Contract no.: 030827

AIM

ADVANCED IN-FLIGHT MEASUREMENT TECHNIQUES

SPECIFIC TARGETED RESEARCH OR INNOVATION PROJECT

Priority 4: AERONAUTICS AND SPACE

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D 0.4-4: Final Version of Exploitation Report

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Dissemination Level		
PU	Public	
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)	x

Introduction

This deliverable summarises the exploitations based on the development accomplished within the AIM project with respect to the specific flight and ground based applications. Some new features of the used measurement techniques will still be valuable for a wide variety of experimental applications even long after the finalisation of the AIM project. Especially regarding future projects with objectives in the direction of flight tests for certification but also for basic research in the field of aerodynamics and structures.

The main objective of the AIM project was the development of image based flight-testing techniques for industrial and scientific applications which requires no modification of the aircraft structure. The exploitation plans established in the initial proposal of AIM mainly emphasises the industrial fields of applications in order to improve the products and reduce costs for flight tests during the development and certification phase. Secondary objectives comprising the research organisations (DLR, NLR, ONERA) and universities (Cranfield University, MPEI) mainly deals with the extension of the knowledge and further development of the techniques themselves but also with the dissemination of the obtained results. 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.

Hence, this report will summarise the exploitable knowledge and its dissemination.

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1 Identification of exploitable knowledge and its field of application

Considering the fact that the primary objective of this project is the improvement of advanced measurement techniques a short introduction of every employed experimental method is preceding the presentation of the obtained exploitable knowledge of each partner. This short overview will help to provide a full picture of all activities and the interfaces between the participating partners of AIM. Figure 1 presents an overview of the advancement of each measurement technique within the project AIM and gives an outlook on the objectives of the follow up project AIM².

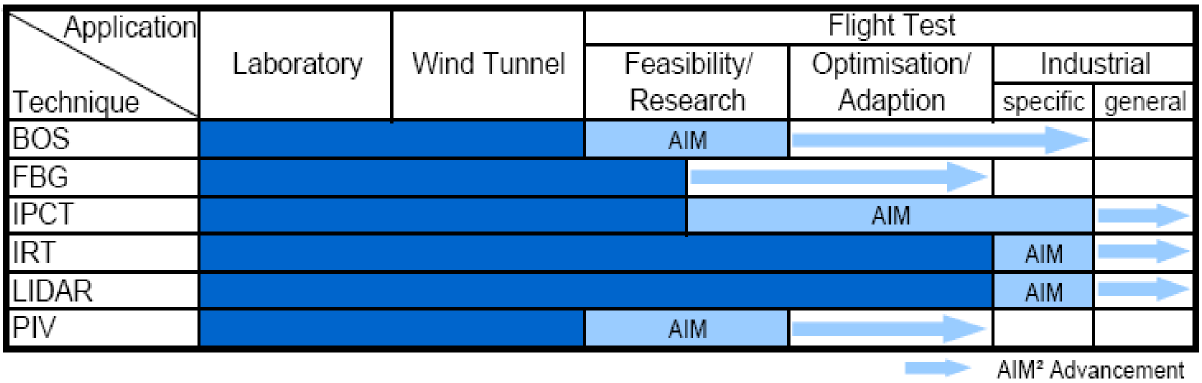

Figure 1: Development of advanced measurement techniques of the project AIM and expected progress within AIM²

In the end an additional summary of all the exploitable knowledge of each individual partner will be presented in this report to emphasise the significance of the project outcome for each member as well as the sectors of application.

1.1 Involved measurement techniques and their progress within AIM

1.1.1 Image Pattern Correlation Technique (IPCT)

Deformation models for aircraft and especially aircraft wing need to be validated in flight. During the certification process of a new aircraft the loads and thus the deformations occurring in free flight have to be measured to prove the safety of the structure. Strain gauges and accelerometers are commonly applied to measure the deformation and the movements of the structure. Non-intrusive measurement methods are preferred for the validation in order to avoid aerodynamic interferences. Also the installation of legacy sensors and their wiring is very time consuming and often leads to substantial modifications of the aircraft structure.

Photogrammetry can be applied for these measurements, although the method has some constraints. To minimise this effort, DLR and NLR developed advanced optical measurement techniques based on the Image Pattern Correlation Technique (IPCT) for in-flight experiments. The in-flight application of IPCT within AIM has demonstrated its enhanced accuracy, reduced installation time, its provision of local surface deformations (that were to-date not feasible) instead of point measurements and dynamics results.

The feasibility of this technique for in-flight structure deformation measurements was demonstrated by investigations first in an research environment (NLR on their own Fairchild Metro II research aircraft, DLR on Piaggios industrial aircraft P180) and than followed by a test under typical industrial conditions (DLR and NLR on AIRBUS' A380 industrial aircraft). The measurements clearly demonstrated its capabilities but also the related critical issues. For instance the criticality to success of obtaining a good reference frame for the cameras in a flexible aircraft cabin was demonstrated. It was shown that the compensation of in flight camera movements may be essential.

As part of the Airbus A380 tests, results of the IPCT method were compared with results from photogrammetric measurements made in parallel using small retro-reflectors fixed to the wing. It clearly showed both methods' strong and weak points. EVEKTOR has made a technical evaluation and cost-benefit analysis of the IPCT method for in-flight application and considered this IPCT method as sophisticated and a promising technique, because of its capabilities to reduce cost and time to test the aircraft.

