WiMo (286745) & **WIMCAM** (641489)
Outer wing metrology & measurement campaigns

State of the art – Background

According to the Air Transport Action Group (ATAG), aviation is responsible for 12% of CO2 emissions from all transport sources and accounts for around 2% of all humanly-generated CO2 emissions. As the aviation industry thrives and passenger traffic doubles over the next twenty years, it's incumbent upon the aeronautical community to take responsibility by creating and cultivating powerful technologies that are environmentally benign.

Within the CleanSky programme, SFWA ITD carried out the 'BLADE' - Breakthrough Laminar Aircraft Demonstrator in Europe, under management of Airbus. This demonstrator is being developed to build wings for passenger planes that allow a natural laminar flow under cruise conditions. This will help reduce fuel consumption and emissions caused by air travel.

Numerous technological challenges must be overcome to build wings that will comply with the necessary tight aerodynamic tolerances for profile waviness and roughness, required to enable a natural laminar flow. Also, the precision manufacturing and assembly must necessarily be accompanied by high precision metrology on scales from meters to sub-millimeters. At present no measurement system exists which is capable of measuring large areas with high lateral and depth resolution.

The WiMo / WimCAM projects aim at the development and testing of a strategy to combine different measurement systems to a single one which allows for measuring large areas with the necessary resolution. In addition new strategies for handling the huge amount of data and evaluate them will be developed. The projects results can therefore fulfil the requirements of a quality control in a production line for the natural laminar flow wing.

Objectives

The companies BIAS & VEW, in the frame of the projects WIMO and then WIMCAM, supported the 'BLADE' demonstrator with the development of an innovative metrology system to measure profile, waviness, steps, gaps, 3D disturbances, and surface roughness of the wings.

WIMO objective is to ensure the development and testing of the measurement system in line with the metrology requirements of Airbus. So the following activities were planned:

- Development of the measurement system
- Definition of the strategy for the measurements campaigns
- Performance of the measurement campaigns up to the final assembly phase of the wings

WIMCAM objective is to ensure that the metrology requirements of Airbus will be satisfied during the flight tests so, in the timeframe of the project, the following upgrades to the existing system were planned:

- Improvement and re-configure of the metrology system by introducing a third recording camera
- Improvement of the measurement procedure and data evaluation for the flight tests as basis for the evaluation of the set wing profile tolerances.
- Measurement of completed wing attached to the A340 aircraft during up-bend test
- Measurement of the full wing on ground, unloaded prior to commencement of the flight test campaign
- Measurement of the full wing on ground, unloaded, after first flight programme
- Measurement of the full wing on ground, unloaded, toward the end of the flight programme
- Detailed local measurements of waviness, steps, gaps, 3D surface imperfections and profile in an area not larger than 1300 mm x 800 mm²

The shift of 'BLADE' flight tests from 2016 to 2017 / 2018 led to review the ambition of the WIMCAM project due to be completed by end of 2016. The remaining activities expected to take place after completion of Clean Sky 1 are to be financed through another funding scheme. The results presented in this document about the WIMCAM project are then limited to the first two points listed above (completed in 2016).

Description of work

The envisaged metrology system and its performance have been demonstrated on relevant reference artefacts and Airbus test samples. We have successfully used it for all on-site BLADE wing measurements, demonstrating portability besides the uncertainty required.

The measurement system is a fringe-projection system, custom built for the specific requirements of wing metrology.
The nominal field of view is 1300x800 mm², making it perfectly suited for measurements in inter-rib spaces, nose and on the upper cover of the BLADE wings with high accuracy. It can be adjusted to any orientation desired, and its position can be registered with laser tracker assistance. This makes it possible to locate unconnected surface segments correctly in 3-D space, thus eliminating the need for large overlaps between surface sub-areas.

