SEVENTH FRAMEWORK
PROGRAMME

DeSiReH

PUBLISHABLE SUMMARY REPORT

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Coordinator:	J. Wild	
Tel & Fax:	T +49 531 295 3336; F +49 531 295 2320	
E-mail:	jochen.wild@dlr.de	
Website address	-	
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Publishable Summary Report

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Acronym: DESIREH

Title: Design, Simulation and Flight Reynolds Number testing for advanced High Lift Solutions

Co-ordinator: Deutsches Zentrum für Luft & Raumfahrt e.V. (DLR)

Beneficiaries:

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SEVENTH FRAMEWORK PROGRAMME

Contents

List of Figures

Abbreviations and Explanations

A/C	Aircraft
ACARE	Advisory Council for Aeronautics Research in Europe
AEROSHAPE	Multi-point aerodynamic shape optimisation
BFS	Backward facing steps
CFD	Computational Fluid Dynamics
CSM	Computational Structural Mechanics
CO	Co-ordinator
DN	Droop Nose
EUROLIFT	EU funded project: European High Lift Programme
ETW	European Transonic Wind Tunnel
ESPT	Enhanced Stereo Pattern Tracking
FFS	Forward facing steps
FLIRET	EU funded project: Flight Reynolds number testing
HARLS	High Aspect Ratio Low Sweep
HELIX	EU funded project: Innovative aerodynamic high lift concepts
HL	High-Lift
HYLDA	EU funded project: Hybrid Laminar Flow Demonstration on Aircraft
HYLTEC	EU funded project: Hybrid Laminar Flow Technique
IPCT	Image Pattern Correlation Technique
LDG	Landing
LS	Low Speed
L/E	Leading edge
NLF	Natural Laminar Flow
NACRE	EU funded project: New aircraft concept research
PIV	Particle Image Velocimetry
RANS	Reynolds-Averaged Navier-Stokes (equations/approach/simulation)
SPT	Stereo Pattern Tracking
TELFONA	EU funded project: Testing for Laminar Flow On New Aircraft
TM	Task Manager
TSP	Temperature Sensitive Paint
TO	Take-Off
T/E	Trailing edge
URANS	Unsteady Reynolds-Averaged Navier-Stokes (approach/simulation)
WT	Wind Tunnel
WPM	Work Package Manager
VLCS	Very Long Chord Slat

Abstract

DeSiReH, design, simulation and flight Reynolds number testing for advanced high lift solutions, is an EC-funded project for improving the aerodynamic design and simulation methodology for high-lift systems of civil transport aircraft.

Objectives are the acceleration of CFD simulations in the industrial design environment with respect to high lift devices for laminar wings, the improvement of enhanced optical measurement methods in cryogenic environment, and the assessment of the suitability of automatic design optimization for high-lift systems.

In addition to the methodological aspect, the findings are verified by addressing a major topic in high-lift design today, namely finding an effective solution for a high-lift system for natural laminar flow (NLF) wings suitable for transport aircraft.

The developed methods are used for both, CFD-based design and verification of a high Reynolds-number wind tunnel test. For the testing, measurement methods were improved.

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 significant fuel saving potential, laminar wings still suffer from the lack of 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, the design space of a NLF High-Lift (HL) system is wider as compared to the design space of a HL-system for a transport aircraft with turbulent wings. The exploration of this wider design space requires automated optimisation algorithms for which code developers often lack specific knowledge. Hence, the related design process may not be efficient.

Today the industrial design of HL-Systems is mainly driven by fast methods of medium to low fidelity methods, depending strongly on the knowledge of the HL-design experts. Hence, a simple exploration of the extended design space is often lacking... This is a particular disadvantage for high-lift concepts for which the design space is less familiar to the expert. The current exploitation of numerical design methods suffers from a substantial lack of knowledge in formulating the design problem for best results even though the methods are well elaborated from the algorithmic side of view.

DeSiReH aims to enable laminar technology by providing an advanced High-Lift device for a NLF-wing. High-lift solutions are urgently needed in order to enable laminar flow technology supporting the reduction of environmental emissions as set by the ACARE Vision 2020. The performance of the High-Lift system derived in DeSiReH is verified at flight Reynolds-number in a dedicated wind tunnel test in the European Transonic Wind tunnel (ETW). The following quantified objectives are addressed:

- 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%
- Design a compatible High-Lift System enabling the NLF-potential to reduce A/C drag by 5%

More qualitative objectives regarding design by numerical methods and wind tunnel testing are submerged and described below within the specialised sections DeSiReH is split in four technical work packages, as shown in Figure 1.

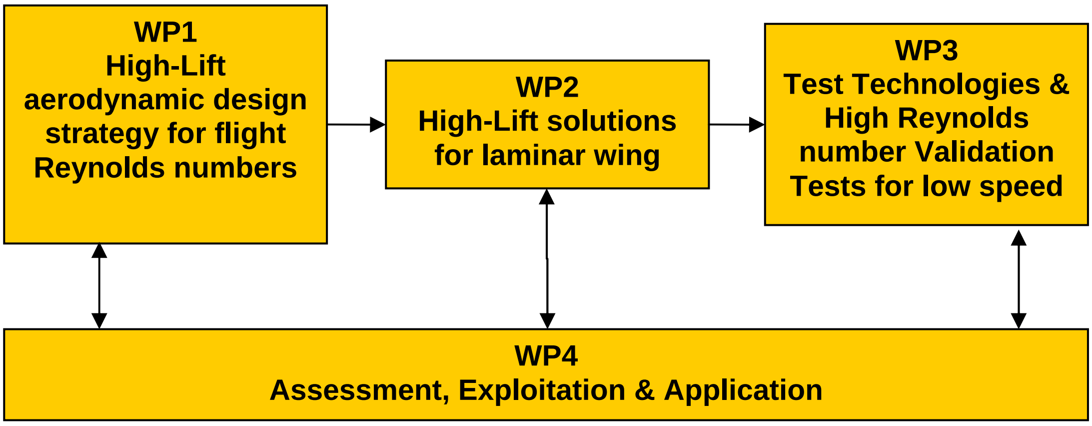

Figure 1: Work package structure and interrelations of the DeSiReH project

DeSiReH establishes synergy effects with past and present European projects. Figure 2 shows the network of EC projects supporting the objective and activities of DeSiReH and their time period.

