Contract no.: 266107

AIM²

ADVANCED IN-FLIGHT MEASUREMENT TECHNIQUES 2

COLLABORATIVE PROJECT

THEME AAT.2010.4.1-1. DESIGN SYSTEMS AND TOOLS

PROJECT FINAL REPORT

Part 4.1 Final publishable summary report

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Revision [1]

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Dissemination Level		
PU	Public	X
PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for members of the consortium (including the Commission Services)	

Purpose of this document

This report contains the final publishable summary report of the AIM² project final report. Besides this report, as well as the project deliverables and the published book "AIM² Advanced Flight Testing Workshop – HANDBOOK of ADVANCED IN-FLIGHT MEASUREMENT TECHNIQUES" (ISBN 978-3-7322-3740-1), a publication of the AIM² main highlights in the Measurement Science and Technology (MST) Journal is intended for mid-2015.

Content

4.1.1 Executive Summary

Flight testing new or modified aircraft is a necessary part of the design process and provides the final validation for the full-scale aircraft design. Flight-test certification is a critical phase because all the trials proving compliance with specifications and regulations must be completed in the shortest possible time, whilst maintaining high-quality standards in the certification process. Usually heavy instrumentation is installed to validate the predicted behaviour of the aircraft and also to detect unforeseen problems so that any modifications can be done quickly. Optical measurement techniques can minimise the installation work and reduce the testing time as they are able to capture a huge amount of parameters within a short time frame. The preceding project AIM – Advanced In-flight Measurement Techniques proved the principal feasibility of applying modern optical measurement techniques to flight testing. It presented possibilities of measuring wing and rotor deformation, surface pressure distribution, heat distribution and flow velocity fields in a non-intrusive way and with minimal sensor set-up. AIM also identified major challenges that had to be dealt with before these advanced optical measurement techniques could progress from the research and development stage and become state-of-the-art measurement techniques for industrial use. The follow-up project AIM² (Advanced In-flight Measurement Techniques 2) was launched in October 2010 with the intension of the further development of new powerful optical measurement techniques towards their routinely application to flight testing. In detail these measurement techniques are:

- Background Oriented Schlieren (BOS) method
- Fiber Bragg Grating (FBG) method
- Image Pattern Correlation Technique (IPCT)
- Infrared Thermography (IRT)
- Light Detection and Ranging (LIDAR)
- Particle Image Velocimetry (PIV)

AIM² focused on developing reliable and easy to use dedicated measurement systems and on defining design and application rules for these new in-flight measurement techniques. The prime objective was to enable aerospace industries to use such mobile measurement systems in future to reduce testing time and costs.

The AIM² project itself was structured in progressive steps starting with basic studies on challenges discovered in the preceding project, leading to optimised measurement systems to be tested under research conditions and finally to be proven in an industrial environment. To do these steps in an effective way the partnership of AIM² comprised four partners from aerospace industries, including one SME, three research organisations and three universities with expertise in optical measurement techniques, flight testing and training. As the project intended to work mainly on the improvement and adaptation to the special conditions of in-flight testing of the measurement techniques the main workload of technical work was more on the side of research organisations than industries. However it has been taken care that the involved industrial partners were able to directly guide the development of the techniques towards the direction most suitable for cost effective industrial flight testing. In addition an assessment of the improved measurement techniques with respect to their applicability has been done. By means of a dedicated flight testing workshop and several publications, leading partners of the aeronautical industry being potential users of the developed measurement systems have been and in the future will be informed about the potential of the techniques.

Further information on the project AIM² is available on the public project website http://aim2.dlr.de/

4.1.2 Description of Project Context and Main Objectives

Like mentioned above, the main focus of the AIM² project, running from October 2010 to September 2014, was the further development of advanced optical and thus non-intrusive measurement techniques towards their easy application to in-flight measurements with industrial demands. Therefore, development of reliable and easy to use dedicated measurement systems as well as definition of design and application rules for these new in-flight measurement techniques have been the main tasks of the project consortium. The prime objective of the 7th European Framework Programme Collaborative Project AIM² was to enable aerospace industries to use mobile image based measurement systems in future to reduce testing time and costs.

In order to complete this challenging task in a good manner, the AIM² consortium was made of ten partner organisations with a high level of knowledge concerning optical measurement techniques and the performance of flight testing activities. The members of the consortium were

- **DLR** (Deutsches Zentrum fuer Luft- und Raumfahrt e.V = German Aerospace Center) – *Coordinator*, the german national establishment for aeronautics and space. The key aspects of the DLR research and development activities are residing in the fields of aeronautics, space technology, transportation and energy. Within these areas DLR joint national and international cooperative ventures. DLR
- **AIRBUS Operations SAS (A-F)** a limited liability company (société par actions simplifiée) duly organised and existing under the laws of France. AIRBUS Operation designs and manufactures aircraft, aircraft parts, systems, equipment and derivative products, and also provides services in the field of aeronautics
- **Avia Propeller (AP)** develops and produces propellers and propellers governors for piston engines (up to 600 HP) and turbine engines (up to 1800HP). Avia Propeller is producing constant speed propellers and has two, three, four and five blade propellers in production**.**
- **Cranfield University (CU)** is a wholly postgraduate university with an international community and a truly global reputation. At Cranfield University, the School of Engineering (SoE) is dedicated to carrying out focused fundamental research and applying it to meet the needs of society and industry.
- **EVEKTOR** spol. s r. o. (Ltd.) is a design and engineering organisation focused on the aeronautical and automotive industry and produces the VUT100 COBRA, which was used as a flight test bed in AIM.
- **Moscow Power Engineering Institute (MPEI)** (Technical University) now is the largest Russian Power Engineering University and scientific centre, one of the main universities in Russia in the field of Power Engineering, Electrical Engineering, Electronics and Computers Science.
- **NLR** (Nationaal Lucht- en Ruimtevaartlaboratorium) independently renders services to government departments and international agencies, aerospace industries and aircraft and spacecraft operators. NLR is a non-profit organisation, one of the Large Technological Institutes of the Netherlands.
- **ONERA** (Office National d'Études et de Recherches Aérospatiales) is the French national aerospace research centre. It is a public research establishment, with eight major facilities in France and is organised in 16 scientific departments, grouped in four branches - Fluid Mechanics and Energetics, Physics, Materials and Structures, Information Processing and Systems.
- **Piaggio Aero Industries (PAI)** S.p.A. is one of the world's oldest aircraft manufacturers being involved in aircraft construction since 1915. The company main businesses are aeroplane design and manufacturing, engine parts manufacturing, aero-structures and aircraft maintenance.

- **Rzeszów University of Technology (RUT)** is the state-owned (Ministry of Science and Higher Education) middle-sized university of polytechnic profile. In the field of aircraft structure design and test the Faculty of Mechanical Engineering and Aeronautics has over 30 years of experience.

The measurement techniques considered within AIM² were:

- The **Background Oriented Schlieren** (BOS) method – an image based density measurement technique using the deviation of light due to refractive index changes in density gradients (e.g. in compressible flow regimes, non-uniform temperature fields, gas mixtures) → a randomly patterned background is recorded without density gradient (reference image) and with density gradient in the line of sight (measurement image), cross correlation algorithms identify pattern shifts and enable the visualisation of density gradients (e.g. vortex core location, jet location). → Within AIM², BOS was intended to be further developed towards easy in-flight application. Different backgrounds were planned to be investigated and the combination of BOS with numerical calculations and a digital mock-up was intended to be used to improve the technique for shock detection measurements. As the measurement setup can be similar to IPCT a combination of both techniques was proposed to be evaluated to enable combined flow-structure coupling. The BOS technique can give basic information on the flow topology on the wing for high Mach numbers and localize vortex trajectories with a very simple setup.
- The **Fiber Bragg Grating** (FBG) method- a deformation and pressure measurement technique using fiber optic sensors → short sections of fibers are labelled with holographic gratings and light is send to through the fiber, the gratings act like wavelength selective mirrors and thus the reflected wavelength spectrum is measured, temperature changes and strain cause changes in grating periods and thus changes in the reflected wavelength yielding to temperature change or strain at grating location. → Within AIM² FBGs were proposed to create and test fiber optic sensors (FOS's) to measure the local surface pressure and in another design to measure strain on the wing surface. Both sensor types were intended to be tested in the lab, the wind-tunnel and finally on an experimental aircraft in flight.
- The **Image Pattern Correlation Technique** (IPCT) – an image based highly accurate surface shape and deformation measurement technique → a random dot pattern is applied on the investigated object and recorded by cameras, by the application of cross correlation and photogrammetry algorithms the measurement of 3D position, shape and local deformation of this surface (e.g. of wings and propeller blades) is enabled. → Within AIM² the installation of the cameras on the aircraft with respect to an easy installation and the minimization of camera movements and compensation techniques for movements, the optimisation of the application of patterns and markers on the wing and the control and high lift surfaces, the calibration and recalibration procedures and the application of IPCT and marker techniques on rotating surfaces as well the application of IPCT and marker techniques on vibrating surfaces were proposed to be improved. Furthermore the user friendliness of the post processing tools and the data processing time were intended to be optimised. Applications to wings and control surfaces, as well as a landing gear structure, were planned. In addition a rotating camera system was proposed to be developed for 360° propeller blade deformation measurements.
- The **Infra-Red Thermography** (IRT) – a surface temperature and surface flow transition measurement technique → the infrared radiation from the investigated surface is recorded delivering an image of the thermal topology of the surface, laminar-turbulent transition causes jump in wall stress coefficient and thus a jump in the heat transfer coefficient enabling the IRT detection and visualisation of transition from laminar to turbulent flow, laminar separations and in some cases also vortices. → Within AIM² the IRT was intended to be improved towards unsteady transition and shock measurements in-flight. Furthermore the application of mirror techniques for

IRT was planned to be evaluated. As the laminar-turbulent transition of the boundary layer has a significant influence on the aerodynamic forces of wings, rudders and the fuselage of an aircraft, the benefit of the development of unsteady IRT is the possibility of easy non-intrusive measurements of the boundary layer characteristics.

- The **Light Detection And Ranging** (LIDAR) method – an optical direct air speed measurement technique → a single frequency laser light wave is radiated and compared with the light wave reflected by natural aerosols, the occurring Doppler shift of the reflected wave length due to aerosol movement enables local air speed measurement, as this is a direct measurement no calibration is required and the LIDAR can be used to calibrate other flight test instrumentation. → Within AIM² air data calibration using LIDAR systems was thought as an innovative tool which may yield an easier calibration procedure. Multiple particles Mie scattering LIDAR are dependent upon natural aerosol seeding conditions which are variable from day to day. However, variable availability of wind speed measurement is still compatible with the function of calibration. Moreover, angular positioning of the sensor inside the aircraft is a major concern, but Piaggio has experience in positioning sensors inside their aircraft. Hence, the further research and development of such an air data calibration system based on non-intrusive methods can be forward-looking towards future certification procedures and has therefore been a part of AIM².
- The **Particle Image Velocimetry** (PIV) – an image based measurement technique for instantaneous flow velocity fields → images of tracer particles in the measured flow illuminated by two co-planar pulsed laser light sheets are recorded and the cross correlation of both particle images delivers a displacement vector field and thus the flow field topology, with known time delay and magnification of the recording system the instantaneous velocity vector field can be measured. → Within AIM² a reliable in-flight PIV setup and the respective test procedures were intended to be developed. Also further research in the field of particle detection and optimisation during flight test were proposed to be performed, to enhance the performance of seeding based flow measurements. In addition, recent developments on the field of PIV hardware for in-flight application such as safer illumination sources and new CCD cameras have been applied to reduce operational restrictions and increase the user friendliness of PIV. With in-flight PIV a powerful tool will exist to measure complete flow fields instantaneously and in a non-intrusive way.

