Grant Agreement n° 233801

DELICAT

Demonstration of LIdar based Clear Air Turbulence detection

Theme 7 (Transport including Aeronautics) – Level 1 project

Final Publishable Report

Extract from deliverable D6300

Start date of project: **April 1st, 2009** Duration: **60 months**

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Written by	Organisation	Date	Signature
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TABLE OF CONTENT

TABLE OF FIGURES

1. EXECUTIVE SUMMARY

Atmospheric turbulence encounters are the leading cause of injuries to passengers and flight crews in non-fatal airline accidents. A whole class of turbulence, representing 40% of turbulence accidents, and designated as Clear Air Turbulence, cannot be detected by any existing airborne equipment, including state-of-the-art weather radar; this explains why the number of turbulence accidents has been growing by a factor of 5 since 1980, 3 times faster than the increase of the air traffic.

Figure 1 Aircraft damaged during a Clear Air Turbulence encounter

Operational concepts for the protection against turbulence hazards include:

- o Short-range (50 m to 300 m) measurement of air speed ahead of the aircraft, and action on the aircraft flight controls to mitigate the effect of turbulence,
- o Medium-range (10 km to 30 km) detection of turbulence and securing of passengers and crewmembers by seat belts fasten.

Both concepts are based on the UV LIDAR technology. The short-range concept was validated in the frame of the FP5 AWIATOR project. The objective of DELICAT is to validate the concept of LIDAR based medium range turbulence detection.

At the end of the project, we can state that the objectives of DELICAT have been globally achieved.

A LIDAR system has been designed, manufactured and tested, with performances compliant with the design objectives. The LIDAR system was successfully integrated on-board the test aircraft and the flight test campaign took place. During the flight tests, all systems worked and performed properly. However, no moderate turbulence event was encountered, despite the intensive meteorological support provided by ICM and Meteo France

The flight test data analysis shows that in the favourable case, it should be possible to detect CAT with moderate severity at medium range, objective of the DELICAT project. However, it is difficult to draw definitive conclusion, because only light turbulence was encountered during the flight tests, and because the absence of Mie / Rayleigh filter, which Hovemere failed to provide, prevented the suppression of aerosol perturbation.

Regarding meteorological activities, ICM and Meteo France developed new methods of CAT prediction, which showed good potential but need more data for tuning and performances verification.

Finally, the integration of short-range and medium-range functions has been assessed.

2. DESCRIPTION OF PROJECT CONTEXT AND OBJECTIVES

Atmospheric turbulence encounters are the leading cause of injuries to passengers and flight crews in non-fatal airline accidents. A whole class of turbulence, representing 40% of turbulence accidents, and designated as Clear Air Turbulence, cannot be detected by any existing airborne equipment, including state-of-the-art weather radar; this fact explains that the number of turbulence accidents has been growing by a factor of 5 since 1980, 3 times faster than the increase of the air traffic.

Operational concepts for the protection against turbulence hazards include:

- Short-range (50 m to 300 m) measurement of air speed ahead of the aircraft, and action on the aircraft flight controls to mitigate the effect of turbulence,

- Medium-range (10 km to 30 km) detection of turbulence and securing of passengers and crewmembers by seat belts fastening.

Both concepts are based on the UV LIDAR technology. The short-range concept was validated in the frame of the FP5 AWIATOR project.

The objective of DELICAT is to validate the concept of LIDAR based medium range turbulence detection.

This validation of medium range turbulence detection is based on the comparison of the information on a turbulent atmospheric area, provided on one side by the remote UV LIDAR and on the other side by the aircraft sensors (acceleration, air speed, temperature). This validation includes the following steps:

- A UV LIDAR system is designed and manufactured, tested in laboratory on the ground, and then installed on-board a research aircraft. This LIDAR system includes the following sub systems

    - LIDAR Transmitter

    - LIDAR Receiver

    - Beam Steering system

- During the flight tests, the atmosphere is analysed by the UV LIDAR and also by the aircraft on-board sensors, which is intended to fly in turbulent and non-turbulent conditions

- The data obtained from the LIDAR and from the aircraft sensors are compared off line once the aircraft on the ground. The correspondence between LIDAR backscattered energy fluctuations and turbulence experienced by the aircraft, for a given atmosphere area, is assessed and evaluated.

In parallel to the LIDAR based activities, the meteorological partners of the DELICAT consortium have specific activities with the objective to improve the understanding of Clear Air Turbulence atmospheric phenomenon and to improve the CAT forecasting capabilities.

Finally, The DELICAT project also includes the analysis of the integration of short-range and medium-range functions.

The DELICAT project Work Breakdown Structure (WBS), corresponding to the objectives of the DELICAT project, is presented next page.

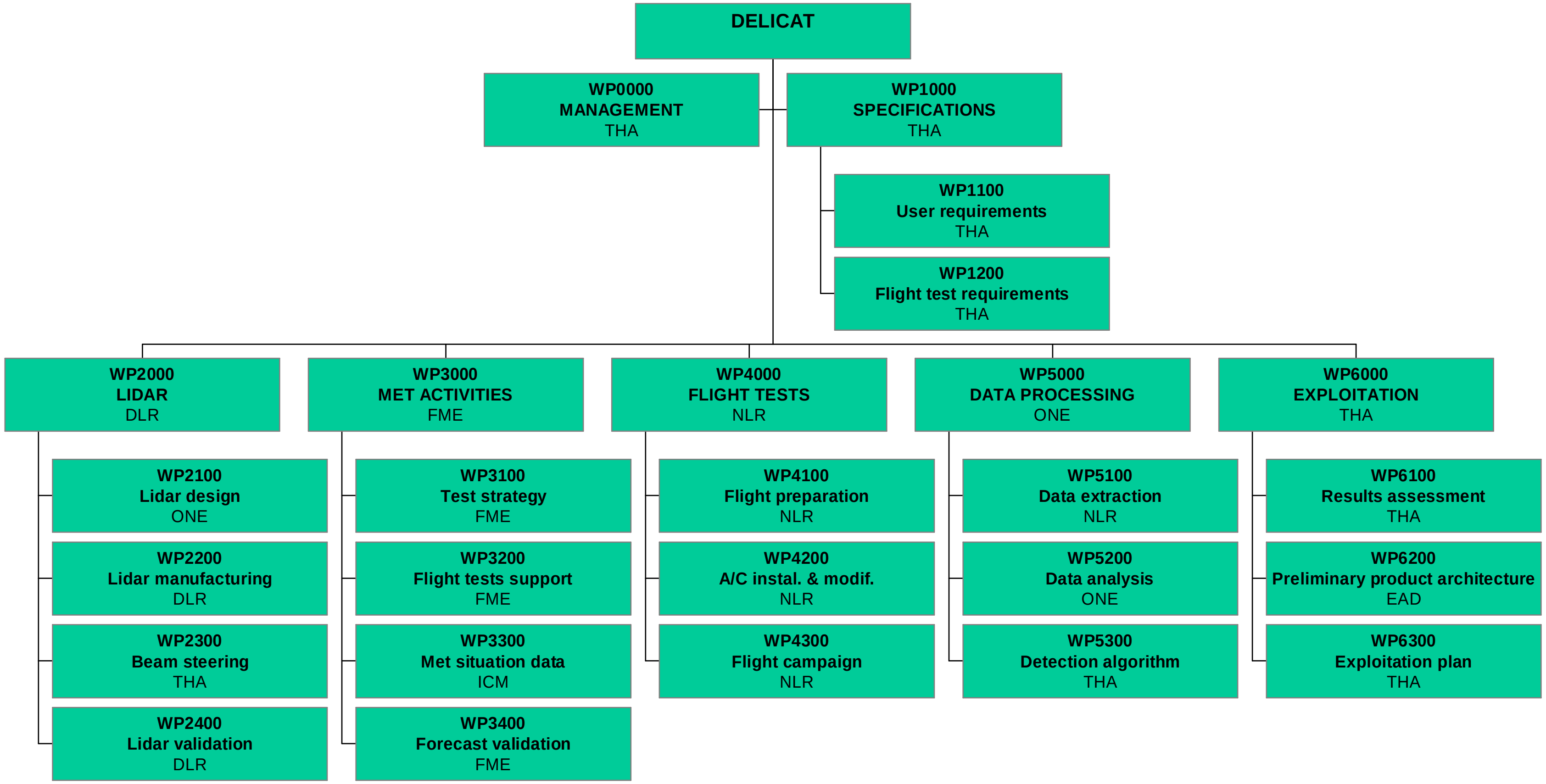


Figure 2 DELICAT Work Breakdown Structure

3. MAIN RESULTS AND FOREGROUNDS

This section presents the main results and foreground of the DELICAT project.

This presentation is organised according to the 1st level Work Packages (WP) of the project.

3.1. MAIN RESULTS AND FOREGROUND FOR WP1000: SPECIFICATIONS

In WP1100, a description of the turbulence hazard has been done, regarding the following aspects:

Impact of turbulence on aviation transport industry

Atmospheric turbulence encounters are the leading cause of injuries to passengers and flight crews in non-fatal airline accidents. A whole class of turbulence, representing 40% of turbulence accidents, and designated as Clear Air Turbulence, cannot be detected by any existing airborne equipment, including state-of-the-art weather radar.

The number of turbulence accidents has been growing by a factor of 5 since 1980, 3 times faster than the increase of the air traffic.

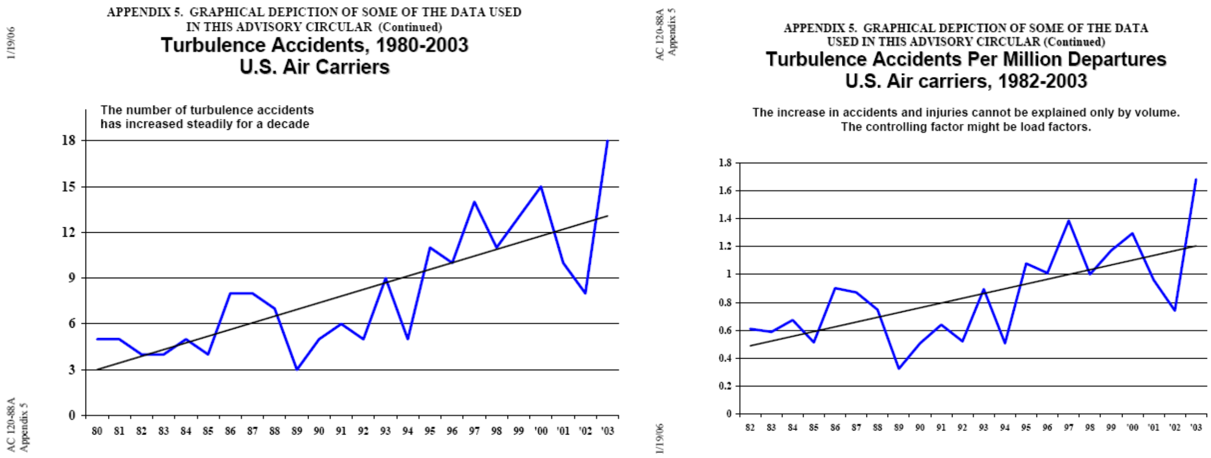
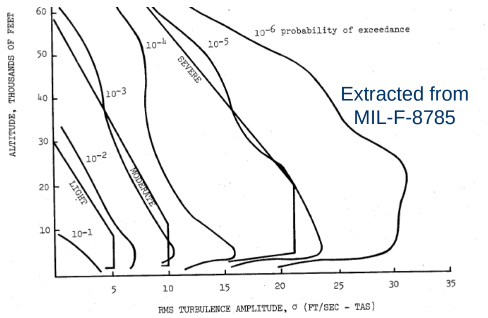


Figure 3 Number of turbulence accidents, 1980 to 2003 – US Air Carriers

Turbulence severity classification

Turbulence is classified as null, light, moderate and severe. There are several turbulence classification criteria, some being aircraft dependant and some being independent from the considered aircraft. The chart hereunder presents the different parameters used for turbulence classification.

PARAMETER	REFERENCE	NULL OR LIGHT	MODERATE	SEVERE
Qualitative	FAA AC120-88A	Slight, erratic changes in altitude and/or attitude	Changes in altitude and/or attitude occur but the aircraft remains in positive control at all times	Large, abrupt change in altitude and/or attitude. Aircraft may be momentarily out of control
Altitude / TAS RMS intensity	MIL-F-8785C			
Peak acceleration	AMDAR	< 0.5 g	Between 0.5 g and 1 g	> 1 g
DEVG	AMDAR	< 4.5 m.s^{-1}	Between 4.5 m.s^{-1} and 9 m.s^{-1} (HIGH)	> 9 m.s^{-1} (INTENSE)
EDR	ICAO	< 0.3 m$^{2/3}$.s^{-1}	Between 0.3 m$^{2/3}$.s^{-1} and 0.5 m$^{2/3}$.s^{-1}	> 0.5 m$^{2/3}$.s^{-1}

Clear Air Turbulence protection needs

Clear Air Turbulence protection needs have been investigated. 3 different protection scenarios have been identified according to the range of action of the detection, and the corresponding requirements have been defined.

