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FINAL PROJECT REPORTING

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

1 EXECUTIVE SUMMARY

1.1 Background and objectives

The AIDA project aims to provide an advanced airborne volcanic ash detection apparatus which will make use of special machine vision interrogation of volcanic ash (tephra) and novel image analysis software. The integrated retrofittable system will examine air in the aircraft's ventilation ducts. By interrogating foreign bodies in the fresh air entering the cabin and identifying the type, size and number of particles per unit time and inferring the presence of low level ash particles in the possible presence of other solids in the air e.g. sand, vapour etc. An early warning may be conveyed to the crew whence appropriate action may be taken to reduce the exposure of the aircraft, thus making possible enormous savings on maintenance costs.

The aviation sector is a growth market and as passenger and aircraft numbers increase, airspace will become increasingly congested. Volcanic activity is a regularly occurring natural event which generates ash clouds that can cover vast areas. This impacts on the safety of aircraft that are required to fly through or near these clouds.

The aim of project AIDA was to develop a self-contained detection and characterization system for real-time measurement of airborne volcanic ash concentration. This will provide pilots and aircraft operators with the required information to ensure safe operation in potentially hazardous environments and to minimise ash damage which in turn keeps downtime and maintenance costs down.

1.2 Outputs/Achievements

The AIDA prototype considers using pulsed polarised laser light alongside Surface feature analyses to detect and count volcanic ash particles amongst other airborne debris. The process uses a logic sequence which utilises polarised light for bi-refringence particle analyses initially classifying ash and not ash. The particles are then classified again using a front lit surface feature recognition system which looks for features such as vesicles which are inherent in volcanic ash particles.

Tests completed displayed the clear differences that can be seen between non-uniform silicates (such as sand and ash) and more uniform particles. Assessment of the classification algorithm was completed with a subset of the collected results. The results showed a 100% accuracy of classifying ash as 'ash' and a 95% accuracy of classifying sand as 'not ash'. This indicates that particle classification is successful, especially taking into account the fact that the error is distributed towards *false positives* rather than *false negatives*; the classifier does not miss volcanic ash particles which is a crucial condition to ensure safety.

1.3 Consortium Members

Greenbank Group UK, UK-ISRI, Innora, WLB, Lenis Global, AeroCARE and AeroSTAR.

Further Information

For further information on the AIDA project, please visit the projects main web site at: www.theaidaproject.eu

2 Project context and the main objectives

2.1 The context

Volcanic ash consists essentially of extremely fine particles of pulverized rock, the composition of which reflects the make-up of the lava inside the volcano. The composition of a volcanic ash cloud, therefore, varies from one volcano to another. However, on the whole an ash cloud is predominantly comprised of silica, together with smaller amounts of the oxides of aluminium, iron, calcium and sodium. The silica is in the form of glassy silicates which under the microscope resemble sharp-edged glass shards. This glassy silicate material is very hard, typically of level 5 or 6 on the Mohs scale, with a proportion of material of hardness equivalent to that of quartz (level 7), which in pulverized form is extremely abrasive. The abrasive nature of volcanic ash is very important in aviation due to its damaging effect on airframe structures, electrical, avionics, and most importantly engine components. In addition to its potential to cause a major aircraft accident, the economic cost of volcanic ash to international civil aviation is enormous - the total loss of aviation due to the 2010 eruption of Eyjafjallajökull is estimated at 1.7 billion Euros and a similar amount is thought to have been lost by the tourist service sector. This is because encounters with ash clouds involve numerous complete engine changes, engine overhauls, airframe refurbishing, window re-polishing and/or replacement and pitot-static system repair, and the inevitable loss of revenue due to aircraft down-time while the foregoing are accomplished. Delays to aircraft and their re-routing around volcanic ash clouds cause considerable expense to airlines that operate in regions prone to volcanic eruptions.

The opportunity we have identified which we believe provides a way of detecting low concentrations of volcanic ash in aircraft, whilst creating a business opportunity, is to produce an Ash Ingestion Detection Apparatus (AIDA). The system will also be of great value in the validation of other methods of ash detection. Further onward development may see the AIDA technology incorporated into more general air quality applications. The system makes use of special machine vision interrogation of airborne particles and novel image analysis software. The integrated retrofittable system will examine air in the aircraft’s ventilation/air conditioning ducts. This will provide a way of detecting low levels of ash in intake air without the need for invasive procedures on aero engines. By interrogating foreign bodies in the fresh air entering the cabin and identifying the type, size and number of particles per unit time and inferring the presence of low levels of ash particles in the possible presence of other solids in the air e.g.

sand etc. an early warning may be conveyed to the fight deck where appropriate action may be taken to reduce the exposure of the aircraft, thus making possible savings on maintenance costs. Such a product will provide a step change in the time response capability of aircrew, ground crew and airline maintenance and aid decision making processes. The system will be a major contribution to the provision of more reliable safety margins without resorting to over-zealous measures and reduced need for aircraft maintenance – two items that impinge most unfavourably on the economics of passenger air travel provision.

2.2 The objective

The AIDA project was setup to provide a means of determining the amount of Ash being ingested by an aircraft during its flight programme to provide ground crews and MRO organisations quantifiable data into how dirty and hazardous an aircraft has become. The biggest concern for the consortium, was the varying type, quantity and size of both volcanic ash particles, and also the presence of other airborne debris. A process of classification using birefringence was determined to be most suitable for the application.

The project was broken down into two major areas, the development of the hardware and the development of the classification algorithm. The hardware investigated the varying of laser intensity and wavelength alongside image resolution and capture quality. The main objective was to produce designs for and manufacture and source components for testing to provide a final arrangement. The optical and detector components were sourced and was assembled using a laboratory laser bench to determine the broad configuration. Some initial testing was undertaken and it soon became apparent that the volcanic ash which was sourced for testing did not show bi-refringence properties. Through further research, it was evident that the properties of volcanic ash varied dramatically depending on the way it was produced. To address this issue, the consortium integrated the optical method of birefringence analysis with particle surface feature recognition to generate a two-step classification algorithm. Thus allowing volcanic ash particles to be bi-refringent or non bi-refringent to still be classified positively. The development included testing with ash only and ash alongside desert dust and sand particles.

The algorithm was developed to take images of particles and provide a series of enhancements for and mathematical morphology to generate a classification system to identify volcanic ash particles. The bi-refringent analysis created a binary, yes or no to initially sift the particles into an immediate ash or possible ash environment. The particles were then analysed for surface features which looked for vesicles which is an inherent feature for all volcanic ash particles.

The overall outcome of the project was to generate a working prototype which integrated the hardware and classification algorithm into one unit which has a small foot print and does not impose a weight implication. Work packages were included to test the final prototype and also to identify a series of procedures and certifications required for real flight trials.

3 Potential impact and main dissemination activities and exploitation results

The focus of the AIDA project was predominantly on research, development, validation, verification, and creation of a prototype. The AIDA deliverables with outlining the main scientific outcomes have been kept confidential and have not been placed in the public domain. This decision is due need to patent the technology. There is currently a patent application in the process of search an examination phase. Applications for trademarks, registered designs etc. are to be listed hereafter. There are, however, several examples of concretely exploitable foreground below.

Boeing regularly publicises a current market outlook, which is an excellent reference source for market insights[1]. Today there are over 20,000 jet aircraft in operation with over 900 airlines. The top five largest fleets are in the USA, China, Russia, UK and Germany. Although the USA remains a major market, there is significant growth in other markets, mainly in Asia. There are a number of growth indicators used and the current indications are that passenger and cargo will average 5.0% growth per year for the next 20 years.

This growth will require 35,280 new aircraft, 41% will be replacement for older aircraft and 59% will be expansion of the fleets. The market value is $4,840billion according to Boeing. Europe is expected to require 7,460 new aircraft to give a fleet of 8,010 aircraft, 75% will be single aisle. Low cost operators are driving the growth with a requirement for efficient single aisle aircraft. This growth is expected to be effectively linear and equates to 1764 new aircraft per year

The impact and results of the project will be exploited by generating a prototype which is available for flight tests. The results of the flight tests will be disseminated as whole. The technology is restricted for dissemination until a successful patent has been filed.

The project has allowed the consortium to provide a proof of concept. It has been recognised that the technology, and some of its components should be protected. There for at this stage the consortium are in favour of avoiding the dissemination of technological achievements. Thus it is difficult to plan dissemination activities in detail.

Exhibition stands and/posters presentations will be used at Major European and worldwide conferences for the presentation of the project results to potential stakeholders.

The full size banners are being displayed in three areas on The Greenbank premises, in the reception area of both the main and the R&D offices as well as in the Sales and Business Development area. Banners are also displayed at ISRI and AeroCARE offices.

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[1] Boeing, Long-Term Market Forecast, http://www.boeing.com/boeing/commercial/cmo/

A patent is in the application process. With a reference of GAIDC/P57122GB with a patent attorney. The current draft has been critically reviewed and has returned minor technical verifications. A filed patent target date is May 2015.

4 Description of main Scientific and Technological results

4.1 The System Prototype overview

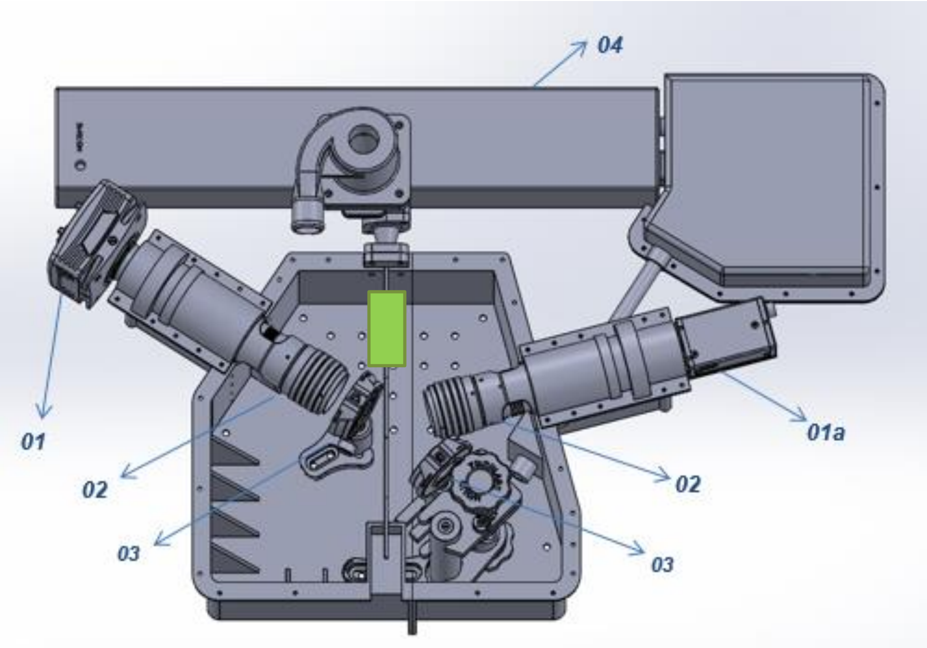
The final prototype as designed by the AIDA project prototype schematic is shown in figure 1. It included a cyclonic separator for slowing the particles and separating it from the main air flow (Air surrounding the aircraft at cruising speeds). A high speed pulsed laser for shuttering the images are captured by two high resolution magnification sets (camera and lens) for image capture, a pair of polarisers to observe any birefringence and various mirrors designed to direct the laser light to the targeted image capture at the intersection of the focal regions of the cameras and the particle flow path. In figure 1 in green are three photodiodes included to act as a bespoke trigger box. The trigger box contained three in-line diodes to view, confirm and verify the presence and speed of the same particle in order to accurately synchronise and trigger the system. Images of the prototype are shown in figure 2.

The optical system is constituted from the laser, polarising lenses, objective lens and camera, which are aligned using the adjustable mounts. The system is able to be calibrated with camera focus, objective lenses and laser adjustments, in order to create a well-focussed image in which small details can be seen.

The AIDA prototype system has a 2/3” b/w 5M pixel CCD sensor camera with a high-magnification zoom objective lens presenting up to 28 times magnification, providing a field of view 60 x 60 pixels per 10µm particle. This enables detailed surface feature capture within a narrow depth of field.

The optical system must be capable to image particles travelling at high speed; therefore, a shuttering system is required. The ideal maximum velocity movement parameter is 1%, and in order to accurately capture surface feature data, down to 1µm in size, the image must be captured in 36ps, and to specify the bounds of 10µm particle the image must be taken within 360ps with the particles travelling at the maximum speed of 280 m/s. The capture time is increased with the effect of the separator slowing the airflow.

Since this requirement is far beyond the technical capabilities of a mechanical shutter, a pulsed laser is required, which must present a frequency both triggerable and rate controllable. Sub-nanosecond lasers are available and with a pulse length of 500ps, a speed of 20m/s is required to achieve a 1% movement parameter. Thereby, the lower limit to the camera frame length defines the maximum pulse frequency as 0.5MHz and, as the system is expected to encounter 25 particles per second, a minimum frequency of 25Hz is defined. Therefore, fine focus is required to obtain detailed images, requiring extremely rapid pulses, 1ns and fine particle control.



REF	Component	Description
01a (right)	Camera	**Giganetix GC2441M,** 2/3" sensor, 5 MP,15 fps
01b (left)	Camera	**Thorlabs 1500M –GE,** 2/3" sensor, 1.4 MP, 23fps
02	Objective Lens	**Thorlabs high magnification zoom lens** 28 x magnification, 0.4mm FOV, 0.01mm DOF
03	Polarizing Lenses	
04	Laser	**Nano L 130-30 Nd:YAG pulsed Litron Laser,** 532 nm. 6 ns ulse

Table 1 - Major components and specification

Figure 1 – System Prototype

Figure 2 - Images of the system prototype

A schematic of the working system can be seen in figure 2.

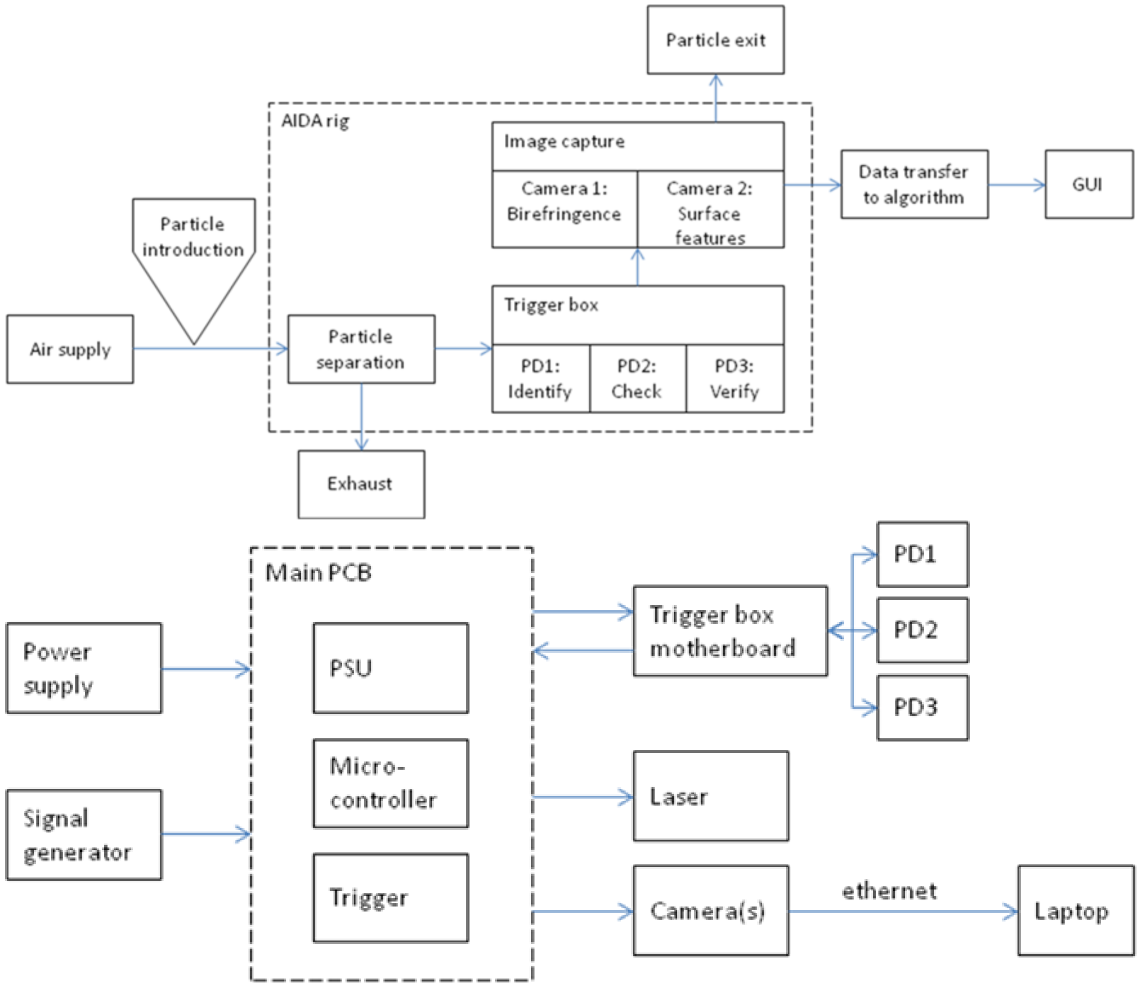


Figure 3- Prototype working schematic

4.2 The separation system

The AIDA project overcame the problem of sampling from high velocity ram air from around the aircraft by using a duel cyclone approach. Cyclonic separators can be used to separate particles of different mass which derives different inertial properties. This is carried out by introducing centripetal acceleration and separating out particles due to the difference in response rates the particles will exhibit. Conventional cyclones or high-efficiency cyclones are the most common design for the separation of particulate from a gas or fluid flow.

