The Sky-Scanner System for Air Traffic Management: a Simulation Software

M. Salerno, G. Costantini, M. Carota, D. Casali

***Abstract*—** Laser detection and tracking of aircrafts based systems (LIDARs, LIgth Detection And Ranging systems) are emerging as a critical design trend in development of new generation ATM (Air Traffic Management) paradigms, of which they are the main innovations. A novel laser tracking technology (SKY-Scanner System) capable to detect and track of aircrafts up to at least 6 nautical miles from the Aerodrome Traffic Zone (ATZ) has been proposed. The proposed methodology is considered at the frontier of technological research but it represents the only realistic way to put solid basis for the fabrication of effective radar and lidar integrated systems for incorporation in new generation ATM paradigms.

The present paper is mainly focused on the simulation software of the above mentioned system. The simulation software is necessary in order to predict the behavior that the system, which is currently under development, will have. The software consists of two modules: Sim-module and Scen-module, both integrated in a single software package. The Sim-module simulates the mechanical system, the interaction of the laser with atmosphere, and the reflection on the surface of the airplane. The Monte-Carlo method will be used in order to take into account of random variables involved in the system, for example noise, turbulence, and error in mechanical positioning system of the lidar. The Scen-module simulates a scenery in which one or more aircraft will move along trajectories the user will specify.

***Keywords*—** Laser, Radar, Lidar, Air Traffic Management, Decision Support Systems.

I. INTRODUCTION

CONVENTIONAL methods for Air Traffic Management (ATM) that have worked until now cannot continue to cope indefinitely. As shown in [1], a new generation ATM is needed [2,3]. Several methods have recently been proposed in order to improve both security and performance [4,5].

Manuscript received December 10, 2008: Revised version received December 9, 2009. This work is supported by European Union's Sixth Framework Programme for Research and Technological Development).

M. Salerno is with the University of Rome "Tor Vergata", Department of Electronic Engineering, via del Politecnico, 1 – 00133 Roma, Italy (e-mail: salerno@uniroma2.it).

G. Costantini is with the University of Rome "Tor Vergata", Department of Electronic Engineering, via del Politecnico, 1 – 00133 Roma, Italy (e-mail: costantini@uniroma2.it).

M. Carota is with the University of Rome "Tor Vergata", Department of Electronic Engineering, via del Politecnico, 1 – 00133 Roma, Italy (e-mail: massimi.carota@uniroma2.it).

D. Casali is with the University of Rome "Tor Vergata", Department of Electronic Engineering, via del Politecnico, 1 – 00133 Roma, Italy (e-mail: daniele.casali@uniroma2.it).

Laser rangefinders have been be effectively used in conjunction to robot and autonomous systems [6,7]; the same concept has be applied in our project for a system that will work in conjunction with radars.

The SKY-Scanner project work, presented by us in [8,9,10] has been designed to meet this objective through the integration of different tasks addressing specific hardware (HW) and software (SW) items. The proposed technology, which is composed of four main sub-systems to be integrated:

- Montecarlo System Simulation;
- Laser Sensor Array (LSA);
- Sensor Management Computer (SMC);
- Command and Control Computer (C2C);

is completely novel, in the sense it has never been conceived to fulfill the proposed target.

Such approach has not been applied in lidar engineering.

Scientific objectives of the proposed research shall include:

- control of the tracking of aircrafts by means of a rotating cylindrical laser range-finder array;
- development of mathematical models of aircraft collision probability and optimal decision on corrective actions (DSS, Decision Support System) based on data fusion between radar data and laser tracking data;
- definition of a new generation ATM paradigm based on data fusion between radar data and laser tracking data and ground to aircraft laser communications.

Technological demonstrator is included in the validation process of the proposed methodology. The last eight months of the first year of the project will take place at the Pescara Airport (Italy) and will be dedicated to a first measurement session of aircraft positions for the definition of the basic reference performances to be exploited in the subsequent field testing session (last eight months of the project), with the employment of a test target developed and provided by ITALI Airlines.

The research, which cuts across trans-disciplinary fields, is such to provide an unequalled mean to theoretically and experimentally characterize the interaction between aircrafts and eye-safe lasers during take-off and landing operations and validate the proposed technology by means of accurate field testing measurement procedures and mathematical models, designed and developed to guarantee a deep and clear understanding of measured data as well as to guarantee a