The work of DeSiReH relies on the results of many EU funded projects such as AEROSHAPE which developed the baseline methods for the numerical design process applied in DeSiReH. 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 NACRE advanced numerical optimization methods have been applied for the design of droop-nose device for a forward swept wing. DeSiReH advanced 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.

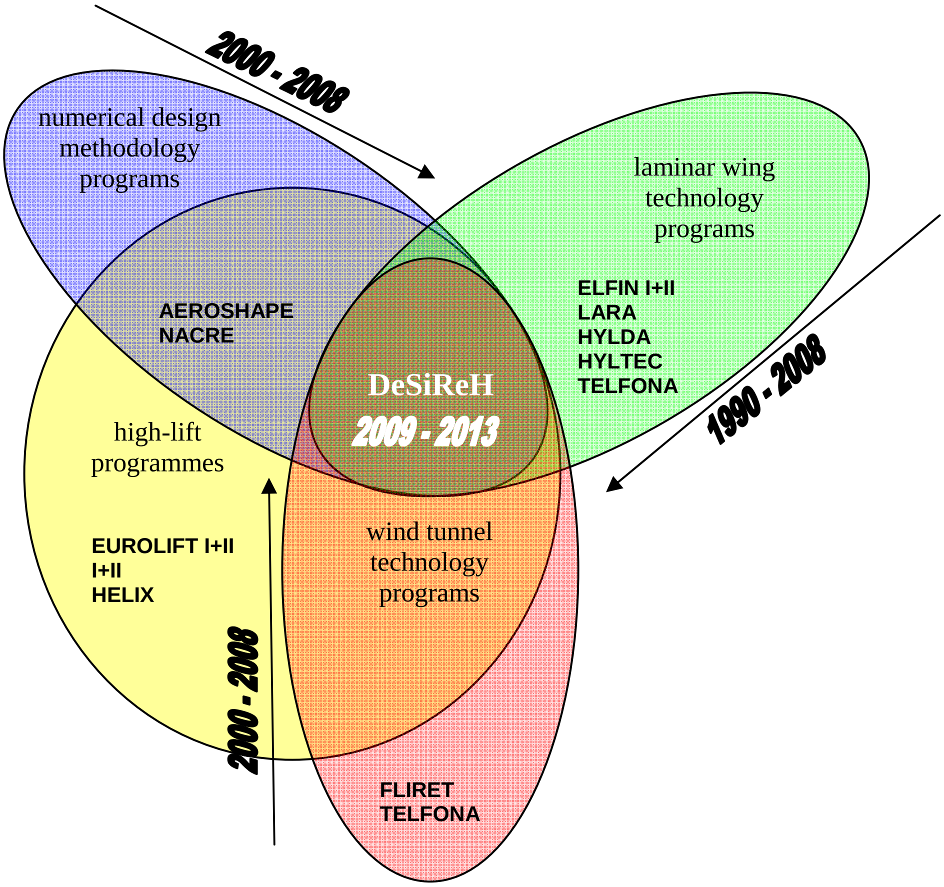

Figure 2: Relation of DeSiReH to former EC projects

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 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. Early projects such as HYLDA and HYLTEC led to flight tests with a hybrid laminar fin on the A320 demonstrating the feasibility of drag reduction. DeSiReH focusses on answering the open question of aerodynamic High-Lift system design under the constraints known from these projects. A starting point is the Krueger flap as tested in HYLTEC. Laminar wing design was part of 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 considerable large number of core partners of the above mentioned 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, DAC, 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.

2 High-Lift aerodynamic design strategy for flight Re-numbers

In workpackage one the 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 in the different flight phases as 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 global, 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 partner 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 had 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 specific 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 left), where efficiency is measured in terms of the computational effort compared to unsteady calculations with global time stepping. Twenty to ninety per cent speed-up of unsteady RANS calculations has been demonstrated [3], the most speed-up was achieved by additionally using preconditioning and a special temporal field extrapolation technique (Figure 5 right),. Furthermore, the evaluation of gridding strategies 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].

