AIM NEWSLETTER NO. 2

December 2008

Advanced In-Flight Measurement Techniques

AIM – What has happened so far?

In 2008 the project AIM went through its second year where several flight tests had been carried out. *AIM* is the abbreviation for *Advanced In-flight Measurement Techniques* and is a *StReP* within the *6th European Framework.* The project has the goal of making highly sophisticated optical measurement techniques applicable to industrial flight tests.

Within the *AIM* consortium, eleven Partners from aircraft industries, airport services and research organisations from 7 countries work closely together. These partners are: *Piaggio Aero Industries* (I), *Eurocopter France* (F), *Eurocopter Deutschland* (D), *Airbus France* (F), *DLR* (D), *ONERA* (F), *NLR* (NL), *EVEKTOR* (CZ), *Flughafen Braunschweig Wolfsburg GmbH* (D), *Cranfield University* (GB), *MPEI-Technical University* (RUS). *AIM* is coordinated by the *DLR* in Göttingen, where Mr. Fritz Boden functions as the coordinator of this 3.6 million € *STReP*.

The project is split into 7 work packages (WP) and further subdivided into several tasks:

- WP0 – management tasks
- WP1 – wing deformation
- WP2 – propeller deformation
- WP3 – helicopter studies
- WP4 – surface pressure
- WP5 – high lift flow structures
- WP6 – industrial flight testing

In WP0 the functionality of the website has been improved over the last year. Now documents and contacts are grouped in the WP - structure and the responsibilities of the partners (management board, administrative board and technical board) are identified. Deliverables are highlighted and marked with their D-number.

Exhibit of *IPCT*-deformation measurement on the helicopter presented at the

New document structure on the *AIM* website

The first two *AIM* Newsletters have been released and can be downloaded from the *AIM*-website. The Review Meeting has been postponed to the 2nd year meeting and thus the Midterm Meeting (held on 26th and 27th of May in Berlin) was a general progress meeting. It took place at the same time as the *ILA* 2008 (*Berlin Air Show*). During the *ILA* a model helicopter with a demonstration of the *Image Pattern Correlation Technique (IPCT)* deformation measurement system as well as the *AIM* project were presented at the *DLR* booth.

During the last year several in-flight measurement campaigns have been carried out to prove the feasibility of the different non-intrusive measurement techniques and demonstrate their application to industrial flight tests. Ground based measurements of the blade tip vortices of the *Bo 105* helicopter have been performed using *Particle Image Velocimetry (PIV)* and the *Light Detection and Ranging Method (LiDaR)*. Furthermore, pre-tests for the validation of *IPCT* and strain gauges on a whirl tower on an *EC-135* main rotor blade took place. The *Infrared Technique* has been tested on a flying *Super Puma* helicopter. Flight tests using *IPCT* for wing and propeller deformation have been carried out on the *Piaggio P180*. Last but not least, *Pressure Sensitive Paint (PSP)* could be successfully implemented in flight trials with the *VfW614 ATTAS*.

During the upcoming final year of *AIM* flight tests with *IPCT* on the *EC-135* helicopter and the *Airbus A380* are planned. In addition the applicability of *PIV* will be tested on a *Dornier Do228* in flight and as a ground based setup for wake vortices of the *VfW614 ATTAS*.

An Assessment Meeting and the midterm review, both held in November 2008 at the *Airbus* site in Toulouse (France) showed the high interest of industry in advanced optical in-flight measurement techniques and also verified the ready acceptance of the project by the *EC*. Given this recognition one can say that *AIM* is on the right path.

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The AIM Partnership Between *Cranfield University* and *DLR* Göttingen

Cranfield University and DLR are both involved in the workpackage 5.3, to develop in-flight Particle Image Velocimetry and test its feasibility. The partnership realised a collaboration in which I was involved in a three month stay (from August-October 2008), in DLR to develop a mock-up and cooperate in the certification of the in-flight test.