RANGE	CONCEPT	REQUIRED DATA	DISTANCE TIME	CRITICAL FUNCTION
Long Range	Avoidance of turbulence encounter	- Severity, position and dimension of turbulent area - Short term evolution of turbulent area and severity	> 2 minutes > 30 km	NO
Medium Range	Protection of passengers and crew by seat belts fasten	Turbulence detection (for a severity threshold) and time to encounter	30 s to 2 minutes 8 km to 30 km	NO
Short Range	Protection of aircraft and passengers by mitigation of the turbulence effect by Flight Controls	3 axis air speed ahead of the aircraft	0.2 s to 1 s 50 m to 300 m	YES

The capabilities of the LIDAR technology with respect to those different scenarios have been analysed:

- The long range protection is not achievable for the LIDAR given the current LIDAR technology status

- The medium range protection is based on the air density and temperature fluctuations associated with the vertical wind speed responsible of aircraft movements while in turbulence. These density fluctuations will modulate the back-scattered light energy, allowing medium range detection of the CAT event. The objective of DELICAT is to validate this detection capability.

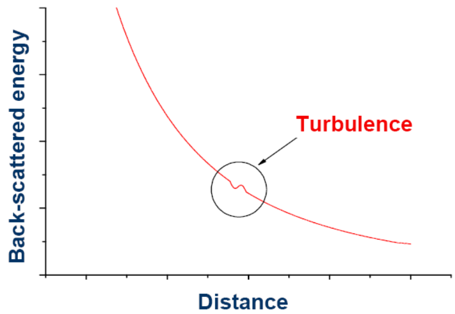


Figure 4 Medium-range LIDAR operation

- The short-range protection is based on the measurement of the 3-axis air speed field, at a short distance ahead of the aircraft, and the automatic action on the flight controls. This measurement has been validated through flight tests in the FP5 AWIATOR project

In WP1200, the first task was to analyse the atmospheric phenomenon associated with turbulence.

Atmospheric phenomenon	Preferred location and season	Position / ground and air mass	Forecasting capability	Typical time of evolution	Comment
Wind shear (jet stream)	Europe in winter	- Evolves with background wind - Strong variations in wind direction and speed around the turbulent area	Good capability to forecast jet position and strength	1 day	Good candidate for a winter campaign: - Quite frequent - Forecasting capability is good - Quite stable in time
Mountain waves	Near mountains (Pyrenees?)	Fixed position with respect to the ground for stationary conditions	Difficult to forecast (for cruise altitude turbulence)	Few hours	Not so good candidate: - Difficult to predict - Requires very specific atmospheric conditions (may be rare)
Clear air above or around Cb clouds	Europe in summer	Evolves with rapidly changing local wind	Good capability to forecast thunderstorms	Less than 1 hour	Good candidate for a summer campaign **HOWEVER NOT ACCEPTABLE FROM FLIGHT SAFETY POINT OF VIEW**

Overall experimental system requirements

- The trajectory and Beam Steering have to ensure that the aircraft will meet the air mass analysed by the LIDAR
  - The aircraft will have a straight trajectory at constant altitude
  - The LIDAR beam shall be parallel to the flight path (objective: accuracy 0.1°, bandwidth 1 Hz)
- The aircraft pitch and side slip angle should stay within the limits defined by the fairing window
- Aircraft and LIDAR systems should be synchronised with each other to allow off-line processing with a common time base
- The aircraft has to be equipped with the nose boom (for Side Slip Angle measurement) and the fairing – Those devices have to be certified

3.2. MAIN RESULTS AND FOREGROUND FOR WP2000: LIDAR

WP2100: Lidar design

Overall LIDAR system structure

The first task of WP2100 was to define the overall LIDAR system structure, and corresponding responsibilities of each partner in the design and manufacturing of the LIDAR subsystems. This task resulted in the overall synopsis presented hereunder.

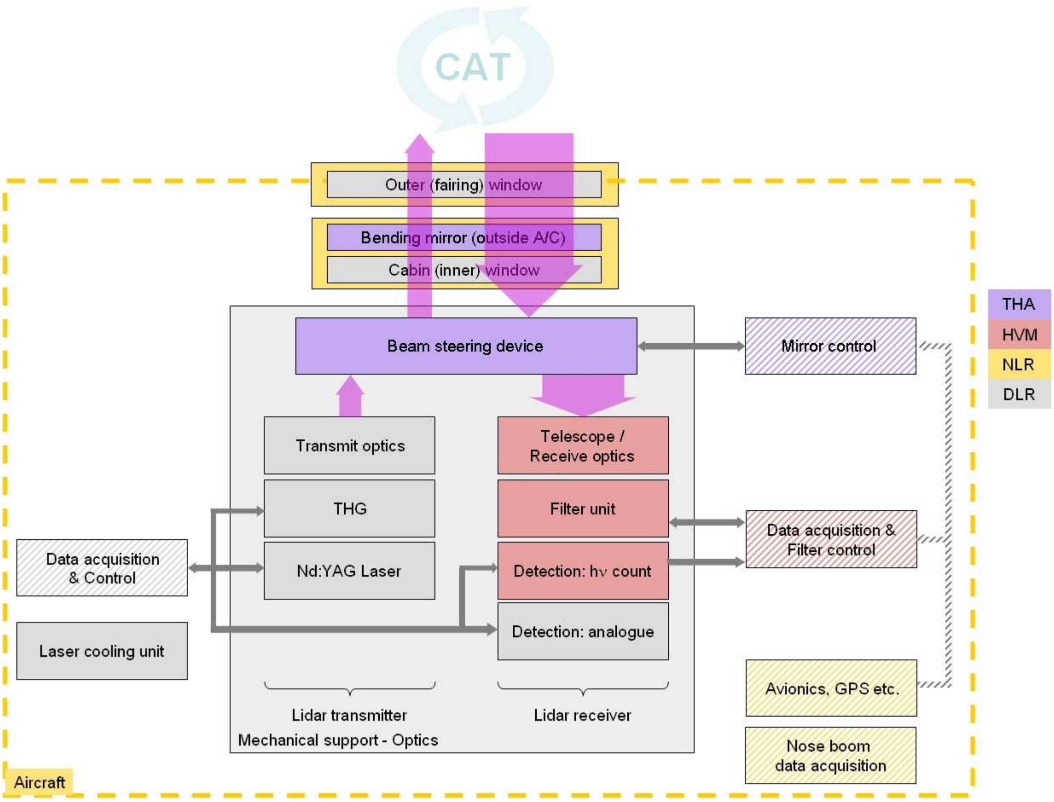


Figure 5 Partners share in LIDAR sub-assemblies

The DELICAT LIDAR system consists basically of three main components: the Transmitter (i.e. laser and transmission optics) and the Receiver unit (receive optics, filtering unit and detection devices) form the main LIDAR system. A third component is represented by the Beam Steering device that tracks the aircraft movements in order to continuously point in the defined flight direction.

These three components also reflect, in that order, the respective responsibilities of DLR, Hovemere and Thales Avionics (except for some details as the analogue detector).

Additional equipment is supplied by NLR for providing the needed aircraft attitude data (beam steering), flight speed (filter control) and other measurements (in situ reference).

Simulation of the performances of the DELICAT experiment

A simulator of the whole LIDAR experiment was developed (3D map realizations of atmospheric parameters, generation of aircraft trajectory, generation of LIDAR signal including the filter transmission and the detection noise). A preliminary signal processing is also included. The following figure presents the global organisation of the simulator.

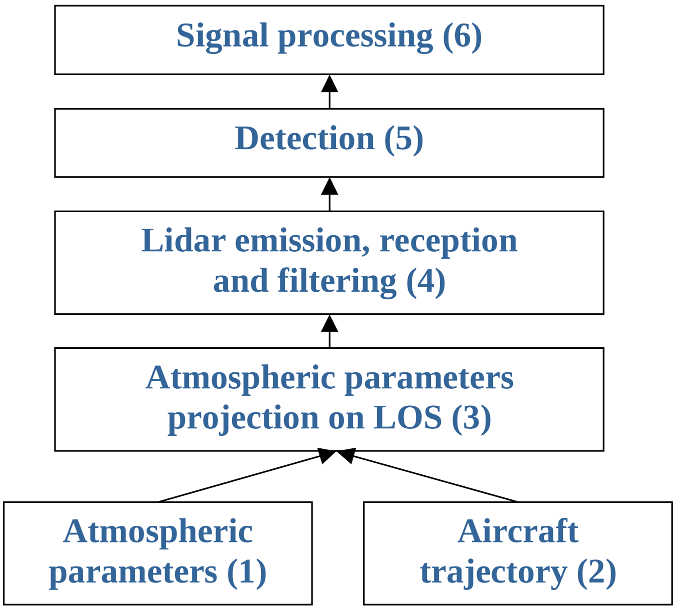


Figure 6 Simulator organisation

This LIDAR simulator was used to predict the performances of the system, based on the expected and achievable sub-assemblies characteristics.

The simulations results show that the technical objective for the LIDAR is very challenging and will require extensive work on the signal processing algorithms to extract CAT signal from noise. Most of the performance limitation comes from aerosol noise and aircraft attitude noise. The sun noise contribution is not a major limitation source.

Those conclusions of the simulation work resulted in quite tough requirements for the overall LIDAR and sub-assemblies requirements: the objective can only be met with very carefully designed and optimised LIDAR sub-assemblies, with great care taken to the interaction between the different sub-systems.

The results found with this simulator were compared with the ones obtained during the FLYSAFE project. Both simulators gave compatible results, given that the DELICAT simulator takes into account more parameters (for example the movements of the aircraft and the performances of the beam steering system, not considered in FLYSAFE approach).

Design of the Transmitter unit

The employed laser transmitter system is based on a diode-pumped Nd:YAG laser that has been developed at DLR for a water-vapour differential absorption LIDAR (DIAL) system, called WALES. The laser system so far available provides IR or green short laser pulses, along with the respective electronic trigger signals. For the DELICAT experiment, the additional functions are the third-harmonic generation stage, detection system for laser pulse energy monitoring and the transmission optics.

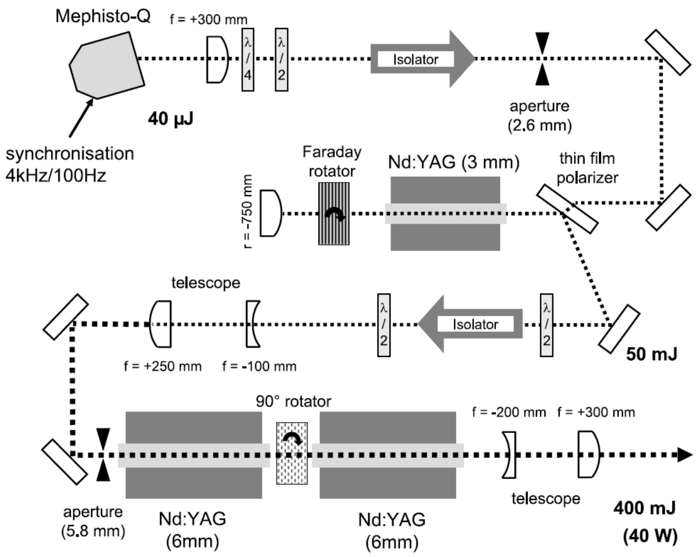


Figure 7 Schematic layout of the Nd:YAG laser (before tripling stage)

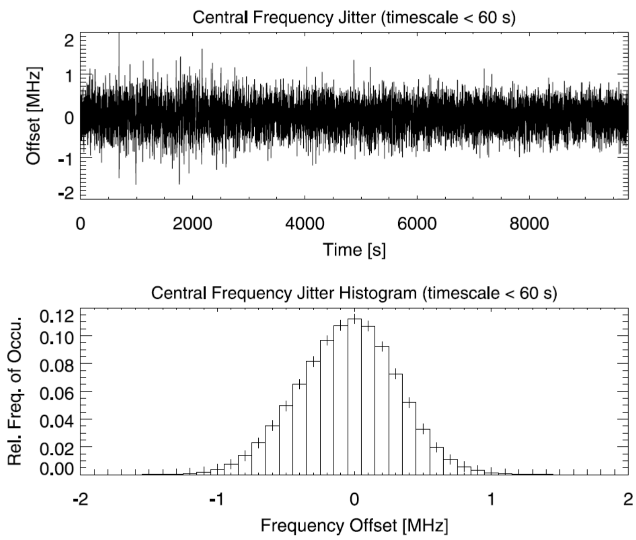


Figure 8 Time series and histogram of the pulse-to-pulse frequency jitter of the Nd:YAG master

The absolute stability is estimated to be better than 1 MHz, and the short-term (< 60 s) pulse-to-pulse frequency jitter was measured to be better than 300 kHz RMS using a heterodyne technique.

The whole pump laser including the optics and all electronic subsystems like power supply and diode drivers is integrated into a single housing with 701 mm × 412 mm × 257 mm dimensions.

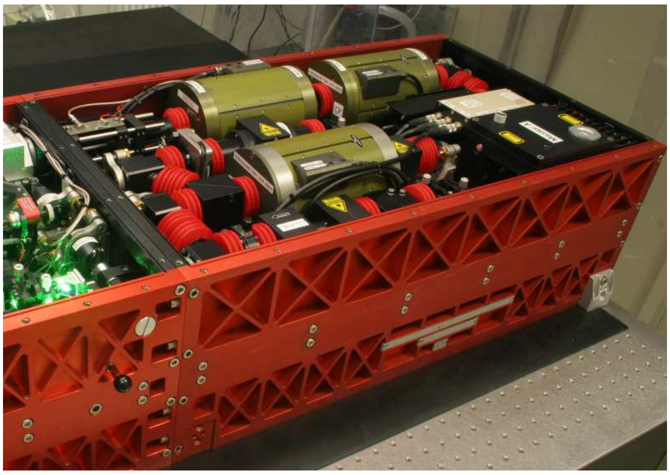


Figure 9 Mechanical housing of the Nd:YAG laser

The housing is divided into two compartments: The upper contains the laser optics, whereas on the lower side, all respective control and power supply electronics are located. In between, there is an intermediate level containing water cooling tubes.

