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Initial issues about Automatic Platform to Monitor Real Time Aircraft Position respect to Volcanic Ash or Desert Sand Clouds

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INITIAL ISSUES ABOUT AUTOMATIC PLATFORM TO MONITOR REAL TIME AIRCRAFT POSITION RESPECT TO VOLCANIC ASH OR DESERT SAND CLOUDS

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ABSTRACT

The safety problem which can arise when a plane encounters volcanic ash or desert sand clouds is discussed. The main aim of Ph.D. dissertation is to explain fundamental principles of a new automatic IT platform, which can monitor real time the presence of volcanic ash or desert sand clouds in the airspace around each airplane; so, this system will increase safety of flights, above all ensuring two very important advantages:

- it will allow flight crews to fly avoiding encounters with volcanic ash or desert sand clouds, which represent a severe risk of disaster;
- it will allow air-traffic controllers to avoid total closure of airspace, when this one is contaminated by those clouds; it causes, when it occurred, big losses of profits for airline companies and workers of this field.

Initially, research was focused on possibility to describe, using inferential-statistical approach, passive scalar transport in turbulent flows characterized by not defined conditions; not reactive pollutant can be accounted as scalar in fluid flow, which they are contaminating, as volcanic ash or desert sand clouds can be considered a passive scalar in atmosphere. the attention of mass-media about the eruption of Icelandic volcano, Eyjafjallajokull, in 2010, drew attention on the social or financial consequences related to presence of volcanic ash in atmosphere,. Then, the aim of a lot of researchers changed because of two reasons, above all: analysis of precedent similar events or models developed to simulate that particular phenomenon post-eruption; the interest of a lot of international scientists about aeronautical problem originated by presence of volcanic ash in atmosphere. So, research studies were focused on an automatic

system to monitor real time airspace and to alert air-traffic controllers soon enough to avoid that flying airplanes could encounter volcanic ash. Desert sand represents a known problem for air-traffic and the very significant difference with volcanic ash is the fusion temperature; this feature makes less dangerous than ash clouds for aircrafts. The system wants to monitor also these particles.

This system, initially, was based on monitoring of air-routes; after about one year, the precise analysis of *Single European Sky ATM Research* (SESAR) project played future guide lines up: airline companies and, so, pilots ask, often, air-traffic controllers to fly using Global Positioning System (GPS), just now, and SESAR wants to make this flying way the only one in the next future [1]. The global vision of all playing actors of the real situation is changed: each aircraft became an independent player and all other entities depended on these; this is the actual line research.

When all parameters are defined and prototypal test results are favourable, it is clear that the automatic platform will represent a very innovative step in flight safety.

INTRODUCTION

The safety problem which can arise when a plane encounters volcanic ash or desert sand clouds is discussed. The main aim of Ph.D. dissertation is to explain fundamental principles of a new automatic platform, which can monitor real time the presence of volcanic ash or desert sand clouds in the airspace around each airplane; so, this system will increase safety of flights, above all ensuring two very important advantages:

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The developed methods are of theoretical and numerical kind.

After the eruption of volcano Eyjafjallajokull, in 2010, *International Civil Aviation Organization*, in May 2010, decided to establish a task force; it would be complementary to the existing *International Airways Volcano Watch Operations Group* (IAVWOPSG) and was tasked to assist in the urgent development of a global safety risk management framework that would make it possible to determine the safe levels of operation in airspace contaminated by volcanic ash [1]. The problem is older than year 2010: it was born with first aircraft. It will be showed that the first accident was on 1944 at Naples.

Main results obtained, especially, concern the following points:

- the particular approach to the problem, which troubles a lot of people all over the world. It is very original: none automatic system able to monitor volcanic ash or desert sand in airspace is projected or realized in the world;
- the process to know the right way to calculate the most important parameters of the first step of this project: two dimensions of scanning surfaces around each aircraft in flight. First results of statistical tests, generated by MATLAB software developed to define shape and size of the "casing", are shown at the end.

Research centers and aeronautical industries all over the world are trying to develop a procedure or a system able to avoid encounters without airspace closure; any scientist is studying an automatic system which can alert real time flight crews and air-traffic controllers, if an encounter seems possible; a lot of them tries to optimize forecasting algorithm to trace the most probable trajectory of cloud. Managing the problem of "big" particles in airspace, above all of volcanic ash, is a new important challenge for civil aviation; if aviation authorities will neglect it yet, it can cause more significant damage to aircrafts and large economic loss, ignoring the risk of death of a lot of persons. The project discussed in following chapters could be an important step for future problem solution.

CONTENTS

CHAPTER 1 – Volcanic Ash versus Aircrafts

1.1 Most severe accidents since 1944

"In the past 30 years, more than 90 jet-powered commercial airplanes have encountered clouds of volcanic ash and suffered damage as result" [2]. Global air traffic is significantly affected by the volcanic ash, especially when unfavorable weather conditions occur. About 500 volcanoes are still active all over the world and the plume thrown up by the eruptions provoked several crisis [3].

The most famous accident about a jet-powered aircraft caused by volcanic ash regards the British Airways Flight 9, a Jumbo-jet Boeing 747, in flight on 24/06/1982, from London to Auckland; shortly after 13:40 UTC (20:40 Jakarta time) above the Indian Ocean, south of Java, the flight crew (consisting of 32-year-old Senior First Officer Roger Greaves and 40-year-old Senior Engineer Officer Barry Townley-Freeman while 41-year-old Captain Eric Moody was in the lavatory) first noted an effect on the windscreen similar to St Elmo's fire. The phenomenon persisted after Moody returned from the lavatory. Despite the weather radar showing clear skies, the crew switched on engine anti-ice and the passenger seat belt signs as a precaution.

As the flight progressed, smoke began to accumulate in the passenger cabin of the aircraft; it was first assumed to be cigarette smoke. However, it soon began to grow thicker and had an ominous odour of sulphur. Passengers who had a view out the aircraft windows noted that the engines were unusually bright, with light shining forward through the fan blades and producing astroboscopic effect.

At approximately 13:42 UTC (20:42 Jakarta time), the number four Rolls-Royce RB211 engine began surging and soon flamed out. The flight crew immediately performed the engine shutdown drill, quickly cutting off fuel supply and arming the fire extinguishers. Less than a minute later, at 13:43 UTC (20:43 Jakarta time), engine two surged and flamed out. Within seconds, and almost simultaneously, engines one and three flamed out.

Without engine thrust, a 747-200 has a glide ratio of approximately 15:1, meaning it can glide forward 15 kilometres for every kilometre it drops. The flight crew quickly determined that the aircraft was capable of gliding for 23 minutes and covering 91 nautical miles (169 km) from its flight level of 37,000 feet (11,000 m). At 13:44 UTC (20:44 Jakarta time), Greaves declared an emergency to the local air traffic control authority, stating that all four engines had failed.

However, Jakarta Area Control misunderstood the message, interpreting the call as meaning that only engine number four had shut down. It was only after a nearby Garuda Indonesia flight relayed the message to Air Traffic Control that it was correctly understood. Despite the crew "squawking" the emergency transponder setting of 7700, the 747 could not be located by Air Traffic Control on their radar screens.

Owing to the high Indonesian mountains on the south coast of the island of Java, an altitude of at least 11,500 feet (3,500 m) was required to cross the coast safely. The crew decided that if the aircraft was unable to maintain altitude by the time they reached 12,000 feet (3,700 m) they would turn back out to sea and attempt to ditch into the Indian Ocean. The crew began engine restart drills, despite being well outside the recommended maximum engine in-flight start envelope altitude of 28,000 feet (8,500 m). The restart attempts failed.

Despite the lack of time, Moody made an announcement to the passengers that has been described as "a masterpiece of understatement":

Ladies and gentlemen, this is your captain speaking. We have a small problem. All four engines have stopped. We are doing our damnedest to get them going again. I trust you are not in too much distress.

As pressure within the cabin fell, oxygen masks dropped from the ceiling – an automatic emergency measure to make up for the lack of air. On the flight deck, however, Greaves's mask was broken; the delivery tube had detached from the rest of the mask. Moody swiftly decided to descend at 1,800 m per minute to an altitude where there was enough pressure in the outside atmosphere to breathe almost normally.

At 13,500 feet (4,100 m), the crew was approaching the altitude at which they would have to turn over the ocean and attempt a risky ditching. Although there were guidelines for the water landing procedure, no one had ever tried it in a Boeing 747, nor has anyone since. As they performed the engine restart procedure, engine number four finally started, and at 13:56 UTC (20:56 Jakarta time), Moody used its power to reduce the rate of descent. Shortly thereafter, engine three restarted, allowing him to climb slowly. Shortly, after that, engines one and two successfully restarted as well. The crew subsequently requested and expedited an increase in altitude to clear the high mountains of Indonesia.

As the aircraft approached its target altitude, the St Elmo's fire effect on the windscreen returned. Moody throttled back; however, engine number two surged again and was shut down. The crew immediately descended and held 12,000 feet (3,700 m).

As Flight 9 approached Jakarta, the crew found it difficult to see anything through the windscreen, and made the approach almost entirely on instruments, despite reports of good visibility. The crew decided to fly the Instrument Landing System (ILS); however, the vertical guidance system was inoperative, so they were forced to fly with only the lateral guidance as the first officer monitored the airport's Distance Measuring Equipment (DME). He then called out how high they should be at each DME step along the final approach to the runway, creating a virtual glide slope for them to follow. It was, in Moody's words, "a bit like negotiating one's way up a badger's arse." Although the runway lights could be made out through a small strip of the windscreen, the landing lights on the aircraft seemed to be inoperable. After landing, the flight crew found it impossible to taxi, due to glare from apron floodlights which made the already sandblasted windscreen opaque.

Post-flight investigation revealed that *City of Edinburgh*'s problems had been caused by flying through a cloud of volcanic ash from the eruption of Mount Galunggung. Because the ash cloud was dry, it did not appear on the weather radar, which was designed to detect the moisture in clouds. The cloud sandblasted the windscreen and landing light covers and clogged the engines. As the ash entered the engines, it melted in the combustion chambers and adhered to the inside of the power-plant. As the engine cooled from inactivity, and as the aircraft descended out of the ash cloud, the molten ash solidified and enough broke off for air to again flow smoothly through the engine, allowing a successful restart. The engines had enough electrical power to restart because one generator and the onboard batteries were still operating; electrical power was required for ignition of the engines: all four engines were replaced [4].

Although the airspace around Mount Galunggung was closed temporarily after the accident, it was reopened days later. It was only after a Singapore Airlines 747 was forced to shut down three of its engines while flying through the same area nineteen days later (13 July) that Indonesian authorities closed the airspace permanently and rerouted airways to avoid the area; a watch was set up to monitor clouds of ash. Flight 9 was not the first encounter with this eruption – a Garuda DC-9 had encountered ash on 5 April 1982 [5].

A nearly identical accident occurred, on the 15 December 1989: KLM Flight 867, also a Jumbo-jet Boeing 747, from Amsterdam to Tokyo, had the same bad surprise [4], flying without all 4 engines. After descending more than 14,000 feet, Captain Karl van der Elst and crew were able to restart the engines and safely land the plane. The pilot knew the story of BA9 Flight so he asked his flight-engineer to try to turn on engines more and more under 4000m Flight Level and he could. In this case, the ash caused more than US$80 million in damage to the aircraft (requiring all four engines to be replaced), but no lives were lost and no one was injured. Luck helped also this flight!

Actually, the first case of damage of aircraft due to volcanic ash cloud is not very noticed or knew. During the Second World War, on 19 March 1944, Mount "Vesuvius" erupted at Naples; allied soldiers built an all-weather temporary airfield at Terzigno (NA), a few kilometers east of the base of Mount Vesuvius, and approximately 20 km east-southeast of Naples, Italy. The 340th bomb group of B-25 Mitchell bombers was here and the planes overed with hot ash that burned the fabric control surfaces, glazed, melted, or cracked the Plexiglass, and even tipped some B-25s onto their tails from the weight of the ash and tephra.

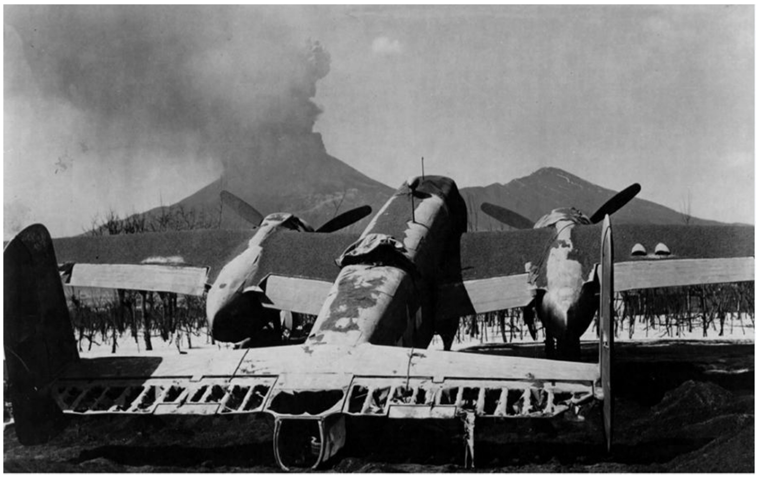

Figure 1.1 - Damaged war plane at Terzigno airfield (NA), after Mount "Vesuvius" eruption, on 19 March of 1944

The eruption destroyed the base and nearly all of the 340th's planes were damaged, as shown in Figure 1.1, although a number could be repaired. The Vesuvian Observatory director, Giuseppe Imbò, was monitoring the volcano in that period and he alerted the allied captain before the eruption; this official didn't consider dangerous the volcanic ash…and we know results, now [6] [7].

At present, the most known aeronautical problem caused by volcanic ash is the eruption of volcano Eyjafjallajokull, in Iceland, between 20 of March and 23 of April of 2010.

Ash clouds from Iceland's spewing volcano halted air traffic across Europe, as authorities closed air spaces over Britain, Ireland and the Nordic countries. Tens of thousands of passengers were stranded in one of most disruptive events to hit air travel in years.

Authorities said it was not even clear when it would be safe enough to fly again. In one sobering prediction, a scientist in Iceland said the ejection of volcanic ash — and therefore the disruptions in air travel — could continue for days or even weeks.

Britain's Civil Aviation Authority said non-emergency flights would be banned in all airports until at least 6 p.m. (1700 GMT, 1 p.m. EDT). Irish authorities also closed their air space for at least eight hours, as did aviation authorities in Denmark, Norway, Sweden and Finland.

The move shut down London's five major airports including Heathrow, a major trans-Atlantic hub that handles upwards of 1,200 flights and 180,000 passengers per day. Shutdowns and cancellations spread to France, Belgium, the Netherlands, Denmark, Ireland, Sweden, Finland and Switzerland.

In Paris, all flights north were canceled until midnight. At Copenhagen's international airport, where spokesman Henrik Peter Joergensen said some 25,000 passengers would be affected there.

"At the present time it is impossible to say when we will resume flying," Joergensen said.

Passengers found themselves looking up at departure boards where every flight was canceled.

"I just wish I was on a beach in Mexico," said a passenger stranded in Glasgow.

In response to concerns that volcanic ash ejected during the 2010 eruptions of Eyjafjallajökull in Iceland would damage aircraft engines, the controlled airspace of many European countries was closed to instrument flight rules traffic, resulting in the largest air-traffic shut-down since World War II. The closures caused millions of passengers to be stranded not only in Europe, but across the world. With large parts of European airspace closed to air traffic, many more countries were affected as flights to and from Europe were cancelled.

After an initial uninterrupted shutdown over much of northern Europe from 15 to 23 April, airspace was closed intermittently in different parts of Europe in the following weeks, as the path of the ash cloud was tracked. The ash cloud caused further disruptions to air travel operations in Republic of Ireland, Northern Ireland and Scotland on 4 and 5 May and in Spain, Portugal, northern Italy, Austria and southern Germany on 9 May. Irish and UK airspace closed again on 16 May and reopened on 17 May.

Iceland's authorities had been warning the airlines for several years, asking them to determine the density of ash that is safe for their jet engines [8].

Most airspace started to close from 15 April. However, in the days following there were brief windows free of the cloud at different locations which were exploited to make a few aircraft movements. There then followed test flights and pressure grew to re-evaluate the criteria for safe levels of ash to fly through.

On 16 April, a 30-minute break at Manchester allowed two flights to land, and one aircraft to be moved to Florida, empty (as there was no time for passengers to board). At Glasgow, an Air Transat flight to Toronto took off while a British Airways flight from New York, and a Thomas Cook flight from Orlando and Icelandair flights from Keflavik landed [9].

On 17 April 2010, the president of German airline Air Berlin, in an interview with the newspaper Bild am Sonntag, stated that the risks for flights due to this volcanic haze were nonexistent, because the assessment was based only on a computer simulation produced by the VAAC. He went on to claim that the Luftfahrt-Bundesamt closed German airspace without checking the accuracy of these simulations. Spokesmen for Lufthansa and KLM stated that during their test flights, required by the European Union, there were no problems with the aircraft [10]. On the morning of 17 April, Lufthansa moved 10 aircraft from Munich to Frankfurt at low altitude following visual flight rules. There were no problems reported and no sign of damage to the planes. The same day, an Airbus belonging to Ural Airlines attempted flying below the ash clouds from Moscow to Rimini. When the airplane was in Austrian airspace, the crew reported being low on fuel and diverted to Vienna, where the airplane landed safely [11].

On the morning of 18 April, KLM successfully carried out a test flight from Amsterdam to Düsseldorf with no problems. Afterwards, seven KLM planes with no passengers returned from Düsseldorf to Amsterdam. Air France also performed a test flight from Paris to Toulouse. In the evening of 18 April, German airspace was partially re-opened for a period of 3 hours allowing a plane of stranded holidaymakers from Faro, Portugal to land at Hanover [12].

Some military aircraft which flew during the period of closure suffered engine damage, although no crashes were reported.

On 15 April, five Finnish Air Force F-18 fighter jets on exercise flew into the ash cloud in northern Finland. Volcanic dust was found on the engines of three of the aircraft and a further inspection revealed extensive damage by molten glass deposits inside the combustion chamber of one of the engines. The engines were sent for disassembly and overhaul. As a result all unnecessary military flights were cancelled except for identification flights to enforce sovereign airspace. Meanwhile a BAE Hawk trainer with special equipment to sample the volcanic dust was being flown from the 41st squadron in Kauhava. [13] Even short test flights with an F-18 revealed engine damage sufficient to destroy engines.

On 19 April, NATO reported finding molten glass in the engines of at least one F-16, the result of flying through the ash cloud, leading to the scaling-down of U.S. military exercises. Royal Air Force flights to Selly Oak Hospital in Birmingham were grounded, and the United Kingdom Ministry of Defence considered flying British casualties of the Afghan War to coalition countries [14].

On 23 April it was announced that British Royal Air Force training flights had been suspended following volcanic ash damage to the engines of Eurofighter Typhoon aircraft [15].

