Forward Swept Wings

Antoine Bouilloux-Lafont, Aditya Naronikar, Nagajyothi Prakash and Shravan Vijayaraghavan
TMAL02, Linköping University, 2017

Today, the wing design of most aeroplanes presents a sweep angle, that is a wing that angles backward (positive sweep) or forward (negative sweep) from the root. Sweeping the wings of subsonic aircraft delays the drag divergence to higher Mach number [1]. In other words, the Mach critical number of the wings is increased, hence allowing the aircraft to fly at higher velocities. For supersonic aircraft, swept wings delay the shock waves and the aerodynamic drag due to compressibility near the speed of sound. Although the general trend for aircraft design is having the wings sweeping backwards, forward swept wings (FSWs) offer as many advantages as the conventional wing configuration.

On an FSW, the air flows inwards towards the root. This ensures that wing tip vortices are not developed by allowing the air flow to stay attached to the wing surface (figure 1). This effect is observed even at high angles of attack (AoA). This translates as very high manoeuvrability in the stall region of the aircraft. [2] Another factor influencing manoeuvrability is that FSWs allow the wing root to be placed further aft, moving the centre of lift closer to the fuselage's centre of gravity, further aft due to the engine location.

Winglets are not necessary for FSWs as the oncoming freestream makes contact with the tip of the wing before it does with the root. This reduces the wake vortices that are formed and thus, the boundary layer at the tips is not affected by the inner portion of the wing. One of FSWs main issues is that wing twist is amplified by aerodynamic forces. This occurs when the wing loading due to lift forces is larger than the structural elastic restoring forces. If the wingtip for a rear swept wing is bent upwards due to turbulence, then the increased pressure at the top portion of the wing would result in pushing the wing back to a flat shape. Inversely, as the tip of a FSW is twisted upward, the increased pressure on the bottom pushes the wing in the direction of the twist. In consequence, FSWs need to be much stronger at higher velocities.

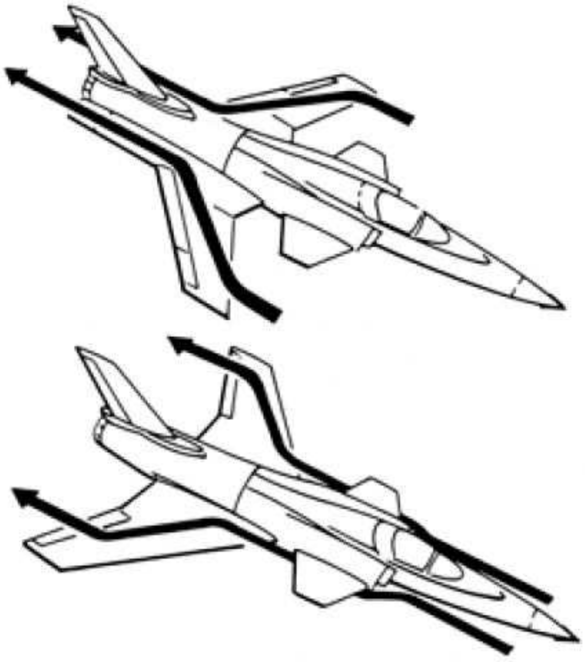

Fig. 1 . Flow pattern over FSW and BSW aircraft [3]

A very stiff FSW would lead the entire airframe to be pulled in the direction of any wingtip twist. This inherent instability gets worse at higher speeds, severely affecting the stability of the aircraft. One way to mitigate the problem would be to make the leading edge of the wing stiff. For a FSW aircraft, stall takes place inboard first and this results in an upward pitching moment. The tail assembly needs to be strong enough to counteract the pitching moment to avoid "super" stall of the aircraft[4]. An FSW has to be much stronger as there is positive feedback from wing bending, and needs to have an increased wing strength or passive/active flutter dampening devices. In fact, if the wings start to bend or flutter, then the primary aero-elastic forces are in the same direction of deflection which is of primary concern. To compensate such an event from happening, the wings need to be stronger and thus, heavier [5].