Receiver system

The receiver system of the DELICAT LIDAR consists of three main subsystems, the receiver optics, the filter unit and the detection unit. The latter two systems also dispose of some control and data acquisition system.

The following schematic present the main elements of the receiver system:

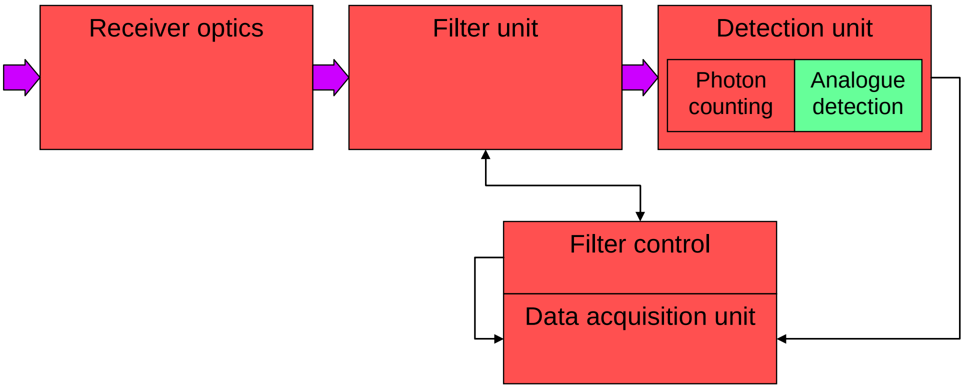


Figure 10 Elements of the LIDAR receiver system

The following figure presents the preliminary physical implementation of the Rayleigh / Mie separator (along with associated photomultipliers). According to the simulations presented above, this filter is a critical part for the overall performances of the LIDAR system.

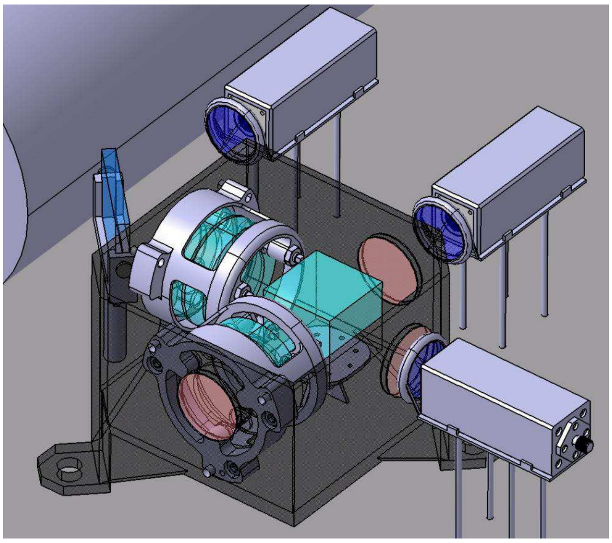


Figure 11 Configuration of the DELICAT Rayleigh-Mie Separator and the PMT Detectors

In order to extend the detection system's dynamic range, both a direct analogue detection in linear gain mode (for short range measurements), as well as a photon counting system (for medium to long range), are implemented. This is achieved by splitting the respective channel with the aid of a beam splitter. The splitting ratio has to be adapted in order to allow for a small overlap between the signal dynamics of the two systems.

The photon counting detection system consists of a high-performance PMT-class detector that transforms each detected photon into an electronic pulse. These electronic pulses are then sent to a fast counter that counts the number of these signals, corresponding to each detected photon in time-intervals corresponding to 7.5 metres range resolution. The photomultipliers chosen for the photon-counting detectors of the Rayleigh and Mie channels are Hamamatsu devices with inbuilt High Voltage generators. They have high quantum efficiency (DQE) at 355 nm, and extremely low thermionic emission. These PMTs are similar to the devices to be used for the analogue channels by DLR, but are operated at somewhat higher voltage and gain.

The analogue or direct detection is based on the continuous digitisation of the output of some photodetector. This device is based on the detection system of the DLR WALES LIDAR, adapted to the needs of DELICAT: for UV, it will be replaced by the appropriate version: R7400U-03 (photocathode: bialkali). PMT, amplifier stages and ADC (Analogue to Digital Conversion) are located on a single PCB that is integrated in a shielded housing in order to avoid stray noise pick-up from other systems.

Beam steering device

The beam-steering device has to compensate for the pitch, roll and yaw movements of the aircraft, in order to always direct the transmitter and receiver beam on the expected flight path.

It was decided to perform the beam steering function in the inside of the cabin to ease its implementation in pressurised, room temperature, instead of very cold, low pressure environment outside of the cabin.

The overall design of the beam steering system is based on two separate moving mirrors to allow for preventive offset generation on the mirrors. This allows for most effective use of the fairing front window that drives all following optical elements' dimensions.

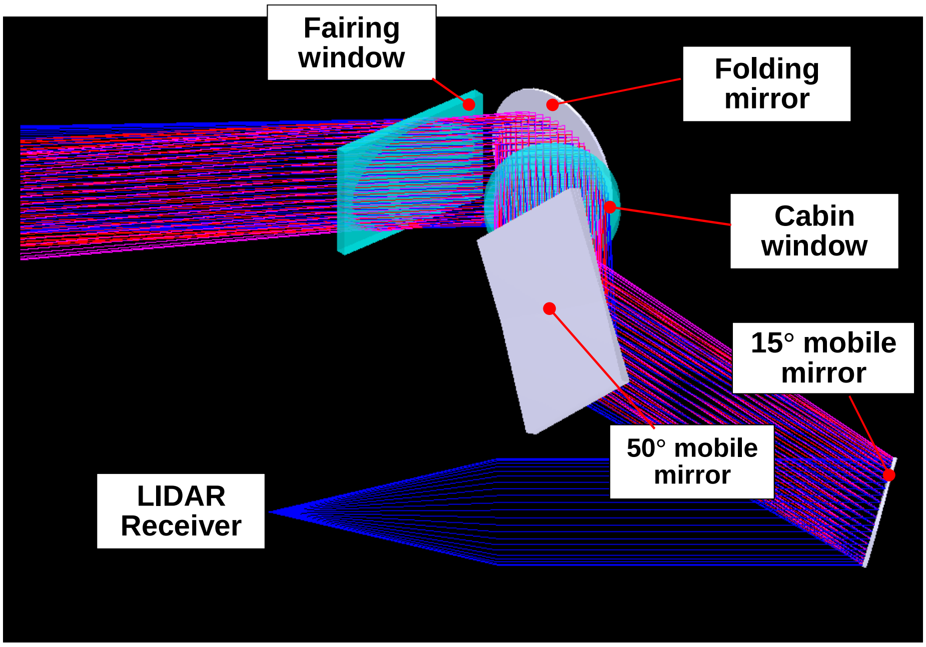


Figure 12 Overall design of the beam steering system

The main beam steering requirements are as follows:

- Pointing accuracy: ±0.1°
- Pointing bandwidth: >1Hz
- Pointing limitation > ±1.5°

The actuators and mounts will be chosen to fulfil several requirements.

- Orthogonal rotations: will be obtained by mechanical design
- Required accuracy, range, speed and accelerations
- Limited mass and dimensions, in order to preserve space in the aircraft.

Integration of the LIDAR in the Aircraft

The integration of the LIDAR system in the aircraft has been discussed extensively between the WP2100 partners and NLR, the difficulty being to meet different requirements regarding:

- The requirements for very accurate mechanical position of the LIDAR with respect to the aircraft structure: a very accurate mechanical design is needed, taking into account all parts of the LIDAR system and some parts of the aircraft, such as the exact dimensions of the fairing and the aircraft cabin fixation points
- The overall dimensions and mass of the DELICAT experiment
- The limited space available in the cabin of the Citation test aircraft
- The security constraints

Those discussions resulted in a first version of the integration of the LIDAR system in the aircraft, presented hereunder.

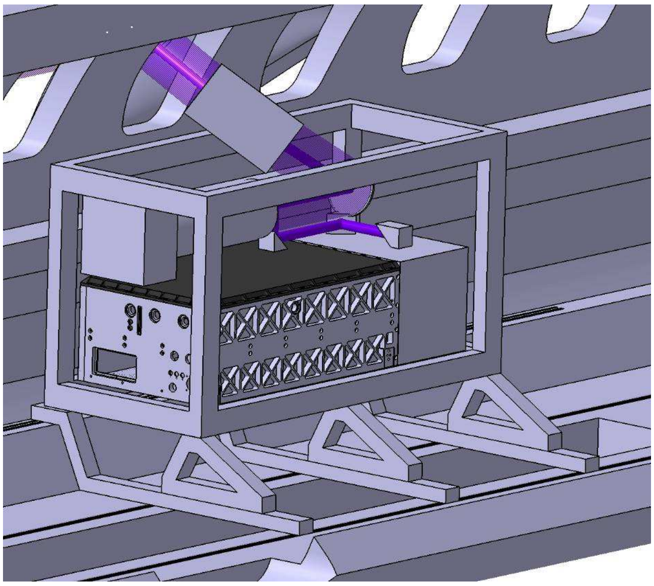


Figure 13 Preliminary CAD view of LIDAR rack installation

Figure 14 Fairing of NLR's Cessna Citation II

Design review

A formal design review was held, for both the overall LIDAR and its sub-assemblies. The following points were analysed and checked:

- Analysis of the overall LIDAR system requirements (including interfaces with the aircraft and requirement linked to certification issues)
- Compliance of the sub-assemblies requirements with the overall LIDAR requirements
- Compliance of the design with the requirements (at LIDAR and subassemblies level)
- Analysis of the various interfaces

WP2200: Lidar Manufacturing

WP2200 includes the manufacturing and component tests of all parts of the lidar system. In addition, information (incl. strength calculation etc.) has to be prepared and provided for WP4000 for flight test preparation (in particular certification issues).

While the Transmitter and Beam Steering have been successfully designed, manufactured and tested by DLR and Thales respectively, Hovemere was not able to provide the Receiver (and especially the Mie / Rayleigh separation filter) compliant with the needs of the DELICAT flight tests experiment.

For this reason, a General Assembly held on 04/04/2013, agreed on using a substitute receiver system developed by DLR for the flight tests. This decision is reflected by an addition of a task in the DOW.

Laser transmitter subsystems and analogue detection chain (DLR)

Lidar transmitter

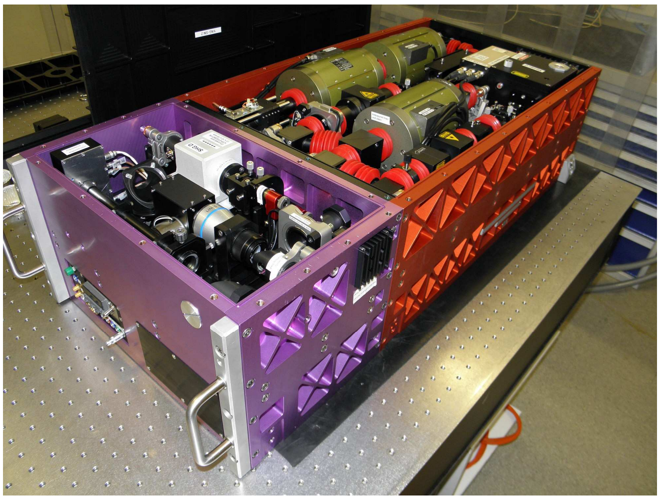


Figure 15 Lidar UV transmitter: Front/magenta: Frequency tripling stage (SHG + SFG), back/red: Nd:YAG MOPA pump laser with three amplifier stages

Laser control and data acquisition:

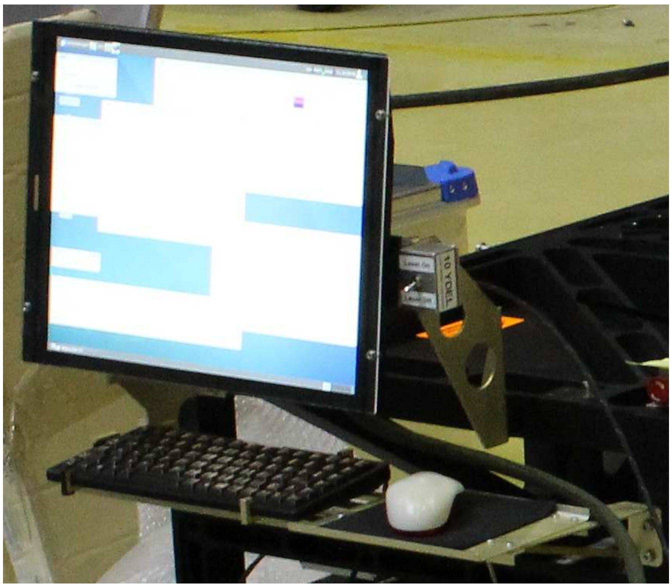


Figure 16 Left: Electronics rack containing the DLR data acquisition unit (top) and the heat exchanger unit (lower part)
Right: Screen for lidar operator control attached to the lidar rack

The DLR DAQ system comes with a screen and a keyboard/mouse control that is attached to the lidar rack. The DAQ unit further allows html webpages to be displayed on its screen (so for the beam steering control HMI).

