# 13. SUPERSONIC BUSINESS JET

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## 13.1 Introduction

In a world where time equals money, people try to travel fast and efficient. Business people are no exception to this statement and while the world market gets more and more global, the need to travel large distances in short amounts of times evolves. Regular business jets already provide efficient transportation in the short range market, but in the long range segment there is still room for improvement. This market niche can be filled with the development of a long range, supersonic business jet, which can provide intercontinental flight at velocities higher than the speed of sound. In this way, it becomes possible to enjoy a nice breakfast in the morning in Amsterdam, and to sign a business agreement four hours later in New York. Regular business jets would need almost eight hours for such a transatlantic trip.

## 13.2 Project objective and design requirements

The project objective is stated as follows: design a supersonic business jet using advanced technologies in high speed aerodynamics and structural design. The following top level requirements are imposed:

- Cruising speed of Mach 2
- Cruise altitude of 60,000 feet
- Range of 5000 NM
- The crew of the plane consists of two pilots and one flight attendant
- The payload consists of seven passengers, each carrying 40 kg luggage
- Sonic boom noise must be reduced, so that aviation authorities will accept supersonic travel over land
- Noise production during landing should be less than 80 dB
- The cabin pressure should be kept at sea level pressure
- Morphing technology should be used in the structure of the wing and / or the ailerons and flaps

Next to these top level requirements, there are many other requirements, concerning costs, performance, regulations, etc. An important cost requirement for example is the unit price, which has to be 80 to 100 M$ in order to be able to sell the aircraft on the market. The runway length should be around 1800 meters, so that the supersonic business jet can also operate on smaller airports where check-in times are kept short. Also, landing close to the destination is then possible, even if it is a regional destination. These are only two examples of other requirements that are considered during the design process.

## 13.3 Concept study and trade-off

After evaluation of nine different straw man concepts for the supersonic business jet, three designs were selected to be developed further. The first concept is the so called Swing Wing concept, which has a mechanism at the wing root that can sweep the wings forward and backward. The main advantage of this concept is that the aircraft has good performance in both subsonic as supersonic flight conditions. The swing mechanism however comes with a weight penalty.

The second concept has a conventional delta wing configuration, usually seen by many classic supersonic aircraft, e.g. the Concorde. Though it has good supersonic performance, performance at low flight speeds is poor and landing typically occurs at a high approach speed and high angle of attack.

The last concept has a small, conventional wing that is connected to an inverted V-tail and is known as the joined wing concept. It has low sonic boom characteristics, but the effects of lift interference at the joined wing surface and wake interference between the wing and the tail provide uncertainties which add to the design risk.

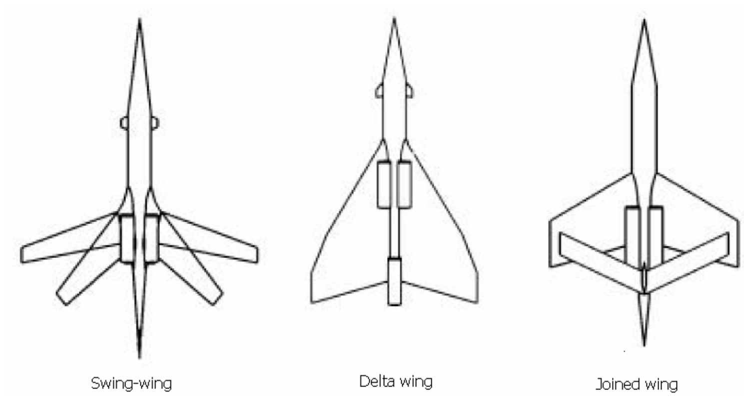


Figure 13.1: Concepts

The three previously described concepts (figure 13.1) were developed further to such an extent that a decent trade-off could be performed. The most important trade-off criteria were sonic boom strength, subsonic performance, supersonic performance, design risk and weight. The concept that had the most potential according to these criteria was the Swing Wing concept.

