OVERVIEW ABOUT LAMINAR FLOW ACTIVITIES AT AIRBUS

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Summary

Research in laminar flow has a long tradition and a lot of work has been performed by research organisations and aircraft manufacturers around the world. With a few exceptions (gliders, light aircraft or small business aircraft) this technology has not found its way into real industrial aircraft application.

Increasing fuel costs and the need for reduction of the environmental impact of airline operations have led to new efforts to apply this technology for the next generation of aircraft. A key element for application of laminar flow technology is a structure concept that fulfils the high aerodynamic surface requirements and that can be manufactured at acceptable costs and production rates at the same time. The paper will explain the experience Airbus has gathered within previous research projects on that topic and the steps which have been and will be performed to introduce this technology in the future transport aircraft.

The main focus of this overview presentation is on activities within the Airbus internal technology project LDA (Low Drag Aircraft) and the related studies in national and European research projects.

The presentation provides some examples of major results in the fields of aerodynamic design and testing but with the clear focus on finding the best compromise for structural concepts enabling laminar flow. Examples of such structure concepts are given. Part of that concept is a Krueger high lift leading edge device providing an insect shielding function which is a major constraint for laminar flow application. An outlook will be given about the next major steps on the route towards the future application of this promising laminar flow technology.

1. INTRODUCTION

Together with new engine technologies laminar flow has the highest potential to reduce the fuel burn. The main reason why this technology has not been introduced so far for large transport aircraft is the fact that for this category of aircraft with very high Reynolds numbers extreme requirements for surface quality have to be fulfilled. Two different types of laminar flow technologies have to be considered: natural laminar flow (NLF) which uses specific shaping of the wing airfoils and hybrid laminar flow control (HLFC) which is a combination of shaping and active means (e.g. suction) to increase boundary layer stability.

Both technologies are applicable for different conditions: NLF is more related to smaller, low sweep wings and HLFC can offer some advantages for a large aircraft flying at high Mach numbers. The surface requirements and therefore the structural concepts are different but there are a lot of common issues for both concepts which will be explained in more details in this paper.

2. PREVIOUS AIRBUS ACTIVITIES ON LAMINAR FLOW TECHNOLOGY

Laminar flow research has a long tradition all over the world [1, 2, 3, 4, 5, 6, 8]. Airbus together with research partners in Europe have started a lot of activities around NLF and HLFC in the 90s. A major objective at that time was to establish a toolset for prediction of laminar extent on wings under realistic flight conditions.

The application of linear stability with determination of limiting amplification factors (N factor) in the relevant environment (wind tunnel; free flight) could be identified as a valuable tool for the aerodynamic design of laminar surfaces [8, 9, 11].

Several major design steps (VFW614 NLF glove flight test; F100NLF glove on upper and lower side flight test; large HLFC wind tunnel models; A320 HLFC fin flight test) could demonstrate the increasing aerodynamic design capability. An overview about the different activities and projects performed together with several partners is given on Fig. 1 and some of the references for these activities can be found in [7, 9, 10, 12]. Major flight or ground tests are indicated in blue, major wind tunnel tests in red and tool development work in green.

A major result of these tests was not only the improved aerodynamic design and measurement capability but also the first indications about the need for high surface quality. An interesting example for that is given on Fig. 2 and in [7]. During the first flight tests with a laminar glove on the F100 wing the extent of laminar flow was poor. Detailed analysis of the manufactured surface quality showed that some kind of waviness was at the origin of the problem. After re-work of the surface a laminar extent was obtained as expected. Very useful information could be derived from this exercise emphasising that surface quality is key for introducing such a technology.

3. MAJOR ACTIVITIES AND STRATEGY FOR APPLICATION OF LAMINAR FLOW TECHNOLOGY

In the next sub-chapters an overview is given about the Airbus activities and the three major elements of introduction of laminar flow technology for large aircraft application is described. All activities on laminar flow technologies and the related studies in national and European research projects are coordinated and steered within the Airbus internal technology project LDA (Low Drag Aircraft). Fig. 3 gives an overview about the major national and European research projects with a strong link to laminar flow research and related topics.

3.1. Aerodynamics

As explained in the previous chapter a useful and validated toolset for aerodynamic design could be build up within Airbus. There is a high confidence in that we are able to predict laminar flow extent with sufficient accuracy. Thanks to measurements in several wind tunnel facilities and the N-factor calibration for these tunnels (e.g. ONERA S1, ETW) both computational and wind tunnel tools can be applied for performance predictions.

The new focus in aerodynamics is achieving now the best compromise on aircraft level between surface quality, complexity/weight and costs. The final answer will not be a wing optimised for performance alone, but one which provides good performance together with sufficient margins and tolerance of surface imperfections. Important to finding this compromise is improving our knowledge of the requirements for surface quality. The objective here is to give as precisely as possible constraints for NLF and HLFC structure concepts. This last point will have a significant effect on manufacturing costs and time.

One example of that activity is given in Fig. 4. Here a very specific cryogenic wind tunnel test has been done to get information about allowable step heights under realistic conditions. Realistic means here: comparable boundary layer stability situation very similar to a real laminar wing application and simulation at nearly flight Reynolds numbers. With this test it could be demonstrated that the effect of steps is strongly dependent on the stability situation and that by proper design, surface requirements can be relaxed.

