SADE NEWS

Smart High Lift Devices for Next Generation Wings

SEVENTH FRAMEWORK PROGRAMME

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Collaborative Level 1 Project

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DLR AIRBUS ARA CIRA Cranfield UNIVERSITY CASSIDIAN FOI PIAGGIO AERO RWTH AACHEN UNIVERSITY SMR Engineering & Development TsAGI TU Delft

Content

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Preface

The SADE project has fully met its goals. All 13 partners have worked hard to reach the challenging research objectives. Besides a lot of theoretical studies on innovative concepts for next generation high lift devices and substructures for such systems - a final highlight is the successful wind tunnel demonstration of a full scale smart droop nose.

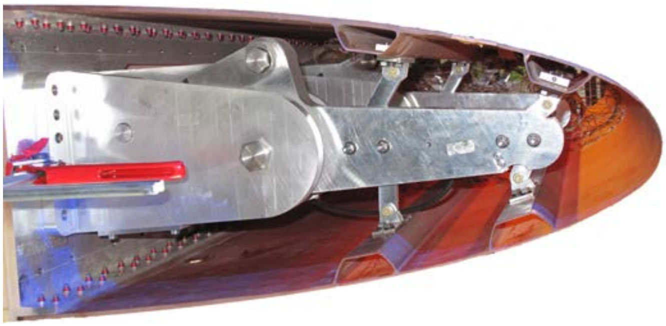
Setup of Smart Droop Nose in TsAGIs T101 wind tunnel (source: BockFilm)

It can be concluded, that SADE stands for a major step forward in the development and evaluation of the potential of morphing airframe technologies in the high lift area. The wind tunnel experiment can be considered a milestone for morphing technologies. It showed that large deformations are possible even for load carrying structures in full scale. The next step has to be the proof, that demands from operation requirements such as bird strike etc. can be incorporated into such morphing leading edges as well. Finally SADE helped to build up and mature a vast amount of additional concepts for droop nose and trailing edge morphing, which might be eventually alternatives to the concept chosen for the wind tunnel experiment. Also tools are available now, that can evaluate the benefit of such systems on an overall aircraft design.

Motivation for Wind Tunnel Test

All aerodynamic concepts for significant reduction of drag such as laminarisation require slim high-aspect-ratio wings. However, state-of-the-art high lift systems will suffer from the reduced construction space and do not cope with the required surface quality. Thus, SADE develops suitable 'morphing' high lift devices: The seamless 'smart leading edge device' is an indispensable enabler for laminar wings and offers a great benefit for reduction of acoustic emissions, the 'smart single slotted flap' with active camber capability permits a further increased lift. Thanks to their ability to adapt the wing's shape, both devices also offer aerodynamic benefits for cruise flight.

Within the first period of the project a general screening of different approaches for smart high lift devices was carried out. This resulted in a number of technologies that were investigated from a kinematic and actuation point of view. Among those concepts, which were selected for detailed design and evaluation are the eccentric beam concept for both leading edge and trailing edge, the use of fluidic actuators and a kinematic chain concept, combined with an elastic skin.



Kinematic chain with elastic skin for a droop nose (source: DLR)

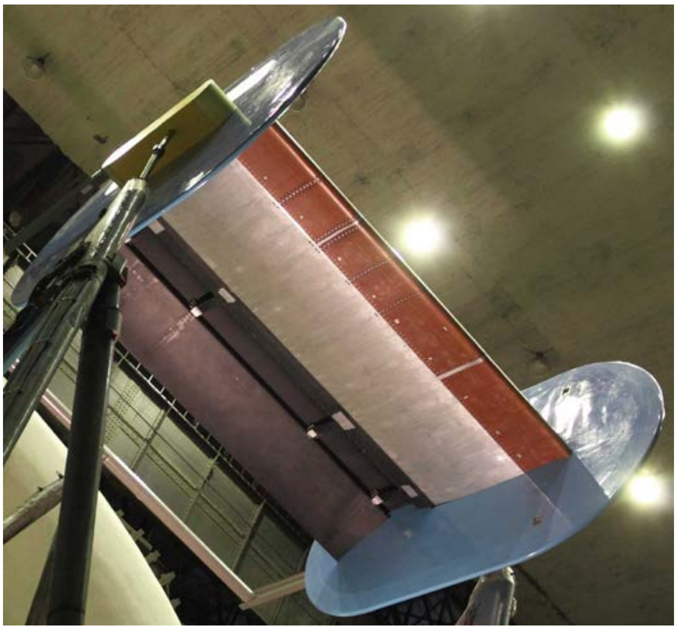
The last one proved to be the most mature concept and was therefore chosen to be further developed for wind tunnel testing within the project. The goal of the test is the proof that a skin can be designed and manufactured that is flexible enough to allow large overall deformations of the nose and reaches two target shapes being guided by a “simple” kinematic chain. At the same time this skin and its underlying kinematics had to carry all occurring aerodynamic loads in both cruise and high lift condition. The structural integrity of this smart high lift device could only be investigated under full scale aerodynamic conditions since structural down scaling does not apply to morphing structures in general. That is why the large scale wind tunnel T101 from TsAGI was selected for the tests. Additionally the aerodynamic efficiency of a droop nose as a high lift device was to be proven experimentally to validate computational results.

