between Los Angeles and Tokyo, demonstrating not only the accomplishment in improvements in performance against those of Concorde, but even the fact that the 8500 km range means the fact that Concorde-NEO would even be able to cross the Pacific Ocean and not only the Atlantic one as the Concorde was.

This would result in an airplane that can lead to many more available routes. These possibilities are therefore part of the field of making the aircraft more attractive to an airline also from the point of view of operating costs, as well as performance, compared to Concorde. With Concorde-NEO it would be possible to open new commercial supersonic routes which, being today strongly used by subsonic aircraft, could represent a new market segment for airlines and therefore a potential source of resources to make the aircraft not as complicated as Concorde to be operated.

In **Errore. L'origine riferimento non è stata trovata.** and **Errore. L'origine riferimento non è stata trovata.** a list of possible city pairs for the Concorde-NEO is depicted.

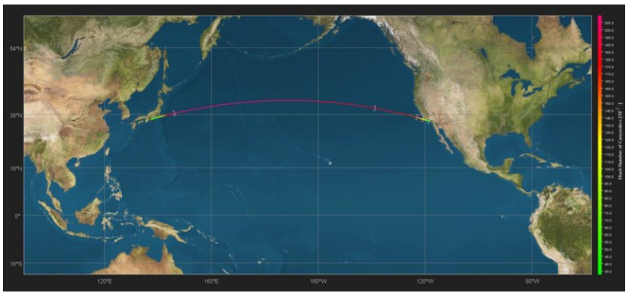

Figure 19: Los Angeles - Tokyo mission example

Departure	Arrival	Range [km]	ETD	ETA	Flight time
London	New York	5555	10:00	08:15	03:15
Paris	New York	5849	20:00	17:25	03:25
Cape Town	Rio de Janeiro	6097	20:00	19:30	03:30
London	Miami	7172	19:00	18:00	04:00
Tokyo	Brisbane	7116	07:00	12:00	04:00
Lisbon	Rio de Janeiro	7690	18:45	20:00	04:15
Durban	Perth	7896	22:00	08:20	04:20
Tokyo	San Francisco	8246	21:30	09:00	04:30
Vancouver	Seoul	8221	11:00	08:30 (+1d)	04:30
Los Angeles	Tokyo	8773	11:15	09:00 (+1d)	04:45

Table 8: City pairs (1)

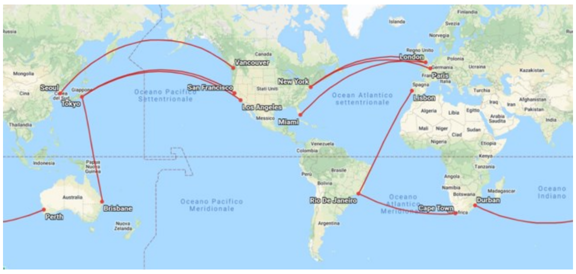

Figure 20: City pairs[4] (2)

5.2. Environmental impact

The aircraft emissions have been studied both in the LTO cycle and in the whole Mission Profile hypothesized.

5.2.1. LTO cycle

Referring now to the Mission Profile assumed for the Concorde-NEO, the characteristics in terms of throttle and time for each phase of the assumed LTO cycle are shown in Table 9.

To carry out the emissions computation it has been used the formula:

$$E_{sub.,phase} = EI_{sub.,phase} * \dot{w}_{fuel_{phase}} * t_{phase} \quad (3)$$

	Take-Off	Climb Out	Approach	Idle-Taxi
Time [*min*]	1,4	1,3	8,5	26,5
Throttle	100%	100%	30%	7%

Table 9: Mission Profile LTO cycle

The emissions in the Mission Profile LTO cycle are reported in Figure 21 per phase and in Figure 22 per substance emitted.