As a further step into this direction other tests are currently performed in the same test facility to study in detail the effect of waviness (e.g. caused in flight by air loads) in combination with steps. Each surface disturbance has specific effects on the boundary situation and the change of extent of laminar flow. With a specific wind tunnel model layout the deformation of the surface under loads can be simulated and very precisely adjusted during the test. The first very interesting results of such a combination of different surface imperfections are available and will help to specify the structure requirements. Some more details will be given in chapter 3.3. All these experimental data are used to validate and calibrate or to develop aerodynamic computational tools to predict such effects for any new NLF or HLFC design.

3.2. Structure

As already underlined with the F100 example seen in the previous chapters the major focus for introduction of laminar flow technology is on a feasible structure concept. In the past all flight test experiments have been performed with a glove technology on top of the existing wing structure. Such a glove was then hand finished with a lot of effort to get high surface quality, which is acceptable in a research environment.

The new approach is to develop and demonstrate wing structure concepts to be applied under typical production standards (high rate, low costs) and enabling laminar flow by providing sufficient high surface quality.

Several surface requirements have to be considered for such a concept:

- No steps or only steps with very limited step height
- Reduced waviness (either from manufacturing or deformation under cruise loads)
- Avoidance of any 3D disturbances (by insects or fasteners, ...)
- Reduced roughness at the leading edge (either from manufacturing or erosion under operational conditions)

This long list shows that this is a real challenge on top of all the additional constraints from manufacturing, assembly, repair, time, costs and weight.

A typical example of waviness effect at cruise conditions is given in Fig. 5 left. The effect of local deformations by air loads is shown. Such a tiny waviness in the order of less than 1 millimeter can create premature transition and therefore means have to be found to reduce those effects. By manufacturing additional effects will come on top of these deformation effects. A typical example is given in Fig 5 right for a CFRP wing box panel. Around each stringer waviness is detected by a very precise surface measurement technique. This waviness is caused by spring in effects around stringers or other substructure and strongly dependent on design features of stringer feet, thickness and manufacturing process and sequence. Detailed studies and measurement of today's production standard are performed at Airbus to quantify and control these effects as precisely as possible for a laminar wing application. The national funded project LaWiPro (laminar wing production) is supporting these activities.

A very important decision is the wing concept itself. Several solutions are possible but each has his own pros and cons. A continuous surface with any separation between wing box and the leading edge part is from an aerodynamic point of view the best, but here repair and integration of systems is a challenge. Another concept with a joint between the box and leading edge offers here some kind of flexibility, but creates a risk of non acceptable steps at the joint. Therefore experiments described in the previous chapter are important to give structure and manufacturing realistic aerodynamic requirements.

A major problem for introduction of laminar flow is the disturbance created by insect debris at the wing leading edge during summer time. Due to the fact that most of these insects can be found during the taxiing, climb or landing phase a very effective way to reduce or avoid insect contamination is to use the high lift leading edge elements as an insect shielding device. Several tests have been performed to demonstrate this [13]. Fig. 6 shows such a pretest performed by DLR on Do228 test aircraft with a Krueger element used as insect shield. A nearly 100% success could be demonstrated. Within this test campaign it could also be demonstrated that a combination of a perforated surface (used for HLFC) can be combined with cleaning fluid to reduce contamination by insect.

Another possibility is to develop specific mechanical cleaning devices. This cleaning process can be supported with coatings which can offer easy to clean properties. The objective here is to develop coatings which are erosion resistant and can be combined with other functions like ice adherence reduction.

Due to the specific pressure distribution needed for laminar flow a very narrow leading edge is created. This is causing several problems for the integration of high lift and other systems. Especially if combined with a suction system for hybrid laminar flow this can create a real challenge. At Airbus therefore a specific kinematics concept for a Krueger system has been developed which fits to the space available for a laminar wing and which can provide at the same time a correct setting of the Krueger for the insect shielding function.

3.3. Demonstration

Before deciding to go for such a risky technology a sufficient maturity has to be reached. Therefore demonstration at realistic conditions is a clear request. For the aerodynamic design of a laminar flow concept the Reynolds number is the key parameter. This Reynolds number should be as near as possible to the flight conditions. This can only be reached by testing directly at flight with the real geometry or by testing in wind tunnels at smaller scale but with specific features to reach flight Reynolds numbers.

The cryogenic test facility ETW (European Transonic Windtunnel) offers here the unique possibility to combine high pressure with extreme low temperature to reach Reynolds numbers comparable to flight. As described in chapter 2 a calibration for such a tunnel is needed, to be able to translate results to flight. This was done by a specific pre-test in the European research project TELFONA [14]. A new test in this facility is under preparation with a 3D model to simulate most realistically the effect of surface imperfections and combinations (e.g. steps and waviness) which can be expected for structure wing concepts described in the previous chapter. By a very specific model layout the waviness as sketched on Fig. 7 can be adapted during the running test, which is especially for a cryogenic facility of high importance to reduce test time and costs. The structure layout simulate as best as possible the real deformation under flight conditions which is a challenge for downsized small wind tunnel models.

Based on several pre-tests and the lessons learnt within Airbus in cryogenic laminar testing in ETW and other test facilities there is a high confidence that with such a test, high quality results about surface imperfections and their effects of laminar wing performance can be collected.

