Forward-swept Wings

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Nomenclature

Designation	Denotation
ASW	Aft-swept wing
FSW	Forward-swept wing
AOA	Angle of attack
DFBW	Digital fly-by-wire
C_G	Aircraft center of gravity

1 Introduction

This article was written for an expert conference at Linköpings Universitet. In this short article the concept of forward-swept wings will be explained and some of its benefits and shortcomings presented.

2 General Characteristics

2.1 Packaging

A *FSW* has the wing-fuselage juncture much further towards the rear of the air-craft which could improve flexibility with the internal packaging [1]. This was the idea behind the Junkers Ju 287 which was able to accommodate a bigger bomb bay in its fuselage as it was not disturbed by wing or gear structures which were located further back [2].

2.2 Aeroelasticity

A reason why forward-swept wings are not seen very often nowadays is their aeroelastic behavior. During climb when the free-stream hits the wing tips they twist up. This leads to even more lift which promotes the described effect even more [1]. To be able to resist the high aerodynamic forces an *FSW* needs to be very rigid. This can be obtained through using composite structures. Today it is even possible to design the aeroelastic behavior of a wing which is called *aeroelastic tailoring* [3].

FWS have higher loads during high AoA compared to *ASW*. This is because at high AoA it forces the wing to twist up and hence increase the normal force of the wing, therefore the structure needs to be reinforced. An *ASW* will have the opposite effect and decrease the forces working on the wing. [4]

3 Inward Spanwise Flow & Stall Characteristics

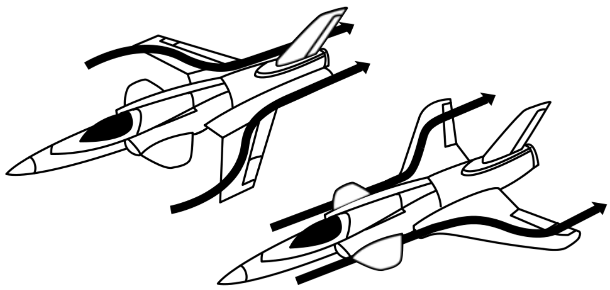

Fig. 1 Comparison of airflow of an FSW and ASW.[5]

An important aerodynamic property of an *FSW* is its stall characteristics. Wing-sweep in either direction retards the effect of wave drag by reducing the effective thickness-to-chord-ratio [6]. Both *ASW* and *FSW* divide the free flow into chordwise flow and spanwise flow. An *ASW* has its spanwise velocity component directed towards the wing tip, in turn creating a thicker boundary layer at the tip compared to the wing-root, which, could lead to a tip-stall and loss of aileron-control at high *AoA*. In contrast, spanwise flow over an *FSW* is directed toward the wing-root resulting in a root-stall, thus leading to more maneuverability at early onsets of stall compared to an *ASW* [4]. A clear visualisation of the oncoming airflow for both ASW and FSW can be seen in figure 1.

A result of *FSW* design is a reduction in drag (due to weaker wing tip vortices) and higher lift which allows a design with smaller wings. The higher lift can be explained by the fact that there is a better airflow at the wing root which in general has a larger chord and can therefore produce more lift than the wing tips.

Moreover, the locations of the stall (tip-stall for an *ASW* and root-stall for a *FSW*) can cause further aerodynamic issues. Since the C_G is in front of the tip (*ASW*) or root (*FSW*) a stall will create a moment which pitches the aircraft up, essentially progressing the stall even further [4]. The result is a more pronounced pitch-up effect in a *FSW* than an *ASW* due to the loss of lift at the root.

4 Instability

Most jet fighters do not have static stability which is the ability to come back to level flight position automatically. The goal of a jet fighter is to be highly maneuverable and instability can contribute to this. If an axis is unstable, only a little amount of energy is needed to initiate a big response/ maneuver. However, more energy is needed to stop or reverse the deviating motion. Instability is a question of balance between being able to make rapid extreme maneuvers and the ability to keep control of the aircraft [7]. Therefore, a lot of very quick adjustments must continuously be made by the aircraft to keep control.

4.1 Pitch Instability

Generally with *FSW*, the center of pressure is ahead of the C_G due to wing root being further back on the fuselage. This usually demands a canard configuration because the empennage would have to generate huge downward forces to compensate for the nose-down moment. Since both surfaces are lift surfaces, this encourages further instability [4].

Another property that promotes the pitch instability of *FSW* is the aeroelasticity of the wing especially at high AoA which has been explained in section 2.2

4.2 Yaw Instability

FSW designs are very unstable when yawing (turning around the horizontal axis). When the plane yaws in one direction the inner wing retreats while the outer advances. While retreating, the inner wings sweep angle towards the free-stream decreases which results in rising drag. The exact opposite happens on the outer wing which enforces the yaw instability. An *ASW* configuration in contrast will stabilize itself during yawing. This is because the advancing and the retreating wing are just swapped compared to the *FSW* which leads to aerodynamic forces that push the plane back into stable flight [8].

4.3 Case Study: Grumman X-29

The Grumman X-29 is probably the most famous example of a supersonic *FSW* aircraft. There were especially two factors that made the development of the X-29 possible in the early 1980s: *DFBW* and composite structures [7, p. 5].

The composite structures have been needed to build a wing that is rigid enough to withstand the high aerodynamic forces and have the desired aeroelastic behavior. Especially when flying at high *AoA* the aerodynamic forces on the tips of the wings are very high.

On the other hand the *DFBW* ensured that the plane was flyable despite its extremely unstable behavior in pitch and yaw. The X-29 had therefore a redundant system of three digital and three analog flight computers which made the probability of a total computer failure as probable as the failure of a mechanical component on a regular airplane [7, p. 30].

The main advantages of this concept were the capability to fly at high *AoA* (approx. up to 60 °) while maintaining good maneuverability and controllability. In addition to that the design of the X-29 which combined canards with a *FSW* reduced drag and as a result of this also fuel consumption [7, p. 18].

Fig. 2 The experimental aircraft Grumman X-29 and it's forward swept wings.[3]

5 Discussion

The concept with *FSW* is an interesting one and has its advantages and disadvantages. Nowadays, we should have the technological means to solve the problems that were encountered with *FSW*. As seen, *FSW* offers advantages in high maneuverability and good stall characteristics. However, *FSW* are not the only approach to make a plane more manoeuvrable. Thrust vectoring is used a lot in fifth generation fighters and is a proven concept for example. This does not mean that we will not see this technology in future concepts, it will depend on what the requirements of the industry will be, like stealth (radar cross section depends a lot on the geometry of the aircraft) or ability to fly unmanned missions.

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