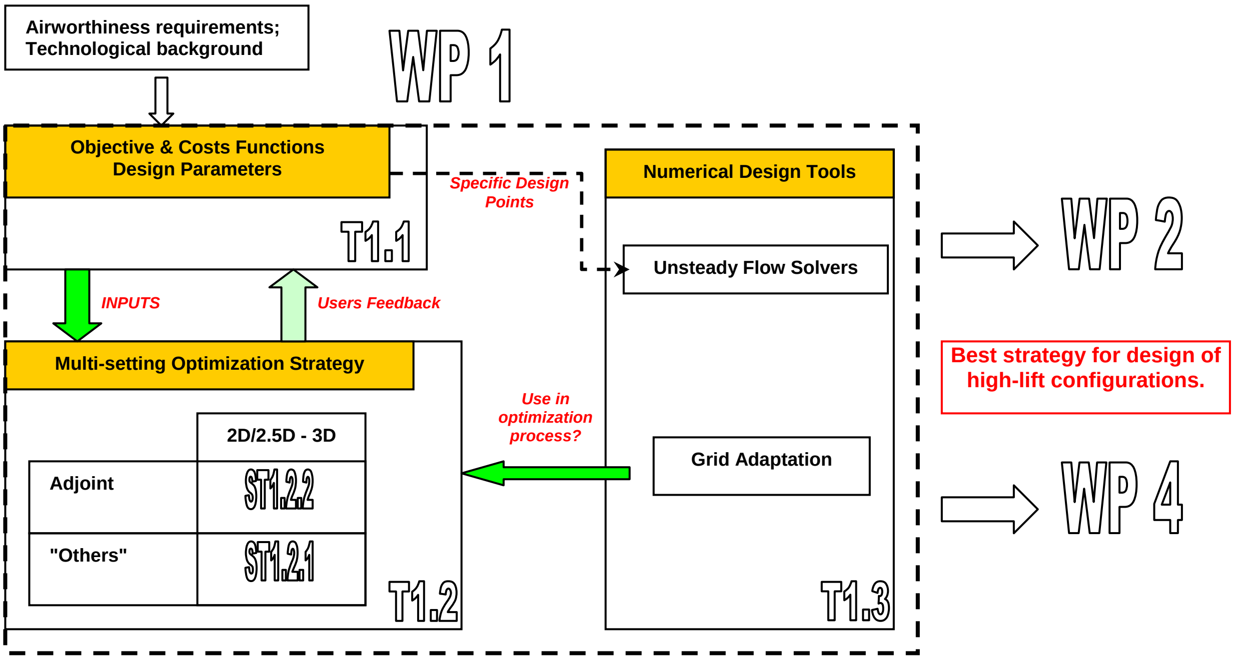

Figure 3: Work process for assessment and maturing CFD based simulation and design

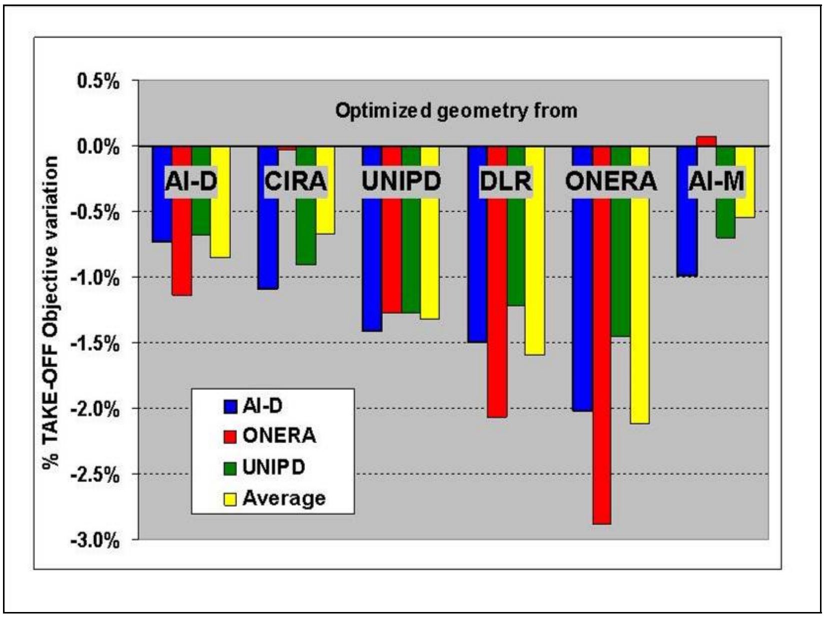

Figure 4: Cross-check of partners' 2D optimized geometries at constant lift

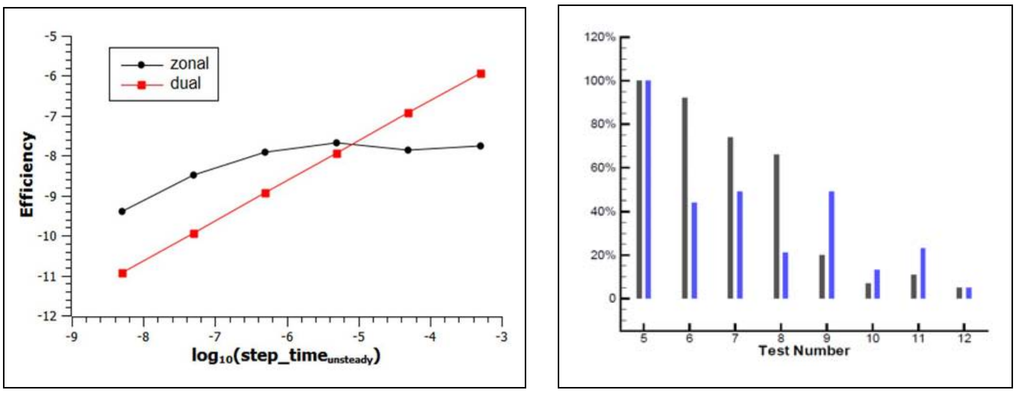

Figure 5: Efficiency improvements of unsteady RANS calculations. Left: 3D wing-body case with the zonal and implicit approach in dual time (TsAGI). Right: achievable speed ups by implicit method, preconditioning and temporal field extrapolation.