Functionality of Wind Tunnel Model

The wind tunnel model is equipped with a flexible nose part and a flap, which can be placed into cruise, take off and landing position. The seamless smart leading edge is designed flexible enough to be morphed from cruise to high lift position, but strong enough to carry the aerodynamic loads into the substructure and to bare the strains of morphing. In order to do so, a skin design process is established, which allows to tailor the skin thickness in a way, that the displacements introduced by the kinematics will morph the skin into the desired shape. Also the load introduction into the skin is of interest. In the end omega stringers were designed to distribute the load of morphing deflections into the skin, taking into account the stringers stability and strength. The difference between the aerodynamically wanted target shape and the achieved shape is within tolerable limits. Besides the skin it is an important task to design the kinematics to deploy to a position of approx. 18 degrees. The kinematics has to follow the trajectories given from structural investigations of the skin with minimum deviations, allow continuous movement (no raster or holding / breaking mechanisms) and it has to keep driving moments low for fully retracted and fully deflected position. Another requirement is to keep only one actuation per span wise station. The results of the skin and kinematic design were combined and a final strength calculation was carried out.

The Wind Tunnel Model

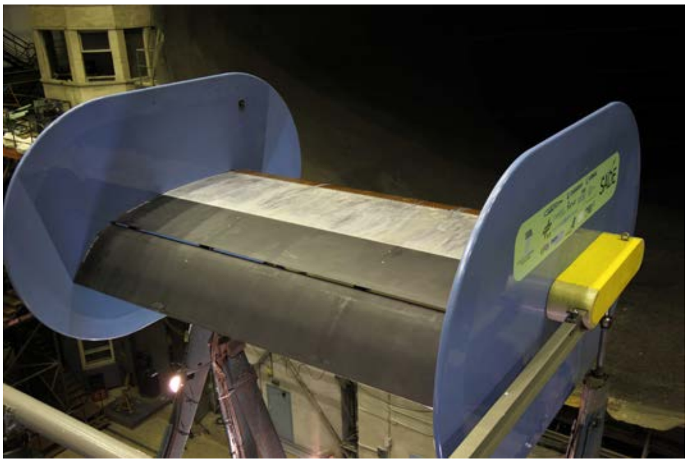
The baseline wing for the development of the geometry of the smart leading edge device model in the wind tunnel is the FNG wing (Next Generation Wing) which was released by Airbus within the LuFo ProHMS project for research activities. The wings planform and design is similar to a medium range single-aisle aircraft like the A320. The wind tunnel model shows the airfoil of one section of that wing, but shows a rectangular planform of 5 m span and 3 m chord with constant profile and no



Lower Front view of wind tunnel model with flap (black), wing box (metallic), morphing droop nose (brown) and side plates (blue) (source: BockFilm)

taper over the span. It consists of a main wing box (designed and built by TsAGI), which is used to mount the model to the wind tunnel base including the balance and feeding through all piping for pressure measurements and wiring for strain gauges. Attached to this is a trailing edge with flap (designed by Piaggio), which can be moved into different positions for take-off, landing and cruise. The droop nose itself, which was connected to the leading edge was design and manufactured by DLR (skin) and EADS (kinematics and assembly). Final assembly and functional testing were carried out at TsAGI. In order to keep a more 2D like flow, two side plates (designed and built by TsAGI) – three meters high and five meters deep were mounted on either side of the wing section.