The consequent next step is to go for tests with the real structure concept at realistic flow conditions. Within the large European research project Smart Fixed Wing Aircraft (SFWA) as part of Clean Sky it is therefore planned to go for a flight test experiment for demonstration of laminar technology. The A340-300 flight test aircraft was selected and a concept developed to exchange the existing outer wing of this aircraft with a new wing with a laminar aero design. In contrast to all previous experiments it is planned not to use an existing structure but to build a complete new wing structure which is as near as possible to a production standard required for a laminar wing structure concept. Fig. 8 shows a sketch of this arrangement. More details about this project can be found in [16, 17, 18]. Both wings are exchanged. This offers the possibility to check different structure concepts at same nominal outer shape.

Four major objectives for such a flight test can be given as follow:

- demonstrate in flight that aero design for a laminar wing is feasible and can be achieved with the tools developed
- fly a wing structure concept that can provide sufficient surface quality to enable laminar flow with expected extent and which is representative for a possible laminar wing structure
- demonstrate this in an environment which is relevant for a laminar wing application
- collect final surface requirements and operational limitations to support a decision to go for such a technology for the next generation fuel efficient aircraft

A major constraint is to do all this for a boundary layer stability situation which is typical for a new aircraft application (Ma, Re range and pressure distribution).

By using an existing aircraft as carrier for such an experiment several constraints are introduced especially for the structure concept. Therefore in parallel some critical structure features will be tested on ground with large structure demonstrators. All knowledge collected by these tests will be introduced in simulation of specific surface imperfections on the flight demonstrator. Specific measurement technique is under development for detailed measurement of local surface deformation in flight. This will offer the possibility to correlate any change in laminar extent to the surface quality conditions and to derive clear guidelines for structure design and manufacturing.

3.4. Operation

If such a laminar wing will make its way into the next product an important question will be how such a wing and the related performance will change over the life time of such an aircraft under operational conditions of typical airlines. Any additional effort in cleaning and maintenance may have an important influence of the overall benefit of such an aircraft for the airline. Therefore it is essential to consider all these influence factors, to collect data and to assess this at aircraft level and the economics for the airline.

Fig. 9 shows some examples of such operational issues. Some of them are weather dependent and have to be considered in fuel planning. Others are again connected with the structure concept and have to be avoided or reduced by design. In most cases it is needed to get more statistics about occurrence and details of the disturbance.

Fig. 10 gives an example of such collection of data. Here detailed measurements are performed on typical findings during operation (paint edges, scratches, nicks, ...) and with a 3D laser microscope detailed geometry data are derived for further aerodynamic and structural assessment. In a new national funded project all these data will be used to develop easy exchange and repair means for the laminar wing operation.

4. OUTLOOK

Laminar flow technology is a very promising element for reducing fuel burn. For application of such a technology a structural concept has to be developed which can provide high surface quality over the complete life time of an aircraft. Such a structure concept has to consider from the beginning production cost and time, and all issues of such a laminar wing during airline operation. Especially this last point is of high interest for customers of such a technology and has to be considered over the full life time of such a laminar aircraft. Increasing fuel costs will be a major driver to accelerate the application and to increase airline interest of such a technology.

Close cooperation between the major discipline aerodynamic, structure and manufacturing is needed to find a solution which is the best compromise on aircraft level. Together with several European research organisations and manufacturing partners the flight test demonstrator in SFWA is under preparation and will deliver a major step for introduction of laminar flow for the next generation of aircraft.

5. REFERENCES

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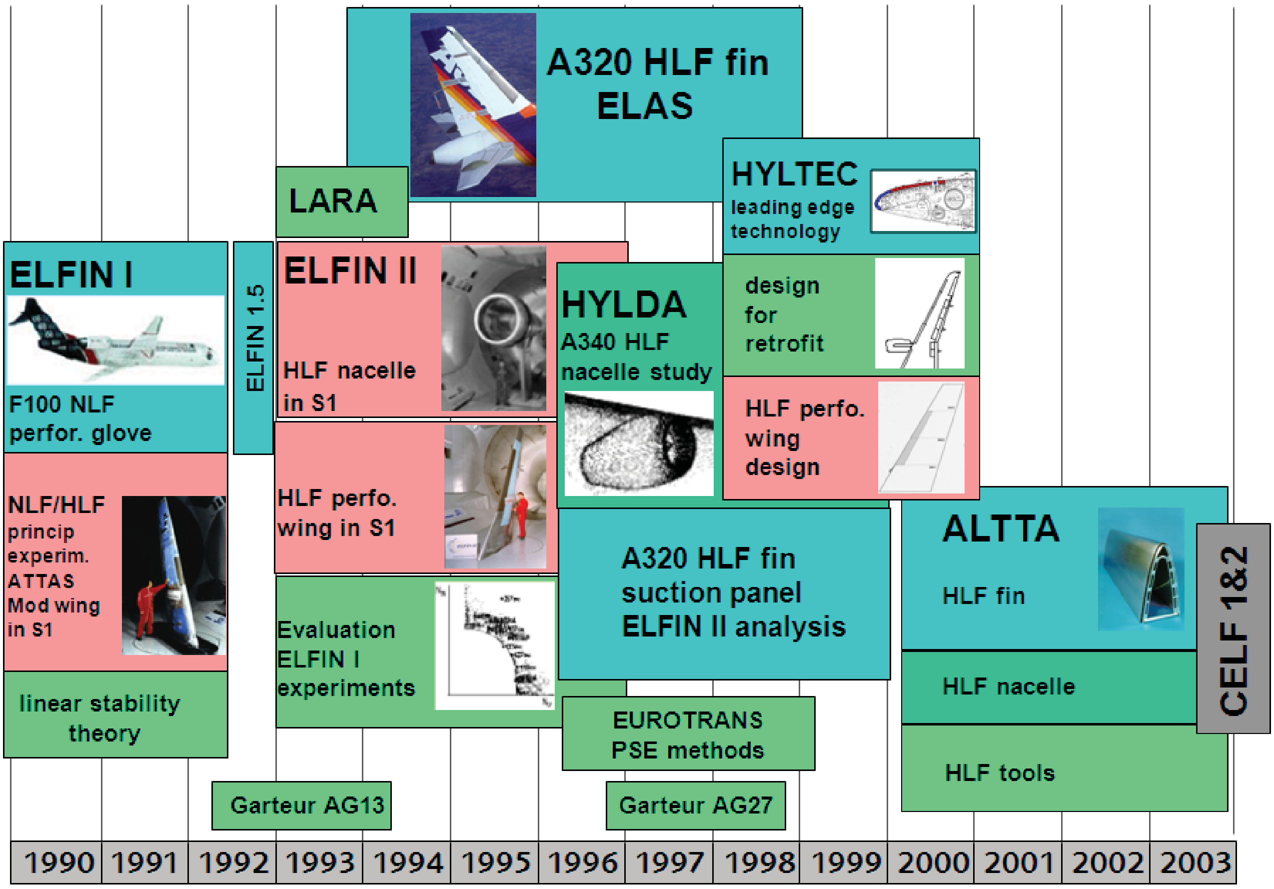


