Istituto Tecnico Industriale
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3° International symposium
on Hypersonic flight

Hypersonic flight

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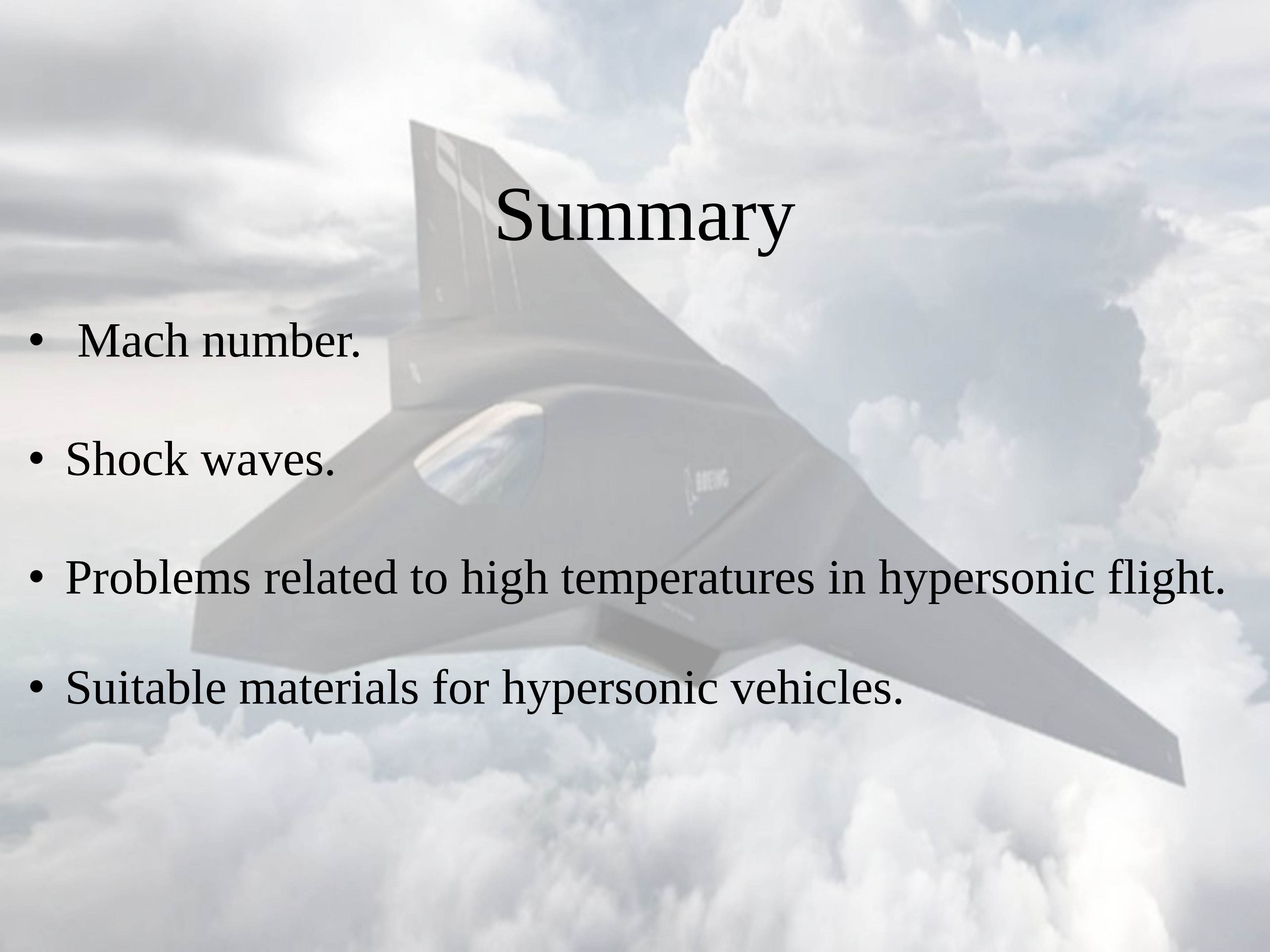


Summary

- Mach number.
- Shock waves.
- Problems related to high temperatures in hypersonic flight.
- Suitable materials for hypersonic vehicles.