The model is equipped in three sections with a total of 58 strain gauges to measure the strain distribution in the skin, 16 strain gauges on the kinematics. The pressure distribution is measured in 3 sections by pressure tubes in 84 positions each. In addition an optical measurement technique is used to measure the deformation of the droop nose under aerodynamic loading.



Backview of wind tunnel model with deployed flap (source: BockFilm)

The Wind Tunnel Test

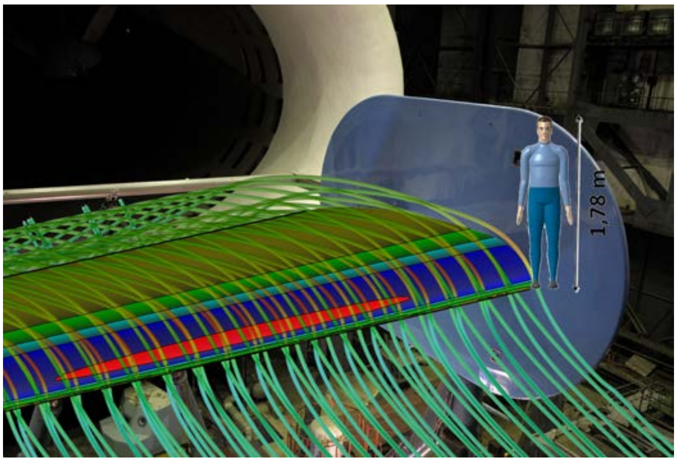
A test matrix of various wind speeds between 30 and 50 m/sec is run, varying the angle of attack between -10° and +22°. Three configurations were tested: take off (nose drooped, trailing edge flaps in take-off position), cruise (nose clean, trailing edge flaps retracted) and landing (nose drooped, trailing edge flaps in landing position.

The campaign is carried out in TsAGI's very large WT-101 near Moscow, which is a continuous tunnel with open test section designed for low speed full scale investigations. It features an elliptic nozzle that measures 14 x 24 m. As mentioned before, the goal of this campaign is a structural proof, that the morphing GFRP skin in capable to be changed in contour significantly, but still caries all aerodynamic loads – this is why a full scale model was required. On the other hand, the CFD predictions for the morphed airfoil were to be verified.

SADE wind tunnel model installed in TsAGI wind tunnel (source: BockFilm)

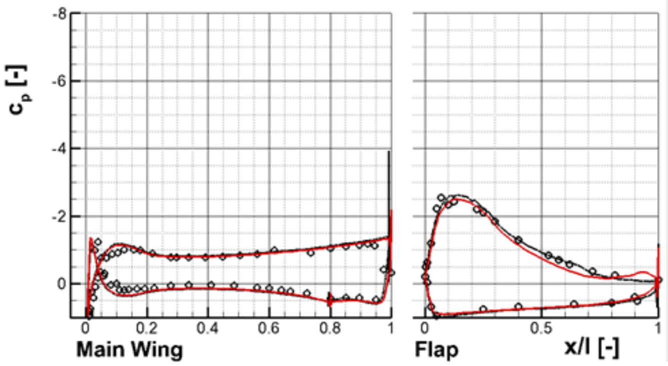
Results of Wind Tunnel Experiment

The first and most obvious result is that no structural damages of the highly stressed skins were detected, even after several hours of testing and several cycles of deforming the nose. This is a proof, that morphing primary structures can even be designed and built for highly loaded components such as aircraft wings for transport aircrafts.



Visualisation of flow around WT model (source: BockFilm & DLR)

The evaluation of the optical deformation measurement showed low overall deformations (<1,4 mm) caused by the aerodynamic loads. The same deflections were found for clean and landing condition. This indicates that the loading in the skins is dominated by the strain through morphing and the aerodynamic loads are causing small deformations compared to that when correctly designed.