Fig. 1: Overview about Airbus activities for laminar flow

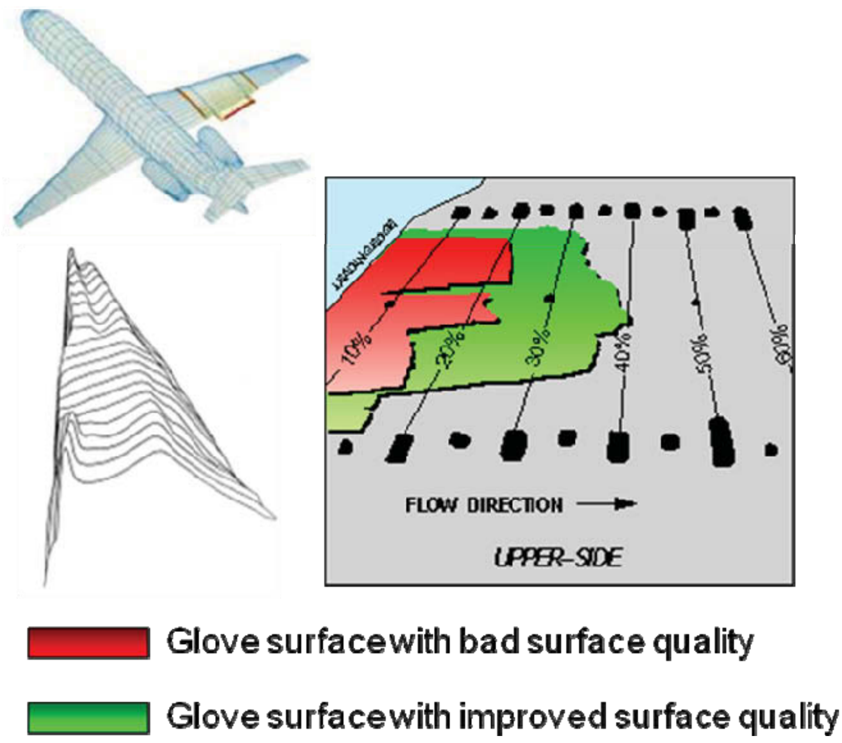


Fig. 2: Effect of repair of F100 flight test glove on extent of laminar flow

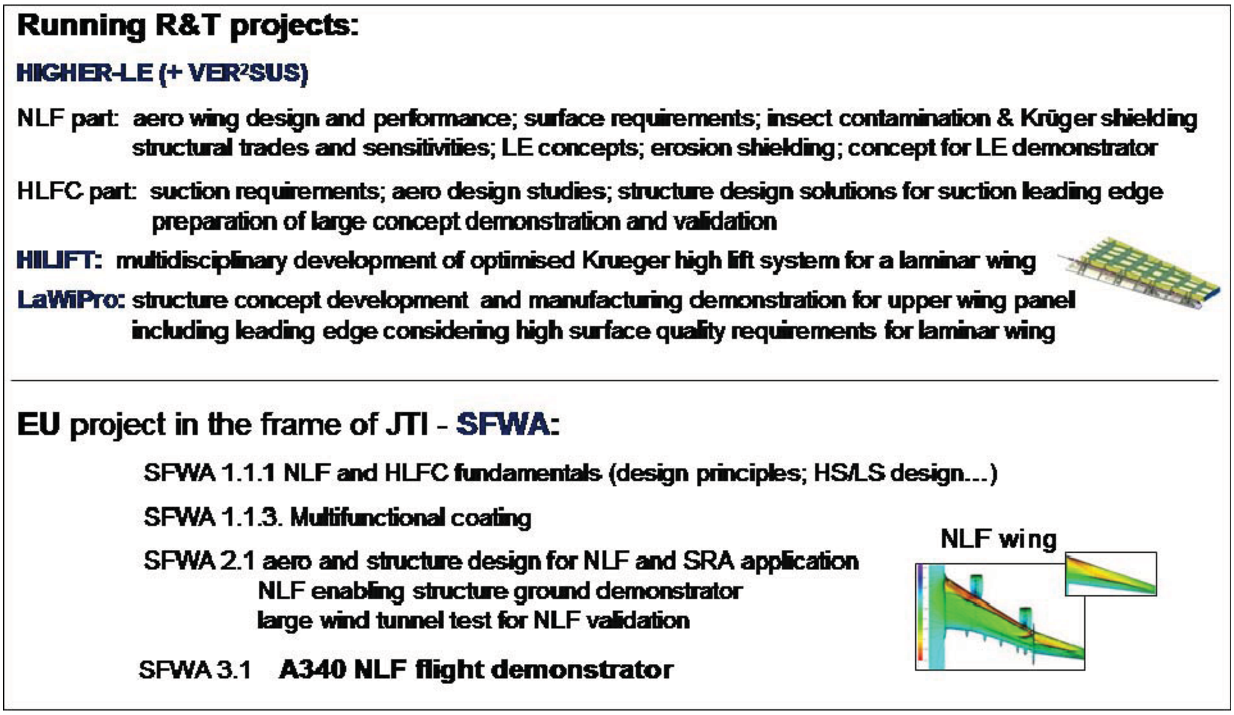