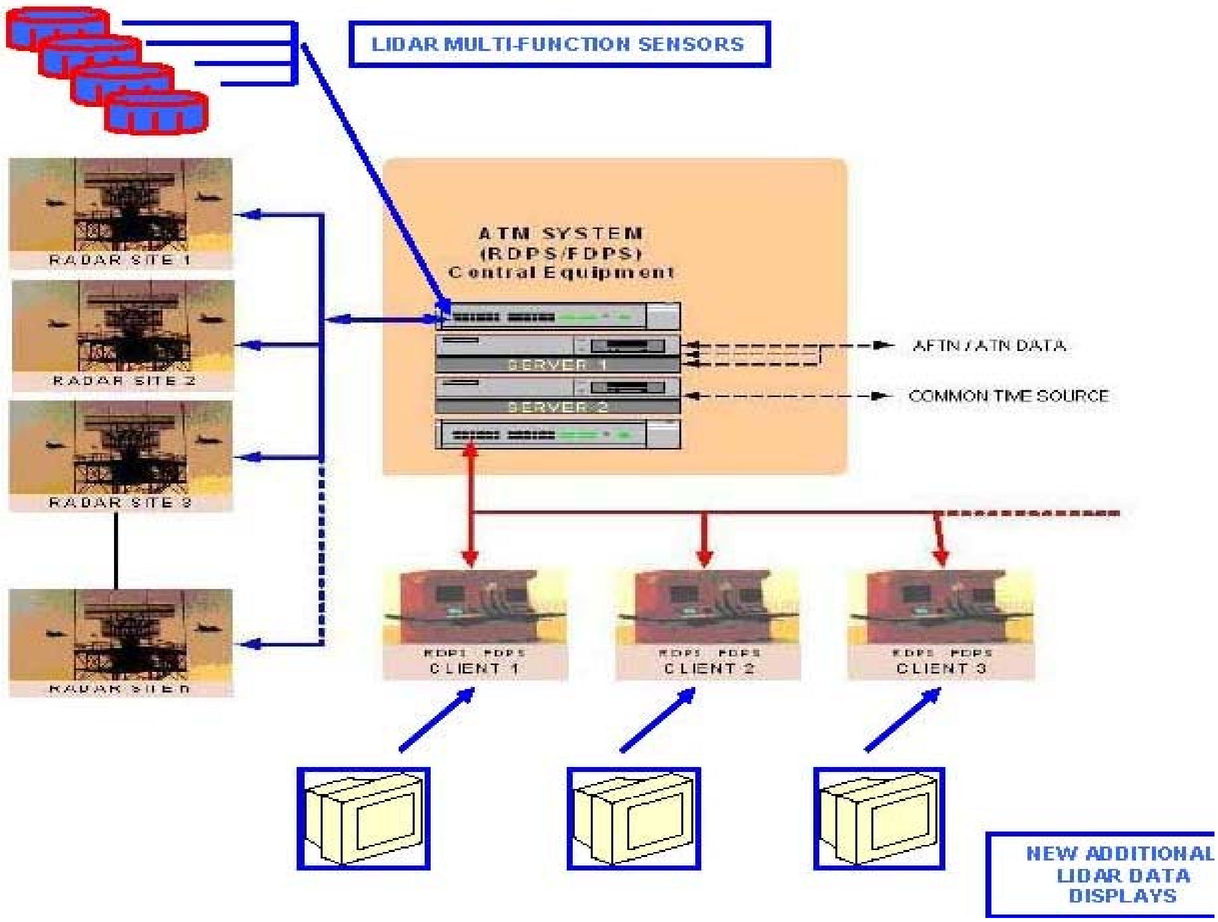

Fig. 1 ATM System Configuration and Sky-Scanner Project Innovations

reliable definition of a new generation ATM paradigm based on data fusion between radar data and laser tracking data and ground to aircraft laser communications.

The project will introduce long-term innovation in the automatic tracking of aircraft with lidar systems, leading to major improvements in following different areas:

- lidar systems for ATC applications;
- Decision Suppor Systems (DSS) tools for new generation ATM paradigms;
- lidar systems for ATZ surveillance and sensible targets surveillance;
- lidar systems for transportation systems laser imaging;
- point to point laser communications;
- laser propelled aircrafts.

The project will promote breakthrough knowledge on laser tracking of aircraft, new DSS models and ATM paradigms based on data fusion between radar data and laser tracking data and ground to aircraft laser communications, such to sustain the reliable development of new perspectives in the ATM world.

In the present paper we will mainly deal about the Monte Carlo System Simulation.

The structure of the work plan is such to produce the following project milestones:

- M1 - System Requirements and First Measurement Session;
- M2 - System Design;
- M3 - Demonstrator Development;
- M4 - Demonstrator Integration;
- M5 - Field Testing.

The potential spin-off of the SKY-Scanner technology is relevant because of its major influence on many industrial applications, ranging from ATC systems to laser communication systems and laser propelled aircrafts. In the former case, a relevant impulse to the improvement of the current ATC systems is expected. To put into perspective, the estimated world market for complex lidar technologies is currently € 400 million (dominated by military applications). On the other hand, the market potential for new integrated surveillance systems as replacement for existing airport radar technology has been estimated at around € 300 billion in the world.

II. Objectives

At a time where much of the attention of the European Air transport industry is focused on the major institutional and organizational changes occurring as part of the European

Commission's Single European Sky legislation, the opportunity for the exploitation of technology continues to develop faster than ever.

