View metadata, citation and similar papers at core.ac.uk brought to you by CORE
provided by Archivio della Ricerca - Università di

TITLE

CURVED PLANFORM WINGS WITH A HIGH ASPECT RATIO FOR AIRCRAFTS OPERATING IN THE TRANSONIC REGIME

Technical Field

The present invention concerns the wings of aircrafts operating at cruising speed in the high subsonic regime defined also as the transonic regime.

Background Art

The cruising speed of aircrafts, commercial and non commercial ones, is established on the basis of a fair compromise between travelling time and consumption, in obedience to the endurance limits of the bearing structures and, in the case of commercial aircrafts, with reference to the machine productivity (commercial speed).

This compromise leads, in most cases, to establish cruising speeds that are kept well below the speed of sound corresponding to the flight altitude, with a margin of about 10-20%, in such a way as to avoid the sudden increase in the drag: for each projected wing configuration the so-called Drag Rise Mach = M_{DR} is defined, and it is attempted to make the aircraft fly with Mach numbers less than M_{DR}.

As shown in figure 1, for example, given an airfoil, the Critical Mach number (to which the critical speed corresponds) is the Mach number of the asymptotic flow $M_0=V_0/a_0$ (wherein a_0 is the speed of sound measured at the altitude considered) by which on the airfoil the sonic condition, that is Mach=1, is reached in some point. Its importance is significant since it indicates that, for values of the number of Mach slightly higher to the number of Critical Mach, the airfoil is immersed in a “mixed” air flow, that is in part subsonic and in part supersonic, thus finishing by operating in the so-called transonic regime. The velocity of the fluid flow around the airfoil in transonic conditions is highly unstable. As a matter of fact, once the Critical Mach is overcome, the bearing surfaces in general are violently shaken due to the formation of a “supersonic bubble” and of a consequent shock wave. As shown in figure 2, due to the dissipating and compressibility effects associated with the status of the aerodynamic field, a good part of the energy of the fluid flow that reaches and goes through the shock wave turns into heat and the so-called Compressibility Drag is produced, which is anything but to be unattended in the calculation of the total drag of the aircraft. Downstream the shock wave (that can be thought of as a permeable fluid wall of negligible thickness with respect to the dimensions of the wing airfoil) the fluid flow slows down abruptly and consequently, the distribution of the pressures around the airfoil is suddenly modified.

As it has just been explained, the shock wave is typically accompanied by a drastic variation of the pressures of aerodynamic nature in the direction of the wing sections (airfoils chords), that in certain conditions can be the cause of the separation of the fluid flow downstream of the shock wave itself, and is the cause of a strong increase in the form drag (basically due to the change of the pressures distribution) of the body immersed in the fluid current (in this case the wings themselves).

In addition, apart from producing an increase in the drag, the shock waves can also be the cause of unstable phenomena due to the interaction between the vibrational dynamics of the bearing structures of the aerodynamic surfaces and the disposition and intensity of the shock waves themselves in chord. Such phenomena can produce criticality for the aero-mechanical stability and the flight quality (directly related to passenger “comfort”) of the entire aircraft.

The more intense the shock waves that are generated on the surfaces of the wings are (the intensity of a shock wave is related to the pressure drop that is produced between upstream and downstream of the shock wave itself), the more important the physical phenomena described above are.

In order that the critical conditions described above occur, associates with the formation of shock waves, it is necessary that in most part of the wing the fluid flow reaches contemporarily a speed equal to the speed of sound relative to the flight altitude at which the aircraft operates (that is, locally the Mach Number=1 condition will have to occur).

From an aerodynamic point of view, as well as from the airfoils shape (the best ones from the point of view of the performance are called supercritical airfoils), a project parameter of which the formation of the shock waves on the wings strongly depends is the sweep angle (to which the so-called planform shape of the wings is related). In general, an increase in the sweep angle delays the reaching of the local critical conditions since it allows to reduce the orthogonal speed component at the leading edge of the wing, which is the responsible for the generation of the aerodynamic forces on the airfoil, as shown in figure 3, for example. As a matter of fact, the particles of fluid that collide with the wings are accelerated only according to a direction contained in the plane wherein the curvature of the airfoils is maximum (plane substantially perpendicular to the leading edge of the wings) and not according to the parallel direction to the leading edge of the wing itself. Therefore, the swept wing, well known in the background art, allows to increase the number of Critical Mach since the shock waves start to form, on other equal terms, for values higher than the flight speed with respect to a wing which leading edge results perpendicular to the flight direction.