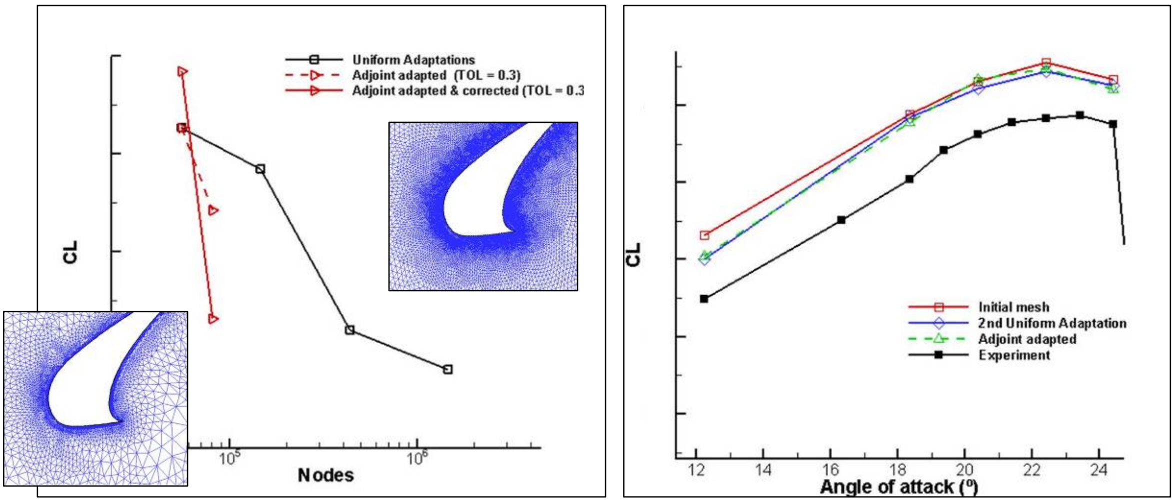

Figure 6: Left: Grid convergence of lift (left) for the AGARD AG08 using uniform adaptation (black) and adjoint based adaptation (red). Right: corresponding polar calculations.

3 High-Lift solutions for laminar wing

The 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 for a wing featuring NLF at cruise condition. The design of such an innovative High-Lift-System is of high industrial relevance consolidating two requirements:

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

The first major aim was to assess different high-lift concepts and to deliver an aerodynamically designed as 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 a baseline wing was obtained from the TELFONA project [5]. The wing was analysed 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 laminar wings. 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 was evaluated by optimizing shape, size and setting of the High-Lift devices as well as the constraints of the clean NLF-wing in cruise configuration. The receptivity of the laminar boundary layer to disturbances caused by steps and gaps created by 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 were 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 used for the detailed design of the wind tunnel model to verify the obtained designs.

The geometries have been employed to setup a detailed CFD analysis of the performance and the deviations due to wind tunnel installation effects. This allowed identifying the influence of the wind-tunnel walls (Figure 10), the model mounting, and the flexibility of the wings (Figure 11) in the pressurized tunnel. The flow models are based on 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. Once the wind tunnel test data was available, comparisons were made to evaluate the accuracy of the predictions.

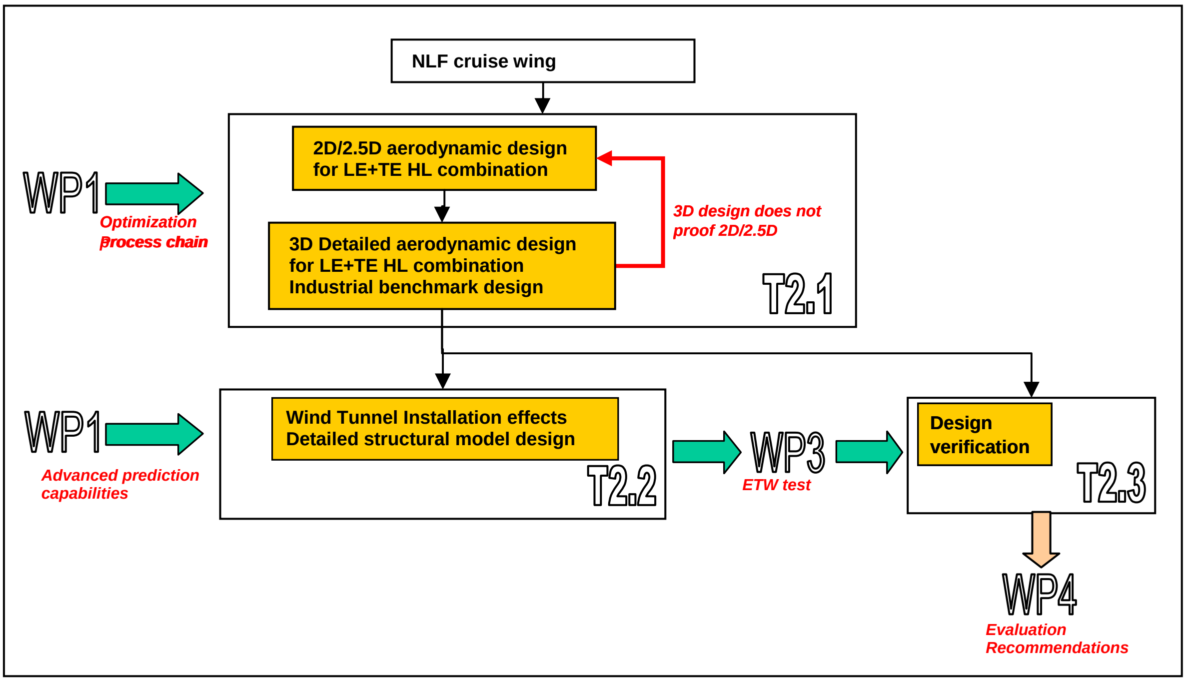

Figure 7: Work process to design and verify the high-lift system for a laminar wing