The primary flow pattern is the spin, or rotational flow, caused by the tangential inlet near the top of the device. While the air and particles are spinning and the particulate is being centrifuged towards the wall of the cyclone, it must travel first downward along the outside of the vessel then reverse direction and travel upward in the centre to exit the gas outlet pipe at the top. This flow pattern is often described as a double vortex consisting of an outer and an inner vortex. In reality though, the flow is a single vortex consisting of a continuous flow stream where the so called outer vortex is pulled within itself from the bottom up.

The separation of a particle from the gas stream is carried out by adequately creating the correct amount of centrifugal force applied to the mixture over an adequate amount of time for the particle to move to the wall of the cyclone. Since the AIDA project is dealing with very low concentrations the design must be able to transport the particle to lower outlet of the cyclone and successfully get it to stay within this zone. A critical factor determining cyclone efficiency is the residence time within the cyclone. The residence time describes the amount of time that is available for a particle to reach the lower outlet of the cyclone before the flow has exited the cyclone. Increasing cyclone diameter and length increases the residence time. The increase in the available time for collection of particles often results in an increase in the total collection efficiency despite some reduction in centrifugal force resulting from the increase in cyclone diameter. The centrifugal force exerted on a particle that is near the outside wall of the cyclone will be reduced if the cyclone diameter of the increases. However the separation of the particles primarily due to the velocity and radius of travel at the core of the vortex flow. Here the velocity and radius is primarily a function of the inlet and outlet velocities and geometry.

The physics of inertia are well known and it is relatively simple to predict the forces required to move a particle to the wall of the high-efficiency cyclone within a given residence time. This is described as theoretical collection. In practice, many particles that subsequently escape the high-efficiency cyclone and are emitted were transported to the wall of the device and into the collection area where they were subsequently re-entrained in the escaping gas flow thus losing the particle which is to be captured. This is an important factor for the AIDA project since any particle lost in particle separation, the particle will be a missed particle for capturing and classifying.

The axial, or secondary, flow pattern in the cyclone is downward along the outside of the high-efficiency cyclone assembly and upwards in the centre. This flow pattern is critical to the performance of a high-efficiency cyclone since we pneumatically transport particles from the top of the cyclone to the lower outlet then the air travels upwards to the upper outlet.

A common, but inaccurate, description of how a high-efficiency cyclone works often goes, “the particles are thrown towards the wall of the high-efficiency cyclone where they are slowed by friction and then fall into the receiver due to gravity.” While the particles do slow somewhat due to friction when they reach the wall of the cyclone, the flow patterns and forces placed upon the particles are many times greater than gravity. Often larger greater mass particles are transported to the lower outlet more slowly than smaller particles due to the particle’s inertia acting upon the sloped surface of the cyclone cone. Collected particles are pneumatically transported by the air stream to the bottom of the assembly in a fraction of the time compared to that of gravity.

Our aim in the cyclone separator was to get the particles to the bottom outlet with the correct tangential and axial velocities so that it remains their and is not re-entrained in the escaping gas flow. If the axial velocities or angle of attack are too great, re- entrainment increases. If they are too low, axial particle flow can become stagnant at some elevation in the high-efficiency cyclone. These particles will accumulate until the mass get large enough to disrupt the flow and they fall by gravity or they may be continuously re-entrained into the escaping gas flow. In either case, the probability of a plug occurring and unacceptable levels of cone erosion go up.

For these reasons, high-efficiency cyclone design is very complicated and it is impossible to accurately predict particle separation from purely theoretical models. The most accurate technique for predicting cyclone performance is the Theoretical-Empirical Method. Based on the maximum specification of the optical equipment there was a requirement to slow the particles down. A method of directing the particles into the imaging path and removing the fast moving particle laden air is carried out using dual cyclone systems. The cyclone technology reduced the fast moving air velocity from outside the air to a more manageable 100 m/s at the point of imaging. Figure 4 shows the design and an example of the CFD analysis completed.

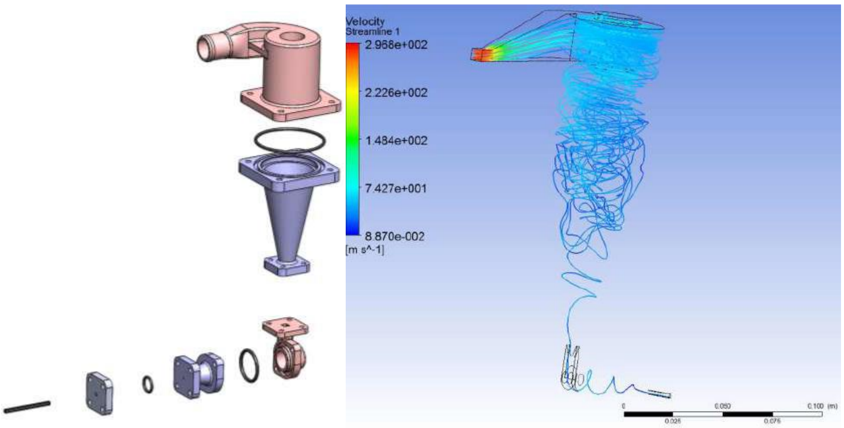


Figure 4- Dual Cyclone Separator with CFD air stream lines

The AIDA project developed a perpendicular duel cyclone arrangement which is used to both step down the velocity significantly from the outside air ram velocity, and also to ensure the particle location as it leaves the cyclone is in a known position. Figure 1. The duel cyclone technology can be adopted by any particulate separation technologies, particularly those involved in high to low velocity transitions.

4.3 Triggering

The PCB designed in the AIDA project controls the particle detection, synchronisation and triggering of the further particle classification stage. The trigger box is shown in figure 5.

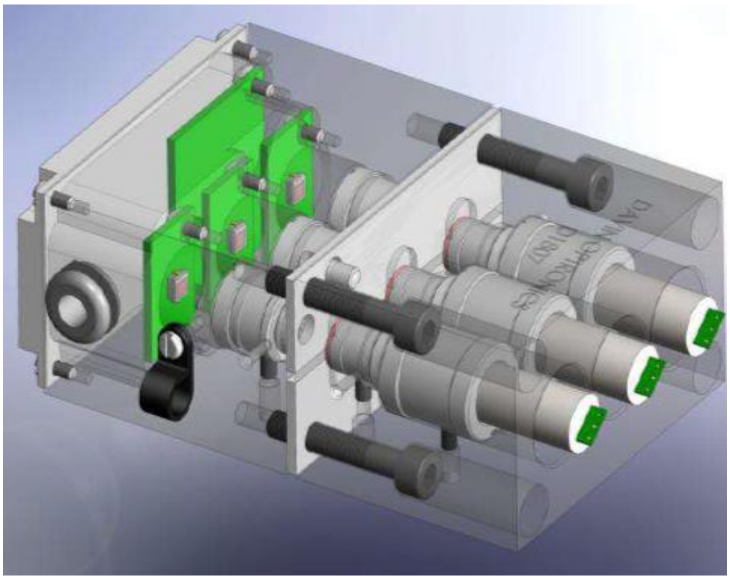


Figure 5- Design of the Trigger box,

A set of three photodiodes has been installed to account for the unknown variables of time and speed, thus an accurate trigger can be developed. Due to potential variability of the air supply rate the first pair of diodes will determine the time gap so flow rate and the second pair the speed so the trigger time can be calculated. As a particle passes through each of the laser beams, a portion of light is scattered and split onto one of the photo diode detectors. Provided the detected light is sufficient, a negative voltage is produced from the output of a highly sensitive trans-impedance amplifier. The signal is used to trigger the electronic circuit, in order to capture the video image from the linear arrays. A signal trace can be seen in Figure 6.

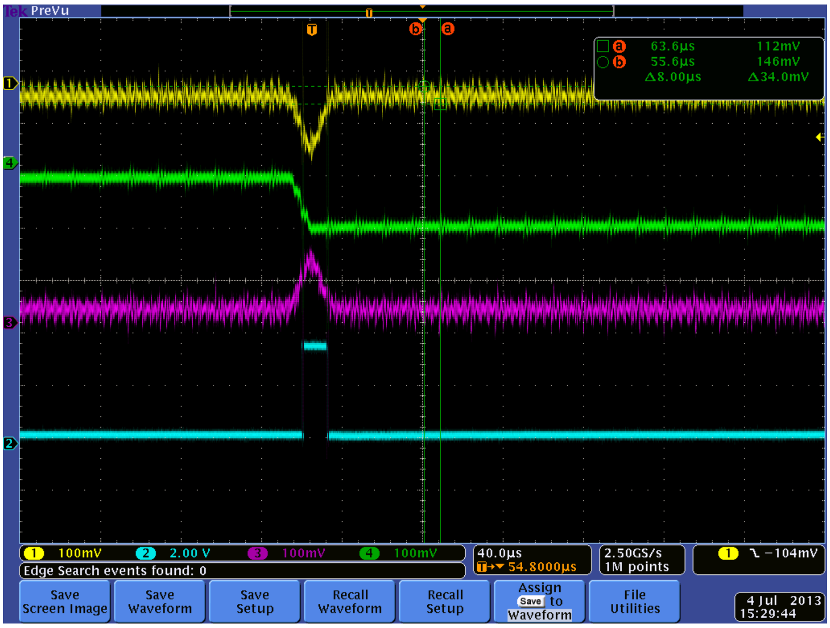


Figure 6- Example of Signal trace from Trigger box, showing particle detection

The PCB will control the particle detection and then synchronisation and triggering of the further classification stage. A set of three photodiodes has been installed to account for the unknown variables of time and speed, thus an accurate trigger can be developed. Due to potential variability of the air supply rate the first pair of diodes will determine the time gap so flow rate and the second pair the speed so the trigger time can be calculated.

As a particle passes through each of the laser beams, a portion of light is scattered and split onto one of the photo diode detectors. Provided the detected light is sufficient, a negative voltage is produced from the output of a highly sensitive trans impedance amplifier. The signal is used to trigger the electronic circuit, in order to capture the video image from the linear arrays.

The PCB is 130 x 130 mm as presented in figure 7 below, and it includes the power circuit, voltage monitoring circuit, microcontroller, trigger / synchronisation circuitry, and photodiode circuitry with the details in. The first PIN diodes are placed 3mm apart with the third ~ 3 cm further. A dedicated PCB is being produced to accommodate the requirements described, thus no diagrams are currently available. An analogue to digital conversion is also included. Power details outlined in table 2.

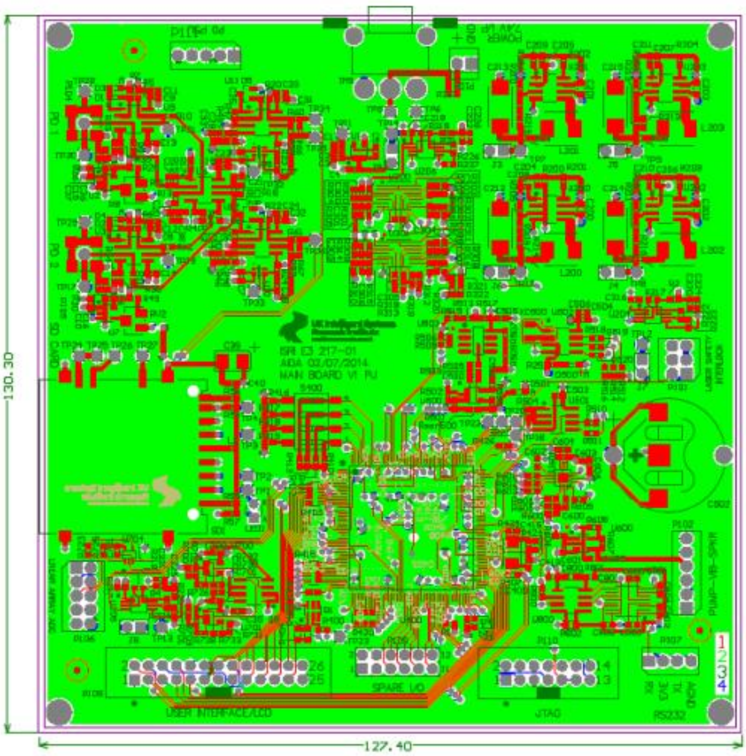


Figure 7 – PCB Electronic schematic

Power Circuit	7.4V @ 457mA = 3.38
	457 mA
Voltage monitoring circuit	+5V @ 20mA
Microcontroller	+1.9V, +3v3V @ 135mA
Photodiode circuitry	+5V @ 75mA

Table 2 - Electronic specification

This technology is a critical precision equipment. It can be used for other technologies which require dynamic particulate capture based on varying trigger times.

4.4 Laser Illumination and Imaging

To image particles travelling at high speed a shuttering system is required. The pulse frequency is able to be both triggerable and rate controllable as pulses of light occurring without a particles present will cause overexposure leading to a lower image quality. The lower limit to the camera frame length defines the maximum pulse frequency as 0.5MHz and, as the system is expected to encounter 25 particles per second, a minimum frequency of 25Hz is defined. This information can be used to image fast moving particles in many applications.

4.5 Particle detection and classification

The requirement of minimal computational complexity in order to achieve high execution speeds. Works in tandem with the illumination and image capture system to generate snapshots of high speed moving particles and process and them in situ.

Image Pre-Processing and Normalisation: Due its fast, straightforward execution and edge-preserving property, *Median Filtering* is considered as the optimal choice for noise elimination and has been implemented in this software module. The module contains *Linear Filtering* methods like average filtering for the sake of completeness. Image normalisation is accomplished by *Histogram Matching* in order for specific luminance abnormalities to be taken into account. *Histogram Equalisation* is also implemented in order for the software module to be as flexible as possible. Functions for Wiener filtering for motion blurring elimination will be considered for future addition, if they are deemed effective.

Image grey-Scale Differentiation: Low computational complexity of thresholding, taking into account the nature of the images the AIDA system is expected to handle, makes it an ideal choice for image segmentation. The grey-scale differentiation software module implements the Otsu’s method as the images are expected to be characterised by bi-modal histograms.

Image Segmentation: In order to keep the computational effort as low as possible, the segmentation of the image is accomplished by using a region – labelling method on the binary mask resulting from the previous software module in order to identify the distinct foreground regions corresponding to imaged particles.

Feature Extraction: The feature extraction software module implements various techniques to retrieve measures of features from various sources as discussed. More precisely, the following image features are extracted:

- Area and Perimeter in pixels
- Sphericity
- Mean and standard deviation of pixel intensities
- Textural features using Law's energy Measures method as well as Gabor Filters
- Additional shape features like Ferret diameters are also considered.