## 13.4 Final design

The Swing Wing proved to be the concept with the most potential and was therefore developed into further detail.

**Fuselage design**

The fuselage was designed with an inside-out approach, where first a large, comfortable cabin was dimensioned. When this was done, a slender fuselage with a sharp nose and a wing fairing for the sweep mechanism was designed. Furthermore, in order to reduce wave drag, which accounts for a large part of the drag at supersonic speeds, the fuselage was optimized with the area rule. This means that the cross-sectional area distribution of the fuselage is optimized for minimum wave drag by approaching the theoretical, ideal area distribution and removing all non-smooth contours. The outer dimensions of the supersonic business jet can be found in figure 13.2. Also, the heating of the fuselage due to supersonic flight speeds was considered and materials were selected such that the developed heat during cruise can easily be resisted. Carbon fibre composite materials assure that the expansion of the fuselage due to aerodynamic heating is kept to a minimum.

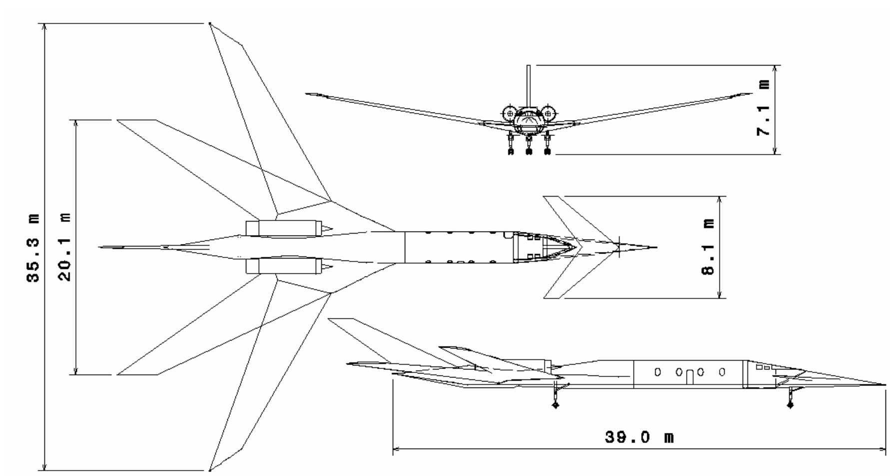


Figure 13.2: Outer dimensions of the supersonic business jet

**Wing design**

After the wing geometry was established, morphing structures were implemented at both the leading edge and the trailing edge of the main wing and on the trailing edge of the canard. Morphing structures are structural elements that can change their shape by using small actuators. In the case of the supersonic business jet, they are used as control surfaces and high lift devices, and because of their smooth, closed surfaces the drag of these surfaces is reduced. The swing wing mechanism (figure 13.3), which adjusts the sweep angle of the main wing, consists of a taper roller, double row bearing which is capable of handling all load conditions. An electro-mechanical actuator, which adjusts the sweep angle, is connected to the wing and locks itself automatically.

Supersonic aircraft like the Concorde were only allowed to travel faster than the speed of sound when overseas, because of the high noise levels. An important requirement was to reduce this sonic boom noise, so the aircraft can fly supersonic overland. The shockwaves that emanate from the nose of the aircraft and the canard are separated from the shockwaves that begin at the main wing. In this way, two small sonic booms with a maximum overpressure of 30 Pa are heard instead of one big sonic boom. It is estimated that supersonic travel overland will be accepted at 14-16 Pa, so this is still two times too high.