Fig. 3: Overview about R&T projects supporting laminar flow technology at Airbus

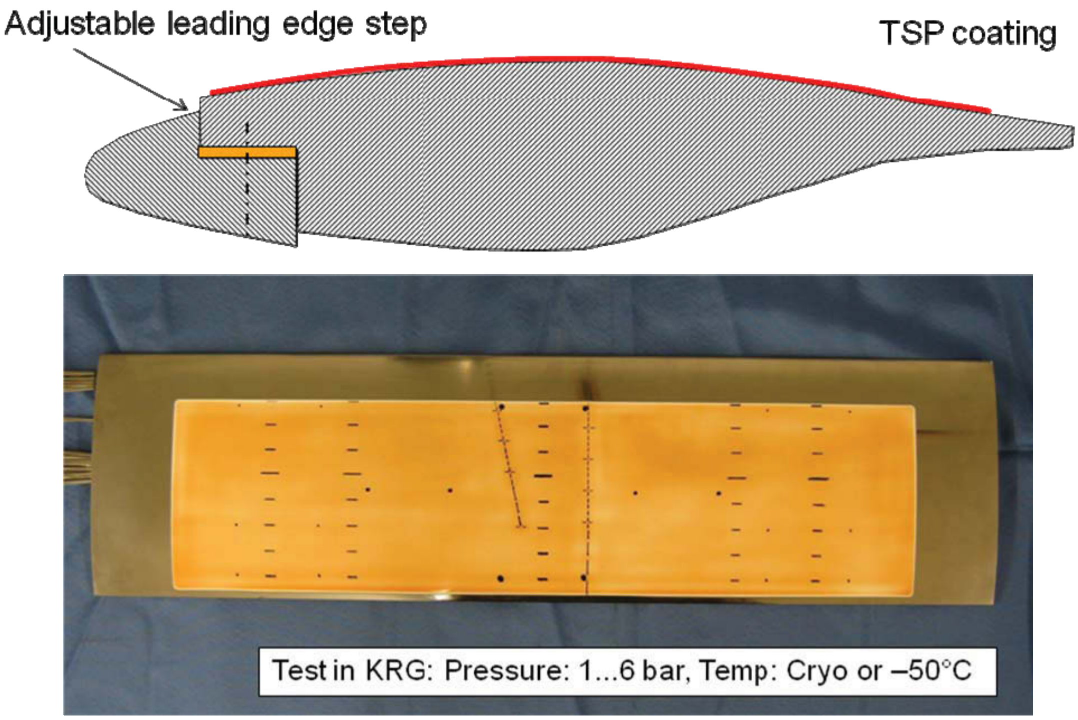


Fig. 4: KRG Wind tunnel model for testing of allowable step height at different Reynolds number