Classification**:** SVMs' speed in classification constitutes a significant advantage and makes them the best choice in this regard. Taking into account that this approach is the primary option described in the DoW, the corresponding software module is based on SVM methods.

High-Resolution images from the experimental static setup developed by ISRI were also used as test cases for the assessment of the Image Pre-processing module as well as the Gray-Scale differentiation module. Due to their limited number, testing on feature extraction and classification was deemed unnecessary since there were not enough particles to reliably evaluate the classification performance.

The Image Pre-processing module as well as the Gray-Scale differentiation module seems to generalize well in high-resolution images captured by the experimental static setup. This has to be validated for images from the actual dynamic setup currently under development by ISRI.

The Classification performance depends heavily on the selection of the features that will comprise the feature vectors. Based on the initial results, birefringence metrics are considered to be very important for the enhancement of classification accuracy because geometrical and texture features seem insufficient as evident by the low accuracy rates achieved so far. This is not unexpected since backlight illumination is unable to resolve particle surface texture. It is possible that laser illumination, being more powerful than microscope's white light source, will eventually achieve surface texture resolution. Feature recognition based on surface properties is a common application for many optical firms, and optical analysis systems. Promoting the use of this technology with bespoke volcanic ash applications in optical conferences will increase the knowledge of the AIDA equipment amongst peers.

The various software modules involve a lot of different parameters especially regarding grayscale differentiation, texture feature extraction and classification. Those will have to be finely tuned taking into account the specific nature of the images of the actual apparatus once the development of the dynamic setup is complete.

This feature extraction can be exploited across many industrial sectors. It has been of interest to Greenbank who work within the power industry. A possible application which has generated interest is within power plant stacks where the PM matter can be counted and classified from amongst liquid vapour.

4.6 Graphical user interface

The Graphical User Interface is simple and straightforward as per the required output determined by interface with our aviation partners. This is formation states “the grounds that a pilot should be given clear information without needing to exercise elaborate control”. The functionality of the GUI is summarized below:

Start Button: Starts the particle analysis application. The application runs continuously retrieving image frames from the camera hardware, investigating them and returning the number of Volcanic Ash Particles identified.

Stop Button: Stops the particle analysis procedure. The procedure can be resumed by clicking on Start Button.

Reset Button: Resets the particle number counter to zero and turns off the warning lights. Once the start button is clicked again the application will start counting from the beginning.

Particle Number Indicator: A text field reporting the number of volcanic particles identified by the system up to the current moment.

Warning Indicator: A “traffic light”- like indicator about the level of the threat posed by the volcanic ash particles that have been identified by the AIDA system. This is an intuitive way of informing the pilot about the current condition and specific instructions can be associated with each level.

In order to clarify the Graphical User Interface operation, a graphical representation of the various stages is provided below. The Graphical user interface is illustrated in the following figures 9 and 10.

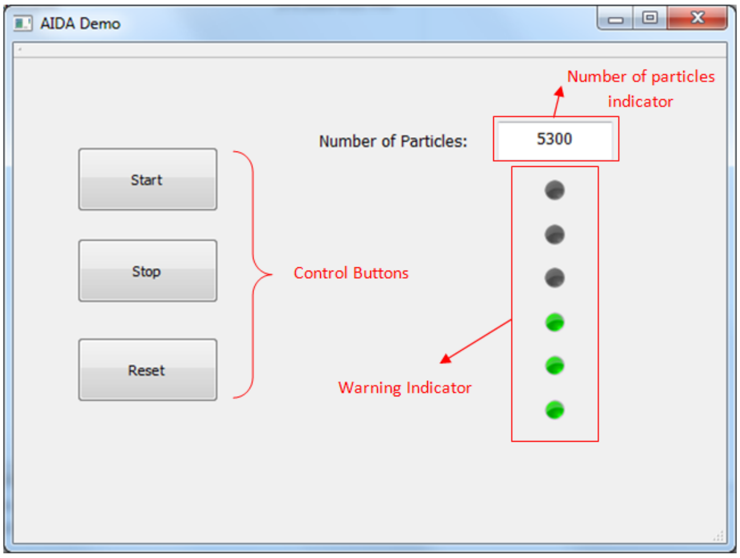


Figure 8 – AIDA Graphical User Interface

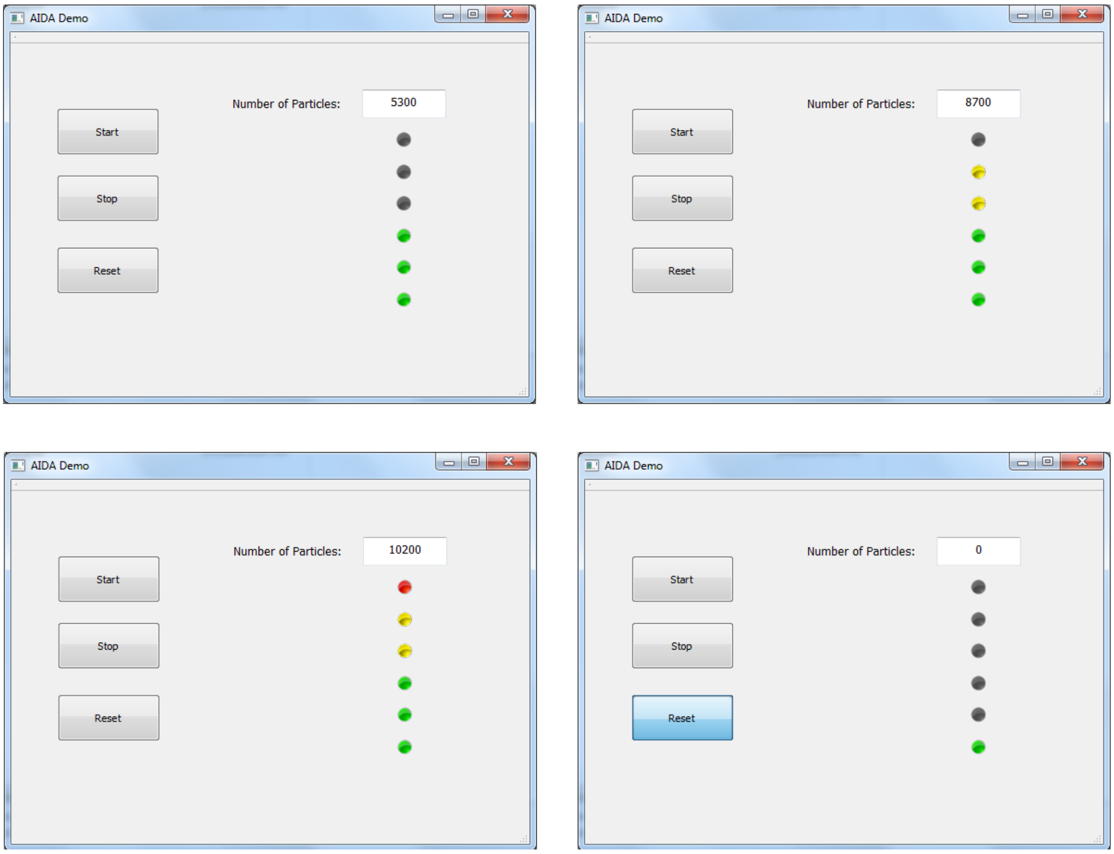


Figure 9- GUI operation: (top left), (top right), (bottom left), operation of the warning system for various particle numbers, (Bottom right) Reset operation: the particle number value is set to zero and the warning indicator is reset

4.7 Testing Results

Due to time constraints a restricted set of tests were undertaken in WP5. However, from the test results completed a series of particulate images were gathered and assessed by the algorithm, see Appendix.

The results showed a positive trend; of the 160 images analysed, 80 were of sand and 80 of volcanic ash, based on textural classification only (i.e. no birefringence data) there was a 0% error in ash identification and a 5% error in sand or 'not ash' classification. As the images collected were relatively noisy there is still work to be done both in image capturing (image clarity is absolutely necessary) and image processing (with respect to automatic particle segmentation) to fully automate the system.

Clean air was used to decontaminate the system between particulate type changes. However, over the longer term, with ash testing, it was shown that using low levels of particulates had no issues however the issue of dust ingress arose when higher loads were used. Some limited blocking was also seen though this may have been due to the small gaps where the pipe slotted into the system rather than too much ash. This was again solved with a strong blast of clean air.

A series of tests were run based on single particulate types, no mixed tests were completed. This alteration was justified as the algorithm was only able to assess single particles i.e. particle images are segmented from the base image then classified so there should be no difference in output based on the type of test run. Both heavy and light loading was investigated as well as the effects expected to be seen in long term testing.

Particles were injected using a syringe which was then continuously pumped to provide an air supply. By this method it was estimated that the particle flow rate was 2.5 m/s. An amount of particles were initially loaded into the system and air supplied until the system was empty, this caused a gradual decrease in particulate concentration. An initial amount of 1 ml was used. Figures 10 and 11 show the difference between images captured of heavy and light loads.

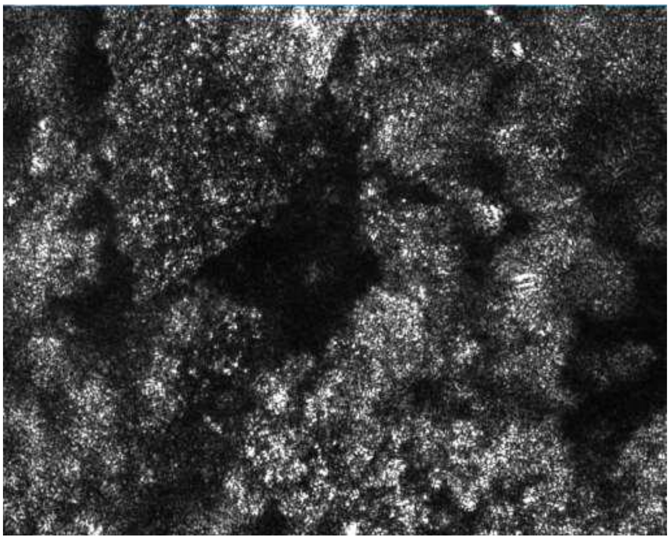


Figure 10- Heavy load of ash

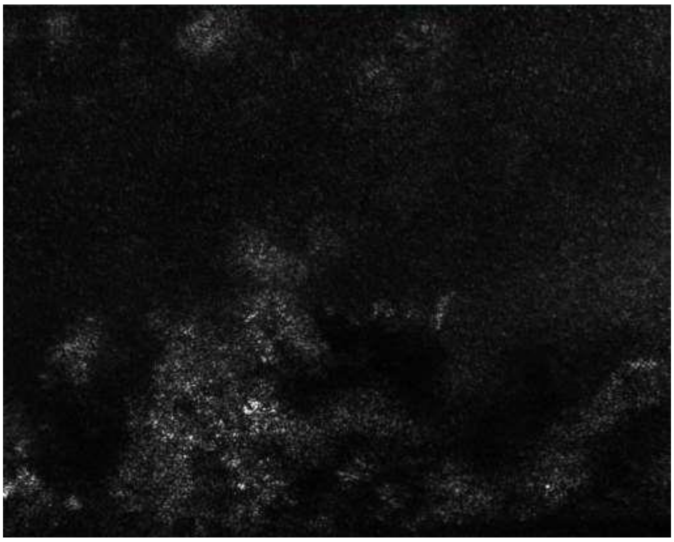


Figure 11 - Light load of ash

The flow pipe was cleaned with a blast of air after every run. The purpose was two-fold one, to prevent particulate contamination and two, to remove any settled dust both in and outside the pipe. Because of the low flow rate a number of larger particles remained in position over a number of frames and sometimes required additional air bursts to clear them. This was much less likely to occur at faster flow rates. Due to the nature of injection, despite best efforts dust ingress was still seen with dust settling on the pipe. This was an issue as it was possible to focus on this rather than flowing dust and any settled dust also affected the background scatter. Long term tests showed of low levels of particulates had no issues however the issue of dust ingress arose when higher loads were used. Some limited blocking was also seen though this may have been due to the small gaps where the pipe slotted into the system rather than too much ash. This was again solved with a strong blast of clean air. The AIDA particle classification technique was validated against a set of particle images segmented from the image sets captured by the AIDA dynamic setup. An rbf-kernel SVM was trained and used for the classification. The parameters of the classifier were fine-tuned upon the image set by means of cross-validation. The results showed promise; of the 160 images analysed, 80 were of sand and 80 of volcanic ash, based on textural classification only (i.e. no birefringence data) there was a 0% error in ash identification and a 5% error in sand or 'not ash' classification.

A subset of the training set is presented in Figure 12.

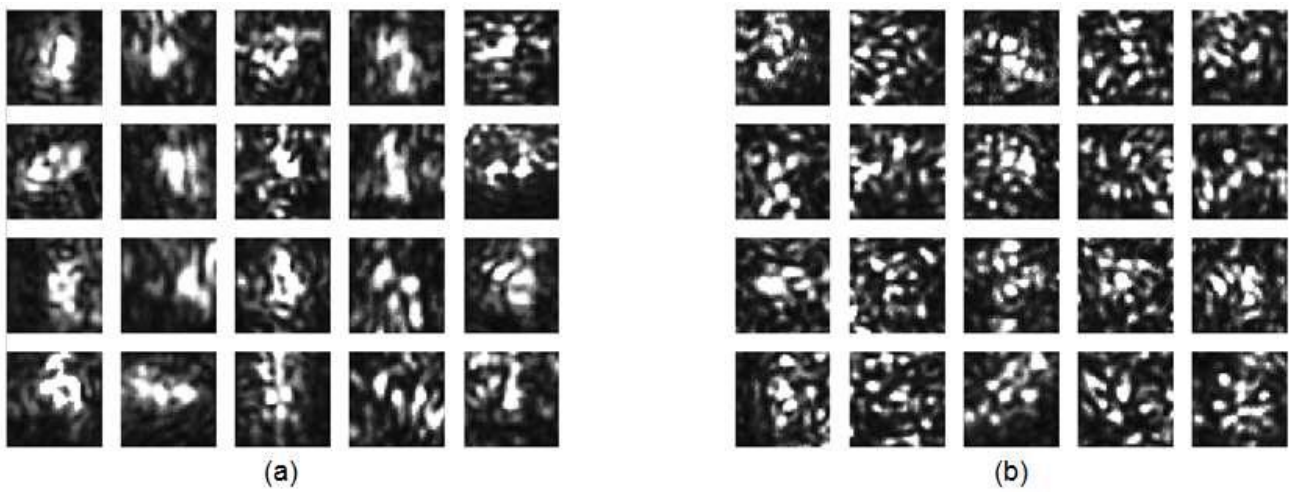


Figure 12- Particle images used as a training set for the SVM classifier. (a) Volcanic Ash, (b) Sand

The above results indicate that particle classification was extremely successful, especially taking into account the fact that the error was distributed towards false positives rather than false negatives; the classifier did not miss volcanic ash particles which was a crucial condition to ensure safety, since misclassifying volcanic ash particles as harmless could prove much more costly than misclassifying sand particles as harmful.

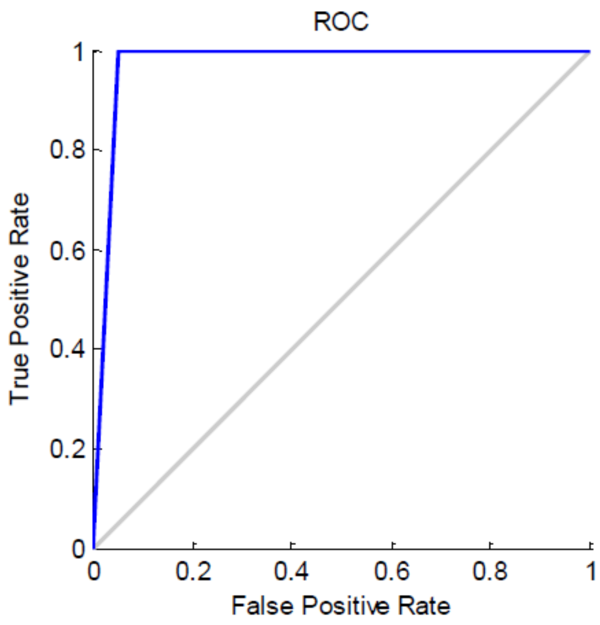


Figure 13- Receiver operating characteristic as a result of the test particle classification

The Figure 14 provides a graphical representation of the results of the SVM training, including the classification boundary. Though the results were promising it was important to note that further improvements would be required in order to fully automate the system. For the classification above, due to the time constraints, particle segmentation was performed manually. As the images collected were relatively noisy there is still work to be done both in image capturing (image clarity is absolutely necessary) and image processing (with respect to automatic particle segmentation).

