Overview on the DeSiReH Project

*Jochen Wild**
**DLR Institute for Aerodynamics and Flow Technology*
Lilienthalplatz 7, 38108 Braunschweig, Germany

Abstract
DESIREH stands for "Design, Simulation and Flight Reynolds Number testing for advanced High Lift Solutions". This EC-funded project is aimed to improve the aerodynamic design and simulation methodology of high-lift systems.
The investigations made include the acceleration of CFD simulations, the improvement of enhanced optical measurement methods in cryogenic environment, and the assessment of the suitability of automatic design optimization for high-lift systems.
Beside the methodological aspect, the findings are verified by exemplarily addressing a major topic in high-lift design today: to find a solution of a high-lift system for a natural laminar flow (NLF) wing for transport aircraft category. The established methods are used both in CFD-based design and the verification by a high Reynolds-number test incorporating the improved measurement methods.
This contribution will give an overview on the frame of the project to introduce the specialized topics in the mini-symposium.

1. Introduction

Considering today's problem of carbon emissions and the forecast of the climatic changes in the near future the advisory group ACARE with its Vision 2020 confronts aircraft industry with the demands for significantly greener aircraft and a reduced time to market of such products. DeSiReH supports the realisation of this vision by improving the aerodynamics of the High-Lift system. This will be achieved by considering - at the same time and in coordinated approach - the numerical design methodology, the measurement techniques for cryogenic conditions for an advanced laminar wing design to be performed in DeSiReH. This will facilitate an improved industrial design process in terms of product quality, efficiency, and development cost reduction with respect to the High-Lift systems.

Laminar wings offer a significant potential in advancing the aerodynamic performance and hence improve the environmental acceptance of future aircraft. While offering a large fuel saving potential, the laminar wings for large transport aircraft still suffer from compatible high-lift leading edge systems. Especially Natural Laminar Flow (NLF) technology poses new design constraints and adds further design parameters to the design space. Hence, design space of a NLF High-Lift (HL) system is wider compared to the design space of a HL-system for a transport aircraft with turbulent wings. The exploration of this wider design space needs automated optimisation algorithms for which code developers often lack the specific knowledge. Hence, a design process driven "only" by the knowledge of tool developers may not be sufficient.

Today the industrial design process of HL-Systems is mainly driven by fast methods of medium and low fidelity, which support the design process driven by the knowledge of HL-design experts. This process depends on the experience and knowledge of the design expert and lacks a simple exploration of the extended design space. This is of particular interest for high-lift concepts for which the design space is less familiar to the expert. The current exploitation of numerical design methods that are well elaborated from the algorithmic side of view suffers a substantial lack of knowledge of formulation of the design problem in order to get usable results.

DESIREH aims to enable laminar wing technology by providing an advanced High-Lift device for a NLF-wing. These high-lift solutions are urgently needed to allow an overall feasibility of the laminar flow technology, which supports the reduction of the environmental emissions as set by the ACARE Vision 2020. The performance of the derived High-Lift system will be verified at flight Reynolds-number in a dedicated wind tunnel test in the ETW. DESIREH addresses the following quantified objectives:

- Reduction of industrial A/C development costs by 5% by reduced and more efficient Wind Tunnel Testing
- Decrease time-to-market by 4% by improved aerodynamic design turn-around time
- Improve industrial High-Lift design process efficiency by 15%
- The design of a compatible High-Lift System enabling the NLF-potential to reduce A/C drag by 5%

Submerged below are more qualitative objectives regarding design by numerical methods and wind tunnel testing. The project is split in four technical work packages, as shown in Figure 1.

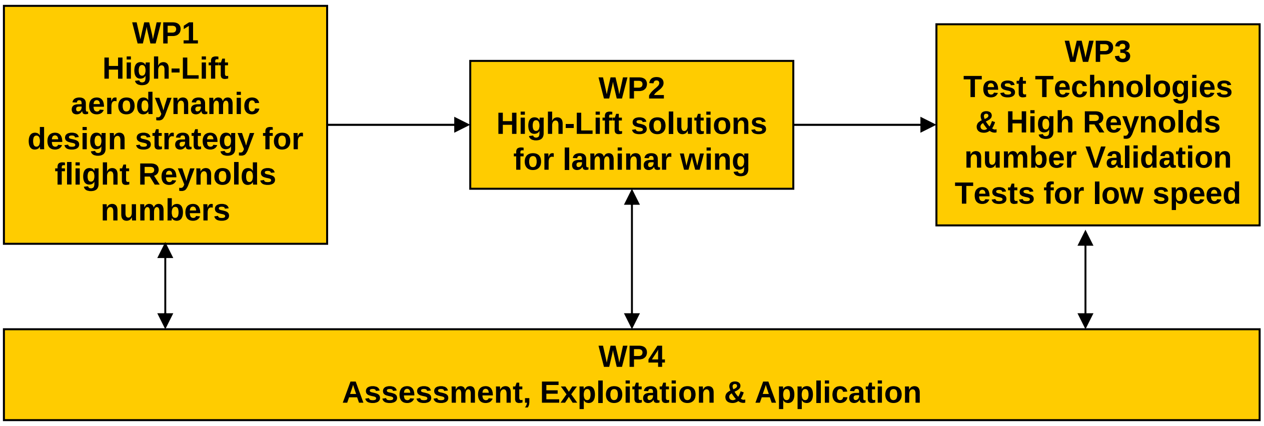

Figure 1: Work package structure and interrelations of the DeSiReH project

DeSiReH establishes synergy effects with currently running European projects as well as past European project, relevant for DeSiReH. Figure 2 shows the network of EC projects supporting the objective and activities of DeSiReH and their time period.