WIMO description of work

- **Development of the integrated measurement system**. Since this was a precondition for the measurement campaigns this contained an enhanced workload. As a first step the adapted stereo fringe-projection system was assembled including the retro-reflectors for the laser-tracker and the roughness measurement system was also fitted with these reflectors. Extensive test measurements were performed and a calibration procedure developed to transform the measured data into a global coordinate system. For the first measurement campaigns parts of the calibration procedure and the integrated measurement were performed manually. For example the laser-tracker was pointed semi-manually to the different locations of the retro-reflectors of the measurement heads. During the second work year this procedure was automated. The reached measurement accuracy was verified according to VDI/VDE 2634. In addition a tool was implemented which allowed on-site measurements performed by manufacturing personnel with assistance of experts via remote control.

- **Clear definition of the requirements of the overall measurements and continued with the development of procedures for the data evaluation.** This included a complete concept for all measurement campaigns during the project. These steps were defined in close collaboration with Airbus since determined the outcome of the project. Especially for the data evaluation different methods were developed and compared to each other. In addition an adequate method for stitching the single measurements together with laser-tracker assistance and to thin out the data without losing relevant information was developed. In the second half of the project a concept was developed for later production integration of such a measurement system including hard- and software concept and on-site procedures.

- **Performance of the different measurement campaigns at the different locations and the execution of the data evaluation of all these measurements**. For every campaign a comprehensive documentation was provided (deviation of measurements from nominal and waviness calculation at predefined locations) corresponding to the requirements of Airbus. In addition the assembly process at Aernnova was monitored completely for allowing of corrective actions during the manufacturing process.

WIMCAM description of work

- **Introduction of a new measurement setup which embedded a third camera in the middle of the two existing cameras**. This method delivers following benefits for the flight tests:
  - The measurement volume will be extended.
  - The measurement uncertainty will be improved.
  - Solving the problem of specular reflection of a glossy finish
  - Solving the problem of lower fringe contrast at the far end of the object

- **Development of algorithms against the influence from the unstable environment.** (e.g. an improved phase measurement technique against environment light change and also a phase measurement technique against phase shift errors). For the work during the flight phases we expect that the measurement environment will be not stable. For example, the environment light intensity (from the sun or the lights in the hall) may change during the phase measurement. And there could be slightly low-frequency vibration of the wing under test. These kinds of environment changes will introduce artifacts in the object measurement result and this will be overcome thanks to our developments.

Results

The developed stereo-camera system consists of one LED projector (1280×800 pixels) and three high-resolution cameras (2752×2206 pixels) *(as shown in Figure 1).* The cameras were calibrated with the so called “vision ray calibration”. For an object measurement, a series of phase shifted fringe patterns were projected onto the surface, where the structured light will be reflected and then recorded by the cameras.

The “phase map” of the fringe images of each camera was calculated by the phase algorithm. In the end, the object shape was reconstructed from the phases by using the system’s calibration and orientation parameters. The used operational

software "shell" is the BIAS FringeProcessor®. Figure 2 and 3 show the fringe-projection system on-site at Aernnova in recording mode *(campaigns: GKN wing recording in 06-2016, Saab wing recording in 07-2016).*

The evaluation of the measurements showed that all relevant parts of the wing are within the tolerance.

a) Timeline & main milestones

The main milestones associated to the activities performed in these projects could be summarized as follow:

- Development and testing of the metrology measurement system (WIMO – period 2011 / 2013)
- Preliminary measurements of wings up to the end of manufacturing (WIMO – period 2013/2015 for both SAAB & GKN wings)
- Measurements in Jig at the start of wings assembly (WIMO – Nov/15 for GKN wing & Jan/16 for SAAB wing)
- Measurements in Jig at an intermediate step of the wings assembly (WIMO – Feb/16 for both wings)
- Measurements in Jig at the end of the wings assembly (WIMO – Jun-Jul/16 for both wings)
- Measurements out of Jig at the end of the wings assembly (WIMO – Jul/16 for both wings)
- Improvement and re-configure of the metrology system & improvement of the measurement procedure and data evaluation for the flight tests (WIMCAM – Aug-Dec/16)

The complete 'BLADE' flight phase is postponed to 2017 / 2018. Therefore, activities concerning the flight phase are not presented in this document.

b) Environmental benefits

Laminar flow wing promises significant environmental benefits and the innovative metrology measurement system developed & tested within these projects is a key enabler to control the set tolerances and to improve the production process of laminar flow wings in the future.