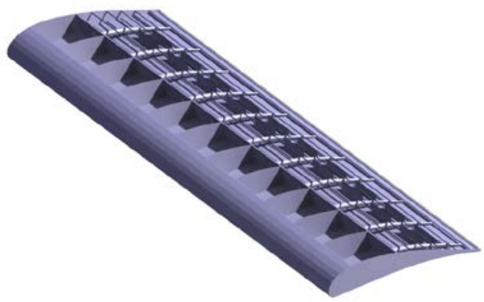
Example of pressure distribution for landing configuration at AoA=0°: red DLR 3D CFD calculation, markers: experimental data (source: TsAGI)

The comparison with 3D CDF showed especially for lower angles of attack up to 10° a very good accordance with the experimental data and proves the calculated aerodynamic performance of a smart step- and gapless droop nose as high lift device.

Detailed evaluation of the pressure distribution and the deformations on the sensitive upper (suction) side of the leading edge revealed that even tiny variations in the distribution of curvature due to manufacturing induce a remarkable effect on the achievable maximum lift.

Complementary Studies

Besides this major result there were several complimentary studies carried out with detailed morphing designs. One of them is the design, manufacturing and testing of a fluidic actuation concept. Those actuators were able to droop the leading edge. It could be shown, that the interface between the actuator and the skin and its friction is of major importance for the performance of the system. The forces generated with three of those within SADE developed actuators succeeded to provide appropriate actuator stroke to reach the desired deformation of the nose.



Model of a morphing trailing edge using the horn concept (source: CU)

One other focus for a complementary study is the evaluation of the horn concept to change the camber of a trailing edge flap. Simulations for a full scale flap have been carried out including structural design, aerodynamic CFD simulations and finally aeroelastics. The static aeroelastic analysis shows that the SSSF deflection remains very small in the order of a few millimetres even when the stiffness of the actuation beam stiffness is reduced to 10% of its original value. The results show that the converged shape of this multidisciplinary optimisation will be even less deflected; hence the aerodynamic benefit resulting from the morphed flap will not be affected. The static aeroelastic behaviour of the structure is satisfied.

Selected Publications

A comprehensive list of publications can be found on the SADE homepage at: http://www.sade-project.eu/.

M. Kintscher, M. Wiedemann, "Design of a smart leading edge device", In: Adaptive, Tolerant and Efficient Composite Structures Springer. Pages 381-390. ISBN 978 3 642 29189 0 (2012)

S. Ameduri, A. Concilio, E. Daniele, "A droop nose laboratory demonstrator: Experimental characterization and validation", ICAST2012: 23rd International Conference on Adaptive Structures and Technologies, October 11-13, 2012, Nanjing, China

T. Kühn, C. Lenfers, "A Numerical Assessment of Side Plate Effects for a Low Aspect Ratio Wind Tunnel Model with a Smart Droop Nose Device", 30th Applied Aerodynamics Conference, 25-28 June 2012, New Orleans, LA, USA

D Li, S Guo, Y. He, J Xiang," Nonlinear aeroelastic analysis of a morphing flap, International Journal of Bifurcation and Chaos", Vol. 22, No. 5, 2012, pp. 1250099.1-11

Z. Sun, S Guo, Q Fu, "Design and Analysis of a Wing Structure with Static Aeroelastic Effect for Optimal Performance", ICCE-20, Beijing, 21-27 July 2012

N. Di Matteo, S. Guo, R. Morishima, "Optimization of morphing LE and flap with actuation system for a variable camber wing", the 53rd AIAA/ASME/ASCE/AHS/ASC Structures, Structural Dynamics, and Materials Conference, Honolulu, Hawaii, 23-26 April 2012

Durk Steenhuizen, Michel van Tooren, "The implementation of a knowledge-based framework for the aerodynamic optimization of a morphing wing device"; Advanced Engineering Informatics 26(2012) 207-218

Guo S, Li D, Liu Y, "Multi objective optimization of a composite wing subject to strength and aeroelastic constraints" Proceedings of IMechE, Part G: J of Aerospace Engineering vol. 226, 9 (2012) SAGE UK Doi 10.1177/0954410011417789

Li D, Guo S, "Modelling and Nonlinear Aeroelastic Analysis of a wing section with morphing trailing edge" Proceedings of IMechE, Part G: J of Aerospace Engineering 3,2012 SAGE UK DOI: 10.1177/0954410012438341

Li D, Guo S, "Study on conditions of chaotic motion of a two-dimensional airfoil in subsonic flow", Journal of Fluid & Structures Volume 33, 8, 2012