published in:
Aviation in Europe - Innovation for Growth
Proceedings of the Seventh European Aeronautics Days
ed. by. D. Knörzer, C. Warsop, C. Diaconescu, J.-P. Sanfrouche
doi:10.2777/62810 (print) 20.2777/49217 (PDF)
ISBN: 978-92-79-59141-9 (print) 978-92-79-59140-2 (PDF)

High-Performance High-Lift Design for Laminar Wings

Jochen WILD

Abstract. This contribution summarizes project results dealing with the design of Krueger devices for laminar wing application, both for natural laminar flow and hybrid laminar flow control wings. The designed Krueger devices feature guaranteed anti-contamination shielding properties and a high aerodynamic performance nearly comparable to classical slat devices. Within verification wind tunnel tests, the design has demonstrated a 5-7%fuel burn reduction compared to a turbulent wing design.

Keywords: Aerodynamics, High-Lift, Laminar Wing, Krueger Device, Optimization

Background

From the perspective of the society, politics, economics and environment it is necessary to reduce the fuel burn of transport aircraft. From an aerodynamic perspective, the most promising technology to support the high-level target of 50% fuel burn reduction by 2050 is the realization of laminar wing design. The laminar technology offers great potential, but is sensitive to surface imperfection (suction side) and contaminations (e.g. insects), which lead to an undesired transition from laminar to turbulent flow. Therefore, for enabling such wing technology a suitable and compatible high-lift system, especially at the leading edge, has to be found. Such a system has to avoid surface steps and gaps at the suction side and should ideally work as a contamination protection device when deflected in low altitudes.

The most promising leading edge device type for a laminar wing is therefore a nose split flap, better known as Krüger device. With such a device it is possible to ensure a surface without imperfections on the upper (suction) side and to shield the leading edge of the main element during take-off and landing. One shortcoming of the currently realized Krüger devices (e.g. B747) is the lower aerodynamic performance compared to slat devices. The objective is thus to investigate Krüger design principles that cover the above requirements for laminar wing application together with an aerodynamic performance as close as possible to classical slat devices.

To underline that this is not a new idea, a look into past reports opens up the strategy to find such a solution. In 1996, Rudolph states in his famous report [1]:

> "***Folding, bull-nose (rigid) Krueger*** *- The simple Krueger flap can be improved by adding a folding bull nose to it. Hinged to the aft end in the stowed position, the folding bull nose is a panel that runs the length of the main Krueger panel. It has a D-shaped cross section, and it is connected with a slave linkage that rotates to deploy the bull nose as the main Krueger panel deploys. Because of the rounded bull nose, the folding, bull-nose Krueger is more tolerant to changes in angle of attack. As a*

result, the flow on the upper surface of the Krueger is attached over a wider angle-of-attack range."

*"**Fixed-camber Krueger** - There has been no effort to develop the fixed-camber Krueger into a device that has characteristics similar to that of a slat, except for the work done on the 757 hybrid laminar flow experiment. Therefore, this area is one in which research could help the future implementation of hybrid or natural laminar flow concepts."*

It is especially the second statement what we currently target in our design work on Krüger devices to enable laminar wing technology.

Krueger design for a natural laminar flow (NLF) wing

In the frame of the project "Design, Simulation and Flight Reynolds Number Testing for Advanced High-Lift Solutions (DeSiReH)" funded by the EC within the 7th framework program, the topic of high-lift design for a natural laminar flow wing was tackled. Based on the experience from the preceding project "EUROLIFT II" [2] a complete aerodynamic design and validation chain was performed. Starting from identifying and specifying the design problem in terms of objectives and parameters, evaluating design methodologies [3], and evaluating current improvements in CFD for high-lift flow simulation [4], different types of high-lift devices (leading and trailing edge) were analyzed for their suitability for a natural laminar wing, which we obtained from the TELFONA project [5].

The major contribution of the work performed was taking into account all the requirements and using numerical optimization directly for this purpose [6]. The requirement for contamination shielding has been directly incorporated in the parameterization of the geometry resulting in a guaranteed shielding property for all generated instances during optimization. The same has been obtained for the limitation from the mechanical integration in terms of respecting the designated kinematics type throughout the design process.