People, who work in aeronautical branch above all to ensure flights safety, realized that volcanic ash was a very dangerous question, on 1991, when Mount Pinatubo, located on Luzon island in Philippines, erupted. The first large ash-producing eruption of Mount Pinatubo took place at 0851 local time (0051 G.m.t.) on June 12, 1991. Analysis of satellite images indicates that the ash cloud from the June 12 eruption was carried by upper level winds at speeds of approximately 15 to 20 m/s along a heading of 215° from the volcano, into the airspace west of Manila. At least three aircraft flew into this ash cloud. The first aircraft encounter was on June 12, 1991, at 1220 local (0420 G.m.t.) at a site approximately 170 km southwest of the volcano. The second encounter took place at 1630 local (0830 G.m.t.) and occurred at a site approximately 1,000 km west of the volcano. The position of the third encounter is unknown. While these encounters were reported in the national and international news media, the gravity of the volcanic threat to aviation safety was not fully appreciated, until the days after the June 15 eruption. The patterns of ash dispersion of these clouds were complicated by the passage of Typhoon YunyaThe heavy tropical rainfall associated with the typhoon saturated the ash as it fell, and loading of airport hangars and facilities with water-saturated ash caused extensive damage to facilities at Cubi Point, Clark, and Basa airports. At least 13 aircraft flew into the ash cloud from the June 15 eruption. Movement of the June ash cloud was detected by the Japanese geostationary meteorological satellite (GMS); by the total ozone mapping spectrometer (TOMS) aboard the Nimbus-7 polar-orbiting satellite; and by the advanced very high resolution radiometer (AVHRR) aboard the NOAA-10 and -11 polar-orbiting satellite. Observations of the eruptions from these satellites were important for detecting and tracking the ash clouds. Ash from the June 15-16, 1991, eruption caused the closing of civilian airports at Manila, Puerto Princesa, and Legaspi and military airfields at Clark Air Base, Basa Air Base, Sangley Point Air Base, and Cubi Point Naval Air Station. At Manila's Ninoy Aquino International Airport (NAIA) and Sangley Point Air Base, between 0.5 and 1 cm of fine sand to powder-size ash fell in a mostly dry condition on June 15-16, 1991. This ash caused these airports to close for 4 days until ash could be removed from runways, taxiways, and apron surfaces. Normal operations at NAIA resumed on July 4, 1991. Volcanic ash on airport surfaces caused reduced visibility and affected aircraft maneuvering, especially when the ash was wet. Ash on airport surfaces was ingested into engines during taxiing, takeoffs, and landings and also contaminated landing gear assemblies and brakes. Ash fall from a minor eruption on July 17, 1991, deposited less than 1 mm of ash over the Manila area, and NAIA was closed for ash removal from 1700 on July 17 through 1900 on July 18. While landing on July 19, one jumbo jet skidded off the runway because of reduced braking action on wet ash. The large number of encounters with the Pinatubo ash cloud, including several encounters that involved airplanes from the same company, reflects a major breakdown in the way that information about the ash cloud hazard was communicated and the ways that users responded to the information. This breakdown occurred at several levels, including between adjacent FIRs as well as within individual airline companies [16].

Figure 1.2 - Eruption of Mount Popocatepetl, on 24 February 2015

Another dangerous volcano is Mount Popocatepetl, in Mexico. It erupted also on 24 February 2015 and the eruption also produced an ash column 4 km high, as well as throwing hot rocks and debris up to 700 m from the crater. Ash drifted to the south and east following the eruption, leading to ashfalls in a number of nearby towns. This is the second time flights from Puebla International have been disrupted by Popocatépetl this year, as shown in Figure 1.2, the first having occurred following an eruption on 15 January. Popocatépetl is one of Mexico's most active volcanoes, having been erupting more-or-less continuously since 1994 [17]. This volcano affected several flights in 1997 and 1998. Although damage was minor in most cases, one flight crew experienced significantly reduced visibility for landing and had to look through the flight deck side windows to taxi after landing. In addition, the airport in Mexico City was closed for up to 24 hr on several occasions during subsequent intermittent eruptions [2].

One of the most active volcanoes in the world is Mt. Etna, in Italy, characterized by explosive activity ranging from mild strombolian to sub-plinian. Activity occurs from the central craters and/or from fractures opened along the volcano flanks. In the last two decades the number of explosive events has increased and, because the volcanic plumes remained in the atmosphere from several hours to days, they forced several times the closure of the International Airport in Catania, only 30 km far from the volcanic vent. The most reported damages to aviation in Italy are, infact, due to Etna's eruptions. Major inconvenience occurred also on 24 September 1986, when NEC formed an eruption column of 10–13 km a.s.l., and on 22 July 1998, when the eruption column reached 12 km a.s.l. Between 26 January and 24 June 2000, SEC produced 64 lava fountains forming weak plumes up to 6 km a.s.l. In particular, on 26 April 2000 an Airbus 320 taking off from Catania to Milan encountered volcanic ash and was forced to flight back to

Catania. The next year, an eruptive fracture opened at 2570 m a.s.l. producing a weak plume rising up to 5–6 km a.s.l. between 21 and 24 July that caused the cancellation of flight operations of Catania and Reggio Calabria airports. Tephra fallout was also a significant phenomenon during the 2002–2003 Etna eruption. Weak plumes having heights between 2.5 and 7 km a.s.l. were almost continuously present between 27 October and the end of the explosive activity in December 2002. The International Airport of Catania was often forced to close to avoid accidents, causing considerable economic losses and inconveniences to the south-eastern population of Sicily. The airport was forced to close again on 24 November 2006 because ash fallout covered the SE flanks of the volcano [18].

On February 2014, volcano Kelud brought to the closure of three international airports in Indonesia.

Volcanic ash clouds flow in airspace around world, not only on the volcanoes during eruptions; the closure of a little part of airspace is not very safe.

Pilots are also very troubled, now [19] !

1.2 Volcanic ash features

Volcanic ash clouds are made up of small abrasive particles that can clog up jet engines and stop them working. Planes are either re-routed or grounded when there is a danger of flying into ash clouds to ensure the safety of passengers and avoid very costly damages [20]. Three possible modes of behavior of eruption columns - intensity of eruption increases from left to right. Wind is from the left in each case. In Figure 1.3, at side of each diagram are shown normalized velocity (v) profiles versus height (h) for these columns. Left, weak isolated thermals, which are influenced by the wind. Center, a higher intensity buoyant column, influenced by wind only at the top. Right, a high intensity, superbuoyant column with a pronounced umbrella region [21].

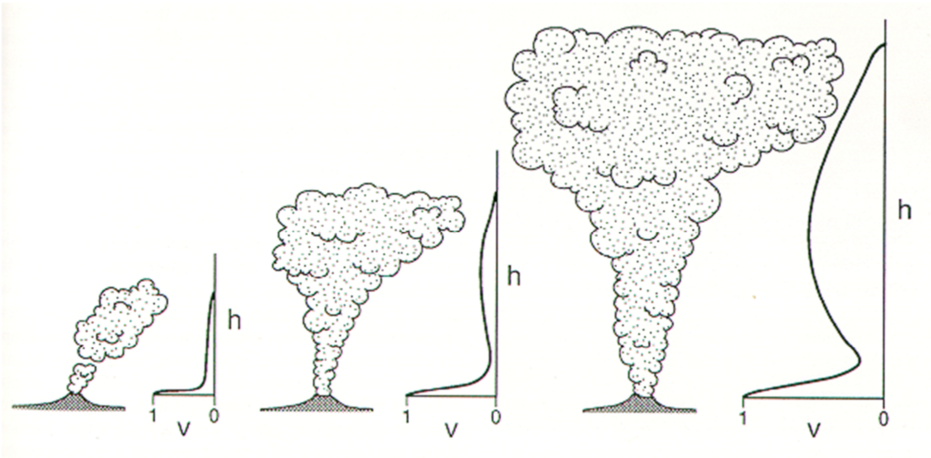

Figure 1.3 - Velocity (v) profiles versus height (h)

Wind and eruption style are the two major controls on the dispersal of ash from an erupting volcano. Eruption style affects (1) volume and size of ash produced by varying rates of magma supply; and (2) the range of altitude(s) to which ash is propelled or rises.

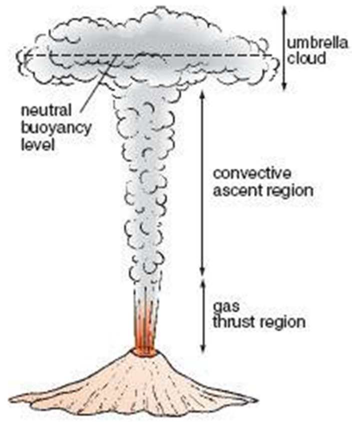

Figure 1.4 – Ash Source

Wind direction and speed above and downwind from an erupting volcano affects the dispersal pattern of volcanic ash in the atmosphere and ash fall on the ground. Both direction and speed typically varies with increasing altitude above the ground and distance from an erupting volcano. Significant change in wind direction and speed may occur during the course of a single long eruption (12-36 hours), which can result in a complex and changing ash-dispersal pattern, especially during cyclones or hurricanes, as on 1997 Mount Pinatubo. During the course of a prolonged series of eruptions that last weeks to months, changing wind patterns will typically blow ash in widely different directions.

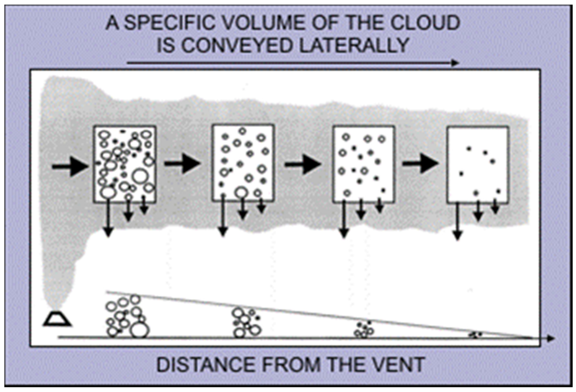

Figure 1.5 – Volume of volcanic ash cloud VS. distance from the vent

The average grain-size of rock fragments and volcanic ash erupted from an exploding volcanic vent varies greatly among different eruptions and during a single explosive eruption that lasts hours to days. Heavier, large-sized rock fragments typically fall back to the ground on or close to the volcano and progressively smaller and lighter fragments are blown farther from the volcano by wind, as shown in Figure 1.5. Volcanic ash, the smallest particles (2 mm in diameter or smaller), can travel hundreds to thousands of kilometers downwind from a volcano depending on wind speed, volume of ash erupted, and height of the eruption

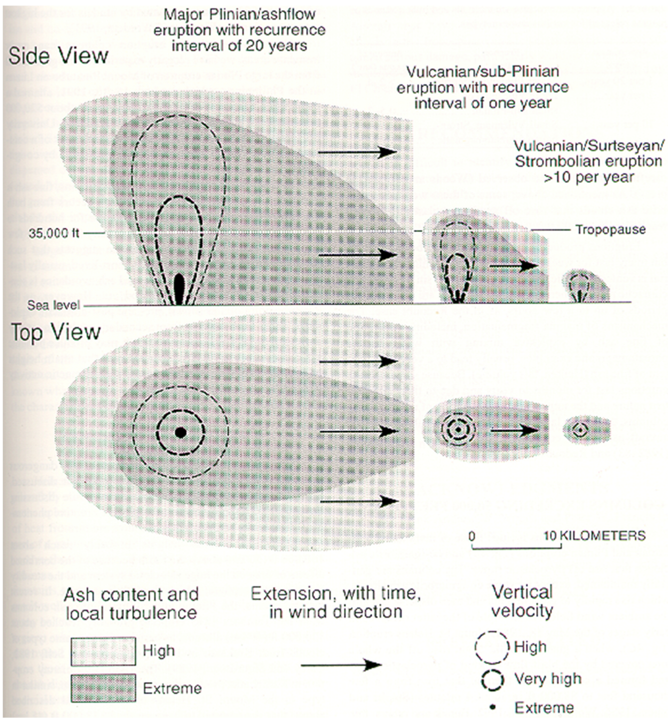

Figure 1.6 - Distribution of hazards to aircraft around explosive eruption columns of three selected frequencies

column [22] [23].Volcanic ash is the material produced by explosive volcanic eruptions that is <2mm in diameter. Fine ash is <0.063mm; coarse ash is between 0.063mm-2mm. Volcanic ash is made up of various proportions of vitric (glassy, non crystalline), crystalline and lithic (non magmatic) particles. The density of individual particles may vary between 700-1200kg/m^3 for pumice, 2350-3200 kg/m^3 for glass shards, 2700-3300kg/m^3 for crystals and 2600-3200 kg/m^3 for lithic particles. Since coarser and denser particles are deposited close to source, fine glass and pumice shards are relatively enriched in ash fall deposits at distal locations [24]; vitric typically contain small voids formed by expansion of magmatic gas before the enclosing magma solidified, known as vesicles. Ash particles can have varying degrees of vesicularity. Vesicular particles can have extremely high surface area to volume ratios. Exsolved magmatic gases condense onto ash particle surfaces, while they are in the conduit and ash plume. It has long been recognized that a range of sulphate and compounds are readily mobilized from fresh volcanic ash. These salts are formed as a consequence of rapid acid dissolution of ash particles within eruption plumes, which is thought to supply the cations involved in the deposition of sulphate and halide salts. The selective leaching of metals from silicate lattices is coupled to proton consumption, consistent with metal-proton exchange reaction. The eruption of Eyjafjallajokull was made up two distinct phases: an early hydromagmatic, explosive phase that generated very fine ash (with 20% mass<10μm and a surface area of 4.3m^2/g) and a later phase (<10 μm less than 2% mass, and a surface area of 0.45m^2/g) [25].

The pH of fresh ash leachates is highly variable. Freshly-fallen volcanic ash clearly has the potential to be corrosive. Its surface coating contains salts and sometimes also acidic gas condensates. These salts are very readily soluble and may deliquesce, if relative humidity is high. Light wet weather conditions will also provide sufficient moisture to mobilise ionic components into a surface flim, whereas heavy rain will wash ash away or remove soluble components. [26] [27].

These salts can be hygroscopic and increase the ability of ash to take up water vapor, which is the dominant gas emitted during most explosive volcanic eruptions. Water vapor concentrations can increase further from the upward transport of evaporated groundwater or glacial ice and from the entrainment of moist environmental air. If water vapor concentration is high enough to form liquid coatings on ash, important implications arise for the aggregation, atmospheric lifetime, and detection ability of the ash. Furthermore, activation of ash into cloud droplets or formation of ice crystals can notably increase plume temperature and buoyancy through latent heat release, as well as indirectly affect climate by contributing cloud condensation nuclei (CCN) and ice nuclei (IN). The occurrence of wetted ash aggregates and frozen hydrometeor fallout is observational proof of ash-water interactions, yet limited data exists to quantify the ability of ash to take up water vapor. All samples exhibited high specific surface areas, were more reactive towards H_2O than N2, and formed a monolayer of H_2O at 0.05 - 20 % relative humidity. This led to the assumption in many microphysical studies that ash is always covered by a liquid layer. However, the high temperature and strong competition for water vapor among the high concentration of ash particles in the plume may deplete the supersaturation, so that few (if any) particles can have complete coverage of water, especially in the near vent region [28].

1.3 Desert sand features

There were mentioned only crisis due to volcanic ash; actually, desert sand represents a well - known problem for aviation. It has been just studied for a lot of years: some issues and accidents to war planes happened during the Second World War; after this conflict, some researchers try to know causes and the desert sand was often indicated as origin [29]. The desert sand clouds or dust plumes represents a very dangerous problem yet; it is a natural event and it cannot stopped; thus it is also currently studied. The impact of transpacific transport of mineral dust on aerosol concentrations in North America during 2001 was estimated using a global chemical transport model (GEOS-Chem). The model captures the magnitude and seasonal cycle of observed surface dust concentrations over the northern Pacific. It simulates the free tropospheric outflow of dust from Asia observed in the TRACE-P and ACE-Asia aircraft campaigns of spring 2001. It reproduces the timing and distribution of Asian dust outbreaks in North America during April–May. Beyond these outbreaks, persistent Asian fine dust (averaging 1.2 $\mu g\ m^{-3}$) was in surface air over the western United States in spring, with much weaker influence (0.25 $\mu g\ m^{-3}$) in summer and fall. Asian influence over the eastern United States is 30–50% lower. Transpacific sources accounted for 41% of the worst dust days in the western United States in 2001 [30]. Dust plume is also affected by freezing, as volcanic ash. the freezing of water by three different types of mineral particles at temperatures between −12°C and −33°C, representing Asia Dust, Sahara Dust and Arizona test Dust, which had particle concentrations of sizes that were log-normally distributed with mode diameters between 0.3 and 0.5 μm and standard deviations, σ_g, of 1.6–1.9. The results from the freezing experiments are consistent with the singular hypothesis of ice nucleation. The dusts showed different nucleation abilities: Arizona test Dust showing a rather sharp increase in ice-active surface site density at temperatures less than –24°C. Asia Dust was the next most efficient freezing nuclei and showed a more gradual increase in activity than the ATD sample [31]. Obviously, it is important to know the chemical composition of desert sand or dust plume: during the ANT VII/1 cruise of the research icebreaker RV Polarstern from Bremerhaven (Germany) to Rio Grande do Sul (Brazil), atmospheric particulate matter was collected by bulk filtration with a time step of 36 hours. Elemental analyses were performed in order to determine atmospheric aerosol concentrations of Al, Si, P, S, K, Ca, Ti, Mn, Fe, and Zn over the North Sea, the Channel, and the North and South Atlantic. The slight and continuous moving in latitude, associated with the large variability in concentration levels and chemical composition, allow researchers to point out the relative influence of the major sources of particulate matter: desert soil-dust in the tropical North Atlantic, anthropogenic emissions in the North Sea and the Channel, and biomass burning and continental biogenic activity in the tropical South Atlantic [32]. Dust loadings containing up to 54 $\mu g/m^3$ Al (submicron plus supermicron fraction) were measured during particularly intense dust events. Mixing of dust with anthropogenic aerosols, mainly NH_4HSO_4, was observed in the fine fraction. It was associated with air masses that had originated over Europe and then traveled over North Africa. The ratio of nitrate to non-sea-salt sulfate was around 0.3. This argues against any significant influence of biomass burning emissions, which have much higher nitrate. However, we also encountered aged fossil fuel pollution plumes, likely from North America. The geochemical signature of mineral dust was consistent with previous results in the area. Si, Fe, and Ti were not enriched with respect to the soil composition, while other elements, such as Ca and S, were. Ca is prevalently present as calcite in African soils, but it is also found as calcium sulfate in the atmosphere [33] . Mineral dust and volcanic ash aerosol both show an enhanced coarse mode (>1 μm) aerosol concentration, but volcanic ash aerosol additionally contains a significant number of Aitken mode particles (<150 nm) not present in mineral dust [34]. The very important difference between volcanic ash and desert sand is the relative melting temperature, T_f: the second kind of particles have a higher T_f than first kind, so volcanic ash can damage engines easily; high temperature of the engines melts volcanic ash particles sooner and they can block the air compressor. The fusion point of pure silica is 1,760 C (3,200 F). However, desert sand, composed above all of Calcium Carbonate (CaCO3 ,Calcite and aragonite), Dolimite (Mg,CaCO3), Halite (NaCl), Iron Oxide (Fe2O3), Gypsum and Feldspar, has a lower melting point due to impurities: this temperature is however greater than 1230°C, even if is very dependent on mix [35].

1.4 Structural damages to aircrafts

Volcanic ash are highly abrasive particles that may damage aircraft components, particularly forward facing surface of external parts and engine components. They are made of sharp rock fragments that will easily erode plastic, metal and even glass pieces. In service events show that aircraft may suffer from extensive damage after volcanic ash encounter. In some cases, all the following parts were removed and replaced, after they were sand blasted:

- windshields
- forward cabin windows
- navigation and landing lights cover
- wing, stabilizer and fin leading edges
- engine nose cowls and thrust reversers
- all pitot and static probes.