Hello everybody,

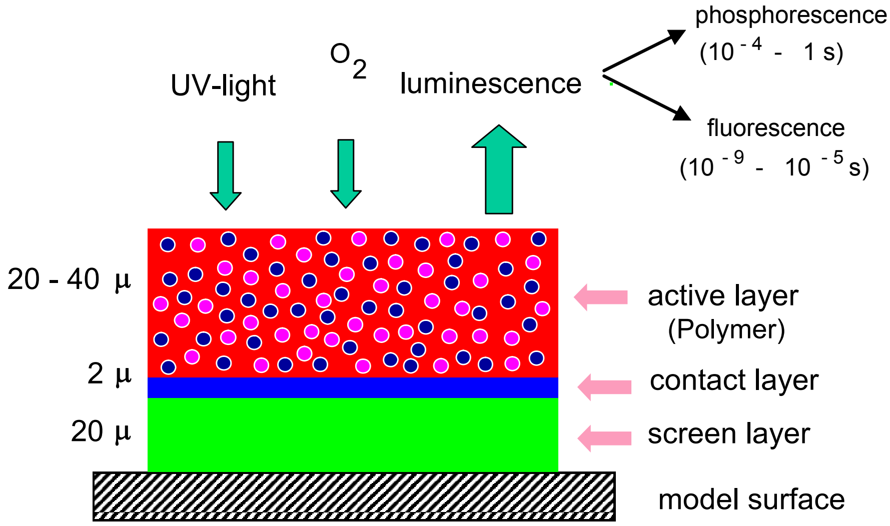
During my stay in the German aerospace centre *DLR*, in Göttingen I was involved in the realization of a *PIV* stereoscopic set-up. We wanted to perform a *PIV* test inside an aircraft cabin; the aircraft was supplied by *Braunschweig Flughafen* and it is a *Dornier* propelled-engine aircraft. The test was successful and required lots of work regarding the certification to produce modification in the aircrafts cabin, the transport of the apparatus between Göttingen and Braunschweig and even much attention has required the design of the set-up aimed to produce an adaptation of a classic stereoscopic *PIV* set-up to a slightly different environment. My two months stay in Göttingen was peaceful and relaxing due to the city of Göttingen to be cute, and a nice place to enjoy life and nature. I had a chance to go shopping, go to cinema and eat in some good characteristic places in the city. I like describing the city of Göttingen like “a place for families”, in fact there is plenty of children around in every area of the city.Relationships with colleagues have been friendly and with a feeling of cooperation. Finally, I also had a chance to travel the surroundings and visit places like Hanover, Kassel and Frankfurt. By now, the work has been finished and I am ready to go back to England where I will keep working on my PhD thesis on Optics. Nevertheless, time studying a doctoral engineering becomes pleasant if integrated with collaboration with research centres like *DLR* and periodical European travels through *AIM* (*Advanced In-flight Measurement Techniques, European* project). While doing this experience I have been working with Fritz Boden, Janos Agocs and Christina Politz and at the same time commuting twice a week to Braunschweig airport to discuss test flight issues and arrange the right permission to perform our experimental test.

Many thanks to *DLR* people who interacted with me and to my supervisor Nicholas Lawson from *Cranfield University*.

Best wishes,

Domenico Casella
University of Cranfield School of Engineering

The Application of Pressure Sensitive Paint



Principle structure of the paint sensor

The measurement of the pressure distribution on parts of the wing during flight is a very ambitious and challenging aim. Some endeavours were carried out in the past by using conventional pressure taps. But these installations have a too strong impact on both the flow and on the structural integrity of the aircraft. In addition the amount of sensors is often limited by the maximum number of pressure taps which can be installed on the wing. Furthermore the discrete location of the pressure taps cannot be changed after implementation. Major problems in interpretation occur if the expected aerodynamic phenomenon to be investigated does not appear at the chosen tap location on the surface of interest. However the *PSP* method enables the measurement of planar pressure distributions over the entire visible surface of the aircraft. It provides maximum flexibility for any given measurement situation.