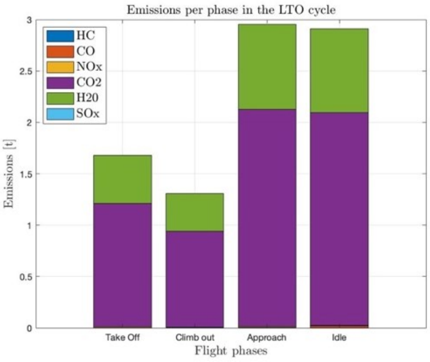

Figure 21: Mission Profile LTO cycle emissions per phase

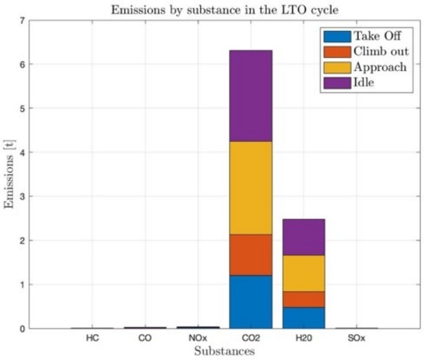

Figure 22: Mission Profile LTO cycle emissions per substance

Reaching a total amount of substances emitted of more or less 7.5 tonnes in the entire Mission Profile LTO cycle, and having the CO_2 as the worst pollutant (Figure 22) due to its higher emission indexes (Figure 13) even if using the biofuels, the most pollutant phase is the approach one (Figure 21). Thus, having the aim of reducing the environmental impact, it would be necessary to intervene for the duration of this phase to reduce it. Since the rate of descent can't be modified that much in order to reduce this phase duration being a civil and not military plane, the only way that the emissions produced in the LTO cycle could be reduced is based on improvements in airports' handling capabilities. Optimizing the time that an airplane must travel on taxiways from the runway to the terminal or apron, would be a fundamental step in reducing the environmental impact because this could lower the emissions produced in the idle phase, which is the second most pollutant in the LTO cycle (Figure 21).

5.2.2. Mission profile

As for the Mission Profile not included in the LTO cycle, the *Fuel Flow Method* by *Boeing* can be used to estimate the emissions produced. To do so, it has been necessary to take two fundamental steps.

The first one was that of assuming all the Mission Profile phases as different and independent cruise segments carried out at constant flight level and velocity assumed as the

---

[4] Source image: https://www.greatcirclemap.com/roadmap

mean values of each phase. If these hypotheses would not have been made, the Fuel Flow Method by Boeing would not have been applicable. The authors are conscious of the limit that these assumptions impose to the evaluation that is going to be presented in the following line; however, the model used in this paper does not want to be a high fidelity one because it has been created just to have a conceptual design stage evaluation of the environmental impact of the project, and then prove or not the requirements' accomplishment.

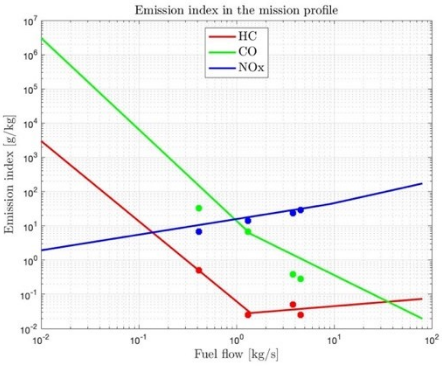

Figure 23: Emission indexes interpolation over fuel flow

Moreover, it is necessary to consider a correction relative to the supersonic part of the mission. This correction of the Boeing method for over Mach 1.0 flight conditions is reported in literature: the *Sustainable Supersonic Fuel Flow Method (S2F2)* [4]. It is based on two different coefficients which stands for the accounting of pressure (k_p) and temperature (k_t) variation due to the supersonic flow regime.

The total emissions per substance emitted in the whole Mission Profile, thus considering the LTO cycle ones too, are shown in the next figures:

- if the throttle is set to 1 for all the Mission Profile, which is an unlikely condition, the emissions reported in Figure 24 are obtained;
- If the throttle varies according to the phase of the Mission Profile (throttle variation derived from the flight simulation performed in ASTOS), which is a plausible condition, the emissions reported in Figure 25 are obtained.

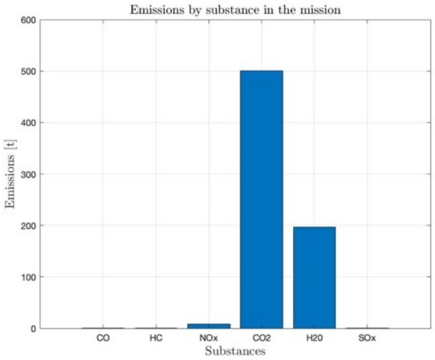

Figure 24: Mission Profile emissions per substance (throttle set to 1)