An ATM system is composed by the following sub-systems (Fig. 1):

- Radar Display Processor System (RDPS);
- Flight Data Processor System (FDPS): Safety Critical Operational Features;
- ATC workstations (RADAR Display, Flight Data Display);
- AFTN Message Handling Systems
- Data recording and playback;
- Maintenance monitoring.

The RDPS is connected to the surveillance systems; its main features are the following:

- Processes radar data from multiple sources;
- Provides composite radar picture to controllers;

Automatic Dependent Surveillance Broadcast (ADS-B) is a new satellite based technology that allows aircraft to broadcast information such as identification, position, and altitude.

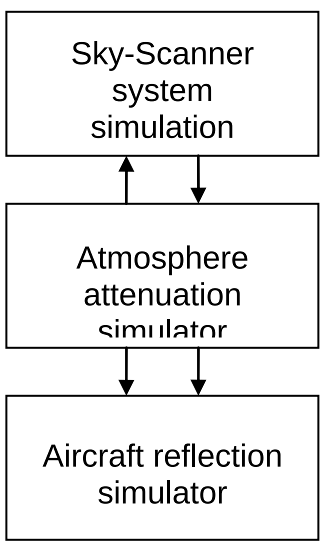

Fig. 2 Block diagram of the simulator.

III. Simulation Software

A block diagram of the software is shown in Fig. 2.

The Sky-Scanner simulation software performs a simulation of the three parts that form both the Sky-Scanner system per se, as well as the environment in which it operates:

Sky-Scanner system

The simulator takes as input parameters the azimuth and elevation values that can be actually supplied to the motor system.

Other parameters that are taken into account are: the error on the positions reached by the pointing system, divergence and wavelength of the laser beam, and the receiver aperture.

Atmosphere attenuation

The user can directly enter transmittance and other environmental information, such as visibility, turbulence of the air, presence of fog, rain or snow, background noise, scintillation, and attenuation.

Aircraft reflection

The user can supply the airplane position, plus some information about its shape, dimensions, and the reflectivity of its surface. This information is used by the software in order to calculate the laser spot area at the distance of the airplane, as well as geometric efficiency.

The software can take into account the presence of at most two airplanes at the same time, called target 1 and target 2. For each airplane, the user must supply all the necessary information.

Moreover, the user can choose between three types of airplane: Metroliner SA 227, Airbus A 321, or custom. In the last case, the edit button is enabled, and a mouse click on it will open a new window, where the user must enter the following data: reflectivity of the surface, length, height, wing span, wing area and wing sweepback.

Given the emitted power, the software can also simulate the received power in a given environment, in relation to the chosen airplane, and laser position conditions.

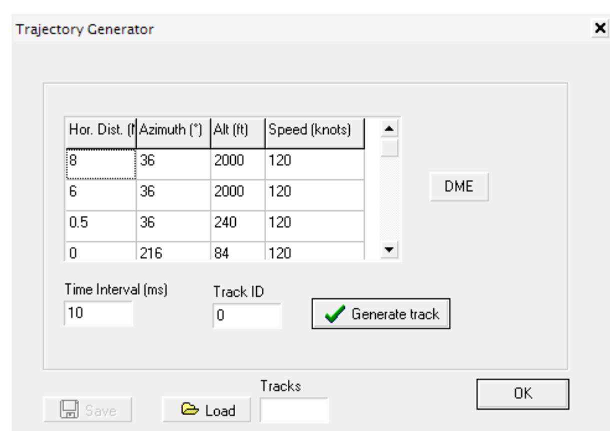

Fig. 3 Trajectory generator.

A. Sky-Scanner System Simulation

The first block of the simulator gives an estimation of the actual position reached by the mechanical positioning system, which can be modeled on the basis of a random variable with a mean value μ that's equal to the expected position and a standard deviation σ depending on the precision of the system. The density distribution of this random variable can be modeled with the normal distribution:

$$p(x) = \frac{1}{\sigma\sqrt{2\pi}} \exp\left(-\frac{(x-\mu)^2}{2\sigma^2}\right),$$

For convenience reason, we can express the actual position as the sum of the requested position plus a random variable e representing the error, centered in 0. If we suppose that the error standard deviation is the same for azimuth and elevation, we can express both values with the following formulas:

$\theta_{act} = \theta_{req} + e$

$\phi_{act} = \phi_{req} + e$

where θ_{req} and θ_{act} are the requested and actual elevation, ϕ_{req} and ϕ_{act} are the requested and actual azimuth, and e is the position error.