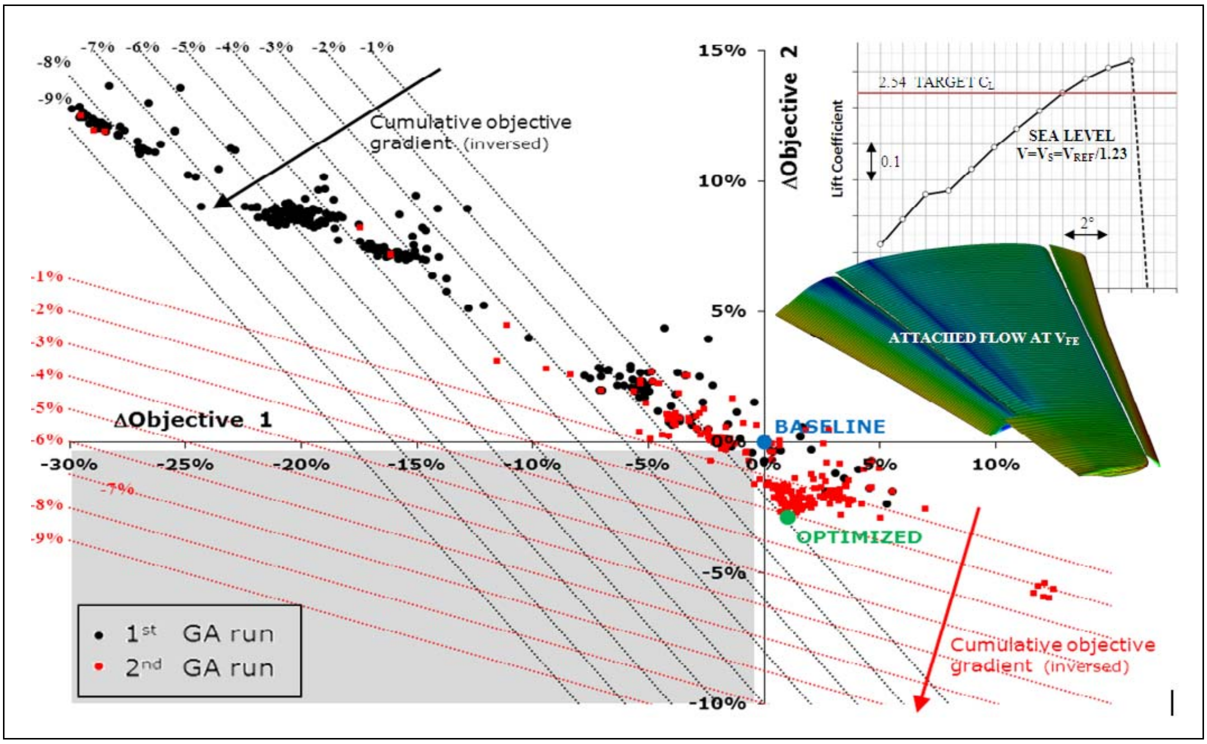

Figure 8: NLF high-lift wing designed by numerical optimization

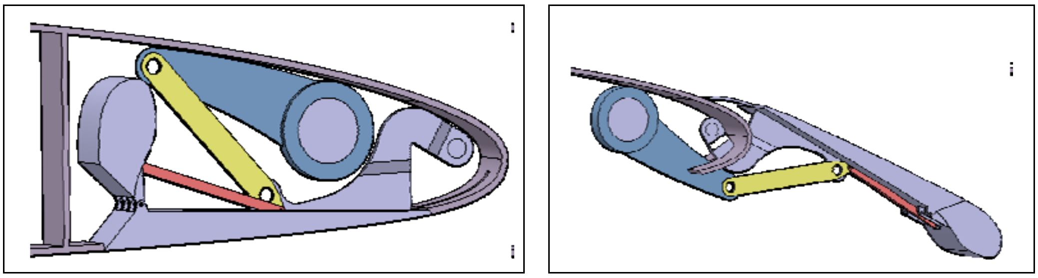

Figure 9: Mechanical integration concept of slotted and folding Krueger kinematics

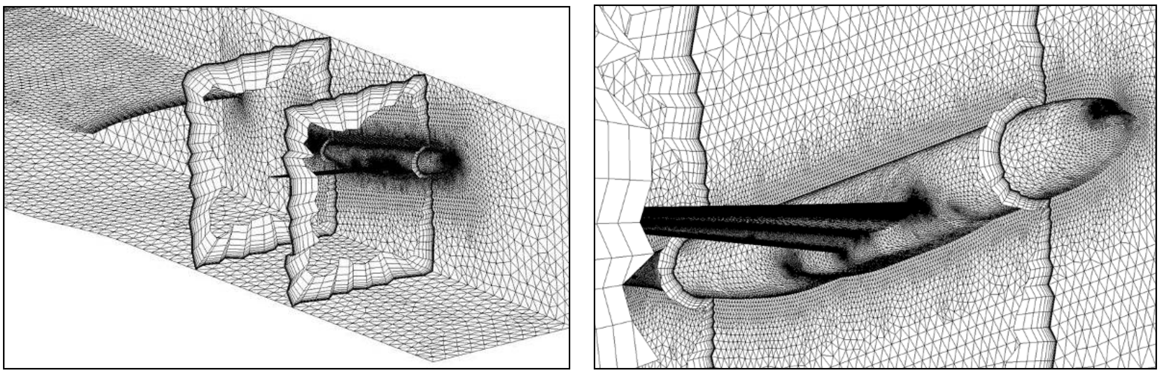

Figure 10 Grid of high-lift configuration in ETW wind tunnel; surface grid & cuts through the prismatic grid