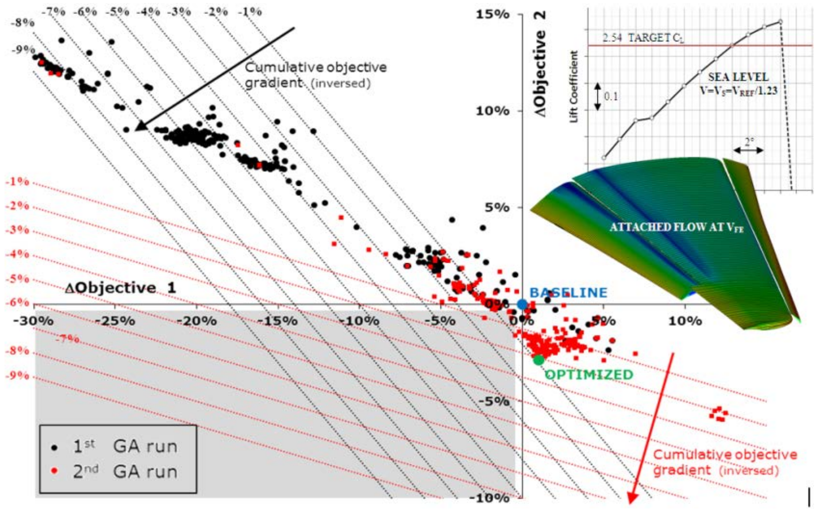

Figure 1.Numerical CFD-based optimization of 3D high-lift natural laminar flow wing with Krüger device.

After performing full 3D optimization (Figure1), the final high-lift wing was incorporated into the DLR-F11 wind tunnel model and tested at flight Reynolds numbers in the European Transonic Windtunnel (ETW) facility [7]. The original model was equipped with a classical turbulent high-lift wing and was tested within the EC funded projects EUROLIFT I and II [8]. The comparison of the high-lift performance in terms of lift coefficient over angle of attack (Figure2) shows a quite similar maximum lift coefficient, where the Krueger based high-lift system obtains its lift at slightly lower angles of attack.

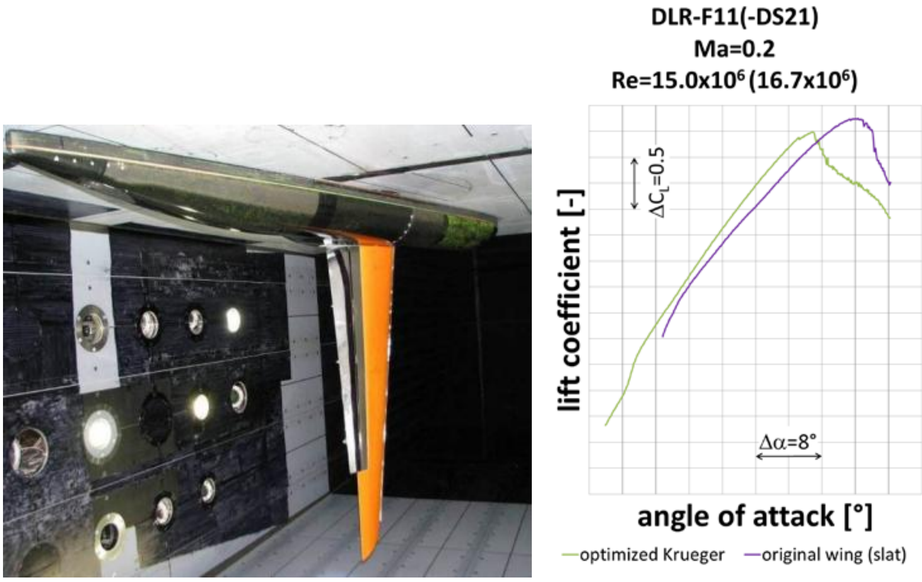

Figure1. Design verification test in ETW at full aircraft Reynolds number verifying an aerodynamic performance comparable to a classical turbulent wing with slat.

Finally, an assessment on aircraft level was performed to quantify the benefits of the new high-lift wing design [9]. Two configurations were considered: (a) a classical turbulent wing with a slat; (b) the designed laminar wing with Krueger device. The global aircraft requirements were kept constant and were driven for high-lift flight phases by the requirement of a landing field length less than 4000ft. The assessment included the impact of laminar/turbulent flow conditions and reserve fuel policy, which is related to the probability to loose partially or fully the benefit of laminar flow (Figure 3). The assessment showed that the laminar flow technology can save 5 to 7% fuel burn on trips between 500 nm and 2000 nm. The benefit is significantly less with conservative assumptions for reserve fuel. It has to be pointed out that one of the main drivers for this net benefit is related to the good aerodynamics of the high-lift system that prevents the need for increasing the wing size for sufficient low-speed aircraft performance.