In order to utilize *PSP*, the investigated area must be coated with a *Pressure-Sensitive Paint*. In such paints a photochemical process takes place where a luminescent coating absorbs energy of the incident light (UV or visible light) and emits light at longer wavelengths. When this luminescence is quenched by the oxygen present in air, an increase of the local pressure (associated with an increase of local oxygen concentration) leads to a decrease of the intensity of the coating’s luminescence. The relationship between this intensity and the pressure is given by the *Stern-Volmer Law*, and this constitutes the fundamental of the *PSP* technique. In short: the intensity of the luminescence of this paint under special illumination is a measure of the local pressure.

PSP is widely used nowadays to measure pressure distributions on a model in a wind tunnel and has been checked for its feasibility to flight tests within *AIM* for the first time.

However, applying *PSP* to flight conditions leads to problems such as suitable illumination,

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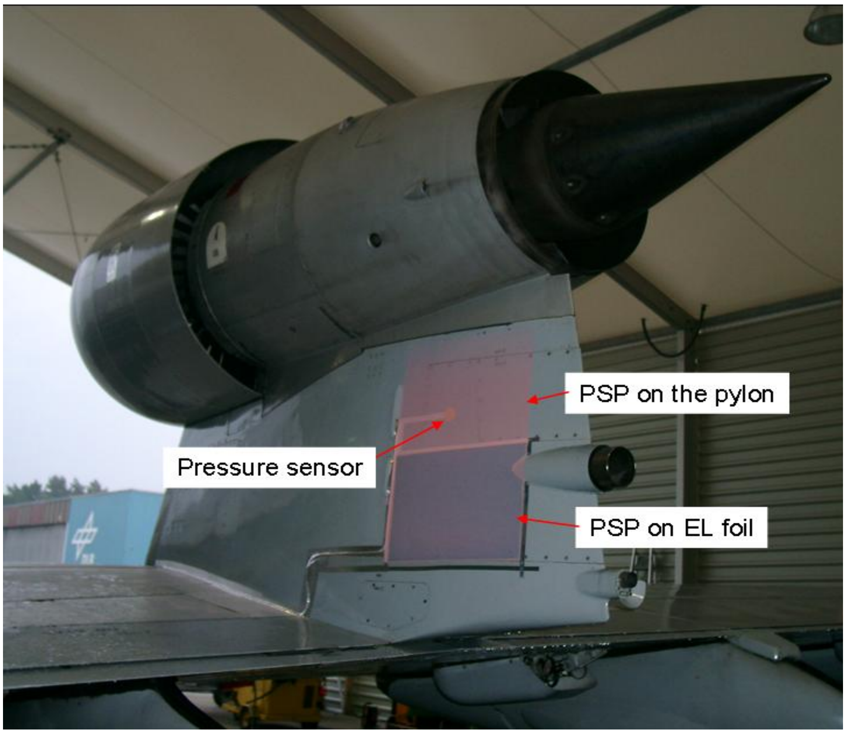


PSP and EL-foil on the pylon

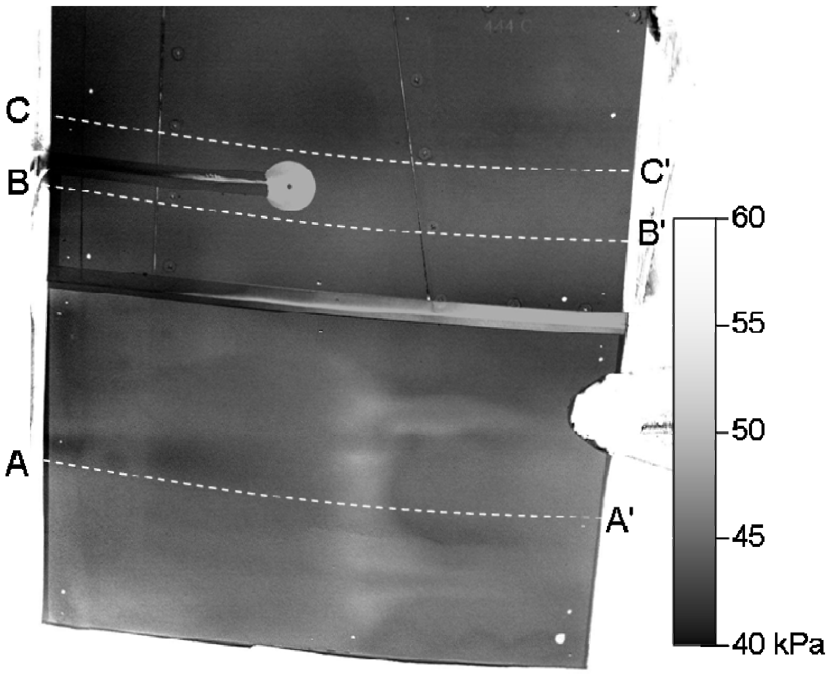
influence of atmosphere during the flight as well as icing and temperature correction that need to be tackled. The biggest problem is the large distance between the detecting CCD-camera and the region of interest (ROI) on a wing where the *PSP* has been coated. This large distance can lead to signals which are too weak for a quantitative *PSP* measurement.