The prerequisite to assess the environmental benefits is to have detailed measurements of the wing cover, and this is what we proposed to do.

c) Dissemination & Communication

Dissemination activities linked to the developed metrology measurement system have currently mainly been performed by Airbus, as part of general presentations & scientific papers made on the 'BLADE' demonstrator.

The project results will contribute to the knowledge about the technologies and they will be published in scientific and engineering journals to enable further usage of the developed measurement and evaluation strategies. This will be made available after completion of the flight test campaigns.

d) Exploitation of results

The experiences made in the project indicate that accompanying measuring procedures during assembling (and later during flight phases) are absolutely necessary to control the set tolerances of a laminar flow wing. And this is essential to support the development and improvement of production process of laminar flow wings in the future in Europe.

The potential for exploitation will be further detailed in the light of the results achieved during the flight test campaign.

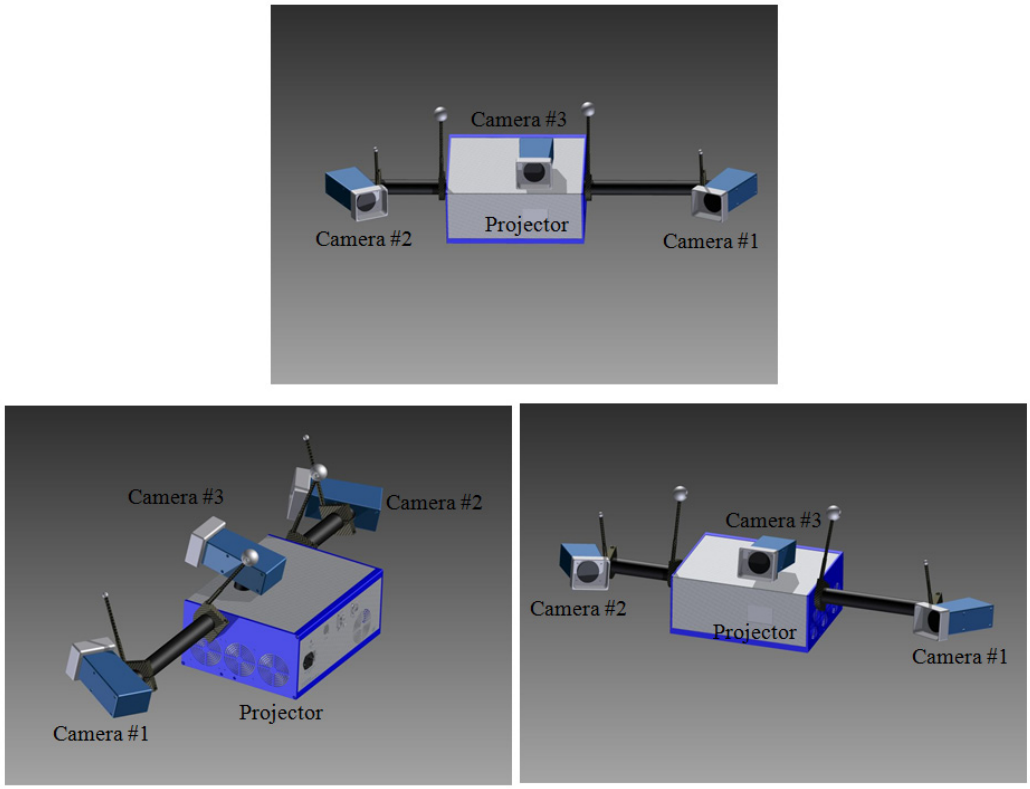

Figure 1: New measurement setup introducing a third camera in the middle of the two existing cameras. The additional camera is located above the projector. Benefits: The measurement volume will be extended and the uncertainty will be improved while solving the problem of specular reflection of a glossy finish at once.