The further development of these techniques has been performed in three progressive steps:

1. basic studies on challenges discovered in AIM
2. test of optimized measurement systems under research conditions
3. application of optimized measurement systems in an industrial environment

Therefore the first step was mainly done in the lab of the research institutes accompanied by a detailed exchange with the industrial partners. In the second step the lessons learned have been used to build up optimized measurement setups and perform flight testing in a “research” environment. For the last step the developments from step one and two have been summarized in a kind of application matrix and with the help of “user templates” some of the measurement systems were tested under “industrial flight test conditions”.

In total eleven full-scale ground and flight tests on eight flight test beds were planned during the AIM² project life-time. Finally nine out of these test campaigns have been conducted, including the preparation of the measurement set-up, the qualification of the flight test installation, the installation of the equipment, the performance of the flight trials and the data processing up to the reporting of the results in scientific papers.

Furthermore a public workshop was planned to present the novel measurement techniques to the flight testing community.

To perform all this developments within the limited project life-time and budget, the AIM² project was split into six work-packages (WP):

- **WP 1 – Management**
  - management of the project; coordination of the technical activities; knowledge management; taking care of gender issues; audits
- **WP 2 – Deformation Measurements on Wings and Control Surfaces**
  - improvement of IPCT and Marker based deformation measurement techniques for wing and control surface deformation measurements
- **WP 3 – Deformation Measurements on Propeller blades**
  - improvement of IPCT and Marker based deformation measurement techniques for 360° propeller deformation measurements
- **WP 4 – Surface Flow Measurements**
  - improvement of FBG and IRT towards surface pressure, transition and shock detection measurements
- **WP 5 – Flow Field Measurements**
  - improvement of PIV and BOS for in-flight flow field measurements and improvement of LIDAR for airspeed measurements
- **WP 6 – Tools and Demonstration**
  - Creation of an application matrix and measurement tool boxes; application of the investigated techniques in industrial environment

More information of the AIM² activities is provided in the following chapter as well as on the AIM² public website “http://aim2.dlr.de”.

As a summary the main objectives of the AIM² project were:

- further development and adaptation of advanced optical measurement tools for cost effective in-flight testing (e.g. wing and propeller deformation, air data calibration, flow visualisation),
- definition of design and application rules for these measurement tools,
- ease of installation and minimisation of direct flight testing time and
- providing basic knowledge about advanced optical in-flight measurement techniques.

In Figure 1 below, the expected development of the AIM² techniques is depicted.

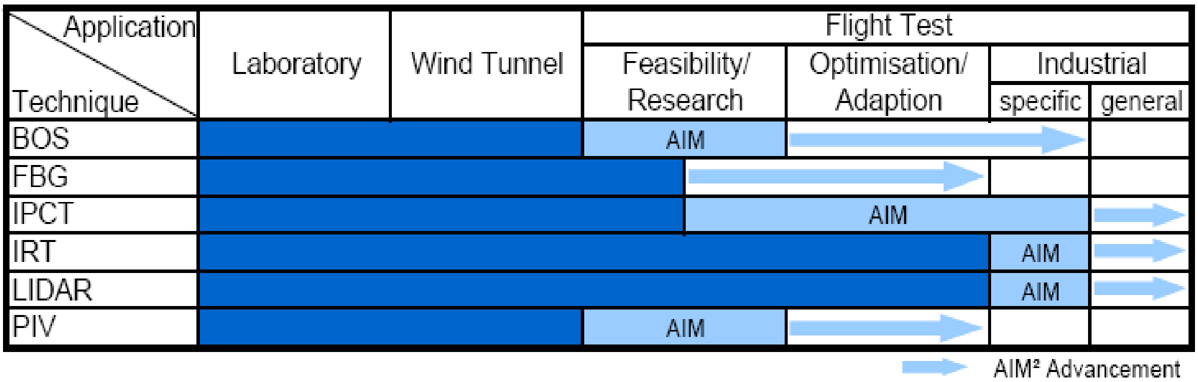

Figure 1: Development of advanced measurement techniques and expected progress within AIM² (status as of September 2010)

4.1.3 Description of Main Science and Technology Achievements

In what follows the main science and technology developments achieved during the AIM² project are described briefly sorted by the WP structure.

4.1.3.1 WP 2 – Deformation Measurements on Wings and Control Surfaces

This work-package was dedicated to the application of optical deformation measurement techniques like the Image Pattern Correlation Technique (IPCT) and Marker based measurement techniques for the purpose of wing and wing control surfaces deformation. The work-package was divided in four tasks:

- Task 2.1 Improvement of IPCT and Marker based techniques towards industrial application
- Task 2.2 Research flight test with transport aircraft concerning wing and aileron deformation
- Task 2.3 Research test with transport aircraft concerning wing vibration
- Task 2.4 Optical wing deformation measurements in an industrial environment

Within Task 2.1 Improvement of IPCT and Marker based techniques towards industrial application evaluation software packages for marker and speckle based pattern correlation techniques have been developed at DLR, MPEI, NLR and RUT. In addition, at MPEI software was developed to evaluate the accuracy depending on various experimental parameters. The influence of parameters such as depth of field, parameters of CCD, and others can be calculated with a mathematical model. Experiments have been set up to investigate using a Scheimpflug adapter to increase the accuracy of the IPCT. Furthermore an algorithm for processing IPCT data recorded on rotating control surface has been developed at NLR. RUT released a pattern generation programme in C++ for large areas and different shapes of speckles and a programme for synthetic IPCT. At the end of this task the Deliverable “D2.1 Overview on investigated optical wing deformation measurement techniques” was released summarizing the state of the art at the beginning of AIM² and all previous works, done by AIM and AIM² consortia in the field of optical, non-intrusive experimental methods of deformation measurements in flight test conditions.

In Task 2.2 Research flight test with transport aircraft concerning wing and aileron deformation NLR performed a flight test with their Fairchild Metro II. Aim for the test flight was to generate images of the speckled wing, flap and aileron under different loads and dynamics to test IPCT (Image Pattern Correlation Technique). A flight test plan was issued; instrumentation was installed in the aircraft. Furthermore the lighting of the speckled pattern was taken in account for adjusting the order of the manoeuvres.

For this test, the single camera IPCT approach was further developed for measuring deformations of dynamically moving surfaces and for measuring the deformations of the rotating flap and aileron surfaces. Right wing sections more inboard were marked with speckled tape for this new flight test campaign compared with the AIM campaign and both parts of the aileron and the flap were taped with speckled sticker material. The pattern locations are depicted in Figure 2a and c. For the purpose of comparison two high-speed, high resolution AOS S-EM cameras were installed in the cabin of the aircraft viewing the speckled pattern on the right wing, the flap and the aileron and recording images at 120 frames per second in sequences of 8 seconds duration. Dynamical measurements were enabled by applying the high-speed cameras. Reference data was recorded from the Inertial Reference System (IRS), a synchro measuring the aileron position and a potentiometer that measured the flap position. Figure 2b shows the measurement setup in the cabin.

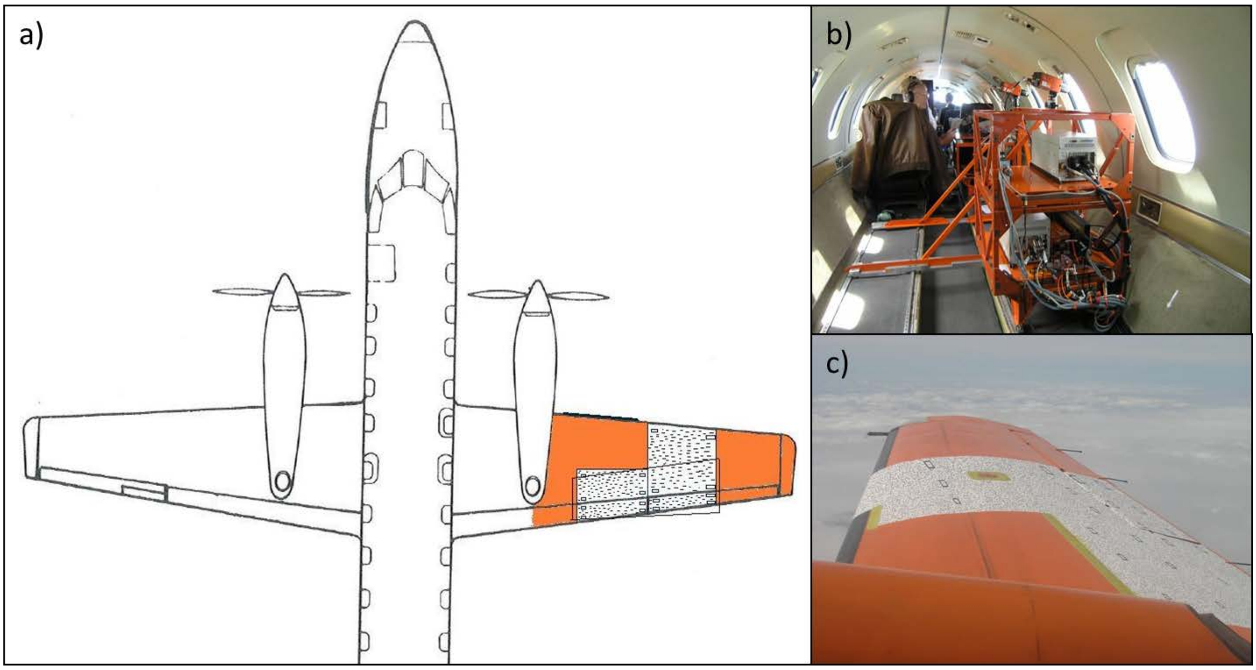

Figure 2: The NLRs Fairchild Metro II IPCT flight test (a - overview on the measured regions on the wing, b - flight test instrumentation in the cabin, c - pattern on the wing)

After the test, the acquired images have been analysed using the OWDM software tool developed by NLR. More information about this activity and detailed measurement results can be found in the AIM² deliverable "D2.2 Flight test results of image correlation technique for wing, flap and aileron deformation and deflections on transport aircraft".

Task 2.3 Research test with transport aircraft concerning wing vibration was dedicated to the improvement of the IPCT evaluation of stereoscopic image pairs recorded during wing vibration measurements. The DLR used two measurement campaigns on transport aircrafts to investigate the applicability of a stereo camera based system to investigate wing vibrations. The Taxi Vibration Test (TVT) on the Airbus A320 MSN 659 DLR-ATRA was performed at summer 2009 in Manching, Germany. The research ground vibration test on the A340-600 MSN 360 was performed in March and April 2011 in Toulouse in the frame of the LuFo IV FTEG (Flight Physics Technology for Green Aircraft) project. For both tests the main aim was to demonstrate new approaches for accelerometer – measurements to determine the Eigen modes of the aircraft. The photogrammetry measurements were performed as add-on tests for demonstration of the method thus this measurement technique had a lower priority and the resources were strongly limited. That's why AIM² was used to allow a more detailed evaluation of the obtained data. For both tests accelerometer data provided by the Institute of Aeroelasticity of the DLR Göttingen were available for comparison and could be used for the validation of the technique.

Finally the decision was made to demonstrate the new IPCT processing strategy on the GVT data sets. In Figure 3 the camera setup as well as the measurement region on the aircraft are shown. There were two AVT high resolution cameras observing the nacelle from ground and four JAI cameras on a high support observing the wing and parts of the nacelle from above. As the main frequencies of the wing are in the range between 1 and 15 Hz the camera frame rate was set to 30 frames per second.