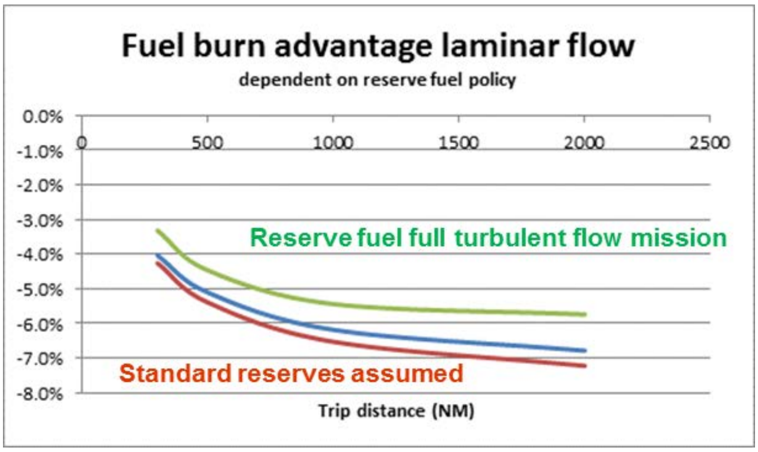

Figure2: Assessment of fuel burn savings of natural laminar wing incorporating high-performance high-lift system.

Krueger design for a hybrid laminar flow control (HLFC) wing

Integration of a Krueger device into a wing leading edge for hybrid laminar flow control (HLFC) faces different requirements, while the general functionality requests on high performance and shielding properties remain. The airfoil shape of an airfoil for HLFC is not as sharp as for NLF, but the wing integration for the interior is more challenging due to the number of additional systems for the suction system for HLFC is more restricting regarding the space allocation.

Within the current EC funded project AFLoNext [10], a full integration study is performed for integrating all the HLFC system together with the Krueger device into an outboard portion of an HLFC wing (Figure 4) [11].

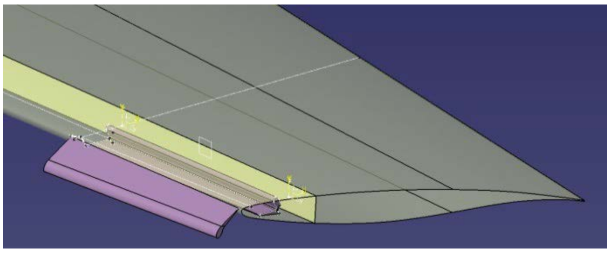

Figure 3.Aerodynamic design of the Krueger device at an outboard HLFC wing shape (image from [11]).

In addition to the studies performed on the NLF wing before, now the complete realization of the systems are done, since space allocation has turned out to be a very crucial issue, especially due to the additional space needed by the HLFC system which makes the interior of the wing leading edge extremely crowded. The realization of the Krueger system is achieved in close cooperation with partners caring about the detailed designs of the Krueger panel structure (INVENT GmbH) and the kinematics (ASCO N.V.).

The aerodynamic design [12], again compared to a classical slat design (Figures 5 and 6), but now on the same wing shape, reveals again a loss of maximum lift coefficient but this time a gain in drag coefficient for the nearly complete range of incidences within the operational regime. It should be noted that the loss in lift is mainly related to the space allocation limiting the feasible size of the Krueger device while the size of the reference slat was not limited by additional system constraints.

Nevertheless, the performed studies reveal that a Krueger device can be designed for very high aerodynamic performance while still respecting the special needs resulting from laminar wing applications. But even for standard wings such a concept has benefits in terms of drag and even system weight.

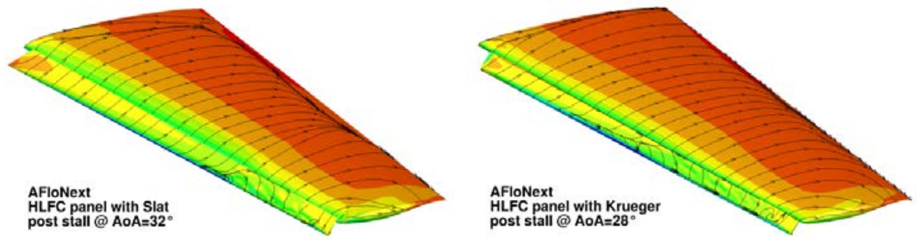

Figure4. Comparison of CFD prediction of HLFC wing segment with leading edge device at stall onset: (left) with slat; (right) with high-performance Krüger device.

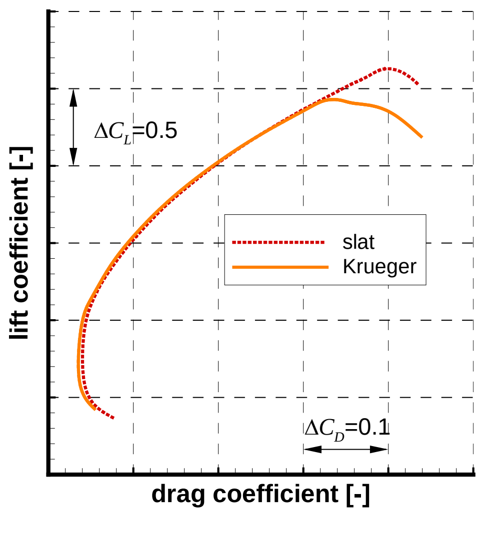

Figure 5. Comparison of aerodynamic performance of HLFC wing segment with different leading edge devices.