In the Figure 1.7 (made by NASA), it is possible to read most important damages occurred to some aircrafts during very famous encounters [36]:

Eruption	Damage caused to aircraft
Mt. St. Helens, US – 1980	A 727 and a DC-8 experienced damage to their windshields and to several aircraft systems.
Galunggung, Indonesia – 1982	A 747 lost thrust from all four engines and descended from 36,000 ft. to 12,500 ft. before all four engines were restarted. All four engines were replaced before the aircraft returned to service.
Mt. Redoubt, US – 1989	A 747 ingested ash in all four engines which required replacement. Many other systems were also repaired or replaced.
Mt. Pinatubo, Philippines – 1991	Flights grounded for several days.
Mt. Popocatepetl, Mexico – 1997	Significantly reduced visibility for landing.

Figure 1.7 – Frequent damage caused to aircrafts

In addition to the aircraft damage that was immediately evident in the days following the encounter, damage related primarily to SO_2 gas has been reported by some airline companies and manufacturers. In June 1992, one year after the eruption of Mount Pinatubo, there was an accident involving loss of engine power on a jumbo jet owing to accumulation of sulfate deposits in jet engines. Isotopic studies of these deposits suggest that the sulfate is derived from the ingestion and oxidation of SO_2 and sulfuric acid aerosols that originated in the Pinatubo eruption cloud of June 15. Related problems recognized in 1992 such as the increased incidence of crazing of acrylic windows and fading of polyurethane paint on jetliners are also due to volcanogenic sulfuric acid droplets in the atmosphere. Frequent inspections of aircraft should reveal any corrosion problems due to volcanogenic sulfur gases [21].

In large eruptions, ash can be ejected from the volcano to heights at which commercial aircraft normally cruise. When these high-altitude ejections occur, volcanic ash can cause considerable harm to aircraft in a large number of ways:

- Erosive Effects: Ash can "blind" pilots by sandblasting the windscreen, taking away the visual cues required for a safe landing. The ash can cause erosive damage to the fuselage, and can form a coating on the plane that affects aerodynamics. In addition, sandblasting can damage the landing lights, causing their beams to diffuse and be ineffective in the forward direction.
- Blocking or Clogging of Pitot Tubes: Pitot Tubes are hollow, forward-facing tubes mounted on an aircraft to support flight instruments. Air speed is measured by comparing the pressure in the forward-facing tube to the ambient pressure. Volcanic ash can accumulate in pitot tubes and prevent accurate functioning of the cockpit air speed indicators. Failure of these systems can have catastrophic consequences. For example, in the Birgenair Flight 301 accident, an insect created a nest in a pitot tube; the resulting incorrect air speed indications ultimately led to the death of 189 passengers and crew.
- Electromagnetic Interference: Volcanic ash particles are charged. As such, they can affect communication by radio and disturb other electrical instruments onboard an aircraft.
- Engine Failure: Volcanic ash can severely damage jet aircraft engines. During flight, large volumes of air are sucked into aircraft engines. Very fine volcanic ash particles melt at about 1,100 °C. As ash particles are sucked into a jet engine, they fuse onto the blades and other parts of the turbine (which operates at about 1,400 °C). Substantial quantities of ash can erode and destroy engine parts or cause jams in the rotating machinery. In addition, ash may clog and fuse to engine sensors, leading to erroneous readings, which may result in improper control and unplanned engine shutdowns. While aircraft-based and ground-based cloud measuring instruments

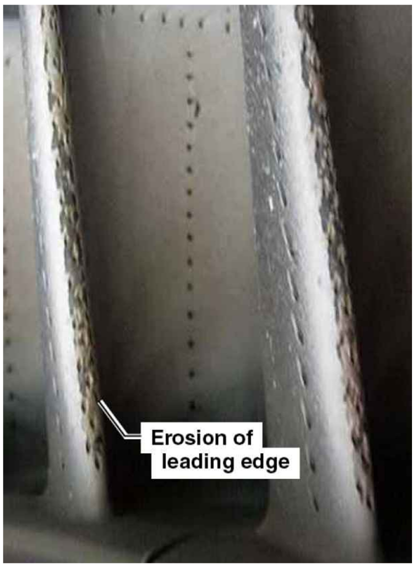

Figure 1.8 - Volcanic ash vs. fan blades

Figure 1.9 - Silicate buildup on engine parts

can detect potentially hazardous water-cloud formations, most do not have the ability to differentiate weather clouds from ash clouds [37].

NASA already performed an ash cloud test on an airliner a full decade ago, albeit unintentionally. In February of 2000, a NASA DC-8 bound for Sweden flew right through an ash plume produced by Icelandic volcano Mt. Hekla. The flight crew couldn't see the plume, and in a stroke of good fortune they landed their plane at their destination without accident. In fact, no visible damage was detected upon arrival, but a closer inspection turned up some harrowing clues to just how devastating volcanic ash can be on an airplane in flight. Interestingly – and quite fortunately for the crew on board – the relatively low dose of hot ash the DC-8 received temporarily turbocharged the engine by polishing the engine parts and letting air move more freely through the components, as it is possible to see in Figure 1.8 and Figure 1.9. But make no mistake; too much more of that kind of performance enhancing would have led to engine failure, and at 30,000 feet all engine failure is a serious issue.

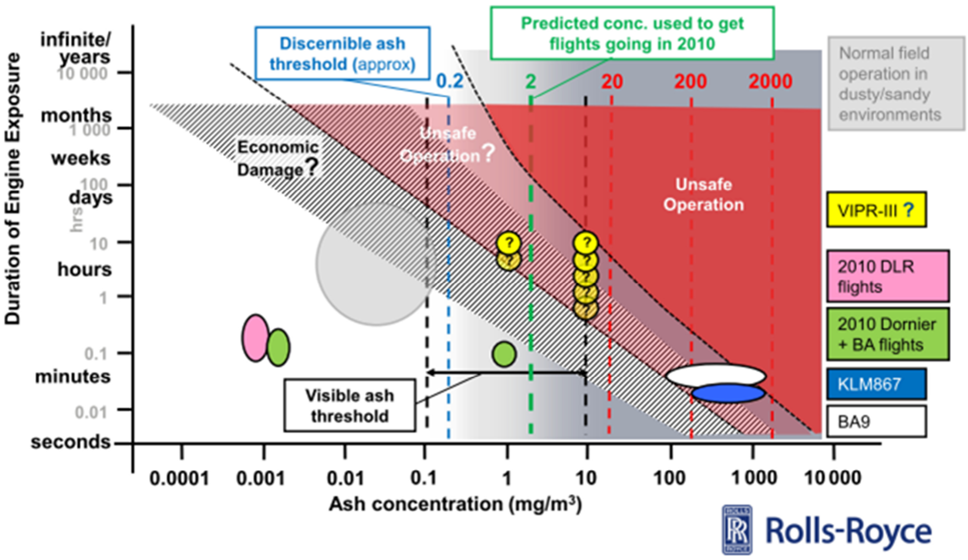

Figure 1.10 - Duration of Exposure vs. Ash Concentration

These tests and other tests or evidences allowed Rolls-Royce, a very important jet engines manufacturer, to realize the graph in Figure 2.10: volcanic ash seems a similar problem to fatigue, damages increase as much as the time of work in dangerous condition. British Airways Flight 9 and KLM flight 867 flew a lot of time in very severe conditions, so aircrafts suffered consequences described previously [38].

CHAPTER 2 – Issues related to the argument

2.1 Financial losses during crisis

During the eruption of Icelandic volcano, Eyjafjallajokull, people understood that a crisis due to volcanic ash clouds can produce very large financial losses, above all for airline companies.

No airline wants to fly its planes through ash clouds since it is a safety hazard and can damage and destroy aircraft engines, but it appears that during the recent volcanic eruptions, the European governmental regulators shut down flights in many areas where the airlines were sure that they could safely fly. As a result, the airlines were out a lot of money due to the overzealousness of the governmental regulators.

When a disaster like this happens, not only do airlines cease to generate revenue, they "go backwards" financially by having to pay out all manner of funds for passenger hotel rooms, meals, re-routing, etc., none of which were caused by anything the airlines did or did not do.

It goes without saying that some Shutdown would be required due to the problems created by the ash clouds. The issue that the airlines dispute is the length of time that the Shutdown was in place, and the expansive geographical area the Shutdown covered. Accordingly, the proximate causal event will have to be precisely defined as to the time and areas covered. The Economic Damages are the profits lost by not being able to fly in certain areas during certain periods when the airlines were comfortable flying but the governmental regulators prohibited them from flying.

Once you have established the most likely future income projections before and after the proximate causal event, the difference in these two projections is the gross amount of the loss for the projection period, not taking time into consideration. That is your base number that you carry forward into the next step [39].

When an encounter happens, a lot of aircraft systems must be replaced or repaired, of course; for example, BA9 flight and KLM 867 flight were repaired and a lot of millions of dollars were spent. If an airplane encounters an ash or dust cloud and crashes, airline will lose the aircraft, insurance company will pay passengers'family but, above all, a lot of people will die.

Repair Action	Low Estimate	High Estimate
Replace engine	$3,000,000	$8,000,000
Repair damage	$250,000	$500,000
Replace fan blades (per set)	$7,000	$25,000

Figure 2.1 - Estimated repair costs to two types of McDonnell Douglas engine

NASA's Applied Sciences Program conducted an evaluation of the impact of the use of NASA Earth observations by the VAAC program. Although the program has been in existence for many years, its impact became most apparent during a major volcanic eruption of 2010. The eruption of Eyjafjallajökull in Iceland provided a test case of the benefits of the program. To estimate benefits, the analytic team obtained data on flight cancellations and revenue losses due to the eruption of Eyjafjallajökull, as well as a range of estimates for the cost of repairing or replacing aircraft systems damaged by interactions with volcanic ash. The team interviewed project and NASA program staff to understand the decision processes that the observations supported, and then used a Bayesian-inspired approach based on historical data to develop an estimate of how much the NASA Earth observations would reduce the uncertainty about the level of ash threat. The team applied this risk reduction to the estimates of potential costs to estimate the risk-adjusted value of the observations. These risk-adjusted results were then extrapolated to the world as a whole to develop an overall estimate of the potential impact of the use of NASA Earth observations in the VAAC program. Potential Revenue Loss Impact from Flight Cancellations As previously stated, the cancellation of flights due to the Iceland volcanic eruption caused major revenue losses for airlines.

The eruption of Eyjafjallajökull began on 12 April 2010. However, it was not until 15 April that airspace began to close. Eruptions continued until 23 April, but after 19 April the London VAAC's data and models showed that flights could safely resume operations in some areas. On that same day, the London VAAC used NASA observations for the first time to refine and validate the findings and predictions of their existing systems and models. As a result of the findings at the London VAAC, in the afternoon of 19 April, German carriers Lufthansa and Air Berlin obtained permission for some flights from and to German airports under Visual (non-instrument) Flight Rules. Lufthansa was permitted to send planes to long-haul destinations to return stranded passengers later that day.

Late on 19 April and early on 20 April, some flights were permitted to take off in northern Europe, including flights from Scotland and northern England, but Manchester Airport, which had planned to open on 20 April, remained closed because of a new ash cloud. The UK Civil Aviation Authority announced that all UK airports would be permitted to open at 10 PM on 20 April. Twenty-six British Airways long-haul flights were already in the air and requesting permission to land. By 20–21 April several airlines confirmed that air service would resume in stages and started publishing lists of selected flights, with most airlines resuming service shortly after.9 Based upon this chronology, it is not possible to definitively identify the counter-factual case of what would have happened in the absence of the NASA observations. Presumably, flight operations would not have resumed as rapidly, as the level of uncertainty about safe flight regions would have remained above the acceptable threshold of the policy makers. Decisions would have been made based on existing data sources, such as:

- On-site volcano monitoring and eruption reporting (including volcanological, seismological, and geological monitoring and analysis);
- Remote monitoring (including ground station monitoring, Doppler radar, airborne monitoring, and other, non-NASA satellite monitoring);
- Modeling and forecasting the expected path of the cloud; and
- Directly observing and communicating the extent of the plumes.

For the counterfactual case, the analytic team considered two sets of decisions by regulators: either to slow the reopening of flight routes to take into account the increased uncertainty about the danger, or to reopen routes at the same rate, assuming more risk of aircraft damage due to uncertainty about which routes were safe. Extrapolating the Eyjafjallajökull data to aviation worldwide, use of NASA Earth observations could provide an expected value of up to $10 million per year in avoided revenue losses [40].

The International Air Transport Association (IATA) estimated that airlines lost $1.7B in revenues over one week, 15-21 April 2010. Figure 2 displays the reduction in flights per day (red line), and the resulting estimated revenue loss (blue line), for this period. The IATA data indicate that, on the day of greatest impact, approximately 80 percent of European flights were cancelled, resulting in approximately $450 million in lost revenue. The next day, 19 April, was the day that the London VAAC began to use the NASA observations to verify and validate their ash modeling and predictions. On the 20th and 21st flight operations were gradually restored to normal. Based on this information, the analytic team assumed that the maximum potential revenue loss in the absence of the NASA observations was approximately $450 million per day; or, stated

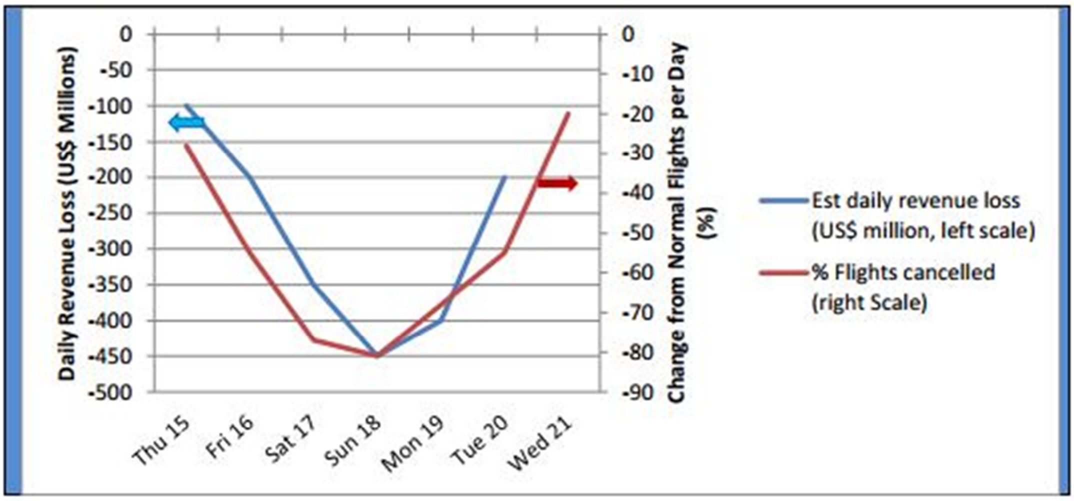

Figure 2.2 - Estimated revenue Loss and percentage of European flights cancelled 15-21 April 2010

differently, $450 million was the maximum possible revenue loss that could be avoided if decision makers had perfect information about the location of dangerous volcanic ash clouds in April 2010 [41]. Their decision cost $1.8 billion in lost revenues for the airlines and $5 billion for the global economy [42].

2.2 Social life and volcanic ash or desert sand clouds

Encounters between Volcanic Ash or Desert Sand Clouds and Airplanes are rare events in a specific region of airspace but they are not so rare during a time interval considering the whole world airspace. The increasing of flight number is linked to number of encounters between aircrafts and volcanic ash clouds, as shown in Figure 2.3 [2]. Indeed, forecasts about future flights number show constant increasing, after low reduction caused by global financial crisis. Therefore, clouds in airspace represent a safety problem, which can be also neglected twenty years ago.

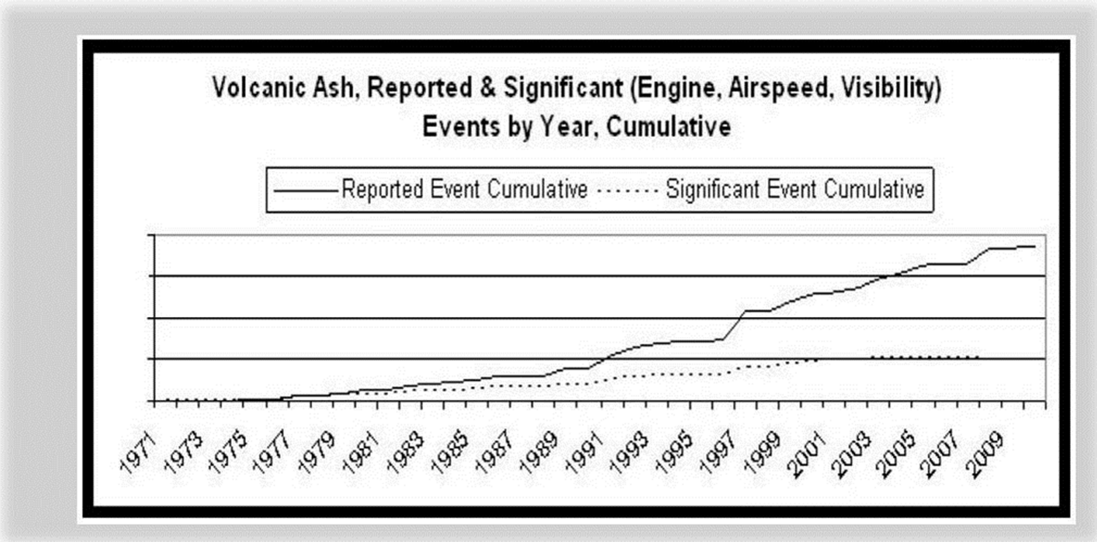

Figure 2.3 – Cumulative Events by year

The closure of a large part of European airspace caused a lot of social consequences, during the eruption of Icelandic volcano; a lot of passengers could not come back home and they had to remain in airport or hotel. Other particular and significant consequences are listed:

- several national leaders, including Barack Obama, Stephen Harper, Angela Merkel, and Nicolas Sarkozy, cancelled their plans to attend to the funeral of President of Poland Lech Kaczyński and his wife, who were killed on 10 April 2010 in a plane crash [43];

- the Forecasting Economic Support Group of ICAO's Committee on Aviation Environment Protection postponed a planned summit in Bern as North American and Scandinavian members would be unable to attend. It caused a huge economic failure;
- the repatriation of five German Bundeswehr soldiers wounded in action on 15 April 2010 in Afghanistan had to be postponed due to the closing of the German airspace. The MEDEVAC plane carrying them from Termez Airbase was rerouted to Istanbul where they are to be treated pending further developments;
- on 20 April 2010, it was reported that around 160 Irish troops, mainly from Dublin and Dundalk and from the Eastern Brigade and due to return home on a chartered plane from a peacekeeping mission in Kosovo, were stranded in the Balkans due to the travel disruption. They remained at Camp Clarke outside Pristina [44] ;
- the President of Portugal, Cavaco Silva had to extend his state visit to the Czech Republic. The President made his way from Prague to Barcelona by car and then took a Falcon of the Portuguese Air Force home to Lisbon;
- the Boston marathon took place without many athletes who had been in the affected countries [45];
- the World Chess Championship was delayed by one day, because the defending World Chess Champion Viswanathan Anand was stranded in Frankfurt;
- fans found travel to the matches extremely difficult with some teams posting significantly lower attendances during the travel disruption.

A fun episode of that incredible catastrophic event regards the trouble of actor/comedian John Cleese, who spent 30,000 Norwegian kroner (roughly €3000) on a taxi journey from Oslo to Brussels, after his flight from Norway was cancelled [46].