Mach Number

$$M = \frac{V}{a}$$

Air speed

Speed of sound

The Mach number is defined as the ratio between the aircraft speed and the speed of sound

M<1 Subsonic

Airbus A 350.
M=0.85

1<M<5 Supersonic

Lockheed Martin-Boeing F-22 Raptor.
M=2

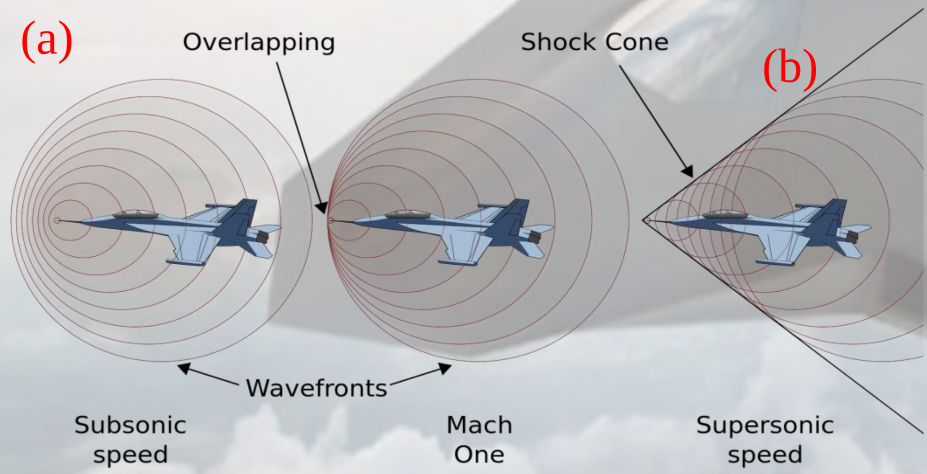
M>5 Hypersonic

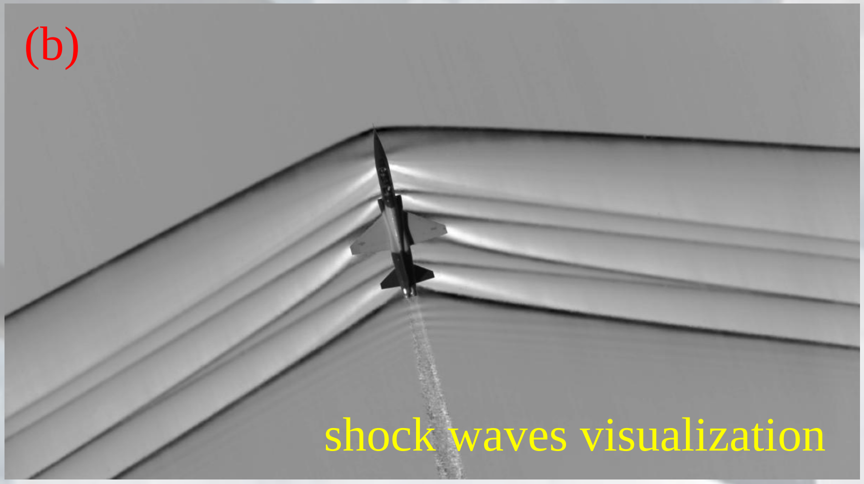
Nasa X-43 A (Test vehicle)
M=10

Shock wave

Pressure waves travel at Mach =1, i.e. at the speed of sound. If a body travels at M<1, small pressure disturbances can travel upstream and warn the air molecules to open in order to allow the body passage (a).
If a body travels at M>1, the aerial-vehicle is faster than the pressure disturbances and the air particles cannot be alerted in advance. In this case, shock wave form while the aerial-vehicle passing through the air (b).

(a)





Air temperature and pressure rise up after a shock wave

Warming up effect

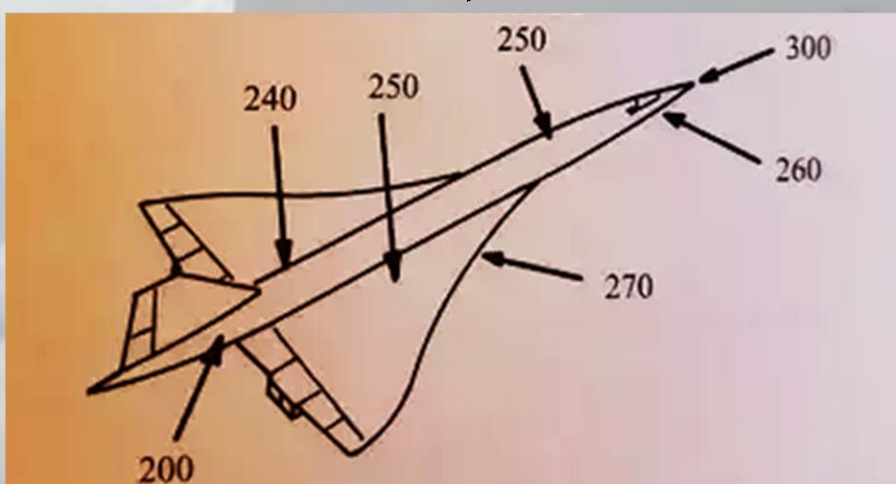
- The kinetic energy of the flow is converted into internal energy when the air flow is subjected to slowing down. This causes a warming up effect whose intensity depends on the Mach number.