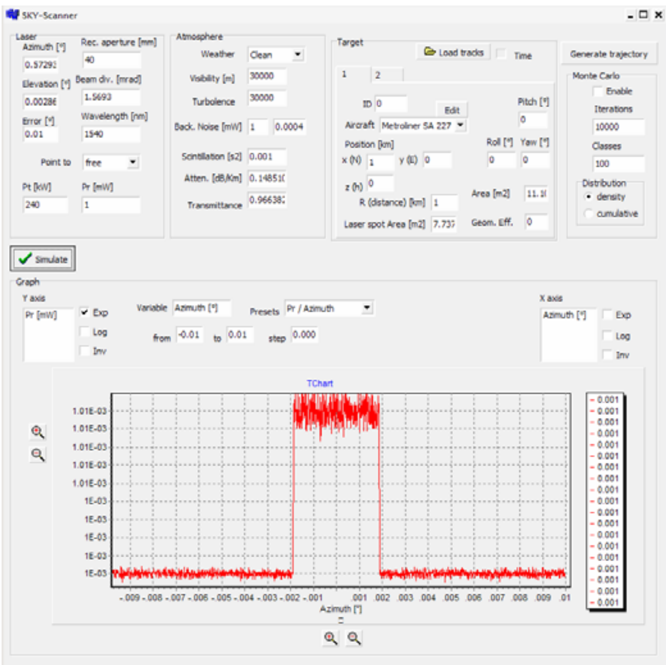

Fig. 4 Received power when azimuth spans from –0.01° to 0.01°.

B. Lidar equation

Atmosphere attenuation and airplane reflection can be a challenging problem if we want to take into account all the underlying physics. For that reason, we need to carefully select the approximations that we can tolerate. For example, air refraction can cause a bending to the laser beam, which leads to an error both on the measured distance and elevation. Nevertheless, in case of non huge target distances of about 10 km, as it happens in our application, this error is almost zero (about 1 mrad) and therefore it can be considered negligible.

A very useful formula that is applied in all lidar applications is the lidar equation, that takes into account the path of the emitted light, the reflection, and the path of the reflected light which returns back to the lidar. The result given by the formula is the received power of the sensor:

$$P_r = P_o \frac{KbT^2YA_r^2}{16R^2} + P_b$$

P_r: received power
P_o: emitted power (peak power 240 KW)
K: efficency optical system
T: atmosphere transmittance
Y: geometric efficency
b: backscattering coefficient
A_r: aperture diameter (40 mm)
R: distance
P_b: background light noise

The most important parameter that influences this formula is the transmittance of the atmosphere, since its value depends on the wavelength of the laser beam as well as on many other parameters. Most of them are empirically modelled.Sky-Scanner System Simulation

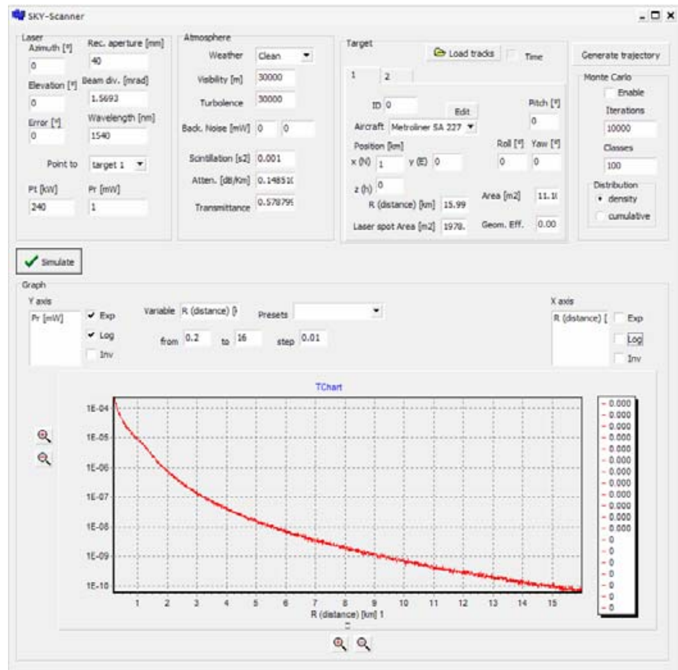

Fig. 5 Received power when distance spans from 0.2 km to 16 km.

C. Airplane Reflection

Lidar equation takes into account the reflection of the laser beam, considering the backscattering coefficient, and assuming that the target is big enough to reflect the whole laser beam. A big challenge that we found in our application is that when the beam divergence is 1.5693 mrad, as in our application, and the distance of the target is more than some kilometre, the laser spot area becomes larger than the reflecting area of the airplane. In fact, the laser spot area at a distance R is:

$$A = \pi (R \sin \delta)^2$$

where A is the laser spot area, R is the distance and δ is the beam divergence.

Actually, as shown in Fig. 5, for distances higher than about 1 km, the received power starts to decrement more quickly than expected by considering only air attenuation; in fact only a little part of the laser spot area is reflected. So, in order to make a realistic simulation, we must add a multiplying coefficient which is the ratio between the laser spot area at the distance of the airplane, and the reflecting area, which depends on the position of the airplane.