In a final result, the Eigen-frequencies, in the range defined by the Nyquist-criterion and frequency resolution were detected with the accelerometers as well as with optical methods, despite of the remaining differences in their magnitudes. With a closer look to the evaluation methods, the differences can be explained with the limitations of the used setup with respect to the temporal resolution and different evaluated sequence lengths between the optical systems and the accelerometer measurements.

Figure 3: The GVT on an A340 chosen for the evaluation in Task 2.3 (a - high resolution cameras on ground observing the nacelle, b - observed wing and nacelle with markers, c - position of the JAI camera systems)

A vibration of the cameras can bias the measurement results and should be considered in the design of the setup. The used setup of the GVT enabled a check for camera vibrations using fixed reference markers on the ground. The detected Eigen-frequency of the cameras of about 1.5 Hz is reflected in the spectra of the aircraft markers partially. The optimum is to avoid any excitations of the cameras by the design of a suitable camera support. An additional measurements of the camera vibration e.g. with the photogrammetry setup itself using fixed reference markers or with additional sensors mounted on the cameras ensures that the camera support does not influence the results or enables an estimation of its influence afterwards. Focusing on the accelerations the influence of the noise due to the accuracy of the deformation measurement becomes even clearer. With the differentiation of the deformation, which means a multiplication with ω^2 in the frequency domain for the used setup the noise is dominating above frequencies of about 2 - 2.5 Hz (see Figure 4). Thus a higher frame rate of the cameras would have not enabled the measurement of higher Eigen-frequencies above the Nyquist limit of 7.25 Hz.

In conclusion the limitation of the photogrammetry methods for vibration testing is first of all driven by the accuracy of the measured deformation. This accuracy can be estimated with the available design tools reliably and is influenced by the setup and the resolution of the cameras mainly. Thus these limitations can be estimated prior the test very well to make a decision about the feasibility and applicability of the photogrammetry method for specific measurement objectives.

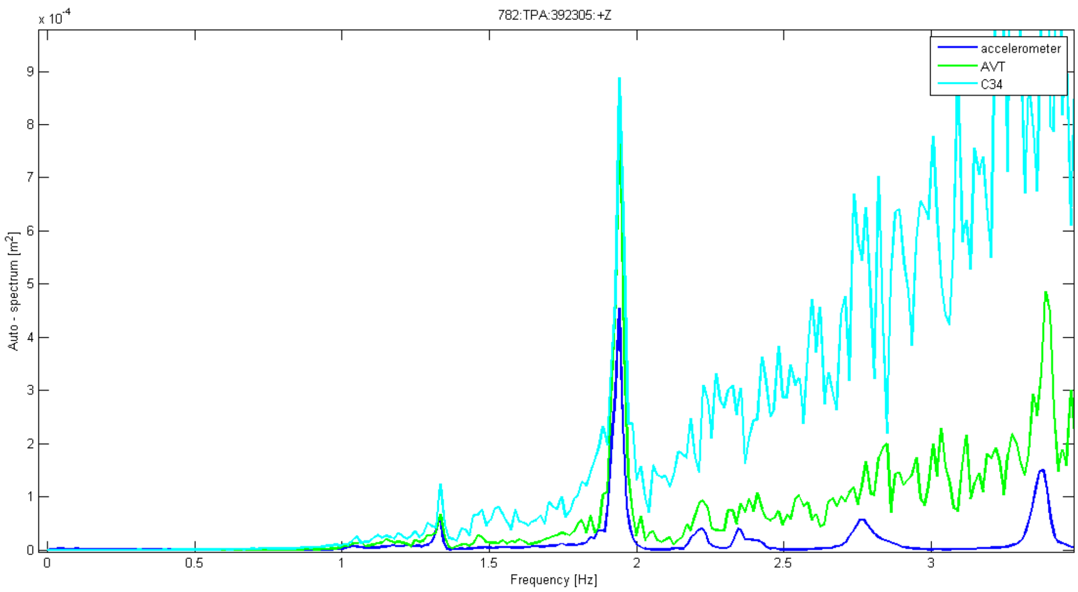

Figure 4: Example result of the image evaluation, comparison of the two camera systems and the accelerometers

Faster cameras with a higher resolution can improve the results– but by recording the raw images one has to consider the even higher demands to the data acquisition to be able to handle the high data rate for the long recording time of a single run. With the further development of hardware components the limit of the maximum possible data rate resulting from camera resolution and frame rate will be pushed forward. A further option to increase the spatial and temporal resolution of the photogrammetry method is to reduce the data rate by the usage of smart cameras with an integrated image processing unit storing not the complete image but e.g. only the image coordinates of the markers. The disadvantage of this approach is that adaptations of the evaluation parameter are not possible after the measurement and the images for a cross check are not available any more. But for well-defined applications a robust on-chip data processing should be possible.

In deliverable “D2.3 Results of the evaluation in Task 2.3” more information about the application of the optical deformation measurements to vibration testing can be found.

In Task 2.4 Optical wing deformation measurements in an industrial environment a stereoscopic camera system has been installed to a VUT100 Cobra airplane to prove practical usage of the IPCT optical method in industrial praxis. The IPCT consisted of two high speed AOS cameras type S-EM mounted on specially designed support system, data acquisition system and dot pattern printed on a foil and installed on the left wing of the airplane. As two IPCT methods were used, also two kinds of marker system was applied during the dot pattern generation.

Figure 5 shows some parts of the installation and the test preparation. In Figure 5a the digital mock-up (DMU) of the camera setup is depicted. By means of the DMU the designs of the pattern and the calibration plate (see Figure 5b) were performed. In addition, the DMU was applied by DLR to create a calibration manual with example images to enable EVEKTOR personnel to perform the camera calibration by their own. Figure 5c and d show the camera support installed in the cabin and the pattern applied to the wing.

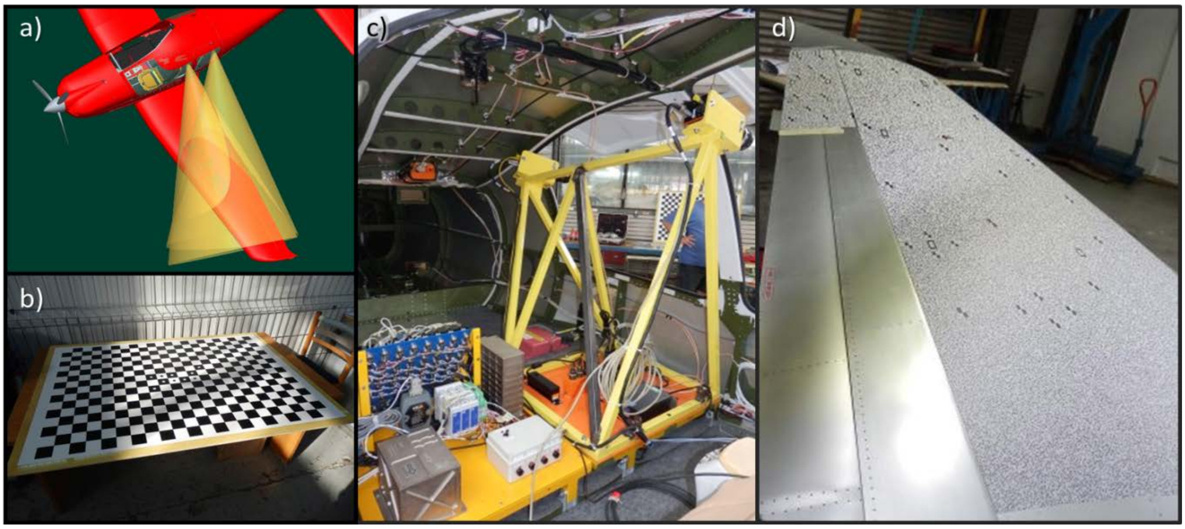

Figure 5: The COBRA test (a - DMU of the camera installation, b - calibration plate, c - camera support, d - pattern on the wing)

For assessment of IPCT results also standard EVE data acquisition system with appropriate sensors was installed into the test airplane. Static and dynamic wing deformations were measured during ground and flight tests. The images recorded during the tests were processed by two methods developed in DLR and NLR. DLR method is based on stereoscopic basis and requires pair images from two cameras. NLR method was developed to use only one camera and known wing geometry and limits of wing movement (supposed deformation only in z direction according A/C axis system). Ground and flight test programs were prepared. All planned tasks were realized and evaluated. Figure 6 and Figure 7 show some example results of the COBRA test activities.

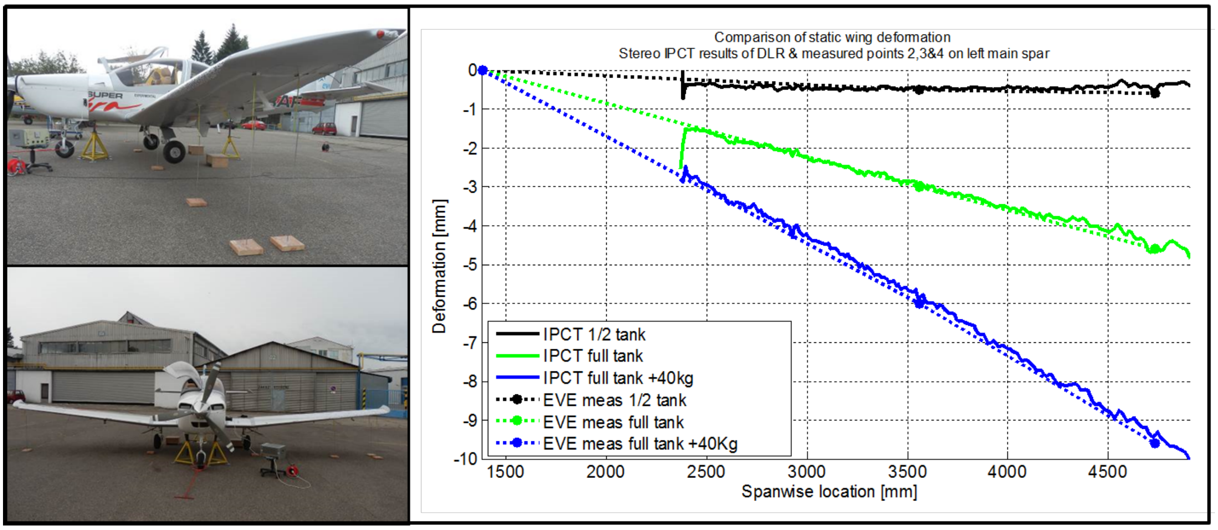

Figure 6: The COBRA ground test - comparison between IPCT and gauge measurement

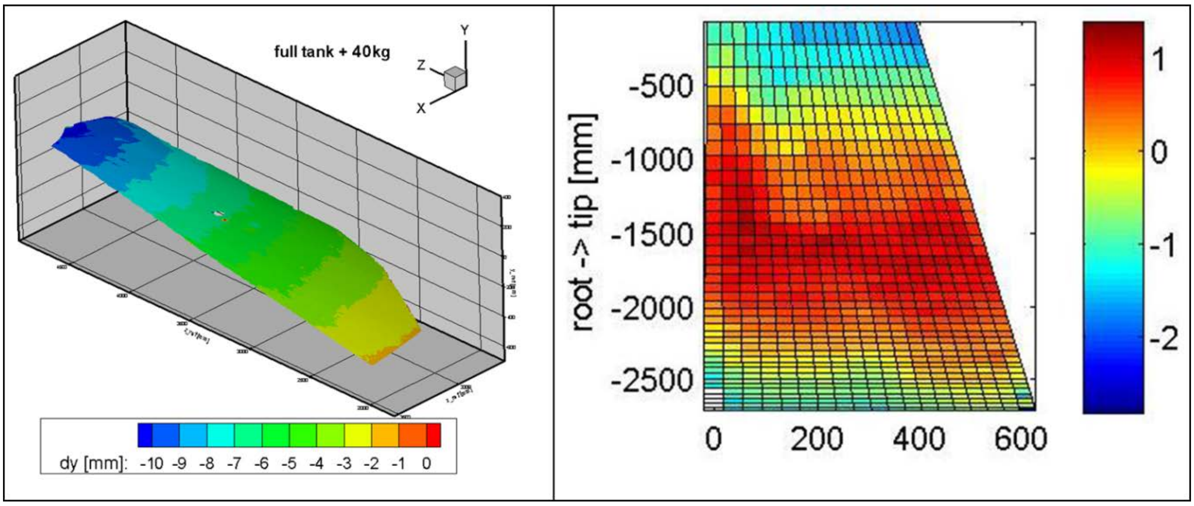

Figure 7: IPCT surface results

Main conclusion – IPCT techniques grow up to stage of practical usability. From laboratory tests they moved to industrial praxis and can be used for real measurements.