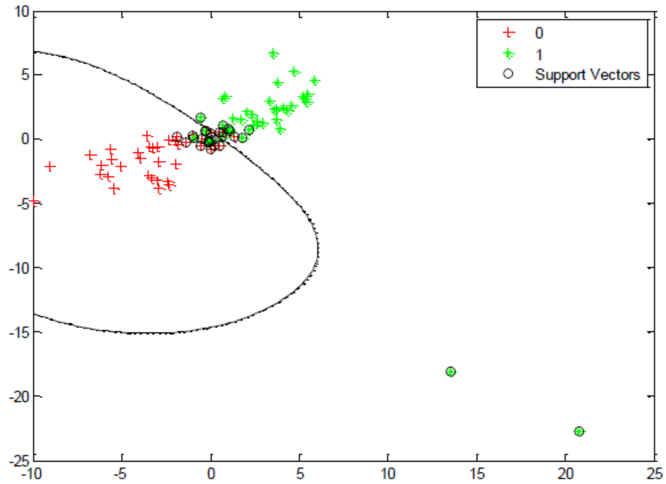


Figure 14- SVM training results: classification labels, support vectors and classification boundary

4.8 Dissemination activities to date

4.8.1 Website

A project web site was set up as part of Work Package 1, Deliverable 1.1 and a report on the completion of this deliverable has been prepared and submitted The website will be used as a central point of contact open to the partners for file sharing and holding discussions; it is also used for publicising the project and the dissemination of information about the project and the individual collaborators to all stake holders and the general public.

Search engine optimisation (SEO) is a key to the strategy used by consortium for optimising the exposure of the website to interested parties utilising search engines to locate the site.

The web site domain name http://www.theaidaproject.eu/ has been secured. In the first quarter of the project the website was set up and will be maintained throughout the duration of the project.

- There is a home page with a high level description of the issue and the value proposition.
- The project page contains an outline of the project.
- The partners page identifies key partners and outline project management structure.

Dissemination activities including news, event, papers and publications are on the News and Events page or Publications page. The initial consortium meeting is the first news items shown. No publications are listed at present.

The Web site contains a confidential area for the consortium members and project beneficiaries

4.8.2 Trade Shows

Over the last 2 years Greenbank has been attending Power and Energy related clients, conferences and exhibitions to show off the range of work that Greenbank carries out. This includes the mentioning of FP7 projects and specifically the AIDA project. Looking forwards it has been recognized by the consortium and some of Greenbank's clients that the even though the application is unrelated, the technology can be, and critically transferred to suit the power industry. The trade shows attended have included the following:

- Power Gen – Russia 2013
- Power Gen – India 2013
- Russia Power – Russia 2014

Greenbank attended the Russian power trade show to demonstrate its expertise in technology to the Russian engineering community. Visitors to the stand included members of the Russian design institute who had particular interest in particle sizing technology. The AIDA technology was described and could be a transferrable technology to the power industry.

4.9 Publishable Materials – Brochures, Flyers, Exhibition Banner

Exhibition stands and/posters presentations will be used at Major European and worldwide conferences for the presentation of the project results to potential stakeholders.

The full size banners are being displayed in three areas on The Greenbank premises, in the reception area of both the main and the R&D offices as well as in the Sales and Business Development area. Banners are also displayed at ISRI and AeroCARE offices.

Figure 15 – AIDA banner

4.9.1 Press Release

The list of papers / publications which have been published are shown in the table below.

No	Title	Main Author	Title of periodical or the series	Number, date or frequency	Publisher	Place of publication	Year of publication	Open access to publication provided
1	Greenbank 60th Anniversary	QED PR	Derby Evening Telegraph	19/02/14		Derby	2014	Y
2	AIDA Article	Stephen Harris	On-board device helps prevent volcanic ash damage to air craft	06/10/14	The Engineer	Online	2014	Y

Table 3- Press release activities

A General Press release was issued to the Derby Telegraph highlighting Greenbank's work and the coordination of the AIDA project. The release also combined a 60 year anniversary describing the company's evolution through the years.

Greenbank is a key global leader in the design and manufacture of products and services for industries

By **Derby Telegraph** | Posted: February 19, 2014 By oastley@derbytelegraph.co.uk

Today marks the 60th anniversary of the foundation of Derbyshire power station technology and manufacturing firm the Greenbank Group. Oliver Astley looks back at its history.

IT all began with a briefcase, a sixpence and two Lancastrian entrepreneurs.

Sixty years later, managing director Charles Conroy accompanied the Prime Minister on a trade mission to China.

Today marks the 60th anniversary of the foundation of Derbyshire power station technology and manufacturing firm the Greenbank Group. Oliver Astley looks back at its history.

IT all began with a briefcase, a sixpence and two Lancastrian entrepreneurs.

Sixty years later, managing director Charles Conroy accompanied the Prime Minister on a trade mission to China.

And the company is diversifying, having been selected for research that could save the aviation industry millions of euros.

Over the past six decades, the Greenbank Group has become a global leader in the design and manufacture of products and services for industries such as power generation and bulk-handling industries including cement, steel, paper and glass.

It has always had a significant research and development department, now turning its expertise towards an innovative volcanic ash detection system.

The company is managing a consortium of European firms as part of Project AIDA, standing for Ash Ingestion Detection Apparatus.

Aimed at alerting aircraft maintenance crews to possible ash contamination within engines, the technology stems from Greenbank's experience detecting particles that can render power stations less efficient.

Funded by the European Union, the two-year project is now entering a critical phase, with partners from across the continent working towards a prototype system.

Dr Neetin Lad, Greenbank's research and development contract manager, said: "Over the past 12 months the consortium has established the science behind the new technology, which is able to distinguish between volcanic ash and more common high-altitude airborne contaminates such as sand or dust.

"Ash is particularly damaging to an aircraft due to the shape of the particles, which can be very abrasive. Turbine blades in the engine can also be damaged when the ash melts and then solidifies."

The full-scale prototype is now taking shape. It uses sophisticated imaging technology to analyse air in the aircraft's ventilation ducts to identify the type, size and number of particles present.

This data can then be downloaded on landing, enabling engineers to decide what action needs to be taken.

At its headquarters in Woodville, Greenbank invests heavily in research and development alongside its other operations, including the supply and manufacture of wear-resistant lining systems, electricity-generating combustion-monitoring equipment and continuous weighing products for materials and bulk-handling systems.

Managing director Charles Conroy said: "We are delighted to be leading this project, and the involvement of a Derbyshire firm reflects the wealth of technological expertise in the county.

"Project AIDA brings together experts from across the continent to address an issue brought into sharp focus by the 2010 eruption of the Eyjafjallajokull volcano in Iceland, which was estimated to cost the aviation industry around 1.7 billion euros.

"If an aircraft has been in contact with an ash cloud, this system will enable airlines and maintenance crews to make an informed decision on the most appropriate maintenance or repairs, which can save money and, more importantly, lives."

Others involved in the project include Lenis, a Turkish company that will supply plastic parts fo the system; Greek automation and robotics specialists Innora; Cypriot software consultants WLB; and AeroCARE, a UK firm in Warrington.

The project has drawn on the capabilities of the UK Intelligent Systems Research Institute in Melton Mowbray, part of a network of research-led organisations that work to develop ground breaking technology across Europe.

Greenbank was asked to lead the project after its research and development team worked on a initiative aimed at developing particle-sizing technology used for emission control systems in coal-fired power stations.

It is all a far cry from the early days of the company.

Figure 16 - An extract from the whole article which focuses on the AIDA project.
http://www.derbytelegraph.co.uk/Greenbank-key-global-leader-design-manufacture/story-20656765-detail/story.html#ixzz2tqcENS5h

As well as this, a general Press release for the AIDA project was produced on 30/1/2014 and issued to several Aviation Industry Publications as listed below. These are being reviewed and we await notification of any publications through our media contacts.

Contact will continue with our PR representative with the publishers on a regular basis to check on the likelihood of publishing articles promoting the technology in their publications.

GREENBANK
Enhancing Performance

PRESS RELEASE

30 JANUARY 2014 – FOR IMMEDIATE USE

EUROPEAN FIRMS JOIN FORCES TO DEVELOP ASH CLOUD DETECTION SYSTEM

A consortium of European companies is set to save the aviation industry millions of euros by developing an advanced volcanic ash detection system.

Led by a UK-based engineering firm, The Greenbank Group, Project AIDA (Ash Ingestion Detection Apparatus) will develop technology alerting maintenance crews to possible ash contamination.

Funded by the European Union, the two-year project is now entering a critical phase, with partners from across the continent working towards a prototype system.

Dr Neetin Lad, Research and Development Contract Manager at Greenbank, explained: "Over the past twelve months the consortium has established the science behind the new technology, which is able to distinguish between volcanic ash and more common high altitude airborne contaminates such as sand or dust.

"Ash is particularly damaging to an aircraft due to the shape of the particles, which can be very abrasive. It can also damage turbine blades by melting and solidifying on the blade surface.

"If this build up is not detected, this glassy material can be dislodged and drawn into the engine, causing catastrophic effects."

When an aircraft flies through an ash cloud, it is also possible for the entire fuselage to be contaminated, causing damage to instrument panels and circuit breakers.

In some cases the electrical and avionics units can be so heavily contaminated that complete replacement is necessary, whilst ash in the cargo-hold fire-warning system can generate nuisance alarms.

"We are now moving to the next stage of development with the creation of a full scale prototype of the system that can be retrofitted to an aircraft," said Dr Lad. "It will analyse air in the aircraft's ventilation ducts, identifying the type, size and number of particles present using sophisticated imaging technology.

"The data can then be downloaded on landing, enabling engineers to decide what action needs to be taken."

The system is bringing together a number of companies from across Europe with expertise in relevant fields.

At its headquarters in Woodville, Derbyshire, Greenbank invests heavily in research and development alongside its other operations, including the supply and manufacture of wear resistant lining systems, electricity generating combustion monitoring equipment and continuous weighing products for materials and bulk handling systems.

It was appointed to a project management role after its R&D team worked on a separate initiative aimed at developing particle-sizing technology used for emission control systems in coal-fired power stations.

Other companies involved include: Lenis, a Turkish company that will supply plastic parts for the system; AeroSTAR SA, which is based in Romania and provides aircraft maintenance services; Greek automation and robotics specialists Innora; Cypriot software consultants WLB; and AeroCARE, a UK company involved in the design and fitting of aircraft interiors from its facilities in Warrington.

The project has also drawn on the capabilities of the UK Intelligent Systems Research Institute in Melton Mowbray, which is part of a network of research-led organisations that work to develop ground-breaking technology solutions across Europe.

Charles Conroy, Greenbank Managing Director, added: "We are delighted to be leading a project that brings together experts from across the continent to address an issue brought into sharp focus by the 2010 eruption of the Eyjafjallajokull volcano in Iceland. At this time the loss to the aviation industry was estimated at around 1.7 billion euros as aircraft across Europe were grounded as a precaution.

"The development of this system will enable airlines and maintenance crews to determine whether an aircraft has been in contact with volcanic ash and, if so, how much. With this information they can make an informed decision on the most appropriate maintenance or repairs, which can save money and more importantly, lives."

END

For further information please contact: Richard Horsley or Martin Farrow at QED Public Relations Ltd on 0115 944 3123.

Figure 17 – Press release article for Made in the midlands January edition

Use of social networking sites such as facebook and twitter are receiving hits and interest. Also Greenbank's own website is also promoting the project explaining the technology to a wide audience.

Figure 18 - https://www.facebook.com/photo.php?fbid=568631383229021

GREENBANK Enhancing Performance

The Greenbank Group UK

Wear Protection, Combustion Technologies, Continuous Weighing

Home | About Us | Terotech Heavy Industrial | Systems | Materials Handling | GAIM | News | Contact Us | Careers | Download | Search

Overview

Top 5 News Articles

Greenbank's R&D is Flying High
13 January 2014

Greenbank secures breakthrough commercial agreements on Prime Minister's trade mission to China
05 December 2013

Greenbank Nominated for National Award for Export
02 October 2013

GravMaster Brochure Released
20 September 2013

Jonny in the Blues
09 September 2013

News Archive

News archive 2014
News archive 2013
News archive 2012
News archive 2011
News archive 2010
News archive 2009
News archive 2008
News archive 2007
News archive 2006
News archive 2005

Greenbank's R&D is Flying High

Project AIDA will deliver an advanced detection technology which will give real time information on the air quality in the airspace the aircraft will pass. The data can be used to guide maintenance which can reduce failures and reduce false alarms from fire monitoring equipment. It will inform the pilots whether they are flying through high concentrations of dust enabling them to take mitigating actions.

The AIDA project aims to provide an advanced airborne volcanic ash detection apparatus which will make use of special machine vision interrogation of volcanic ash (tephra) and novel image analysis software. The integrated retrofittable system will examine air in the aircraft's ventilation ducts. By interrogating foreign bodies in the fresh air entering the cabin and identifying the type, size and number of particles per unit time and inferring the presence of low level ash particles in the possible presence of other solids in the air e.g. sand etc an early warning may be conveyed to the crew whence appropriate action may be taken to reduce the exposure of the aircraft, thus making possible enormous savings on maintenance costs.

The aviation sector is a growth market and as passenger and aircraft numbers increase, airspace will become increasingly congested. Volcanic activity is a regularly occurring natural event which generates ash clouds that can cover vast areas. These impacts on the safety of aircraft that are required to fly through or near these clouds.

The aim of project AIDA is to develop a self-contained detection and characterization system for real-time measurement of airborne volcanic ash concentration. This will provide pilots and aircraft operators with the required information to ensure safe operation in potentially hazardous environments and to minimise ash damage which in turn keeps downtime and maintenance costs down.

Aircraft frequently encounter volcanic ash when airborne. In the aftermath of these encounters, virtually the entire fuselage of an aircraft can be contaminated with ash, necessitating a thorough cleaning of the cockpit, instrument panel, circuit breaker panels, passenger and baggage compartments. The electrical and avionics units can be so heavily contaminated that complete

Figure 19 –Evidence of live news, http://www.greenbankgroup.com/live/news/news79.asp

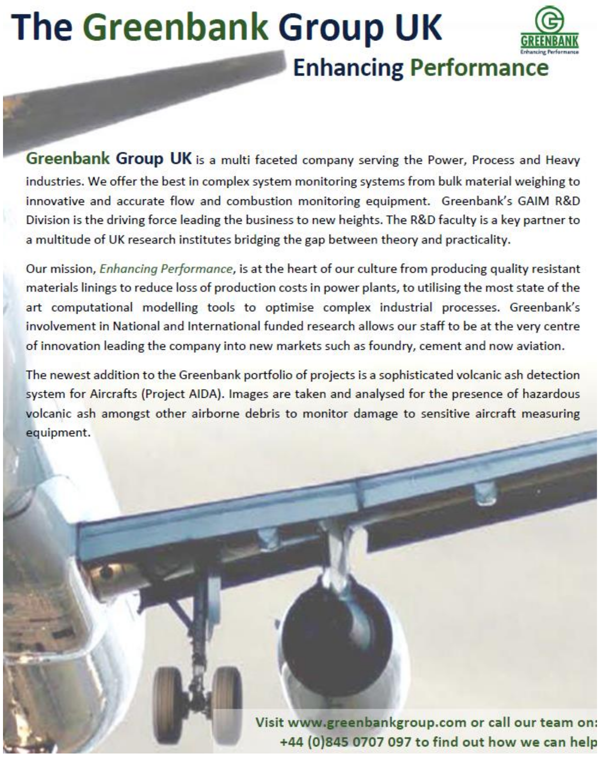


Figure 20 - MADE IN THE UK magazine for the October edition.

4.9.2 WIKI page

A wiki page was created to disseminate via a Wikipedia page the Project and an outcome of the results.