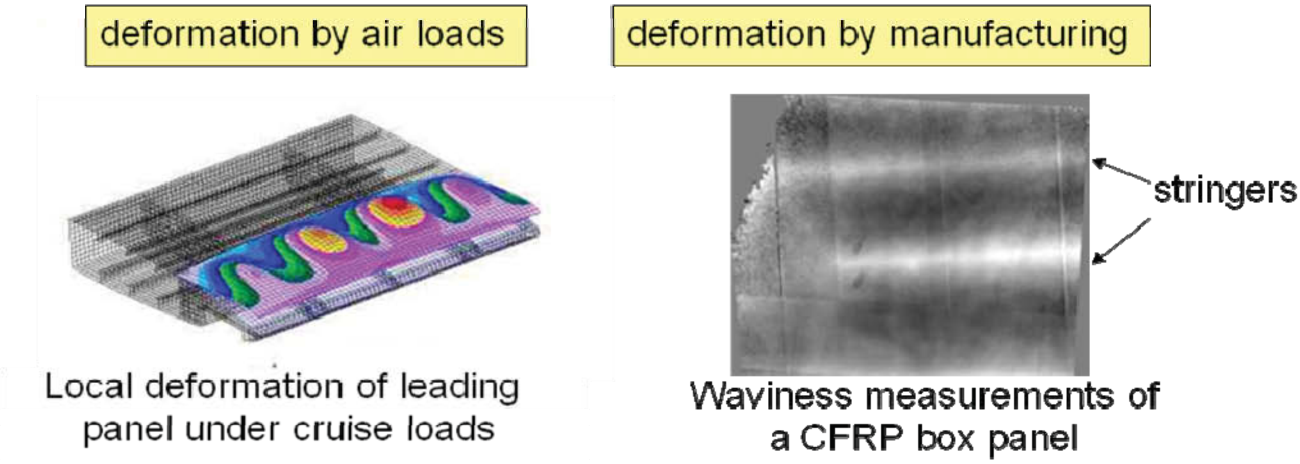
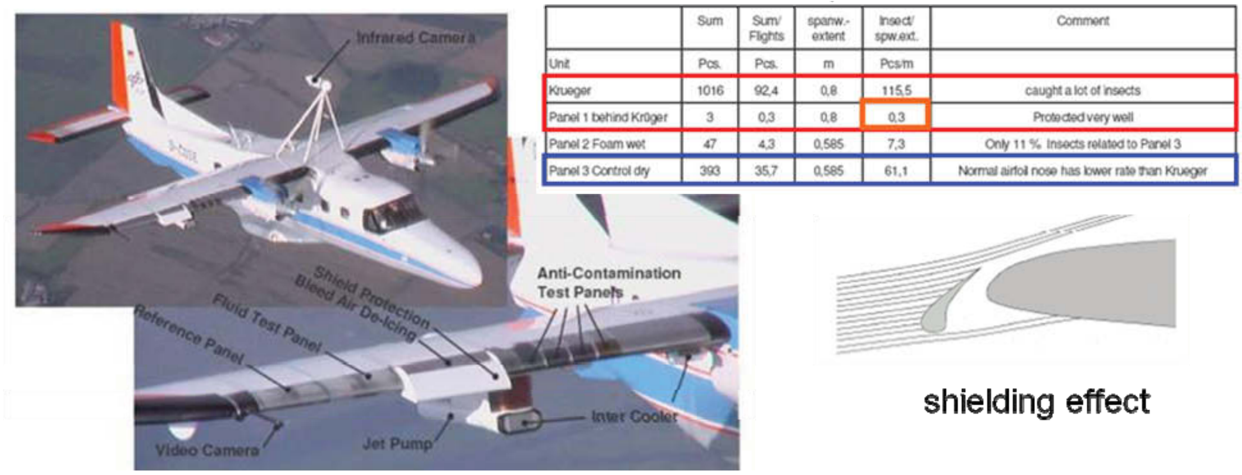


Fig. 5: Examples of waviness caused by loads and manufacturing



	Sum	Sum/ Flights	spanw.-extent	Insect/ spw.ext.	Comment
Unit	Pcs.	Pcs.	m	Pcs/m	
Krueger	1016	92,4	0,8	115,5	caught a lot of insects
Panel 1 behind Kröger	3	0,3	0,8	0,3	Protected very well
Panel 2 Foam wet	47	4,3	0,585	7,3	Only 11 % Insects related to Panel 3
Panel 3 Control dry	393	35,7	0,585	61,1	Normal airfoil nose has lower rate than Krueger

Fig. 6: Flight tests with DLR Do228 and Krueger element as insect shielding device