In the further scope of the project, a ground based demonstrator including fully functional Krueger device, is currently being developed. This will be ground tested and incorporated into a wind tunnel test in CIRA icing wind tunnel later this year. Finally the project aims on performing also a bird strike test on this ground based demonstrator.

Conclusion

Within the mentioned projects, we succeeded to design vented folding bull-nose Krueger devices for laminar wing application for both natural laminar flow and hybrid laminar flow control wings. The designed Krueger devices feature guaranteed shielding properties (to prevent insect contamination) and a high aerodynamic performance nearly comparable to classical slat devices. For both types of wings, a feasible kinematics and mechanical integration has been found that fits the Krueger device also in the very restricted space at HLFC leading edges. The design methodology has proven to be suitable for designing directly for real flight conditions. During verification wind tunnel tests the performance targets were met. Based on this data a 5-7% fuel burn benefit has been assessed on aircraft level for the NLF wing, heavily related to the avoidance of wing size increase due to a satisfactory high-lift performance.

Acknowledgements. The project DeSiReH was funded by the European Commission (EC) under Grant Agreement ACP8-GA-2009-233607. The project AFLoNext is funded by the EC under Grant Agreement ACP3-GA-2013-604013.

References

[1] P.K.C. Rudolph: High-Lift Systems on Commercial Subsonic Airliners, NASA-CR 4746 (1996).
[2] J. Wild, J. Brezillon, O. Amoignon, J. Quest, F. Moens and D. Quagliarella: Advanced design by numerical methods and wind-tunnel verification within European high-lift program. Journal of Aircraft, Vol. 46, No. 1 (2009).
[3] E. Benini, R. Ponza, P. Iannelli, H. Strüber, Z. Hrncir, F. Moens and T. Kuehn: Multi-point shape and setting optimization of high-lift airfoils in both take-off and landing conditions. ECCOMAS 2012 Conference proceedings, Vienna, Austria (2012), Paper 3819.
[4] P. Eliasson, C.M. Marongiu and S. Bosnyakov: Acceleration of URANS for application to separated high-lift flows. ECCOMAS 2012 Conference proceedings, Vienna, Austria (2012), Paper 2234.
[5] D. Sawyers: Progress in Natural Laminar Flow Wing Design and Wind Tunnel Testing, Aerodays 2011, Madrid, Spain (2011).
[6] P. Iannelli, J. Wild, M. Minervino, F. Moens and A. Vervliet: Analysis and Application of Suitable CFD-Based Optimization Strategies for High-Lift System Design, ECCOMAS 2012 Conference proceedings, Vienna, Austria (2012), Paper 2235.
[7] D. Meissner, F. Cusset, J. Wild and M. Schulz: Experimental Verification of the DeSiReH High-Lift Wing at Aircraft Flight Conditions, EUCASS 2013 conference, Munich (2013).
[8] R. Rudnik and E. Germain: Re-No. Scaling Effects on the EUROLIFT High Lift Configurations, 45th AIAA Aerospace Sciences Meeting and Exhibit, AIAA Paper 2007-0752, 2007.
[9] H. Strüber and J. Wild: Aerodynamic Design of a High-Lift System Compatible with a Natural Laminar Flow Wing within the DeSiReH Project, 29th Congress of the International Council of the Aeronautical Sciences, 7.-12. Sep. 2014, St. Petersburg, Russia. ISBN 3-932182-80-4, 2014.
[10] http://www.aflonext.eu
[11] J. Wild: Krüger design for an HLFC wing", 5th CEAS Air and Space Conference (2015).
[12] D.M. Franke and J. Wild: "Aerodynamic Design of a Folded Krüger Device for a HLFC Wing", 19. DGLR-Fachsymposium der STAB 2014, in print for publication in "New Results in Numerical and Experimental Fluid Mechanics X", Notes on Numerical Fluid Mechanics and Multidisciplinary Design, Springer, Heidelberg (2016).

About the Author

Dr.-Ing. Jochen Wild
Deutsches Zentrum für Luft- und Raumfahrt e.V. (DLR)
Institute of Aerodynamics and Flow Technology
Lilienthalplatz 7
D-38108 Braunschweig, Germany
Tel.: +49 531 295 3336
Jochen.Wild@dlr.de