The link for the article is below:

https://en.wikipedia.org/wiki/Ash_Ingestion_Detection_for_Aircraft_(AIDA)

The text uploaded is as follows:

"Aircraft are susceptible encounters with volcanic ash particles during flight. The volcanic ash particles which are ingested can easily contaminate the fuselage of the aircraft. The contamination will necessitate the cleaning of the cockpit electronics and panels, panels, circuit breaker panels and passenger and baggage compartments. The electrical and aircraft avionics systems can be so heavily be covered with volcanic ash particles to the point where a complete replacement is required, due to over heating or diminished accuracy of the equipment. The ash can be drawn into cargo-hold and affect the fire-warning system and can cause spurious alarms. The ash itself is hazardous to the engines by melting and solidifying as a glassy material on the turbine blades, affects the small tolerances which make the turbine efficient. The glassy material which is formed on the blades also has the possibility of shattering and throwing hard debris through the engine which can cause damage.

An EU FP7 project was setup between a consortium of partners: Greenbank Group UK, Intelligent Systems Research Institute, Innora, WLB, Lenis Global, AeroCARE and AeroSTAR. The project delivers an advanced airborne volcanic ash detection prototype which uses bespoke machine vision interrogation of volcanic ash and an intelligent image analysis algorithm to classify the a cluster of debris into ash and not ash.

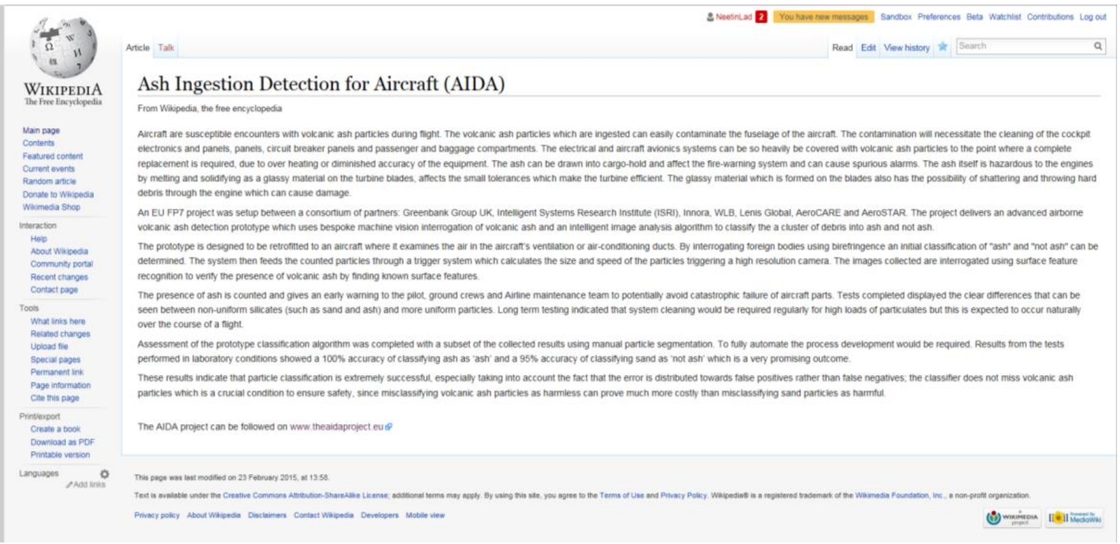
The prototype is designed to be retrofitted to an aircraft where it examines the air in the aircraft's ventilation or air-conditioning ducts. By interrogating foreign bodies using birefringence an initial classification of ash not ash can be determined. The system then feeds the counted particles through a trigger system which calculates the size and speed of the particles triggering a high resolution camera. The images collected are interrogated using surface feature recognition to verify the presence of volcanic ash by finding known surface features.

The presence of ash is counted and gives an early warning to the pilot, ground crews and Airline maintenance team to potentially avoid catastrophic failure of aircraft parts.

Tests completed displayed the clear differences that can be seen between non-uniform silicates (such as sand and ash) and more uniform particles. Long term testing indicated that system cleaning would be required regularly for high loads of particulates but this is expected to occur naturally over the course of a flight. Assessment of the classification algorithm was completed with a subset of the collected results using manual particle segmentation so to fully automate the process development would be required. Results showed a 100% accuracy of classifying ash as 'ash' and a 95% accuracy of classifying sand as 'not ash' which is a very promising outcome."

The above results indicate that particle classification is extremely successful, especially taking into account the fact that the error is distributed towards *false positives* rather than *false negatives*; the classifier does not miss volcanic ash particles which is a crucial condition to ensure safety, since misclassifying volcanic ash particles as harmless can prove much more costly than misclassifying sand particles as harmful.

Evidence of the uploaded page is identified in Figure 21.


Ash Ingestion Detection for Aircraft (AIDA)

From Wikipedia, the free encyclopedia

Aircraft are susceptible encounters with volcanic ash particles during flight. The volcanic ash particles which are ingested can easily contaminate the fuselage of the aircraft. The contamination will necessitate the cleaning of the cockpit electronics and panels, panels, circuit breaker panels and passenger and baggage compartments. The electrical and aircraft avionics systems can be so heavily be covered with volcanic ash particles to the point where a complete replacement is required, due to over heating or diminished accuracy of the equipment. The ash can be drawn into cargo-hold and affect the fire-warning system and can cause spurious alarms. The ash itself is hazardous to the engines by melting and solidifying as a glassy material on the turbine blades, affects the small tolerances which make the turbine efficient. The glassy material which is formed on the blades also has the possibility of shattering and throwing hard debris through the engine which can cause damage.

An EU FP7 project was setup between a consortium of partners: Greenbank Group UK, Intelligent Systems Research Institute (ISRI), Innora, WLB, Lenis Global, AeroCARE and AeroSTAR. The project delivers an advanced airborne volcanic ash detection prototype which uses bespoke machine vision interrogation of volcanic ash and an intelligent image analysis algorithm to classify the a cluster of debris into ash and not ash.

The prototype is designed to be retrofitted to an aircraft where it examines the air in the aircraft's ventilation or air-conditioning ducts. By interrogating foreign bodies using birefringence an initial classification of "ash" and "not ash" can be determined. The system then feeds the counted particles through a trigger system which calculates the size and speed of the particles triggering a high resolution camera. The images collected are interrogated using surface feature recognition to verify the presence of volcanic ash by finding known surface features.

The presence of ash is counted and gives an early warning to the pilot, ground crews and Airline maintenance team to potentially avoid catastrophic failure of aircraft parts. Tests completed displayed the clear differences that can be seen between non-uniform silicates (such as sand and ash) and more uniform particles. Long term testing indicated that system cleaning would be required regularly for high loads of particulates but this is expected to occur naturally over the course of a flight.

Assessment of the prototype classification algorithm was completed with a subset of the collected results using manual particle segmentation. To fully automate the process development would be required. Results from the tests performed in laboratory conditions showed a 100% accuracy of classifying ash as 'ash' and a 95% accuracy of classifying sand as 'not ash' which is a very promising outcome.

These results indicate that particle classification is extremely successful, especially taking into account the fact that the error is distributed towards false positives rather than false negatives; the classifier does not miss volcanic ash particles which is a crucial condition to ensure safety, since misclassifying volcanic ash particles as harmless can prove much more costly than misclassifying sand particles as harmful.

The AIDA project can be followed on www.theaidaproject.eu

This page was last modified on 23 February 2015, at 13:58.

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Figure 21 – Evidence of AIDA Wikipedia page.

Greenbank will continue to monitor the page and add any new data or project progression going forwards. The wiki article will be limited to not give away any IP or technical details.

4.9.3 Non-Confidential Company Discussions – Company visits

Greenbank's visit to AeroSTAR one of the largest aviation MRO's in Romania to discuss where the AIDA prototype will be situated on the aircraft.

Greenbank also visited AeroSTAR's heavy maintenance base (Part 145) which included the two hangers dedicated to the maintenance of the Boeing 737, Airbus 320 family and the Bae-146/RJ as shown in figure XX

Greenbank and AeroSTAR are working closely to create a road map to commercialisation.

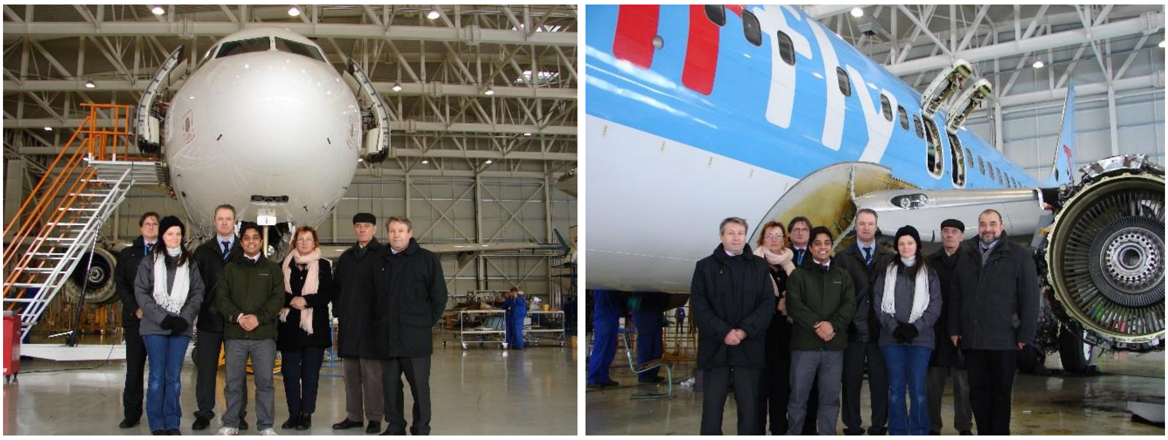

Figure 22- Greenbank and ISRI visit AeroSTAR, Romania

Left picture from the left

Anton Pal Aerostar, Head of R& D Dept.
Doina Matanie Aerostar, Head of Marketing Dept
Tiberiu Mocanu Aerostar, R&D/ Avionics
Neetin Lad Greenbank, Contracts Manager
Steve Whitby Greenbank, Business Development Manager
Victoria Collins PERA- ISRI,UK , Projects Manager
Sorin Petras Aerostar, Quality Director
Ovidiu Buhai Aerostar, Director- Aviation MRO & Upgrades Div.

Right Picture From the left

Tiberiu Mocanu Aerostar, R&D/ Avionics
Victoria Collins PERA- ISRI,UK , Projects Manager
Steve Whitby Greenbank, Business Development Manager
Doina Matanie Aerostar, Head of Marketing Dept
Sorin Petras Aerostar, Quality Director
Anton Pal Aerostar, Head of R& D Dept.

4.9.4 Publish Papers, Conferences / Exhibition Attendance

The exploitation of AIDA will occur in the phases detailed below through the Trade publications, National & European media;

Aerospace Testing International
Aerospace
(SAE International) Aerospace Engineering
AFM-Airline Fleet Management
Aircraft Interiors International
Air International
Airline Business
Airlines International
Airliner World
Aviation News
Aviation Insurance & Risk Management
Aviation Maintenance
Aviation Safety
Aviation Today (As Avionics)
Aviation Week & Space Technology
Avionics Magazine
Flight International
Jane's Aircraft Component Manufacturers
Jane's Avionics

Table 4 – List of Scientific (peer reviewed) Publications.

Product Development (Years 1-2):

Get local regional radio/TV interested in a product launch. (Completed)

Initial Exploitation (Year 2-3):

Editorial in European aviation publication

Advertising in National aviation publications

European Expansion (Year 3-5):

Follow on editorial in European aviation publication

Advertising in European aviation publications

Global Expansion (Year 5-8):

Editorial in International aviation publication

Advertising in International aviation publications

4.9.5 Published Video

A short video was produced to disseminate the working prototype and an overview of the technology. The video identifies the broad description of the technology and how it is used to detect the ash.

The first scene describes the project title, and the partners involved.

Figure 23- Scene 1

Introduced the project.

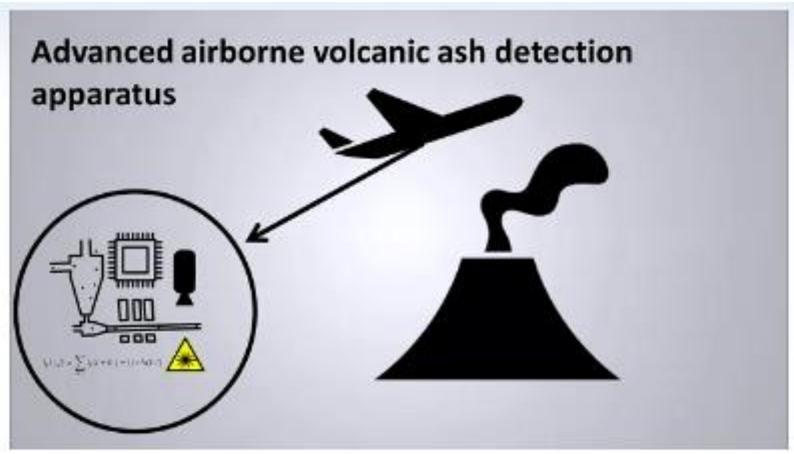

Figure 24- Scene 2

The air flow design explained in a very broad manner.

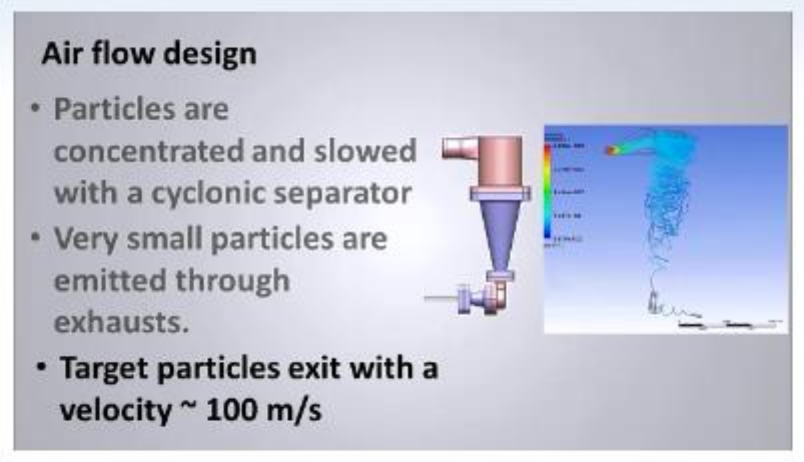

Figure 25- Scene 4

Showing how particles are captured.

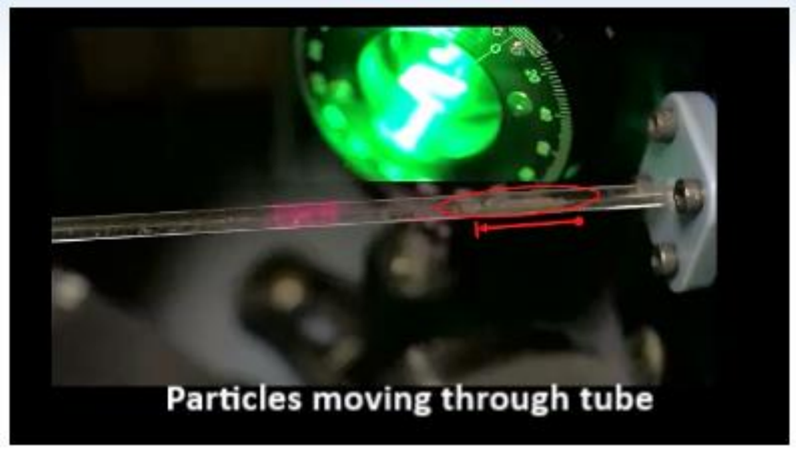

Figure 26- Scene 8

The video is found on the following link:

https://www.youtube.com/watch?v=CZzYNMa4Lb4

The video has a key search for “AIDA”, “Ash”, “Aircraft” and “Detection”. The contact details of Greenbank Group UK has been given so that the company can be contacted for further information. The website calls for aviation industrial partners

Due to the requirement to patent, no scientific publications have been made.