From the numerical design process programs especially the achievements of the AEROSHAPE project form the baseline that accounts for the availability of the methods, so that within DeSiReH no dedicated software development is captured. With this expertise the wing section design of a High-Lift system has been demonstrated within EUROLIFT II, based also on the validation of CFD solvers for high-lift flows within EUROLIFT I. Within the NACRE Integrated Project advanced numerical optimization methods have also been applied for the design of droop-nose device for a forward swept wing. DeSiReH targets to advance the application of these design methods towards full 3D high-lift wing design, incorporating design targets and parameters as close as possible to real aircraft design issues. An additional high-lift technology related program was HELIX. The aim of this project was to explore new approaches to generate sufficient low-speed aerodynamic performance based on a concept level approach. This experience is also respected in an appropriate way.

The experimental work performed in DeSiReH is closely related to FLIRET, which dealt with the assessment of model mounting effects in ETW. DeSiReH makes extensive use of the FLIRET results. Transition measurement techniques have been investigated in the TELFONA project for high-speed experiments. Another good knowledge on how to perform low speed experiments for high-lift configurations has been gained in the already mentioned EUROLIFT I+II projects. DeSiReH extends this knowledge towards low-speed experiments in ETW.

For the laminar wing technology almost 2 decades of research projects form a well elaborated basis for the DeSiReH approach. Only naming the latest projects HYLDA and HYLTEC, which finally led to flight tests with a hybrid laminar fin on the A320, showed the feasibility of the drag reduction. DeSiReH now aims to answer the open question of aerodynamic High-Lift system design under the constraints known from these projects. A starting point is given also by the Krueger flap tested in HYLTEC. Laminar wing design also has been incorporated into the NACRE project for a forward swept wing and in TELFONA for a high-aspect ratio low-sweep (HARLS wing). Especially the TELFONA laminar wing serves as the baseline for the high-lift design carried out within DeSiReH.

Knowledge transfer from these projects is achieved by the fact that a considerably large number of core partners of each of these projects are involved in DeSiReH. The project consortium consists of 20 partners from Europe and Russia, from industry (Airbus Operations, ASCO Industries, Dassault Aviation, EADS CASA, Piaggio Aero Industries), SME (Aircraft Development and Systems Engineering ADSE, Dziomba Aeronautical Consulting, European Transonic Wind tunnel ETW, IBK Innovations), research (CIRA, DLR, FOI, INTA, NLR, ONERA, TsAGI), and academics (Braunschweig Institute of Technology, University of Padua, University of Naples).

The project duration has been 52 months, from March 2009 to June 2013.

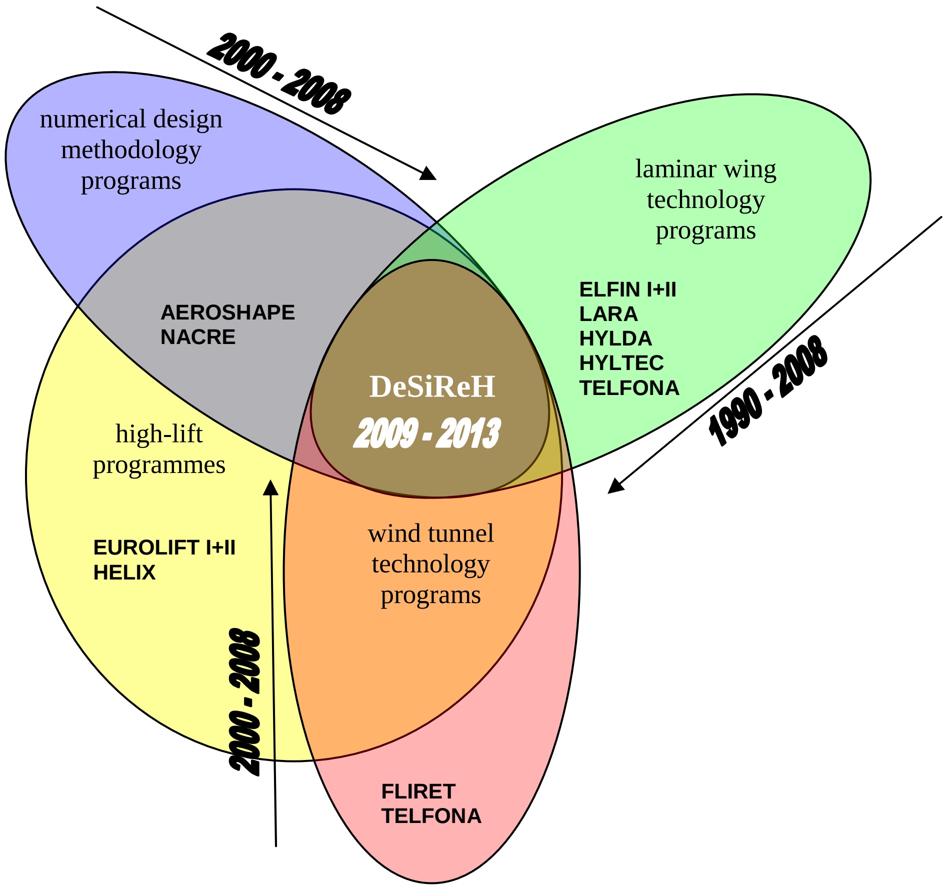

Figure 2: Relation of DeSiReH to former EC projects

2. High-Lift aerodynamic design strategy for flight Reynolds numbers

From the beginning of the project, work concentrated on evaluating and assessing numerical methods for the design and simulation of high-lift systems (Figure 3). A broader understanding of the problem to design high-lift systems within an industrial context was achieved in three ways. First, industrial recommendations for the design process were specified by the main industrial partners. Second, the various design targets of high-lift systems were derived by screening certification regulations and evaluating the aerodynamic importance during the different flight phases during take-off, approach and landing. Third, a common understanding of the design space of high-lift systems was generated.

Based on these results common design cases were specified for activities to evaluate design procedures for a more globally optimal design, accounting for all flight phases simultaneously in contrast to the state-of-the-art stepwise approach. Regarding the comparative analysis of optimization approaches for the classical optimization methods all optimizations were performed and the solutions were compared by crosschecking partners results [1] (Figure 4). Some partners also made comparisons especially for the optimizations using adjoint techniques. Although very promising, the real world application turned out to be not as straight-forward and the robustness of the methods have to be increased before usage in an industrial context.

