Low-boom supersonic business jet: aerodynamic analysis and mission simulation towards a CO2 emission standard

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Abstract. This study aims at investigating the aerodynamic characteristics and mission performance of a supersonic business jet at a conceptual design stage. Moreover, the environmental impact of such concept is analyzed to support the development of a potential CO_2 emissions standard for supersonic transport aircraft. The case study considered for the analysis is a supersonic business jet.

Introduction

High-speed transport has gained a renewed interest within the aerospace community during the past few decades. However, concerns about environmental impact, specifically CO_2 emissions, require a thorough analysis of aerodynamics and mission performance. This study focuses on a Mach 1.5 low-boom supersonic business jet, analyzing its aerodynamic characteristics and mission simulation to support the development of a CO_2 emissions standard for supersonic transport aircraft. CFD simulations are exploited to examine lift, drag, and pitching moment coefficients. Mission simulation is used to evaluate the performance in terms of fuel consumption and maximum range. The study also assesses CO_2 emissions standards, which are compared to subsonic limits and other supersonic concepts. The findings are expected to contribute to the design and regulation of environmentally sustainable future supersonic aircrafts.

Case Study

The case study is a Mach 1.5 low-boom supersonic business jet, 100% SAF-powered. An isometric view of the aircraft is presented in Fig. 1, while the main data are reported in Table 1.

The vehicle's configuration is derived from the *Nasa X-59 QueSST* [1], which is a configuration specifically studied for minimizing the sonic boom signature, ensuring a modest far-field pressure distribution and a reduced time distance between the two peaks of the N-wave [2].

However, to accommodate up to twelve passengers and three members of the crew, the central part of the fuselage has been enlarged, assuming a seat pitch of *1.4m*. This change in geometry generated a gap between the leading edge of the root chord of the wing and the cockpit, that were originally at the same longitudinal coordinate from the front of the vehicle, allowing the placement of the passengers' entrance door. Moreover, due to the necessity of having two thrusters for range and safety-related reasons, the two state of the art turbofan engines have been moved from the tail, under the vertical stabilizer, to the wing of the plane.

Fig. 1 Isometric view of the airplane

Table 1 Aircraft main data

Payload [kg]	1500
MTOW [kg]	39283
Empty weight [kg]	19048
Fuel mass [kg]	18434
Wing surface [m^2]	112
Wingspan [m]	14
Fuselage diameter [m]	2.2
Length [m]	44
Range [km]	3800
Mach cruise	1.5

Aerodynamic analysis

To investigate the aerodynamic characteristics of the case study, inviscid and steady *CFD* simulations are performed. Two different mesh grids are generated, one for the subsonic domain (about 5.2 million elements) and the second one for the supersonic one (about 2.8 million elements). *ANSYS ICEMCFD* [3] is used to generate the mesh grids, while *ANSYS FLUENT 2022R2* [4] is used as pre-processor and solver. An overview of the mesh grid is shown in Fig. 2.