Figure 2: Fringe-projection measuring procedure applied to the BLADE GKN wing (front nose section & lower cover)

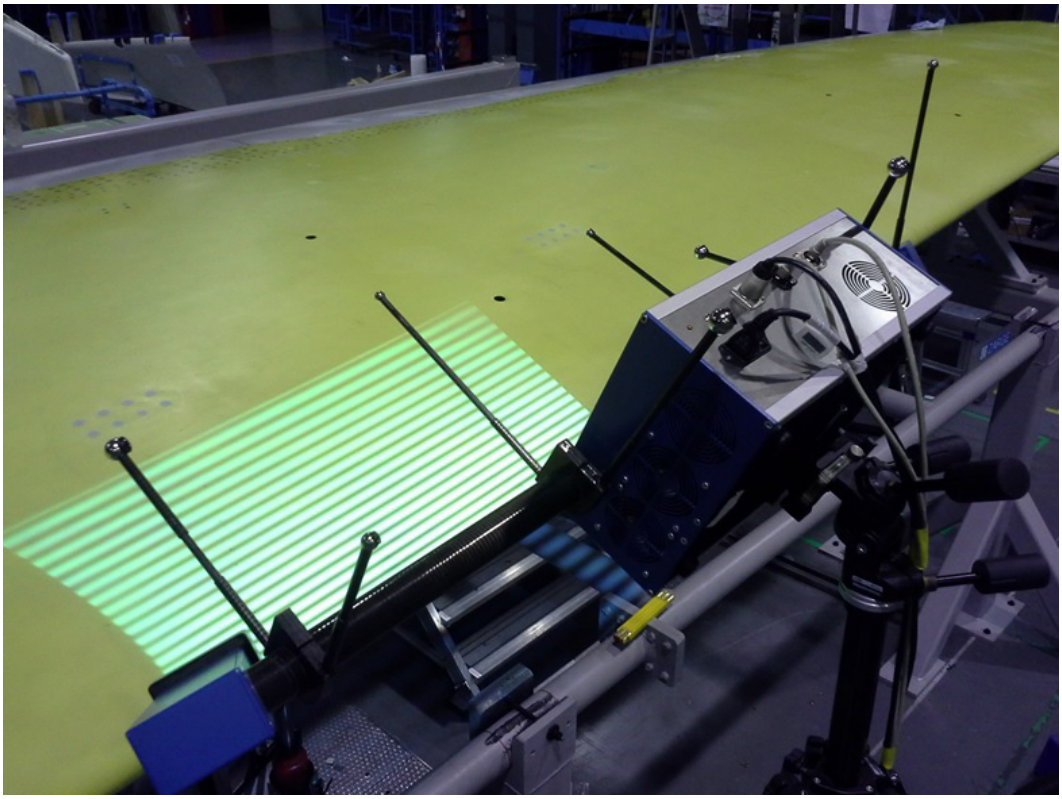

Figure 3: Fringe-projection measuring procedure of the BLADE Saab wing (front nose section & upper cover)

Project Summary

Acronym	WiMo	WimCAM
Name of proposal	A340 Outer wing metrology	BLADE Wing Measurement Campaign
Involved ITD	Smart Fixed Wing Aircraft ITD	Smart Fixed Wing Aircraft ITD
Grant Agreement	286745	641489
Instrument	Clean Sky	Clean Sky
Maximum Clean Sky contribution	1,061,546.70 €	217,703.00 €
Starting date	01.04.2011	01.10.2015
Ending date	31.12.2016	31.12.2016
Duration	69 month	15 month
Coordinator contact details	Michael KALMS kalms@bias.de BIAS - Klagenfurter Str.2, 28359 Bremen, Germany	
Project Officer	Sebastien DUBOIS (CSJU) sebastien.dubois@cleansky.eu	
Participating members	BIAS - Bremer Institut für angewandte Strahltechnik GmbH VEW - Vereinigte Elektronikwerkstätten GmbH	