2.3 Current flight procedures to avoid encounters

"Ash clouds are not an everyday issue and they do not provide frequent hazard. But if encountered, volcanic ash can spoil your entire day." (Engen, 1994)

In 1995, first dangerous encounters between airplanes and ash-clouds and a lot of problems caused by some eruptions described previously inspired ICAO to increase flights safety; so, it established 9 Volcanic Ash Advisory Centers (VAAC). VAACs were established in the following locations:

- Anchorage, AK, USA;
- Washington, DC, USA;

- Buenos Aires, Argentina;
- Darwin, Australia;
- London, UK;
- Montreal, Canada;
- Tokyo, Japan;
- Toulouse, France;
- Wellington, New Zealand.

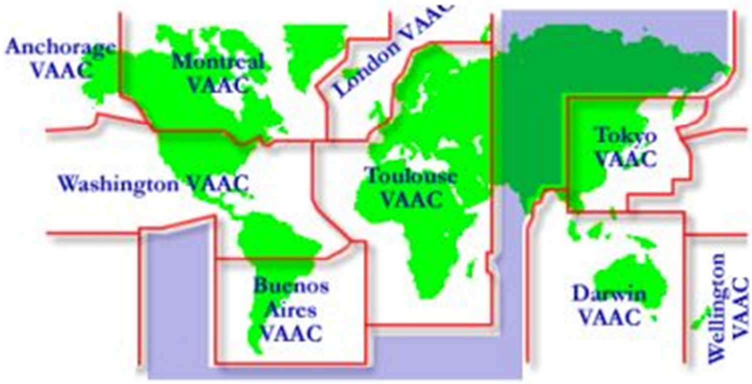

Figure 2.4 - Geographic area of responsibility of each VAAC

Each VAAC observes and reports on a particular region of the world, so each location has a geographic area of responsibility for which it reports all information regarding volcanic events. It provides an important link among volcano observatories, meteorological agencies, air traffic control centers, and operators. These centers are charged with gathering information on the presence and motion of volcanic clouds and assessing any hazards to aviation.

One product of the VAACs is the Volcanic Ash Advisory Statement (VAAS). In addition to providing VAASs directly to the airlines, the VAACs also provide information to appropriate meteorological organizations that subsequently issue significant meteorological information (SIGMET) and other reports. The ICAO publication "International Airways Volcano Watch" (ICAO annex III) contains further information and contact names and numbers. Detailed information on the VAACs, including contacts for each of the nine centers, is available at [47]

Operators rely on the VAACs for information, and many operators maintain direct contact with volcano observatories within their flight domains. For instance, the Alaska Volcano Observatory (AVO) in Anchorage, with links to Fairbanks, issues a weekly bulletin by e-mail and fax detailing the activity of key volcanoes in Alaska. During periods of volcanic unrest and eruption, bulletins are issued frequently as conditions change. Anyone can request to be placed on distribution for the bulletins. The AVO web site [48] also provides updated information. Finally, many operators maintain personal relationships with individuals in the volcano observatories that monitor volcanoes within a particular flight domain. For instance, Alaska Airlines maintains contact with key individuals at the AVO because a significant portion of Alaska's flight domain could be affected by Alaskan volcanoes.

Therefore, aviation regulators around the world, such as the Federal Aviation Administration (FAA) and EUROCONTROL, rely on the data from the VAACs, including NASA observations, to map the location and height of ash plumes. Without the ash plume location information, aircraft must either risk traveling through volcanic ash clouds, or officials must cancel flights to avoid potentially fatal encounters with these ash clouds [50].

Aircraft in flight are warned of ongoing volcanic eruptions via SIGnificant METerological (SIGMET) messages from regional Meteorological Warning Offices (MWOs) established by the International Civil Aviation Organization (ICAO, 2000). The SIGMETs are based on Volcanic Ash Advisories (VAAs) issued by VAACs, which describe details of the volcanic eruption such as: volcano name, date, time, location, height and extent of the ash cloud, and speed and direction of movement of the ash cloud. Information in the VAAs is obtained from analysis of:

1. satellite imagery;
2. aircraft pilot reports;
3. volcano observatory advisories;
4. on rare occasions, ground-based radars;
5. other surface observations.

Thus, remote sensing data is but one part of the volcanic hazard observation system. It is well known that many of the smaller volcanic eruptions are completely undetected by multi-spectral satellite techniques, particularly in moist tropical or subtropical regions where there is extensive cloud cover [50].

On 2010, after eruption of icelandic volcano, ICAO decided to create an International Volcanic Ash Task Force (IVATF) at work on a global safety risk management framework, so as to be better prepared for a similar event should it occur. After first dangerous encounters, many years previously, ICAO started to write up a list of advices to help flight crews to avoid encounters with or to recognize as soon as possible the flight through an ash or dust cloud. ICAO continually updates these recommendations; suggestions to avoid encounters are:

- Flight crews should stay upwind of volcanic ash and dust;
- Flight crews should note that airborne weather radar is ineffective for distinguishing ash and small dust particles.

If an airplane on flight encounters an ash cloud, ICAO believes that flight crew can recognize that event by:

- Odor. When encountering a volcanic ash cloud, flight crews usually notice a smoky or acrid odor that can smell like electrical smoke, burned dust, or sulfur.
- Haze. Most flight crews, as well as cabin crew or passengers, see a haze develop within the airplane. Dust can settle on surfaces.
- Changing engine conditions. Surging, torching from the tailpipe, and flameouts can occur. Engine temperatures can change unexpectedly, and white glow can appear at the engine inlet.

- Airspeed. If volcanic ash fouls the pitot tube, the indicated airspeed can decrease or fluctuate erratically.
- Pressurization. Cabin pressure can change, including possible loss of cabin pressurization.
- Static discharges. A phenomenon similar to St. Elmo's fire or glow can occur. In these instances, blue-colored sparks can appear to flow up the outside of the windshield or a white glow can appear at the leading edges of the wings or at the front of the engine inlets.

In these cases, ICAO suggests to:

1. Reduce thrust to idle immediately. By reducing thrust, engines may suffer less buildup of molten debris on turbine blades and hot-section components. Idle thrust allows engines to continue producing electrical power, bleed air for pressurization, and hydraulic power for airplane control.
2. Turn the autothrottles off. This prevents the engines from increasing thrust above idle. Ash debris in the engine can result in reduced surge margins, and limiting the number of thrust adjustments improves the chances of engine recovery.
3. Exit the ash cloud as quickly as possible. A 180-degree turn out of the cloud using a descending turn is the quickest exit strategy. Many ash clouds extend for hundreds of miles, so assuming that the encounter will end shortly can be false. Climbing out of the ash cloud could result in increased engine debris buildup as the result of increased temperatures. The increased engine buildup can cause total thrust loss.
4. Turn on engine and wing anti-ice devices and all air conditioning packs. These actions improve engine stall margins by increasing the flow of bleed air.
5. If possible, start the auxiliary power unit (APU). The APU can power systems n the event of a multiple engine power loss. It can also be used to restart engines through the use of APU bleed air.
6. Use oxygen, if volcanic dust fills the flight deck. Use flight deck oxygen at the 100 percent setting.
7. Turn on the continuous ignition.
8. Monitor engine exhaust gas temperature (EGT). Because of potential engine debris buildup, the EGT can climb excessively. The flight crew should prevent EGT exceedances. Shut down the engine and restart if the EGT is approaching limits similar to a hung start.

9. Fly the airplane by monitoring airspeed and pitch attitude. If necessary, follow the procedure for flight with unreliable airspeed.

It is possible to note the benefits that NASA credits with VAAC creation n the following NASA scheme [49].

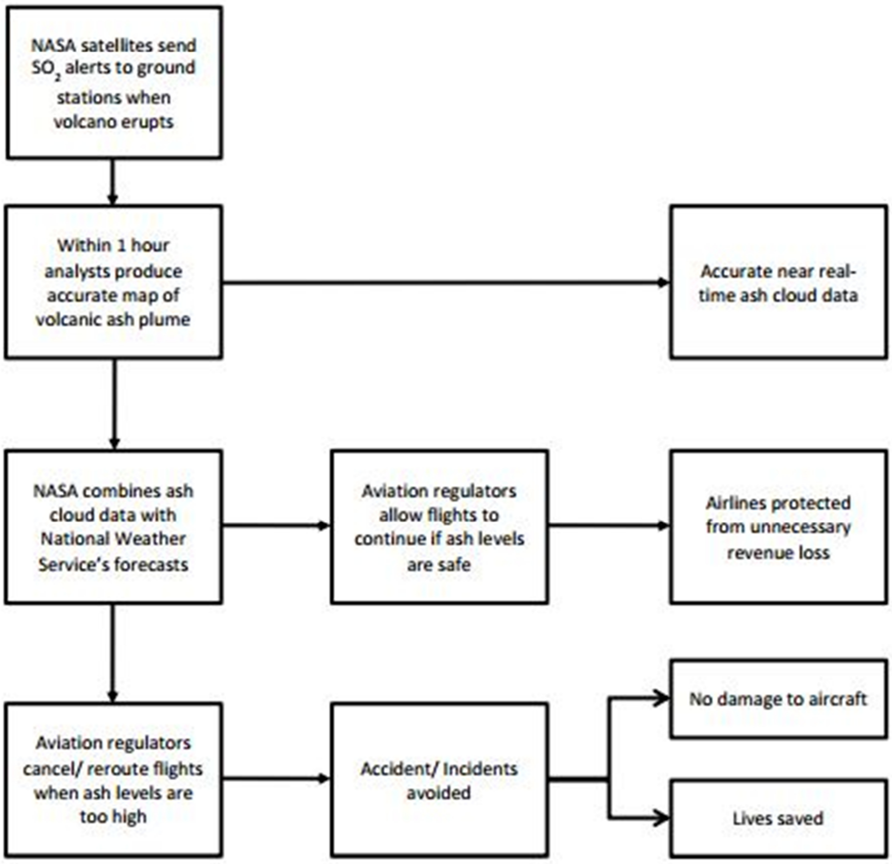

Figure 2.5 Potential Benefits of Volcanic Ash Advisories

CHAPTER 3 – Overview on international studies

3.1 Scientific Approaches

A very practical and important act of a public organization, almost to simplify communications with public officials, is the realization of a numerical volcano alert code which was introduced by Philippine Institute of Volcanology and Seismology (PHIVOLCS) in May 1991. Aviation officials adopted the alert code and designated corresponding flight restrictions and contingency routings for air traffic under each alert level. Under the original code, the appearance at the surface of new lava indicated an eruption was in progress and required that the original Alert Level 5 be maintained, even though little or no ash might be produced. Revision of the code became necessary after July 1992, when seismicity and nonexplosive growth of a lava dome required that PHIVOLCS maintain the highest alert at Alert Level 5 even though the eruption produced little or no ash. With the revised code, adopted on November 27, 1992, Alert Level 5 specifies a hazardous explosive eruption in progress with pyroclastic flows and (or) eruption column rising at least 6 km or 20,000 ft above sea level.

Satellite-based remote sensing methods provided information for the detection and tracking of the Pinatubo ash clouds. To be of maximum benefit to aviation, these data should be collected at a central station, quickly and succinctly interpreted, and widely broadcast and disseminated in a form that is understandable to users including airline dispatchers and pilots. Delays of minutes to hours reduce the value and utility of the information. It is important for countries with satellite capabilities to determine the extent and movement of ash clouds to pass on such information quickly to countries and agencies at risk from drifting ash clouds. Following the Pinatubo emergency, the World Meteorological Organization and the International Civil Aviation Organization have requested the assistance of the governments of Australia, Japan, and the United States to develop satellite techniques that would provide warning of ash cloud movement that threatens aviation safety in areas where satellite data are not available [16].

After a few years, VAAC were created but, after eruption of icelandic volcano Eyjafjallajökull, their work increased. The function of each of the nine centres under the International Airways Volcano Watch is to respond to reports of volcanic ash within their region and provide forecasts to the aviation community of ash cloud extent and movement. Observations may come from ground stations and Volcano observatories, aircraft in flight or orbiting satellites.

The London VAAC and the Met Office's realized a very good model to forecast the transport and spread of volcanic ash; the algorithm is implemented and software is NAME (Numerical Atmospheric-dispersion Modelling Environment). The development of NAME began following the Chernobyl accident in 1986 and since that time has been used to model a wide range of atmospheric dispersion events, including previous volcanic eruptions and the Buncefield oil depot explosion in 2005. In addition to its role as an emergency response guidance tool, the model is used for routine air quality forecasting and meteorological research activities. NAME provides a flexible modelling environment which is able to predict dispersion over distances ranging from a few kilometres to the whole globe and for time periods from minutes upwards. Using NAME it is possible to specify point or spatially extended sources at any location in the atmosphere or at the surface, together with relevant source parameters such as the mass emission rate and duration. NAME is a Lagrangian particle model that calculates the dispersion of pollutants by tracking model 'particles' through the simulated atmosphere. The process is initiated by the release of model particles into the atmosphere from a user defined source. Each model 'particle' can have its own characteristics. For example, particles can represent different compounds, gases or chemicals, and particles can have real particulate sizes. For particulate matter species such as volcanic ash, each model particle represents a certain mass of the actual species. Once emitted, particles move in a manner determined by the meteorology. NAME is an offline model so the meteorology is a key input to the model.

The NAME VAAC outputs are based on 6 hour time averages (taken over the 6 hours preceding the forecast time) [51].

In Italy, Mount Etna is a very dangerous source of volcanic ash, three airports are near this volcano and they are often closed. Therefore, the Italian Civil Protection Department, in conjunction with ENAC (the Civil Aviation Authority), ENAV (the Company for Air Navigation Services), the Italian Air Force and INGV (the National Institute for Geophysics and Volcanology) has drawn up procedures to provide daily forecast maps of areas potentially affected by ash dispersal and to enable air traffic controllers to be alerted immediately in the event of an eruption. The Department coordinates the following operations on a daily basis:

- the Italian Air Force and ARPA SIM (Regional Agency for Prevention and the Environment – Hydro-meteorological Service) in Emilia Romagna communicate wind field forecasts for the next 48-hours to the INGV in Catania;
- the INGV inserts the forecast data into mathematical simulation models that consider the characteristics of a typical column of ash from Etna: height, mass and volume erupted, temperature, granulometry, etc.;

the INGV sends the Department the forecast maps and after comparison with air sectors and approval, these are put at the disposal of the relevant air traffic control boards [52] [53].

Another software developed to forecast volcanic ash cloud trajectories is FALL3D: it is a 3-D time-dependent Eulerian model which circumvents many of the simplifications behind thesimplified ADM. The model can be used to forecast both particle concentration in the atmosphere (i.e. ash cloud evolution) and particle loading at ground level [54].

Another project is developed with cooperation of Caribbean States: Strengthening Resilience in Volcanic Area (STREVA) is an innovative interdisciplinary project of the University of East Anglia (UK), that aims to work collaboratively across different disciplines to develop and apply a risk assessment framework to generate plans that will reduce the negative consequences of volcanic activity on people and assets. The STREVA project brings together diverse researchers from universities and research institutes from within the UK and from those areas affected directly by volcanic activity.

The STREVA team has been collaborating with the Seismic Research Centre, University of the West Indies and Management Organization (NEMO) since 2014, to explore the awareness and importance of volcanic risk from the perspective of decision-makers, government officials, emergency responders, monitoring agencies and the general public of St. Vincent and the Grenadines.

It is remarkable, the study "on an end-to-end SysteM for volcanic ASH plume monitoring and prediction" (SMASH) project, funded by the ESA, has the objective to develop and validate new algorithms that implement polar orbiting satellite remote sensing data for volcanic source term characterisation, and for the quantitative retrieval of volcanic ash and SO2 plumes (http://www.evoss.eu) [55]. This project is realized with collaboration of: Compagnia Generale per lo Spazio S.p.A (Italy); University of Oxford (United Kingdom); Institut de Physique du Globe de Paris – IPGP (France); German Aerospace Centre - DLR (Germany); Finnish Meteorological Institute (Finland).

Indeed, a very multi-purpose and complete software, available for all people, is HYSPLIT: this is a complete system for computing simple air parcel trajectories to complex dispersion and deposition simulations. The intial development was a result of a joint effort between NOAA and Australia's Bureau of Meteorology. Recent upgrades include enhancements provided by a number of different contributors. Some new features include improved advection algorithms, updated stability and dispersion equations, continued improvements to the graphical user interface, and the option to include modules for chemical transformations. Without the

additional dispersion modules, Hysplit computes the advection of a single pollutant particle, or simply its trajectory [56].
VAACs have the target, as just discussed, of forecasting development of ash clouds as best as they can but the previous summary makes clear that a lot of research centers or state organizations follow that approach, trying to minimize the delay between moment of first alarm and moment of available forecasting. So, real time information is considered the best condition by all people interested to the problem but none seems working to obtain it. Safety though is also linked to real time information.

3.2 Industrial Approaches

Famous airplanes manufacturers (BOEING, NICARNICA, AIRBUS, ELBIT Systems) are also studying to create a system able to increase vision capability of pilots so that they can reveal they are flying in a volcanic ash cloud or, if alerted early, they can avoid encounters.
Boeing company licensed some new devices to detect the approach of an aircraft to a volcanic plume having an ash concentration which is dangerous to aircraft, including a volcanic plume that is embedded in clouds, or to a gas plume having a volcanic gas concentration which is dangerous (i.e., toxic) to humans. The detection system is installed onboard an aircraft. The onboard system comprises one or more electronic gas sensors that are exposed to incoming cockpit or cabin air. This exposes the sensors to roughly the same gas concentrations as are present in the outside air. Each sensor measures the concentration of a respective gas in the incoming air which is moderately abundant in nearly all volcanic plumes, such as H_2, CO_2, SO_2 and H_2S. The detection system measures the concentration of one or more volcanic gases in air circulating in a space inside an aircraft and then generates a perceptible alarm when one or more measured volcanic gas concentrations exceed a respective user-specified threshold or when a pattern of volcanic gas concentration is recognized with a user-specified confidence level. These systems are configured so that the alarm indicates the proximity of dangerous levels of either a volcanic gas or of volcanic ash [57].
BOEING company also considered an additional problem: in daytime clear weather, pilots can see and avoid the visually distinctive cloud from an erupting volcano. However, volcanic plumes are often encountered during nighttime and/or embedded within other clouds. Even after detection, the mechanism to issue a notice to airmen imposes a delay for processing and distribution, during which an unwarned aircraft may encounter the plume. Satellite observations are not continuous and an eruption that occurs between satellite passes may go

undetected for 6 to 12 hours, which is more than enough time for aircraft to encounter the plume. Therefore, the company realized a new invention, which combines the use of high-quality GPS receivers onboard aircraft to measure signal quality with a computerized navigation system to compute the relative positions of the aircraft and satellites. A computer then uses the phase shift information from the receivers to detect the presence of a volcanic plume between the aircraft and the satellites. If a volcanic plume is detected in an aircraft's path, a warning is issued to the aircrew. Otherwise, the phase shift measurements can be collected and used by the computer to build a three-dimensional model of the atmosphere that shows the extent and location of the volcanic plume [58].