The objective to accelerate the numerical flow simulation for a better efficiency in aerodynamic design, most important in high-lift design due to a specifically high computational effort, had been initiated by selecting common cases and providing common computational grids. A significant efficiency enhancement of URANS methods has been obtained through improving the initialization procedure for the flow solution at next time level, by introducing implicit techniques, and by implementing zonal/fractional time-stepping (Figure 5). 20% to 90% speed up of unsteady RANS calculations has been demonstrated [3]. The evaluation of gridding strategies additionally showed a possible reduction off computational effort by up to 75% due to reduction of grid nodes and use of wall functions. Grid adaptation methods (based on flow sensors, entropy, and adjoint fields) have been evaluated (Figure 6), giving clear indications about meshing strategies for more efficient CFD application for high-lift flows [4].

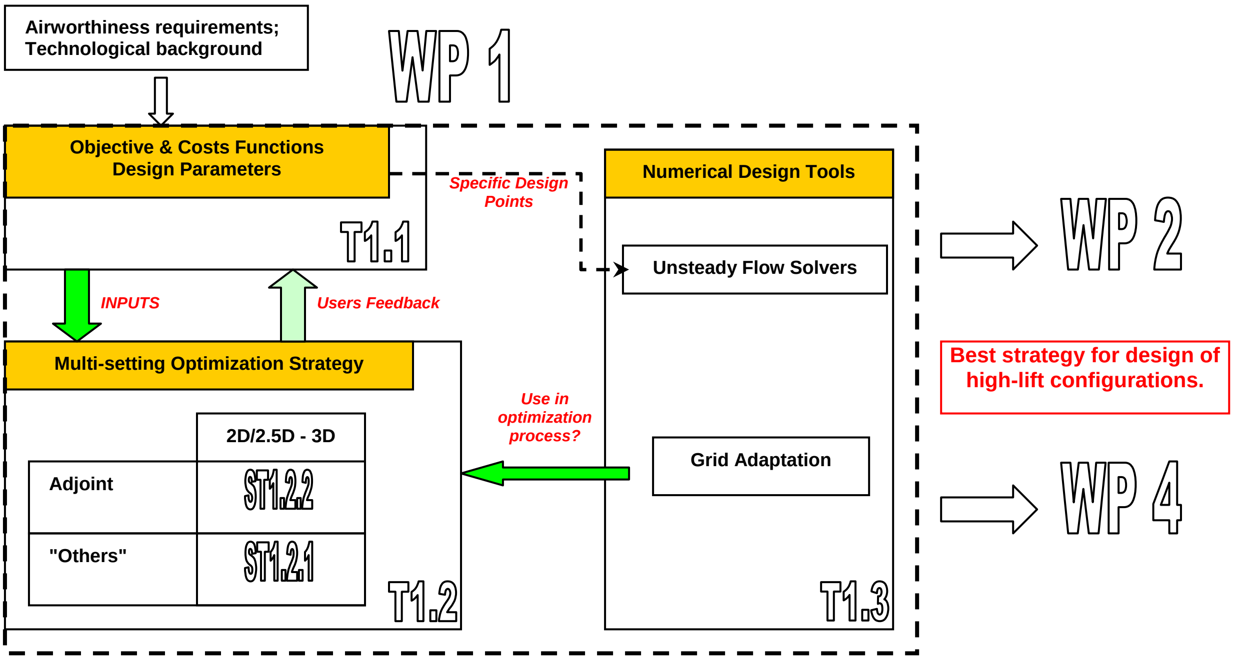

Figure 3: Work process for assessment and maturing CFD based simulation and design

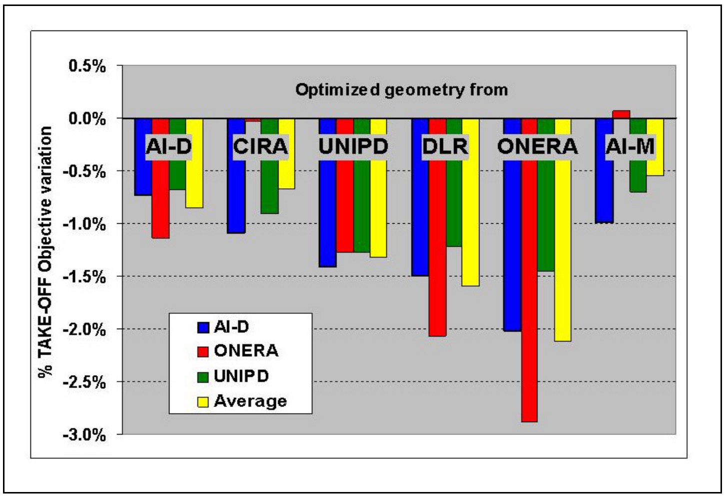

Figure 4: Cross-check of partners' 2D optimized geometries at constant lift.

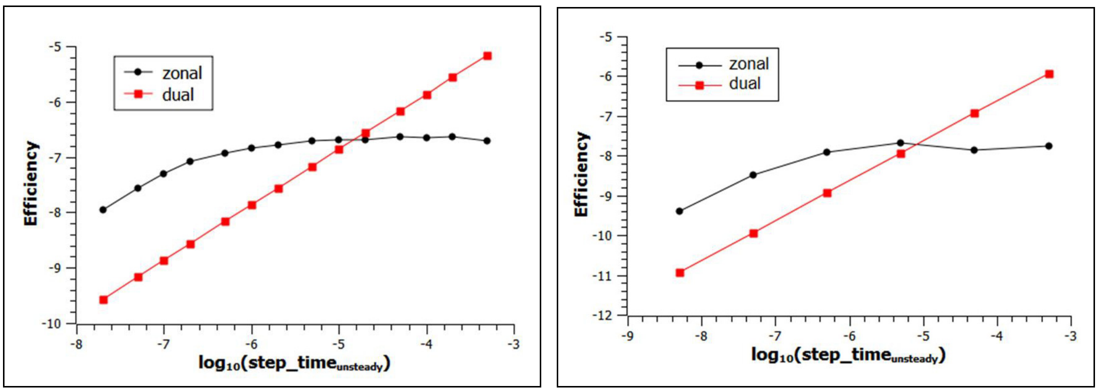

Figure 5: Efficiency improvement with the zonal and implicit approach in dual time. Left: 2D airfoil case. Right: 3D wing-body case.