1.1.2 Quantitative Visualisation Technique (QVT)

The qualitative visualisation of flows and moving objects has been improved considerably by the development of CCD sensors with high temporal and spatial resolution. By using advanced recording methods, fast repetitive events (e.g. rotating propeller blades, oscillating wings, fuel injections) can be observed in an accurate and reliable way. During the past years, DLR developed a special multi-camera video system for various applications of quantitative visualisation – the so called Videostroboscope. The cameras of this system work in non-standard video mode, i.e. their shuttering and triggering are freely programmable, and they can be synchronised with external events. The QVT system has been applied to a number of industrial tests in aerodynamics, turbo machinery and medical applications and should now be in a position to find its way into extensive aerospace application.

Within AIM the Videostroboscope was applied to the P180 propeller deformation measurements, the P180 wing vibration and in-flight deformation measurements, the A380 wing deformation measurements and the EC-135 main rotor blade deformation measurements.

To perform these tests in an optimal way, the existing recording system had been improved. The power supply of the 19" rack PC was adopted to be able to cope with 28VDC as well as 110 to 230V AC with different frequency. In addition an internal uninterruptible power supply (UPS) was installed to maintain power for up to 10 minutes after A/C power loss. Moreover a shockproof solid state hard disk drive was installed to prevent data loss due to hard disk vibrations. For the subsequent data transfer (for evaluation) the system comprises two removable hard disk drives. The Videostroboscope has also been extended recently by a specially developed GPS / IRIG-B receiver module. This module delivers the absolute time with a resolution of 1 millisecond and the aircraft position indications which are recorded simultaneously with the acquisition of images. This data ensures precise synchronization with other measurements carried out in the aircraft.

Beside the improvements of the Videostroboscope PC the JAI CV-A1 and JAI CV-A2 cameras had been modified. These cameras have a high resolution combined with very short shutter times (which is ideal for propeller deformation and oscillation measurements), but they have a problem with trigger jitter. Therefore, DLR improved the camera electronics (by using own extra resources) to get rid of this jitter problem. In addition the cameras now have a shorter shutter time and the option to be operated in double frame mode (PIV mode).

All these improvements of the QVT equipment and the lessons learned during the AIM flight tests will be very useful for further applications.

1.1.3 Background Oriented Schlieren Method (BOS)

The Background Oriented Schlieren Technique (BOS) is an image-based measurement method for the visualisation of density gradients. BOS provides information about the 2D displacement and has the potential to deconvolute the integrated information by applying density models or by using several cameras in parallel with different viewing angles. As little experience exists with the application of BOS to in-flight testing, ground tests with transport (propeller) aircraft and helicopters have to be performed to identify problems which need to be solved prior to the first flight tests.

Helicopter Studies Based on BOS

Within the scope of the subtask 3.2.2 on helicopter flight tests, the first three-component velocity measurements of the blade tip vortices of a full-scale Bo105 helicopter have been conducted. Three component velocity fields of young wing tip vortices, i.e. at vortex ages raging from 1° to 30°, were obtained by means of stereoscopic PIV. The present velocity measurements provide a complete description of young, full-scale tip vortices in hover flight, in ground effect and allowed for the validation of an earlier investigation of vortex core densities by means of BOS. Furthermore, the obtained vortex velocity profiles provide a basis for the validation of the Scully vortex model and the vortex parameters derived from CFD simulations. Notwithstanding the complexity and the imponderability of the experimental conditions, these measurements are a step towards future full-scale, in-flight testing of rotorcraft. Future efforts will include vortex trajectory measurements based on high-speed PIV, which are less constrained by the measurement resolution. Further pursuing the development of airborne measurement techniques, a rotor synchronised image acquisition system was developed and certified which can be utilised to study tip vortex characteristics in situ under various fight conditions.

Ground Based Vortex Detections by Means of BOS

Detecting wake vortices caused by aircrafts during the final approach is a fundamental task to deal with on an airport. A feasible vortex sensing system can enhance the safety and improve the spacing efficiency. Within AIM the Background Oriented Schlieren Method was suggested as a non-intrusive method for the acquisition of high lift flow structures induced by aircrafts. Within three measurement campaigns on the German airport Braunschweig-Wolfsburg conducted by DLR, several aircraft of different types during their departure and final approach have been recorded and analysed.

The BOS measurement was based on two different setups. The first setup was placed on the tower of the airport Wolfsburg-Braunschweig. The distance between the camera (i.e. image plane) and the object on the runway was over 300 m. This turned out to be too far away for simple 100 mm object lenses. Therefore a second setup was proposed, were the camera was placed closer to the runway. Due to very strong restrictions of obstacles placements within the vicinity of the runway the camera and storage units has to keep a certain distance and relatively high to the runway edge. The evaluation of the results indicated a poor data yield. Only strong density gradients were captured.

After all, the BOS method is still a very immature technique for this particular field of application. The conducted experiments within AIM identified the pitfalls of this method but also enable the exploitation of new knowledge for future approaches.