This is the reason why we need pitch, roll, and yaw of the airplane. Anyway this ratio depends mainly on the distance of the target.

D. Monte Carlo Simulation

The system can perform a Monte Carlo simulation, where every variable involved in the above mentioned parameters can be considered as a stochastic variable, and the simulation can be repeated n times. Finally, the results can be represented as the density or cumulative distribution of a chosen variable if we are interested to just one variable. More often we want to have an idea of how much the randomicity would affect the graph of a variable vs. another variable. So, many simulation are performed, with different values of the random variables, and the resulting graphs are overlapped. If the number of simulations is sufficiently high, the result will usually be like a thick line, where the thickness is proportional to the variance of the given variable.

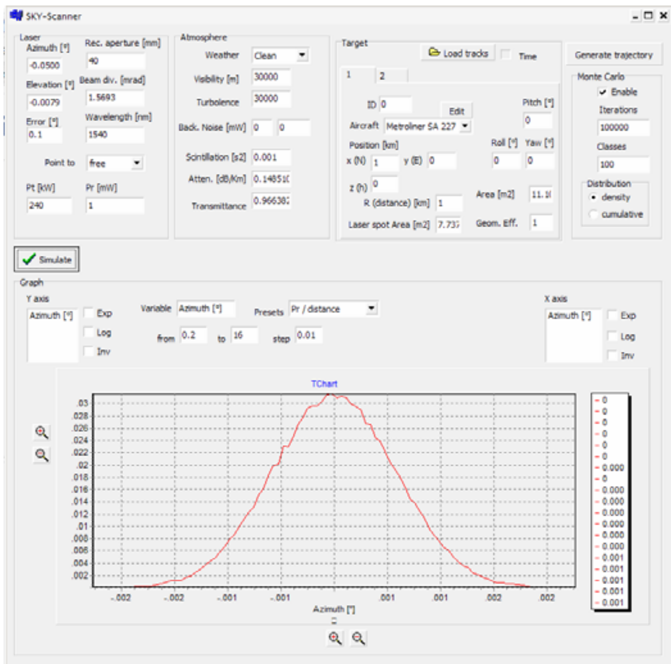

Fig. 6 Density distribution of azimuth position of the laser when imposed azimuth is 0° (error is simulated).

E. Trajectory Generator

In order to generate a trajectory to be simulated, we can click on the generate trajectory button, and have a window to be shown like the one reported in Fig. 3. By means of this window, we can enter a table of reference points that will be interpolated by the software.

For every reference point, we must specify: the ground distance from the airport, in Nautical Miles, the azimuth in degrees from north (clockwise direction is taken as positive), altitude in feet on the sea level, and speed in knots. If the user knows the required DME value, he can insert it in place of the ground distance and then press the DME button: the value will automatically be converted in ground distance, according to the given altitude. The user has also to specify the time step, and the ID value of the trajectory, and then press generate track button. The generated track can be saved in a file.

If more than one track must be put in the same file, the user can load a file. Then he will find the IDs of all the tracks recorded in the file listed in the tracks box. After that, he can set the parameters for a new track and select a new ID that is different from the existing ones. The generated track will be added to the existing ones, and the result can be saved in a new file.

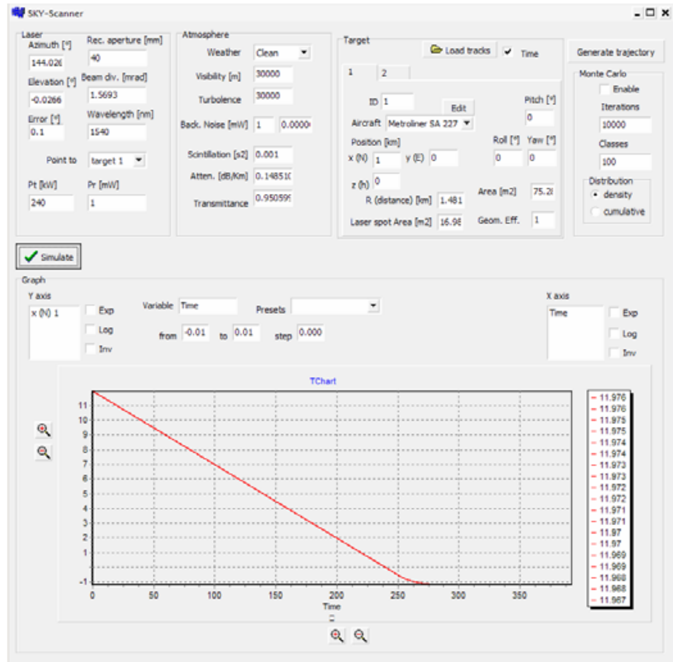

Fig. 7 Landing of a Fairchild Metroliner SA 227.