Another disadvantage of FSWs is Aeroelastic Divergence, which occurs when the wing loading due to lift forces is larger than the structural elastic restoring forces. This results in an increase in the deformation until the failure of the structure. To overcome divergence, the material and construction of the wing must be able to handle the associated high wing-loading forces. Hence, composite materials would be a viable choice for FSWs manufacturing, adding the required stiffness to the structure whilst maintaining a minimum weight. Research shows that a 35-sweep angle FSW made of composite materials is roughly 10% of the weight of an equivalent structure made of Aluminium[3].The component lay-up and/or stacking procedure as well as the composition of each composite component used in the design of an FSW can be effectively calculated using the ‘Aeroelastic Tailoring’ optimization method [2]. Aeroelastic Tailoring optimizes the structure of the composite in order to reduce aircraft weight, improves stability whilst maintaining good manoeuvrability and aerodynamic performance. Research shows that as the forward-sweep angle is increased, the optimum structural mass increases. Also, the Bending Stiffness, Flexural Rigidity and Torsional Rigidity decreases from wing root to wing tip [2].

Ever since the 1980s, the forward swept wing aircraft had been long studied and left behind. Except for the failed Russian attempt to compete against foreign military aircraft with the SU-47 "Berkut" in 1997, the concept of FSW was left to aviation history pages [6]. Nevertheless, in more recent times, FSW seem to come back into consideration for new modern aircraft designs. Nowadays, some designs for gliders include FSW with a small sweep angle. The LET L-13 Blanik, originally designed in 1956, remains a model for current glider designs (L-23NG [7]). The use of this particular wing configuration for gliders is mainly explained by their relatively low speed where the wing twist, stiffness and stability being well managed without over increasing the wing structure weight.

The Institute of Aeroelasticity of the German Aerospace Center (DLR) also recently conducted projects concerning a short to medium range commercial aircraft using FSW. The aim of those, such as the LamAiR and iGreen aircraft projects, was to modify the existing Airbus A320-200 model by adding a FSW in order to reduce fuel consumption and emissions. The DLR projects concluded that the design of such aircraft was plausible, reducing up to 9% and 10.8% the fuel consumption and emissions, respectively [8].

Another example of this old technology resurrection is the SR-10 trainer aircraft designed by KB SAT (Modern Aviation Technologies). With a 10 degrees FSW, the Russian modern composite aircraft, accommodating two passengers in a tandem scheme, made its maiden flight on the 25th of December 2015. KB SAT claims this configuration makes the SR-10 highly maneuverable and hence a great asset for sport aircraft competitions. The Russian army has already ordered four of these new full-composite aircraft and KB SAT is expecting a mass production over the next few years [9]. Based on the recent success of the SR-10, KB SAT announced at the 2017 MAKS Air Show (Moscow) an upcoming Unmanned Combat Aerial Vehicle (UCAV) variant. Indeed, in addition to its weapon payload, KB SAT specified that the future so-called AR-10 UCAV would have an extended range of 100 km compared to the SR-10 model (ref KB SAT).

Authenticity and Plagiarism

By submitting this report, the author(s) listed above declare that this document is exclusively product of their own genuine work, and that they have not plagiarized or taken advantage from any other student’s work. If any irregularity is detected, the case will be forwarded to the University Disciplinary Board.

REFERENCES

[1] Anderson, John David, Jr. *Introduction to flight*. 8th ed. Boston: McGraw-Hill, 2016.

[2] *Composite stacking sequence optimization for aeroelastically tailored forward-swept wings*. Structural and Multidisciplinary Optimization.

[3] Johnsen F A. *Sweeping Forward: Developing and Flight Testing the Grumman X-29A Forward Swept Wing Research Aircraft*. National Aeronautics and Space Administration, 2013.

[4] Miller J. *The X-planes*. Aerofax, 1988.

[5] *Characteristic flow patterns and aerodynamic performance on a forward-swept wing*. Journal of Mechanical Science and Technology.

[6] Gordon Y. *Sukhoi S-37 and Mikoyan MFI: Russian Fifth-Generation Fighter Demonstrators*. Midland Publishing, 2002.

[7] Blanik Aircraft CZ s r o. 2017.

[8] Seitz A, Kruse M, Wunderlich T, Bold J and Heinrich L. *The DLR Project LamAiR: Design of a NLF Forward Swept Wing for Short and Medium Range Transport Application*. AIAA, 2011.

[9] Modern Aviation Technologies K B. 2017.