The *PSP* in-flight measurement within the *AIM* project was performed in October 2008 using the *ATTAS* aircraft of the *DLR* in Braunschweig/Germany. The figure below shows the experimental setup of the *PSP*- and *IRT*-systems used in this test. *PSP*, which was attached to the right engine pylon, was illuminated by a LED-array from an observation window or alternatively with an Electro-Luminescence (EL) foil placed underneath the *PSP* layer. The distance between the cameras and the coated surface was about 2 m. The emitted light from the *PSP* was observed by a CCD camera which was installed at the observation window. The temperature distribution on the *PSP* layer was captured by an IR camera to correct for the influence of changing temperature on the *PSP* results. An additional pressure sensor was implemented within the region of interest for the purpose of comparison with the *PSP* results.

A preliminary result obtained using the LED-array as a light source is shown in the figure below. The flight test parameters were Ma=0.56, altitude of 21000 ft and static air temperature of -24°C. The temperature correction of the *PSP* result was made using just one central value of the temperature for each reference and run image.

The pressure distribution on the pylon is shown in the figure below. The final data evaluation of the pressure distribution on the pylon was based on three different cross-sections (A-A', B-B' and C-C') which are compared with the data of the pressure sensor in the figure below.

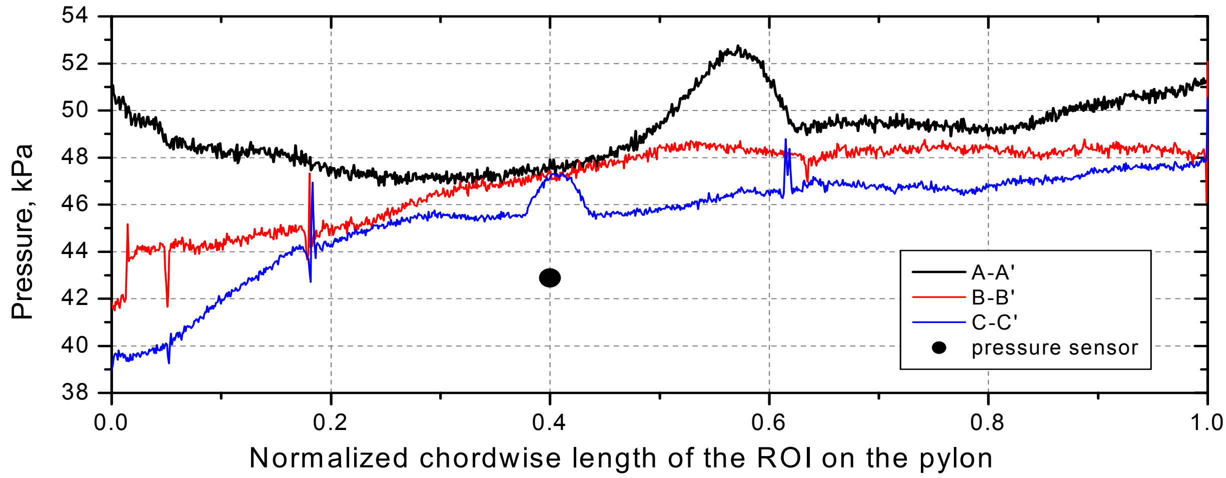
The diagram indicates a high pressure region at 55% of section A-A'. This data peak correlates with the white region on the right figure above. The pressure sensor has an offset of 5 kPa in comparison with the sections B-B' and C-C', between which the sensor is located. This error can most likely be attributed to the very low temperature on the pylon, by the temperature dependency of the



Pressure distribution at Ma=0.56

PSP and by the adoption of just one temperature over the whole probed area for the applied correction. More accurate values are to be expected by using a full-field precise temperature correction from the IR data.