IV. Simulation Results

In Fig. 4-13 some examples of graph are shown. In Fig. 4, a plot is given of the received power vs. azimuth, where the variable parameter is the azimuth, which spans from -0.01° to 0.01°, with a step of 0.0001°. The aircraft is at position x = 1 km, y = 0 km, z = 0 km, which means that it is at the ground level, exactly at 1 km at north of the Sky-Scanner. The detected width is about 0.004°, which depends on the distance and size of the aircraft.

In Fig. 5, the received power vs. distance from the Sky-Scanner is shown, where the variable parameter is the distance, which spans from 200 m to 16 km, with a step of 10 m.

In order to perform a Monte Carlo simulation, the user must check the enable check box over the Monte Carlo box. The number of iterations must be entered, and the density or cumulative distribution must be selected together with a number of classes. Classes is the horizontal resolution: a low number of classes means a low resolution, but a higher number means that a much higher number of iteration is needed in order to have valid results. In Fig. 6 the density distribution of the azimuth is shown. This graph was obtained by selecting azimuth both for *X* axis and *Y* axis, and enabling

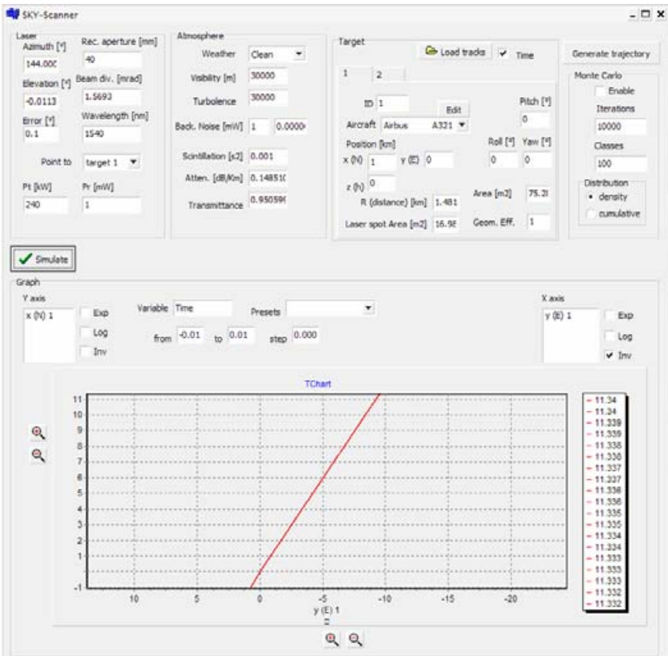

Fig. 8 Landing of an Airbus A321

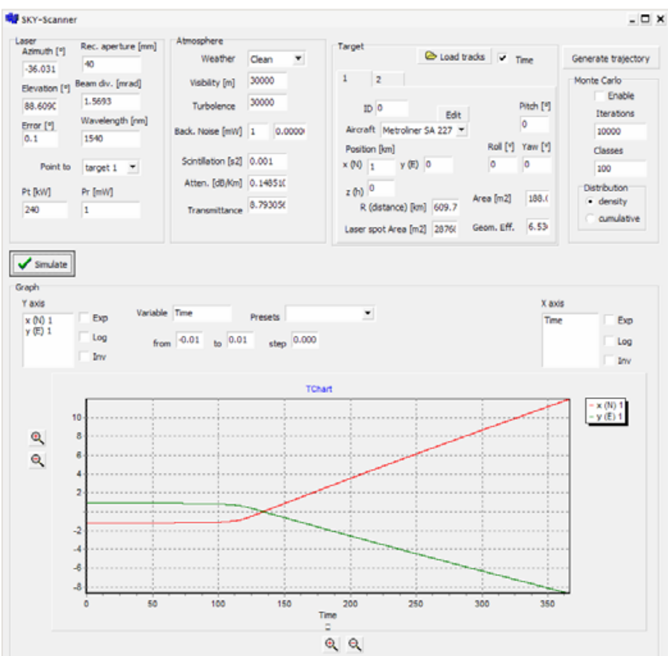

Fig. 9 Take-off of a Metroliner.

the Monte Carlo simulation. 100000 iterations have been performed and 100 classes were considered. The graph shows that azimuth is a random variable with a Gaussian distribution centered in 0°.

In order to perform a test of the single target capabilities, we generated the following scenarios:

- Landing of a Fairchild Metroliner SA 227
- Landing of an Airbus A321
- Take-off of a Metroliner
- Take-off of a A321.

Results are shown in Fig. 7-10.

In Fig. 7 we show a landing trajectory for a Fairchild Metroliner SA 227.

In the *x* axis the time is reported (in seconds) and in the y axis the value of the "*x*" in km. Direction *x* is oriented towards north.

In Fig. 8 another example is shown, where an Airbus A321 is landing. In this graph, we report the *North* direction in the axis *Y* and *East* direction in axis *X*. *X* axis is inverted, so that it actually shows the *West* direction like in a map.