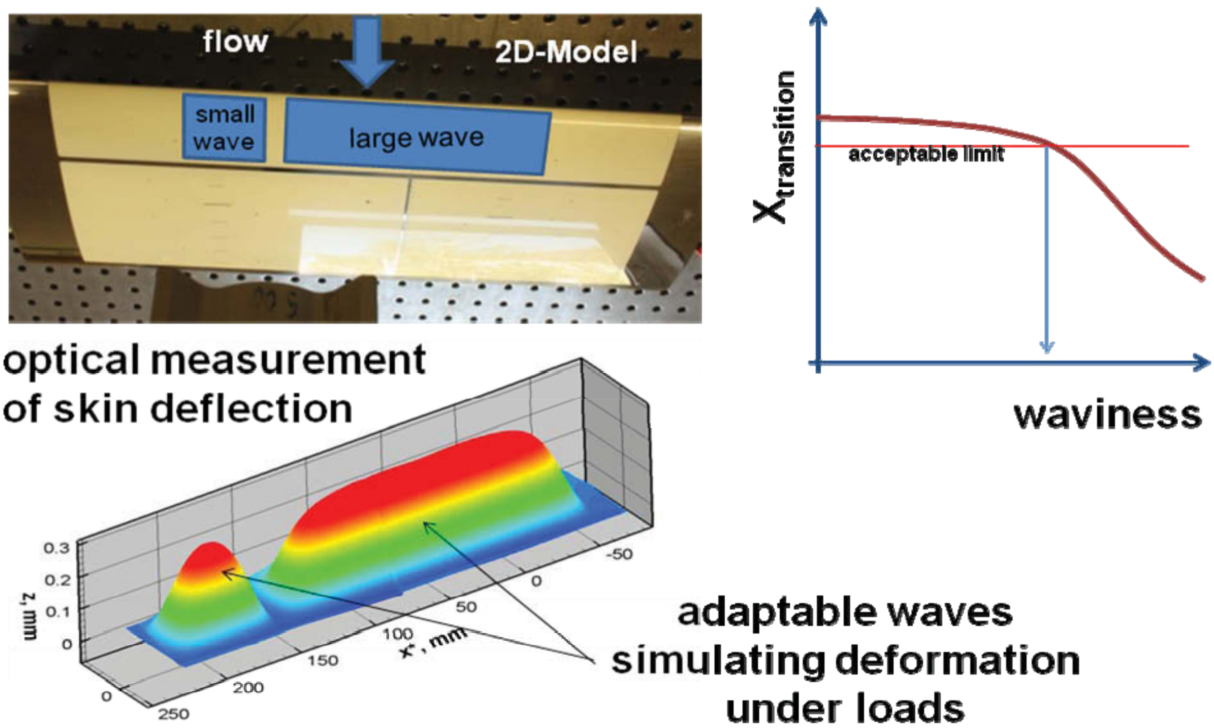


Fig. 7: New wind tunnel model technology to test effect of waviness

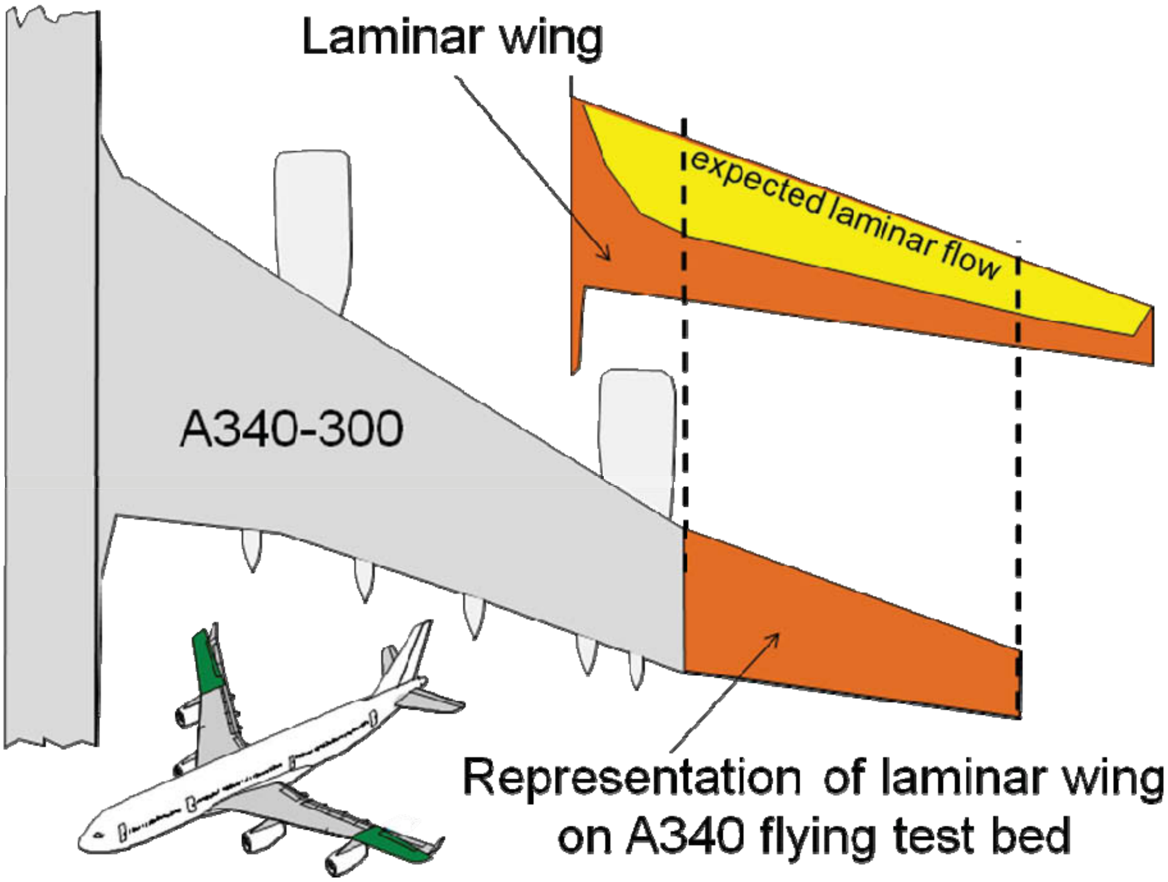


Fig. 8: A340 Flight test demonstration planned in the frame of the European research proiect SFWA