- The stronger is the flow deceleration the higher will be the temperature after deceleration.

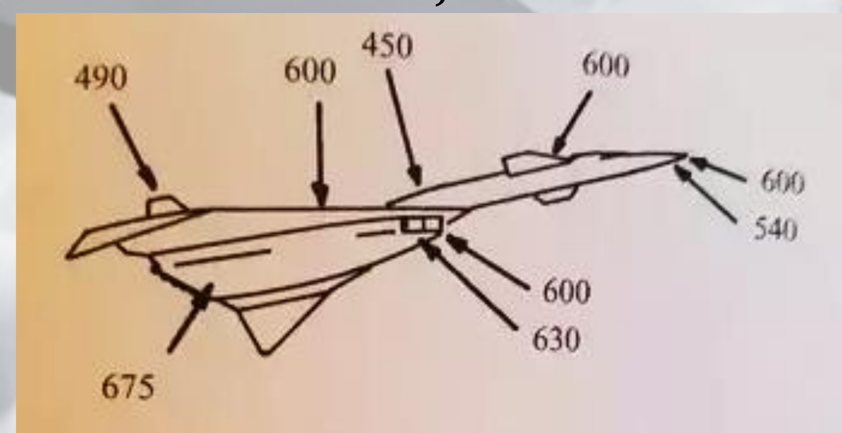
- In general the maximum temperature values are attained where the flow velocity, after deceleration, becomes 0. This happens in correspondence of the aircraft stagnation points (typically aircraft nose and wing leading edges).

Temperature on the aircraft external skin in °F
600 °F=315 °C, 300 °F=149 °C

Concorde, M=2.2



XB-70 , M=3



Warming up effect

M<1 Subsonic → No shock wave → Very low and negligible warming up effect → **M=0.8** **$T_{max} \approx T_{env}$**

1<M<5 Supersonic → Shock wave → Mild warming up effect → **M=2** **$T_{max} \approx 120$ °C**

M>5 Hypersonic → Very strong shock wave → Strong or dramatic warming up effect → **M=5** **$T_{max} \approx 10^3$ °C**

Thermo-mechanical properties of materials play a key role especially in hypersonic flight and they have to be considered during the aerial-vehicle design.

Materials mechanical properties for hypersonic jet

- **Excellent Dimensional Stability.** Structures should not modify their shape and dimensions when subjected to high temperature (low coefficient of thermal expansion).
- **Excellent Creep Resistance.** Structures should not deform permanently when they are subjected to persistent mechanical stresses at high temperature.
- **Excellent Fatigue Resistance.** Structures have to withstand when subjected to cyclic load/temperature over time.