In accordance with such a solution wherein the aircrafts are therefore characterized by a sweep angle of the wings uniform along the span, the attainment of the Mach=1 value on the wings (local critical condition) in reached practically contemporarily along all the wing (from the root section to the tip section).

For this reason, it is absolutely necessary to limit the cruising speed in such a way as to guarantee that the development of the shock waves (that is necessarily accompanied to cruising Mach numbers close to 1) is not the cause of an undesired increase in the drag (and therefore an increase in the consumption of fuel at equal aircraft’s range) and is not particularly violent either as to cause aero-mechanical criticality (for example, dynamic instability of the bearing surfaces) inside the flight envelope of the aircraft.

It is therefore clear that such a solution greatly limits the cruising speeds, negatively affecting the overall flight efficiency, especially in the case of commercial flights.

Disclosure of invention

It is therefore the aim of the present invention to provide an innovative wing that resolves at least in part the above-mentioned inconveniences.

In particular, it is the aim of the present invention to provide an innovative wing with a curvature projected on a plane such as to allow to increase the cruising speed, thus delaying the reaching of the transonic critical conditions, the formation of the shock waves and the increase in the drag.

These and other aims are reached with the present wing (1) operating in the transonic regime in accordance with claim 1.

In particular, in accordance with the invention, the leading edge (4) results to be curved according to a line (4) such that, locally, the angle (Λ) formed by the forwarding direction of the wing and the perpendicular to the tangent of the leading edge in the considered point increases progressively from the root section (2) towards the tip section (3) of the wing (1).

The consequence of such an increase of angle (Λ) is that the speed component (Vu) of the wing orthogonal to the said tangent at the leading edge in the considered point (speed responsible for the reaching of the transonic critical conditions) decreases progressively from the root section to the tip section.

In virtue of what has been described, unlike what happens in traditional swept wings wherein the transonic condition is established simultaneously on the whole wing, the aircraft can now reach much higher speeds protecting a good part of the wing from the formation of shock waves.

Not only does all this allow to increase the cruising speeds though keeping high the level of flight safety but it also has a beneficial effect on resistance, which reduction is estimated in around 5% with respect to the traditional wings with uniform sweep.

Such a solution, moreover, does not impede the realization of a trailing edge of the wing itself, curved or rectilinear or partially rectilinear, least of all the use of standard mobile control surfaces used in the swept wings or fixed ends surfaces for reducing the induced drag (Winglets).

Such a solution does not prejudice either the low Mach numbers aerodynamic performances.

Advantageously, such a line (4) can be with constant radius of curvature or with non-constant radius of curvature.

Advantageously, the entire length of the leading edge can thus be realized according to the said curved continuous line with constant radius of curvature or with non-constant radius of curvature.

Alternatively, in an advantageous manner, the curved leading edge (4) can comprise one or more than one rectilinear line with constant sweep angle combined one with the other or, advantageously, it can comprise one or more than one rectilinear line with constant sweep angle combined with one or more than one curved line with constant radius of curvature or with non-constant radius of curvature.

In particular, advantageously, the leading edge can comprise only one rectilinear line with constant sweep angle which is connected to only one curved line with constant radius of curvature or with non-constant radius of curvature.

In that case, advantageously, the length of the section of the curved line with constant radius of curvature or with non-constant radius of curvature is superior to the 30% of the overall length of the line (4), preferably superior to the 60%.

Advantageously, the curve with constant radius of curvature can, for example, comprise a circular arc.

Alternatively, the curve with non-constant radius of curvature can comprise an ellipse or parabola arc.

Advantageously, the wing is a high aspect ratio one.

Advantageously, the line of the aerodynamic centres (10) of the airfoils is also curved.

In particular, advantageously, the line of the aerodynamic centres (10) is arranged along the span according to the shape of the airfoil of the leading edge.

Last, it is here described an aircraft operating in the transonic regime and characterized in that it comprises a wing (1) as described.

