EXPERT CONFERENCE: Forward Swept Wings (FSW)

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1 Introduction

Forward swept wing configuration is based on a negative angle of sweep, if compared to the traditional swept wings. This configuration was used for the first time in Germany in 1936, right before the second world war. Initially, the German company Messerschimdtt AG experimented the concept of forward swept wings; but the first airplane to fly with this kind of configuration was the Junkers Ju 287 (made once again by a German company, Junkers GmbH) in 1944.

Fig. 1 . Junkers Ju 287

Forward swept design was found to be more stressing for the wings; at that time there still were not materials suitable for such application. When the composite materials started to be available for aviation purposes, this kind of configuration could actually be adopted. In fact, U.S. Airforce managed to build an aircraft with this design around 1975, the Grumman X-29, while the Russian company Sukhoi developed the Su-47.

Fig. 2 . Grumman X-29

Fig. 3 . Sukhoi Su-47

The forward swept wing, since its weight is more towards the front, is mounted further downstream than the backward swept wing: this allows the aircraft to have more room for objects like, for instance, bombs. This was the main searched advantage, since, as we will see afterwards, this kind of wing does not have such aerodynamic advantages.

2 Aerodynamic principles

As the backward swept wings, the forward swept wings were designed to delay adverse compressibility effects and reduce their severity when they do occur [1]. Due to their swept angle, the normal mach number can be reduced by a factor of $cos(\Lambda_{LE})$. However, the main difference between both wing designs is the direction of the spanwise flow, which not only provides certain advantages but also drawbacks, commented in section 3. The figure 4 provides an accurate visualization of the direction of the spanwise flow [2].

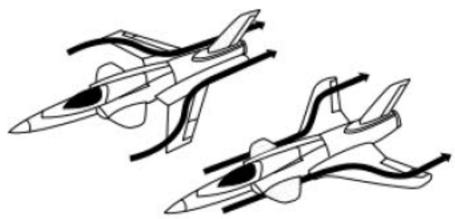

Fig. 4 . Spanwise airflow over a forward swept wing and over a backward swept wing [1].

Whilst the boundary layer over a backward swept wing develops from the wing root towards the wing tip, the boundary layer over a forward swept wing develops from the wing tip towards the wing root. This inward flow has a direct impact in the aerodynamics of forward swept wings, such as the favourable stall-progression pattern shown in figure 5. Due to the fact that the stall occurs first at the root in forward swept wings, aileron effectiveness is preserved at high angles of attack with a consequent improvement in maneuverability [1].

3 Advantages and drawbacks

Aerodynamic advantages can be grouped into reduced drag and enhanced maneuverability at transonic Mach

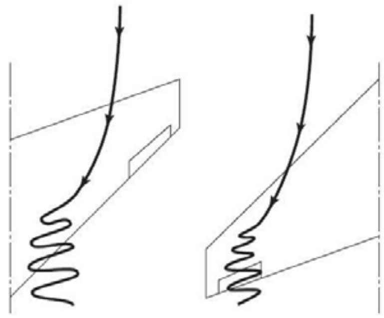

Fig. 5 . Stall-progression patterns for a forward swept and backward swept wing [1].

numbers and at high-angles of attack. As it occurs in all swept wing distributions, a swept angle helps to postpone compressibility effects. Indeed, the shock wave which occurs on the upper surface is delayed until almost the trailing edge, so it becomes as detrimental as possible. Comparing BSW and FSW with the same leading edge sweep angle, the shock wave occurs closer to the trailing edge for FSW, therefore it lowers down the shock strength and wave drag. Moreover, FSW have higher aspect ratio than similar BSW: this decreases induced drag. As it has been said before, the flow goes from the tip to the root. This phenomenon leads to better maneuverability due to the effectiveness of the aileron even at high angles of attack [1].

Furthermore, FSW have a smaller effective sweep angle than geometrical one at the leading edge (which is the other way around for BSW). This condition leads to a favourable behaviour for laminar flows. Due to the relationship between Reynolds number and sweep angle shown in equation 1 (where U_1 is the slope of the normal velocity to the leading edge and $\overline{Re}$ is the Reynolds value when transition occurs);

$$\overline{Re} = \sin\Lambda \cdot \left(\frac{Re}{U_1}\right)^{\frac{1}{2}} \tag{1}$$

Then, the lower the sweep angle, the higher the Reynolds number of the flow will be, which turns into a higher Reynolds number before transition for tapered FSW [3].

In addition to that, FSW allow an easier gear installation. Finally, turbulent flow from the fuselage does not contaminate the leading edge flow of FSW (due to inward flow, Figure 4) as it occurs in BSW, which leads to no disturbances of the laminar flow [3].

One of the main disadvantages that forward swept wings face consists on the structural divergence the wings suffered, in other words, aeroelastic divergence. At backward swept wings, the bending produced by the lift distribution reduces the streamwise angle of attack in the wing. The decrease of incidence angle of the wing will oppose to the elastic twist, hence, self reduces the possibility of structural wing divergence. On the other hand, the opposite behaviour will be faced for forward swept wings. Indeed, the spanwise incidence angle of wing will be increased due to the bending produced by the lift, enlarging even more the elastic twist. Therefore, divergence speed will be much lower for this kind of sweep configuration [4]. This effect would be mitigated by using modern composite materials to manufacture the wing, increasing the torsional stiffness, hence, the divergence velocity.

Apart from the structural issues, stability control is a topic to discuss about. Indeed, forward swept wing (negative Λ) will produce lateral instability.

When analyzing the roll stability, it can be observed in equation 2[5], it is obtained an unstable behaviour ($(C_{n_\beta})_w < 0$) for the wing contribution due to the negative angle of the FSW.

$$(C_{n_\beta})_w = C_D \frac{\bar{y}}{b} sin2\Lambda > 0 \rightarrow Stable \tag{2}$$

A similar phenomenon is experienced in the jaw stability, indeed, it can be observed in equation 3[5] that in FSW configuration an unstable ($(C_{l_\beta})_w > 0$) behaviour is faced when a sideslip angle is induced.

$$(C_{l_\beta})_w = -\frac{1}{4} C_L sin2\Lambda < 0 \rightarrow Stable \tag{3}$$

In addition, a higher wing-fuselage interference will take place since flow is developed from the tip to the root. Implementation of winglets could be problematic too.

4 Conclusions

Forward swept wings have been an attractive configuration due to some of their direct advantages such as enhanced maneuverability, wave drag reduction and favourable behaviour at laminar flow conditions. Because of all these reasons, its use has mainly been related to military applications.

Nevertheless, its development is currently on stand-by since many structural and stability control issues are still unsolved, making this wings concept not as useful as backward swept wings.

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