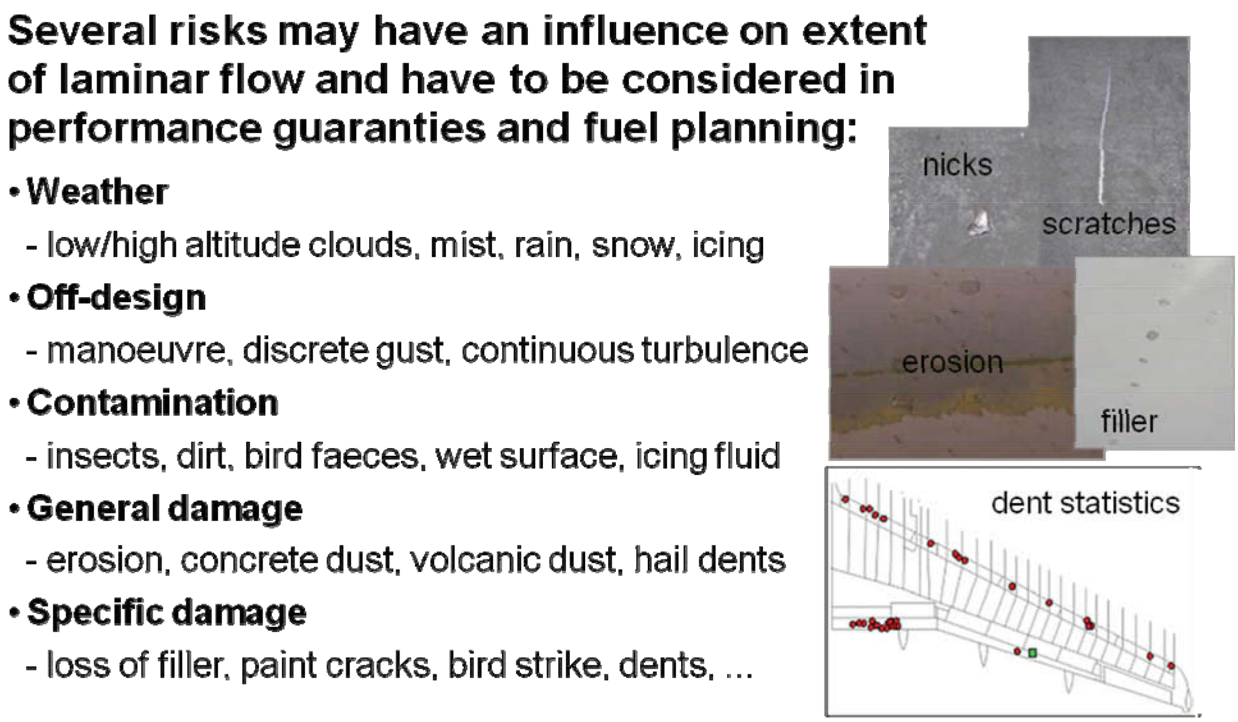


Fig. 9: Overview about major operational risks of laminar wing technology

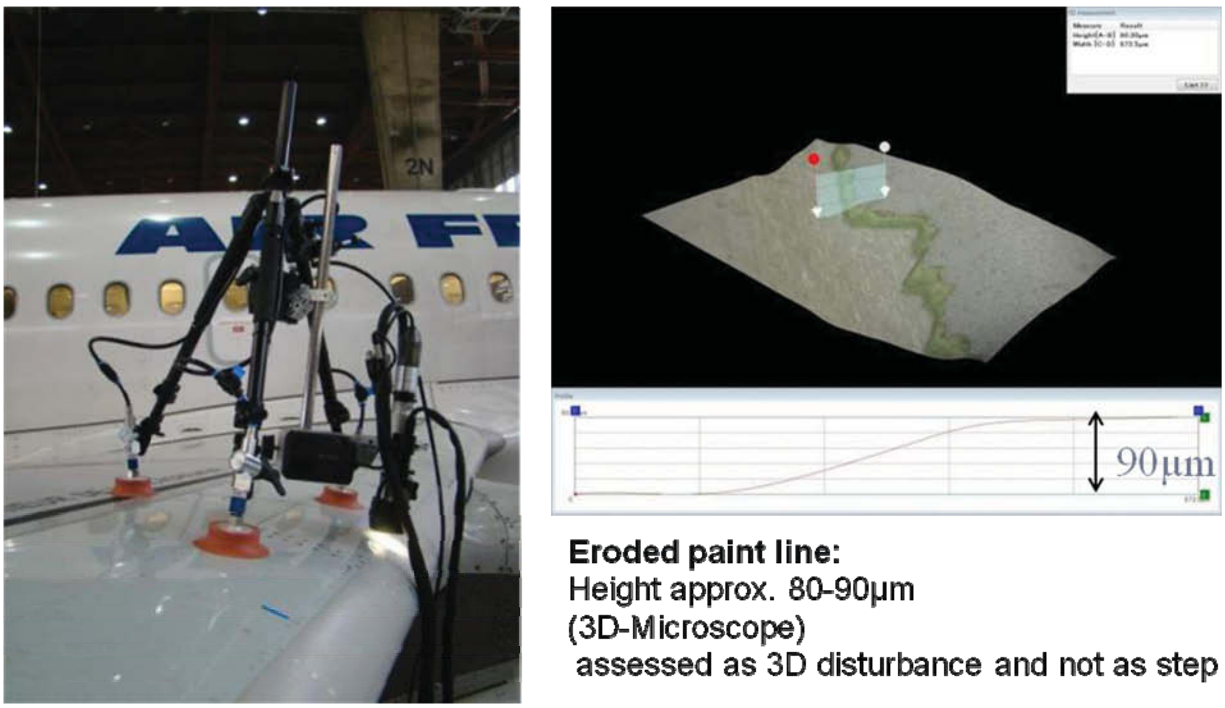


Fig. 10: Example of measurements of surface imperfections during airline operation