Laser cooling system:

The heat dissipation of the laser (~1kW) is evacuated by a water circuit to a heat exchanger and transferred to a second (oil) cycle that finally evacuates the heat to the outside air via a cooler body attached to a NLR-built window panel.

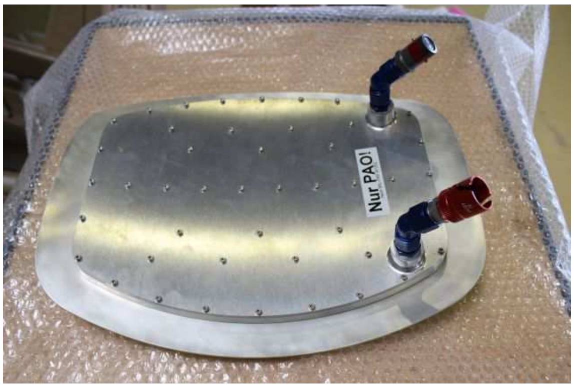


Figure 17 Cooling body (DLR) mated to NLR window panel

Initial Receiver subsystem and data acquisition system (HVM)

The receiver system was delivered to DLR by mid-June 2012. It had not been tested to full extent (functional tests of WP2400), due to lacking testing equipment at HVM.

In the following test period in DLR, it was shown that the receiver did not comply with its specifications and could not - in the present configuration - attain the project goals. A mitigation of this issue by HVM could not be shown to hold to the schedule with the ultimate date for the flight test campaign.

The most critical part of the Hovemere Receiver is the Mie / Rayleigh separation filter. Hovemere decided to base this critical function on a thermal principle. This thermal principle requires controlling the temperature of the optical etalon with accuracy, stability and homogeneity in the order of 0.01°C. The issue was then that it is actually extremely difficult to perform such temperature control in the operational conditions of the flight test (not to mention the necessary time to obtain the thermal stabilization to such accuracy).

In addition, such thermal principle is clearly inadequate for possible future equipment, given the much tougher environment requirements (compared to the quite benign conditions of the DELICAT flight test) and the necessity to adapt very quickly the separation filter central frequency to the actual flight conditions and flight speed.

On 04/04/2013, the DELICAT Extraordinary General Assembly (EGA) decided the following points:

- Unanimous decision declaring the HVM receiver as usable for ground tests only
- Unanimous decision for the use of the DLR more robust receiver for the flight tests

However, the absence of Mie / Rayleigh separation filter has prevented the separation of Mie and Rayleigh contributions during the flight tests, which induced uncertainty when processing the LIDAR data collected during the flight tests. This fact represented a major obstacle when attempting to derive CAT detection algorithms from the flight test data and to validate the basic principle of the CAT detection method that the DELICAT project has proposed

Alternative receiver (DLR)

This task was added due to the decision of the EGA to use the DLR-built alternative robust receiver in place of the HVM receiver not meeting its requirements.

This receiving system is designed to be a versatile platform for various applications. It contains a polarizing element for the analysis of depolarisation by aerosols or ice crystals. Such a setup does not allow a true separation of aerosol from molecular backscatter but allows a certain degree of evidence of aerosol presence in the sensed volume.

The DLR receiver has been ground tested: atmospheric tests have been performed while the last opto-mechanical parts were made available.

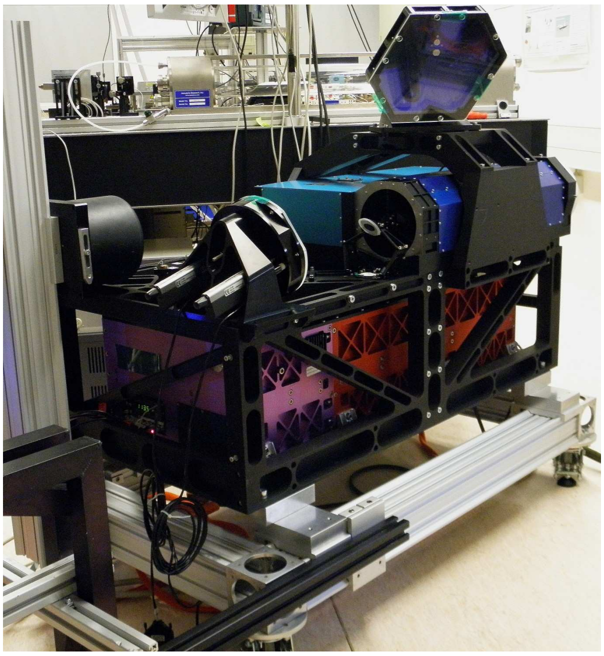


Figure 18 The completely integrated DELICAT lidar with DLR receiver and THA beam steering mirrors during atmospheric tests at DLR

Integration of manufactured sub-systems for the setup of the final lidar system (DLR)

LIDAR rack:

The lidar rack structure was assembled for integration with the other lidar sub-assemblies.

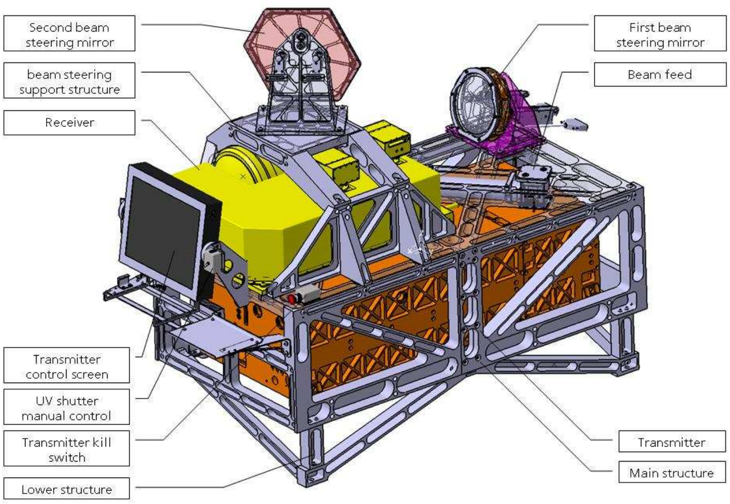


Figure 19 CAD overview of the lidar system mounted in the rack

An installation rehearsal was performed in the Citation 2 cabin in order to test the mechanical compatibility with NLR's attachments and the installation procedure.

Figure 20 Lidar rack as integrated in the Citation 2 cabin in April 2012

Minor mechanics modification on the NLR/DLR interface had to be performed as a consequence. The general installation, however, proved very straightforward.

Documentation:

As a contribution to WP4200 (Aircraft installation and modification /NLR), DLR supplied several documents to be used in the certification process with the Dutch CAA (IL&T).

	Report identification	Title	Version	Date
1	2100_ICD-M1_Aircraft-LidarRack	DELICAT Interface Control Document	V1.2	17/04/2012
2	DLR-IPA-LI-DEL-R.AD.02	Lidar Rack - Assembly Documentation	V0.3	17/04/2013
3	DLR-IPA-LI-DEL-R.SP.00	Strength Proof		19/04/2013
4	DLR-IPA-LI-DEL-ER.AD.01	Electronics Rack - Assembly Documentation	V0.2	17/04/2013
5	D2400_CoolingSystem	Lidar Validation Report Pt3 – Cooling System	V0.0	15/03/2012
6	D2400_LaserSafety	Laser Safety	V0.1	15/02/2013
7	DLR-IPA-LI-DEL-EL-DL-1	List of Devices and Cables	B	17/04/2013

WP2300: Beam Steering

Mirrors

The different mirrors (15° mirror, 50° mirror and folding mirror) have been designed.

Mirror	15° mirror	50° mirror	folding mirror
Clear Aperture Shape	circular	elliptic	elliptic
Clear aperture / beam footprint	Ø148 mm	240 mm × 184 mm	208 mm × 154 mm
Mechanical Shape	circular	Irregular hexagon	Circular truncated
Mechanical aperture	Ø160 mm	248 mm × 235 mm	Ø218 mm with horizontal edges at 164 mm
Thickness	18 mm	30 mm	22 mm
Material	Fused Silica	Fused Silica	Fused Silica
Mass	0.80 kg	2.66 kg	1.55 kg
Incidence angle	15°±1°	45°±1°	46°±1°

Mirrors mechanical mounts

The mechanical mounts for the 15° mirror (mobile), 50° mirror (mobile) and folding mirror (fixed) have been designed using CAD tools. Finite element analysis (Ansys) has been used to ensure sufficient stiffness and absence of low frequency resonance.

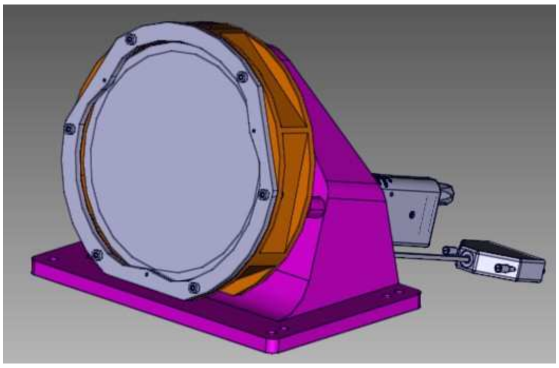
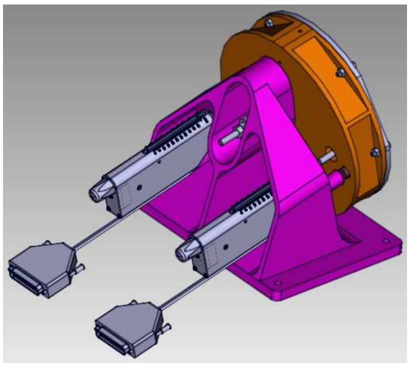



Figure 21 Overall view of the 15° moving mirror

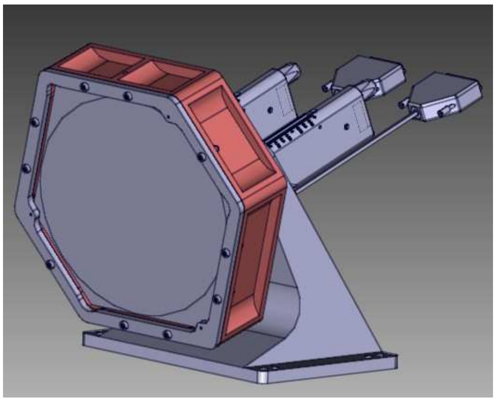
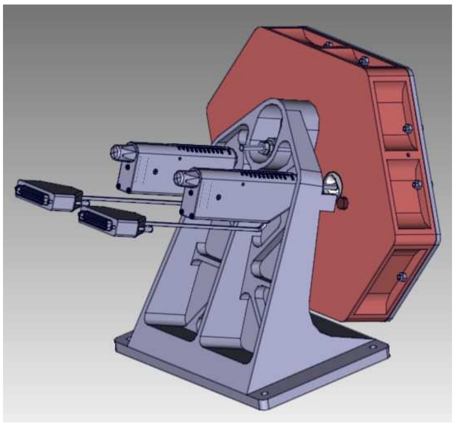



Figure 22 Overall view of the 50° moving mirror

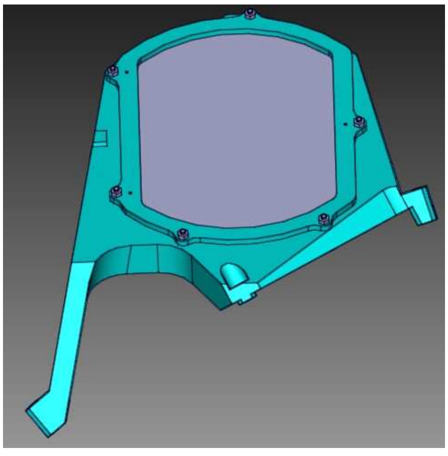
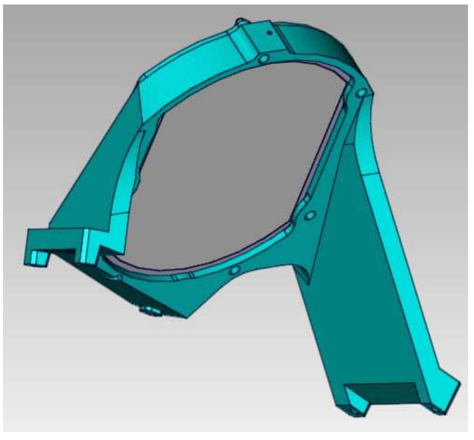



Figure 23 Overall view of the folding fixed mirror

Beam Steering Control

The 15° and 50° moving mirrors are piloted by the B eam steering Control (BSC) device, which performs the following functions:

- o The BSC receive and decodes the ARINC data Pitch, Roll and SSA from the aircraft systems
- o The BSC computes the required position of the 4 actuators as a function of the aircraft ARINC data
- o The BSC drives the actuators to this required position, and monitor the actual actuator position
- o The BSC generates the data stream to be recorded by the aircraft recording system and sends those data to the aircraft systems through ARINC format
- o The BSC generates the page presenting the status of the Beam Steering (available to the external MMI laptop via a web server) and accept commands from the MMI laptop
- o The BSC stores the Configuration file that defines the Beam Steering functional configuration (including the reference position of the beam steering, once defined during the alignment of the LIDAR with respect to the aircraft)

The Beam Steering Control includes the following hardware parts:

- o A PC computer
- o An ARINC 429 communication board
- o An ESP 301 actuators controller / driver

Those different sub-assemblies have been integrated in a rack provided by NLR, with the addition of necessary connectors and switches / indicators, and shock protection dampers.

