Abstract— The further globalization and mobility freedom indicate rapid increasing in needs of personal used air transport systems (see NASA SATS program). Such new and further general aviation (GA) requires totally new, innovative ideas and the use of the newest technological achievements to ensure a new, inexpensive, and secure control system.

The goal of this paper is the analysis and the definition of the impact of European small aircraft (SA) activity on the current and future ATM. It will also deal with the analysis of the current small aircraft resembling air traffic attributes; the identification of market requirements (different in needs of European and US GA development), and the prediction of European SA activity.

I. INTRODUCTION

Today’s air traffic volume is projected to be doubled by 2020 [1,2]. On the other hand, today there are [3,4] 300 000 private and small aircraft pilots in Europe. They fly more than 60 000 small aircraft. With accordance to our investigation, this market in new democratic countries, in new members of European Union (EU) will develop rapidly, even with greater ratio than conventional air traffic, and which would continuously be very high over the next 20 years [5]. In the figure 1.1. microjet means an aircraft with a maximum take-off weight between 5000 and 10000 lbs, such as Honda Jet, Avocet, Safire, etc. It is important to be mentioned, that microjet from our perspective could be understood as a small aircraft (coming from the practice of NASA SATS program [2,6]), a personal aircraft (for personal air transportation purposes [4,7]) an air taxi [8], and even a UAV.

Hence, air transportation volume increases rapidly, in the face of the existing system is already reaching its limits, and probably it will not be able to meet the future needs (in several domains such as environmental consideration, security, and safety, etc. [2]) of tomorrow’s capacity. Moreover, the saturated fact of today’s big airports could oblige personal aircraft flights to use regional airports, or other underutilized landing possibilities in the uncontrolled airspace. Unfortunately in most of the cases, these airfields are not equipped with modern radio-location systems for controlling the air traffic.

In the aim of decreasing the negative effects (such as the large economic costs of flight delays and cancellations) coming from the future scenario, current ATC/ATM, airport and airline operators might call for a change. Such development of the air transportation of the future has a perfect timing [1], because just in a few years air traffic will reach record levels, so till then we have a little time to prepare ourselves for the work ahead of us.

Hence, at near future we could develop a new small aircraft transportation system for wide public usage that could enhance people’s quality of life and ensures their freedom [6]. In that future, traveling habits will change: maximum satisfaction of
market requirements (such as traveling on demand, point-to-point and in a more flexible way [6]) will take over the lead. This future state and the possibility to decrease the negative effect of traffic growing can only be reached, if aviation uses radically new, innovative ideas, while breaking down the currently existing limits and constrains. In any case, the technology is already available to establish a safety, economical and environment friendly new air transportation system, based on personal air transportation purposes.

II. RESEARCH FOCUS

To ensure the future needs, the impact of small aircraft on air transportation system has to be analyzed. Among several areas, our research deals with air traffic control, air traffic management domain. Therefore the development of a new concept, where air traffic controllers, pilots and other users are able to have an enhanced system, that replies to future needs.

Moreover, from our perspective, small aircraft has to be designed to be affordable to anybody, thus low-cost solutions are welcome. This task will probably require a new small aircraft (similarly to the NASA SATS project [2],[6]), which could be piloted by everybody, without any special or extra knowledge and abilities. Naturally, such aircraft could be used very widely which could significantly increase the air traffic volume. As mentioned previously, the existing system will probably not be able to meet that tomorrow’s traffic growth. Therefore we have to develop radically new concepts, and / or instruments to be able to accomplish future tasks (such as pilot workload monitoring, simplified control [4], automatic control system, etc.), and to minimize the interaction of SA on conventional air traffic.

III. OBJECTIVES

The initial objective is to obtain relevant information and a wide knowledge on the development of the European SA activity. In order to define its main characteristics and trends, we firstly should analyze the current air traffic situation, by taking into account the flights that are the most close to a small aircraft of our objective. This approach might restrict the area to be focused on, and give us a fist idea, how SA might interact with conventional air traffic.

Using the results of the traffic analysis, our objective is to forecast/analyze the impact of small aircraft on different fields of ATM. That demands an interaction model, which could visualize, and describe mathematically the relationships between some of the most important elements of personal air transportation. By using different scenarios, the identification of the bottleneck, thus the future ATM problems and domains - that might call for further investigation - could be named.

After this study and the definition of SA’s impact level on current ATM, we should be able to foresee, whether SA calls for a radically new ATM (with developed rules, and procedures) or the existing could be adapted / changed to future small aircraft and conventional air transportation requirements.

Once that definition - between a new or adapted ATM - and the identification of the bottleneck for our future work have been made, the focus on the main objective becomes possible, hence to minimize the impact / interaction of small aircraft on the air transportation system. This task could be imagined by giving proposals, solutions for the particular domain, and/or shifting the ATM attributes towards a new system that could give solutions for future requirements of small aircraft purposes.