1.1.4 Pressure Sensitive Paint (PSP)

For in-flight testing it is hard to obtain pressure distributions on wing surfaces at high spatial resolution due to the limitation of the maximum number of pressure taps which can be installed in the available space on the wing. As the position of the pressure taps cannot be changed after manufacturing, major problems can occur if the expected aerodynamic phenomenon to be investigated does not appear at the expected locations on the model surface. In contrast, the PSP method enables the measurement of planar pressure distributions over the visible surface of the aircraft/model. It provides maximum flexibility for any given measurement situation.

In WP4, a feasibility test for the in-flight pressure measurement using PSP technique has been performed in October 2008. PSP was applied to a pylon surface of the ATTAS aircraft. In the test, three PSP measurement methods:

- intensity method with LED-array,
- intensity method with Electro Luminescence (EL) foil and
- lifetime method

were employed to measure pressure distributions. Obtained results showed the good feasibility of PSP measurement in-flight test. Especially the intensity method with LED-array and EL-foil could provide results in good image quality. The high power light of the LED-array provided the images of good quality. An EL foil which was applied to the pylon surface outside of the cabin and firstly employed in flight tests worked very well even at high altitudes.

From the obtained results, one can conclude that the PSP technique successfully passed the first feasibility tests and the gained results will be published in a journal.

1.1.5 Infrared Technique (IRT)

The Infrared Thermography Technique is based on the measurement of the infrared radiation from surfaces and allows a global determination and visualisation of the surface temperature distribution with high accuracy. The main objective of the application of the infrared technique within the AIM project is the determination of the surface temperature of helicopter (non-) rotating parts and the visualisation of engine exhaust gas flow at the Eurocopter Flight Test Centre.

Regarding the recent progress made in the infrared technology, the Eurocopter Flight Test Centre and the DLR have initiated investigations through the AIM project in order to study and test the possibilities of using this technology for helicopter flight test purposes in an industrial environment.

These tests show that the infrared technique is today fully applicable to helicopter industrial flight test and offers some obvious advantages compared with techniques generally used to measure surface temperature:

- the technique is non intrusive,
- the associated method enables to derive a real mapping of the temperature and not only discrete results,
- the required test facilities are very simple to handle and to fit on a prototype (similar to usual digital video camera).

The results obtained are promising but their accuracy needs to be improved. If a proper knowledge of the emissivity of the surface coating in particular as a function of the sight angle and of the temperature is necessary, the influence of other parameters also have to be taken into account carefully and eventually be quantified, especially the influence of external radiations sources such as the engines exhaust pipe because the emitted radiations can be reflected on the structure of interest. In addition, engines exhaust gas shall also be taken into account, because due to its various components and high temperature it can emit radiations in the infrared wavelength band used.

1.1.6 Particle Image Velocimetry (PIV)

Particle Image Velocimetry (PIV) is now a mature measurement technique for the investigation of complex instantaneous and mean planar flow fields in a plane of interest in a seeded fluid flow. The range of application of the PIV technique has expanded widely and is now able to cover many different research areas, including micro- and supersonic flows. However, there is still the necessity for further development and extension of the PIV technique, for example, for larger scales. For this reason the AIM project dedicated itself to the investigation of the feasibility of the PIV technique to ground based and in-flight experiments.

The Airborne PIV System

PIV is a mature wind tunnel optical diagnostic technique which allows the measurement of three instantaneous components of velocity from a single plane of interest by using a pair of digital cameras and a double pulsed laser light sheet. Although PIV has become an established technique in many research and industrial wind tunnel applications, at the start of AIM, it had not been applied as an in-flight measurement technique. Therefore, the AIM project, through Work Package 5.3, was tasked with initially assessing the feasibility of applying the PIV technique to a Jetstream 31 turbojet operated by Cranfield University. This initial feasibility study recommended a Jetstream passenger window which was modified for optical access for the laser light sheet, but at a prohibitively high cost due to the pressurised nature of the fuselage. Further feasibility work was completed by Cranfield University and DLR on the application of PIV to an alternative aircraft, the DLR Dornier Do228 D-CODE.

Using this set-up, PIV data was successfully recorded at dusk and processed when flying through natural cloud droplets as seeding in e.g. strato-cumulus layers at app. 6000 feet over a series of airspeeds ranging from 130 – 180 knots and aircraft configurations.

The main limitation of the current in-flight PIV technique are the requirement to use high powered double pulsed Class IV laser systems and the resulting restrictions in aircraft operation. Furthermore, additional restrictions result from flight crew laser safety and the areas where PIV data is recorded due to the constraint to mount all the equipment inside the aircraft fuselage.

Large Scale Wake Vortex Detection Based on PIV

The proposed setup for ground based wake vortex detection by means of PIV on a German airport was involving the whole area of the airport due to the safety restrictions of the German authorities. Hence, the laser light sheet has to pass a long distance (around 350 m) under atmospheric influence before reaching the measurement area. PIV light sheet properties are not known under these conditions. Recently, a facility specifically designed for the investigation of laser light propagation under atmospheric conditions has been established at the DLR site in Lampoldshausen (Germany). The laser safety area of the facility consists of a sender laboratory and a receiver station separated by an open-air section of approximately 130 m.

This facility has been used to conduct tests on the PIV light sheet properties in the given environment. The results of these tests identified the boundaries of the PIV hardware for such an ambitious application. During this measurement campaign a lot of very valuable experiences regarding large scale PIV laser operations could be obtained and will be the foundation of future applications with similar dimensions.