A1: LIST OF SCIENTIFIC (PEER REVIEWED) PUBLICATIONS, STARTING WITH THE MOST IMPORTANT ONES										
NO.	Title	Main author	Title of the periodical or the series	Number, date or frequency	Publisher	Place of publication	Year of publication	Relevant pages	Permanent identifiers[2] (if available)	Is/Will open access[3] provided to this publication?
1	*N/A*									

[2] A permanent identifier should be a persistent link to the published version full text if open access or abstract if article is pay per view) or to the final manuscript accepted for publication (link to article in repository).

[3] Open Access is defined as free of charge access for anyone via Internet. Please answer "yes" if the open access to the publication is already established and also if the embargo period for open access is not yet over but you intend to establish open access afterwards.

A2: LIST OF DISSEMINATION ACTIVITIES								
NO.	**Type of activities[4]**	**Main leader**	**Title**	**Date**	**Place**	**Type of audience5**	**Size of audience**	**Countries addressed**
1	*Press release, Derby Telegraph*	*Greenbank*	*Greenbank is a key global leader in the design and manufacture of products and services for industries*	*19/02/14*	*UK*	*General Public Audience*	*UK National*	*UK*
2	*Press Releases, Made in UK*	*Greenbank*	*The Greenbank Group, Enhancing performance*	*30/01/14*	*UK*	*Novel Technology Audience*	*UK and Europe*	*Various*
3	*Press release, Made in Midlands*	*Greenbank*	*The Greenbank Group, Enhancing performance*	*18/01/14*	*UK*	*Novel Technology Audience*	*UK National*	*UK*
4	*Regional Technology Awards (Made in the Midlands)*	*Greenbank*	*Made in the UK Technology Award Winner: Greenbank Group*	*16/07/14*	*UK*	*Novel Technology Audience*	*UK National*	*UK*
5	*Awards Publication*	*Greenbank*	*Technology award* *http://www.insidermedia.com/insider/midlands/115114-automotive-insulations-wins-made-midlands-prize*	*16/07/14*	*UK*	*Novel Technology Audience*	*UK National*	*UK*
	Article, in company website	*Greenbank*	*Greenbank's R&D is Flying High* *http://www.greenbankgroup.com/live/news/news79.asp*	*13/01/14*	*UK*	*Manufacturing Engineering, Maintenance and Technology Audience*	*UK National*	*UK*
6	*Article, in company website*	*Greenbank*	*Volcanic Ash Detection System Secures National Accolade*	*22/07/14*	*UK*	*Manufacturing Engineering,*	*UK National*	*UK*

[4] A drop down list allows choosing the dissemination activity: publications, conferences, workshops, web, press releases, flyers, articles published in the popular press, videos, media briefings, presentations, exhibitions, thesis, interviews, films, TV clips, posters, Other.

[5] A drop down list allows choosing the type of public: Scientific Community (higher education, Research), Industry, Civil Society, Policy makers, Medias ('multiple choices' is possible.

			http://www.greenbankgroup.com/live/news/news94.asp			*Maintenance and Technology Audience*		
7	*Article, in company website*	*Greenbank*	*Project Aida Update* *http://www.greenbankgroup.com/live/news/news83.asp*	*05/02/14*	*UK*	*Manufacturing Engineering, Maintenance and Technology Audience*	*UK National*	*UK*
8	*Article, in company website*	*Greenbank*	*Greenbank Proud to Announce Made-in-Midlands 2014 Technology Award* *http://www.greenbankgroup.com/live/news/news90.asp*	*20/05/14*	*UK*	*Manufacturing Engineering, Maintenance and Technology Audience*	*UK and Europe*	*UK*
9	*Press release, The Engineer*	*ISRI*	*On-board device helps prevent volcanic ash damage to aircraft* *http://www.theengineer.co.uk/aerospace/news/on-board-device-helps-prevent-volcanic-ash-damage-to-aircraft/1019299.article*	*06/10/14*	*UK*	*Engineering and Engineering business Audience*	*Worldwide*	*UK*
10	*Project website*	*ISRI*	*www.theaidaproject.eu*	*01/02/13*	*UK*	*General Public Audience*	*Worldwide*	*All*
11	*Twitter https://twitter.com/GreenbankGroup*	*Greenbank*	-	*13/01/14*	*UK*	*All Interested*	*Worldwide*	*Various*
12	*News Reel http://www.greenbankgroup.com/live/news/news79.asp*	*Greenbank*	*Greenbank's R&D is flying high*	*13/01/14*	*UK*	*All Customers Internal/external*	*Worldwide*	*All*
13	*Display Banners*	*Greenbank*	*AIDA Banners*	*01/02/14*	*Project Partners*	*Project Partner Customers*	*UK and Europe*	*Europe*

14	*Communication with large Aero-engine manufacturer*	*Greenbank*	*Contact with Rolls Royce PR*	*03/03/14*	*UK*	*Chief Scientific Officer*	*UK*	*UK*
15	*Visit to Siemens gas turbine works*	*Greenbank*	*Awareness*	*20/03/14*	*UK*	*Turbine Engineers*	*UK*	*UK*

Section B (Confidential[6] or public: confidential information to be marked clearly)

Part B1

The applications for patents, trademarks, registered designs, etc. shall be listed according to the table B1 provided hereafter.

B1 LIST OF APPLICATIONS FOR PATENTS, TRADEMARKS, REGISTERED DESIGNS, ETC.					
Type of IP Rights	**Confidential**	**Foreseen Embargo date**	**Application reference**	**Subject of Title of the application**	**Applicant (s) (as on the application)**
Ash Detector Patent. *Including sampling method, and multiple imaging techniques for ash detection*	*Yes*	*YES (four years)*	*Draft ref. GAIDC/P57122GB*	*Ash Detector*	*Dr. Neetin Lad-Greenbank Terotech Ltd.* *Russ Hardy, Pera Technology Ltd.*

[6] Note to be confused with the "EU CONFIDENTIAL" classification for some security research projects.

Part B2

Please complete the table hereafter:

No.	Type of Exploitable Foreground[Ŧ]	Description of Exploitable foreground	Confidential	Exploitable product(s) or measure(s)	Sector(s) of application[§]	Owners & Other Beneficiary(s) involved
1	*Exploitation of R&D results.*	*System image example type, and classified results.*	*NO*	*Volcanic Ash classification software*	*M72.2*	*GB* *ISRI* *INNORA*
2	*Exploitation of R&D results.*	*Sampling system*	*YES*	*Low concentration material sampling device*	*M72.2*	*GB* *ISRI*
3	*Exploitation of R&D results.*	*Trigger box system*	*YES*	*Trigger laser and camera system with article detection and velocity calculations*	*M72.2*	*GB* *ISRI*
4	*Exploitation of R&D results.*	*Classification Algorithm*	*YES*	*Classification algorithm code to classify Specific materials from a cluster based image.*	*M72.2*	*GB* *INNORA*
5	*Exploitation of R&D results.*	*Optical arrangement for bi – reinfringence of Volcanic ash.*	*YES*	*Specific configuration of optics and lenses for producing PDIA and bi-reinfringence.*	*M72.2*	*GB* *ISRI*

6	*General advancement of knowledge*	*Generic properties of Volcanic ash with features which differ from other airborne systems.*	*NO*	*The consortium better understands the Properties of volcanic ash and the differences between other airborne debris.*	*M72.2*	*GB* *ISRI* *INNORA* *WLB* *AEROCARE* *AEROSTAR* *LENNIS*
9	*General advancement of knowledge*	*Modelling of duel perpendicular cyclone technology with aim for velocity reduction.*	*NO*		*M72.2*	*GB* *ISRI* *INNORA* *WLB* *AEROCARE* *AEROSTAR* *LENNIS*
10	*Potential for commercial exploitation*	*Test results from prototype kit.*	*NO*		*M72.2*	*GB*
11	*Potential for commercial exploitation*	*Preliminary flight test results.*	*NO*		*M72.2*	

[Ŧ] A drop down list allows choosing the type of foreground: General advancement of knowledge, Commercial exploitation of R&D results, Exploitation of R&D results via standards, exploitation of results through EU policies, exploitation of results through (social) innovation.

[§] A drop down list allows choosing the type sector (NACE nomenclature): http://ec.europa.eu/competition/mergers/cases/index/nace_all.html

4.10 Exploitation strategy

4.11 Introduction

Project AIDA will deliver an advanced detection technology which will give real time information on the air quality in the airspace the aircraft will pass. The data can be used to guide maintenance which can reduce failures and reduce false alarms from fire monitoring equipment. It will inform the pilots of the amount of ash the aircraft has ingested over time. This data can also be given to the ground crews and airline companies who can make the technical decisions on the air worthiness of the aircraft.

4.12 Value creation opportunity for the AIDA technology in the aviation market

The key benefit of the AIDA development is that it will enable aircraft operators to optimise flight paths through low-density ash clouds deemed to have safe ash concentrations under current guidelines. This will ensure safe operation during the flight, minimise fuel use and minimise cleaning and maintenance costs after exposure to volcanic ash. AIDA is the only technology which enables operators to comply with operating guidelines for flight through low density ash clouds.

Safety is a key consideration as the aircraft will generally be carrying 100 to 200 passengers and crew. The information from AIDA will enable pilots to make informed decisions to optimise flight safety, especially if ash concentrations are higher than forecast.

The value creation opportunity of the AIDA technology is to reduce the maintenance costs for an aircraft, in particular for engines, electronics, avionics and airframes. Real time ash monitoring will optimise operational costs and aircraft safety enabling pilots to make informed decisions that reduce the wear on the aircraft and will reduce the overall maintenance costs. .

Air frame: Exposure to high concentrations of ash and dust can damage engines, airframes, windows, pitot static systems fire-warning and other electronics systems, necessitating maintenance or replacement and causing loss of revenue due to unplanned downtime.

Electronic systems: The cleaning of aircraft systems should prevent nuisance fire alarms which are caused by the ash and dust contaminating the sensors on the fire-warning system. Cleaning must be optimised and logging exposure to levels of ash will enable effective scheduling of cleaning. Cleaning of electronics systems can prevent overheating and failure or these units which can be replaced prior to potential failure, improving safety and potentially reducing downtime and support costs.

Aircraft engines: The glassy silicates in volcanic ash are highly problematic. Their melting point is 1100°C which is significantly lower than the operating temperature for gas turbines at cruising thrust, which is generally around 1400°C. If the silicates melt they are deposited in the cooler end of the hot section where they are highly damaging and extremely difficult (if not impossible) to remove. Real time data would enable the pilot to take action and reduce the thrust and hence the turbine inlet temperature to below the melting point of the silica minimising deposits and allowing particulates to pass through the engine. This would significantly enhance safety when operating near ash clouds.

The consortium recognises that AIDA has multiple strands to the value proposition and expects to consult with end users to assess the importance and prioritisation of each strand from a customer perspective.

4.13 The need for the AIDA technology in the aircraft maintenance market

The awareness of the problems associated with aircraft passing through dust clouds such as volcanic ash is relatively new. In 2010, the volcano at Eyjafjallajökull erupted and the cost of this disruption was estimated at €1.7billion[7] to the aviation sector and a similar loss to the tourist service sector. The particles in dust clouds vary and identification of the type of particle is key to understanding the wear due to abrasion. There are additional problems associated with volcanic ash as it is contaminated with sulphuric acid. The ash/acid mix is highly corrosive and can even cause pitting of windscreens[8]. Although the number of volcano eruptions is stable with 50 to 70 each year of which up to 4 are classified as large (i.e. 0.1km^3 tephra[9]). The problem will increase as the number of flights increases and routes becomes more congested.

There are technologies which provides advanced warning about dust clouds either from land based systems or more recently, from an on-board system, further analysis of these technologies is given in section 1.8.2. These technologies do provide information that allow routes to be planned around dust clouds or enable mitigating actions to be taken. These technologies do not provide information on actual exposure levels or types of particles.

4.14 The minimum performance requirements of the AIDA technology to enter the aviation market

There is no industry standard at present for the measurement of ash and particulates. As a consequence of this lack of standard, the reaction and the risk management strategies to the ash cloud from Eyjafjallajökull were variable.

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[7] Palsson, Dr T, The Keilir Aviation Academy Conference Summary and Conclusions, Atlantic Conference on Eyjafjallajokull and Aviation 15-16 September 2010

[8] Manual on Volcanic Ash, Radioactive Material and Toxic Chemical Clouds, ICAO, Second Ed., 2007

[9] Simkin, T. and L. Siebert, *Volcanoes of the world*, 2nd ed., Geoscience Press, Inc., Tucson, 1991, 349 pp.

The European Commission has described the guiding principles, which aircraft operators should use to plan flights through airspace potentially contaminated with ash[10]. According to these principles it is likely that the operator could operate in airspace that would otherwise be closed if it has a risk assessment methodology based on high quality information from approved sources. Flights should not be planned into airspace in which predicted ash density exceeds 4x10mg/m^3 or the actual density exceeds 2x10mg/m^3 [11].

The AIDA system will provide the apparatus and methodology for the continuous real-time on-board early detection of volcanic ash encounters that will provide aircrew with the knowledge that airspace has a safe level of ash i.e. <2x10mg/m^3 and where levels exceed this, the device would provide accurate, live analysis of ash levels to enable the appropriate action to be taken.

The actual resolution should be higher than this as further research will be undertaken to understand whether the lower limit is realistic as the basis for future standard. The CAA has suggested a target range measuring concentrations between 1x10mg/m^3 and 10x10mg/m^3.

4.15 Description of the AIDA technology

The AIDA system for ash detection in air will consist of a self contained detection and analysis unit capable of providing real-time detailed information on the presence of volcanic ash. The particle analysis will be achieved through the combination and integration of 2 points of analysis. An initial detection and recognition unit is followed by a more detailed classification unit. Three different measurement types can then be made. One detector will measure for the presence of birefringence, one for size and shape using PDIA technology and the final more detailed point of analysis will determine the surface morphology of passing particles. A single pulsed laser can provide the necessary illumination with additional diffusers, lenses and filters arranged for each separate technology.

4.15.1 AIDA technology elements

There are 2 key analysis technologies in the AIDA system. These are:

- An ash recognition device based on an advanced image analysis technique to enable the development of a device, which will recognise volcanic ash by surface morphology. The target false alarm rate of <5%
- A classification methodology which has sufficient ability to enable the discrimination between volcanic ash and other silicates with a false alarm rate of <2%, using a

[10] Possible courses of action for EASA to address the issue of ‘Volcanic ash ingestion in turbine engines’, EASA, A-NPA 2012-21

[11] Guidance regarding flight operations in the vicinity of volcanic ash (CAP 1236), Safety and Airspace Regulation Group, CAA, 2011

polarisation birefringence selection technique

The system will be easy to use as the data analysis will provide information to aircrew through:

- a user-friendly cockpit display and warning system which provide in-flight information on volcanic ash encounters to facilitate effective decision making

In addition, the consortium expects to consult with potential users to define customer requirements for a graphical user interface (GUI).

The consortium will provide detailed information about the technologies it has developed in the final PUDK

4.15.2 Benefits of the AIDA technology

There is no existing technology that delivers real time monitoring of volcanic ash in the atmosphere in which the particulate matter likely to be highly problematic. In this case these functions are delivered by a combination of the particle concentration measurement and particle classification and identification of volcanic ash.

4.16 The Aviation market

Boeing regularly publicises a current market outlook, which is an excellent reference source for market insights[12]. Today there are over 20,000 jet aircraft in operation with over 900 airlines. The top five largest fleets are in the USA, China, Russia, UK and Germany. Although the USA remains a major market, there is significant growth in other markets, mainly in Asia. There are a number of growth indicators used and the current indications are that passenger and cargo will average 5.0% growth per year for the next 20 years.

This growth will require 35,280 new aircraft, 41% will be replacement for older aircraft and 59% will be expansion of the fleets. The market value is $4,840billion according to Boeing. Europe is expected to require 7,460 new aircraft to give a fleet of 8,010 aircraft, 75% will be single aisle. Low cost operators are driving the growth with a requirement for efficient single aisle aircraft. This growth is expected to be effectively linear and equates to 1764 new aircraft per year

The split between passenger aircraft and freight is 91% passenger today growing to 93% passenger by 2032.

The analysis is for civilian aircraft only and excludes military aircraft.