BOEING company has a very significant experience in aeronautical world and it realized that it is difficult to optically distinguish volcanic ash from other solid particles, e.g., smoke or ice: the boundaries of water-droplet clouds are typically much sharper than the boundary of a diffuse days-old volcanic plume, so the transition from low scatter to high scatter is relatively quick for clouds but relatively slow for volcanic plumes. A new onboard processor is projected and it can be programmed to recognize that when the airplane is in the stratosphere, or well above the freezing level in the troposphere, there will be no water-vapor clouds. two or more light sources may be utilized concurrently in conjunction with respective cameras. In embodiments having two or more cameras, the electronic image data from each camera may be outputted to respective processors or a single processor. In accordance with one embodiment, an alert will be activated in response to the electronic image data from any camera being compatible with the presence of volcanic ash particles in the surrounding atmosphere [59].

AIRBUS company collaborates with NICARNICA and EASYJET companies and they are developing “Airborne Volcanic Object Identifier and Detector (AVOID)”, which is, at the same, an on board-devices system; it utilises infrared technology fitted to aircraft to supply images to pilots and an airline’s operations control centre. The images will enable pilots to see an ash cloud, up to 100km ahead of the aircraft

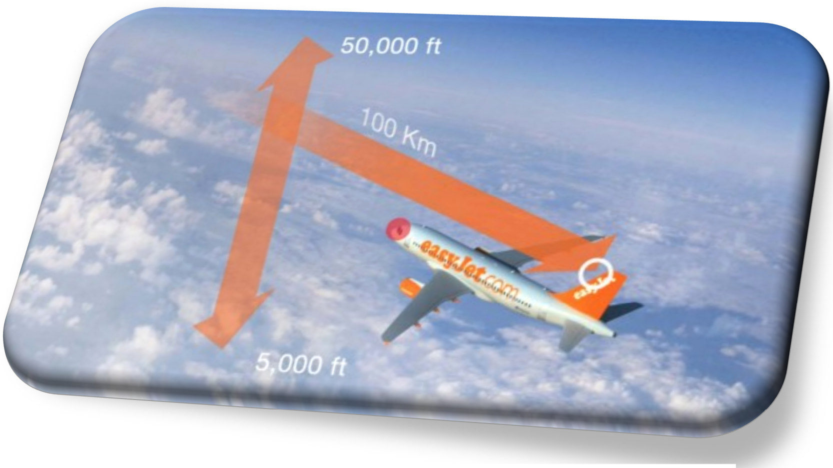

Figure 3.1 – Increasing of vision capcability by A.V.O.I.D. system

and at altitudes between 5,000ft and 50,000ft, as shown in Figure 3.1. The system, therefore, will allow them to make small 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 today [60].

This system is already in an experimental step; indeed, on october 2013, an A400M Airbus test plane dispersed one tonne of Icelandic ash into the atmosphere at between 9,000ft and 11,000ft thereby creating conditions consistent with the 2010 eruption. A second Airbus test aircraft, an A340-300, with the AVOID technology fitted, flew towards the ash cloud identifying and measuring it from around 60km away.The experiment also used a small aircraft, a Diamond DA42 from Düsseldorf University of Applied Sciences, to fly into the ash cloud to take measurements which help to corroborate the measurements made by the AVOID system.

Figure 3. 3 - Photo of A.V.O.I.D.

Figure 3. 2 – Lateral photo of A.V.O.I.D.

On July 2014, Nicarnica company join forces with israelian company "ELBIT Systems factory" to improve the development of this system [61]. Indeed, it has to be installed on external surface of aircraft and, so, it damages its aerodinamic efficiency as shown in Figures 3.2 - 3.3.

CHAPTER 4 - The Monitoring and Alerting System

The main aim is to provide the competent civil and aviation authorities with real time information on the volcanic ash propagation. This allows to define no-flight levels, to re-route scheduled flights and to give warning massages to planes already on flight.
Some advantageous conditions are due to the use of instruments and technological method already developed and available. None of new technological instruments have to been implemented.
The following methods are fundaments to create an automatic platform, which can offer significant opportunities:

i. to avoid the total closure of airspace on some large zones;
ii. to give warning massages to air-traffic controllers and, so, to planes already on flight;
iii. to help pilots when a volcanic ash or desert sand cloud occupies own routes.

Integrating alarm signals with no-alarm sectors related to each plane flying in the same airspace region, air–traffic controllers can define some no-flight levels, if necessary: they will able to decide if airspace, in that zone, would have to be incompletely open; it is very difficult that an airspace region could be closed.

4.1 First model

At the beginning, the project intended to monitor airspace real time using a permanent system composed of high range sensors to be installed on the land. Some kinds of sensor were considered and, then L.I.D.A.R. or Ceilometers were chosen; these sensors are used to monitor aerosol in atmosphere but a lot of scientists have tested them to monitor volcanic ash for many years and results are very good now [52][62]. L.I.D.A.R. and ceilometers devices can monitor a cylindrical volume, which has radius and height equal to their sensitivity; that radius is about 20kilometers for devices, which are used to find ash or dust particles in atmosphere. A scheme of sensor operation is shown in Figure 4.1.

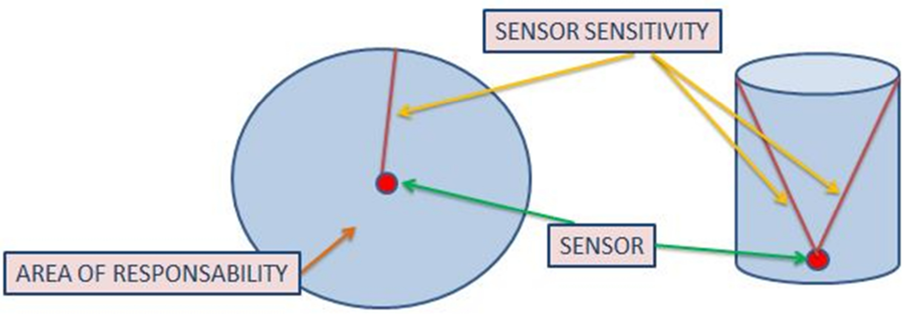

Figure 4.1 – Cylindrical volume monitored by a sensor sensitivity: upper view and frontal view

A network of

L.I.D.A.R. already exists in Europe but it is not able to monitor whole airspace [63] [64].

The region of the airspace, where monitoring is required, is called "Area of Interest". The model is based on two basic assumptions: terrestrial zone related to "Area of Interest" is far from sources of volcanic ash or desert sand clouds and only a flight level is considered. So, it is a 2D model; the 3D model should be the future step. The principal actor of this model is the air-route: flight crews had to follow a specific route, before Single European Sky ATM Research (SESAR) development and before perfection and diffusion of G.P.S. technology. This region is divided in some zones of risk; risk "R" is defined as:

$$R = P \times Vu \times Val$$

- "P" represents probability that an encounter happens; it depends on:
  1. number of volcanoes;
  2. eruption frequencies

  in a large zone including "Area of Interest".
- "Vu" represents vulnerability, the capability of airplane to withstand encounters; it depends on:
  1. kind of eruption of volcanoes in "Area of Interest";
  2. physical conditions of volcanic ash o dust cloud;
  3. weather conditions;
  4. air-routes on airspace of "Area of Interest";
  5. flight frequency;
  6. wind speed;
  7. wind direction;
- "Val" represents value of elements in danger; it depends on:
  1. flight frequency on each air-route;
  2. population density;
  3. average number of flight passenger in those air-routes;
  4. average dimension of crash area;
  5. estimated cost of each human life;
  6. average airplane cost;
  7. cost of airspace closure.

It is necessary to define the extension of the minimal zone of study and to calculate the value of risk "R" for each one of these: it will be possible to obtain a map of iso-risk zone.

A qualitative example of three risk zones is shown in Figure 4.2: yellow and blue lines split green "Area of Interest" in three different sectors. Air-routes coordinates are acquired by a software developed on purpose using Mathworks MATLAB: in this overture, each air-route is considered linear (it is well known that each curve can be considered as the union of linear parts). Software allows to choose a lot of parameters to display a virtual map of "Area of Interest" and relative air-routes in risk zones. These parameters are shown in a setup menu, as in Figure 4.3. It is possible to import coordinates and data of real cases or to generate random configurations: in this case, air-routes are represented by connections of some airports, whose number is chosen by user.

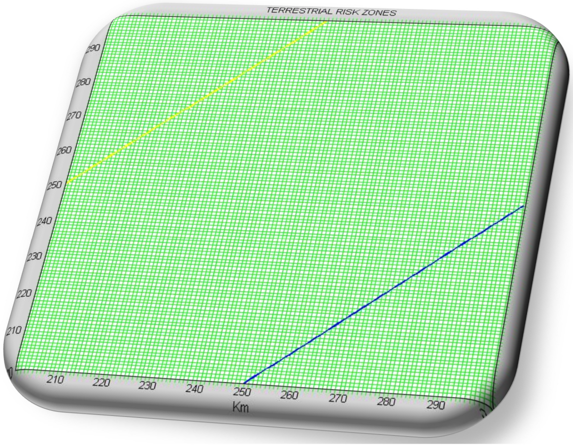

Figure 4.2 – "Area of Interest" and risk zones

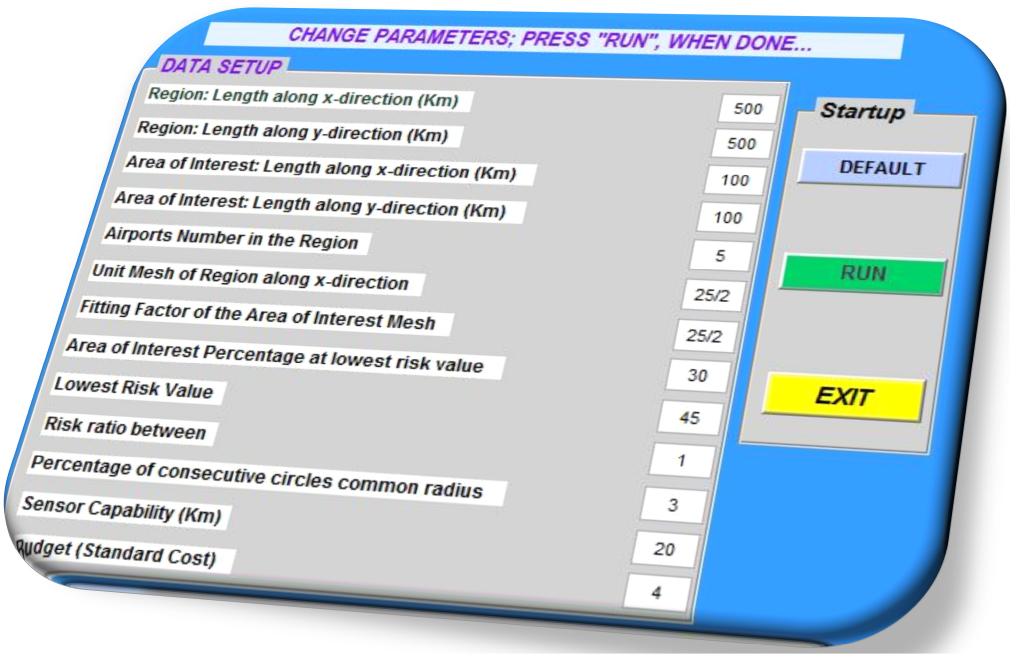

Figure 4.3 – Setup Menu

An example of air-routes is represented by green lines in Figure 4.4. Following images of this paragraph will be relative to the same configuration.

The value of risk parameter is useful to define a virtual “Alert Perimeter” in airspace.

An aircraft has to be alerted early respect to visualization of ash or dust cloud, because it needs for a technical time to change its direction; this distance can be called “D_{alert}”. While aircraft covers “D_{alert}”, the cloud would cover another distance, “D_{ash}”, following own direction; this distance is smaller than “D_{alert}”, because cloud speed, called “v_{alert}”, is related to wind speed at that flight level: speed of aircraft is bigger than wind speed, of course. So, if flight crew is alerted when the distance between air-route and cloud is “D_{safe}”, larger than “D_{alert}”, aircraft will avoid the encounter. It is advantageous to build a virtual “Alert Perimeter”: software has to build parallel lines on the left and on the right of each air-route; it has to create a buffer around each air-route, then intersection of all buffers related to all air-routes will set up a whole buffer. An example of this buffer is represented by black dots in Figure 4.5.

“Alert Perimeter” will be the perimeter of this buffer. An example of “Alert Perimeter” is represented by violet dots in Figure 4.6.

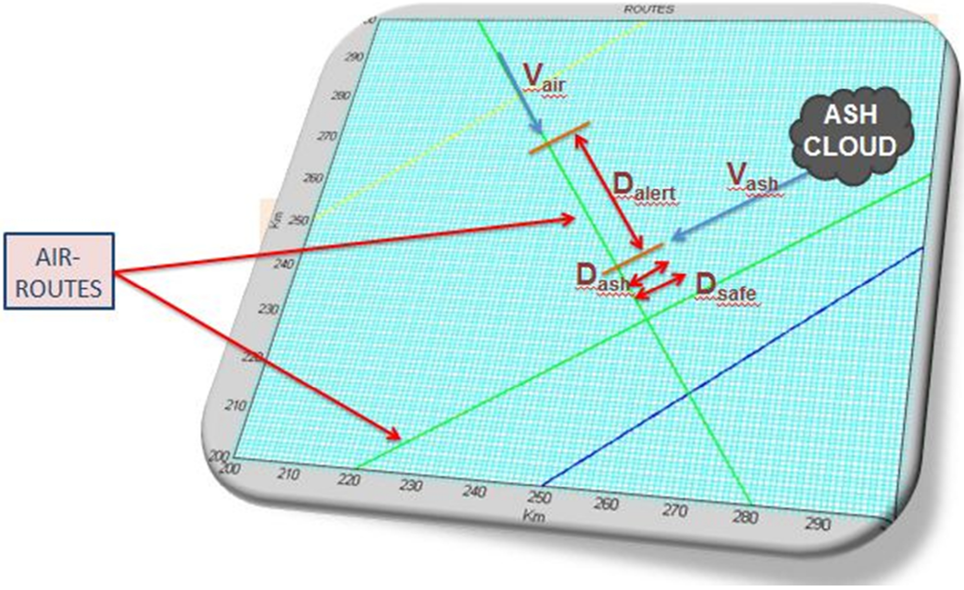

Figure 4.4 – Graphic explanation of buffer implementation

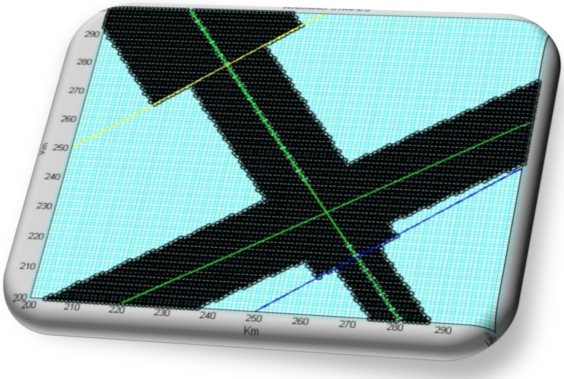
Figure 4.6 Buffer related to all air-routes

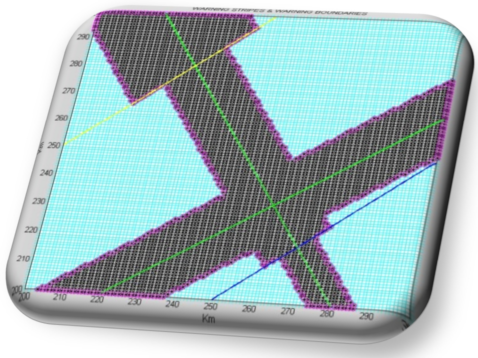
Figure 4.5 – – Buffer and “Alert Perimeter”

Buffer dimension will be the product of local value of risk "R" and "D_{ash}"; three different values of buffer are displayed in Figure 4.5, because the risk value is bigger in the triangle, lower in the lowest triangle and medium in the zone between yellow and blue lines.

It is important underline that "D_{ash}" depends on four time intervals, which are:

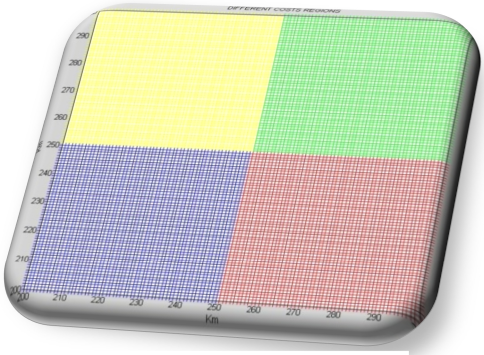

Figure 4.7 – Regional costs

1. time passed from first instrumental alert to visualization on air-traffic controllers displays;
2. time spent by air-traffic controllers to decide the right change direction;
3. time spent by air-traffic controllers to transmit that choose to flight crew;
4. time spent by pilot to set up operation;
5. technical time to conclude change direction.

The "Alert Perimeter" has to be monitored by a sufficient number of sensors.

Terrestrial region related to "Area of Interest" is not uniform, so installation cost of each sensor could be relative to different zones of region: in Figure 4.7, different colors represent different installation zones of cost of sensors of same kind; each of them is characterized by its performance and its regional cost [65].

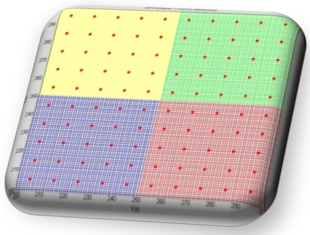

Figure 4.8 – Mesh of sensors

Software generates a regular mesh of sensors related to terrestrial region of "Area of Interest": each sensor has own area of responsibility and it must monitor this area. An example of mesh of sensors is shown in Figure 4.8: each red dot represents a sensor; they are also displayed in different regions of installation costs.

Software allows to define overlapping between consecutive sensors, if "Percentage of consecutive circles common radius" is changed. Figure 4.9 shows that each point of "Area of Interest" is monitored by more than one sensor, as user required.

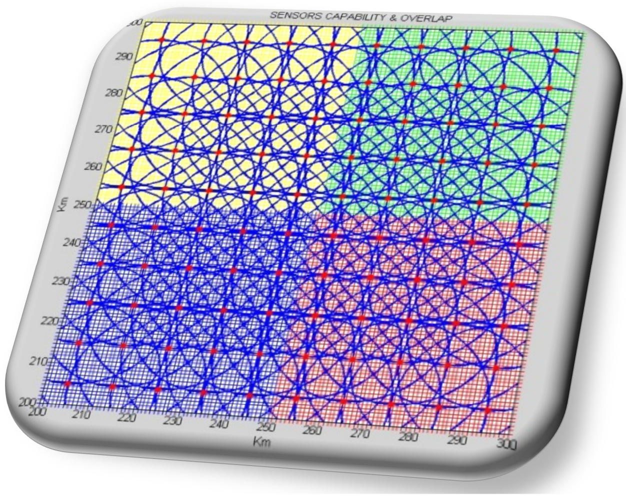

Figure 4.9 – Consecutive sensors overlapping

The aim is to place the sensors optimizing an objective function which is a linear combination of cost and performance, guaranteeing that all the planes on flight can receive the warning with a sufficient advance along their route. Figure 4.10 shows that a lot of sensors are not useful to monitor the simple considered configuration, so they can be deleted; in a real case, they could be not installed and a lot of money could be saved.

Moreover, a higher reliability of the system should be guaranteed covering each point of a route with more than one sensor.

The first step of automatic platform monitoring a flight level is, so, to locate sensors: this problem can be modeled as a *set covering problem (SCP)*, where we want to determine the minimum number of sensors to be located, which allows us to cover all the points of the warning boundaries, using a covering optimization models [66]. The model of problem is shown in Figure 4.11.