Providing a feasible seeding for large scale outdoor PIV measurements is a very basic but challenging task. Hence, several different seeding systems and their integration into the suggested PIV setup were considered e.g. soap bubbles, flares. In the end, helium-filled soap bubbles (HFSB) turned out to be the best seeding option for this kind of boundary conditions. Therefore, an advanced generator system was developed and tested. Different approaches for the design of a HFSBG have been considered. The outcome of all these considerations and pre-tests was a bubble generator with a highly advanced and well proven nozzle system to produce neutrally buoyant helium filled soap bubbles. As a result bubbles with an almost consistent diameter of around 2-3 mm are generated with a high production rate. At the beginning of the HFSB generator developing phase a small prototype consisting of four nozzles was designed to evaluate the concept. Each nozzle was able to produce 200.000 bubbles/sec. Three different versions of this seeding generator were designed, applied and evaluated. The last concept promised to be the most efficient one. Future experimental applications will test its sufficiency.

After all, this HFSBG concept is part of successful project proposals and will continue its development and application process.

1.1.7 Light Detection and Ranging (LiDaR)

On the basis of recent developments, fibre LiDaR technology becomes a serious candidate for lightweight, compact, eye-safe airborne anemometer probes. The contribution of the ONERA to this technology is the design of a 1.5 µm LiDaR sensor which is able to detect the tip vortex. The experiments took place during a ground-based test campaign of the DLR helicopter in hover flight in ground effect conditions. The main outcome of this work is the specification of a future 1.5 µm LiDaR anemometer for onboard research and industrial tests.

The study results demonstrated for the first time the capability of LiDaR technology to characterise helicopter blade tip vortices. Blade tip vortex velocities of hovering helicopter were measured by 1.5 µm LiDaR sensor with very good speed accuracy (1 m/s) and characterised in terms of circulation using Hallock-Burnham vortex model.

Tests analysis confirmed the good choice of LiDaR instrumental parameters which was built using off the shelf components. Tests also showed that seeding was critical. The homogeneity of seeding appears to be a major issue for LiDaR measurements of such small phenomena. Clouds water tracers could provide a homogeneous, efficient and uniform seeding to improve LiDaR measurement sensitivity and allow the use of a classical commercial laser source.

LiDaR technique is promising for onboard measurement in real flight conditions. Indeed, LiDaR technique measures the Doppler shift of light scattered from atmospheric particles, and hence infers the line-of-sight flow velocity allowing a picture of vortex flow to be built up. The velocity measurement is direct and absolute (no calibration is needed) and its accuracy can be up to 0.25 m/s and commonly 1 m/s. Thanks to 1.5 µm technology, a compact and reliable sensor can be realised and easily integrated in helicopter. This technology presents many advantages: design of all fibered optical LiDaR architecture with limited adjustments, separation of the sensor head and the optical bench using an optical fibre link, reduced cost and integration constrains. Flight measurements within clouds could be a good solution for efficient and powerful vortex LiDaR characterisation.

1.2 Exploitable knowledge by individual partners

All together 11 partners are cooperating within the AIM project. Most of the partners are research organisations or industrial enterprises which were already involved in several scientific projects. Each partner provides expertise in a particular field of activity within every developing and application-oriented stage of an experimental measurement technology. Hence, the exploitation and dissemination will be carried out in subsequent processes starting with an internal exploitation by each partner and continuing with testing activities and dissemination.

AIRBUS – France (A-F)

1	
Exploitation knowledge description	Installation of **In-flight IPCT system** - Pattern sticker manufacturing - Pattern installation and removal - Definition of flight test installation - Flight test installation and removal Flight test definition Results analysis comparison IPCT / Photogrammetry. IPCT could have a complete wing deformation instead of some chords without limitation of time measurement.
Exploitable product(s) or measure(s)	The installation has been kept during 6 test flights before removal. All parameters have been recorded in order to compute post process. Also the installation dossier is completed with all document required for certification. The results have been analyzed and show that the process is promising but need to be automated
Sector(s) of application	Before aircraft certification, wing twist and bending need to be assessed.
Further additional **research & development**	In order to produce robust measurement for flight testing following topics need to be improve : - Tool to determine the best configuration for camera (region of interest, field of view, camera position, achievable accuracy) - Quick installation with stiff support - Tool for calibration - Tools to give real time quality for measurement (monitoring of camera movement, image contrast) - Tool to extract measurement from images, in real time or post processing
Timetable for commercial use	Depending on resources, 3 to 4 years.
Patents or other **IPR** protection	N/A
Marketing & commercial contacts	None
Potential **impact** from exploitation of results	Cost and time reduction could be obtain on installation and results analysis. The complete deformation study will help to validate computed model in order to have more efficient and economic aircrafts.
Owner & other partners involved	The installation process belongs to Airbus. Other partners involved are DLR and NLR

Cranfield University (Cranfield)