4.17 Ash detection market

The ash detection system is particularly applicable to aircraft operating near active volcanic regions although it could potentially be installed on all aircraft as a safety

[12] Boeing, Long-Term Market Forecast, http://www.boeing.com/boeing/commercial/cmo/

measure. It could be applied to civilian and military aircraft. According to the market research report of Boeing for civilian aircraft there is the potential for 35,280 new systems over 20 years or 1764 per year. There is the additional potential for 5960 systems retrofitted on the existing fleet (i.e. fleet in operation today and expected to be in operation in 20 years). As this is the aging part of the fleet it is less likely that there will be high penetration within this sector of the market.

Market penetration of 10% is a reasonable forecast and gives 176 systems annually installed on new aircraft and almost 600 systems retrofitted to existing fleets over 5 years or an average of 120 systems per year giving a total expected market of 296 systems per year. With an installed price of €25,000 this gives an accessible global market value of €7.4million per annum. As the market in Europe will be for 373 new aircraft per year, this must be viewed as a global opportunity. With 10% market penetration within Europe, it has been estimated that savings of over €120m will be delivered just through more aircraft maintenance savings. The consortium recognises that, prior to commercialisation; further market research is required to fully understand the market, its requirements and the size.

For comparison purposes only, the closest market is aircraft condition monitoring, generally this is based on vibration analysis using accelerometers and monitors wear in gas turbines. The consortium is planning for the final PUDK to investigate further whether the market for aircraft condition monitoring may inform the business case for AIDA.

There are other potential markets that could be explored after completion of the project. The focus is on civilian aircraft but the technology could be applied to military aircraft. There are no plans to investigate and evaluate these other markets at this stage. However the consortium is planning to investigate potential technology transfer and licensing opportunities over the next 15 months and to present its findings in the final PUDK.

4.18 Business opportunity for AIDA technology

The business opportunity for the AIDA system is to reduce aircraft operators' downtime and maximise revenues with an enhanced aircraft health assessment systems for aircraft which could fly in or near volcanic ash dust clouds. It is based on assessment of exposure to particulates, the service that the AIDA technology will provide in future is effectively enhanced condition monitoring.

The business will commercialise the technology by manufacturing and installing a certified product onto commercial aircraft. It will also provide an aftersales service to ensure safe, long-term operation.

The total cost of the materials equates to approximately £15,000 where the breakdown is electronics £500, mechanics £3500, Optical set up including camera is £11,000k. This costing is based on laboratory style equipment with high precision optical mounts and vary focal lenses. The system is deemed to reduce in total material cost as the project is taken further, sourcing smaller laser systems, with in house design switching systems, fixed specification cameras to suit the setup identified in this project and also fixed focal length camera lenses and the removal of all mounting systems. The target selling price of the final product is €25,000.

The AIDA consortium expects that the technology will provide a turnover €5m p.a. within 5 years of launch based on current estimations.

4.18.1 Service provision of the AIDA technology for Aviation sector

The product will be a fully integrated real-time volcanic ash detection system for aircraft enabling pilots to ensure that the flight path is through safe concentrations of ash. Based on the current understanding of the market, the consortium believes that AIDA is the only technology that delivers this real-time information to confirm the aircraft is in a safe operating environment in compliance with current guidelines for volcanic ash air pollution.

4.18.2 Functionality and performance of the competing technologies according to market intelligence

As identified in section 1.3 there are several systems in use that can examine ash clouds to assess the safety of flight paths, including ground based radar, doppler radar, visual observation, satellite observation, light detection, ranging and passive infrared. A further description of those technologies is identified below.

Ground based Radar

Ground based radar is particularly effective when <100km from the eruption and is the best technique for measuring the ash column height. A comprehensive array of static ground based radar dedicated to ash detection does not exist and would not be cost effective. A mobile radar system could be developed and deployed to volcanoes showing signs of increased activity. This system is not known to exist at present.

Ash particles are smaller than the objects detected by conventional radar and as a consequence they are only detected effectively with short waveband radar. The X band is the shortest of the conventional wavebands and is used to detect precipitation, this is only effective for ash detection when the ash cloud is dense and contains larger particles. As the larger particles are the first to settle, the X band radar becomes ineffective at detection although the ash still presents a major hazard to aircraft. The K band has a shorter wavelength and is suitable for ash detection but is not in common use.

Doppler Radar

Improved Doppler radars are extremely sensitive, have good attenuation characteristics, and have powerful signal processing capabilities, they are already being installed at aerodromes and along air routes e.g. in the United States Weather Surveillance Radar. Although such radars will not generally be located conveniently to monitor volcanic eruptions, in certain areas, e.g. Alaska and Japan, it is likely that future eruptions increasingly will be monitored by ground-based Doppler radar. Aside from its obvious operational use in providing ash column altitude and extent during an eruption, Doppler radar should also greatly enhance our knowledge of the detailed characteristics of volcanic ash columns/clouds such as the vertical velocity of the ascending column and the ash particle fall speed. Such information could be correlated with ground ash sampling to compare with theoretical models currently in use.

Visual Observation

Direct visual observation of volcanic activity is an important method for observing and recording areas with potential hazards. These hazards are filed as a NOTAM with by aviation authority and disseminated to aircraft pilots to alert them about locations which present a potential hazard. The Ash cloud NOTAM is also known as an ASHTAM. The ASHTAM is particularly useful for identifying hazards in remote areas.

The ASHTAM is only an alert message, it is not suitable as the basis of a risk assessment methodology. It is most effective with visible relatively dense ash clouds and cannot be used to measure ash concentration.

Satellite Observation

A number of satellite systems are currently in operation which can assist in detecting volcanic ash columns/clouds. In practice there are a number of difficulties which limit the effectiveness of satellite monitoring of volcanic eruptions and ash cloud. Firstly, the satellite systems available are not optimized to detect volcanic ash. Secondly, it is generally easier to detect and monitor a volcanic ash cloud if it is already known that a volcanic eruption has occurred. Detecting the eruption itself from current satellite data is extremely difficult and will likely remain so for some considerable time.

Light Detection and Ranging (LIDAR) and passive Infrared

Research is proceeding rapidly on light detection and ranging (LIDAR) sensors which can detect and measure the particle size/density spectrum of virtually any aerosol including volcanic ash clouds, and it is expected that these sensors will be used for research into the particle size/concentration in volcanic ash clouds. Mobile LIDAR systems have been in use for several years however they are less effective over long ranges, in dense media and in certain weather conditions.

There have been a number of proposals for airborne sensors which could detect volcanic ash ahead of the aircraft, including LIDAR. Airborne LIDAR sensors would essentially be miniaturized versions of the ground-based sensor.

EasyJet was the world’s first airline to trial a technology called AVOID (Airborne Volcanic Object Identifier and Detector). The system, essentially a weather radar for ash. AVOID is a system that involves placing infrared technology onto an aircraft to supply images to both the pilots and an airline’s flight control centre. The images will enable pilots to see an ash cloud up to 100 km ahead of the aircraft. This can allow pilots to make adjustments to the plane's flight path to avoid any ash cloud. The concept is very similar to weather radars which are standard on commercial airliners.

AVOID is a detection system for identifying the location of ash clouds and taking evasive action. It does not enable measurement of particles and safe flight through low density ash clouds. The commercial availability of this technology will impact on the market potential for the AIDA technology.

The consortium will compare the AIDA system against the above systems and any new technology released in the short term as part of the cost benefit analysis and competitor analysis. In future assessments, the AVOID technology is viewed as the baseline technology against which AIDA and other systems should be measured.

4.18.3 Performance requirements of the market for technology AIDA to be cost effective and competitive

The key performance requirement for aircraft operators is optimised running cost. The AIDA technology will enable safe operation through low density ash clouds and enable pilots to avoid high density zones or take mitigating action to avoid damaging turbine components. It is estimated by the consortium that in total AIDA will save the aircraft operators €120m p.a. through minimised maintenance downtime and damage cost, additional savings will be delivered by optimised routes but these are more difficult to assess and are route dependant. Evidence of actual savings will be required for use in marketing. The consortium will perform further investigation in to aircraft running costs and to provide a detailed outline of how the AIDA technology will impact on them. The consortium is planning to review in this context the financial implications of the 2010 Eyjafjallajökull eruption and similar eruptions.

AIDA will enable pilots to identify safe and unsafe concentrations of tephra (material produced by volcanic eruption) and move out of dust clouds with unsafe levels of ash particles. Enhanced safety will be delivered if the technology can measure over a tephra concentration range of $1 mg/m^3$ to $10 mg/m^3$ as specified by the CAA.

It will reduce the number of false alarms from dust sensitive equipment; prevent electronic components from overheating and ensure full operability of airframe components and ensure safe operation. The consortium is planning to quantify in the final PUDK the costs of false alarms in aircraft systems caused by particle contamination of the electronic systems.

The full cost benefit analysis for the AIDA will be performed once the market price is known. The consortium will calculate the annual savings delivered based on an investment of €25,000 per aircraft.

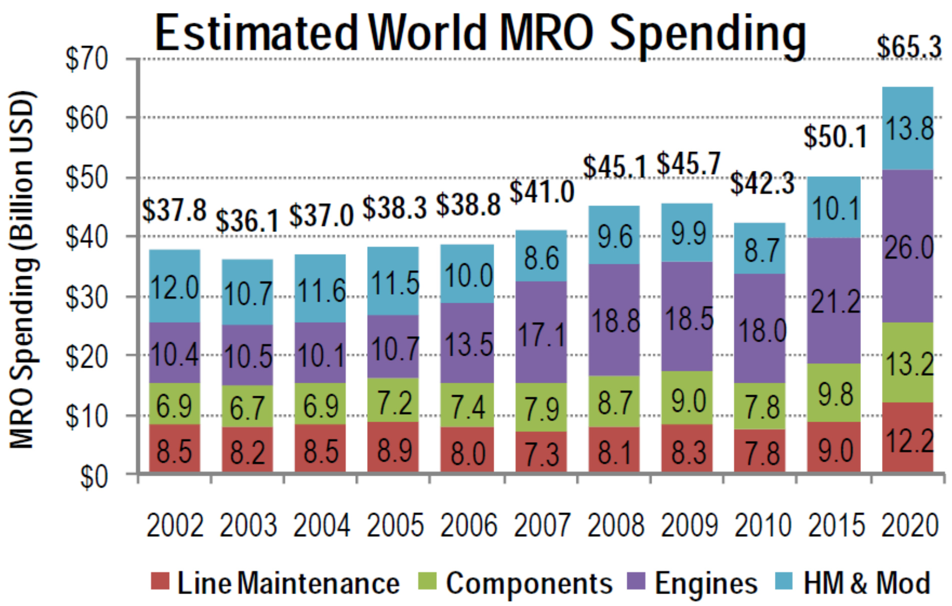

Figure 27 – Estimated World MRO Spending, Sourced from Aviation week/ overhaul maintenance, April 2010 issue.

From Lufthansa-Technik[13] it is described that the lowest-level maintenance event is the pre-flight (or light check) check that precedes every flight and involves an inspection of the aircraft by the cockpit crew and mechanics. This check for visible external damage or leaks lasts between 15 and 60 minutes, depending on the aircraft type. The next type of maintenance event a ramp check (heavy check), in which mechanics test individual functions of the aircraft, inspect the tires and brakes and replenish the oil and hydraulic fluids. A visual inspection of the aircraft is also carried out, both externally and in the cabin. Such a check, which is carried out on a daily basis, requires between six and 35 man-hours. The weekly service check (deep clean) , a combination of the work performed in the ramp check with tasks such as topping up the water and oil and thorough cleaning of the cabin, which takes between ten and 55 man-hours.

The A- and C-checks are significantly more labor-intensive. The A-check is carried out every 350 to 750 flying hours and, depending on the requirement, will take between 45 and about 260 man-hours. As well as general inspections of the interior and the aircraft hull, it also covers service checks as well as engine and function checks. At the same time the technicians replenish consumables such as oil, water and air and eliminate defects whose rectification has been postponed on the grounds that they did not impair flight safety.

Even more detailed is the maintenance work carried out in connection with the C-check, the biggest maintenance event before an overhaul. This entails thorough inspections inside and outside, along with meticulous examination of structures (load-bearing components on the fuselage and wings) and functions. For example, the technicians would use ultrasonic techniques to look for cracks in critical components. For the C-

[13] Lufthansa-Technik AG, http://www.lufthansa-technik.com/aircraft-services-details

check, which can take between 1,500 and 2,000 man-hours of work, an aircraft will spend up to five days in the maintenance hangar.

Breaking this description into separate costs as identified from Roland Berger Strategy (www.Rolandberger.co.uk) consultants[14] specified for a single aircraft the maintenance costs in terms of revenue is.

Light check: Labour rate x man-hours = 120 x 150 = USD 18,000

Heavy check: Labour rate x man-hours = 120 x 1,200 = USD 144,000

Deep clean: Labour rate x man-hours = 60 x 100 = USD 6,000

Modification: Labour rate x man-hours = 120 x 1,000 = USD 120,000

Including materials costs

Light check: Labour revenue + materials revenue = 18,000 + 2,000 = USD 20,000

Heavy check: Labour revenue + materials revenue = 144,000 + 144,000 = USD 288,000

Deep clean: Labour revenue + materials revenue = 6,000 + 0 = USD 6,000

Modification: Labour revenue + materials revenue = 120,000 + 120,000 = USD 240,000

There are three light checks and deep cleans each year, and a third of a heavy check and modification in the average business jets year. Therefore the average annual MRO revenue is:

[3 x (20,000 + 6,000)] + [1/3 x (288,000 + 240,000)] = USD 254,000

By approximation 4,000 business jets, each with an annual MRO bill of USD 0.25m, then the annual value of the business jet MRO market is around USD 1 bn.

There is also the business liner narrow body and the business liner wide body to incorporate into this calculation.

Using only the costs for light and heavy check, deep clean and modifications on an annual basis the total labour rate + man hours is USD 288,000. Using the Aida system to check ash ingestion by the aircraft the can negate or diminish the hours required checking or cleaning ash build up.

As a worst case scenario we can assume that for a single aircraft liner, the man hours for all three checks can be reduced by 1%.allowing an annual saving of 2880 USD per liner per year.

[14] Roland Berger Strategy Consultants, www.Rolandberger.co.uk

0% man hours saving

	Rate (USD)	Man Hours	Total USD
Light check	$120	150	$18 000
Heavy check	$120	1200	$144 000
Deep clean	$60	100	$6000
Modification	$120	1000	$120 000
		Total	$288 000

1% man hours saving

	Rate (USD)	Man Hours	Total USD
Light check	$120	148.5	$17 820
Heavy check	$120	1188	$142 560
Deep clean	$60	99	$5940
Modification	$120	990	$118 800
		Total	$285 120
		Total Saving	$2880

3% man hours saving

	Rate (USD)	Man Hours	Total USD
Light check	$120	145.5	$17 460
Heavy check	$120	1164	$139 680
Deep clean	$60	97	$5820
Modification	$120	970	$116 400
		Total	$279 360
		Total Saving per	$8640

6% man hours saving

	Rate (USD)	Man Hours	Total USD
Light check	$120	141	$16 920
Heavy check	$120	1128	$135 360
Deep clean	$60	94	$5640
Modification	$120	940	$112 800
		Total	$270 720
		Total Saving	$17 280

Table 5- Saving in USD due to man hour saving.

Man hours saving	Year										
	1	2	3	4	5	6	7	8	9	10	11
1%	-28560	-25680	-22800	-19920	-17040	-14160	-11280	-8400	-5520	-2640	239
3%	-28560	-19920	-11280	-2640	5999	14639	23279	31919	40559	49199	57839
6%	-28560	-11280	5999	23279	40559	57839	75119	92399	109679	126959	144239

Table 6 – ROI with increase in man hour saving per aircraft. With an investment of 25,000 EUR (28,560.12 USD - 2015 exchange rate)

4.19 Route to market for the AIDA technology

A list of milestones has been derived to provide a road map to take this project forward. This sequential list has been developed in part with the aviation partners, AeroCare and AeroSTAR.