This result from the first flight test proved the feasibility of *PSP* even under flight-test conditions. Thus the *PSP* technique can become an excellent tool for the investigation of aerodynamic phenomena on complex 3D models. The influence of vortex interactions of the pressure map on the surface of the model can be clearly analyzed using *PSP*. In addition the pressure data can be obtained in near real time.



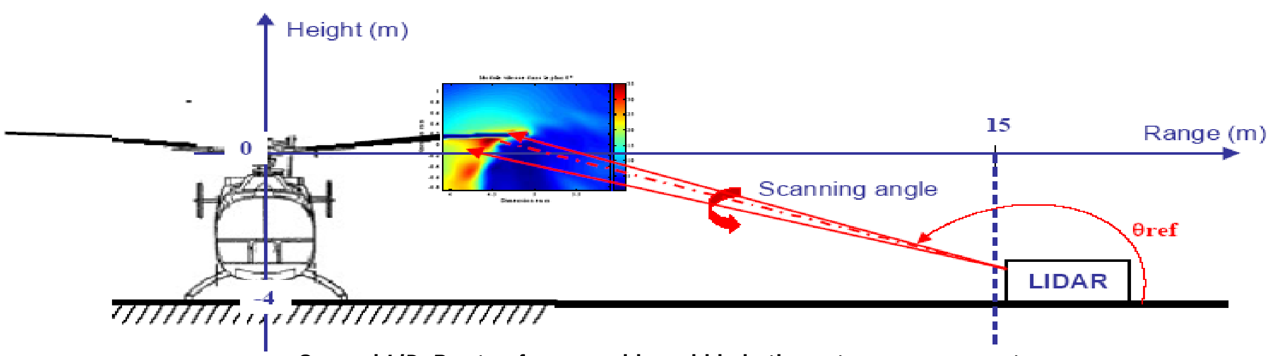
PSP **data obtained at different cross section during in-flight tests**

Light Detection and Ranging Method (LiDaR)

On the basis of recent developments, fibre *LiDaR* technology has become a good 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 on-board research and industrial tests.

In general, *LiDaR* is an optical remote measurement technique that determines the precise properties of scattered light to obtain important information of a distant target. This procedure is based on a Doppler shift measurement of a light wave obtained from a single frequency laser that is reflected from naturally occurring atmospheric aerosols (*Mie* scattering). The frequency shift of the reflected wave is proportional to the air velocity component in the viewing direction and is detected via an interferometer which measures the beat frequency resulting from the interference between the back-scattered wave from the aerosols and a reference wave (local oscillator). If required, the true air speed in three dimensions could be derived from multi-axis sensing either with the help of at least 3 beams or with a scanning device. *LiDaR* is able to determine the velocity without the need for in-flight calibration and with no distortion.

In 2007, the work of the *ONERA* led to the specification of the



General *LiDaR* setup for ground based blade tip vortex measurement

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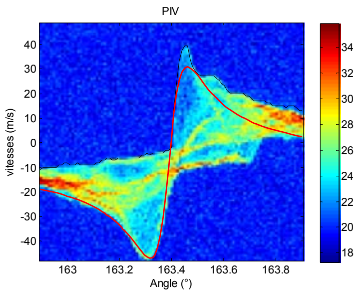


Comparing *LiDaR* and *PIV* data of a blade tip vortex

1.5 µm *LiDaR* sensor and was aimed at a simulation of the 1.5 µm *LiDaR* performance. The year 2008 was devoted to the 1.5 µm *LiDaR* sensor implementation and to measurement tests with their evaluation on a *DLR* helicopter in hover flight. Outdoor ground-based *LiDaR* measurements have been performed on *DLR's Bo 105* helicopter in hover flight above ground.