Figure 24 Beam Steering Control Rack

A specific development was devoted to the Man / Machine Interface (MMI) of the BSC, in order to allow in-flight remote control of the BSC through a dedicated web server.

Beam Steering validation

The Beam Steering has been validated through different experiments, taking into account its full functionality. The beam Steering design complies with its requirements.

WP2400: Lidar validation

Ground-based synthesis test of complete LIDAR system (DLR)

The complete Lidar has been fully integrated and installed in a laboratory room located under the lidar dome giving vertical access to the sky via a 200 mm aperture in the lab ceiling. The laser beam is directed onto a 400 mm 45°-mirror and thus vertically bended. The cabin window spare is located in the 200 mm ceiling aperture to protect the lab and the mirror from dust and humidity deposal.

A pre-alignment of the Lidar transmit beam ('Beam feed') with respect to the receiver – utilizing a retro-reflector in front of the transmit beam and the telescope – allows avoiding long searches for the overlap (transmit beam and receiver FOV). This method proved very effective and will also be employed once integrated in the aircraft cabin.

'First light' occurred on 21/02/2013. In the subsequent weeks, the lidar was regularly operated when meteorologically favourable conditions were present.

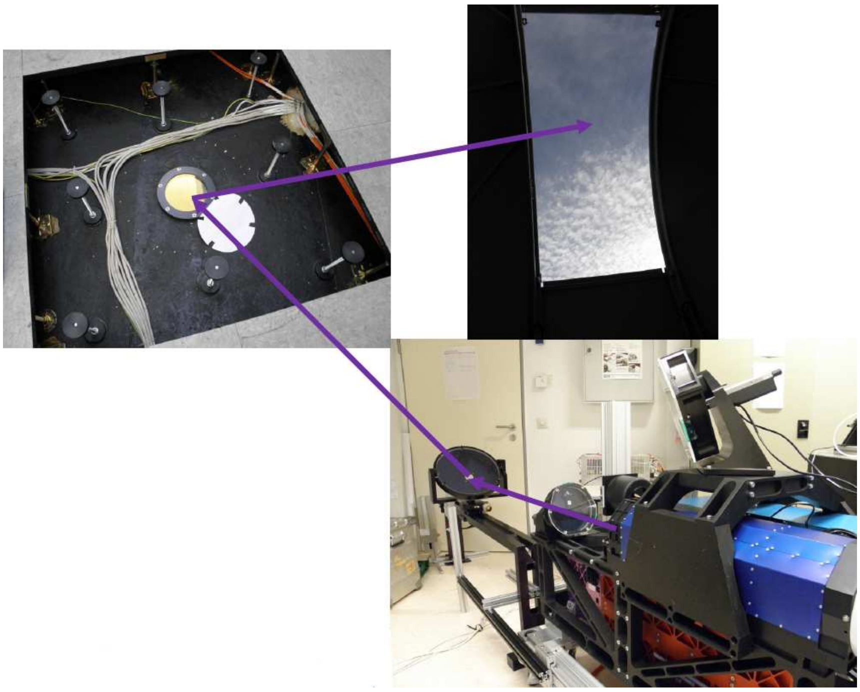


Figure 25 The lidar setup during atmospheric tests at DLR

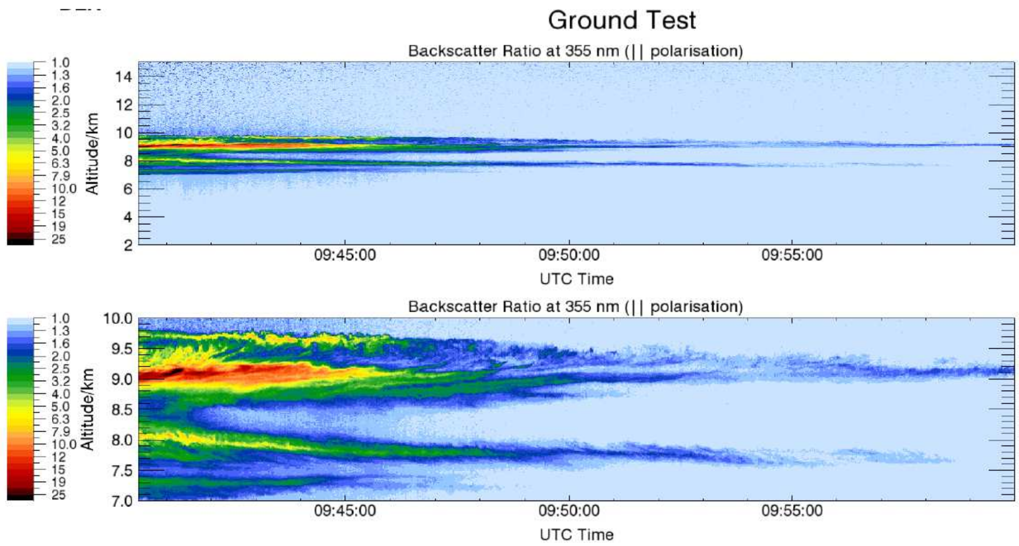


Figure 26 Exemplary Lidar signal on 08/03/2013 showing passing Cirrus clouds between 7 and 9.5 km altitude

A first analysis of the receiver (de-)polarisation calibration shows a possible ratio of better than 1:90 (up to 1:160). Measurements on classical ‘depolarising’ aerosols, namely ice crystals in Cirrus clouds show the typical expected depolarisation values.

The overall performance was compared to simulations and declared as apt for flight tests.

Comparison of measured LIDAR signals to simulation runs

A comparison of the Lidar measurement series with a DLR Lidar simulator shows good agreement.

Figure hereunder shows the statistical error of the measurements introduced by the different noise sources, compared with a modelled error (with and without solar background radiation). Given the simplistic model, in particular the lacking knowledge of the actual aerosol condition in the boundary layer, this comparison shows good agreement.

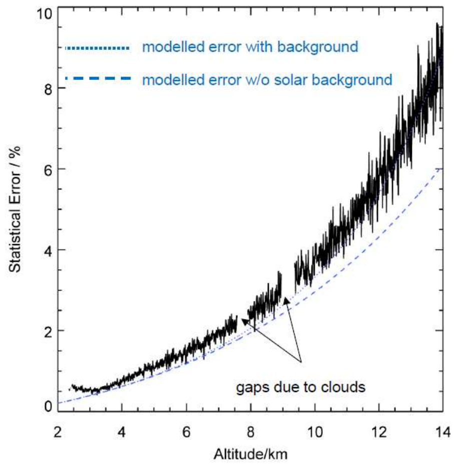


Figure 27 Comparison of computed statistical error of acquired signal (100 pulse average) with modelled error

3.3. MAIN RESULTS AND FOREGROUND FOR WP3000: MET ACTIVITIES

WP3100: Test strategy

The WP3100 is divided in two tasks, the first one being the review of previous studies and the second one being a preliminary selection of the preferred test areas and times of year, based on existing climatology.

Review of previous studies

University of Warsaw has performed a bibliography on the different CAT indices: Richardson number, Colson - Panofsky index, Ellrod Indices (IT1 and IT2), Dutton index, Brown index, horizontal wind speed index, DVT “Divergence trend” term. Mountain wave indices have also been investigated.

Preliminary selection of the test areas and times of year based on existing climatology

Météo France and University of Warsaw have identified the preliminary algorithms on the numerical weather models data sets.

Based on these first results, Météo France and University of Warsaw have done a climatology study to define the most promising phenomenon / location / time of the year for the DELICAT experiment. These studies will continue during the WP3200.

Météo France has also performed a climatology based on SIGMET messages.

From the wind climatology based on ERA40 the most frequent location of the strongest winds can be identified. These winds are located in average on the North Atlantic, crossing Great Britain, oriented from the west to the east. The strength varies with the season. The heaviest winds occur in winter, and the lowest winds in summer.

As far as Europe is concerned, CAT is found more frequently in winter over the north-eastern part of the Atlantic. In summer the frequencies are reduced. The indices indicate Great Britain and Western Europe as the favourite locations for CAT encounters. They also point the Alps as a possible location for turbulence: the influence of the orography, with the presence of the Alps and the Apennine mountains, disturb the fluxes and can generate turbulence at high altitude.

In conclusion, wintertime appears to be the most favourable period for the presence of strong winds and jets. At this period, the jet axis crosses the North Atlantic, and reaches Europe at the latitude of the British Isles. The Alps area seems also to be a good location for orography-induced turbulence. This is confirmed by three different climatologies.

WP3200: Flight tests support

Aerosol climatology based on MOCAGE output

As a part of preparation of the flight tests climatology of aerosol concentration was calculated by ICM. The data used for the calculations were output files of MOCAGE NWP model run in Meteo France. The supplied file included two years of simulations: 2011 and 2012. The results that were presented to the partners concentrated on two months May and June since this was the planned period for Flight tests. The climatology output distributed to the partners consisted of mean aerosol concentration values for selected period. During the calculations also the diurnal variability was tested yet no significant variability at this timescale was found in the areas of interest.

Preparation of the real time support for the flight test

The domain for the flight test campaign has been selected. It covers almost completely Europe (centred on western part).

The meteorological assistance organisation has been done. Different products will be available in order to help the partners in the GO/NOGO decision. Some others are the results of the work package 3300 and are dedicated to the meteorological community.

Among the different products:

- o Planning of DAY+1 and DAY+2

    - o Briefing by phone meeting is organised. It is the opportunity for the forecaster to explain the meteorological situation of the next days in order to prepare the prospective flights. It helps to manage the location of the plane and to prepare the flight in advance. It can be decided by the PI, if it is necessary, to move the aircraft in a city closest of the turbulent areas than Amsterdam.

- o In case of a flight the DAY D, an earlier briefing is planned by phone meeting. Then the forecaster can give the last recommendations about the flight of the day

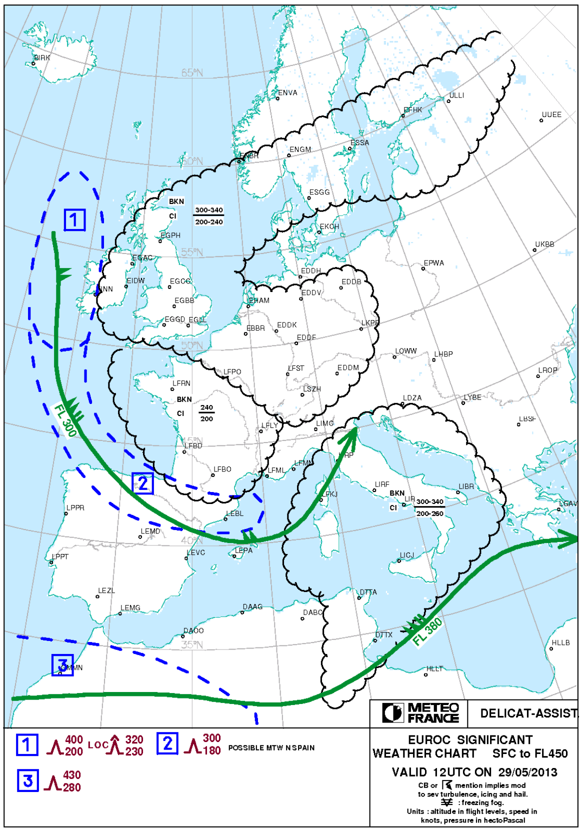


Figure 28 Example of D+1 day chart, where the forecasted CAT and Cirrus areas are indicated

Moreover, several documents are provided:

- To the pilots : an access to the official OACI documents, like SIGWX charts, TAF and METAR messages, satellite and radar maps, winds charts.
- To the partners: The Meteo-France numerical weather prediction model MOCAGE forecast information on aerosols, particles of diameter of less than 10 microns. These maps of the PM10 aerosols particles are plotted at levels FL180, FL240, FL300, FL340, for every three hours of the Dday, D+1 day, D+2 day.

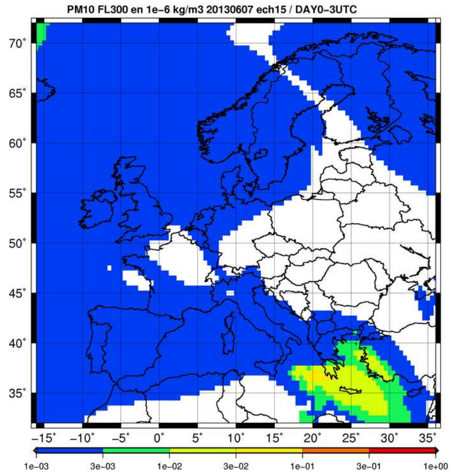


Figure 29 Example of PM10 aerosols chart

- To the meteorologists: Maps of different CAT indices provided by ICM and by Meteo France.

In order to collect at the same place the meteorological information useful for the flight planning, a website hosted at Meteo France has been developed.