In Fig. 9 the take-off of a Metroliner is shown, in this case we show time in the *X* axis. And in the *Y* axis we show both *X* (*North*) value and *Y* (*East*) value. North value, which is the red line, is incrementing, while *East* value, which is the green line, is decrementing. That means the airplane is moving toward NW direction.

Fig. 10 Take-off of an A321.

In Fig. 10 the take-off of an A321 is shown. In this graph, we display the *z* value (height) at the *Y* axis, and *x* value (*North*) in the *X* axis.

In order to perform a test of the multitarget capabilities, including possibility of collisions, we generated the following scenarios:

- Landing A321 colliding with taking off Metroliner
- Landing Metroliner colliding with taking-off A321
- Landing A321 colliding with a landing Metroliner

Results are shown in Fig. 11-13.

In Fig. 11 we load a table where a landing A321 is going to collide with a A321 taking-off. The trajectory of the A321 is associated with ID 1 and represented with the red line, the trajectory of the Metroliner is associated with ID 2 and

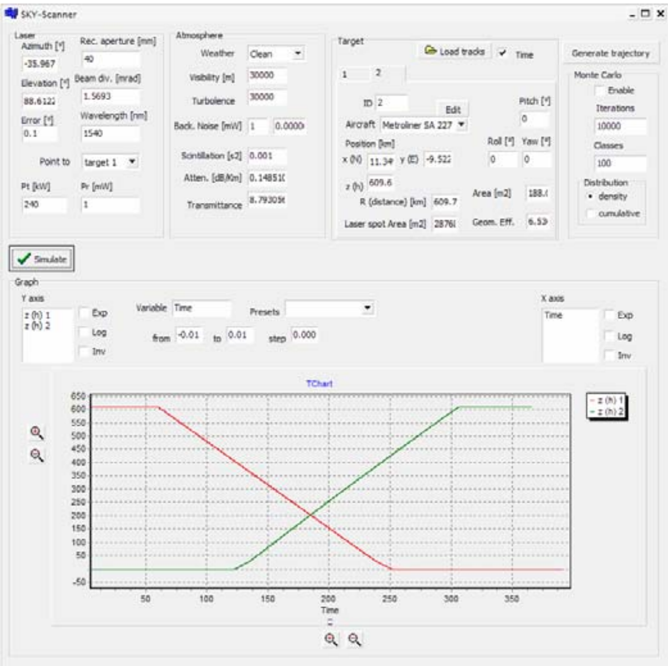

Fig. 11 Landing A321 colliding with taking off Metroliner.

represented with the green line. We show the height of both airplanes vs. time.

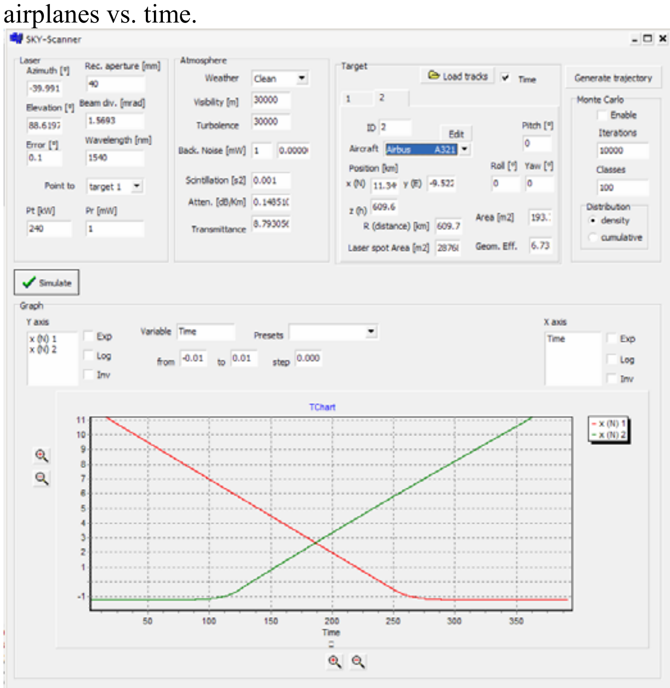

Fig. 12 Landing Metroliner colliding with taking-off A321.

In Fig. 12 we show a landing Metroliner, represented with red line, with ID 1, colliding with a A321 taking off. We show the *x* value (*East*) of both airplanes vs. time.

In Fig. 13 we show a collision between an A321 and a Metroliner, when both of them are landing with different azimuths. They collide when they reach, together, position 0 (the threshold of runaway). North direction is displayed in the *Y* axis and *East* direction in the inverted *X* axis, like in a map.

As you can see, the azimuth of the A321 (represented with the red line) is 36°, while the azimuth of the Metroliner (represented with the green line) is 40°.