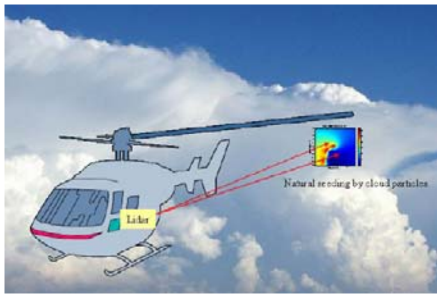
LiDaR tests require tracer particles to increase measurement sensitivity and therefore to improve the quality of the wind field imaging. During the *LiDaR* tests, a seeding device with smoke particles was used. It was shown that the seeding of these particles was very difficult, so that a high and uniform seeding density in the region of interest could not be obtained. This system was less efficient than the initially planned oil seeding, which uses an air compressor to inject the tracer particles into the vortex flow. A changed collective pitch and rotor thrust setting during the experiment caused strong distortions of the seeding distribution within the observation zone. This is the reason why the *LiDaR* measurements were performed most of the time with the helicopter running without rotor thrust.

However, these tests provided interesting results. *LiDaR* experiments were carried out for two days with 6 hours of helicopter time. Measurements were made at different vortex ages corresponding to the observation planes of 10°, 40° and 70° behind the trailing edge of the blade. The experiments were carried out with a velocity accuracy of 1 m/s and a velocity dynamic of ± 40 m/s.

The obtained results indicated a maximum vortex speed of 15 m/s and -25 m/s with an angular distance between these two speeds of about 0.25°. A wind field or vortex close to the blade tip vortex was also captured and measured by the *LiDaR* sensor.

To compare *LiDaR* results with given *PIV* data, several simulations of *LiDaR* experiments have been carried out on the bases of vortex velocity data measured during *PIV* tests. The velocity field provided by *DLR* had been determined on a *Bo 105* for 2T thrust at a vortex observation plane of 3° behind the blade and for 1° of field of view. The figure above shows a vortex field of small dimension with an angular spreading of 1° and a maximum speed of -45 m/s. The angular size of the vortex core is about 0.15° (distance between 2 speed maxima). PIV measurements are fitted by the vortex model (red curve). We also observe that the blade vortex is disturbed by another wind field.

During the *LiDaR* tests some recordings led to incomplete *LiDaR* images due to the fact that the image did not show the whole vortex. An applied fit with a *PIV* based vortex model using the slope of velocity given by *LiDaR* is able to provide the missing information.



Vortex detection with an airborne LiDaR system

To conclude, despite the imperfect seeding, experimental results of the *LiDaR* tests prove the capability of the *LiDaR* technique to detect helicopter blade tip vortices. Blade tip vortex velocities of a hovering helicopter were measured by a 1.5 µm *LiDaR* sensor with very good speed accuracy (1 m/s) and characterized in terms of circulation using the *Hallock-Burnham* vortex model.

Flight measurements in clouds could be a very good solution for efficient and powerful *LiDaR* vortex detection (figure below). At altitudes lower than 5 km, cloud types are mostly stratus or cumuli which are made of water droplets with an average size of 8 µm. The atmospheric absorption is very high but not disadvantageous for laser performance because propagation ranges are very small. On the other hand, backscattered coefficient of water droplets is very high. Therefore, these clouds could provide homogeneous, efficient and uniform seeding to improve *LiDaR* measurement sensitivity.