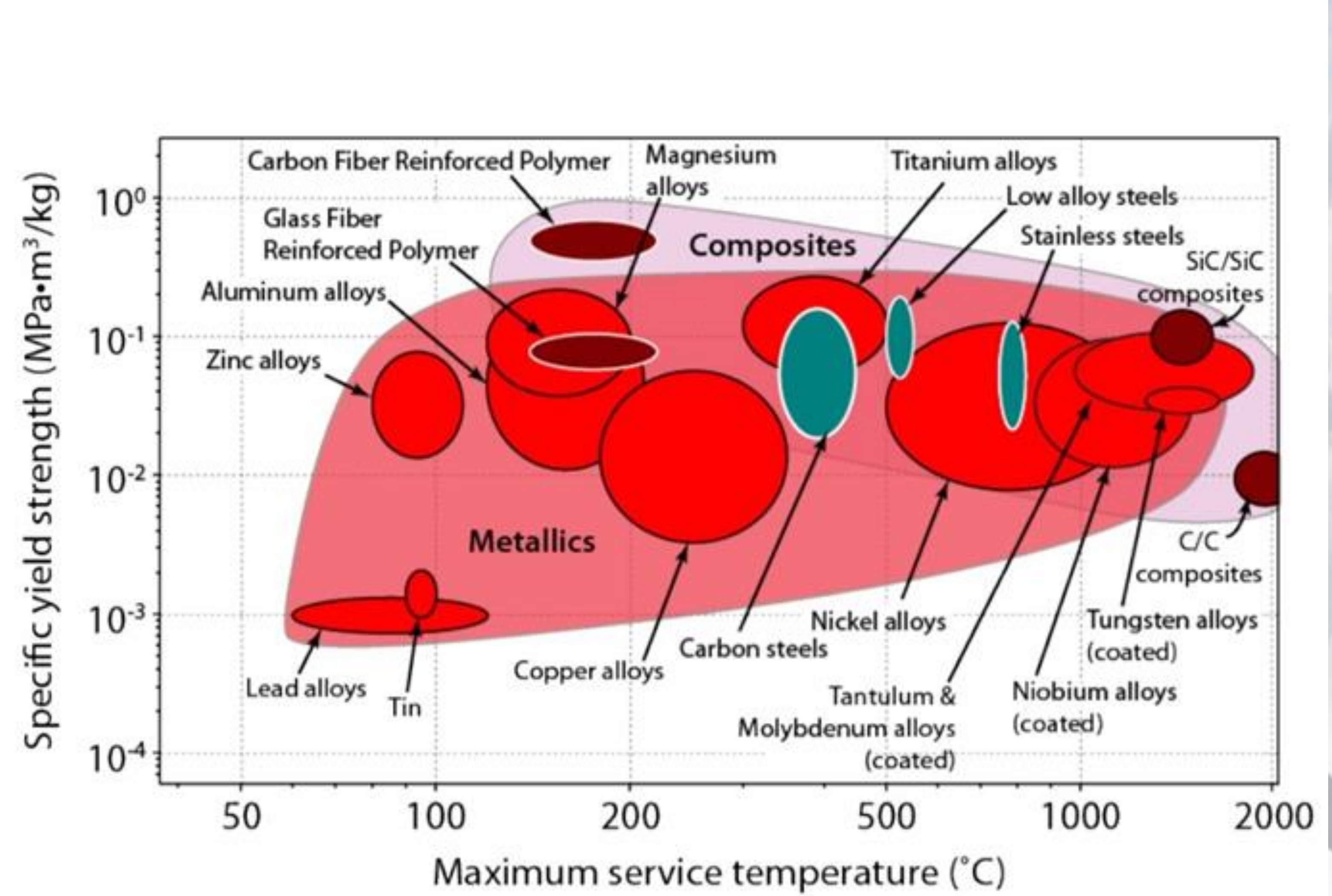
- **Low Density.**

- **High Strength.**

- **High Elastic Modulus.**

- **Excellent Oxidation Resistance.**

Materials mechanical properties



High performance materials

Titanium and Titanium alloys :

low density (4.5 g/cm^3), high strength (greater than 1200 MPa) and elastic modulus (80-145 GPa) metal. It maintains the mechanical properties also at high temperature of 400-500 °C. It has good characteristics in terms of corrosion and oxidation resistance.

Nickel and Nickel super alloys:

super alloys are based on group VIIIB elements and usually consist of various combinations of Fe, Ni, Co, and Cr, as well as lesser amounts of W, Mo, Ta, Nb, Ti, and Al. They are used in aircraft turbine engines that require high performance at elevated temperatures (T up to 1600 °C). Super alloys are also used to manufacture some components for rocket engines.

SiC-SiC composites:

materials that are made up of ceramic fibers or particles that lie in a ceramic matrix phase. They can resist to high temperatures and their creep rate at high temperatures is also extremely low. Moreover, they have an excellent oxidation resistance at high temperature (operation range >1000 °C).

High performance materials

CC composites:
composite material consisting of carbon fiber reinforcement in a matrix of graphite. Their strength is up to 700 MPa and their properties are retained also above 2000 °C. Thanks to their superior characteristics, they have been used for the nose cone and wing leading edges of the Space Shuttle orbiter.

Why not polymeric composite materials?:
Typical composite materials used in aerospace, as the carbon fiber reinforced polymer (CFRP), involve epoxy matrices. Composites involving epoxy matrices are suitable for applications under 200 °C because of the glass transition temperature of about 200°C. Instead composite materials based on polyimide matrix can be used also for applications where the temperature rises up to 300 °C, thanks to the polyimide higher glass transition temperature (about 300 °C). In particular carbon fiber reinforced polyimide composites seem to be the only feasible solution in order to extend the use of polymeric composites at higher temperature applications, as the hypersonic flight.

Conclusions

For an hypersonic aerial-vehicle the following materials can be used with reference to the local operating temperature.

Hypersonic flight is a very complex challenge with implications in several engineering fields. When hypersonic flight is a daily reality it will mean that another step in the human technological development has been accomplished.

Thank you