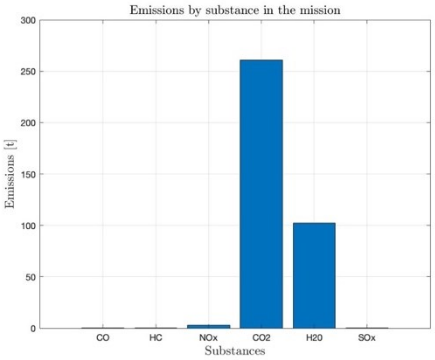

Figure 25: Mission Profile emissions per substance (variable throttle)

The results obtained in the variable throttle case are more consistent than those obtained for the constant throttle one. Moreover, such reduced emissions in the variable throttle case compared to the fixed one are also attributable to the fact that Concorde-NEO, like Concorde, has a supersonic engine operation centred on the role of compression performed by the engine intake. This allows the aircraft to fly supersonic while maintaining a reduced throttle, thus also limiting the emission of pollutants.

5.2.3. LTO cycle and competitors

After having analyzed all these results, the authors have decided to compare them with some aircraft in order to give importance to this values.

The Concorde-NEO is a supersonic aircraft, and not many more exist. After a careful analysis of potential competitors both in terms of range performance and passengers' capacity, no valuable and currently flying supersonic aircraft have been found. The authors, indeed, do not want to compare the results obtained with those of an old and polluting airplane like the Concorde, or even estimate the pollution of a not flying yet aircraft like the Overture.

It has then been chosen to compare the results obtained with some currently flying aircraft, even if this means making a comparison between supersonic and subsonic airplanes. This has been considered as not limiting as comparing the results with old or not flying yet aircrafts as the competitors selected have all been chosen by two strict criteria:

- some types of aircrafts have been selected in the narrow-body category for their passengers' capacity close to that of Concorde-NEO (120).
- others have been selected in the wide body category for having a range comparable to that of Concorde-NEO[5].

The selected aircrafts and their propulsion systems are reported in Table 10.

In order to make a comparison as solid as possible in terms of scientific relevance, and having not the possibility of simulating a mission profile for each of the aircrafts reported in Table 10, it has been chosen to compare the Concorde-NEO emission with those of competitors aircrafts at just LTO cycle level. In this way, using those parameters reported in the ICAO regulations, it is possible to use the same values in terms of throttle and phase duration time for each type of aircraft selected.

AIRCRAFT	ENGINE
A320-NEO	PW1129G-JM
A320-NEO	LEAP-1A26/26E1
B737-MAX 8	LEAP-1B21
B787-9 DREAMLINER	GEnx-1B70/P2
B787-9 DREAMLINER	Trent 1000-AE3
A330-900	Trent7000-72
A350-1000	Trent XWB-97
B777-300ER	GE90-115B

Table 10: Competitor aircrafts

Last, but not least, it has been assumed that all the competitors' aircrafts use the Jet A-1 fuel. This choice has been made in order to prevent any possible uncertainty on the results obtained because of biofuels’ emission indexes variations with reference to Jet A-1 are not certified yet.

Applying all the process previously depicted in detail for the Concorde-NEO emissions estimation, the results for all the competitor aircrafts are reported in Figure 26.

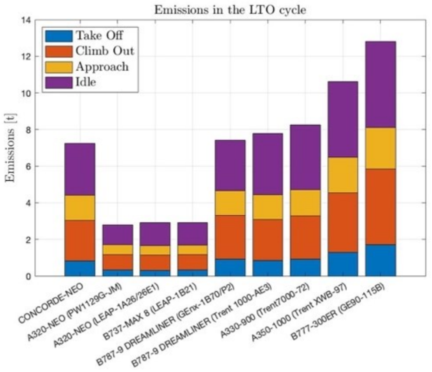

Figure 26: Competitor aircrafts' emissions

From Figure 26 it can be depicted some important trends:

- as the MTOW of the aircraft falls, the emissions produced descend because the engine onboard is smaller and thus need to generate less thrust;
- on the contrary, as the MTOW of the aircraft rises, the emissions produced increase because the engine onboard are bigger since they need to generate more thrust.

As per the net value of emissions, a four-engine supersonic aircraft like the Concorde-NEO is going to pollute as the new and most fuel-efficient widebody aircraft like the B787-9 DREAMLINER.