1	
Exploitable knowledge description	**Optical model for imaging through distorting medium**
Exploitable product(s) or measure(s)	Matlab based model for the prediction of distortion effects when imaging through a distorting medium
Sector(s) of application	Wind tunnel optical instrumentation / in-flight optical instrumentation
Further additional **research & development**	Model refinement and front end development.
Timetable for commercial use	No specific timetable for commercial use has been defined.
Patents or other **IPR** protection	N.A.
Marketing & commercial contacts	Universities / Scientific institutions
Potential **impact** from exploitation of results	Optimisation of wind tunnel and flight test imaging systems
Owner & other partners involved	DLR / Cranfield University

Deutsches Zentrum für Luft- und Raumfahrt e.V. (DLR)

1	
Exploitable knowledge description	**In-flight PIV technique**
Exploitable product(s) or measure(s)	Within AIM an airborne (Stereo) PIV system has been developed and tested on a DLR research aircraft. The obtained results proved the feasibility of such a measurement technique for subsonic velocities up to 100 m/s.
Sector(s) of application	In-flight flow visualisation e.g. wing or fuselage boundary layer, engine & wing interaction, propeller aerodynamics
Further additional **research & development**	Acquisition and analysis of the instantaneous flow field around the aircraft and determination of cloud particles as PIV seeding.
Timetable for commercial use	No specific timetable for commercial use has been defined.
Patents or other **IPR** protection	N.A.
Marketing & commercial contacts	Aircraft manufacturers
Potential **impact** from exploitation of results	Quantification of the flow around an aircraft in flight. Further development of supporting tools for the aircraft certification process. Powerful tool for fundamental aerodynamic research.
Owner & other partners involved	DLR together with Cranfield University

2	
Exploitable knowledge description	**Helium Filled Soap Bubble Generator (HFSBG)**
Exploitable product(s) or measure(s)	In order to allow a large scale PIV measurement in an outdoor environment a large seeding device, based on the production of a large amount of helium filled (neutrally buoyant) soap bubbles was designed. This device is a further development of an existing nozzle system.
Sector(s) of application	Wind tunnel and large scale (outdoor) flow visualisation for measurement of wake vortices on an airport.
Further additional **research**	Dedicated measurements to verify the viability of the generator for

& development	small scale PIV applications comprising the investigation of bird flight and aircraft cabin aerodynamics.
Timetable for commercial use	No specific timetable for commercial use has been defined.
Patents or other **IPR** protection	N.A.
Marketing & commercial contacts	Scientific institutions, Universities
Potential **impact** from exploitation of results	Extension and enhancement of fields of application for mature flow measurement techniques (e.g. PIV).
Owner & other partners involved	DLR

3	
Exploitable knowledge description	**Helicopter flight tests based on PIV and BOS**
Exploitable product(s) or measure(s)	Within AIM the first three-component velocity measurements of the blade tip vortices of a full-scale Bo105 helicopter have been conducted.
Sector(s) of application	In-flight flow visualisation of the blade tip vortex and the investigation of the blade vortex interaction
Further additional **research & development**	Three component velocity fields of young wing tip vortices, i.e. at vortex ages raging from 1° to 30°, were obtained by means of stereoscopic PIV. The present velocity measurements provide a complete description of young, full-scale tip vortices in hover flight, in ground effect and allowed for the validation of an earlier investigation of vortex core densities by means of BOS. Furthermore, the obtained vortex velocity profiles provide a basis for the validation of the Scully vortex model and the vortex parameters derived from CFD simulations. Acquisition and analysis of the instantaneous flow field of the aircraft and determination of cloud particles as PIV seeding.
Timetable for commercial use	No specific timetable for commercial use has been defined.
Patents or other **IPR** protection	N.A.
Marketing & commercial contacts	Rotorcraft manufacturers
Potential **impact** from exploitation of results	Further pursuing the development of airborne measurement techniques, a rotor synchronised image acquisition system was developed and certified which can be utilised to study tip vortex characteristics in situ under various fight conditions.
Owner & other partners involved	DLR

4	
Exploitable knowledge description	**Optical in-flight deformation measurement system (QVT / IPCT)**
Exploitable product(s) or measure(s)	Within AIM the DLR QVT system had been improved towards in-flight application. Also the post processing software tools for marker detection and stereo IPCT had been improved significantly.
Sector(s) of application	In-flight deformation measurements (wings, propeller blades, helicopter rotor blades), position detection, time synchronised imaging, blade pitch measurements.
Further additional **research & development**	Fast evaluation (best online evaluation), finding application rules to make the technique applicable for non-experienced users.
Timetable for commercial	No specific timetable for commercial use has been defined.

use	
Patents or other **IPR** protection	N.A.
Marketing & commercial contacts	Aircraft manufacturers, system suppliers
Potential **impact** from exploitation of results	Non intrusive shape and deformation measurements over optically accessible large areas; non-intrusive blade pitch measurements
Owner & other partners involved	DLR is owner of the system, other partners involved are NLR, Airbus, Piaggio, and EVEKTOR.