Static deformation – IPCT provide info of deformation over whole visible surface. Precision is even better than using classical methods (ground tests) applicable in field (not laboratory) conditions. During the flight tests a wing deformation can be directly measured by using IPCT, while standard methods are not able to directly measure this deformation and only indirect methods with only limited precision can be used.

Dynamic deformation – IPCT can cover the same range of tests with results comparable to accelerometers measurements. Both measurement techniques give results in comparable order of magnitude and with the same frequency characteristics. If the deformation is evaluated over whole area by using IPCT, oscillation mode and its shape can be observed or local problems like buckling can be found.

IPCT is a powerful tool to measure static and dynamic deformation with accuracy sufficient for industrial usage. Limitations are given through the recordable amount of image data, camera resolution and frame rate and stiffness of the camera mounting system. IPCT can be used as supplementary method to accelerometers measurement to check mode and shape of oscillation. High frequencies with usually low deformation amplitudes are still a problem to catch, but this can be changed in future as the optical methods will come into technical praxis and further development will be done.

Although IPCT methods become applicable in technical praxis, there are still a lot of details, which must be carefully observed and every single test must be thoroughly prepared. Main reserves are in next fields which can be improved or kept in mind:

- Camera mounting (stiffness) – this is the basis for proper measurement
- Data synchronization and sampling (best, if camera and DAS sampling are of the same rate, moreover triggered at same moment)
- Markers positions measurement according the airplane axis system definition (improve methodology, how to practically determine and set axis system of the whole airplane)

On the other hand the methodology was proved to be applicable in industrial conditions and whole measuring chain was tested and found functional. Small mistakes and imperfections were improved and in the future they are supposed to be avoided. Optical measuring methods are capable to stand side by side with classical ones and are ready to enter the world of in-flight measurements.

The detailed description of the test and all results are written down in the deliverable “D2.4 Flight test results of Task 2.4”.

Deliverable “D2.5 Final Work Package 2 report” summarizes all WP2 activities and in addition delivers a small assessment of the applicability of the optical methods.

4.1.3.2 WP 3 – Deformation Measurements on Propeller blades

In the former AIM –project the deformation measurements on the propeller of the Piaggio P180 using a camera system in a fixed frame was demonstrated successfully. With a fixed camera set up only a cut out of the propeller disc could be observed. The aim of WP 3 was to improve the QVT setup to be able to measure the complete revolution of the propeller blade (360°) with one camera system and to demonstrate the possibilities of the techniques in an industrial environment. The involved partners were Evektor, AVIA propeller and DLR, responsible for the design and setup of the optical measurement system.

WP3 was divided into three different tasks sorting the development of the camera system into logical progressive steps. These tasks were:

- Task 3.1. Improvement of IPCT and Marker based techniques toward industrial application
- Task 3.2. Development of a setup for 360° propeller blade deformation measurements
- Task 3.3. Flight test with 360° propeller blade deformation measurement system

Task 3.1 Improvement of IPCT and Marker based techniques toward industrial application was similar to Task 2.1. Therefore, the prerequisites concerning the IPCT processing software were prepared in WP 2. The requirements on propeller deformation measurements and possibilities and limitations for a camera installation on the propeller were discussed between the partners in a first meeting at AVIA propeller in Prague. A propeller blade was provides by AVIA propeller to perform first simplified setup tests to check different camera positions and their pro and cons. The tests enabled a definition of the prerequisites to design an appropriate rotating deformation measurement system. The deliverable “D3.1 Prerequisites for an optimized optical propeller blade deformation measurement setup” gives an overview about the performed tests and conclusions made for the rough set-up for an optical 360° propeller blade deformation measurement system.

Within Task 3.2 Development of a setup for 360° propeller blade deformation measurements the optical measurement system has been designed according to the findings in Task 3.1. Later, the system was verified for operation during mock up tests and finally the prototype for the flight test was produced. The setup ensured blade visibility during whole 360° rotation. Cameras, control and storage systems as well as a power supply were located in the dedicated cabinet, which was located on the propeller flange instead the propeller spinner. Deliverable “D3.2 Design of an optical 360° propeller blade deformation measurement system” contains detailed information about the whole rotating camera system. In addition a DMU was setup to simulate the measurement and to design the final pattern to be painted onto the blades surface.

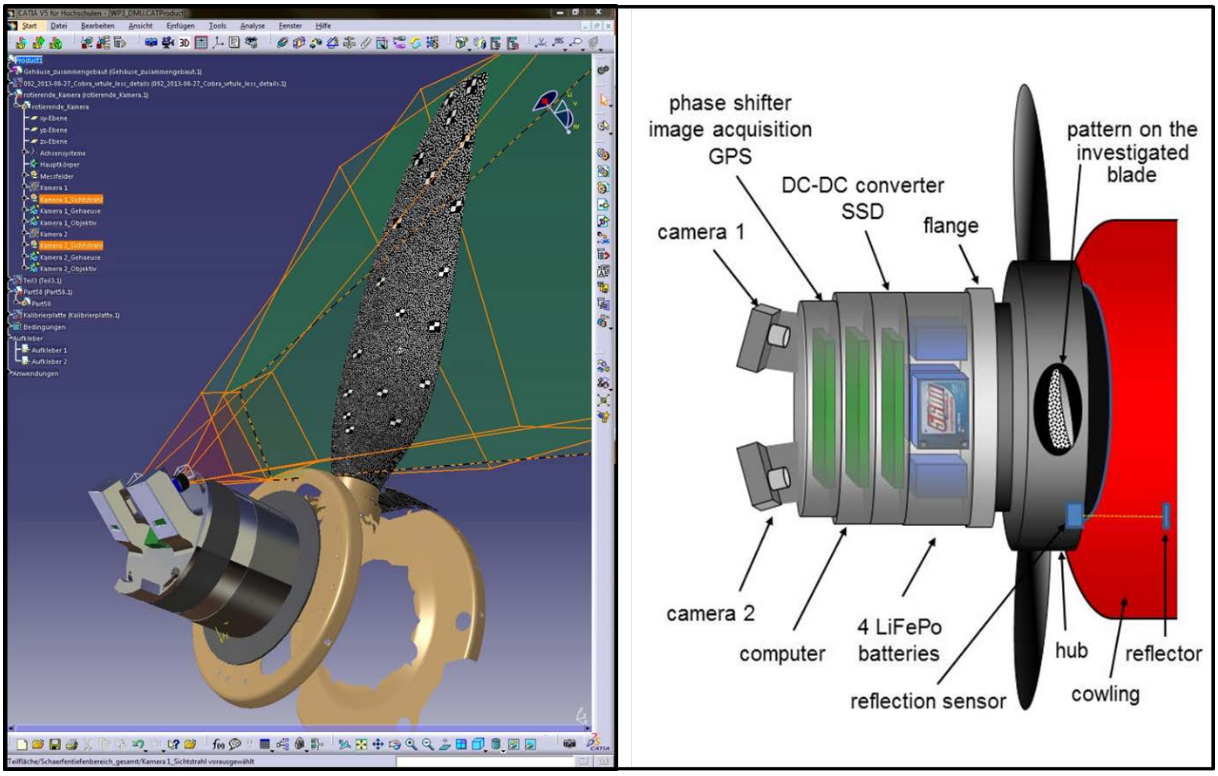

Figure 8: Rotating camera (left - DMU for pre-tests and pattern design, right - schematic diagram of the rotating camera)

Finally in Task 3.3., the Flight test with 360° propeller blade deformation measurement system has been performed using the IPCT setup. Moreover the tests using up to date strain gauge technique were performed for comparing results. The complete program and detail description of the ground and flight tests are possible to find in the document called “AIM2_WP3.3-Flight_test_plan”. The IPCT system was tested on the VUT100-121 (200HP) Cobra airplane. This type was chosen instead originally intended VUT100-131 (315HP) Super Cobra because of different type of engine (4 cylinder instead 6 cylinder), which has more rough run and thus more interesting and more severe propeller blade loading. Unfortunately this airplane was not equipped by EVE experimental data recording system, so flight test program had to be slightly modified to deal with this situation. Nevertheless the airplane was equipped with AP data acquisition system for comparative tests.

During the preparation of the flight test, the designed pattern for the blade had to be applied properly onto its surface. Therefore, a paint mask has been created from the pattern file designed in the DMU. The blade was primed with black paint. Next the paint mask was applied onto the surface and white painted was brushed on top. After drying and removing the mask, the blade was ready for the test. Figure 9 shows the main steps of this process.

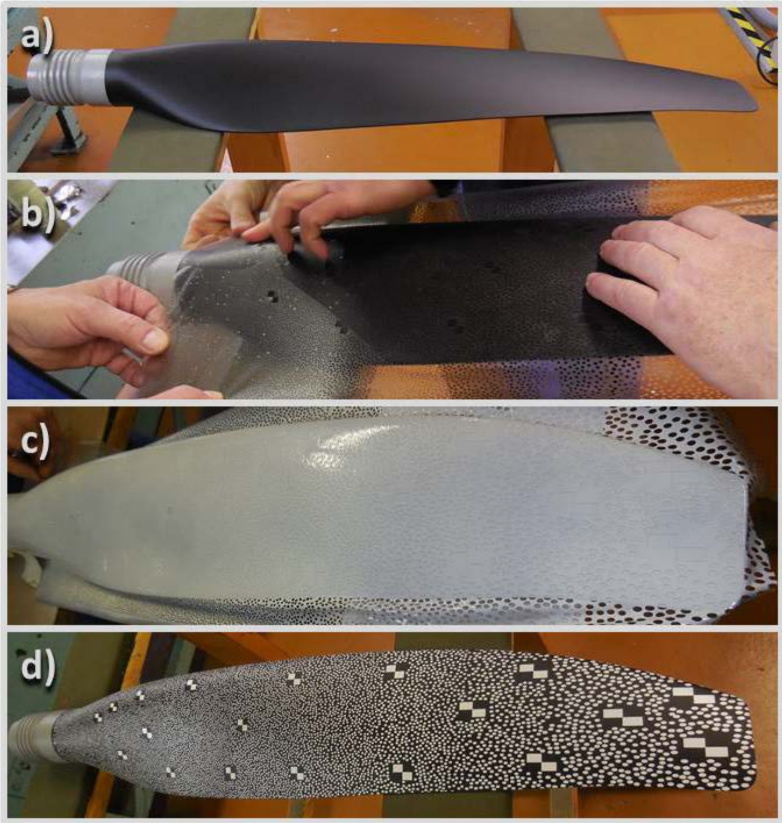

Figure 9: Painting of the propeller blade (a - prime coating of the blade surface with black paint, b - applying paint mask, c - brush white paint, d - final painted blade after removing the paint mask)

Except actual measurement and data recording processes also practical operation of the testing apparatus (setup installation, handling and setting the cameras, data storage, battery exchanging) was observed as well as followed data processing and obtaining the results. Figure 10 shows some images of the rotating camera mounted on the airplane, an example recording of one of the two cameras, as well as an example surface obtained from the recordings.