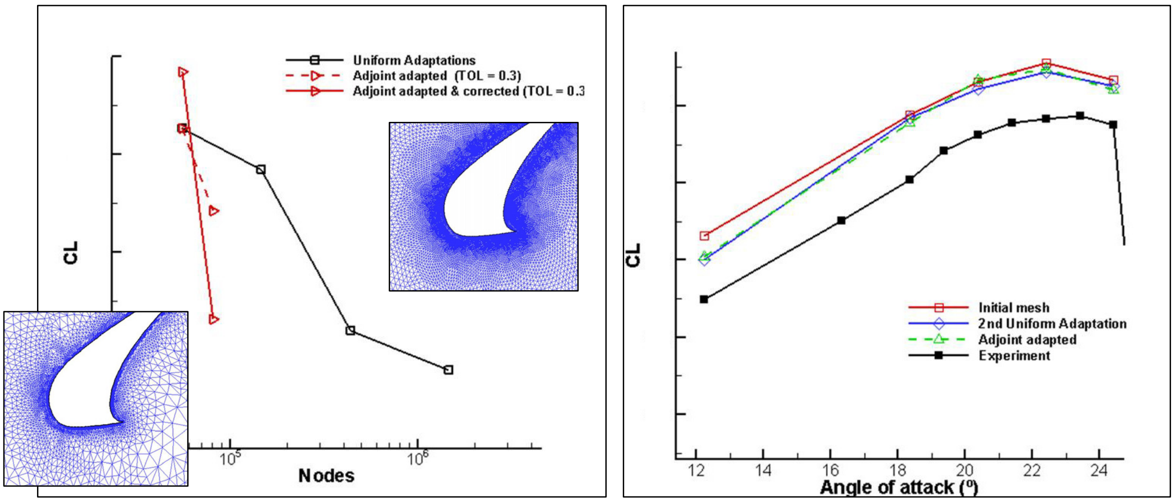

Figure 6: Left: Grid convergence of lift (left) for the AGARD AG08 using uniform adaptation (black) and adjoint based adaptation (red). Right: corresponding polar calculations.

3. High-Lift solutions for laminar wing

A second work package (Figure 7) addressed the design of innovative high-lift solutions to enable laminar wing technology. The matured design methods and strategies described before were applied to design a High-Lift-System a wing featuring NLF at cruise condition. The design of such an innovative High-Lift-System is a highly industrial relevant problem and consolidates two requirements:

1. The qualification of the matured methods and strategies for their implementation in the industrial design process;
2. Provide an important contribution to enable the NLF-technology by designing a compatible and efficient high-lift system.

The first major aim of was to assess different high-lift concepts and to deliver an aerodynamically designed optimal feasible high-lift solution for a NLF wing. In the first step the focus was put on detecting feasible concepts by means of 2D/2.5D wing section design. For the real design of the high-lift system for the laminar wing, first a baseline wing was obtained from the TELFONA project [5]. The wing was analyzed in its stall behaviour to derive recommendations for the design as well as to select an appropriate design wing section for conceptual studies. At this design section several concepts have been designed to see their principal potential for usability for the laminar wing. At the leading edge Krueger devices, droop-noses or even very long chord slats were investigated. At the trailing edge the concepts range from classical fixed-vane flaps over drooped spoiler flap solutions to a large flap concept. The obtained results were cross-computed in order to eliminate solver dependencies. In order to down-select the concepts the best obtainable performance by optimizing the shape, size and setting of High-Lift devices including consideration of the NLF constraint of the cruise wing. The receptivity of the laminar boundary layer of the cruise wing at the steps and gaps positions of the retracted High-Lift components were evaluated by transition prediction methods. The design study and their down-selection unveiled the Krueger to be the device of choice at the leading edge. For the trailing edge both the spoiler droop flap and the large flap concept are initially selected for further integration onto the 3D wing.

In a second step the down-selected concepts were extended to the 3D wing geometry. With the same systematic approach, but now based on full 3D simulations, the High-Lift devices have been be optimized in combination with the most promising leading and trailing edge (Figure 8). The 3D wing designs taking into account constraints from the mechanical integration aspects have been performed (Figure 9). The geometry was delivered for the detailed design of the wind tunnel model to verify the obtained designs.

The geometries have been used to setup detailed CFD analysis of the performance and the deviations due to wind tunnel installation effects. The activities identify the effects of wind-tunnel walls (Figure 10), model mounting, and the wing flexibility of the model (Figure 11) in the pressurized tunnel. The flow models are based on the RANS and/or URANS equations. The structural model for the prediction of wing deformations is based on a FEM description of the wind tunnel model. After the wind tunnel tests described in the next section comparisons were made to evaluate the accuracy of the predictions