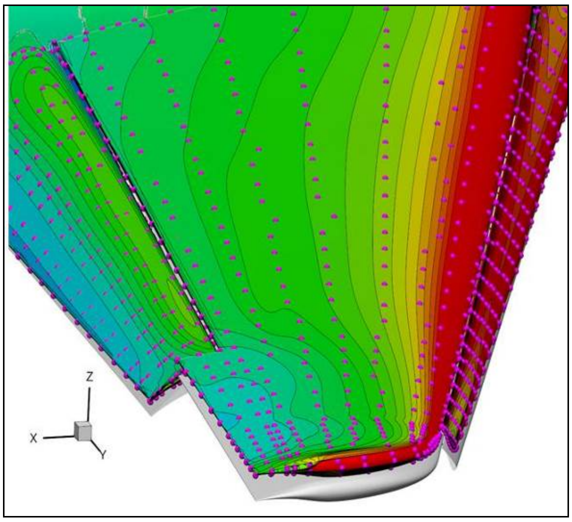

Figure 11: Rigid and deformed wing shape predicted by CFD-CSM coupled simulations

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

Nowadays, aircraft engineering offices aim at reducing the overall Wind Tunnel time and cost, while generating reliable data for direct flight application as well as for the further development of numerical simulation tools. 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 supports this approach with a typical application aiming to design a high lift system which achieves the required high-lift performance in take-off and landing while being compliant with a NLF wing in cruise.

In the third work package (Figure 12), the design process applied before is validated in a wind tunnel test with a half model (Figure 13) at flight Reynolds number. It was performed under cryogenic conditions in the European Transonic Wind tunnel - ETW (Figure 14).

With the high fidelity data of the test, the high lift design and the quality of the CFD predictions were validated. Special, non-intrusive measurement techniques were combined to generate high quality aerodynamic data at the edge of flow separation on high lift devices and for laminar-turbulent transition of boundary layers. All applied techniques had to be compliant with the pressurized cryogenic environment of ETW.

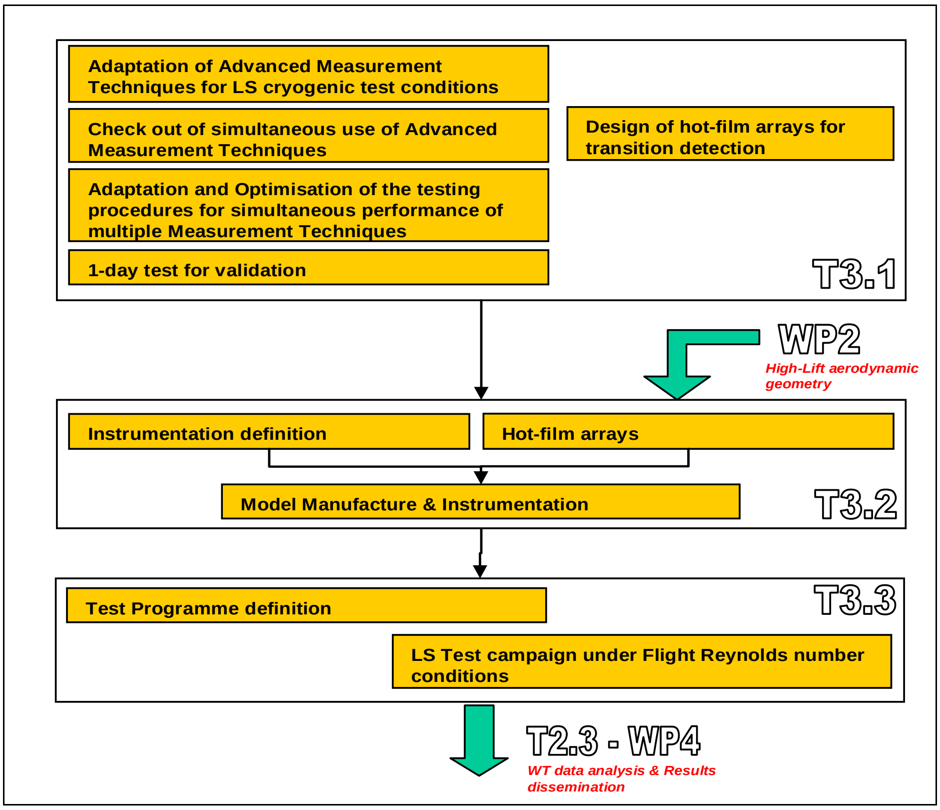

Figure 12: Work process for maturing measurement methods and verification tests of the high-lift wing

It was one of the objectives of the project to improve and accelerate the industrial design process of high lift devices by applying advanced measurement techniques in a single 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 tunnel pressure causing specific model deformations. Resulting geometry changes affect the local flow and any comparison with sophisticated CFD methods needs the exact knowledge of the geometry during testing.
- *Flow visualisation by Particle Image Velocimetry* (PIV), in particular downstream of the wing trailing edge, enhances the understanding of the aerodynamic behaviour and potentially enables to assess the local drag (Figure 15).
- *Boundary layer transition detection by Temperature Sensitive Paint (TSP)*, as the transition position of the boundary layer has also an impact an achieved aerodynamic performance (Figure 16).