Brief description of drawings

Further features and advantages of the present wing (1), according to the invention, will result clearer with the description of one of its embodiments that follows, made to illustrate but not to limit, with reference to the annexed drawings, wherein:

- Figures from 1 to 3 show some realization elements and a half wing in accordance with the background art, in particular fig. 1 and fig. 2 represent airfoils, while fig. 3 represents the view on a plane of a swept half wing with rectilinear-shaped leading edge;
- Figure 4 shows a view on a plane of a half wing with at least the leading edge of the wing curved, that is a projection on a plane which is curve-shaped;
- Figures from 5a to 5d show graphics of a comparative fluid-dynamic analysis;
- Figures from 6a to 6d further show comparative graphics of the aerodynamic lift and drag;
- Figure 7a show a view on a plane wherein a traditional wing is overlapped to a wing in accordance with the present invention;
- Figure 7b shows a curved wing realized with constant or increasing curvature from the root to the tip.
- Figure 7c shows a curved wing realized with a part with constant sweep angle (zone in proximity of the root of the wing) and a part with constant or non-uniform curvature.

Description of one preferred embodiment

As shown in figure 4, the leading edge 4, in particular the projection of it on a horizontal plane, has such a curved shape as to cause the progressive increase of the sweep angle Λ from the root section 2 to the tip section 3 of the wing. Contemporarily, as a consequence of this, the speed component $V(Useful) = Vo*\cos\Lambda(s)$ orthogonal to the leading edge of the wing decreases progressively along the said curve from the root 2 towards the wing tip 3, in opposition to what happens in an ordinary swept wing wherein such a speed component remains constant.

In the present description, the term curved leading edge should therefore be considered in an absolutely non-limiting manner, comprising such a term both a curved continuous line and a whole of broken lines joined in succession one to the other according to different angles.

The curved leading edge can be, for example, with constant radius of curvature, such as a circular arc, or with variable radius of curvature, such as an ellipse or parabola arc.

The same curved leading edge can be obtained through straight segments combined one with the other in sequence (broken line) according to different angles or combining one or more than one broken line with one or more than one curved line sections.

The consequence of this is that the Mach number of the “useful” fluid current (function of the V(Useful) defined above) that collides with the wing decreases progressively from the wing root to the wing tip.

In virtue of its particular planform shape (non-constant sweep angle along the span), the wing that is the subject of the invention impedes the simultaneous attainment of the local critical conditions (Local Mach Number=1) along all the wing span, thus allowing to increase the cruising speed of the aircraft.

The preceding remark implies that, also when on the sections of the wing placed in proximity of the fuselage the critical conditions are reached, the remaining part of the wing will continue to be mainly in subsonic regime and in this area of the wing those rapid and extended phenomena of instability and increase in resistance, which are typical of conventional swept wings, also if supercritical, will not happen. In Figures 5a, 5b, 5c and 5d, the results of a comparative fluid mechanic analysis conducted considering two wings (the first a swept wing and the second a curved wing) are synthetically summarized, the said wings having the same span (30 m) and the same planform surface (see also Fig. 7a). The two half wings considered have a planform surface equal to about 190 m2 and a wing aspect ratio equal to about 9,5. The two half wings have been designed using the same supercritical wing airfoil. In the cited figures, it can be seen how the distribution of the local Mach number and of the pressure coefficient by effect of the shape of the wings is modified. The shock wave present on the curved wing results less extended with respect to the shock wave present on the swept wing. Considering this, the critical conditions of a curved planform wing with a high aspect ratio (speed of sound reached in ample portions of the wing) will take place with flight speed values higher than in the case of a conventional swept wing: this fact implies the possibility for the aircraft of operating at cruising speeds superior to those currently allowed by the use of conventional high aspect ratio wings.

The preliminary comparative study already mentioned has shown that, simulating the same cruising flight conditions to those at which the most modern commercial aircrafts fly, the curved planform wing produces lower drag values of at least the 5% (for example, see Fig. 6c, 6d) with respect to a swept wing of the same aspect ratio.

Always figure 7a shows, in accordance with the invention, a comparison between a traditional swept wing and a wing in accordance with the present invention wherein the line of the aerodynamic centres 10 of the airfoils is curved.

For the particularity of the planform shape of the wing such a line is developed, in span, following the airfoil shape of the curved leading edge of the wing itself.