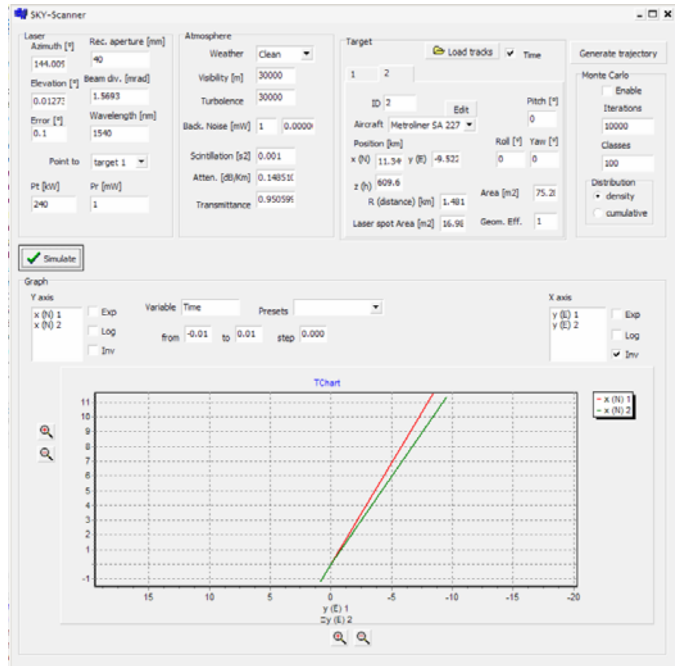

Fig. 13 Landing A321 colliding with a landing Metroliner

V. Conclusions

In this paper, the simulation software for an innovative LIDAR technology for air traffic management is presented. The research covers many areas in the field of LIDARS, Air Traffic Managements, Decision Support Systems, data fusion between radar data and laser tracking data and ground to aircraft laser communications.

Acknowledgment

The This work is supported by European Union’s Sixth Framework Programme for Research and Technological Development..

References

[1] S. Zerkowitz, “Is the need for a new ATM operational concept a strategic necessity?”, *Aerospace and Electronic Systems Magazine, IEEE,* Volume 18, Issue 1, Jan. 2003 Pages: 10 – 12.

[2] J. Kosecka, C. Tomlin, G. Pappas, S. Sastry, “Generation of conflict resolution manoeuvres for air traffic management”, *Intelligent Robots and Systems,* 1997. IROS '97., Proceedings of the 1997 IEEE/RSJ International Conference on, Volume 3, 7-11 Sept. 1997 Pages: 1598 - 1603 vol.3.

[3] J.W. Jackson, S.M. Green, “Control applications and challenges in air traffic management”, *American Control Conference, 1998. Proceedings of the,* 1998 Volume 3, 24-26 June 1998 Pages: 1772 - 1788 vol.3.

[4] T.J. Callantine, "Air traffic management system domain and control strategy analysis", *IEEE International Conference on Systems*, Man and Cybernetics, 10-13 Oct. 2004 Vol. 7, pages: 6268- 6273.

[5] I.R. de Oliveira, F.S. Carvalho, J. Batista Camargo, L.M. Sato, "Multi-Agent Tools for Air Traffic Management", *11th IEEE International Conference on Computational Science and Engineering Workshops,* 2008. CSEWORKSHOPS '08. 16-18 July 2008 Pages: 355 – 360.

[6] Lei Wang, J. Shu, T. Emura, M. Kumagai, "A 3D scanning laser rangefinder and its application to an autonomous guided vehicle" *Vehicular Technology Conference Proceedings*, 2000. VTC 2000-Spring Tokyo. 2000 IEEE 51st, Volume 1, 15-18 May 2000 Pages: 331 - 335 vol.1.

[7] H. Lamela, E. Garcia, "A low power laser rangefinder for autonomous robot applications", *Industrial Electronics, Control, and Instrumentation, 1996., Proceedings of the 1996* IEEE IECON 22nd International Conference on, Volume 1, 5-10 Aug. 1996 Pages: 161 - 167 vol.1

[8] M. Salerno, D. Rondinella, M. V. Crispino, G. Costantini, M. Carota, D. Casali, "Sky-Scanner: an Innovative LIDAR Technology for Air Traffic Management", *Proceedings of the 1st WSEAS International Conference on SENSORS and SIGNALS*, Bucharest, Romania, November 7-9, 2008, Pages 46-55.

[9] M. Salerno, D. Rondinella, M.V. Crispino, G. Costantini, M. Carota, D. Casali, "Sky-Scanner: a New Paradigm for Air Traffic Management", International Journal of Circuits, Systems, and Signal Processing, Issue 2, Volume 2, 2008, pages 131-139.

[10] M. Salerno, G. Costantini, M. Carota, D. Casali, "A Simulation Software for the Sky-Scanner System", Proceedings of the 2st WSEAS International Conference on SENSORS and SIGNALS, Baltimore, USA, November 7-9, 2009.