Eurocopter SAS (EC-F)

1	
Exploitable knowledge description	**In-flight IRT measurement and processing.** Details of the obtained technological knowledge can be described as: 1. Modelling of the involved phenomenon (IR thermography) 2. Identification in laboratory of the IR characteristics (emissivity) of different surface coatings. Test results analysis and selection of the most proper coatings for flight tests purposes 3. Design, manufacturing and fitting on helicopter of IRT system 4. Processing and Analysis of the results derived from IRT system
Exploitable product(s) or measure(s)	Within AIM, airborne IRT set was tested on a Eurocopter helicopter prototype. The obtained results demonstrated the feasibility of such a measurement technique for helicopters throughout the required flight domain. Identification in laboratory of the IR characteristics (emissivity) of different surface coatings then used in flight. Acquisition of the instantaneous IR images derived from the system, then post processing of these images to derive the time history of structural temperatures in flight.
Sector(s) of application	In flight structural temperature measurement (various flight tests required for helicopter development, certification or qualification).
Further additional **research & development**	An interesting axis would be to use updated IR cameras enabling higher performances
Timetable for commercial use	Usable today
Patents or other **IPR** protection	N.A.
Marketing & commercial contacts	None
Potential **impact** from exploitation of results	Measurement of the structural temperature of an aircraft in flight. Significant simplification of aircraft test installation and cost reduction for flight test. Surface-based temperature knowledge instead of point measurements providing deeper knowledge of in-flight temperature mapping. Fully usable for certification process.
Owner & other partners involved	Eurocopter and DLR

Eurocopter Deutschland (EC-D)

1	
Exploitable knowledge description	**No exploitable knowledge identified.**

Exploitable product(s) or measure(s)	
Sector(s) of application	
Further additional **research & development**	
Timetable for commercial use	
Patents or other **IPR** protection	
Marketing & commercial contacts	
Potential **impact** from exploitation of results	
Owner & other partners involved	

Evektor (Evektor)

1	
Exploitable knowledge description	**In-flight QVT/IPCT technique for wing and propeller deformation measurement**
Exploitable product(s) or measure(s)	Within AIM, the applicability of QVT/IPCT method was tested on a Piaggio P-180 research aircraft. The obtained results proved the applicability of such a measurement technique for propeller and wing deformation. Both the static deformation and in a limited range the dynamic deformation.
Sector(s) of application	Laboratory, ground and in-flight non-intrusive aircraft measurements.
Further additional **research & development**	A further development of hardware will improve the frame frequency of QVT method. Further development of IPCT software will automatize and quicken post processing of images.
Timetable for commercial use	No specific timetable for commercial use has been defined.
Patents or other **IPR** protection	N.A.
Marketing & commercial contacts	Aircraft and car industry.
Potential **impact** from exploitation of results	Deformation of air wing and propeller (in a laboratory, on ground and in flight). Further development of supporting tools for an aircraft development and certification process.
Owner & other partners involved	DLR

Flughafen Braunschweig-Wolfsburg (FB)

1	
Exploitable knowledge description	**No exploitable knowledge identified.**
Exploitable product(s) or measure(s)	
Sector(s) of application	
Further additional **research & development**	
Timetable for commercial use	
Patents or other **IPR** protection	

Marketing & commercial contacts	
Potential **impact** from exploi-tation of results	
Owner & other partners involved	

Moscow Power Engineering Institute / Technical University (MPEI)

1	
Exploitable knowledge description	**No exploitable knowledge identified.**
Exploitable product(s) or measure(s)	
Sector(s) of application	
Further additional **research & development**	
Timetable for commercial use	
Patents or other **IPR** protec-tion	
Marketing & commercial contacts	
Potential **impact** from exploi-tation of results	
Owner & other partners involved	

Stichting Nationaal Lucht- en Ruimtevaartlaboratorium (NLR)

1	
Exploitable knowledge description	**In-flight IPCT data collection and processing system.** Details of the obtained technological knowledge can be described as: 1. In-flight time-based and triggered image collection 2. Dot pattern generation tool 3. Optimal approach for dot pattern provision to wing surface 4. Method for in-flight camera deflection compensation due to fu-selage flexibility 5. Image pattern cross correlation for obtaining displacement vec-tors 6. Geometrical 3D transformation from image pixel coordinates to geometrical coordinates 7. Analysis and results visualization software
Exploitable product(s) or measure(s)	The method has successfully proven its capabilities for in-flight deformation measurements providing enhanced accuracy, results in terms of surface-based deflections and ease of installation and processing. The product is still in a prototype status to be made mature and user friendly for industrial application.
Sector(s) of application	In-flight (wing) surface deflection measurements, to be used in aircraft certification trials. Also application in wind tunnels is feasi-ble or deformation measurements in different fields such as wind turbine rotor deformation measurements.
Further additional **research & development**	The following further developments of the IPCT tool is foreseen: 1. Developing the set of instrumentation and software routines into a user friendly tool for in-flight deformation measurements

	and analysis. 2. Deformation assessment of moving and rotating surfaces such as flaps, slats and rotors, including determination of gap changes between surfaces. 3.Determination of spatial vibration modes of surfaces
Timetable for commercial use	app. two to three years
Patents or other **IPR** protection	N/A
Marketing & commercial contacts	None
Potential **impact** from exploitation of result	Significant simplification of aircraft installation and cost reduction for wing deflection measurement instrumentation. Surface-based deflection knowledge instead of point measurements providing deeper knowledge of in-flight wing behavior, ultimately leading to more efficient and economic aircraft.
Owner & other partners involved	NLR is tool owner; other partners involved are DLR, Airbus, Piaggio, and EVEKTOR.