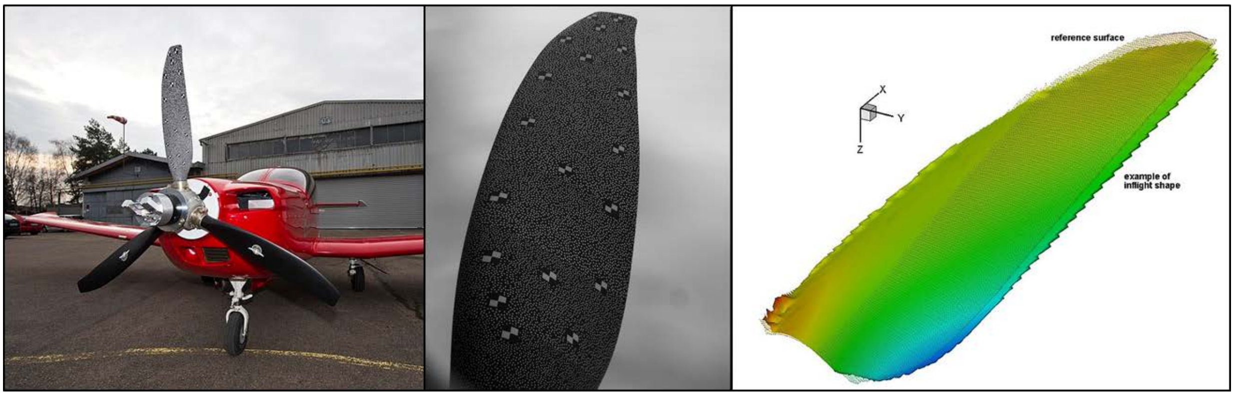

Figure 10: Rotating camera mounted on the airplane (left), example recording (mid) and example result (right)

A detailed overview on this performed test is given in deliverable "D3.3 Flight test results of Task 3.3". This document partly contains an assessment of the method. A complete assessment and comparison with current methods are in the deliverable "D3.4 Final Task report including assessment of the applied optical measurement technique".

4.1.3.3 WP 4 – Surface Flow Measurements

WP 4 was mainly focused on surface flow measurements based on FBGs as well as the IRT. In addition an FBG sensor to measure strain was applied. Again, the WP was divided in several tasks according to progressive development steps. Those tasks have been:

- Task 4.1. Development of FBG and IRT towards industrial application
- Task 4.2. Research flight test with FBG for strain and surface pressure measurements on a small aircraft
- Task 4.3. In-flight application of IRT for surface flow measurements in an industrial environment

In Task 4.1 Development of FBG and IRT towards industrial application both, the FBG methods as well as the IRT basics have been investigated. For the pressure measurement, an FBG system was designed based on a Fabry Perot dynamic pressure sensor. This system has been manufactured and successfully tested in the laboratory at Cranfield and later in the wind tunnel. As the sensor effectively measures point dynamic static pressure, for the wind tunnel test also a conventional unsteady PZT pressure sensor mounted in an equivalent position was applied to check the FBG sensor performance. To ensure correctly scaled wind tunnel results, the original Bulldog aircraft was laser scanned to obtain real dimensions and a 30% wind tunnel model has been constructed based on this data and model aircraft plans. Both unsteady sensors have been positioned on a plate behind the cockpit canopy during the wind tunnel tests. These results tested the reliability and robustness of the sensors and checked the quality of the data signal from the FBG sensor. Results from these scaled tests gave confidence in the sensor test plate design to be fitted on the real aircraft. In Deliverable “D4.1 FBG System for Flight Test” drawings of the installation are available.

For the FBG strain measurement, the laboratory testing has focused on selection of suitable glue for the mounting of the FBG fibres. Initial tensile tests in the 3rd quarter of 2011 on an aircraft skin sample, showed an offset between the conventional strain gauge strain and FBG surface strain. This discrepancy has been addressed through a further series of strain tests using modified mounting positions and glue on the samples. Finally suitable glue was identified and the information was sent to the subcontractor for mounting the sensors on the airplane.

The goal of the IRT part of Task 4.1 was the further development of unsteady infrared thermography. Models and wings made of normal materials (steel, aluminium, GFK) show a very slow response (high thermal response time) to changes of the surface temperature distribution and therefore to changes of the boundary flow. A solution of this problem could be found in finding appropriate materials with a much faster response (low response time) i.e. materials with low heat capacity and low lateral thermal conductivity.

The first investigation has been a study of available literature in order to find appropriate materials (done by RUT). A list of materials with promising features could be found. The next step was a selection of about ten different materials which has been investigated in the lab to measure the values for heat capacity, density, thermal diffusivity and thermal response time. This work in the lab has been done by RUT and DLR independently. The results of both lab tests agreed very well. Theoretically the best choice for dynamic IRT measurements is covering which consist of 1 to 3 mm thick insulation with good value of thermal response time/ thermal diffusivity stick directly to wing/fuselage surface and the foil as thin as possible and with a good radiative properties stick to the insulation. Measurements of thermal response time of various combinations of foil and insulation were performed. According to these results a matrix of potential materials has been created in order to be investigated at a flight test with the PW6 glider at Rzeszow University.

The development of a special designed IRT system for the flight tests with the PW6 has been finished. The main features of this special IRT system were a very compressed setup. An embedded PC with a 12 VDC power input for the infrared data acquisition was powered by a very light LiFePo4 accumulator which allows an autonomous operation of the system for more than two hours. A GPS module with a high precision time output was used to generate an accurate time stamp with the infrared data and to synchronize the infrared data with flight data of the flight data acquisition (developed by RUT) which was also equipped with similar GPS module. Special developed software allowed a continuous data acquisition with a frame rate of 50 frames/s. The software has been simplified as possible to the only required functions and the acquisition can be started by a simple start/stop button by the pilot.

The complete IRT system was intensively tested in the DLR lab and then delivered to the flight department of the Rzeszow University in spring of 2013. Then the IRT system was then installed in the PW6 glider by the team of RUT. Ground tests with the complete system installed in the PW6 have been successfully performed and the IRT system was ready for flight in summer 2013.

Due to unexpected occasions the permit to fly (airworthiness) could not be reached until the autumn of 2013 and therefore the first flight and the flight tests had to be postponed to the spring of 2014. The complete description of the installation can be found in deliverable “D4.2 IRT System Design for unsteady In-flight Measurements”.

The Subtask concerning mirror techniques for IRT has been cancelled due to unavailability of the subcontractor.

Within Task 4.2 Research flight test with FBG for strain and surface pressure measurements on a small aircraft, after a time-consuming process with the subcontractors for the modification and the authorities providing a permit to fly, the FBG systems have been installed to the Scottish Aviation Bulldog acrobatic airplane operated by Cranfield University and a flight test has been performed.

The sensor technologies investigated were an FBG system for measuring spanwise strain adjacent to the wing spar and an FP pressure sensor positioned on a removable plate on top of the fuselage, behind the cockpit. A Kulite pressure transducer was also installed adjacent to the FP sensor for comparison and validation.

The aircraft was modified and certified under CS-25 standards and a series of 7 flight tests were conducted to assess the sensors in a flight test environment. The flight envelope included a series of steady state straight and level tests and a set of dynamic aerobatic manoeuvres including a spin over a loading range of -1g to +4g.

After some initial problems, including under-specified speed tape lifting during flight and an earthing problem with the Kulite pressure sensor, all the sensors performed as expected when compared to the laboratory calibrations, with the FBG strain system giving a resolution of less than 0.5 µm/m and the FP sensor having a resolution of better than 0.2 Pa.

Further work is required to check the degradation of the sensors post-flight and following this a further flight test campaign to consolidate and expand the test envelope of the sensors.

In Figure 11 the details of the modifications and the installations made on the Bulldog are shown. Further details of this activity can be found in “D4.3 Report about Flight Tests in Task 4.2”

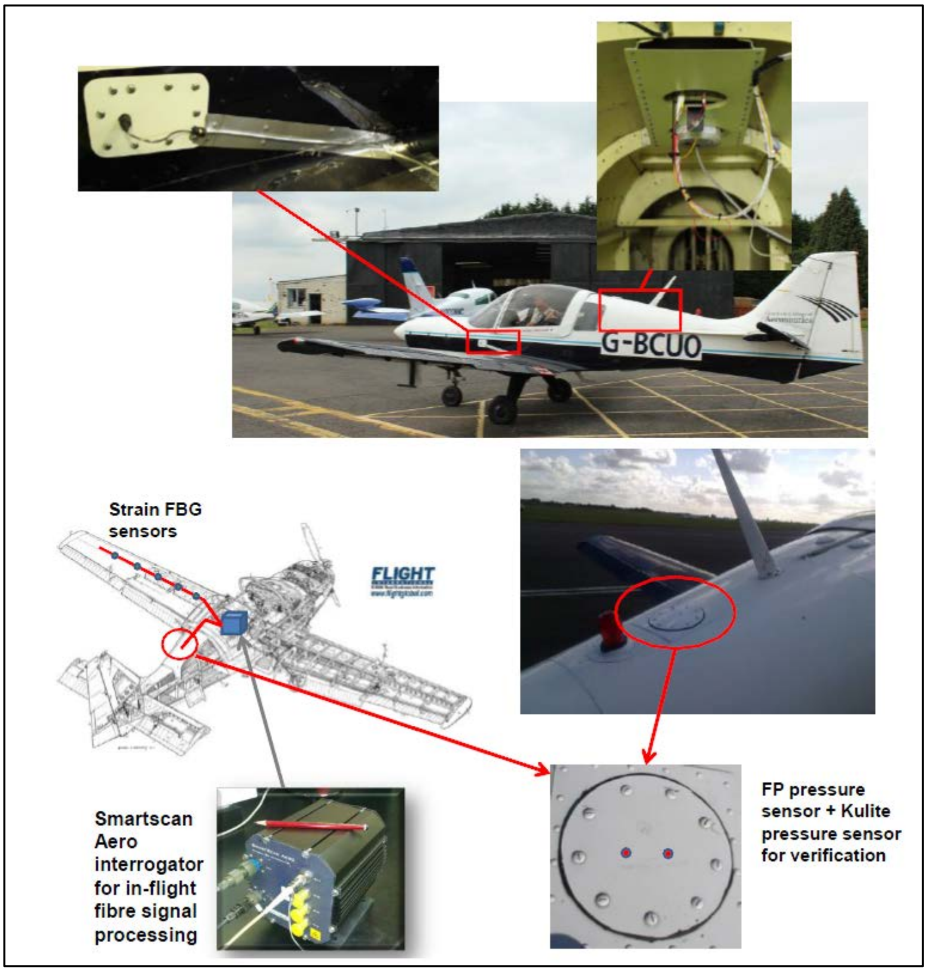

Figure 11: Details of the FBG installation on the Bulldog (taken from D4.3)

In Task 4.3, In-flight application of IRT for surface flow measurements in an industrial environment the apparatus necessary to perform research of the dynamic behaviour of boundary layer transition with Infrared Technique was successfully developed, tested and installed on the glider. Materials which can be used for such research were collected and tested in laboratory and during in-flight tests. IRT test flights started on 25-06-2014 with flight No 03 and ended with flight No 18 on 28-08-2014. During the eleven IRT in-flight tests collected over 100 GB of IR sequences (e.g. see Figure 12) and flight parameters data which are need to be coupled and further analysed. The analysis of the data will be performed now after the AIM² project. Further work is required to check in what scope of dynamics of boundary layer transition Infrared Technique can be successfully used and has acceptable accuracy. In the deliverable "D4.4 Report about Flight Tests in Task 4.3" more information about this activity is provided.