ICM Website

ICM provides a supporting forecast consisting of set of CAT indices (Ellrod TI1, TI2, Richardson number, Brown index, Colson-Panofsky index, Horizontal Temperature gradient, and TKE). This forecast is then summarized by providing a combined weighted index and everyday recommendation. Additionally to the forecasts mentioned above ICM can supply (in case the partners request it) a variety of fields related to clouds and humidity.

The base of the ICM forecast is the COAMPS NWP model run twice a day (00 UTC and 12 UTC). The model horizontal resolution is 14km with 40 vertical levels.

The processed fields – indices are then placed on a website. Each index is available every 6h for 84h of forecast (up to D+3) on 5 vertical levels (FL200, FL 250, FL300, FL 350, FL400).

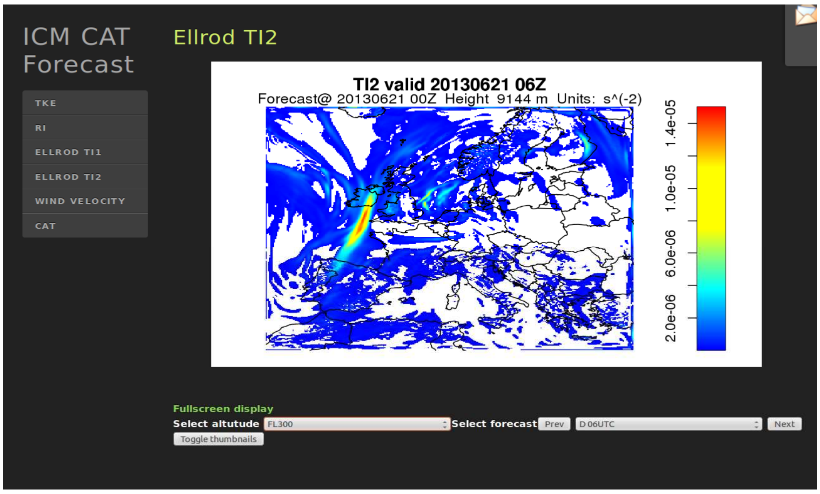


Figure 30 The ICM website - development version

WP3300: Met situation data

ICM development

ICM performed research regarding turbulence induced by gravity waves (GW). The observation set used were AMDARS provided by Meteo France. The preliminary conclusions are that alone this type of index is comparable in performance to other classic indices. Yet great potential was uncovered during testing combination of random forest (RF) machine learning and gravity wave index.

Figure hereunder presents a comparison of RF GW index and GTG1 developed by NOAA. The similar location of both curves suggests a very good performance – comparable with a complex system fed by live observations. The rough shape of the black curve results from the fact that RF decided only which of three categories of CAT was present (no, light, moderate or greater).

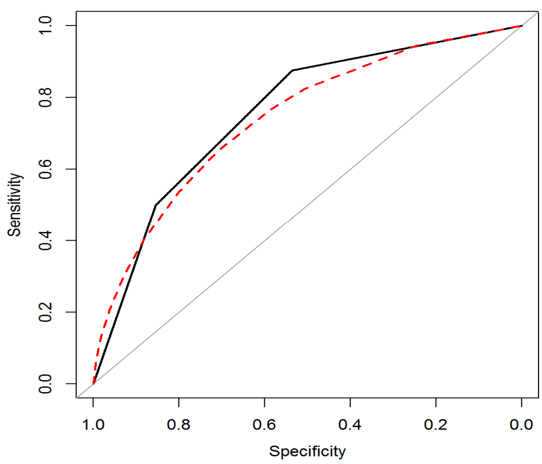


Figure 31 A comparison of ROC curve for gravity wave index and random forest combination (black solid) and GTG1 (red dashed)

Meteo-France development

The Eddy Dissipation Rate - EDR index:

EDR is usually used as a turbulence index in aeronautics. But the value measured on the airplanes is not the same as the one calculated by the NWP model. This latest has to be studied. The EDR value, not commonly used by the forecasters, has been calculated at the NWP model high vertical resolution.

WP3400: Forecast validation

When the CAT indices have been developed, the numerical weather prediction models (NWP model) had low resolution. With the improvement of the computer capacities and the data observed and assimilated in the NWP models, many progresses have been done. The aim of the work package is to evaluate the influence of these evolutions on the CAT indices and to evaluate their adaptation on the new NWP models.

The observation data base is constituted by the AMDAR messages collected at Météo-France.

Verification method

Many verification methods exist and could be applied to run the verification process. After research on the previous studies and depending on the experiences on aviation verification, three methods have been proposed.

- The interpolation of the nearest data on the observation point. This process takes into account the nearest vertical levels and the nearest points on these levels. The interpolation can modify the values when forecasted points are distant from the observation point. Especially when the resolution is very low.

- The nearest point.

- The neighbouring points. A domain of points surrounding the observation data is considered. This domain can be modified on its horizontal and vertical extension. The verification takes into account the variability of the domain size.

The “neighbouring points” method has been chosen by Météo-France. University of Warsaw chooses the nearest point method for initial verification and modified neighbouring points method for refinement.

Observation data-set

The observation data base is constituted by the AMDAR messages collected at Météo-France.

Within the E-AMDAR program commercial aircraft, using integrated sensors, measure meteorological parameters. These meteorological data are transferred to the ground in real-time, using the meteorological network, inside text messages called AMDAR (Aircraft meteorological data relay).

Currently, commercial aircrafts are equipped with sensors, which are able to measure temperature, pressure, wind intensity and direction, and geographical position.

The AMDAR message contains these parameters and, in addition, two parameters relevant to turbulence calculated on-board: a “turbulence intensity” IT along with a “gust index” GT.

In order to eliminate turbulence induced from convection, data are filtered by using lightning observation. If there is an lightning observation in a range of 50 kilometres and within a one hour time window AMDAR data are excluded.

Depending on the results of the first five months of 2010 the verification study focuses on the AMDAR data collected during the first three months of the year 2010: January, February, and March. They show the most interesting events of turbulence events.

Forecasted data-set at Meteo France

The model used is ARPEGE, the Météo-France operational numerical weather product model. The horizontal resolution is 0.1°. The domain covers Eu rope, It extends from the 20N to 72N, and from the 32W to 42E.

CAT indices: The CAT indices chosen in the previous work package are the following: Ellrod1 and Ellrod2 indices (named TI1 and TI2), temperature horizontal gradients (GradhT), Richardson number (Ri), Eddy Dissipation Rate (EDR), TKE, Dutton index

The indices are calculated on the Météo-France operational numerical weather product model (NWP) ARPEGE. The horizontal resolution is 0.1°. The doma in covers Europe. It extends from the 20N to 72N, and from the 32W to 42E. The model will run four times (00 06 12 18 TU) every day. The forecast are calculated from the “analysis” equivalent to step 0, to the step 24 hours, by one hour step. It allows seeing the impact of the forecast time in the forecasting process.

Statistical indices

The forecasted indices have been compared again the IT values and again the DEVG values from the AMDAR.

Some usual statistical indices have been calculated for each indices, for the 4 run times by 3 hours step, like the POD (probability of detection of the event), the PODNO (probability of detection of the NO event). Then the ROC curves have been drawn.

Results

The first results show no effect of the running time. Depending on the model running time more or less observation are included. It seems that this amount of observation included in the model has no effect on the results of the CAT indices.

The statistical results are better when the Derived vertical gust (DEVG) value (independent of the type of plane) is considered, than when it is the Turbulence index (TI)

The vertical resolution has less impact on the statistics than could be expected. But it depends on the type of index.

The Ellrod1 index seems to show better performance against the other indices.

3.4. MAIN RESULTS AND FOREGROUND FOR WP4000: FLIGHT TESTS

WP4100: Flight preparation

Various activities relating to aircraft modifications and instrumentation have been performed:

- The UV Cabin Window has been designed, purchased and pressure / temperature tested
- The cooler plate, required for cooling the LIDAR equipment without raising cabin temperature, has been designed, manufactured and tested.
- Fairing mounting provision has been modified in order to withstand increased loads at higher Mach numbers and higher altitudes.
- The electrical interface for real-time data exchange between Thales' Beam Steering Device and NLR's Nose boom probes, inertial reference System and data recording system has been implemented and tested in NLR's Arinc Datalogger system.
- The RVSM trials have been performed to demonstrate that PH-LAB still does meet the legal RVSM requirements with the nose boom and the fairing.
- The Flight Test Plan has been established.

WP4200: Aircraft installation and modification

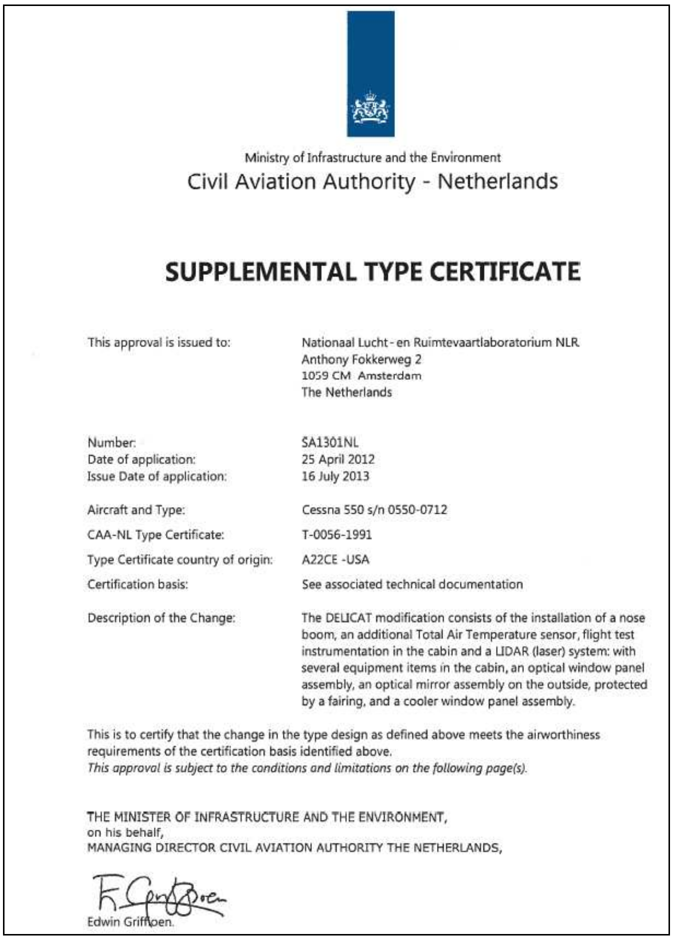
The Cessna Citation has been instrumented with all necessary instrumentation, such as LIDAR including cooling devices, beam steering, nose boom vanes, IRS, fast TAT probe, data acquisition and monitoring systems. All systems were integrated, aligned, calibrated and validated.

All aircraft modifications were reported to the Dutch CAA, IL&T, by means of the Certification Plan, the 'Modifications Definition Document' and the 'Certification Report'. Various aircraft certifications issues needed to be solved, e.g. concerning laser safety, cabin fire safety as well as structural and aerodynamic issues that were investigated in a certification flight test.

The certification approval of the modified Cessna Citation aircraft was received on July 16, 2013, IL&T providing a 'Supplemental Type Certificate' (STC), based on which the aircraft was ready for starting the flight test campaign.

Figure 32 Test aircraft equipped with nose boom and fairing

Figure 33 Lidar Installed on board the aircraft : left : Lidar rack – Right : Electronic rack



Ministry of Infrastructure and the Environment
Civil Aviation Authority - Netherlands

SUPPLEMENTAL TYPE CERTIFICATE

This approval is issued to:	Nationaal Lucht- en Ruimtevaartlaboratorium NLR Anthony Fokkerweg 2 1059 CM Amsterdam The Netherlands
Number:	SA1301NL
Date of application:	25 April 2012
Issue Date of application:	16 July 2013
Aircraft and Type:	Cessna 550 s/n 0550-0712
CAA-NL Type Certificate:	T-0056-1991
Type Certificate country of origin:	A22CE -USA
Certification basis:	See associated technical documentation
Description of the Change:	The DELICAT modification consists of the installation of a nose boom, an additional Total Air Temperature sensor, flight test instrumentation in the cabin and a LIDAR (laser) system: with several equipment items in the cabin, an optical window panel assembly, an optical mirror assembly on the outside, protected by a fairing, and a cooler window panel assembly.

This is to certify that the change in the type design as defined above meets the airworthiness requirements of the certification basis identified above.
This approval is subject to the conditions and limitations on the following page(s).

THE MINISTER OF INFRASTRUCTURE AND THE ENVIRONMENT,
on his behalf,
MANAGING DIRECTOR CIVIL AVIATION AUTHORITY THE NETHERLANDS,

Edwin Griffioen.

Figure 34 DELICAT experiment Supplemental Type Certificate

WP4300: Flight campaign

A total of 18 DELICAT flights have been flown with the NLR Citation II. These included:

- 11 DELICAT CAT flights (including one shakedown flight)
- 1 DELICAT certification flight
- 6 DELICAT RVSM compliancy flights

The following chart summarizes the different flight tests.