Office National d'Études et de Recherches Aérospatiales (ONERA)

1	
Exploitable knowledge description	**In-flight Lidar sensor specification**
Exploitable product(s) or measure(s)	Within AIM, 1.5µm Lidar sensor dedicated to blade vortex characterization was tested on ground on a DLR helicopter in hover flight. The study result demonstrated for the first time the capability of Lidar technology to characterize blade tip vortices of hovering helicopter with very good speed accuracy (1m/s).
Sector(s) of application	In-flight velocities field measurement e.g. wing or fuselage flow for aircraft, blade tip vortices for helicopter
Further additional **research & development**	In-flight 1.5µm Lidar tests
Timetable for commercial use	No specific timetable for commercial use has been defined.
Patents or other **IPR** protection	N.A
Marketing & commercial contacts	Aircraft- and helicopter manufacturers
Potential **impact** from exploitation of results	Detection and quantification of the flow around an helicopter in flight : help for Navigation and certification
Owner & other partners involved	ONERA

Piaggio

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Exploitable knowledge description	**Wing and propeller blade deformation measurement by means of IPCT**
Exploitable product(s) or measure(s)	The wing deformation study allowed a verification of this technology for industrial applications. The test proved that it is also possible to make dynamic measurement such as deformation due to vibrations or measurement of fast revolving propeller. The activities within AIM allowed collecting information in order to

	make this kind of measurement a standard process.
Sector(s) of application	In-flight loads (steady and unsteady) evaluation on aircraft structure
Further additional **research & development**	Based on the current results a user friendly set of hardware and software tools should be developed and tested in a further flight test campaigns.
Timetable for commercial use	N/A. (No experience in this sector)
Patents or other **IPR** protection	N/A
Marketing & commercial contacts	None
Potential **impact** from exploitation of result	The camera installation on a small aircraft is still a very complex process. The usage of the tool should be planned in advance on a new aircraft. A system which provides camera fairing and a way to quickly connect the cameras to the structure would improve matter.
Owner & other partners involved	DLR is the tool owner. Other partners involved are NLR, Airbus, Piaggio and EVEKTOR.

2 Dissemination of Knowledge

One important role in the dissemination of knowledge especially for the project partners plays the AIM website which is online since January 2007. The homepage of the project is intended to enable an easy data exchange among the partners. On the AIM website, which can be found under http://aim.dlr.de, all members of the consortium and some guest accounts can be found, together with their contact data. This internal dissemination helps to improve the efficiency of the project work. Hence, the main point-of-contact from each partner can modify or register new members from his group and therewith the contact data can easily be kept up to date. In the File Exchange part of the website every partner can upload and download deliverables, presentations, minutes of the meetings, reports and literature of common interest. Until now the AIM website is in a state of basic functionality, but it was continuously improved over the whole duration of the project.

Furthermore, for a distribution of the obtained knowledge and results within the project AIM most of the partners took the chance to publish the results on symposia, conferences or exhibitions. A reference list of all presented papers is given in the Appendix. The types of audience were mainly international or European research organisations and universities as well as the aerospace industry. The final workshop of the AIM project, conducted in October 2009, invited all partners and guest to contribute to the subject. The knowledge exchange was quite fruitful and the adjacent discussions defined a good fundament for the follow – up project of AIM – AIM². The Midterm Meeting was held in May 2008 in Berlin at the same time as the ILA (*Berlin Air Show*) took place. The partners took that chance at the DLR booth to present the project and in particular the *Image Pattern Correlation Technique* to a public audience.

In addition to conferences or online presentations, other publication and elements of the mass media were involved. The AIM Newsletter 1 – 3 mainly intended to inform the partner and a large audience on current activities of the project. Technical details and methods were presented and explained in the Measurement Technique Brochure published in November 2008. This brochure was the theoretical foundation of the assessment meeting in the same month.

Another important aspect of the dissemination of experiences was given by the stay of Domenico Casella (Cranfield University) at the DLR in Göttingen. The aim was to support the in-flight PIV campaign of Work Package 5 and help preparing the flight tests and theoretical investigations. Mr. Casella stayed twice in Göttingen and reported about his stay in the second Newsletter.

3 Established durable Relationships and Co-operations

The complexity of flight testing necessitates a strong exchange of knowledge, experiences, hardware and test beds (i.e. aircrafts, helicopters) to carry out most of the defined tasks. Therefore, strong co-operations were established to allow an efficient accomplishment of the flight or ground based tests incl. their particular preparations. Every partner played a specific role which leads to a strong prioritisation of the individual exploitations but also to durable relationships among the 11 partners.

By networking among partners within AIM and working together on technological developments a number of links have been established between the partners. Concerning IPCT, the co-operation between aircraft manufacturers (Airbus, Piaggio) and aerospace research centres (DLR, NLR) has made a start for a fruitful co-operation and technology exchange in the field of optical deformation measurement techniques for in-flight application.

In addition, the work accomplished in Work Package 5 underlined a good partnership between the Cranfield Universtiy and DLR. This partnership was officially established in a *Collaborative Research Agreement* and shall ease the exchange of knowledge and personnel for future activities in the same field of research.

Two measurement campaigns strongly relied on an exchange of knowledge and hardware. The investigation of applicability of the infrared technique on helicopters in order to detect e.g. hot exhaust gases close to the turbine was based on an active exchange of experiences with this particular experimental method between Eurocopter SAS and DLR Braunschweig. The ONERA performed their feasibility test for the developed Lidar system at the airport in Braunschweig with a DLR helicopter. These co-operations allowed flexible reactions on unexpected problems.