Apart from the purely aerodynamic point of view, the operative conditions of an aircraft having curved planform wings can present improvements also from the structural point of view. In fact, to the minor intensity of the shock waves that are formed on a curved wing is accompanied a reduction of the aero-elastic coupling between the natural modes of vibrating (bending and torsion modes) of the wing (typically involved in the attainment of the conditions of dynamic instability of the wings - flutter) and the position in chord of the shock waves themselves (that during the oscillations of the wing surfaces tends to modify itself with a consequent modification of the pressure field and therefore of the bending and torsion on the wing). In other words, the fact that the shock waves result less extended in the case of a curved wing reduces the risk of the beginning of the dynamic aero-elastic phenomena at high speeds, particularly dangerous because of the structural resistance of the wings, and consequently renders the realization of the bearing structures of the curved wings possible (at equal other conditions: used materials, detail design of the structural elements, ecc.) with traditional technologies and with a non-unattendable reduction of the weight, which is positively reflected on the aero-mechanics performance of the aircraft as a whole. In fact, it is known that a reduction of the structural weight implies a reduction of the specific consumption of fuel of the aircraft.

The structural part of the wing, as described, can also be realized in separate sections combinable in assembly phase. Each section, for example realized by moulding in stamps of carbon fibre laminates, finishes at its ends wit metal heads that can consecutively be easily worked in tolerance using the machine tools. The assembly of the separate sections takes place through the reciprocal connection of the metal heads using appropriate assembly jigs.

In the present description the term wing should be considered in a generic way, comprising such term both only the half wing as well as the whole of two half wings forming the wing of the aircraft.

CLAIMS

1. A wing (1) for an aircraft operating in the transonic regime comprising:

- A root section (2);
- A tip section (3) and;
- A leading edge (4) for connecting the root section to the tip section, and

characterized in that the leading edge (4) is curved according to a line (4) such that, locally, the angle (Λ) formed by the driving direction of the wing and the perpendicular to the tangent of the leading edge increases progressively from the root section (2) to the tip section (3) of the wing (1) in such a way that the speed component (Vu) of the wing orthogonal to the leading edge decreases progressively from the root section to the tip section, reducing the Mach number progressively.

2. A wing, according to claim 1, wherein the line (4) is with constant radius of curvature or with non-constant radius of curvature.

3. A wing, according to claim 2, wherein the entire length of the leading edge is realized according to the said curved continuous line with constant radius of curvature or with non-constant radius of curvature.

4. A wing, according to claim 1, wherein the said curved leading edge (4) comprises one or more than one rectilinear lines with constant sweep angle combined with one or more than one curved lines with constant radius of curvature or with non-constant radius of curvature.

5. A wing, according to claim 4, wherein the leading edge comprises a rectilinear line with constant sweep angle which is connected to a curved line with constant radius of curvature or with non-constant radius of curvature.

6. A wing, according to claim 5, wherein the length of the section of curved line with constant radius of curvature or with non-constant radius of curvature is superior to the 30% of the overall length of the line (4), preferably superior to the 60%.

7. A wing, according to one or more of the preceding claims, wherein the said curve with constant radius of curvature comprises a circular arc.

8. A wing, according to one or more of the preceding claims, wherein the said curve with non-constant radius of curvature comprises an ellipse or parabola arc.

9. A wing, according to one or more of the preceding claims, wherein the wing is a high aspect ratio wing.

10. A wing, according to one or more of the preceding claims from 1 to 9, wherein the line of the aerodynamic centres (10) of the airfoils is curve.

11. A wing, according to claim 10, wherein the said line is placed in span according to the shape of the airfoil of the leading edge.

12. A wing, according to one or more of the preceding claims, characterized in that it is realized in sections successively modular.

13. A wing, according to claim 12, wherein each section is realized by moulding in stamps of laminates in carbon fibre.

14. An aircraft operating in the transonic regime **characterized in that** it comprises a wing (1), as per one or more than one of the preceding claims.

ABSTRACT

CURVED PLANFORM WINGS WITH A HIGH ASPECT RATIO FOR AIRCRAFTS OPERATING IN THE TRANSONIC REGIME

The present invention concerns an innovative wing (1) specific for an aircraft operating in the transonic regime and comprising:

- A root section (2);
- A tip section (3) and;
- A leading edge (4) for connecting the root section to the tip section.

In accordance with the invention, the curved leading edge (4) is configured according to a line by which locally the angle (Λ) formed by the forwarding direction of the wing and the perpendicular to the tangent of the leading edge increases progressively from the root section (2) to the tip section (3) of the wing (1).

In such a way, the speed component (Vu) of the wing orthogonal to the leading edge decreases progressively from the root section to the tip section, thus reducing the local Mach number progressively.