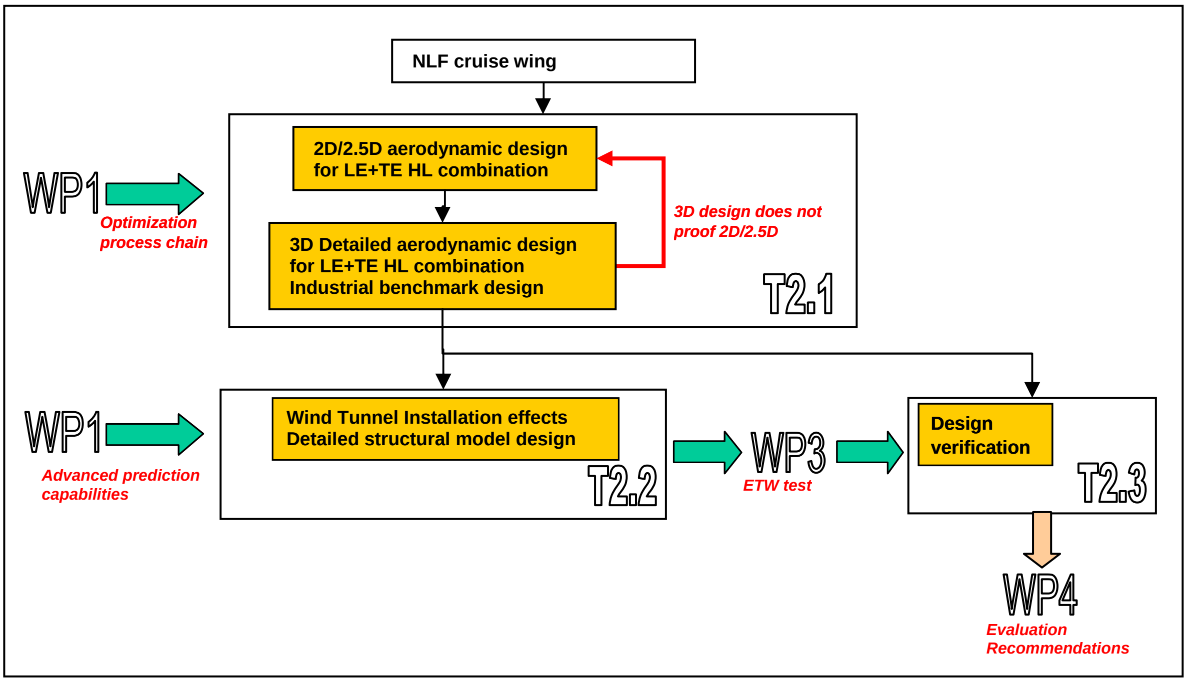

Figure 7: Work process to design and verify the high-lift system for a laminar wing

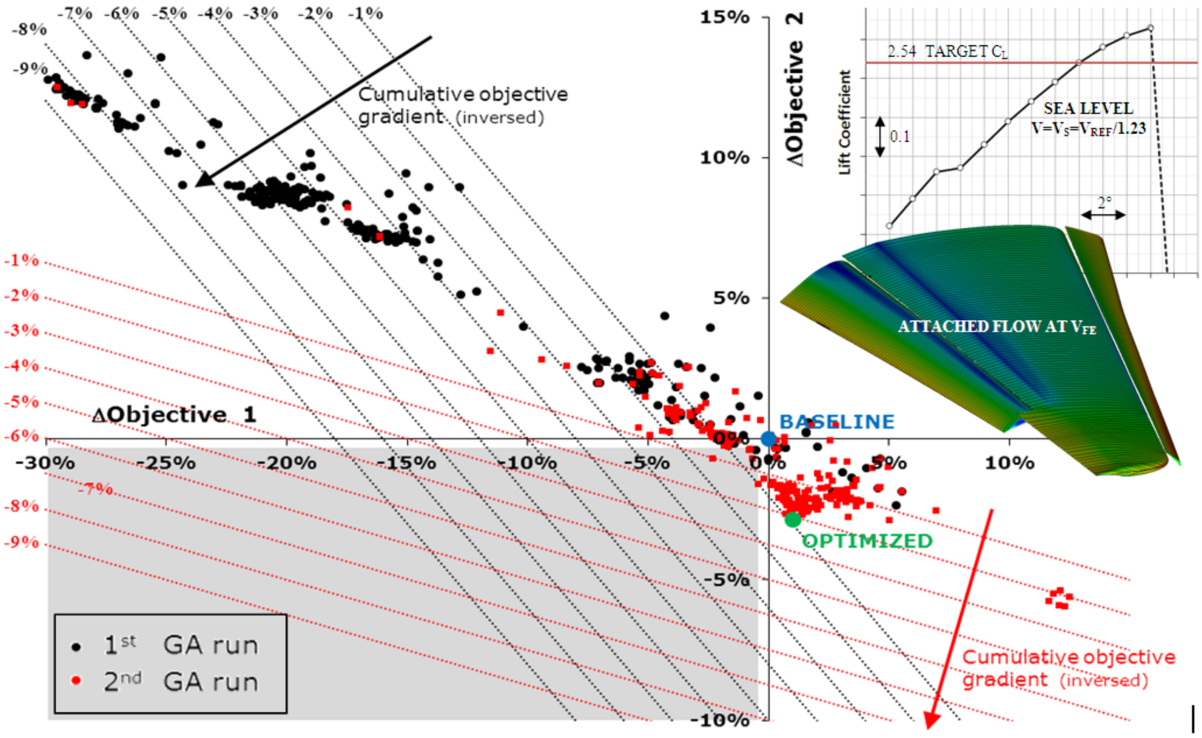

Figure 8: NLF high-lift wing designed by numerical optimization

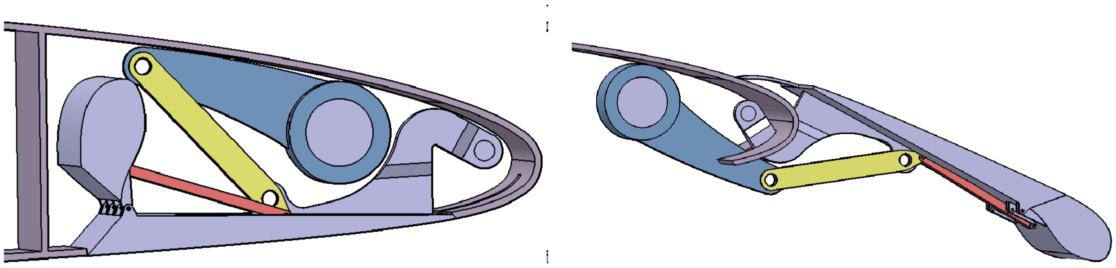

Figure 9: Mechanical integration concept of slotted and folding Krueger kinematics