1. Greenbank takes over all pre-existing R&D related rights for the detection system -02 February 2015
2. All existing data is reviewed by Greenbank and an aviation partner, including any cost benefit and/or market strategic analysis - deficiencies may require further study. – December 2015
3. Potential sources of further R&D funding explored (such as H2020, Innovate UK, or funding by an aviation partner. - December 2015
4. Likely early adopters are identified and approached by Greenbank/ Aviation partner to explore the level of interest – December 2015 - anticipated government agencies that fly Bombardier DHC-8.
5. Aircraft identified for airborne proof of concept test flights (experimental flight permit), Stage two H2020 funding opportunities to aid with costs.- Spring 2016
6. Engineering review of existing design by Greenbank/ Aviation Partner through a Design Authority. Minimal design changes required for safe for flight condition made by Greenbank / Aviation partner. - Summer 2016
7. Proof of concept flight tests conducted by Greenbank / Aviation Company. Further interest generated through media. Stage two H2020 funding opportunities to aid with costs - Summer 2016
8. Initial Supplemental Type Certificate (STC) for initial aircraft type (likely Bombardier DHC-8) - Summer 2016
9. Conduction of preliminary design of eventual production ash detection system - Summer 2016
10. Conduction of certification plan including any special conditions accepted by British Air Transport Association (BATA) – Autumn 2016
11. Present preliminary design to other Aviation Partners - Winter 2016

12. Completion detail design and fabricate alpha full scale prototype - Winter 2016
13. Undergo test readiness review - Summer 2016
14. Aviation partner carries out certification ground testing including DO-160 certification and initial aircraft installation - Summer 2016
15. Aviation partner carries out certification flight testing, testing complete – Autumn 2016
16. Aviation partner carries out presents critical design review - Winter 2015/2016
17. Supplemental Type Certificate issued for first aircraft type- Winter 2017
18. Sales and production begin for global aircraft market - Winter 2017
19. Further STC development for global aircraft fleet - Winter 2017 through 2020
20. Peak production/installation period 2019-2025.
21. Maturity - 2025.

4.20 Licensing

Licensing will be considered for exploitation of all IP, here the risk for exploitation is taken on by the licensing partner and the consortium take the royalties generated by product sale. It is particularly valid where the IP has applications in additional markets outside of the target sector.

4.21 Partnerships

The technology could be commercialised through strategic partnerships with appropriate companies. Where the technology is changing a market the existing players in that market are potential future partners in this case partnering with the AVOID system and integrating the two technologies could create a stronger value proposition. Partnering with a market leader could open up their existing customer base with a retrofit opportunity.

4.22 Self-Commercialisation

The partners within the consortium have the skills, resources and customer base to commercialise the technologies. The objective is for the consortium to commercialise the technology and explore options to utilise the IP in their respective areas of expertise.

If significant investment is required to finalise development testing and certification then the consortium will consider a joint venture company which can own the IP and attract external investment.

4.23 The licensing value

Licensing could be a key method of commercialisation in future. A royalty rate in the range between 5% and 10% would normally be expected. The addition of the royalty must be factored into the pricing model. A cost increase would increase the return on investment. The consortium recognises that accurate quantification of the actual value that the technology delivers must be assessed and accurate costing must be completed before the royalty rates can be reviewed.

4.24 Preferred route

The consortium preference is for Greenbank to lead on the commercialisation, other parties to act as suppliers & subcontractors and will utilise their customer databases to promote the product and accelerate commercialisation. All of the SME consortium members already possess the capabilities to sell and market the AIDA system, due to their existing supplier/customer relationships and their current market positions. An added benefit of the end user validation and industry integration study which will be carried out under the auspices of C.S.AEROSTAR S.A.

IP value will be realised by royalties paid on sales reflecting input. Where IP has value outside the core market, the consortium will consider the optimum model from the options above, however this is an option for future consideration and is not fundamental to the initial commercialisation strategy.

4.25 Grants

The AIDA project is successful in proving the concept of the technology. At present it is deemed that the prototype successfully meets the Technology readiness level between 3-5. Further research is required to ruggedize the system, and make the necessary changes from a proof of concept to validated flight tests and commercialisation. Within the first year of project end it is proposed that the consortium enter into a new project addressing the outlined potential. It is required that a possible AIDA 2 from a H2020 grant could be a possible route.

Horizon 2020 is a means to reduce the risk of development of the system towards certification and field trials. The goal is to create a proposal for AIDA 2 to remove barriers to innovation and makes it easier for the consortia to partner up with ne aviation partners who can provide flight testing.

Horizon 2020 can provide a structured approach into achieving a technology readiness level of up to 6-8, reducing red tape and time so participants can focus on the research. H2020 will allow the project to remain focused and provides a definitive budget and business case.

4.26 Manufacturing process and supply chain

The consortium members collectively form a robust supply chain in which each SME partner has been selected due to its expertise in certain fields. The consortium as a whole will be able to take the concept of the AIDA system through the manufacturing stages and installation processes required for full commercialisation of the system.

- Greenbank will assemble the various components of the final AIDA system into an integrated whole.
- AeroSTAR will be the system installer and is already certified to install prototype devices on aircraft.
- Lenis will manufacture injection molded plastic parts such as the containment system.
- WLB will provide the recognition algorithm

Other components will be purchased from suppliers outside the consortium.

It is expected that full production tooling for the production version and automated manufacture is expected to be achieved within 12 months of project completion.

It is envisaged that the full certification required for full commercialization, will be completed within 24 months of the production completion.

This supply chain will service the initial demand after commercialisation although additional partners will be required should there be a global demand, the consortium may license its IPR to other companies to enable larger scale manufacturing and assembly.

The AIDA consortium will develop a detailed manufacturing and supply strategy over the next 15 month and present this in the final PUDK document in month 24.

4.27 Risk factors

A risk assessment has been undertaken and risk log established with analysis and prioritisation of technical, commercial, managerial and partnership risks. There are a number of technical risks identified, however there is a high level of experience between the consortium members and where risks exist, mitigating actions identified. The technical risk is considered low.

- The target cost is €25,000, the mitigating actions identified to resolve technical issues will generally add cost. If this target cost is exceeded this will compromise any perceived cost / benefit analysis.
- The commercial risk is the major risk on the project. The existence of robust cloud identification tools such as AVOID with their limitations may be considered adequate for the industry. As the technology is already available it could become

the accepted best practice and become the market leader. The true nature of the market requirements and the competing technologies is yet to be established.

- Poor customer acceptance is an additional commercial risk which would affect the forecasts.
- Mitigation of these risks would come through evidence that the AIDA system can deliver greater cost effectiveness and improved safety especially in key areas e.g. in large ash clouds which have been widely dispersed. There are aerospace testing bodies or companies identified such as Facility for Airborne Atmospheric Measurements (FAAM) which can deliver technical reports and publish papers which would provide strong evidence to facilitate potential end user's buying decision.
- Lobbying for legislation is an addition option to change the market dynamics. This can be highly effective if the functionality delivered by AIDA is set out as a requirement. However, legislation may set requirements satisfied with a lower cost option and can also hinder market development. Mitigation options are limited as lobbying can be costly, especially as this is a global issue, however working with trade associations for effective lobbying is a realistic option for the consortium.
- Maintaining awareness of competing technologies and their functionality would enable AIDA to add suitable functionality to ensure the product is competitive and commercially attractive. This could come from integrating the AIDA technology with the emerging technology if they are complementary.
- One technology option that would be difficult to mitigate against is engine and airframe technologies which are ash resistant thus reducing the value of the AIDA technology

4.28 Commercialisation financial model, timescales & strategies beyond EC funding for the AIDA project

Prior to commercialisation the technology is expected to require ruggedised and optimised for volume production. Ruggedisation is required to ensure the final product is resilient to temperature ranges, forces and vibrations experienced in the field. This is built into the cash flow forecast. Investment will be required for production facilities although where possible existing facilities will be used. A significant cost will be the testing and certification. The cash flow indicates that a maximum investment of €4m will be required.

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4.29 Report on societal implications

A	**General Information** *(completed automatically when **Grant Agreement number** is entered.*	
Grant Agreement Number:		304788
Title of Project:		AIDA
Name and Title of Coordinator:		Greenbank Group UK
B	**Ethics**	

1. Did your project undergo an Ethics Review (and/or Screening)? • If Yes: have you described the progress of compliance with the relevant Ethics Review/Screening Requirements in the frame of the periodic/final project reports? Special Reminder: the progress of compliance with the Ethics Review/Screening Requirements should be described in the Period/Final Project Reports under the Section 3.2.2 *'Work Progress and Achievements'*	No
2. Please indicate whether your project involved any of the following issues (tick box) :	
RESEARCH ON HUMANS	
• Did the project involve children?	No
• Did the project involve patients?	No
• Did the project involve persons not able to give consent?	No
• Did the project involve adult healthy volunteers?	No
• Did the project involve Human genetic material?	No
• Did the project involve Human biological samples?	No
• Did the project involve Human data collection?	No
RESEARCH ON HUMAN EMBRYO/FOETUS	
• Did the project involve Human Embryos?	No
• Did the project involve Human Foetal Tissue / Cells?	No

• Did the project involve Human Embryonic Stem Cells (hESCs)?	No
• Did the project on human Embryonic Stem Cells involve cells in culture?	No
• Did the project on human Embryonic Stem Cells involve the derivation of cells from Embryos?	No
PRIVACY	
• Did the project involve processing of genetic information or personal data (eg. health, sexual lifestyle, ethnicity, political opinion, religious or philosophical conviction)?	No
• Did the project involve tracking the location or observation of people?	No
RESEARCH ON ANIMALS	
• Did the project involve research on animals?	No
• Were those animals transgenic small laboratory animals?	No
• Were those animals transgenic farm animals?	No
• Were those animals cloned farm animals?	No
• Were those animals non-human primates?	No
RESEARCH INVOLVING DEVELOPING COUNTRIES	
• Did the project involve the use of local resources (genetic, animal, plant etc)?	No
• Was the project of benefit to local community (capacity building, access to healthcare, education etc)?	No
DUAL USE	
• Research having direct military use	No
• Research having the potential for terrorist abuse	No

C Workforce Statistics

3. Workforce statistics for the project: Please indicate in the table below the number of people who worked on the project (on a headcount basis).

Type of Position	Number of Women	Number of Men
Scientific Coordinator	0	2
Work package leaders	2	0
Experienced researchers (i.e. PhD holders)	0	0
PhD Students	0	0

Other	32	1

4. How many additional researchers (in companies and universities) were recruited specifically for this project?	**2**
Of which, indicate the number of men:	2

D Gender Aspects

5. Did you carry out specific Gender Equality Actions under the project?

○ Yes
√ No

6. Which of the following actions did you carry out and how effective were they?

	Not at all effective → Very effective
❑ Design and implement an equal opportunity policy	○ ○ ○ ○ ○N/A
❑ Set targets to achieve a gender balance in the workforce	○ ○ ○ ○ ○N/A
❑ Organise conferences and workshops on gender	○ ○ ○ ○ ○N/A
❑ Actions to improve work-life balance	○ ○ ○ ○ ○
√ Other:	*Not applicable*

7. Was there a gender dimension associated with the research content – i.e. wherever people were the focus of the research as, for example, consumers, users, patients or in trials, was the issue of gender considered and addressed?

○ Yes- please specify

√ No

E Synergies with Science Education

8. Did your project involve working with students and/or school pupils (e.g. open days, participation in science festivals and events, prizes/competitions or joint projects)?

○ Yes- please specify

√ No

9. Did the project generate any science education material (e.g. kits, websites, explanatory booklets, DVDs)?

○ Yes- please specify

√ No

F Interdisciplinarity

10. Which disciplines (see list below) are involved in your project?

√ Main discipline[15]: 2.2

○ Associated discipline[15]: 1.1

2.2 Electrical engineering, electronics [electrical engineering, electronics, communication engineering and systems, computer engineering (hardware only) and other allied subjects]

○ Associated discipline[15]:

2.3. Other engineering sciences (such as chemical, aeronautical and space, mechanical, metallurgical and materials engineering, and their specialised subdivisions; forest products; applied sciences such as geodesy, industrial chemistry, etc.; the science and technology of food production; specialised technologies of interdisciplinary fields, e.g. systems analysis, metallurgy, mining, textile technology and other applied subjects)

[15] Insert number from list below (Frascati Manual).

G Engaging with Civil society and policy makers		
11a Did your project engage with societal actors beyond the research community? *(if 'No', go to Question 14)*	○ √	Yes No
11b If yes, did you engage with citizens (citizens' panels / juries) or organised civil society (NGOs, patients' groups etc.)? √ No ○ Yes- in determining what research should be performed ○ Yes - in implementing the research ○ Yes, in communicating /disseminating / using the results of the project		
11c In doing so, did your project involve actors whose role is mainly to organise the dialogue with citizens and organised civil society (e.g. professional mediator; communication company, science museums)?	○ √	Yes No
12. Did you engage with government / public bodies or policy makers (including international organisations)		
√ No ○ Yes- in framing the research agenda ○ Yes - in implementing the research agenda ○ Yes, in communicating /disseminating / using the results of the project		
13a Will the project generate outputs (expertise or scientific advice) which could be used by policy makers? ○ Yes – as a **primary** objective (please indicate areas below- multiple answers possible) ○ Yes – as a **secondary** objective (please indicate areas below - multiple answer possible) √ No		

13b If Yes, in which fields?

Agriculture		Energy		Human rights	
Audiovisual and Media		Enlargement		Information Society	
Budget		Enterprise		Institutional affairs	
Competition		Environment		Internal Market	
Consumers		External Relations		Justice, freedom and security	
Culture		External Trade		Public Health	
Customs		Fisheries and Maritime Affairs		Regional Policy	
Development Economic and Monetary Affairs		Food Safety		Research and Innovation	
Education, Training, Youth		Foreign and Security Policy		Space	
Employment and Social Affairs		Fraud		Taxation	
		Humanitarian aid		Transport	

13c If Yes, at which level?

- ○ Local / regional levels
- ○ National level
- ○ European level
- ○ International level

H Use and dissemination		
14. How many Articles were published/accepted for publication in peer-reviewed journals?		0
To how many of these is open access[16] provided?		0
How many of these are published in open access journals?		0
How many of these are published in open repositories?		0
To how many of these is open access not provided?		0
Please check all applicable reasons for not providing open access:		None
❑ publisher's licensing agreement would not permit publishing in a repository ❑ no suitable repository available ❑ no suitable open access journal available ❑ no funds available to publish in an open access journal ❑ lack of time and resources ❑ lack of information on open access ❑ other[17]: ……………		
15. How many new patent applications ('priority filings') have been made? *("Technologically unique": multiple applications for the same invention in different jurisdictions should be counted as just one application of grant).*		1
16. Indicate how many of the following Intellectual Property Rights were applied for (give number in each box).	Trademark	0
	Registered design	0
	Other	0
17. How many spin-off companies were created / are planned as a direct result of the project?		0
Indicate the approximate number of additional jobs in these companies:		

18. Please indicate whether your project has a potential impact on employment, in comparison with the situation before your project:

√ Increase in employment, or	√ In small & medium-sized enterprises
❑ Safeguard employment, or	❑ In large companies
❑ Decrease in employment,	❑ None of the above / not relevant to the project
❑ Difficult to estimate / not possible to quantify	

[16] Open Access is defined as free of charge access for anyone via Internet.

19. For your project partnership please estimate the employment effect resulting directly from your participation in Full Time Equivalent (*FTE = one person working fulltime for a year*) jobs: Difficult to estimate / not possible to quantify	*Indicate figure: 2*

I	**Media and Communication to the general public**
20.	**As part of the project, were any of the beneficiaries professionals in communication or media relations?** ○ Yes √ No
21.	**As part of the project, have any beneficiaries received professional media / communication training / advice to improve communication with the general public?** ○ Yes √ No
22	**Which of the following have been used to communicate information about your project to the general public, or have resulted from your project?**

√	Press Release	√	Coverage in specialist press
❑	Media briefing	❑	Coverage in general (non-specialist) press
❑	TV coverage / report	❑	Coverage in national press
❑	Radio coverage / report	❑	Coverage in international press
√	Brochures /posters / flyers	√	Website for the general public / internet
√	DVD /Film /Multimedia	❑	Event targeting general public (festival, conference, exhibition, science café)

23 In which languages are the information products for the general public produced?

❑	Language of the coordinator	√	English
❑	Other language(s)		

[17] For instance: classification for security project.