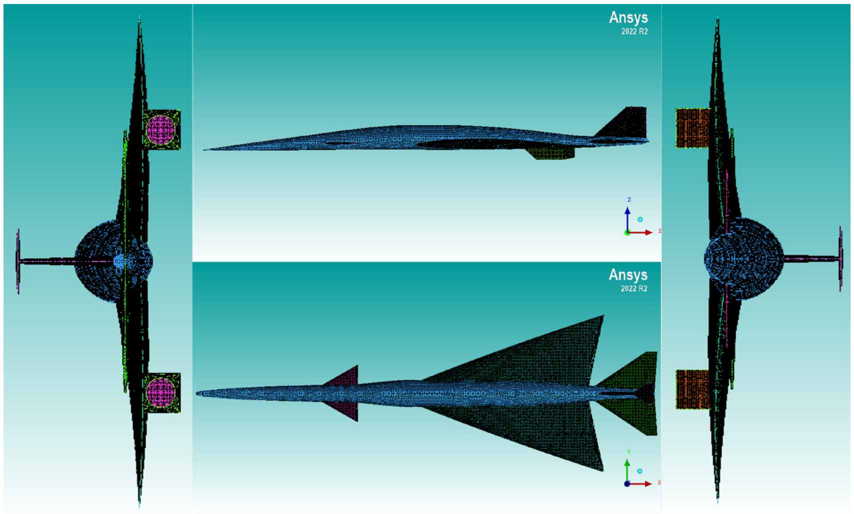

Fig. 2 Mesh grid

The resulting lift and drag coefficients as a function of the angle of attack and for different Mach numbers are reported in Fig. 3 and Fig. 4, respectively. The drag polar is also reported in Fig. 5, while the pitching moment coefficient trend for different angles of attack is shown in Fig. 6.