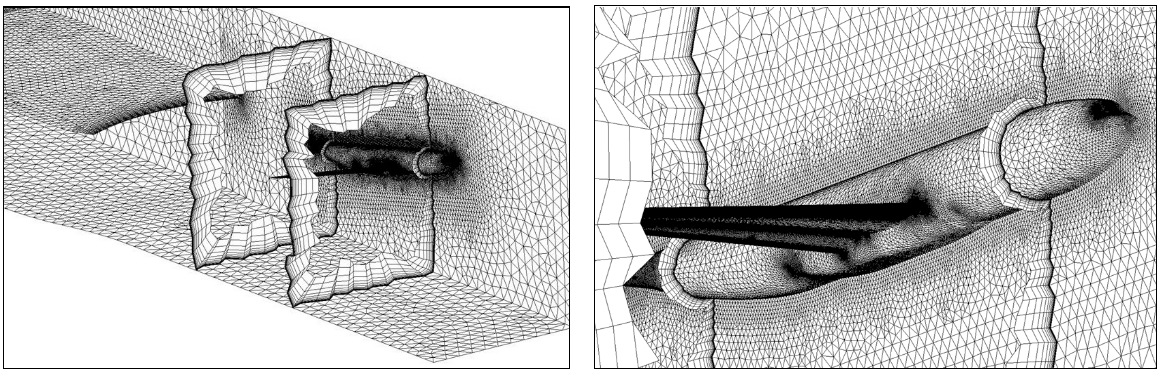

Figure 10 grid of high-lift configuration inside ETW wind tunnel; surface grid & cuts through the prismatic grid

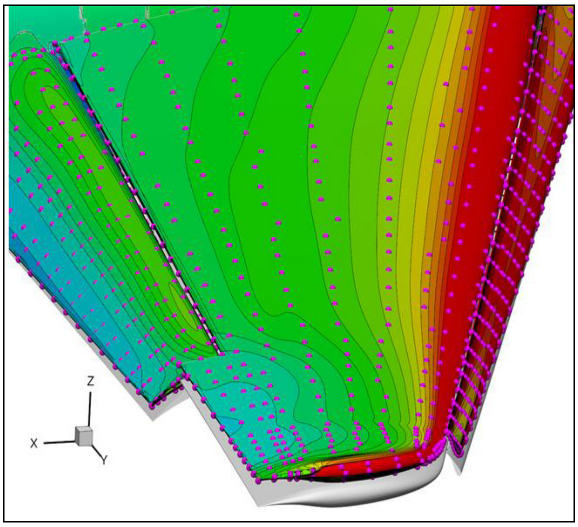

Figure 11: Rigid and deformed wing shape predicted by CFD-CSM coupled simulations

4. Test Technologies & High Reynolds Number Validation Tests for Low-Speed

Nowadays, aircraft engineering offices aim at reducing the overall Wind Tunnel process time and cost and provide reliable data for direct flight application and further development of numerical simulation. In the future classical wind tunnel testing for specific aircraft development will be reduced, while developing synergies between physical and numerical simulation with an overall aim to optimise data production, to best explore flight physics of new configurations and to open the envelope for industrial application of new test technologies. DeSiReH is in line with such expectations with a typical application aiming to design a high lift system achieving the required high-lift performance in take-off and landing while being compliant with a NLF wing in cruise. In the frame of the third work package (Figure 12), the design process applied before is validated in a wind tunnel test with a half model (Figure 13). In order to test at true flight Reynolds conditions, it is performed under pressurized cryogenic conditions at the European Transonic Wind tunnel (ETW) (Figure 14).

The wind tunnel test provides high fidelity experimental data for verification of the high-lift design performed in the previous work package and validation of the CFD predictions. To overcome potential limitations of CFD predictions on still challenging topics as high lift aerodynamic behaviour at the edge of flow separation, or boundary layer turbulent transition, the wind tunnel test includes advanced non intrusive measurement techniques providing local information on the flow field.

At last this measurement technique shall be compliant with the pressurized cryogenic environment of ETW. The work package aimed at improving the capability to use in an industrial way, such advanced measurement techniques within the same test campaign. In parallel with conventional techniques (balance and pressure measurement) these advanced techniques used in DeSiReH are:

- *Model deformation measurement by Stereo Pattern Tracking (SPT):* since high Reynolds numbers are partly obtained at the expense of high pressure increasing model deformations. Resulting geometry changes affect the local flow and any comparison with sophisticated CFD methods has to be based on an exact knowledge of the geometry during testing.
- *Flow visualisation by Particle Image Velocimetry* (PIV), in particular downstream the wing trailing edge, enhances the aerodynamic behaviour understanding and potentially enables to assess the local drag (Figure 15).
- *Boundary layer transition detection by Temperature Sensitive Paint (TSP)*, as the transition position has also an impact an achieved aerodynamic performance (Figure 16).