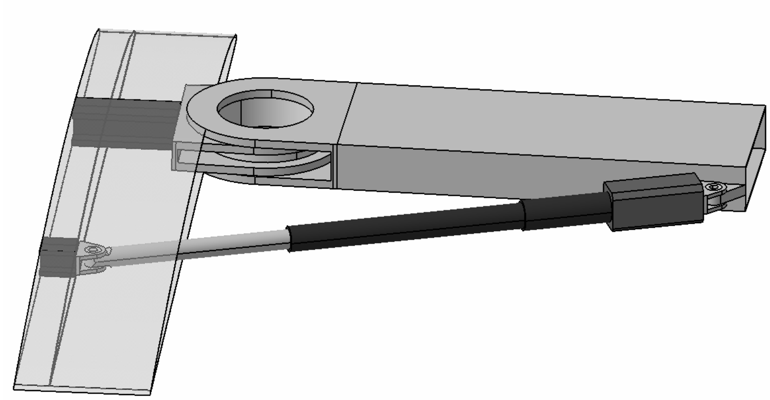

Figure 13.3: Swing wing mechanism

**Propulsion**

The high drag associated with flying through the sound barrier and the high wave drag at Mach 2 requires the installation of a powerful engine. An engine that complies with the requirements is the F119-PW-100, which was designed for the F-22 Raptor. After scaling, the modified engine delivers 128 kN per engine, which is sufficient for our purposes.

## 13.5 Overview of the characteristics of the supersonic business jet

A 3D rendered image of the supersonic business jet can be found in figure 13.4.

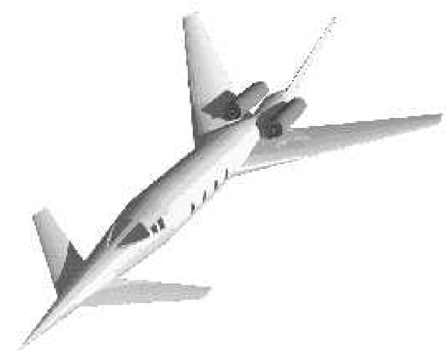

Figure 13.4: 3D model of the supersonic business jet

The specifications of the supersonic business jet are tabulated in table 13.1.

| Dimensions | | | Wing geometry | | |
|---|---|---|---|---|---|
| Length | 39.0 | m | Wing area | 135 | $m^2$ |
| Span | 35.3 | m | Aspect ratio sub-/supersonic | 3/9 | - |
| Height | 7.1 | m | Sweep angle sub-/supersonic | 35/60 | ° |
| Cabin diameter | 2.46 | m | $C_{Lmax}$ | 2.0 | - |
| **Weights** | | | **Performance** | | |
| MTOW | 402,000 | N | Cruise speed | 2 | Mach |
| OEW | 211,000 | N | Cruise altitude | 18300 | m |
| Payload | 8,830 | N | Range | 4400 | NM |
| Fuel | 182,000 | N | Required runway length | 1800 | m |

Table 13.1: Specifications overview of the supersonic business jet

## 13.6 Conclusions and recommendations

The supersonic business jet has variable sweep wings for optimal subsonic and supersonic performance, at the penalty of a slight weight increase. The leading and trailing edge of the main wing use morphing technology to replace flaps, slats and ailerons. This morphing technology keeps the wing surface smooth, increasing aerodynamic performance. Furthermore, the aircraft has a payload capacity of 900 kg. This is sufficient to carry seven persons with 40 kg of luggage each. The pressure in the cabin is kept at sea level in order to ensure optimal passenger comfort. The price of the aircraft is estimated to be $97 million. It can be concluded, that most of the design requirements are met.

The range of the aircraft is 4400 NM. Although this range is sufficient for transatlantic flights, it is less than the required 5000 NM. This range can be improved by extending the fuel capacity on board, since there is volume in the fuselage left which can be used for additional tanks.

Sonic boom regulations allow a maximum overpressure of 14 Pa for the shockwaves, for supersonic overland flight. The maximum overpressure for the business jet was reduced to a value of 30 Pa, which is about two times too high. The sonic boom noise can be further reduced with the use of advanced CFD models.

It can be concluded that it is technically feasible to build a supersonic business jet. However, still a lot of research is necessary. Nevertheless, it should be possible to successfully introduce a supersonic business jet on the market within ten years.  The aircraft will have superior performance, longer range and shorter flight times compared to current business jets, which will justify the high purchase price.