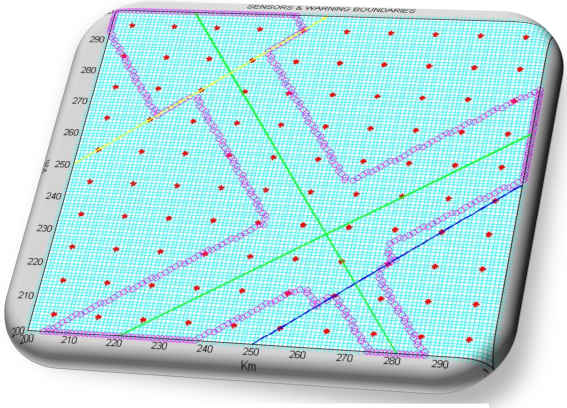

Figure 4.10 – "Alert Perimeter" and sensors

$$Min\ z = \sum_{j \in J} y_j$$ *Minimizing the number of sensors*

$$Min\ z = \sum_{j \in J} h_j y_j$$ *Minimizing the installation costs*

$$\sum_{j \in N_i} y_j \geq 1 \qquad \forall i \in I$$ *At least a sensor able to cover a point i has to be located*

$$y_j = (0,1) \qquad \forall j \in J$$ *Integrality Constraints*

$N_i = \{ j : c_{ij} \leq R \}$ set of sensors *j* able to cover a point *i*, such that the distance c_{ij} between a point *i* and a sensor *j* is lower than or equal to the covering ray *R*

Figure 4.11 – SCP Model

The proposed model has been optimally solved by the usage of FICO-Xpress optimization software and tested on two real test cases using the airspace of northern Italy as "Area of Interest"; it is shown in Figure 4.12. The terrestrial zone of this "Area of Interest" is divided in three iso-risk zones for example, they are not identified by using previous rules.

Figure 4.12 – Northern Italy and examples of iso-risk zones

The set covering model has been experienced on different test instances: air-routes density is similar to the real configuration. The test cases differ for:

- number of routes (→ number of warning boundary points)
- number of possible LIDAR locations
- distribution of the routes
- width of the warning boundaries

First test case is shown in Figure 4.13 and relative "Alert Perimeter" are violet dots in Figure 4.14.

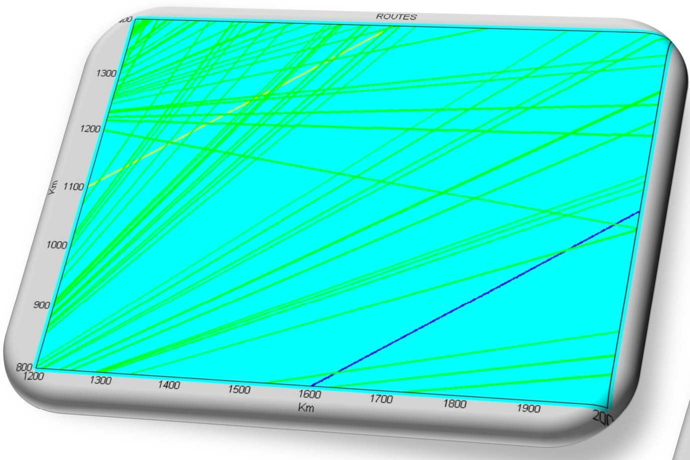

Figure 4.13 - Air-routes configuration of first test case

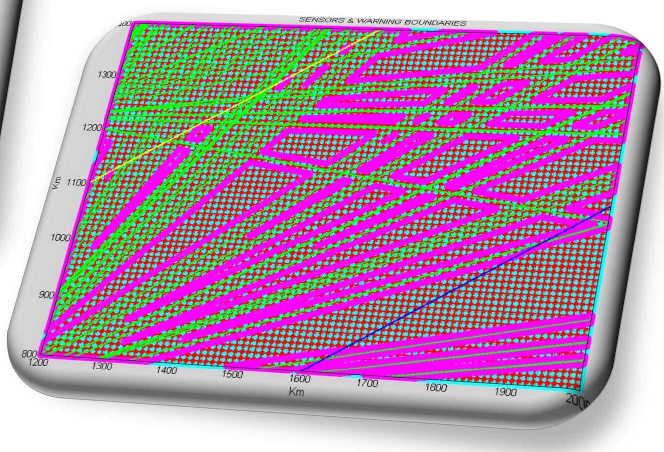

Figure 4.14 – "Aler Perimeter" of first test case

Software Xpress identified domain to monitor, which is shown in Figure 4.15, and generated the solution, which is shown in Figure 4.16: using that optimization model, it calculates the best points where sensors should have been located and it prints their coordinates. The regular mesh of sensors was composed by 2682 entities; Xpress calculations determine that only 298 sensors are necessary to monitor that configuration of air-routes.

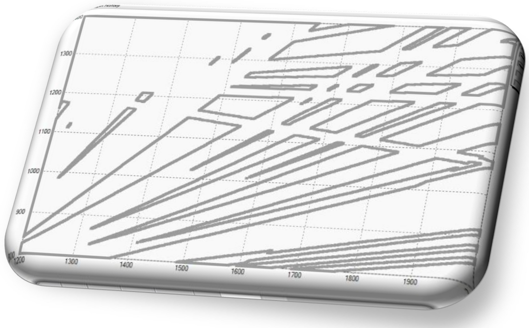

Figure 4.15 – Domain identified by FICO Xpress

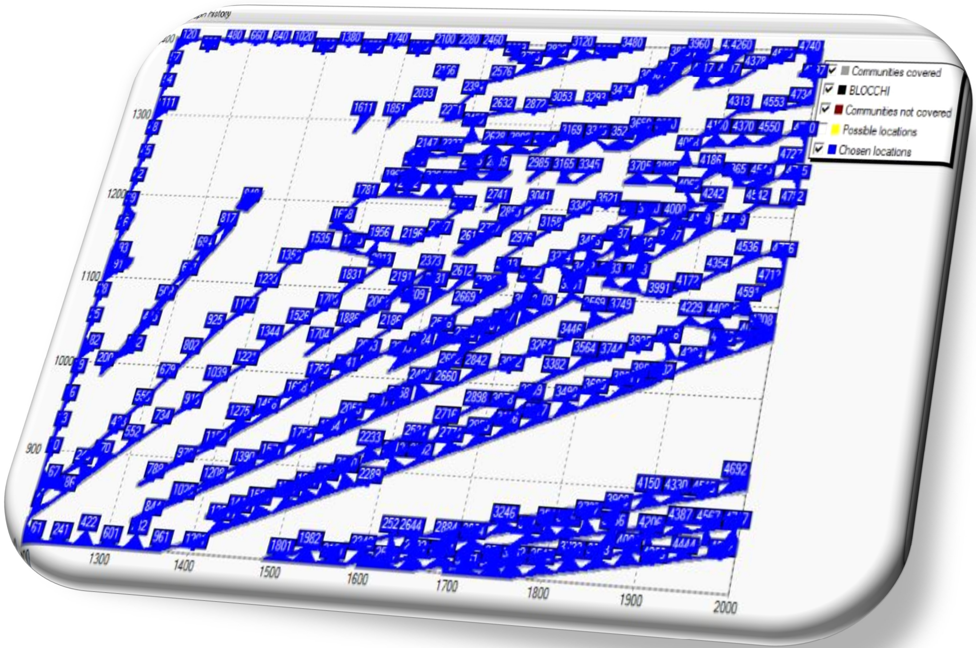

Figure 4.16 Sensors placed by FICO Xpress, in first test case, using covering optimization model

Second test case is shown in Figure 4.17 and relative "Alert Perimeter" are violet dots in Figure 4.18.

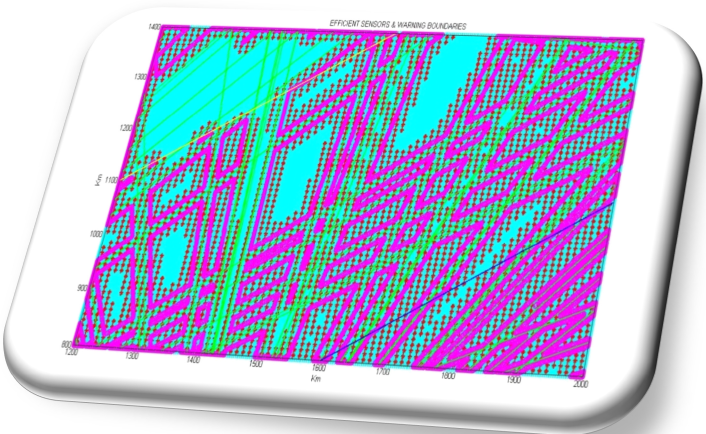

Figure 4.18 – "Aler Perimeter" of second test case

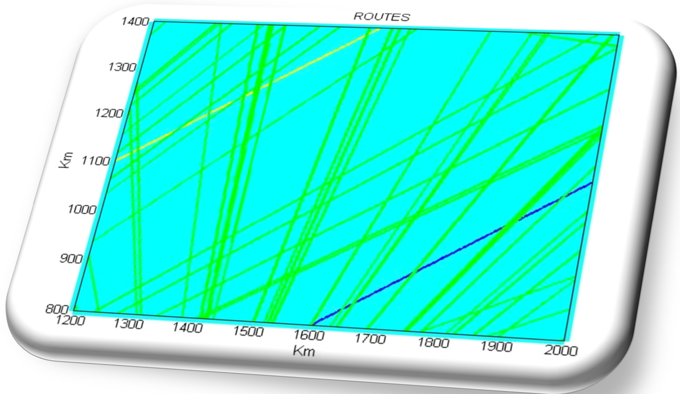

Figure 4.17 – Air-routes configuration of second test case

Software Xpress identified domain to monitor, which is shown in Figure 4.19, and generated the solution, which is shown in Figure 4.20: using that optimization model, it calculates the best points where sensors should have been located and it prints their coordinates. The regular mesh of sensors was composed by 2990 entities; Xpress calculations determine that only 330 sensors are necessary to monitor that configuration of air-routes [67].

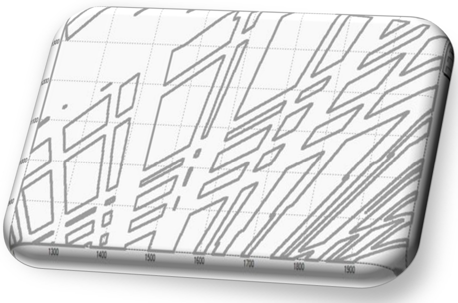

Figure 4. 19 - Domain identified by FICO Xpress

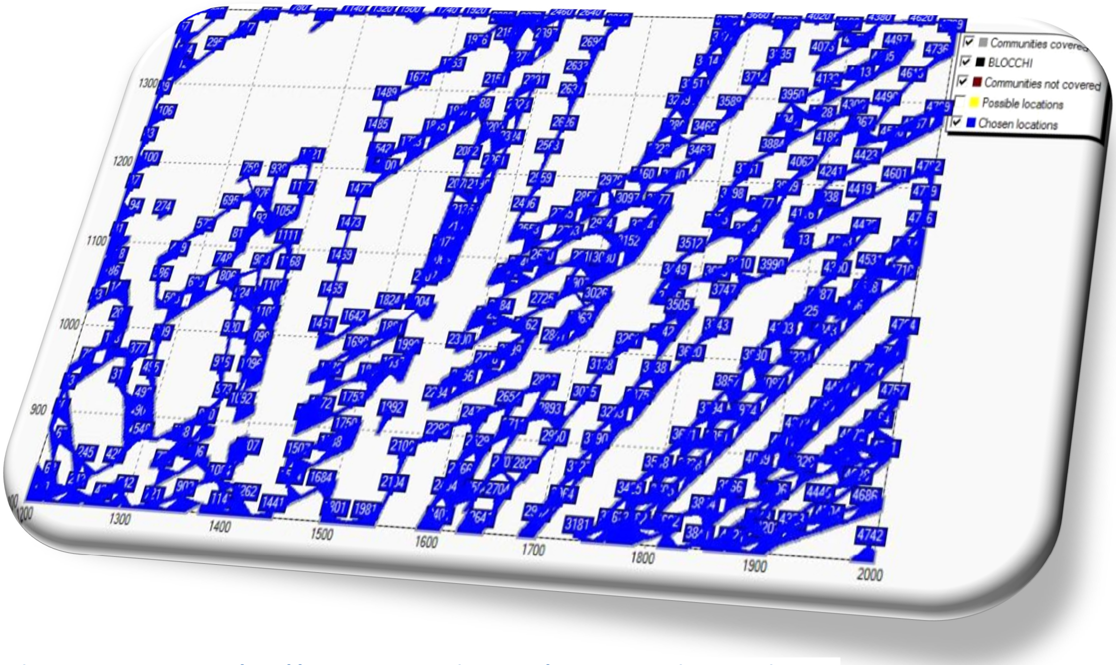

Figure 4. 20 - Sensors placed by FICO Xpress, in second test case, using covering

Sale price and installation cost of each sensor are very high; Single European Sky ATM Research (SESAR) project aims to smarter aviation, so it wants to make air-routes more autonomous [68]. That independence is associated to GPS navigation and to absence of precise air-routes but exact terrestrial coordinates, where sensors have to be located, leave.

Fundaments of automatic platform had to be changed, of course.

4.2 Current studies and new model

More instrumental results, originated from earlier devices, have been jointed to give the possibility to evaluate airspace conditions. The most important role in the new model is played by each flight: air-traffic controllers help pilots to avoid volcanic-ash or desert-sand clouds.
Air-routes cannot be considered as fixed entities therefore another actor has to be monitored to avoid encounters.
Scenery in exam is shown in Figure 4.21: in this example, there are 5 aircrafts, represented by black "+", each of them with own instantaneous route, represented by violet line, and a volcanic ash or desert sand cloud, represented by yellow dots, with own movement direction, represented by blue line. Considering previous observations, the constant entities in this model are airplanes; they are to be monitored, as a random example shows in Figure 4.22.

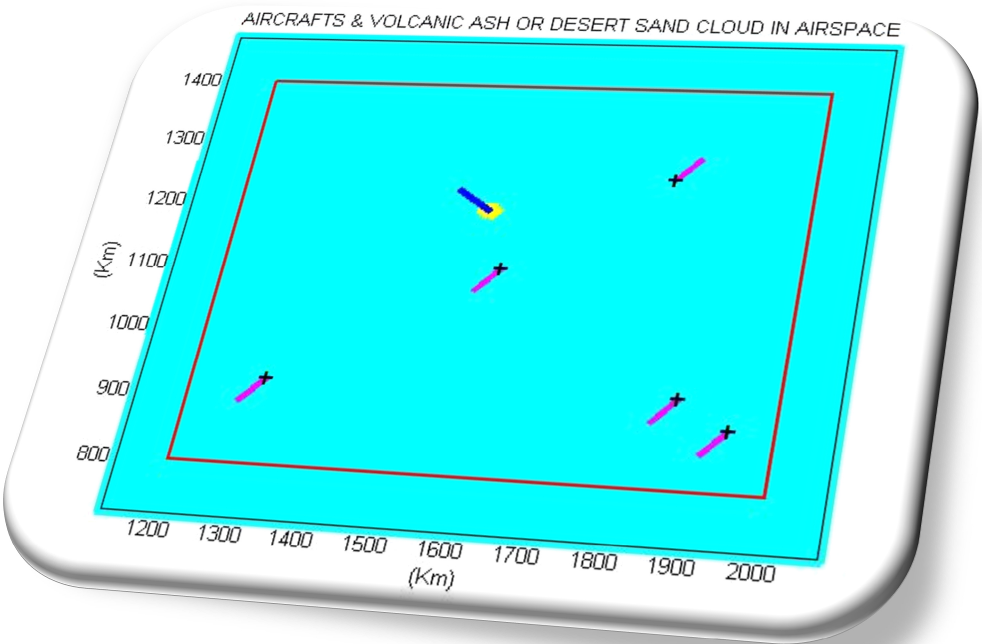

Figure 4.21 – Aircrafts & Volcanic Ash or Desert Sand Cloud in airspace

"Alert Perimeter" becomes a specific characteristic of each airplane and depends on few flight conditions, of course:

1. aircraft speed;
2. cloud speed;

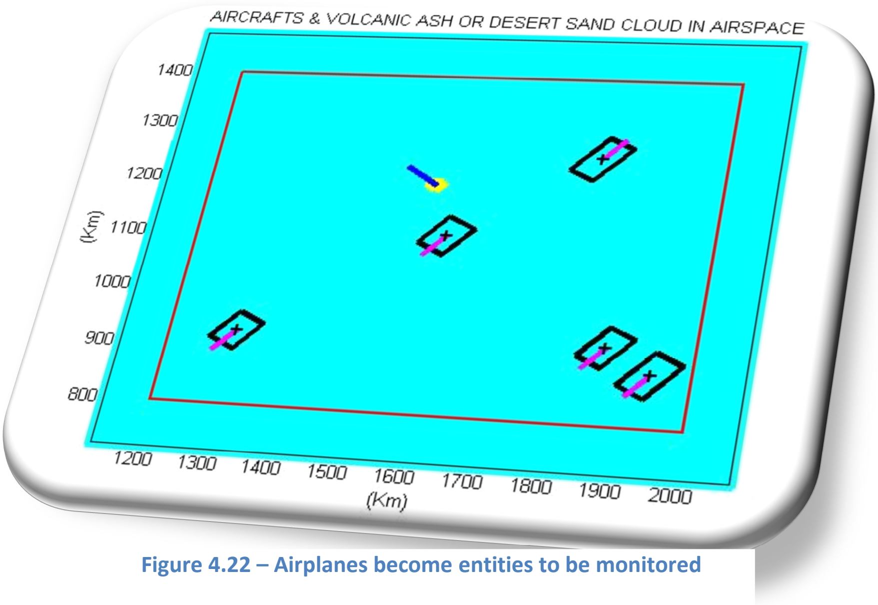

Figure 4.22 – Airplanes become entities to be monitored

3. movement direction of aircraft respect to cloud.