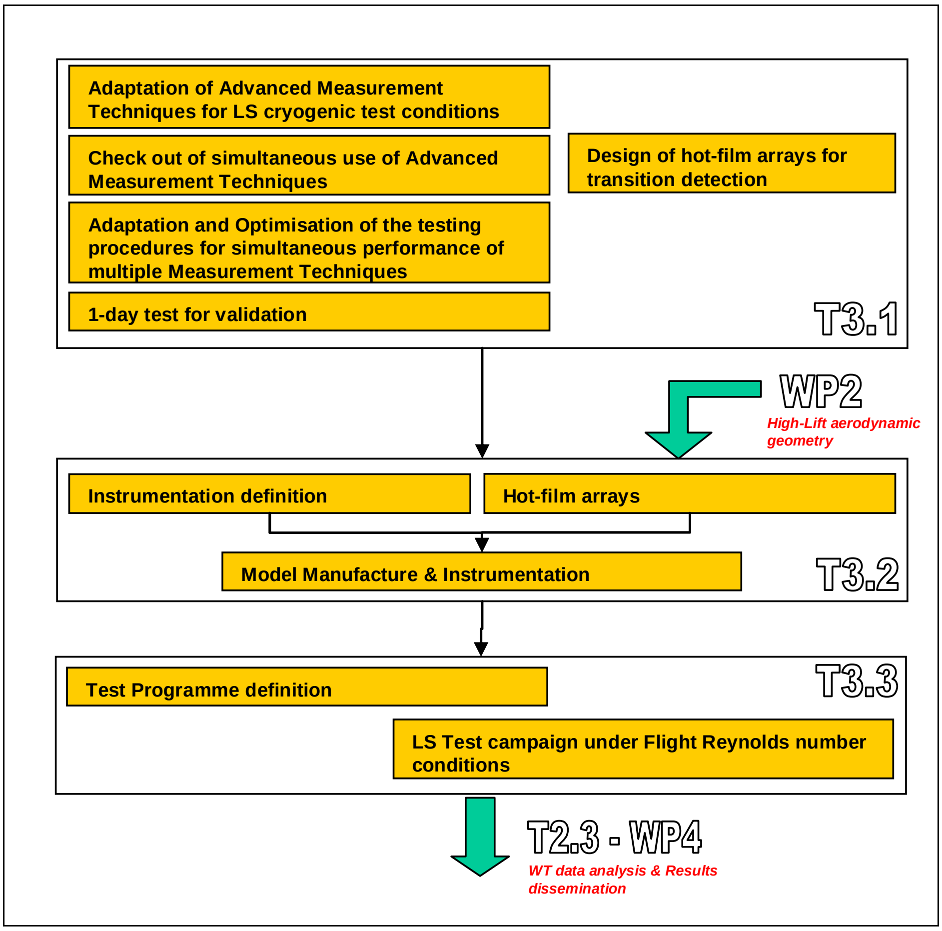

Figure 12: Work process for maturing measurement methods and perform verification test of the high-lift wing

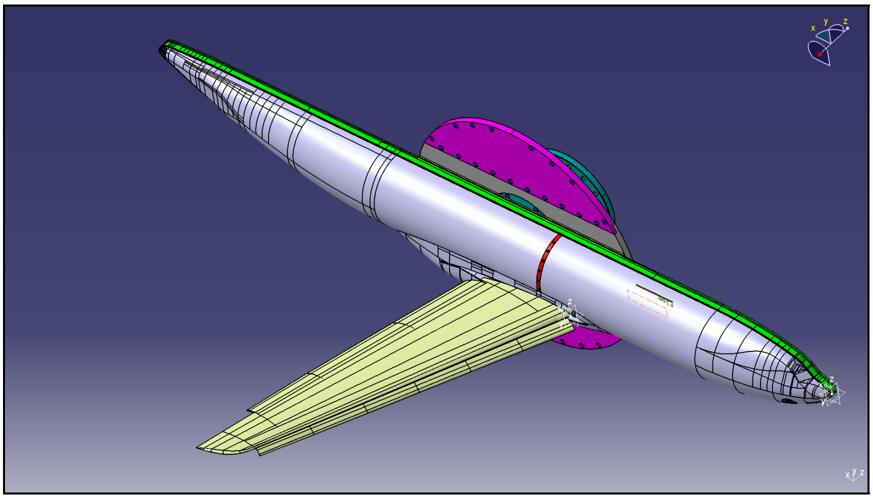

Figure 13: CAD model of the DESIREH high-lift wing scaled 1:11.75 mounted to the fuselage of the DLR-F11 (KH3Y) model and the ETW turn table

Figure 14: DLR-F11 with DeSiReH high-lift wing mounted in ETW test section

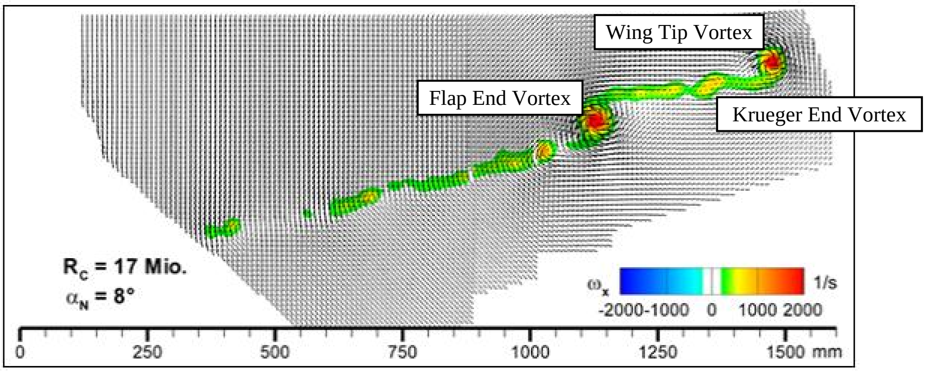

Figure 15: PIV image of flow field after trailing edge perpendicular to flow field

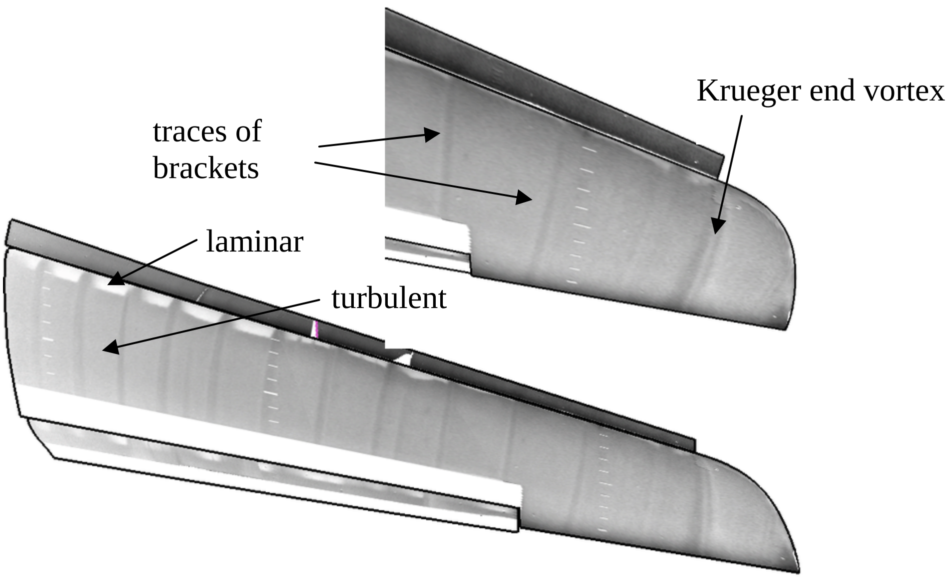

Figure 16: TSP image visualizing laminar-turbulent transition and vortex structures above surface