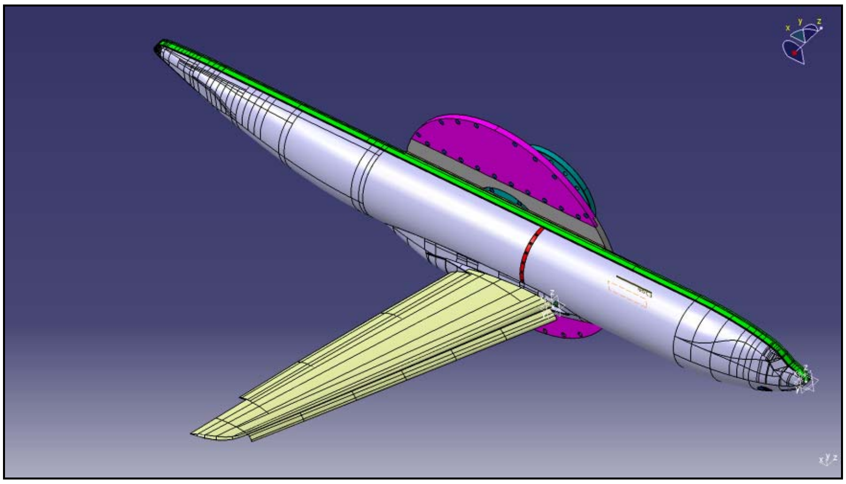

Figure 13: CAD model of the DESIREH high-lift wing scaled 1:11.75 mounted to the fuselage of the DLR-F11 (KH3Y) model and the ETW turn table

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

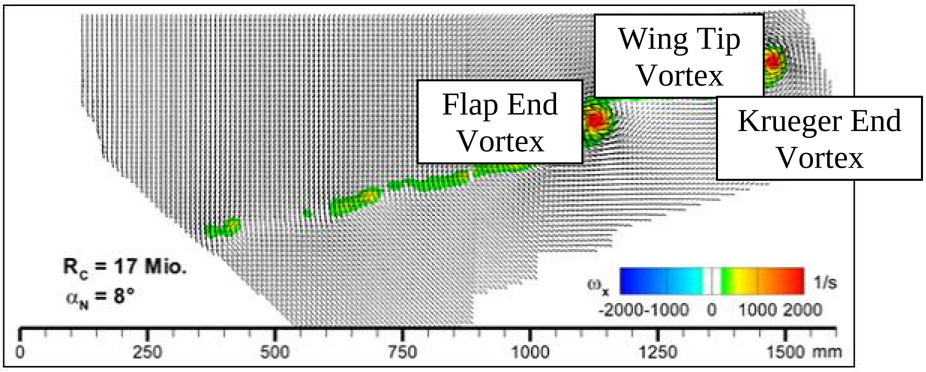

Figure 15: PIV image of flow field after trailing edge perpendicular to flow field

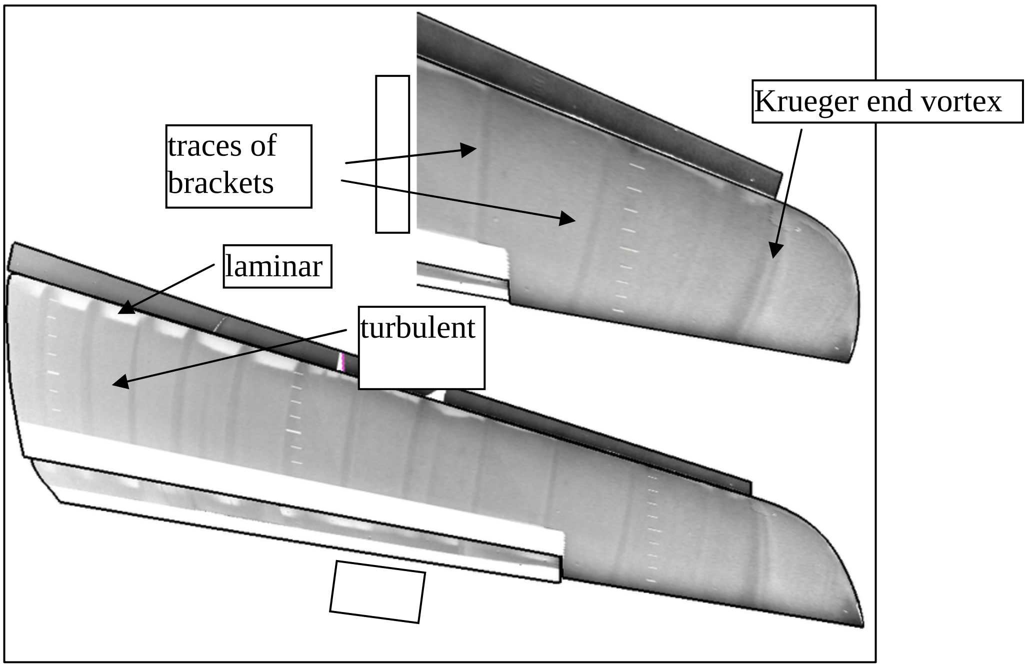

Figure 16: TSP image visualizing laminar-turbulent transition and vortex structures above surface

5 Assessment, Exploitation & Application

DeSiReH is devoted to deliver improved high-lift design methods, laminar wing compatible aerodynamic high-lift design solutions and to verify the developed high-lift design at Flight Reynolds numbers. The advanced experimental measurement techniques employed had to be qualified for use under cryogenic conditions. Finally the overall strategy as developed and applied in DESIREH was assessed (Figure 17). This was done by providing industrial input and constraints to assess the technical solutions 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 also delivered.