It can depend on risk value discussed in previous chapter, because that interpretation can help to improve flights safety. In Figure 4.22, dimensions of each “Alert Perimeter” are chosen without any physical reflection; moreover, it has to be considered that each “Alert Perimeter” has a z-component. If the third dimension is evaluated, it is possible to remove the hypothesis of only a flight level in exam: this model is a 3D-model; then, “Alert Perimeter” is a shell, which encloses the aircraft, so it can also monitor particles, which can encounter aircraft from along z-direction: it is possible also to remove the hypothesis about sources of particles (volcanic ash or desert sand) far from “Area of Interest”. Following illustrative figures are

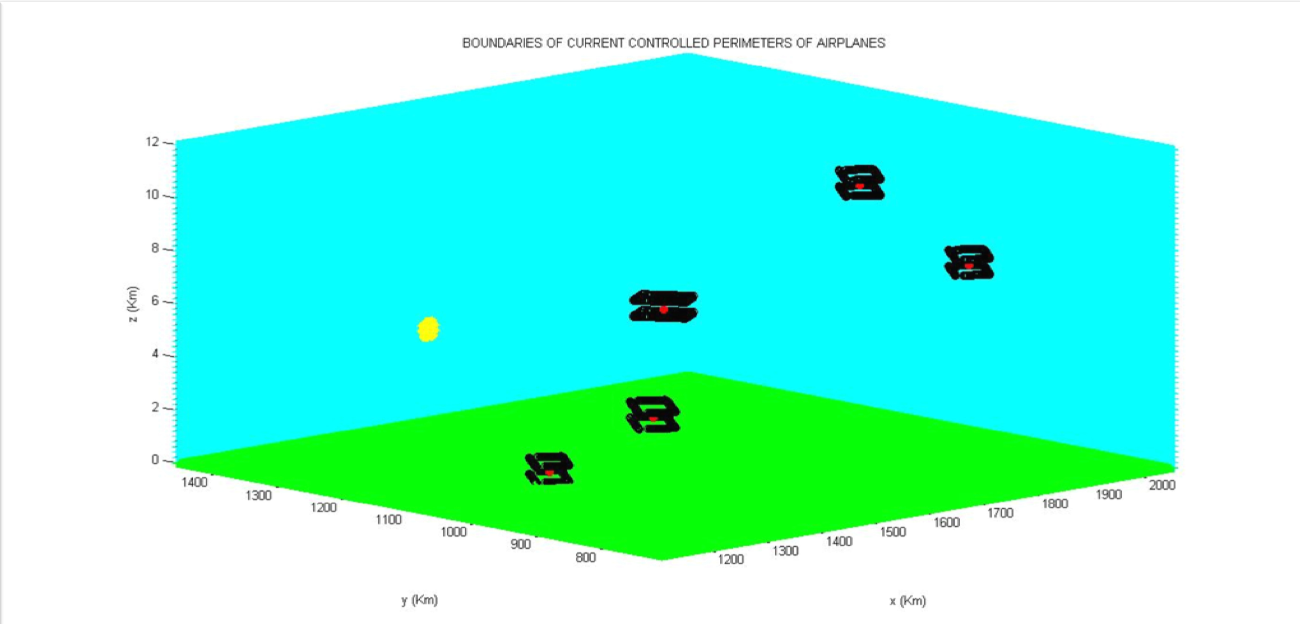

Figure 4..24– Cloud and boundaries of “Alert Perimeters” of aircrafts

realized using Mathworks MATLAB. In Figure 4.22, all aircrafts and cloud are at same flight level; in Figure 4.23, boundaries of “Alert Perimeters” are shown as black lines, aircrafts are represented as big red dot and cloud is represented as yellow dots. Dimensions of cloud and “Alert Perimeters” are not related to any calculation, in that figure.

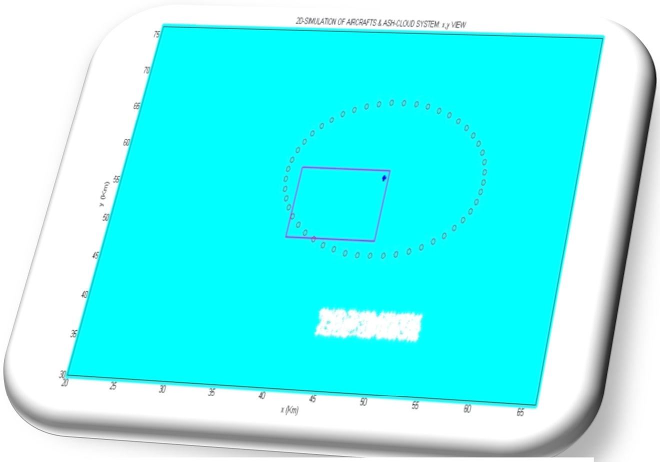

Figure 4.23 – Upper view of cloud, aircraft and its “Alert Perimeter”

Shape of “Alert Perimeter” is to be changed: the position of cloud is unknown and each aircraft has not a favorite direction to encounter the cloud; it is clear that the 2D-shape of "Alert Perimeter" has to be a circle. A mock-up of new model is shown in Figure 4.24: aircraft is represented by blue "+", boundary of "Alert Perimeter" by red dots, cloud by white dots and "Area of Interest" by violet lines. The 3D-shape of "Alert Perimeter" cannot be a sphere, because the radius will be surely larger than maximum flight level for aircrafts: that would lose any importance or would give often false alarm, as configuration in Figure 4.25 shows. Therefore, this circle will extend itself long z-direction and the 3D-shape of each "Alert Perimeter" will be the external surface of a cylinder, as shown in Figure 4.26: the cloud is far away from aircraft, so "Alert Perimeter" does not encounter any particle.

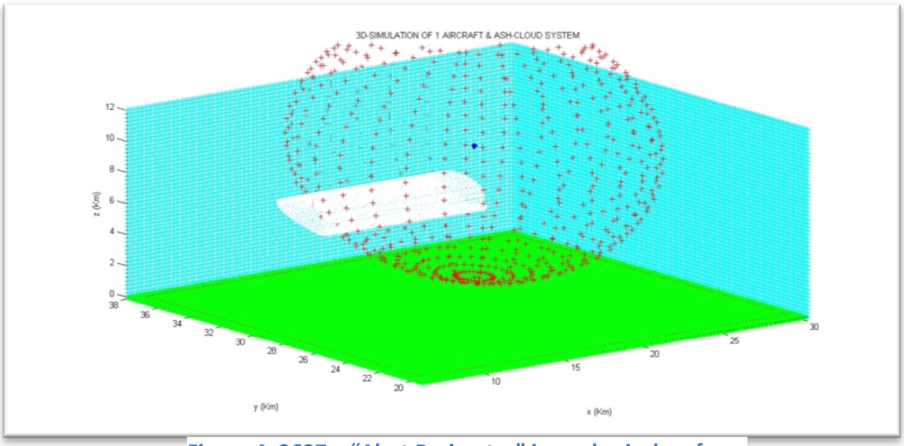

Figure 4. 2627 – "Alert Perimeter" is a spherical surface

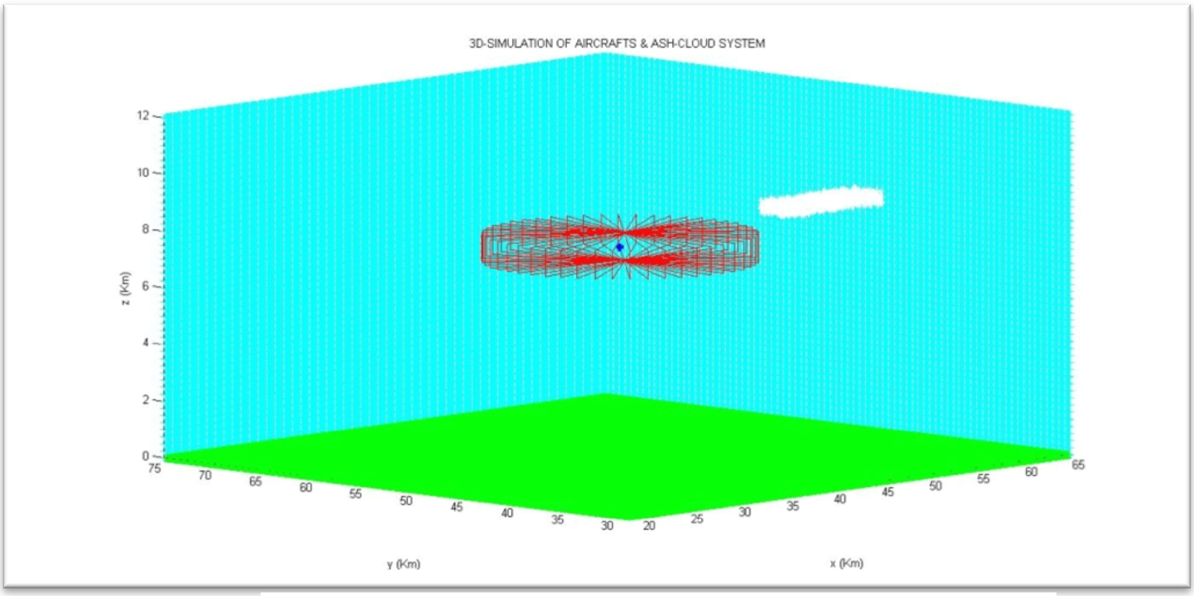

Figure 4. 25 – 3D-example of cloud, aircraft and its "Alert Perimeter"

It is remarkable that all particles of (volcanic ash o desert sand) cloud are unknown, so the virtual shell, which is named "Alert Perimeter", could reveal particles in all directions at any time. If the virtual cylinder is too big, some negative consequences could happen:

- number of points to monitor increases too much and, so, lead times of satellites or sensors could be significant;

➢ probability that particles of cloud cross around the “Alert Perimeter” and this one does not reveal their presence. When an aircraft encounters a (volcanic ash or desert sand) cloud, an unknown quantity of particles flow in cylinder, which becomes contaminated; “Alert Perimeter” though reveals only particles on external surface of cylinder and nothing is known about quantity just crossed.

Therefore, two important parameters are unknown: radius and height of virtual cylinder. It is basic to define those parameters, if automatic platform has to be realized.

The worst flight direction is meeting at right angles the cloud and those parameters will be at first set in that configuration.

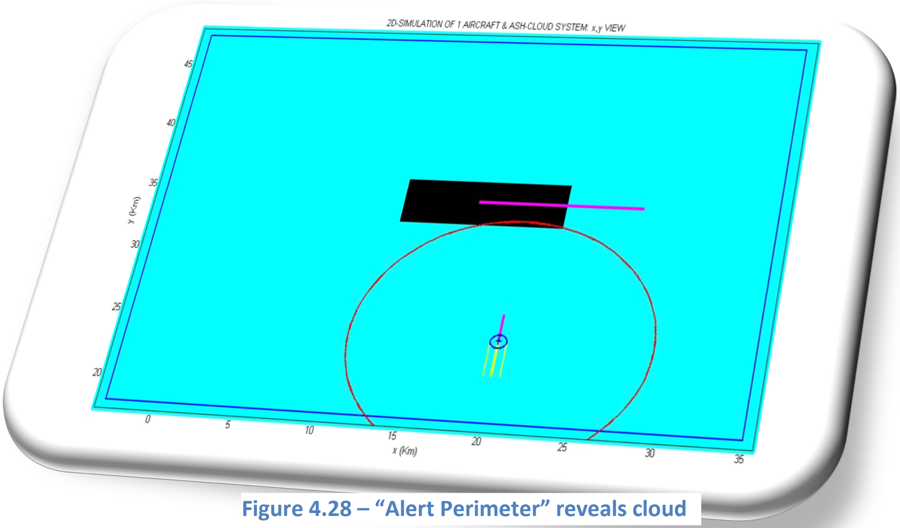

Figure 4.28 – “Alert Perimeter” reveals cloud

Aircraft route and cloud direction are orthogonal in upper view quoted Figure 4.27: they are represented by violet lines, cloud is represented by black lines, aircraft is represented by blue “+” and boundary of “Alert Perimeter” are represented by red line. Aircraft is going near cloud: when “Alert Perimeter” reveals some particles, it alerts air-traffic controllers and flight crew, so pilot will able to drift and to fly along a new air-route parallel to cloud direction. The “Alert Perimeter” depends on aircraft speed, of course; it depends also on delay between first alert signal and the conclusion of change direction of aircraft; this delay depends also on five intervals:

1. time passed from first instrumental alert to visualization on air-traffic controllers displays;
2. time spent by air-traffic controllers to decide the right change direction;
3. time spent by air-traffic controllers to transmit that choose to flight crew;
4. time spent by pilot to set up operation;
5. technical time to conclude change direction.

During the sum of previous list of times, the aircraft goes near the cloud, as shown in the sequence of Figures 4.28 – 4.31; the radius of “Alert Perimeter“ has to become over and over again shorter than previous instant, because the cylinder has constantly to reveal the position of the nearest particles of cloud.

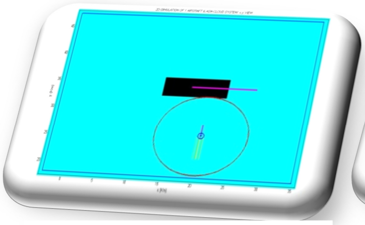

Figure 4.29 - "Alert Perimeter" reveals for first time particles of cloud

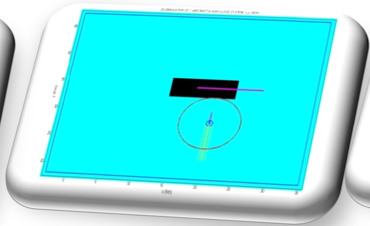

Figure 4. 31 - Aircraft is going near cloud

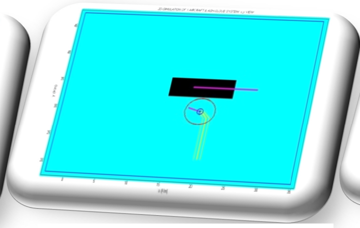

Figure 4.32 - Aircraft changes direction

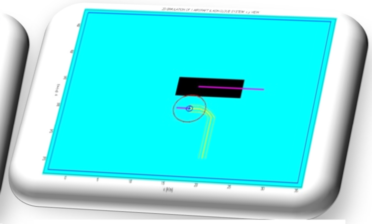

Figure 4.30 - New air-route is parallel to cloud direction

The radius of "Alert Perimeter" is, so, a deterministic measure, if described intervals are good estimated. For this reason, those intervals are variable, they are not fixed and they depends also on aleatory parameters, therefore the radius of "Alert Perimeter" cannot be the radius of surface, which alerts when a volcanic ash or desert sand cloud is revealed; then, it represents the minimum distance where aircraft can safely change direction and avoid encounter. In the last figures, a blue circumference is drawn: it is the upper view of "Critical Sphere": aircraft engines are able to suck up to a given distance; the radius of "Critical Sphere" is exactly equal or few longer than this distance. Another radius has to be considered: a "Monitoring Cylinder" has to be virtually implemented and its radius has to be larger than radius of "Alert Perimeter". External surface of this cylinder will try to find cloud around the aircraft. The configuration of

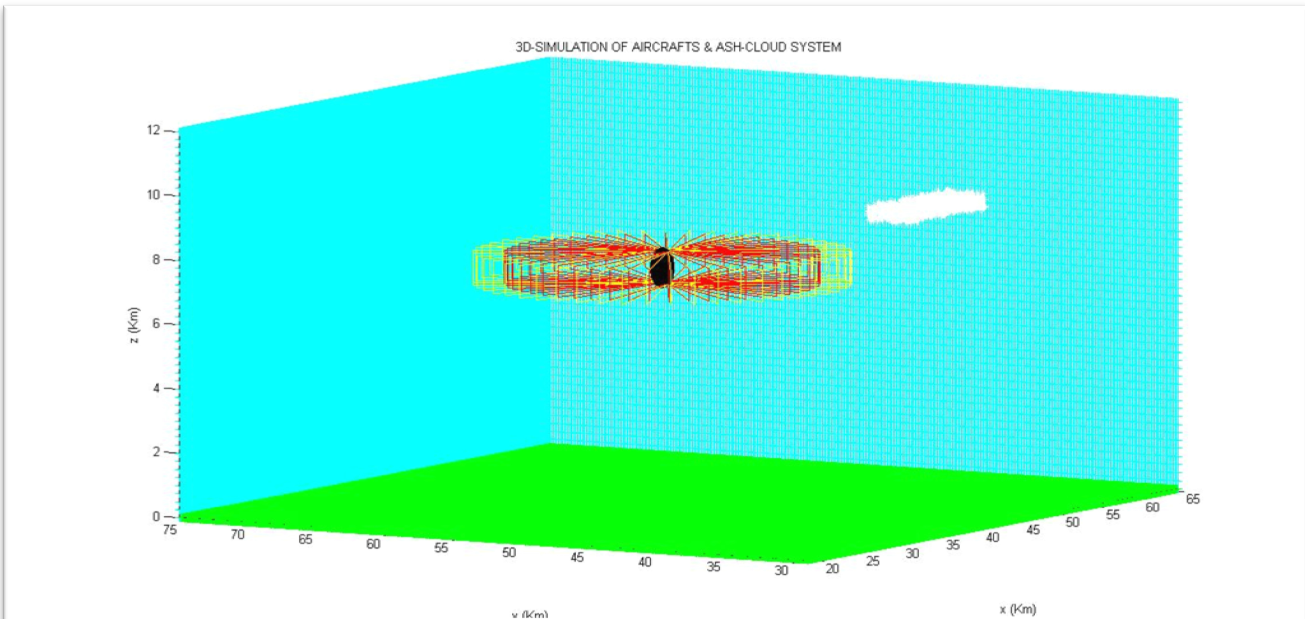

Figure 4.33 – 3D representation of all virtual sufaces of an aircraft: "Monitoring Cylinder", "Alert Perimeter" and "Critical Sphere"

virtual surfaces necessary to improve flight safety against encounters with volcanic ash or desert sand clouds are shown, for example, in the following figures 4.33 – 4.35. “Monitoring cylinder” is represented by yellow lines; “Alert Perimeter” is represented red lines and “Critical Sphere” is represented by black ‘*’. The volcanic ash or desert sand cloud is represented by white dots.:

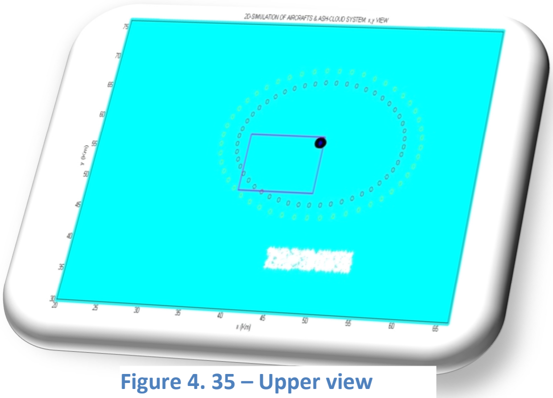

Figure 4. 35 – Upper view

in these images, height of two cylinder is equal to radius of “Critical Sphere”; this is only an illustrative assumption. Those distances and radius of “Monitoring Cylinder” have to be defined and they could also depend on regional costs discussed in previous paragraph [65]. In the next paragraph, studies to set that radius will be explained.

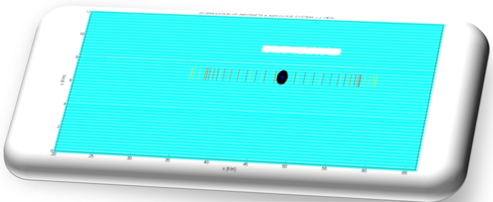

Figure 4. 34 – Frontal view

4.3 Results on first critical parameter

The first parameter, which was examined, is radius of “Monitoring Cylinder”. It depends on some aleatory factors, therefore a statistical approach was chosen to define it: a series of seven simulations based on Monte Carlo method was realized.

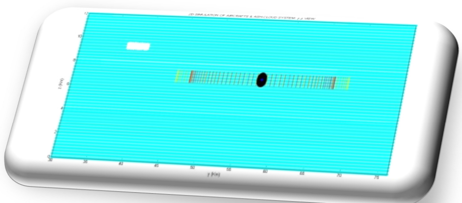

Figure 4.36 – Right side view

Each simulation is composed of $2 \cdot 10^5$ iterations: during each iteration two aircrafts and a cloud are randomly placed in a region of airspace. Length of “Area of Interest” is equal to 15 kilometers, width of “Area of Interest” is equal to 15 kilometers and height of “Area of Interest” is equal to 12 kilometers, of course. Cloud is simulated by 1000 particles and those particles are randomly placed in a parallelepiped, which has length equal to 20 kilometers, width equal to 3 kilometers and height equal to 0.5 kilometers. The lowest vertex of this volume is placed following three simple rules: x-coordinate is fixed at 5 kilometers plus a random value equal to 25% of cloud length at the utmost for each iteration; y-coordinate is fixed at 5 kilometers plus a random value equal to 25% of cloud width at the utmost for each iteration; z-coordinate is fixed at 9 kilometers plus a random value equal to 25% of cloud height at the utmost for each iteration. Aircrafts flight levels are random over 7 kilometers, other two coordinates are randomly chosen for each iteration. Cloud position is quite fixed: x-coordinate can change its value for 25% of cloud length, y-coordinate can change its value for 25% of cloud width, z-coordinate can change its value for 25% of cloud height. Each iteration represents a case study and it is independent from other iterations.