Advanced Application of Infrared Technology to Helicopter Flight Tests

The *Infrared Thermography Technique* is based on the measurement of the infrared radiation from surfaces and enables 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

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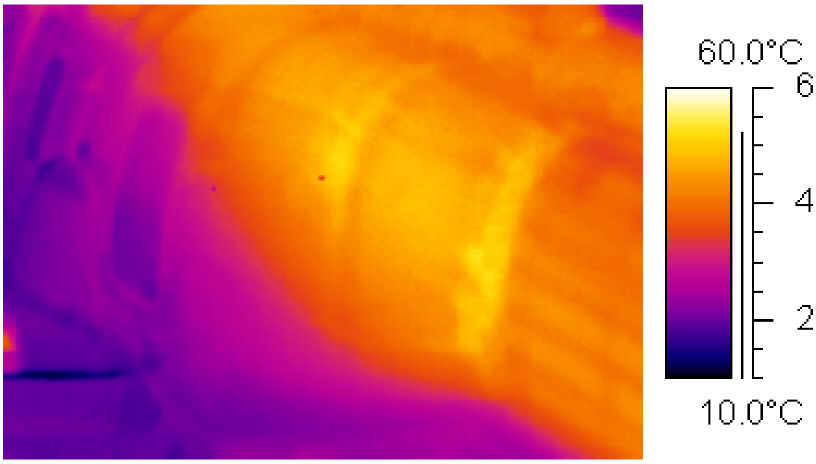

Temperature mapping derived from the object infrared image

including the engine exhaust gas flow.

The electromagnetic spectrum can be divided into different wavelength bands. The infrared band covers wavelengths ranging between visible light (at 0.7 µm) and the microwave limit (1000 µm). An IR camera can in particular measure and image the emitted infrared radiation coming from a hot object. The fact that the spectral distribution of this radiation depends on the object surface temperature makes it possible for the camera to measure its surface temperature. These spectral distributions are defined by *Planck's Law* and *Wien's Displacement Law* (decreasing of the main wavelength as the temperature increases). It is further known that the total power emitted in a given IR wavelength band is proportional to the 4th power of the absolute temperature of the object (*Stefan-Boltzmann's Law*). It is this correlation which is used in the IR measurement technique to derive object temperature.

It is important to note that while thermal imaging displays the amount of infrared energy emitted by an object, it is quite difficult to get an accurate temperature reading of a specific object using this method. The energy displayed in a thermal image represents three types of energy: emitted energy, atmosphere energy and reflected energy. The energy received is the sum of all these three radiation energy sources.

By finally knowing the temperature distribution on a surface, different conclusions can be derived. Very often the temperature itself is the desired value. This is the case e.g. for measurements concerning the temperature of the airframe. *EC-F* already carries out such measurements, especially around the exhaust of turbines where the temperature is of high interest in assessing the stresses on the airframe. Since *IRT* has already been successfully used for investigations on fixed wing aircraft (as was done by *DLR* in Braunschweig), the application in this case is of low risk. However, there is still a major difference between the known applications and the helicopter experiments because the direct view of the investigated surface is limited. Strong density gradients due to the passing blade tip vortices and the exhaust plume in front of the surface will have an impact on the spatial accuracy of the measurement. This problem must somehow be solved or its influence estimated.

To integrate such a system into the flight test environment, the whole assembly should be able to withstand strong vibrations of a high frequency range, high temperatures and a polluted gas flow. Therefore the best compromise between a camera placed on ground or one installed on the helicopter has to be investigated, as also does the use of removable controlled emissive paints. In addition, to prove the feasibility of this measurement technique, this method will have to be capable of determining the structural temperature with an absolute accuracy of about +/- 5°C and it should be easy to implement in a flight environment.

To measure surface temperatures, the infrared technique offers some clear advantages compared with traditional techniques (2D + non intrusive methods). No major problems are expected for the application of standard *IRT* for flight testing. The present *Infrared Technique* seems to be fully applicable to helicopter industrial flight tests. Nevertheless, demonstrations have to be performed in order to evaluate the severe flight environment (emissivity, reflection and transmission). The flight test proposed within the *AIM* framework concerns the measurement of the surface temperature of a helicopter structure heated by the engine exhaust gas flow.

However, in order to apply *IRT* simultaneously with e.g *Pressure Sensitive Paint*, the accuracy must be improved; problems such as moving reflections during flight tests (e.g. clouds, different thermal structures of landscape) must be overcome. This requires sophisticated procedures and algorithms for calibration, de-warping and the matching of images.