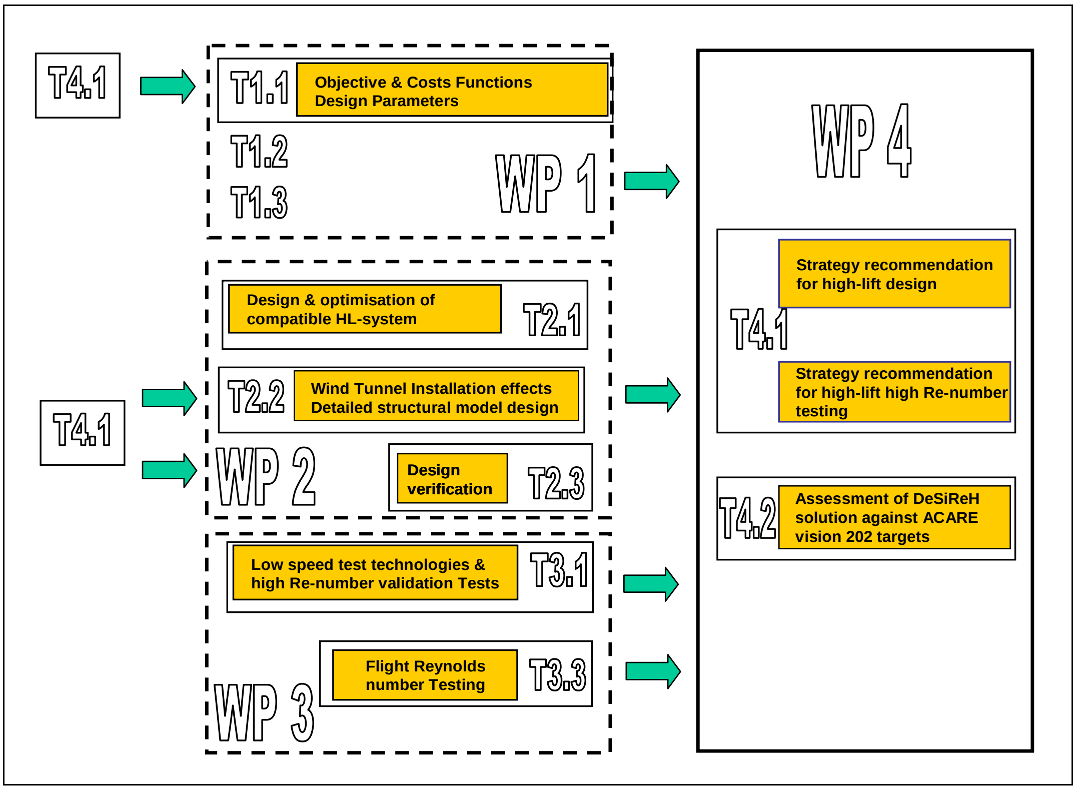

Figure 17: Work process for assessment and evaluation

One part of work package four 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. Although stating a quantified improvement is difficult, several aspects have been valued to improve the design process and quality according to the project objectives.

The second part of the work package assesses the environmental benefit of the high-lift design solution with respect to the objectives of ACARE Vision 2020 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.

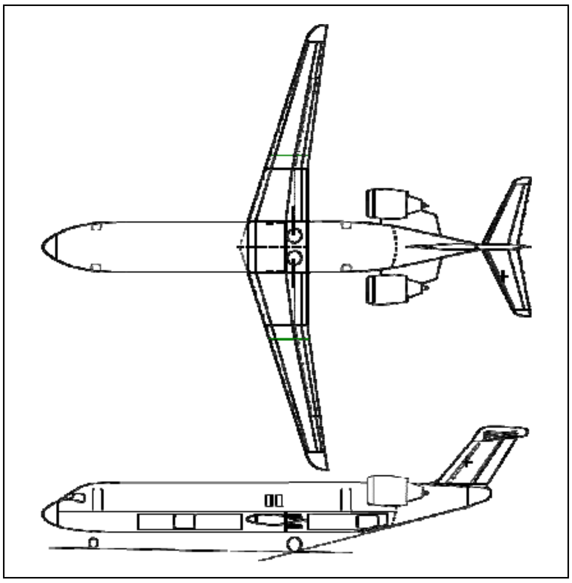

Figure 18: Generic aircraft used to evaluate the DeSiReH high-lift wing design on overall aircraft level

The impact regarding the various ACARE targets of operating these NLF compatible aircraft designs has been quantified by a comparison to a conventional turbulent aircraft design serving as a reference. A reserve fuel policy for assessing the benefit of laminar flow has been taken into account. Figure 19 shows the evaluated fuel savings depending on the fuel policy, showing a trip-fuel and emission reductions of between 5 and 7% on flights between 500 nm and 2000 nm distance. The project objective to enable the laminar wing by a suitable high-lift system has thereby been verified.

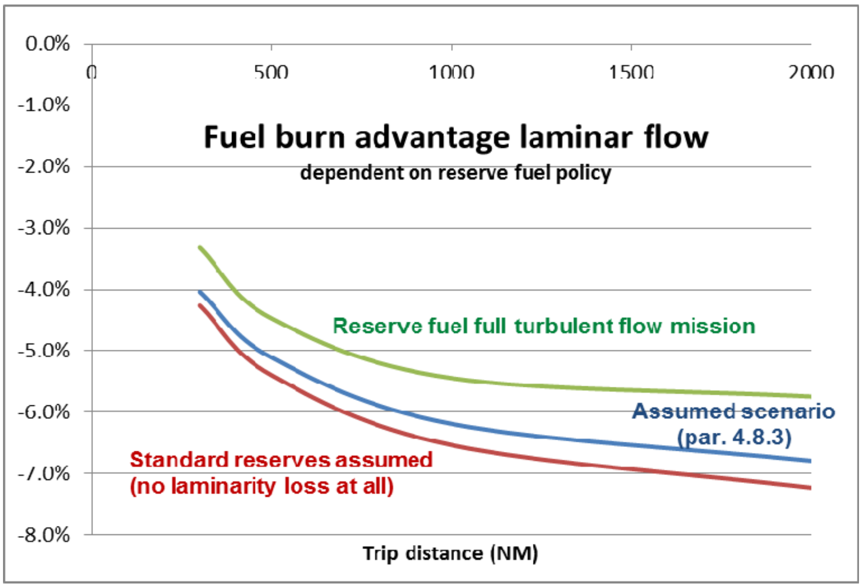

Figure 19: Fuel burn savings depending on range and reserve fuel policy

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