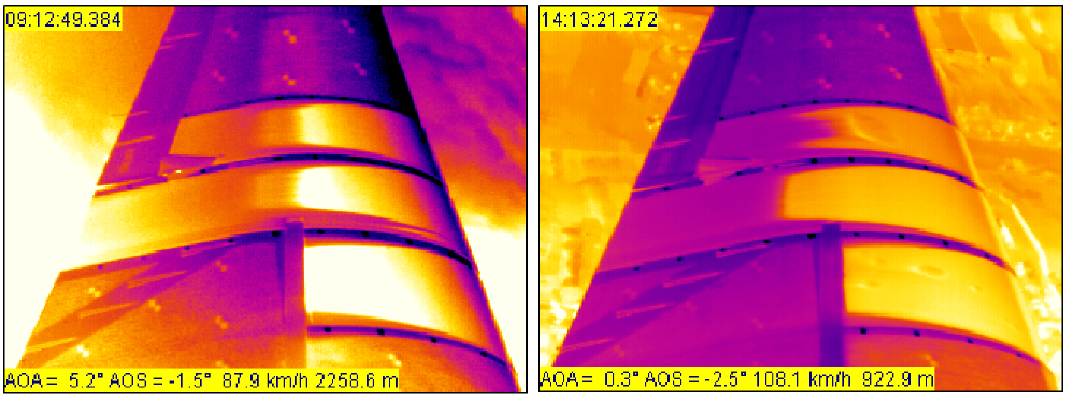

Figure 12: Example recordings from the IRT flight test

4.1.3.4 WP 5 – Flow Field Measurements

In WP 5 the optical flow field measurement techniques PIV, BOS and LIDAR have been investigated. The work-package was divided in three tasks:

- Task 5.1. Development & Research on Flow Field Measurements
- Task 5.2. Research Testing of Flow Field Measurement Techniques
- Task 5.3. Demonstration of Air Data Calibration by Means of LIDAR

In Task 5.1 Development & Research on Flow Field Measurements the basic improvement of the PIV, LIDAR and BOS method for in-flight applications was concerned. Problems relating to integration of these measurement techniques to their particular field of application have been addressed.

Preliminary studies regarding the particle sizing device identified an Interferometric Laser Imaging for Droplet Sizing (ILIDS) system as the most viable approach for flight test demands. Therefore, extensive laboratory studies with such and similar systems were carried out at Cranfield University and at DLR which intended to further improve this system towards a design freeze and to overcome still remaining uncertainties and difficulties coming along with the restricting requirements given by the test environment.

A study on atmospheric particles and their detection has been performed by Cranfield University. This study reviewed the available technologies that can be used for airborne measurement of cloud droplet size for in-flight particle imaging velocimetry (PIV) measurements. The particles of interest were assumed to be in the range 10µm to 500µm in diameter and a survey of commercially available instruments and techniques that may be suitable has been compiled along with some explanatory background information. Deliverable “D 5.1 Atmospheric Particle Detection Systems” summarizes the results of this study.

Furthermore a literature study about potential seeding systems derived from different fields of application has been done and reported in deliverable “D 5.2: Feasibility Study about an Airborne Artificial Seeding Generator”.

A detailed study on light sources and cameras to ease the in-flight PIV application has also been done. The deliverable “D 5.3 – Technical report about in-flight PIV light sources and camera systems” reports about this study.

For the assessment of the feasibility of BOS for vortex or shock detection on the wing a DMU and a ray tracer tool developed by DLR have been used to estimate the feasibility of such a set up. Based on the results of the BOS-simulations recommendations for future applications have been made in the deliverable “D5.4 BOS imaging and acquisition system for in-flight applications (based on DMU)”.

ONERA and Piaggio Aero performed the definition of the LIDAR installation and started the construction phase. A first test plan for a total of 3 flights was established. In addition, a reference air data boom was intended to be installed during the flight test for calibration purposes. In the deliverable “D 5.5 Development of lidar for dynamic testing of AOA, AOS and static error correction (WP 5.1.4)” the LIDAR FTI is described in detail.

Within Task 5.2, Research Testing of Flow Field Measurement Techniques an in-flight PIV setup has been realised and flight tested on the DLRs Dornier Do-228 D-CODE. The applied FTI included a particle sizing system and a dedicated PIV setup.

The selected particle sizing system based on the ILIDS - method received its permit to flight at the beginning of June 2013. The ILIDS - installation consisted of an 8 MPx camera, data acquisition system and the PIV laser light sheet. The deliverable “D 5.7 Report about certification and installation of mobile particle detection system" describes this installation and the certification process in detail.

Five PIV flight tests were conducted with this system within different cloud types. The data processing of the flight test results is still ongoing. Problems occur with the validation of the processing software. Slight differences with the selected setting lead to different results regarding the particle size distribution. Therefore a validation test based on known mono - dispersed particle sizes must be conducted to confirm the results obtained with the software. The report D5.8 will be submitted after validating the results.

The results of the successful in-flight PIV measurement are in detail described in the deliverable "D 5.9 PIV Flight Test Results and Analysis". First results confirmed the feasibility of PIV for flight test applications if the correspondent system design and validation has been carefully adjusted to the unique boundary conditions of flight testing. At different flight conditions, also differential pressure probes captured simultaneous data of the velocity profiles of the fuselage boundary layer. Drift of the pressure data even under constant conditions indicated that the accurate determination of the absolute velocity value was not possible due to variations in aircraft airspeed and flightpath. Thus a method based on the utilisation of the aircraft reference system allowed a correction of the data. Furthermore, the outer region of the viscous flow was also studied and well known laws could be identified in the boundary layer results.

Nevertheless, a more comprehensive evaluation of the data is necessary to allow a comparison between the different measurement systems. Further results and discussions for example regarding the accuracy of this experimental system will be submitted in a forthcoming journal paper.

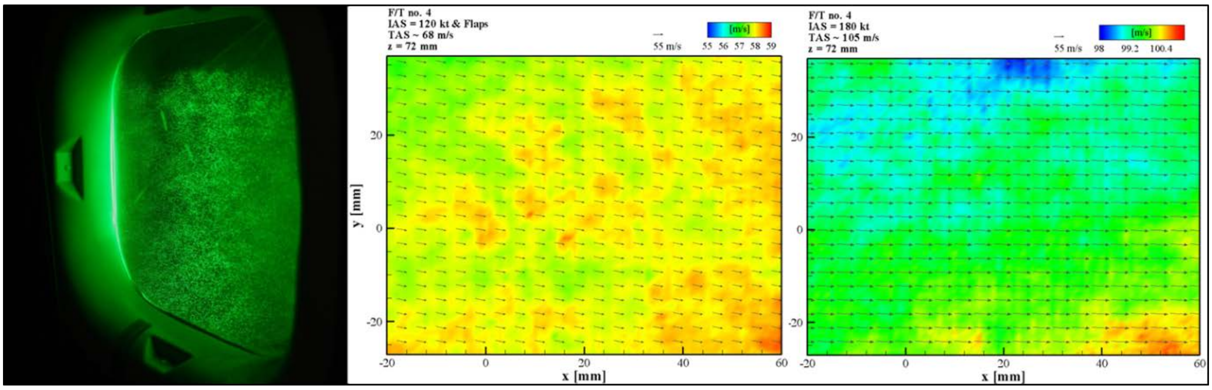

Figure 13: Particles illuminated by the Laser (left) and some first example PIV results (right)

The Task 5.3 Demonstration of Air Data Calibration by Means of LIDAR was successfully completed by flight tests conducted from 2014 February 17th to 26th on the Piaggio site in Genova. The LIDAR anemometer had to be evaluated in flight as reference source to perform air data calibration. Therefore, it had to be able to measure the aircraft true airspeed (TAS) and to infer parameters that were necessary to the aircraft certification such as static error, angle of sideslip and angle of attack.

Figure 14 shows the Lidar installation on board the P180 prototype. The Lidar sensor included:

- The driving unit which was composed of 4 racks which are compatible with aeronautic constrains (laser rack, optical/electronical detection rack, power rack and PC rack) and are located in a bay provided by Piaggio.
- The Sensor head which is precisely positioned with respect to the aircraft reference frame. The 4 lidar beams are sent through an optical grade glass window to probe the atmosphere and measure the true air speed.

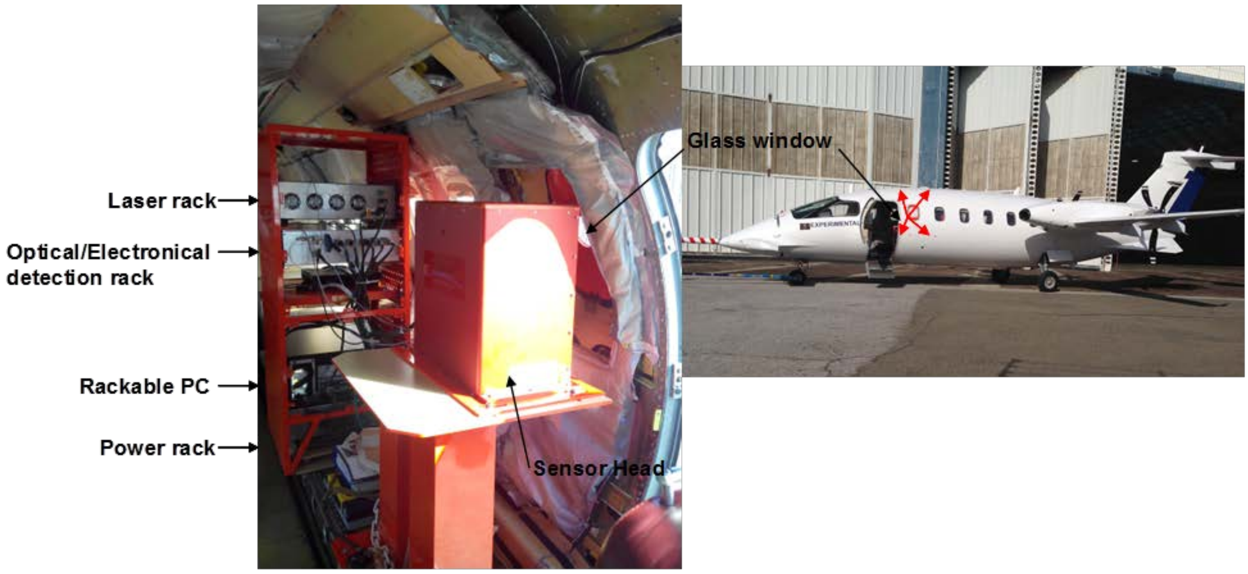

Figure 14: LIDAR anemometer installation on board P.180

LIDAR flight tests were performed successfully on-board the Piaggio P180. During 3 hours of flight tests, 40 LIDAR data sets have been recorded for comparison with aircraft Flight Test Instrument (FTI) data. For all recordings, LIDAR air data have been graphically compared to the air data provided by the a/c Flight Test Instrumentation and reconstruction was done in the reference frame of the LIDAR. Very good agreement on TAS, AOA and AOS variations were observed. A slight bias on AOA and AOS was observed but it remains below the 0.5° specification. Assuming perfect calibration of the FTI, the bias can be explained by the precision of the mechanical adjustment of the LIDAR sensor head with respect to the a/c reference frame. It can also arise from the position of the LIDAR with respect to the aircraft centre of rotation since no geometrical corrections were performed on the air data calculations for this preliminary analysis.