In addition, one thing that can be deduced from the previous graph is the difference in architecture between Concorde-NEO and all its competitors: the Concorde-NEO is not equipped with only 2 engines, but with 4. This

---

[5] Even some narrow body aircraft would be able to cover the range of Concorde-NEO, but it would mean reduce the passengers capacity and this would not be a sort of typical flight condition for an aircraft.

derives both from the Concorde configuration requirement, and even from the fact that without these 4 engines the level of thrust necessary to sustain supersonic flight would have never been reached, and therefore the project would have failed. In conclusion, therefore, it is true that Concorde-NEO consumes as much as its competitor in terms of range, even if this competitor can carry practically twice as many passengers, but it is also true that with the same level of pollution in the LTO cycle, Concorde-NEO is still an aircraft capable of flying in supersonic range and thus covering the routes of its competitor in half the time. The same applies to even larger aircrafts than the B787-9 DREAMLINER as shown in Figure 26, and even the benefit is greater because the emissions of the Concorde-NEO compared to these aircrafts are much lower, even by a few tons. Therefore, the Concorde-NEO is an environmentally preferable solution for a large wide-body aircraft.

When comparing emissions with competitors narrow body aircrafts, the LTO cycle pollution level of the Concorde-NEO is significantly higher. This could be an indicator that from an environmental point of view a smaller subsonic aircraft, which must generate less thrust, may be preferable to a supersonic one.

Another noteworthy aspect is the comparison of the indices of each aircraft obtained by scaling the emissions produced over the MTOW of each one.

From Figure 27 it can be seen that Concorde-NEO is the most polluting of all its competitors, which could make the result not as satisfactory as expected. If a more careful analysis is made of what this result implies, what is depicted in Figure 27, according to the authors, may even highlight a satisfactory result. First of all, it must be noted that Concorde-NEO has a 4 engine propulsion system as opposed to the 2 of all its competitors, a fact that inevitably leads to higher emissions simply because of the number of engines used. In addition, ICAO regulations require that LTO cycle emission evaluations for supersonic aircraft should be conducted with the afterburners on, a fact that leads to a net increase in fuel consumption compared to a normal engine with turbofan architecture. Furthermore, the Concorde-NEO engine architecture is a low BPR turbofan, while all competing aircrafts are high BPR turbofans: from a fuel consumption perspective, it is more fuel efficient to speed up by a little percentage a large amount of air, thus a higher BPR architecture, than speed up by a high percentage a little amount of air as the low BPR does.

All this leads the authors to say that, although Concorde-NEO would have about 40% more emissions/MTOW than the currently most fuel-efficient competitor in the world like the B787-9 DREAMLINER, the result obtained is not to be disdained. It has been possible to create an aircraft that, although it has lower net pollution than the B787-9 DREAMLINER, compared to the MTOW it consumes more. Nevertheless, the two aircrafts can cover the same types of oceanic routes, but the big difference is that the Concorde-NEO has the advantage of halving the time compared to its competitor.

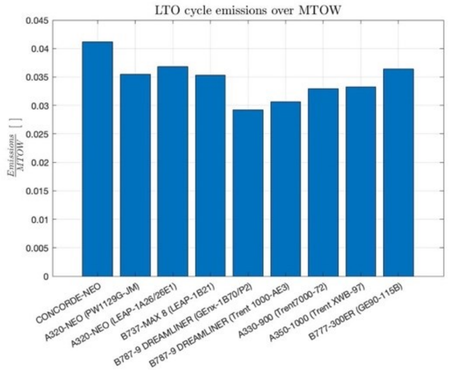

Figure 27: LTO cycle emissions over MTOW

Obviously, all these considerations are valid only and exclusively for the LTO cycle conducted with the parameters prescribed by ICAO regulations.

5.2.4. Biofuels vs Jet A-1

Finally, the last consideration that can be made on the results obtained from the comparison between the Concorde-NEO and the competitor aircrafts is the fact that the supersonic one is powered by biofuel while the latter are all powered by Jet A-1. As can be seen from Figure 26, the overall direct emissions of the Concorde-NEO are in line with those of the other competitors despite the use of biofuel. This proves that the total emissions of an aircraft do not vary with the type of fuel used, because the higher quantities of substances emitted have emission indexes that are independent of the variation of the fuel burned, like carbon dioxide and water vapor.

As a proof of this fact, an evaluation of what should be the emissions of the Concorde-NEO has also been made too.

From these results using Jet A-1 to fuel the Concorde-NEO engines, the emissions that were predominant with biofuel remain the same, as the change in fuel does not affect CO_2 and H_2O emissions. The use of Jet A-1 instead of biofuel, as already seen, influences CO, HC and NO_x emissions; but, as these three substances are negligible in terms of quantity emitted compared to carbon dioxide and water vapour, their variation is not appreciable.