	Date dd-mm	Ordernr.	Place take-off code	Place landing code	Time off blocks	Time take-off	Time landing	Time on blocks	Block time h:mm:ss	Flight time h:mm:ss
AUGUST 2013		CAT FLIGHTS								
	6-aug	2048310.4.2	EHAM	LPPR	04:30	04:35	08:45	08:50	4:20	4:10
	7-aug	2048310.4.2	LPPR	EHAM	17:15	17:20	21:00	21:05	3:50	3:40
	8-aug	2048310.4.2	EHAM	LFBT	11:40	11:45	13:40	13:45	2:05	1:55
	8-aug	2048310.4.2	LFBT	EHAM	19:00	19:05	21:40	21:45	2:45	2:35
	12-aug	2048310.4.2	EHAM	EINN	11:30	11:35	14:35	14:40	3:10	3:00
	12-aug	2048310.4.2	EINN	EHAM	17:04	17:08	19:43	19:49	2:45	2:35
TOTAL									**18:55:00**	**17:55:00**
JULY 2013		CAT FLIGHTS								
	17-jul	2048310.4.2	EHAM	EHAM	12:40	12:48	15:48	15:55	3:15	3:00
	26-jul	2048310.4.2	EHAM	EGPD	10:09	10:18	12:53	12:54	2:45	2:35
	26-jul	2048310.4.2	EGPD	EHAM	14:28	14:35	16:15	16:18	1:50	1:40
	31-jul	2048310.4.2	EHAM	ENZV	10:13	10:22	13:02	13:03	2:50	2:40
	31-jul	2048310.4.2	ENZV	EHAM	14:48	14:52	16:32	16:33	1:45	1:40
TOTAL									**12:25:00**	**11:35:00**
JULY 2013		CERTIFICATION FLIGHT								
	1-jul	2048310.4.2	EHAM	EHAM	13:25	13:30	13:35	13:40	0:15	0:05
TOTAL									**0:15:00**	**0:05:00**
JANUARY 2011		RVSM COMPLIANCY								
	4-jan	2048310.7.2	EHAM	EHAM	8:10	8:15	10:50	10:55	2:45	2:35
TOTAL									**2:45:00**	**2:35:00**
AUGUST 2010		RVSM COMPLIANCY								
	20-aug	2048310.7.2	EHAM	EHGG	6:30	6:35	7:00	7:05	0:35	0:25
	20-aug	2048310.7.2	EHGG	EHGG	8:25	8:30	8:45	8:50	0:25	0:15
	20-aug	2048310.7.2	EHGG	EHGG	9:30	9:35	10:40	10:45	1:15	1:05
	20-aug	2048310.7.2	EHGG	EHGG	12:15	12:17	13:16	13:20	1:05	0:59
	20-aug	2048310.7.2	EHGG	EHAM	14:50	14:55	16:00	16:05	1:15	1:05
TOTAL									**4:35:00**	**3:49:00**

Figure 35 Flights list

On a daily basis, a “regular” Meteo teleconference was held at 0830z time hosted by NLR to decide upon initiating a (series of) test flight. Participants in these phone calls were DLR, FME, ICM and NLR. Documents available on the FME extranet website were:

- Forecasted maps, for the days D+1 and D+2, indicating the best areas where the turbulence could exist with less risk of cirrus.
- The TEMSI charts, every 3 hours, for the Dday.
- The aerosols maps, for the PM10 (size low than 10 microns), and PM25 (size low than 25 microns), for the flight test altitude.
- Link to the Meteo-France official aeronautical web service, named AEROWEB. Aeronautical messages (TAF, METAR, SIGMET), aeronautical charts (wind and temperature) were provided, and satellite and radar images.

The LiDAR team representative DLR, decided if a CAT flight would be useful based on weather forecasts provided by FME and ICM. In general a go-ahead was given when favourable CAT conditions, no cirrus clouds, reachable in time with low concentration of aerosol were present.

The final Go/No-go decision for a flight trial was given by NLR, taking into account, aircraft status, flight test and experimental equipment status (NLR, and DLR), crew status (NLR, DLR) weather forecasts (e.g. no icing conditions) and ATC issues. If a Go was given the Flight Plan was prepared and filed with ATC. The LiDAR was prepared (warm-up, check) and prior to the flight a briefing was held.

The test flights were executed in Europe. The yellow lines in Figure 36 indicate the routes flown.

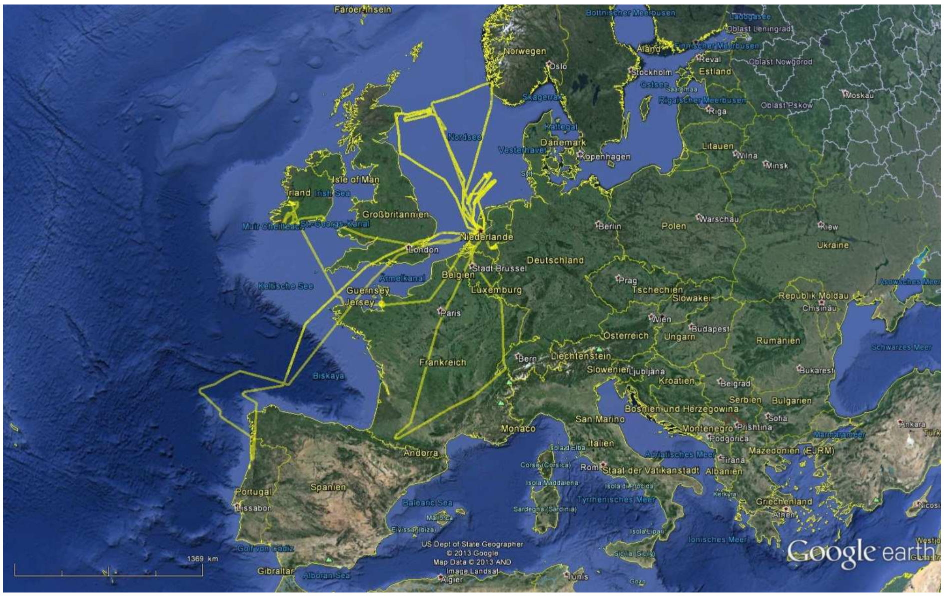


Figure 36 Flights location

In general CAT conditions were not favourable in Europe and Mediterranean during this (summer) period. Linked-up high pressure zones dominated above W-Europe. Jet stream systems and thus CAT areas were present on a limited scale, limiting opportunities for CAT flight testing. The aircraft was only dispatched when, as a minimum, moderate CAT was forecasted. On a few occasions severe CAT was forecasted over Europe.

During flight execution the intensity of CAT areas found was dominantly light to (now and then) moderate. On a few occasions, moderate to severe CAT was forecasted over Europe, however when flying in the forecasted area the encountered CAT was light to hardly moderate only. Several other commercial airline aircraft in close vicinity reported more intensified turbulence; however the NLR research flight did not encounter this reported CAT. It turned out that, at least for this summer period, moderate turbulence areas seemed to be rare and very locally situated.

The occurrences of light to moderate turbulence felt by aircraft were present in flights 1, 2, 6, 8 and 9; the maximum turbulence observed was in the order of 5 m/s^2 (or 0.5 g). No severe turbulence was encountered during any flight.

3.5. MAIN RESULTS AND FOREGROUND FOR WP5000: DATA PROCESSING

WP5100: Data extraction

During flight measurement data has been recorded on the Citation Measurement System hard disk storage device as raw Arinc429 format data files. All data that are transferred on the Arinc channels are being recorded, including parameters that are not specified in the DELICAT parameter list.

Data was collected from the following systems:

1. LIDAR receiver
2. Inertial Reference System (IRS)
3. Digital Air Data Computer (DADC)
4. Fast TAT probe
5. Nose boom horizontal and vertical vanes
6. Beam Steering System

Recorded raw data files were retrieved from the Cessna Measurement System (CMS) using memory sticks and secured into the DELICAT data directories at NLR's online computer network system, which were further back-upped to an electronic archive on a daily basis by NLR computer services as additional securing means.

Measurement data was distributed one day after flight via internet to the DELICAT partners as flight-parameter files in a partner-preferred format.

Recording and distribution of the LIDAR data was executed by DLR's LIDAR system itself, while the massive amount of LIDAR data was distributed to partners by DLR through exchange of data storage devices (hard drives).

WP5200: Data analysis

Within WP 5200, UV LIDAR data and Aircraft data as well as flight engineer reports are processed to identify useful time ranges, for further processing. Small-scale Atmospheric parameters have also been studied.

Identification of useful time ranges

Filters use Aircraft parameters to flag each laser shot as "usable" or "unusable'. Various filters are used and combined:

- Filter on altitude (ALD)
- Filter on averaged angle of side slip from boom (ASB)
- Filter on averaged angle of pitch from IRS (APIRS)
- Filter on averaged angle of roll from IRS ARIRS
- Global filter (based on a combination of 10 second average of previous filters)

Figure 37 illustrates the different filters results on flights 4.

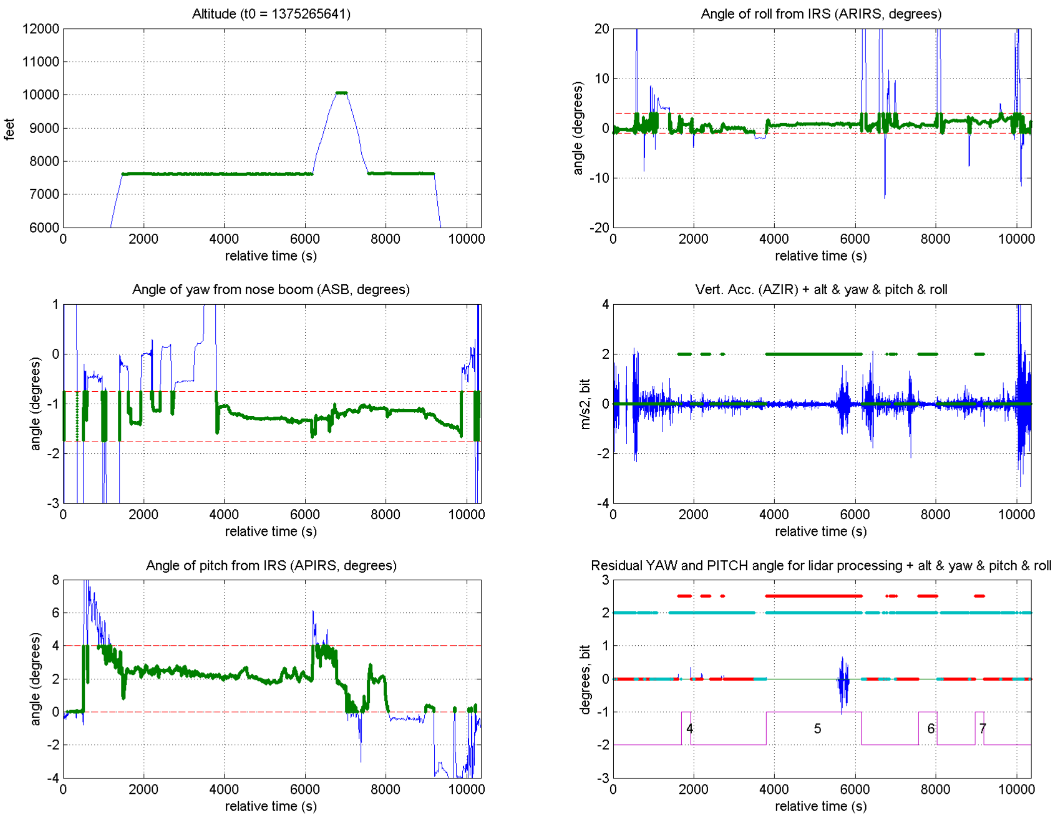


Figure 37 Flight details – Flight 4

In Figure 37 are presented : Top left: Altitude in blue ; filter results in green ; Middle left : Angle of Yaw in blue , filter limits in dashed red , filter results in green : Bottom left : Angle of Pitch in blue ; filter limits in dashed red , filter results in green ; Top right : Angle of roll in blue ; filter limits in dashed red , filter results in green; Middle right : Vertical acceleration ,in green result of overall filter ; Bottom right : residual Yaw and Pitch, in purple usable zones .

30 areas have been identified as interesting areas defined with the following constrain: "the global filter must be continuously 1 for >200s".

WP5300: Detection algorithms

The challenges for defining and testing CAT detection algorithms within WP5300 were the following:

- A large amount of data is available but contains only a few CAT encounters, with low amplitude
- Molecular signal can be polluted by presence of aerosol due to the absence of Mie / Rayleigh separation filter. Cross polar can help when aerosols are depolarizing, but in case of non-depolarizing aerosols, no discrimination is possible

All involved partners used quite similar data pre-processing: algorithms:

CAT detection algorithms were defined and tested by following partners: ONERA, CNRS, INOE, IAP, LDI and TRT.

The results obtained by the different partners about CAT detection algorithms are quite different according to the different methods and data sets processed, which is not surprising with respect to the very innovative aspect of the work performed within DELICAT.

The overall conclusion resulting from the work performed within WP5300 is that, in the case where no aerosol is present, it should be possible to detect CATS by using the fluctuations of the LIDAR backscattered signal, provided the turbulence is at a moderate level.

Although this conclusion needs to be confirmed by other experiments including the encounter of real moderate turbulences (which was the goal of the DELICAT project), this result is quite encouraging with respect to the objectives of the DELICAT project.