A lack of LIDAR data was observed momentarily during flight tests over the sea. The loss of LIDAR sensitivity is the consequence of low aerosols content. Spatial fluctuations of the backscattering coefficient were observed with altitude change but also during horizontal flight at stabilized altitude. However, 3 hours of flight tests are not enough to conclude on LIDAR measurement availability. Further analysis and an extension of the flight campaign would be required in order to provide statistics on the LIDAR signal availability.

The following Figures illustrate the use of Lidar in dynamic calibration during a pull up manoeuvre. The graphical comparison is based on 6 graphics for each test:

- The top left figure shows the radial wind speed on each LIDAR axes.
- The top centre figure shows the 3 components of wind speed measured by the LIDAR.
- The top right figure shows the altitude given by FTI.
- The 3 bottom figures compare LIDAR (red) and FTI (blue & green) data for true air speed (TAS), angle of attack (AOA) and angle of side slip (AOS).

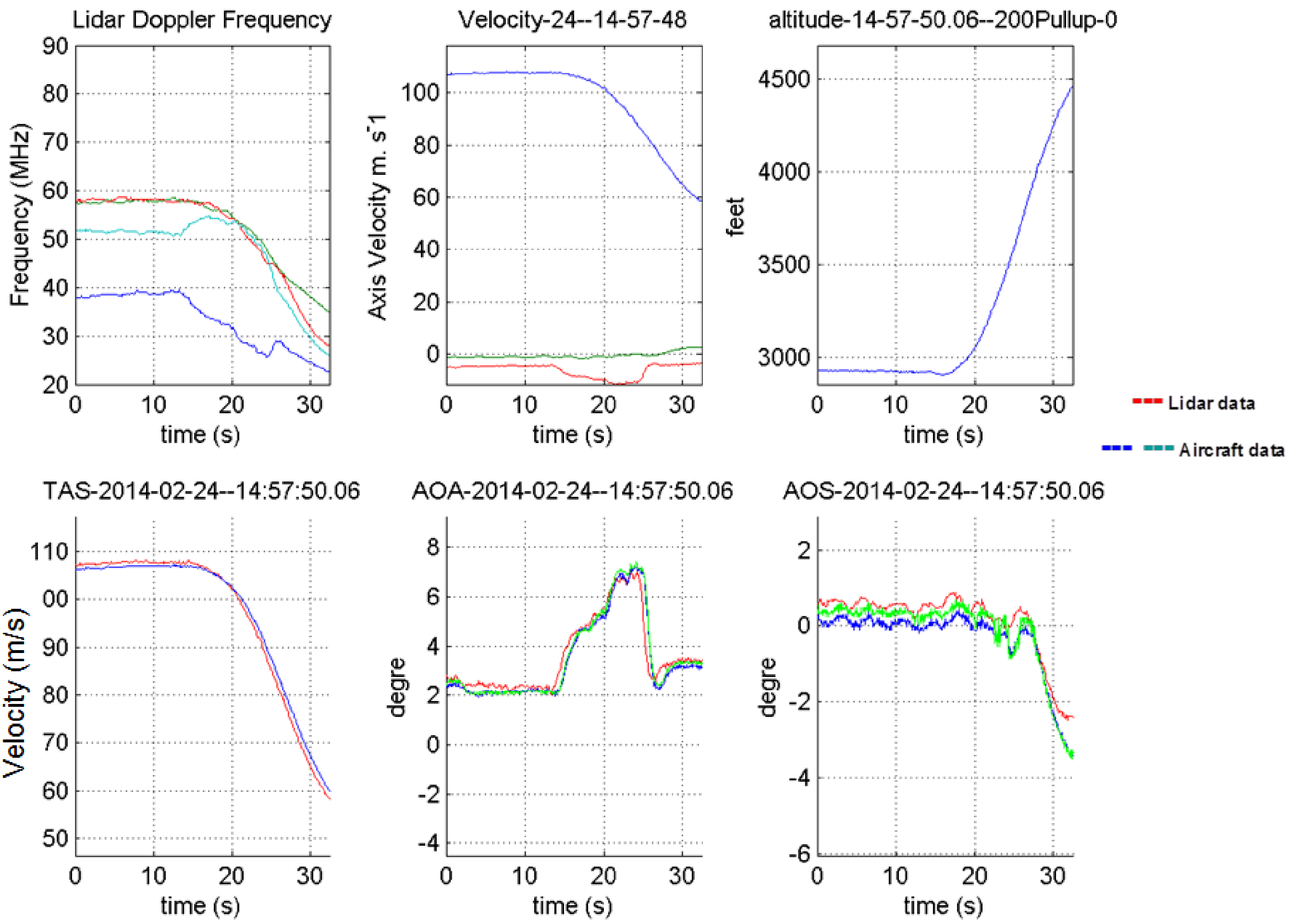

Figure 15: RollerCoaster for AOA – Pull up

In this test, the aircraft performed a pull up manoeuvre at 2.5 g. The manoeuvre started at 15s, and the AOA rose, and the pull up ended at 25s, and AOA decreased. Despite being synchronized with GPS time, the LIDAR was almost 1s ahead of FTI. A good agreement between LIDAR and FTI was found in this test.

Deliverable "D5.10: LIDAR flight tests and analysis (WP 5.3)" contains more information.

4.1.3.5 WP 6 – Tools and Demonstration

In WP 6 the developments made in the other work-packages have been "collected" and "applied" by means of an application matrix, a tool collection, a public workshop as well as application under "industrial flight test conditions". The work-package was divided into six task:

- Task 6.1. Creation of an Application Matrix for the advanced in-flight measurement techniques
- Task 6.2. Development of useful tools for advanced in-flight measurement techniques
- Task 6.3. Research flight test on a Motor glider concerning wing deformation and verification of numerical calculations
- Task 6.4. Advanced Flight Testing Workshop
- Task 6.5. Combined image based flow and deformation measurements on a transport aircraft

- Task 6.6 Landing gear deformation measurements in an industrial environment using optical measurement techniques

In Task 6.1 Creation of an Application Matrix for the advanced in-flight measurement techniques, the lessons learned were collected and matrices were developed for the advanced in-flight optical measurement technologies that cover the key characteristics of a user requirement and of system set-up characteristics. The results of the development are given in the form of templates. The templates are generic to cover a large range of optical technologies and are designed to be simple to use. The templates for the user requirements and the system set-up characteristics were tested by filling in the templates for the measurement technologies investigated in AIM2. The main user requirements and the main system set-up characteristics are well described in the completed templates. The templates are very useful to check that relevant aspects of the requirements and of the measurement set-up for AIM² technologies are taken into consideration. They can guide the planning of a measurement campaign.

In the deliverable “D 6.1 Application Matrix for advanced optical in-flight measurement techniques” these templates are described.

The Task 6.2 Development of useful tools for advanced in-flight measurement techniques was intended to be used for collecting all software tools developed and used within the AIM² projects. The initial idea of a software toolbox to be downloaded or distributed via a CD-ROM was not realized, but at least a list of useful tools and “tool description form” completed by some of the AIM² tools were created. All those achievements can be found in deliverable “D6.2 Development of Software toolbox”.

The main research goal of Task 6.3 Research flight test on a Motor glider concerning wing deformation and verification of numerical calculations was the possibility of stress state numerical FEM calculations in the deformed structure, based on the deformation field obtained from in-flight measurements only.

The detailed description of the flight measurement campaign with IPCT equipment and raw data transformation into reasonable deformation field of the wing is included in the Deliverable “D6.3 Results of the research flight test in Task 6.3”. Following chapters deal, how to utilise these data for FEM applications. The deliverable “D6.4 Comparison of the measured data with numerical data” describes the progress in the second subtask for creating a feedback for FEM. It consists of an implementation of measured flight test data into numerical calculations of structure deformation.

The research aircraft PW-6U was modified to carry additional measurement and data recording equipment. Two IPCT cameras were installed in a specially designed housing attached to the fuselage by a vertical pod 1.5 m above the A/C centre line (see Figure 16).

Figure 16: Camera pod on the PW-6 glider (left - pod opened for camera adjustment on ground, right - PW-6 glider with pod flying)

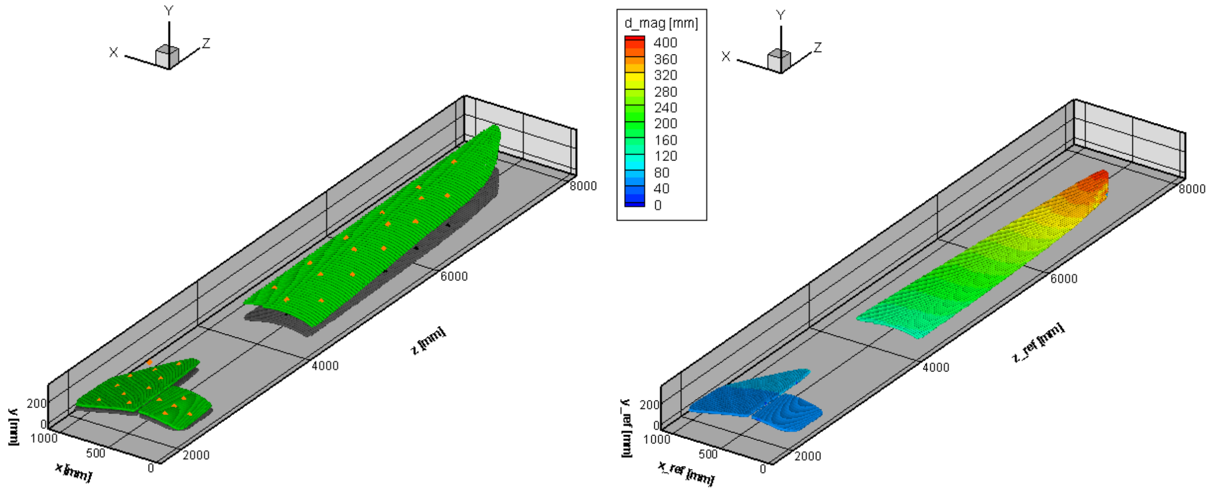

Figure 17: IPCT surface results for CASE01 with an upward wing load of approx. 1.8g; left direct comparison of ground shape (grey surface, black markers) and flight shape (green surface, orange markers), right subtraction of flight and ground shape to visualize wing deformation by colour coded projection to ground shape

The scientific flight test campaign was focused on the assessment of a new application scenario for the deformation measurement method IPCT. In order to realize this project several challenges were successfully taken. On the one hand a class of aircraft like the composite training glider PW-6U had not been examined with IPCT before and this type of aircraft initially was not dedicated to research. Also the major part of the researchers had to be trained as the team had had no experience with the measurement method. The results of the PW-6U test campaign proved the reliable applicability of IPCT for test beds of this category.

The proposed method of numerical model verification proved its applicability at the level of research presented in the deliverable mentioned above. However, the concept itself is promising but additional development steps should be pursued to improve the final results. This particular measurements on a glider provided wing deformation data for further analysis of the composite structure. The authors proposed an advanced approach for aircraft structure analysis by combining optical deformation measurement data gathered in-flight with a numerical FEM model.

Within Task 6.4 Advanced Flight Testing Workshop from 9th to 14th of September 2013 the AIM² Advanced Flight Testing workshop took place at the Aviation Training Center of Rzészow University in Poland. 20 participants from aircraft industries, research institutes and universities attended the lectures about the AIM² measurement techniques IPCT, FBG, LIDAR, PIV, BOS and IRT. Furthermore they had the great opportunity to join several exercises on real aircraft with advanced FTI and to discuss with the specialists of each measurement technique. For some impressions from the workshop take a look to the photos at http://www.workshop.prz.edu.pl/.