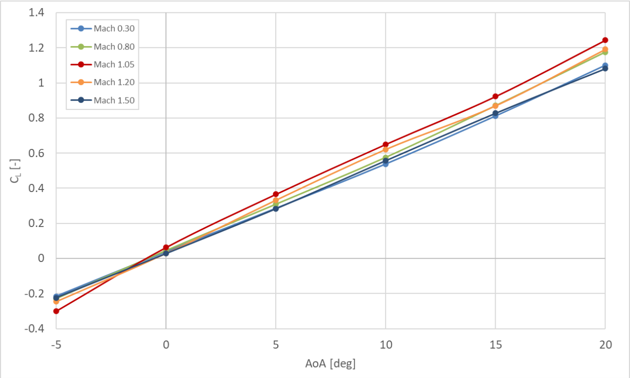

Fig. 3 Lift coefficient vs Angle of Attack for different Mach numbers

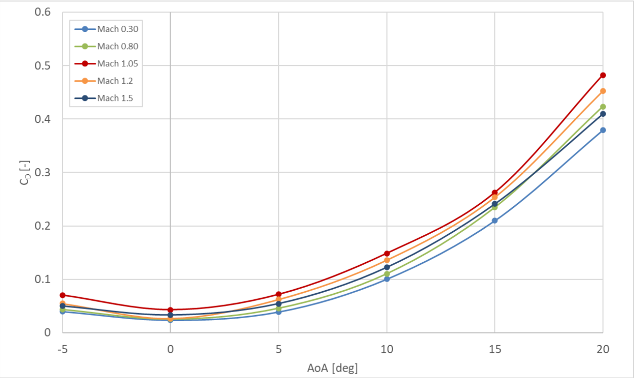

Fig. 4 Drag coefficient vs Angle of Attack for different Mach numbers

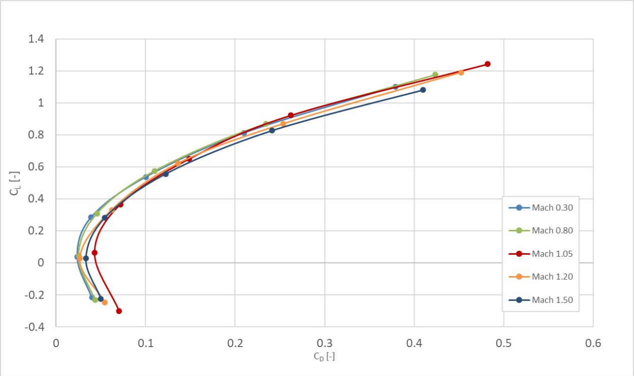

Fig. 5 Lift coefficient vs Drag coefficient for different Mach numbers

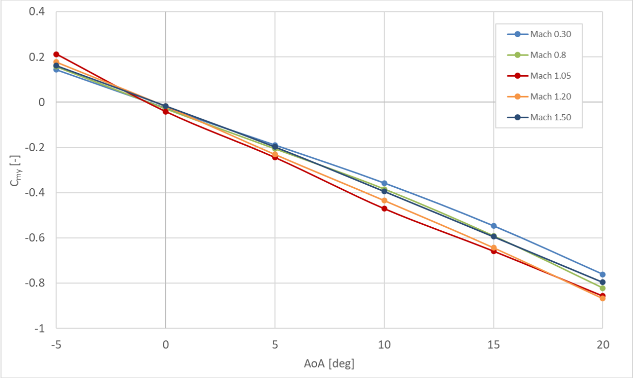

Fig. 6 Pitching moment coefficient vs Angle of Attack for different Mach numbers

Mission simulation

Once the aerodynamic database is available, the aircraft's performance along the reference mission can be studied using the ASTOS software. The main results of the mission simulation are presented in this section. The altitude and Mach profiles during the mission are reported in Fig. 7, while the total and propellant mass variation over time is shown in Fig. 8. The aircraft performs the cruise at Mach = 1.5, while the altitude varies from 14 to 17 km. The propellant on-board is sufficient to cover a range of 3800 km. The angle of attack variation during the mission is reported in Fig. 9, while the L/D ratio is shown in Fig. 10.

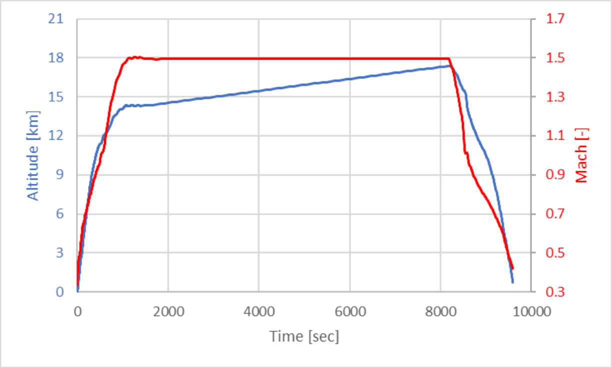

Fig. 7 Altitude and Mach profile during the mission

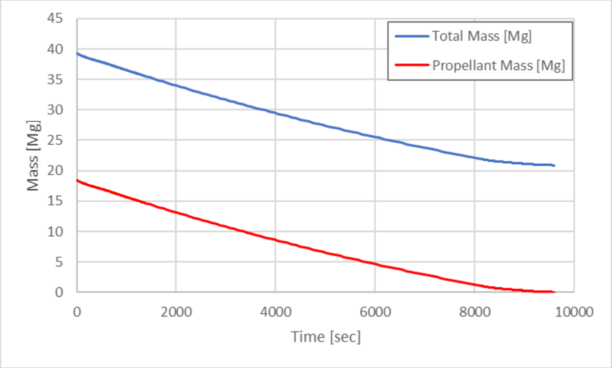

Fig. 8 Total and propellant mass variation during the mission

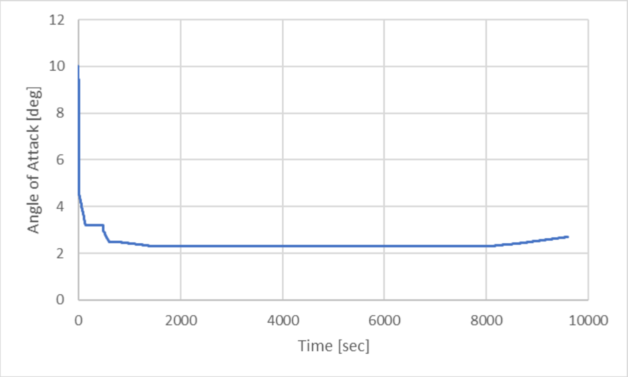

Fig. 9 Angle of attack vs time

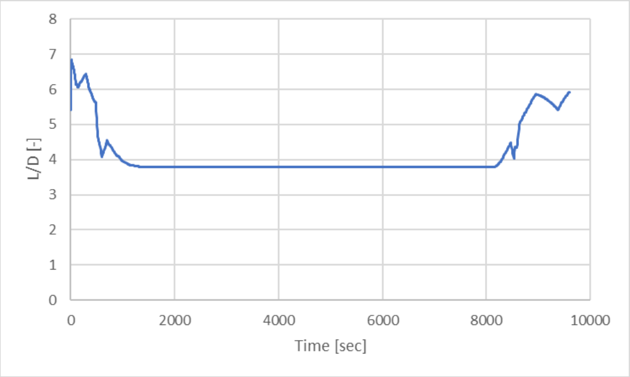

Fig. 10 Lift to Drag ratio vs time

CO_2 emission standard

The CO_2 emission standard is based on *Specific Air Range (SAR)* in cruise flight and *Reference Geometric Factor (RGF)* as presented in the following equation [5], [6]:

$$CO_2\ Metric\ Value = \frac{\left(\frac{1}{SAR}\right)_{avg}}{RGF^{0.24}}$$

Where $SAR = kilometer\ range/unit\ of\ kg\ fuel$ is a cruise point fuel burn performance while RGF is just a measure of cabin size. In line with requirements for subsonic airplanes, *SAR* values were computed for 3 specific reference points, which are function of Maximum Take-Off Mass (MTOM) and are presented in Fig. 11:

1. $High\ mass\ point = 0.92 \cdot MTOM$
2. $Low\ mass\ point = (0.45 \cdot MTOM) + (0.63 \cdot MTOM^{0.924})$
3. $Mid\ mass\ point =$ average of high and low

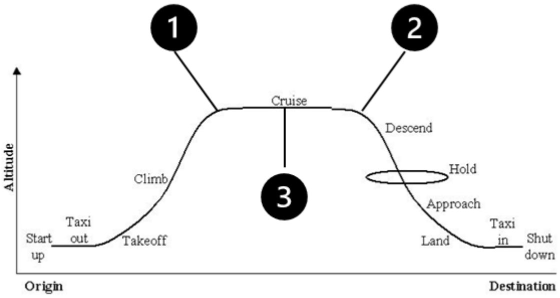

Fig. 11 Mass points for a subsonic mission

Since for supersonic aircrafts these reference points may not be representative of cruise conditions, *SAR* was evaluated at modified points, so that the high and low mass points coincided with the actual cruise start and end conditions. The evaluated CO_2 metric value for both the subsonic reference mass points and the modified ones is reported in Fig. 12. These results are compared to the CO_2 limits for subsonic aircrafts (reported with continuous lines) and to other supersonic concepts, such as a Mach 2 passenger aircraft, a Mach 1.4 and a Mach 1.6 business jet concepts.

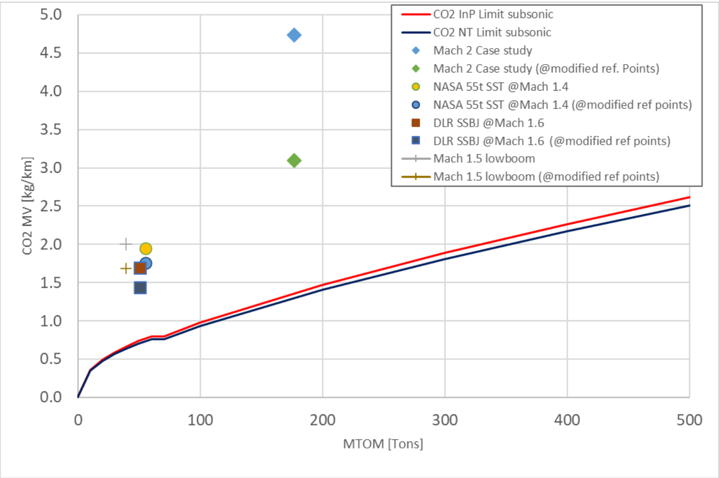

Fig. 12 CO_2 Metric value

Conclusion

A Mach 1.5 low-boom supersonic business jet concept has been analyzed in this study. The aerodynamic characteristics and mission performance of such aircraft have been computed at a preliminary design level. The capability to cover a range up to 3800 km was verified. Moreover, the Co2 metric value has been computed according to present regulations. Eventually, a comparison with other supersonic concepts has shown that the evaluated metric value has some similarities with the values computed for those aircrafts.

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