The radius of each “Critical sphere” is equal to 0.5 kilometers; the value of radius of “Alert Perimeter” is fixed and it is equal to 10 kilometers; the value of radius of “Monitoring Cylinder” changes after each simulation or after each series of iterations. During the first simulation, the value of radius of “Monitoring Cylinder” exceeds the value of radius of “Alert Perimeter” of 5%; during the second simulation, the value of radius of “Monitoring Cylinder” exceeds the value of radius of “Alert Perimeter” of 10%; during the third simulation, the value of radius of “Monitoring Cylinder” exceeds the value of radius of “Alert Perimeter” of 20%; during the fourth simulation, the value of radius of “Monitoring Cylinder” exceeds the value of radius of “Alert Perimeter” of 30%; during the fifth simulation, the value of radius of “Monitoring Cylinder” exceeds the value of radius of “Alert Perimeter” of 40%; during the sixth simulation, the value of radius of “Monitoring Cylinder” exceeds the value of radius of “Alert Perimeter” of 50%; during the seventh simulation, the value of radius of “Monitoring Cylinder” exceeds the value of radius of “Alert Perimeter” of 60%.

Sequence of configurations used during first simulation is the same in all other six simulations: homologous iterations are the same iterations cross over seven simulations.

Particles revealed by “Alert Perimeter” and “Monitoring Cylinder” together are deleted by list of “Monitoring Cylinder”; particles revealed by “Alert Perimeter” and “Critical Sphere” together are deleted by list of “Alert Perimeter”. Therefore results are really independent.

An example of the configuration used in each iteration is shown in Figure 4.36.

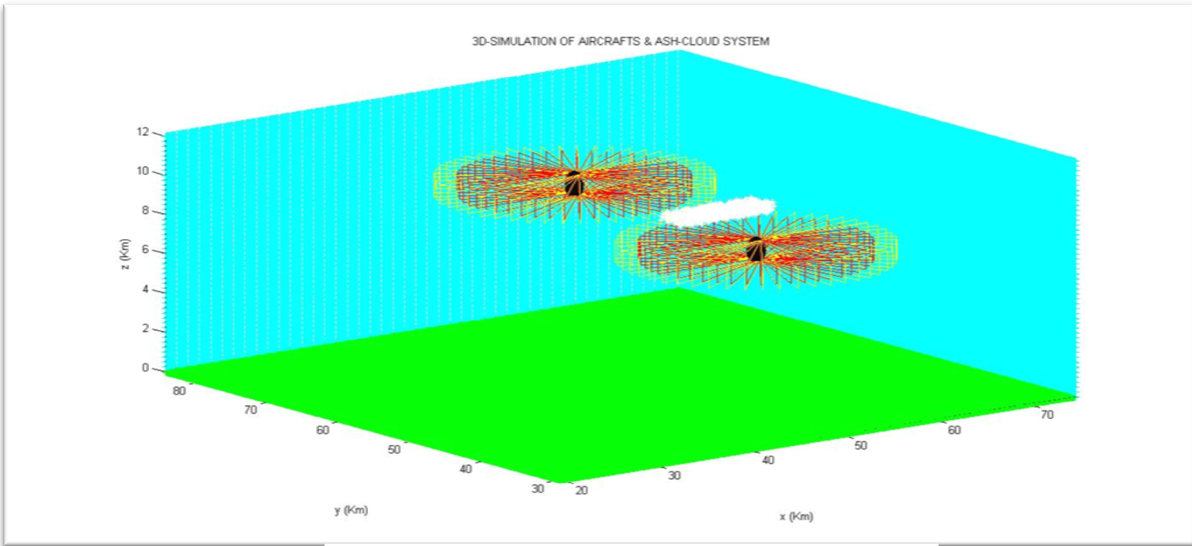

Figure 4.37 – Example of configuration of each iteration

Number of particles revealed by “Monitoring Cylinder”, “Alert Perimeter” and “Critical Sphere” of all two aircrafts together after first simulation is shown in Figure 4.37 - 4.39.

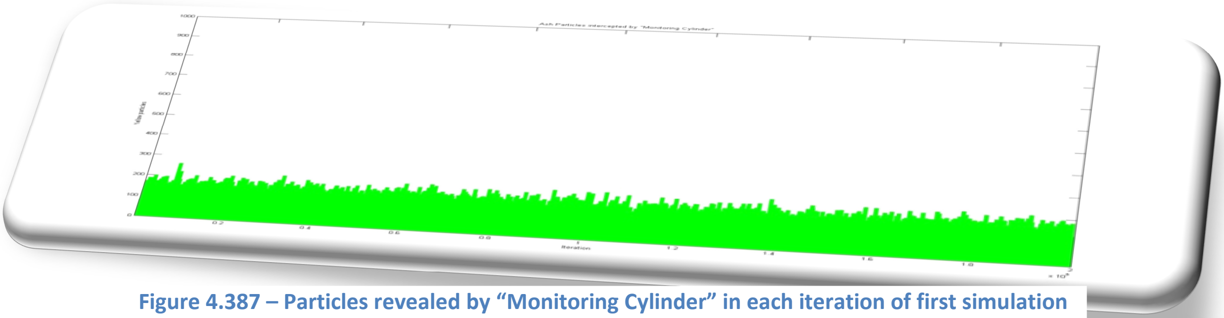

Figure 4.387 – Particles revealed by “Monitoring Cylinder” in each iteration of first simulation

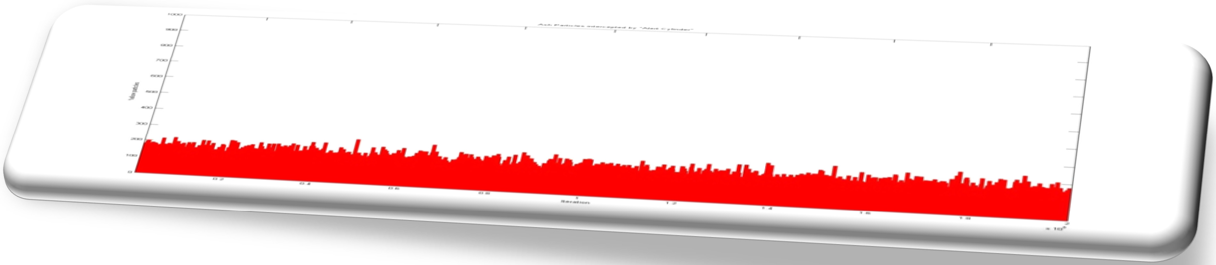

Figure 4.3839 - Particles revealed by “Alert Perimeter” in each iteration of first simulation

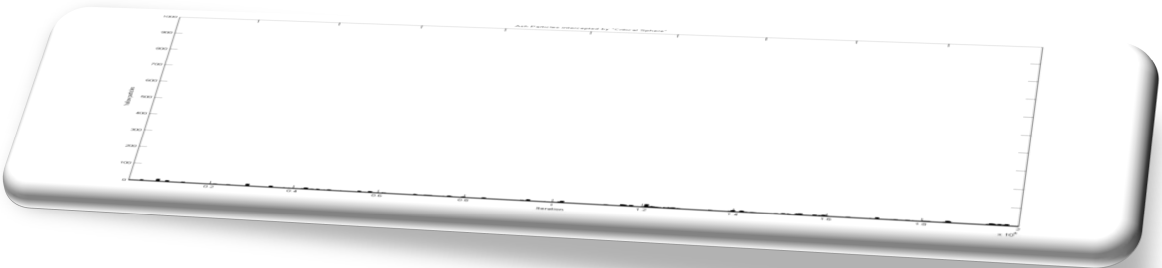

Figure 4.39 - Particles revealed by “Critical Sphere”in each iteration of first simulation

Graphics related to “Alert Perimeter” and “Critical Sphere” are not different after each of seven simulations, of course. It was difficult to evaluate graphics of results related to “Monitoring Cylinder”, so it was realized a distribution in frequency classes of number of particles revealed by “Monitoring Cylinder”: each class is composed of ten numbers and the division is regular, so the first class is 1-10, the second is 11-20 and so on to the last, 991-1000; 100 frequency classes are realized. Number of iterations, which revealed a value of each frequency class, is saved; an only graphic was realized, frequency classes are reported on x-axis and numbers of iterations are reported on y-axis. Different lines represent:

- black line is related to first simulation;
- green line is related to second simulation;
- blue line is related to third simulation;
- magenta line is related to fourth simulation;
- yellow line is related to fifth simulation;
- cyan line is related to sixth simulation;
- red line is related to seventh simulation;

That graphic is shown in Figure 4.40 and it is zoomed in Figure 4.41.

It is clear that, if radius of "Monitoring Cylinder" increases, the twentieth class represents the safe limit: that frequency class has maximum limit equal to 200 particles; each particle has a mean free path equal to 24.7 centimeters…very large !

It is remarkable that fifth class can represent an intermediate level of safety: the sixth

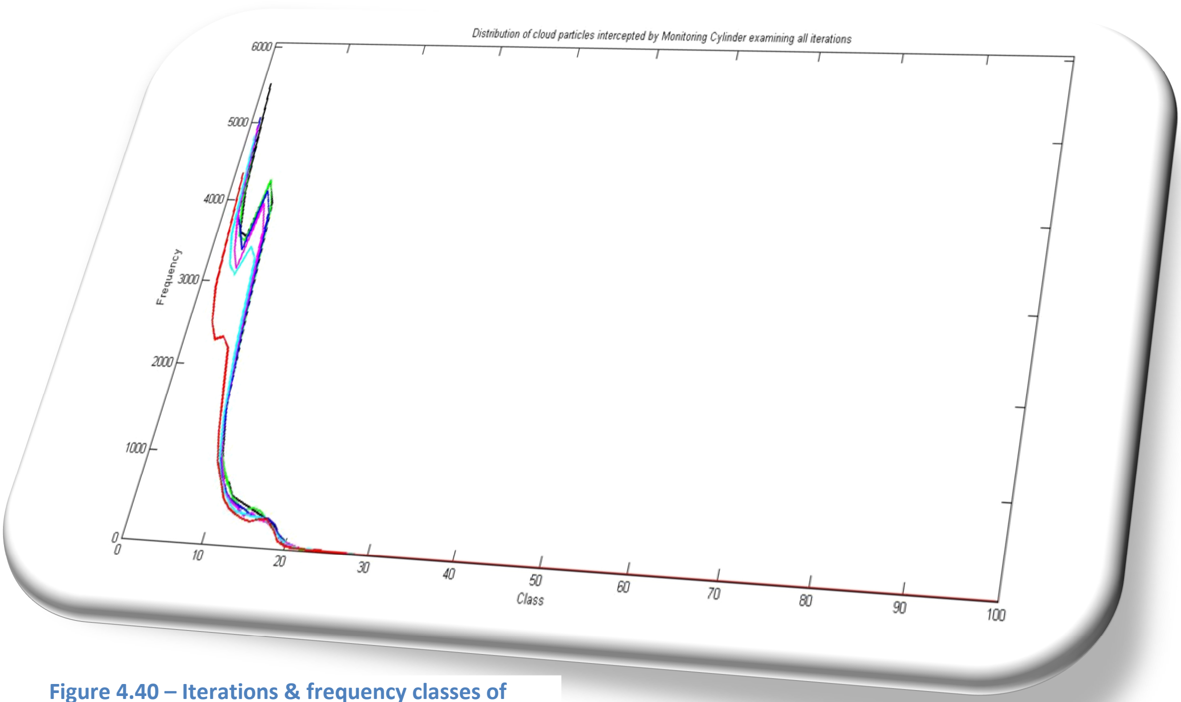

Figure 4.40 – Iterations & frequency classes of particles

simulation allowed to reveal about the same number of particles during much more iterations than the seventh; the safe limit is quite the same but, during a very larger number of iterations than seventh simulation, low numbers of particles were revealed: safety increases during these more probable events. Therefore, the value of radius of "Monitoring Cylinder" related to sixth simulation is the best, after this first step of studies.

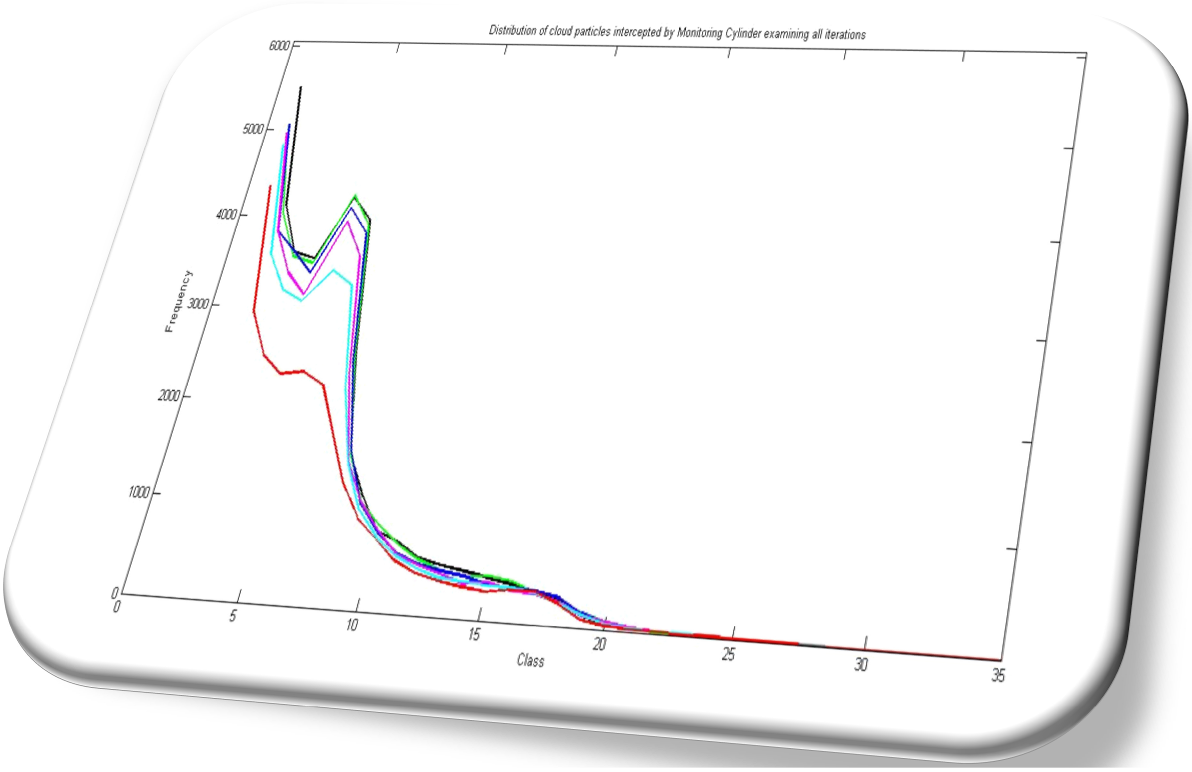

Figure 4.41 – Zoom in of graphic related to Iterations & frequency classes of particles

CONCLUSIONS

Automatic platform is founded on a web-based software, which is able to integrate satellites terrestrial sensors data; therefore, it can alert air-traffic controllers and flight crews at first, then it will help to forecast trajectories of monitored plumes of volcanic ash or desert sand.

Defining values of parameters discussed in the previous chapter represents the final step of preliminary studies; principal causes and consequences of problem about encounters between volcanic ash or desert sand and aircrafts are explained in the first part of dissertation; it was explained that encounters represent a very dangerous issue for people all over the world. That question already proved, above all in 2010, that it could cause very significant social and financial failures; it was neglected by organizations in charge until Icelandic eruptions on 2010. Current studies of scientists and aeronautical industries do not aim a global automatic system able to alert air-traffic controllers and flight crews in time to avoid encounters; at the present moment, researchers or pilots, who sight plumes, cry havoc and airspace is closed; that pilot and his passengers were in danger and others aircrafts are in danger, until aeronautical authorities close airspace: a lot of hours pass, with current rules…and that is not enough !

The statistical approach described in the last paragraph helps to define a risk value related to the amplitude of monitoring cylinder; other tests are useful and necessary to determine its limit dependent also on aircraft and cloud speeds.

It is important that each aircraft has a virtual shell possibly able to monitor a surface also larger than the optimal one: safety must be priority !

The statistical approach can also help to set this safety level.

Further studies are required to:

- ✓ prove that values of radius will be also safe, when relative directions of movement are not orthogonal;
- ✓ define best height of virtual monitoring cylinder and alerting cylinder;
- ✓ to develop a beta-version of desired software; then, this prototype will be used to do some tests using plane models and different sensors.

PARTICIPATIONS TO STARTUP COMPETITIONS

The projects described in previous chapters were admitted to some italian competitions for interesting technological purposes; promoters of each competition wants to help young inventors to develop own ideas and to obtain an innovative commercial product.

During 2014, those projects were admitted to:

- "Creative Clusters AEROSPACE", which was organized by "Regione Campania" through "Campania Innovazione" society; project was named "Ash and Sand Hazard Route Airspace Monitoring (ASHRAM)" and was tutored by 2 technical partners of "Campania Innovazione": "Centro Italiano di Ricerche Aerospaziali" and "Distretto Aerospaziale Campano". They have followed the team, who created the project, for 3 months, helping inventors on innovation and business progression through coaching, mentoring and networking. C.I.R.A. was the technical tutor of project and wanted "ASHRAM" team to meet 3 international partners during "Borsa dell'Innovazione e dell'Alta Tecnologia", on 10-12 December at Naples.
- "Start Cup Campania", which is a regional competition between all university of Campania. Project was named "No Ash and Sand in AirSpace (NASAS)". The aim of competition is the realization of business plan. An independent committee defines the ten most significant ideas and, then, chooses first five ideas; these winners receive a little award and are able to compete against winners of same competition organized in all other italian regions.

During 2015, the last version of project is competing to:

- "UniCredit StartLab", which is a Startup Accelerator for the best business project, promoted by UniCredit Group. The projects are judged by an expert team above all about its innovative contents; selected projects will be tutored for 12 months: expert consultant, business men and investors, who work together UniCredit team, will help authors to develop their project. UniCredit will ensure bank support and money awards for best projects.

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TABLE OF FIGURES

ACKNOWLEDGEMENTS

As Much As You Can

Even if you can't shape your life the way you want,
at least try as much as you can
not to degrade it
by too much contact with the world,
by too much activity and talk.
Do not degrade it by dragging it along,
taking it around and exposing it so often
to the daily silliness
of social relations and parties,
until it comes to seem a boring hanger-on.

Written by **CONSTANTINOS KAVAFIS**

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PER QUANTO PUOI

E se non puoi la vita che desideri

cerca almeno questo

per quanto sta in te: non sciuparla

nel troppo commercio con la gente

con troppe parole in un viavai frenetico.

Non sciuparla portandola in giro

in balìa del quotidiano

gioco balordo degli incontri

e degli inviti,

fino a farne una stucchevole estranea.

Scritta da **CONSTANTINOS KAVAFIS**

Traduzione di:

Margherita Dalmati
& Nelo Risi

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«Cominciate col fare ciò che è necessario,

poi ciò che è possibile.

E all'improvviso vi sorprenderete

a fare l'impossibile».

(San Francesco d'Assisi)