Besides the deliverable “D6.6 Proceedings of testing workshop”, the handbook of the workshop “AIM² Advanced Flight Testing Workshop - HANDBOOK of ADVANCED IN-FLIGHT MEASUREMENT TECHNIQUES” was published under ISBN 978-3-7322-3740-1 (printed book) and 978-3-8482-6870-2 (e-book).

The Task 6.5 Combined image based flow and deformation measurements on a transport aircraft has unfortunately been cancelled.

The Task 6.6 Landing gear deformation measurements in an industrial environment using optical measurement techniques was not fully completed due to the unavailability of the testing aircraft. This task has been realized up to the hardware installation on the Piaggio

P.180 only. A detailed description of all parts of the installation as well as an overview on the overall measurement set-up and a description of tests to be performed have been accomplished. Unfortunately due to the fact, that the P.180 experimental airplane was not available the final test has not been performed. Nevertheless the equipment for the test is complete and as soon if PAI and DLR find a suitable time slot and funding opportunity the test can be performed in the future easily.

For a final validation of the camera and marker setup and to discuss the final hardware installation a fit check with the complete image acquisition system as well as some example marker was performed at the aircraft in Genova in July 2014. The test revealed some minor changes and adoption to be made. Those were fixed shortly after this fit check. A screenshot from the DMU setup is shown in Figure 18 below.

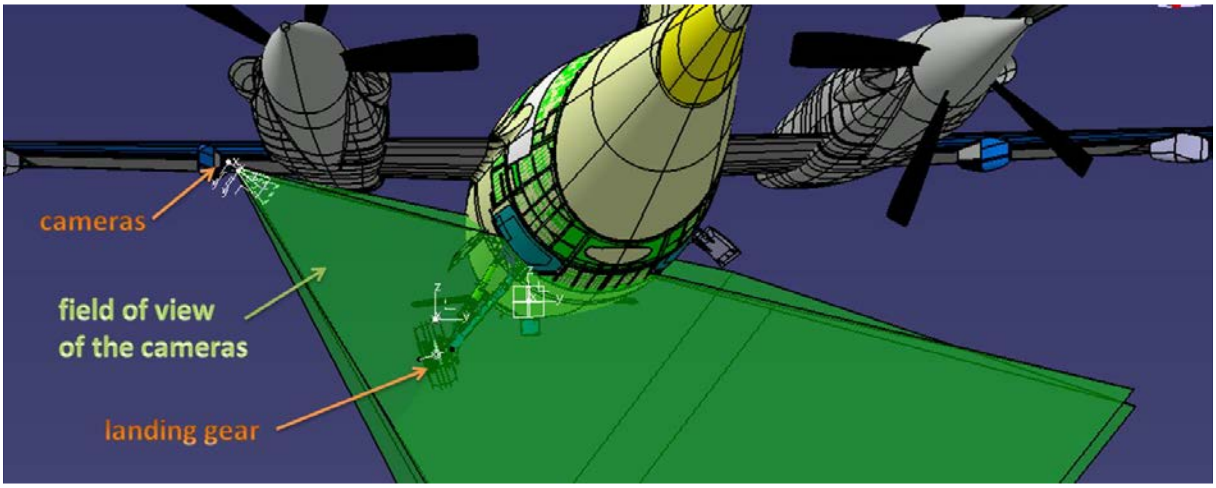

Figure 18: Designed setup for the landing gear measurements on the P.180

The complete description of the test setup, but without the test performance and the data processing, is written down in the deliverable “D 6.8 Report of landing gear measurements in Task 6.6”.

4.1.4 Potential Impact, Main Dissemination Activities and Exploitation of Results

4.1.4.1 Potential Impact

According to the description of work AIM² mainly focused on the "AREA 7.1.4.1 Aircraft development costs" of the topic "7.1.4. IMPROVING COST EFFICIENCY" in the work program 2010. Concerning this area AIM² addressed the subtopic AAT.2010.4.1-1. "Design system and tools" and in particular advanced testing tools and methods to improve cost-efficiency and reduce testing time of on-ground and in-flight tests. The developed and improved advanced in-flight measurement techniques have a high potential to minimise the installation effort and the testing time significantly.

As the installation of classical sensors often takes a long time and is mostly related to the modification of the investigated structure, the advanced non-intrusive measurement techniques tested in AIM² are able to reduce that time and prevent modifications that may cause different behaviour of flow and structure compared to the tested object without test installation. Due to the fact that the AIM² measurement techniques are able to record measurement parameters over a complete area within one instant of time, they can also reduce the testing time, and as additional benefit, improve the spatial resolution considerably. This was directly demonstrated during the in-flight PIV tests, were on the one hand a classical probe was traversed whilst the PIV was able to record a complete flow field with one double pulse. Such advantages outbalance the increased time required for post-processing of image based data due to the huge amount of information.

Since the flight test installation time (aircraft occupation hours) and the flight test time (aircraft flight hours) are the most expensive parts of the aircraft a reduction of these times by using image based measurement techniques will have a strong impact on aircraft development costs as far as flight testing and certification are concerned. On top of that, the reduction of the aircraft test flight hours will also minimise the environmental effects in burning less fuel.

In addition especially for PIV new information is obtained (instantaneous flow velocity fields in boundary layers, separated flows etc.) which cannot be obtained with classical point-wise working in-flight measurement techniques. The same applies for the deformation measurement techniques, which enable a direct measurement of the pitch angle plus the shape (i.e. for the propeller application) or the shape plus the relative position of control surfaces (i.e. for the wing application). Those measurements are by the knowledge of the author not directly possible by means of classical methods like strain gauges or accelerometers (especially for the reference conditions on ground).

Because of the easy and mainly completely reversible installation of the AIM² techniques the structural behaviour and the flow field characteristics can also be investigated on existing standard aircraft in operation in order to check the reasons for unusual incidences ad-hoc. Furthermore the effectiveness of new operation procedures can directly be observed without massive flight test installations. The impact of these new abilities will be a reduced time for aircraft improvement or new developments. In a long term approach this enables the improvement of the aircraft performance leading to lower fuel consumption and enable accurate and optimised control of control surfaces and high lift devices.

The performed improvement of the FBG technique will lead to easy to install pressure and strain measurement sensors. Very lightweight and thin pressure measurement foils can be realised and adopted easily to the shape of the investigated surface (e.g. leading or trailing edge of the wing, slat cove, laminar profiles). The influence on the flow will be very low because only a thin layer is needed.

The tested LIDAR can be used now to measure the true airspeed and wind effects with a high accuracy, even for low velocities and thus can be used as simple and fast calibration tool for other FTI.

Below the Tables from the DoW concerning the AIM² Impact are provided including an extra column concerning the achievements within the project duration

DoW - Table B 3.1-1: Expected results and Impact (technical and economic)

Project result	Range of Application	Expected Impact	Achievements within AIM²
Improvement of optical deformation measurement techniques for wings, control surfaces and high lift devices, including dynamic measurements	Aircraft development and design; improvement of existing aircraft	Decreasing testing time and installation effort; enabling in-flight vibration measurements	IPCT measurements in WP2 and WP6 demonstrated in-flight vibration measurements and deformation measurements with a short testing time
Improvement of optical deformation measurement techniques for propeller and rotor systems	Propeller (and turbine development) and design; (design of helicopter rotors)	Enabling non-intrusive blade deformation measurements over the complete revolution; reduction of installation efforts	In WP3 for the first time a rotating camera for propeller deformation measurements was tested, enabling similar activities on other propellers, rotors and turbines
Improvement of FBG for pressure measurements	Surface pressure measurements	Less flow disturbing accurate surface pressure measurements and reduction of installation efforts	Easy FBG installation successfully tested in WP4 and now available for further testing.
Improvement of IRT towards dynamic measurements	Boundary layer characterisation measurements, shock foot print, transition lines	Enabling fast and reliable measurement of surface flow with less installation effort	Tests in WP4 demonstrated dynamic IRT measurements and revealed suitable materials for further activities
Improvement of in-flight BOS	Measurement of shock and vortex positions	Fast and easy detection of flow phenomena causing drag and fatigue	Investigations within WP5 identified extended workforce concerning the BOS measurement preparation for shock detection; Vortex location measurements can be achieved quiet easily
Improvement of in-flight PIV	Measurement of flow field around the aircraft	Capturing complete flow fields in one instant of time, reducing testing time	In-flight PIV campaign with parallel probe measurements show applicability of PIV for in-flight measurements, first In-flight PIV application in other project performed
Improvement of LIDAR for true airspeed measurements	Measuring flow and wind velocities around the aircraft and FTI calibration	Saving time for FTI calibration and increasing accuracy of calibration	Measurement campaign in WP5 revealed potential of LIDAR for eased FTI calibration

DoW - Table B 3.1-2: Expected results and Impact (social and environmental)

Project result	Range of Application	Expected Impact	Achievements within AIM²
Showing solutions for significant reduction in testing time	flight and ground testing, certification	Lower total fuel burn for flight tests due to reduced flight testing time	All AIM² flight tests demonstrated a reduction of installation and testing time. The required time shifted from testing and installation time to time on the computer for data processing and preparation
Tools for investigation of flow fields around the aircraft	Aircraft design, design of lift optimisation and drag reduction concepts	Improved competitiveness of European aerospace industry	With in-flight PIV the flow field around the aircraft can now be investigated in a non-intrusive way – this is world widely unique (as far the authors know)

DoW - Table B 3.1-3: Expected results and Impact (community added value)

Project result	Range of Application	Expected Impact	Achievements within AIM²
Workshop on advanced in-flight measurement techniques	Flight test operations	Capability of Flight test centres (industry, universities, research organisations) to apply optical measurement techniques	After the successful flight testing workshop some organisations (e.g. TU Darmstadt and ILOT (Warsaw)) started using the AIM² methods. In addition the published book is a nice handy guide.
Introduction of modern optical in-flight measurement techniques to the European Aerospace industry	Aircraft development and certification	Capability of flight test centres to minimise installation and testing time	EVEKTOR, Airbus and Piaggio are going to consider AIM² techniques for future testing activities.

The established networks between the developing and applying institutions turned out to be quite valuable with respect to the consolidation of strong and productive co-operations. Therefore it is planned to keep this co-operation alive.

4.1.4.2 Main Dissemination Activities

For the dissemination of the AIM² achievements different approaches have been used. For instance the participants of the project attended several conferences (e.g. the annual symposia of the society of flight test engineers (SFTE), the European Test and Telemetry Conferences (ETC and ETTC, biennially alternating), Aerospace Testing, Airtec, DGLR congress, STAB symposia) and presented their AIM² activities. Another dissemination action was the publication of the latest news and newsletters concerning the AIM² methods on the public AIM² website (http://aim2.dlr.de) or on the partner organisations websites as well as in local press.

The biggest dissemination action within the project life time was the performance of the AIM² Advanced Flight Testing workshop that has taken place at the Aviation Training Center of Rzészow University in Poland from 9th to 14th of September 2013 (see http://www.workshop.prz.edu.pl/). For this workshop, the book "AIM² Advanced Flight Testing Workshop - HANDBOOK of ADVANCED IN-FLIGHT MEASUREMENT TECHNIQUES" was published under ISBN 978-3-7322-3740-1 (printed book) and 978-3-8482-6870-2 (e-book), being available for the public as a handy guide concerning advanced in-flight measurement techniques.

At the end of the project, the final meeting was held at DLR Goettingen as the 2nd Symposium on Advanced In-flight Measurement Techniques from 9th to 10th of September 2014. The most of the presented topics will be published in the Journal of Measurement Science and Technology in 2015. (Remark: those publications are not yet contained in the list of publications in this report)

A list of publications can be found in Section 4.2.

4.1.4.3 Exploitation of Results

The exploitation of results is presented in the deliverable D1.13 Exploitation Report.