5. Assessment, Exploitation & Application

The technical work packages of the DeSiReH project are devoted to deliver improved high-lift design methods, a laminar wing compatible aerodynamic high-lift design solutions and to verify the high-lift design at Flight Reynolds numbers as well as qualifying advanced experimental measurement techniques under cryogenic conditions. For a common evaluation of the achieved results a separate work package (Figure 17) assesses the overall strategy by providing industrial input and constraints, to assess the technical solutions of the work packages and to conclude with recommendations for the application of the DeSiReH achievements. An evaluation of the environmental benefit of the DeSiReH solution against the objectives of the ACARE Vision 2020 is delivered.

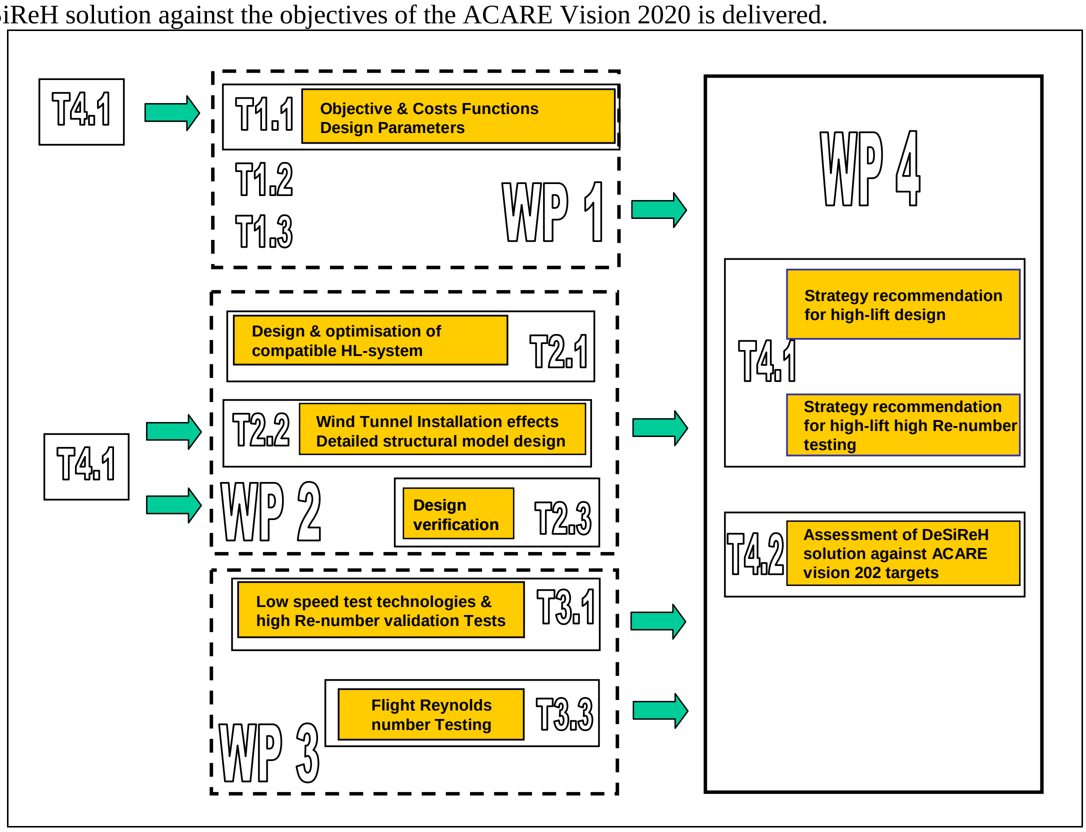

Figure 17: Work process for assessment and evaluation

One part of the work package addresses the assessment of the improved high-lift design methodology. Furthermore strategy recommendations are concluded from the assessment of the industrial application of the advanced experimental measurement techniques and the numerical performance prediction vs. the experimental verification. The second part assesses the environmental benefit of the high-lift design solution with respect to the ACARE Vision 2020 objectives on an overall aircraft level. A generic aircraft has been created (Figure 18) to assess the benefits of the NLF technology for the wing used in DeSiReH. All details of the high-lift system design are properly integrated into this assessment to get a complete evaluation.

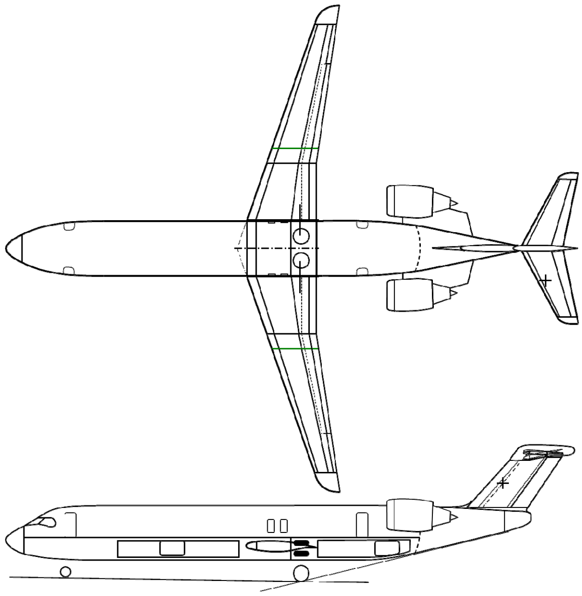

Figure 18: Generic aircraft used to evaluate the DeSiReH high-lift wing design on overall aircraft level

3. Summary

The paper provides an overview on the activities performed within the project DeSiReH. The objectives and the work plan have been outlined how DeSiReH aimed to achieve four major goals for improving the high-lift design process. A few key achievements were high-lighted, but for more detailed information readers are referred to the specialized contributions within this mini-symposium [6]-[14].

Acknowledgements

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