4. POTENTIAL IMPACT - EXPLOITATION OF RESULTS AND MAIN DISSEMINATION ACTIVITIES

4.1. POTENTIAL IMPACT AND EXPLOITATION OF RESULTS

The objective of the DELICAT project was to validate the concept of Clear Air Turbulence detection at medium range (10 km to 30 km), using a UV Lidar.

This validation included the development of a UV LIDAR system, tested in laboratory on the ground, and then installed on-board a research aircraft. This Lidar system is composed if 3 sub-assemblies:

- A Transmitter,
- A Beam Steering system
- A Receiver, including a Mie / Rayleigh separation filter

The Transmitter and Beam Steering systems performed according to the project needs.

Regarding the Receiver and especially the Mie / Rayleigh separation filter, Hovemere was not able to develop a system suitable for the DELICAT project experimental needs.

Regarding meteorological activities, ICM and Meteo France developed new methods of CAT prediction, which showed good potential but need more data for tuning and performances verification before those new methods can be actually used for CAT prediction on a regular basis.

Based on those facts, the potential direct exploitation of the results of the DELICAT project is described hereunder.

Further processing of the flight test data

Both Lidar data and aircraft data were recorded during the flight tests. Those data were processed (off-line) by the DELICAT project partners in the frame of WP5000 in order to define and test CAT detection algorithms.

In addition to the work already performed within the DELICAT project, further processing could be performed on the flight test data in order to improve the understanding of all phenomenon observed during the DELICAT experiment, as well as to improve the statistical aspect and the completeness of the data processing.

Further flight tests using existing hardware and newly developed Mie / Rayleigh separation filter

In general CAT conditions were not favourable during the DELICAT flight test experiment. This was mainly due to the project planning, which made it impossible to perform the tests in the forecasted more encouraging seasons

During flight execution the intensity of CAT areas found was dominantly light: the maximum turbulence observed was in the order of 5 m/s^2 (or 0.5 g) in very rare occasions (max. CAT level mostly was below 0.2g). In addition, only very few turbulence events were encountered, even though the encountered turbulences were of light severity.

The absence of a Mie Rayleigh separation filter was another major obstacle for the analysis of the flight tests data and the definition of CAT detection algorithms.

It would then be very useful to perform complementary flight tests in order to draw more definitive conclusions about the capability to detect CAT at medium range using a UV Lidar.

- The Lidar Transmitter already exists and is compliant with the experimental needs. The Transmitter can be re-used for further flight tests without any modification,
- The Beam Steering system already exists and is compliant with the experimental needs. It may be adapted to comply with the specific conditions of a possible new experiment, if any,
- The Lidar Receiver, and especially the Mie / Rayleigh separation filter, needs to be re-designed in order to comply with the experimental needs. The thermal principle of the filter designed by Hovemere is clearly not adequate and needs to be reconsidered,
- Finally, the aircraft modifications have been implemented, and the certification authorities have granted a 'Supplemental Type Certificate' (STC), based on which the aircraft is able to perform a flight tests campaign,
- With the lidar data being analysed in detail, many improvements may be contributed to the system developed within DELICAT.

Further analysis regarding new methods of CAT prediction

ICM and Meteo France have developed, within the DELICAT project, new methods of CAT prediction that could be very useful in the context of the development of the European aeronautical transport. However, more data and research is necessary before these methods could go operational.

Those complementary analysis and research could use, for example, more commercial flight data provided such flight data can be made available for the study.

4.2. MAIN DISSEMINATION ACTIVITIES

The main dissemination activities, already performed with the DELICAT project or still to be performed, are presented in the chart hereunder.

The dissemination activities were mainly directed toward the scientific community, with the exception of the presentation of the DELICAT project in the frame of the Aerodays 2011 event, organised by the European Community with a larger audience including the aeronautical industry stakeholders and the public audience.

NO.	Type of activities	Main leader	Title	Date/Period	Place	Type of audience	Size of audience	Countries addressed
1	Conference	Thales	Aerodays 2011	31 march 2011	Madrid, Spain	Aeronautical community, public	50	International
2	Conference	DLR	25th International Laser radar conference	5-9 July 2010	St.Petersburg, Russian Federation	Scientists	~500	International
3	Workshop	DLR	Aviation Turbulence Workshop	28-29 August 2013	Boulder, Colorado, USA	Scientists, Rulemaker (FAA)	~50	US
4	Conference	DLR	1st ECATS conference on 'Technical challenges for aviation in a changing environment'	18-21 November 2013	Berlin, Germany	Scientists	~150	European / International

NO.	Type of activities	Main leader	Title	Date/Period	Place	Type of audience	Size of audience	Countries addressed
5	Colloquium	DLR ICM	Aviation and turbulence in the free atmosphere	15 January 2014	London, UK	Scientists, students	~50	British plus 4 other countries
6	Press release and Online-Article	DLR	Greater safety in aviation – detecting turbulence in advance	5 August 2013	Online: http://www.dlr.de/dlr/en/desktopdefault.aspx/tabid-10081/151_read-7615	Public, journalists		International
7	Articles in Paper and Online Magazines	(based on DLR press release)	Luftturbulenzen erkennen	August through October 2013	More than 22 published articles	Public		German,Dutch, International
8	Conference	HVM	Cospar	2014	Russia	International scientists	100 +	International
9	Conference	FME	American Meteorological Society : Aviation, Range, and Aerospace Meteorology	26 February 2010	Los Angeles California USA	Scientific community	350	International
10	Conference	FME	European Turbulence Conference ECT13	12 September 2012	Warsaw Poland	Scientific community	450	International

NO.	Type of activities	Main leader	Title	Date/Period	Place	Type of audience	Size of audience	Countries addressed
11	Presentation	NLR	Research Colloquium	November 27,2013	Amsterdam, The Netherlands	Scientific Community	Approximately 40 persons	Netherlands
12	Presentation / paper	NLR	SFTE EC Symposium	15-18 June, 2014	Luleå, Sweden	Aeronautical community	Approximately 200 persons	European level
13	Conference	Gurvich, A. S.	SPIE: Free-Space Laser Communication and Atmospheric Propagation XXV	February 2, 2013	San Francisco, California, USA	Scientists		International
14	Wiorkshop: FP7 Transport call Baltic opportunity workshop	LDI	European Conference on Nanotechnologies	13.09.2011	Riga Technical University	Academic	30	Estonia, Lativa, Lithuania
15	Conference	K. Bajer	12 European Turbulence Conference	7-10 Sep 2009	Marburg, Germany	Scientific Community	400	20 countries
16	Presentation	K. Bajer	Education for Climate – Climate for Eduction	24 Oct 2009	Toruń, Poland	Teachers, Educators	30	Poland

NO.	Type of activities	Main leader	Title	Date/Period	Place	Type of audience	Size of audience	Countries addressed
17	Presentation	K. Bajer	Clear Air Turbulence – the DELICAT project	17 Apr 2010	Goniądz, Poland	Scientific community	50	Poland
18	Presentation	K. Bajer	DEmonstration of LIdar-based Clear Air Turbulence detection (DELICAT)	28 May 2010	Warsaw, Poland	Scientific community	20	Poland
19	Presentation	K. Bajer	Clear Air Turbulence – the DELICAT project	18 Mar 2011	Potsdam, Germany	Scientific community	70	16 countries
20	Presentation	K. Bajer	Turbulence in the sky and in a combustion chamber	12 May 20011	Gdańsk, Poland	Scientific community	50	8
21	Conference	K. Bajer	13 European Turbulence Conference	12-15 Sep 2011	Warsaw, Poland	Scientific community	450	35 countries

NO.	Type of activities	Main leader	Title	Date/Period	Place	Type of audience	Size of audience	Countries addressed
22	Presentation	J.M. Kopeć	Prediction of claear-air turbulence induced by short gravity waves by	12 Sep 2011	Warsaw, Poland	Scientific Community	60	International Audience
23	Presentation	J.M. Kopeć	Prediction of clear-air turbulence induced by gravity waves	22 Nov 2012	Reading, Great Britain	Scientific Community	10	Great Britain
24	Poster	J.M. Kopeć	Testing of a New Gravity Waves Based Clear-Air Turbulence Diagnostic	8 Jan 2013	Austin, USA	Scientific Community	Unknown – conference had 2000 participants	International, mainly USA
25	Conference	K. Bajer	14 European Turbulence Conference	1-4 Sep 2013	Lyon, France	Scientific community	480	34 countries

NO.	Type of activities	Main leader	Title	Date/Period	Place	Type of audience	Size of audience	Countries addressed
25	Presentation	J.M Kopeć	Forecasting of Clear-Air Turbulence Induced by Low Convective Clouds	12 Sep 2013	Reading, Great Britain	Scientific Community	50	Intrenational

4.3. PROJECT PUBLIC WEBSITE

The web site has been established by INOE and is available at the address: www.delicat-fp7.org or http://www.inoe.ro/DELICAT.

The web site includes a public part and a part only accessible to the partners (through a password).

The public part contains:

- A general description of the project,
- The list of the project deliverables,
- A presentation of the project objectives,
- A presentation of the different beneficiaries and their contributions to DELICAT, as well as a point of contact,
- The public presentations and documents prepared in the frame of the DELICAT project.

APPENDIX A : ACRONYMS

ADC	**A**nalogue to **D**igital **C**onversion
ADIRS	**A**ir **D**ata and **I**nertial **R**eference **S**ystem
AI	**A**pproved **I**nspectors
AMDAR	**A**ircraft **M**eteorological **DA**ta **R**elay
AOA	**A**ngle **O**f **A**ttack
ARINC	**A**eronautica**l** **R**adio, **Inc**orporated
ASL	**A**bove **S**ea **L**evel
ATM	**A**ir **T**raffic **M**anagement
BBO	**B**eta-**B**arium **B**orate ((β-BaB_2O_4)
BFA	**B**locking **F**ilter **A**ssembly
BS	**B**eam **S**teering
CAA	**C**ivil **A**viation **A**uthority
CAD	**C**omputer **A**ided **D**esign
CAS	**C**omputed **A**ir **S**peed
CAT	**C**lear **A**ir **T**urbulence
COAMPS	**C**oupled **O**cean / **A**tmosphere **P**rediction **S**ystem
DAM	**D**esign **A**ircraft **M**odification
DELICAT	**DE**monstration of **LI**dar based **C**lear **A**ir **T**urbulence detection
DEVG	**D**erived **E**quivalent **V**ertical **G**ust velocity
DIAL	**DI**fferential **A**bsorption **L**IDAR
DOW	**D**escription **O**f **W**ork
DPR	**D**esign **P**arts for **R**esearch work
DQE	**D**etective **Q**uantum **E**fficiency
ECMWF	**E**uropean **C**entre for **M**edium-Range **W**eather **F**orecasts
EDR	**E**ddy **D**issipation **R**ate
EGA	**E**xtraordinary **G**eneral **A**ssembly

ERA40	ECMWF re-analysis project 40 (meteorological reanalysis project)
FAA	**F**ederal **A**viation **A**dministration
FL	**F**light **L**evel
FPX	**F**ramework **P**rogram n°**X**
GPS	**G**lobal **P**ositioning **S**ystem
GWL	Dutch acronym for approval modification aerial vehicle
IAS	**I**ndicated **A**ir **S**peed
ICAO	**I**nternational **C**ivil **A**viation **O**rganisation
ICD	**I**nterface **C**ontrol **D**ocument
IR	**I**nfra-**R**ed
IRIG	**I**nter-**R**ange **I**nstrumentation **G**roup
IRS	**I**nertial **R**eference **S**ystem
IT	**T**urbulence **I**ndex
IWP	**I**nstrumentation **W**ork **P**ackage
JAR	**J**oint **A**viation **R**equirements
Kts	**K**no**ts** (1 knot = 1 Nautical mile per hour = 1.852 per hour)
LIDAR	**LI**ght **D**etection **A**nd **R**anging
LOS	**L**ine **O**f **S**ight
LSBB	**L**ow **S**peed **B**uffet **B**oundary
MMS	**M**aximum **M**anoeuvring **S**peed
MOS	**M**aximum **O**perating **S**peed
Nd:YAG	**N**eodymium-**d**oped **Y**ttrium **A**luminium **G**arnet
Nm	**N**autical **m**ile (1 Nm = 1.85 km)
NOAA	**N**ational **O**ceanic and **A**tmospheric **A**dministration (US)
NOHD	**N**ominal **O**cular **H**azard **D**amage
NWP	**N**umerical **W**eather **P**rediction
PBS	**P**olarising **B**eam **S**plitter
PMT	**P**hoto **M**ultiplier **T**ube

PO	**P**roject **O**fficer
PSD	**P**ower **S**pectral **D**ensity
RF	**R**andom **F**orest
RMS	**R**oot **M**ean **S**quare
ROC	**R**eceiver **O**perating **C**haracteristic
RVSM	**R**educed **V**ertical **S**eparation **M**anoeuvres
SFG	**S**um-**F**requency **G**eneration
SHG	**S**econd **H**armonic **G**eneration
SIGMET	**S**ignificant **M**eteorological **I**nformation
TAS	**T**rue **A**ir **S**peed
TBC	**T**o **B**e **C**onfirmed
TBD	**T**o **B**e **D**efined
THG	**T**hird **H**armonic **G**eneration
UM	**U**nified **M**odel
UV	**U**ltra-**V**iolet
WBS	**W**ork **B**reakdown **S**tructure
WP	**W**ork **P**ackage
WRT	**W**ith **R**espect **T**o