After all, the project website will still be available after the finalisation of the project. Therefore, the contact data and documented co-operations will still remain published at least on a level of internal dissemination.

4 Future Activities Related to Exploitation

Several activities that are initiated under AIM will be continued after the end of the AIM contract period. One of these activities is the AIM website to be kept alive and updated with new information. Other future activities relate with future (EC/FPx) projects in which the developed techniques will be applied or its capabilities enhanced. In this domain the following future activities can already mentioned:

- Within the JTI Clean Sky project the IPCT accuracy is assessed in order to investigate whether the technique can be applied for research on laminar to turbulent flow transitions at the wing surface.
- The results obtained within AIM will be enhanced with additional capabilities and worked out to ready-to-use tools for in-flight investigations within the EC/FP7 project AIM².

5 Appendix

Published Papers

Augère B., Bailly J., Besson C., Dolfi A., Goular D., Fleury D., Valla M.: *1.5 µm Lidar for Helicopter Blade Tip Vortex Detection*, presented at 15th Coherent Laser Radar Conference, Toulouse (France), 2009

Augère B., Bailly J., Besson C., Dolfi A., Goular D., Fleury D., Valla M.: *1.5 µm Lidar for Helicopter Blade Tip Vortex Detection*, presented at 35th European Rotorcraft Forum 2009, Hamburg (Germany), 2009

Boden F., Torres A., Maucher C.: *Advanced optical rotor blade deformation measurements on a flying helicopter,* presented at 35th European Rotorcraft Forum 2009, Hamburg (Germany), 2009

Boden F., Stasicki B., Torres A.: *Optische Deformationsmessung am Propeller- und Hubschrauberrotorblatt im Freiflug,* Deutscher Luft- und Raumfahrtkongress 2009, 2009-09-08 - 2009-09-10, Aachen (Germany), 2009

Boden F., Kirmse T., Stasicki B., Lanari C.: *Advanced optical in-flight measurements on deformation of wings and propeller blades*, Society of Flight Test Engineers - European Chapter, 19th Annual Symposium, 2008-09-22 - 2008-09-24, Manching (Germany), 2008

Boden, F.: *Dynamische Deformationsmessung mittels digitaler Bildkorrelation an Flugzeugstrukturen im Flugversuch*, presented at the 7th Oldenburger 3D-Tage "Optische 3D-Messtechnik – Photogrammetrie – Laserscanning" , 2008-01-30 - 2008-01-31 , Oldenburg (Germany), 2008

Kindler K., Goldhahn E., Leopold F., Raffel M.: *Recent developments in background oriented Schlieren methods for rotor blade tip vortex measurements*, Experiments in Fluids, Volume 43, Numbers 2-3 / August, 2007

Kindler K., Mulleners K., Richard H., Raffel M.: *A full-scale particle image velocimetry investigation of young rotor blade tip vortices*, presented at the American Helicopter Society 65th Annual Forum, 2009-05-27 – 2009-05-29, Grapevine / Texas (USA), 2009

Petit C., Jentink H.W., Boden F., Kannemans H., Veermann H.P.J., Kirmse T.: *Introducing a new measurement method for wing twist and bending*, European Test & Telemetry Conference 2009, 2009-06-24 – 2009-06-26, Toulouse (France), 2009

Politz C., Boden F., Lawson N., Casella D., Kreienfeld M.: *Application of non-intrusive optical methods for in-flight flow visualisation*, 40th Annual SFTE International Symposium 2009, 2009-09-07 – 2009-09-11, Linköping / Stockholm (Sweden), 2009

Politz C., Konrath R., Boden F., Agocs J., Schröder A.: *Particle Image Velocimetry for In-Flight Application – Preparation, Test and Lessons Learnded*, presented at 14th International Symposium on Flow Visualization, Paper No. 14, 2010-06-21 – 2010-06-24, EXCO Daegu (Korea), 2010

Politz C., Lawson N.J., Konrath R., Agocs J., Schröder A.: *In-flight flow visualisation using Particle Image Velocimetry*, presented at 15th Int. Symp. on Applications of Laser Techniques to Fluid Mechanics, Paper No. 1615, 2010-07-05 – 2010-07-08, Lisbon (Portugal), 2010

Stasicki B., Boden F., Bodensiek K.: *Application of Image Pattern Correlation for non-intrusive deformation measurements of fast rotating objects on aircrafts*, presented at 4th International Conference on Experimental Mechanics ICEM 2009, 2009-11-18 – 2009-11-20, Republic of Singapore, 2009

Stasicki B., Boden F.: *Application of high-speed videography for in-flight deformation measurements of aircraft propellers,* presented at 28th International Congress on High-Speed Imaging and Photonics (ICHSIP 28), 2008-11-09 - 2008-11-14, Canberra (Australia), 2008

Veerman H.P.J., Kannemans H., Jentink H.W.: *High Accuracy In-Flight Wing Deformation Measurements based on Optical Correlation Technique*, NLR-TP-2008-718, presented at 19th SFTE (EC) Symposium, 2008-09-22 – 2008-09-24, paper 3-2, Manching / EADS (Germany), 2008