	Biofuels (SIP)	Jet A1	Biofuels vs Jet A1
Emissions$_{CO}$	0,0977 t	0,1006 t	-2,8827 %
Emissions$_{HC}$	0,0032 t	0,0032 t	0 %
Emissions$_{NOX}$	2,9570 t	2,9541 t	+0,0982 %

Table 11: Mission Profile emissions variation Biofuels vs Jet A-1

This gives a clear idea of the role of biofuels in reducing pollution: the advantage in terms of environmental impact would be over the entire life cycle of the Biofuels, from production to use, because in the fuel use phase alone the gain in terms of reduction in the number of substances emitted is marginal, even an increase has been seen for NO_x.

6. Conclusions

Concerning the conclusions of the project just outlined, thanks to the simulation on ASTOS, first the feasibility of a better aircraft than Concorde was demonstrated: both in terms of performance and carried payload, nevertheless the MTOW is lower.

In terms of environmental impact, on the other hand, an aircraft with Concorde configuration and much more fuel-efficient than the Anglo-French aircraft was obtained, having low BPR turbofan architecture thrusters instead of turbojets. This already has a 22% gain in terms of SFC, thus in emissions produced. However, a detailed numerical comparison on emitted substances between Concorde and Concorde-NEO could not be made as a result of the lack of data on the Olympus 593 emissions indexes on the ICAO Aircraft Engine Emissions Databank.

Also, despite being supersonic with an afterburner, the Concorde-NEO should have net emissions in line with the more fuel-efficient modern subsonic doing similar routes. As a negative figure, however, it has been seen that by scaling the emissions over MTOW, Concorde-NEO is disadvantageous in terms of environmental impact, but still this result is justified by the fact that it is an aircraft that would fly twice as fast as others and has twice as many engines, so already more polluting.

Thus, as anticipated in the introduction, the project presented so far demonstrates the feasibility, at a conceptual design level, of a supersonic commercial transport aircraft with clear advantages in terms of both performance and environmental impact over the Concorde from which it was inspired, as well as in line with the impact of current subsonic aircraft with similar range.

7. Contact Authors

Clinca Giovanni, giovanniclinca4@gmail.com
D'Amico Francesco Antonio, damicofrancescoantonio@gmail.com
Fornaseri Federico, fornaseri.f@gmail.com
Borghi Marco, marco.borghi97@gmail.com
Versino Emanuela, emanuelaversino@gmail.com

8. Copyright Statement

9. Bibliography

[1] J. D. Mattingly, W. H. Heiser, K. M. Boyer, B. A. Haven and D. T. Pratt, Aircraft Engine Design, american Institute of Aeronautics, Third Edition, 2019.

[2] C. Weiland, Aerodynamic Data of Space Vehicles, Springer, 2016.

[3] «ICAO Aircraft Engine Emissions Databank,» 10th May 2022. [Online]. Available: https://www.easa.europa.eu/domains/environment/icao-aircraft-engine-emissions-databank.

[4] R. Fusaro, N. Viola and D. Galassini, "Sustainable Supersonic Fuel Flow Method: An Evolution of the Boeing Fuel Flow Method for Supersonic Aircraft Using Sustainable Aviation Fuels," 2021. [Online]. Available: https://doi.org/10.3390/aerospace8110331.

[5] "Concorde," [Online]. Available: http://concordesst.com.

[6] "Heritage Concorde," [Online]. Available: https://www.heritageconcorde.com.

[7] "High Biofuel Blend in Aviation," [Online]. Available: https://ec.europa.eu/energy/sites/ener/files/documents/final_report_for_publication.pdf.

[8] "IATA," [Online]. Available: https://www.iata.org/contentassets/d13875e9ed784f75bac90f000760e998/saf-what-is-saf.pdf.

[9] "Eurocontrol - Aircraft Performance Database," [Online]. Available: https://contentzone.eurocontrol.int/aircraftperformance/details.aspx?ICAO=CONC&NameFilter=concorde.

10. Other team members

MSc. Students of Politecnico di Torino: Boukas Filippo Alessandro, Bucaria Salvatore, Cencioni Davide, Chmet Lorenzo, Consolani Elia, Girardi Paolo, Strazzer Erich, Volpatto Davide