IV. CURRENT EUROPEAN SMALL AIRCRAFT RESEMBLING AIR TRAFFIC ANALYSIS

In Europe the traffic analyze with small aircraft in head is a pioneer task. Our investigation covers a nine-month period (in 2004) by analyzing one day from the weekends and weekdays, from EUROCONTROL’s CFMU database. This allowed us to examine more than 50,000 European flights (which all correspond to our definition of SA); to recognize the impact of seasons; and finally to study, whether business or leisure flights are more often to happen.

The result and the distribution of the number of flights for the whole examination period is shown in the figure 4.1. It could be concluded, that the number of flights that take place during the weekdays is nearly twice as important, that is for the weekends, even so the average number of flights for the whole period is 1429. This could mean that the distribution of flights represents more a business market segment, where the flexibility of passengers is underlined.

In order to be able to place, and to assess how these flights are going to penetrate to the airspace, the evaluation of the flight level density is crucial. The study takes into consideration the cruising path that is visible in the figure 4.2. As we might observe, most of the flights take place around FL 100, and just a very few percent of them (18%) are flying at least up to FL 200. The reason for such a low altitude could be a propulsion technology preference, or the possibility of very short flights. To come to know, which supposition is proper, further traffic analyses are needed in both domains. Firstly we investigated the current small aircraft and propulsion technology preference. The figure 4.2. shows, that 59% of the flights are propellered, 29% are turboprop, and 12% are jet
small aircraft. We ended up with nearly the same result, by analyzing the 15 mostly preferred small aircraft that covers 73% of the total traffic. Due to such a high percentage, this selection seems more than representative, where we might observe that propellered technology is still in majority, followed by turboprops and jets. Hence, the above mentioned flight level preference could be a result of propeller propulsion technology preference, which is mainly used for short flight distances (not more than 500km) and for low altitudes. The demonstration of that hypothesis, calls for further analysis in flight distance domain.

At the same time, as CFMU database does not contain flight distance data, we used GPS coordinates and great circle distance calculation to support the computations. Finally, the figure 4.3. shows that the most frequent flight distance belongs to 150 km, which is already 12% of the total small aircraft flights. Then 85% of them are not longer than 500 km, and just 3% (!) are more than 1000 km, which gives an average of 310 km. Thus we could conclude that currently short flights at low altitudes are more often to happen, with the preference of a propellered small aircraft. To understand what could be behind such a distribution, and how that traffic could be look like, we represented one typical day of small aircraft flights in Europe, using COSAAC Software (see figure 4.4.). There, the flights are very different one from the other, and it would be difficult to define preferable routes, or city pairs as it might be possible for conventional air traffic. One exception is the traffic between England and some of its islands (such as Alderney, Jersey, Guernsey) where even scheduled flights could be found several times a day, which shifts them to the top in the most frequent city pairs list. As for city pairs, in total we found more than 12,000 for the whole examination period, where just 4.3% of them occurred at least once in a week. This result was crucial to evaluate whether any kind of scheduled flights had taken place, and to assess which kind of market segment is more often to happen. Moreover, some of the city pairs have the same origin, and destination, which could mean, that the current air traffic faces with a large number of training flights, or flight plan errors.

V. LESSONS LEARNED FROM AIR TRAFFIC ANALYSIS

Even so cruising altitude distribution of small aircraft flights has been mentioned, their impact on airspace density, and on other flights requires further analysis. Here both, current state of small aircraft and commercial flights have been examined. That representation of FL distribution makes possible the assessment of the most preferable altitude for both cases, thus the evaluation whether any kind of impact exists, or could exist in the future. The figure 5.1. shows that nowadays the above mentioned flights are quite separated by more than 20,000 feet between their most crowded areas. By taking the minimum value of their summarized distribution, an optimal limit between small aircraft and commercial flights could be represented, where each of them has a minimal impact on the other. In that manner, 93% of commercial flights will take place above that altitude (FL 190), which will be impacted by 18% of small aircraft. Anyhow, even if that trend in small aircraft altitude preference remains the same, a raised number of flights could
shift the previously mentioned 18% to higher values, which might seriously impact the commercial air traffic. Moreover the same problem should be faced, if any aircraft performance or flight distance value change, which calls for further ATM studies (such as the assessment of the number of conflicts, sectorization constraints, etc.) in order to meet target objectives and make small aircraft transportation relevant.

An additional study to gain more accurate information on the current state of aviation could be the 3 dimensional altitude distribution within a given sector (including incoming and outgoing flights) at an airport vicinity.

The figure 5.2. shows the complexity of traffic situation, which is no more a clearly separated cruising altitude distribution, but much more a mixture of small aircraft and commercial flights, with some descending, climbing and cruising airplanes at airport surroundings. From that point of view, commercial flights should face with serious problems, while they desire to pass through the low level airspace crowded with small aircraft, especially in case of an increased traffic volume. Many solutions could exist to solve this problem. One of them lies in the idea to oblige small aircraft flights to make a deviation at airport vicinity, which might enable the rest of airspace users with the same service, as today. From a small aircraft point of view, airport surrounding means the areas with commercial flights lower than FL 190, which as previously mentioned the optimal altitude where the impact of both small aircraft and commercial flights in minimal. In the aim, to imagine how seriously such a procedure could limit the freedom of small aircraft users, we calculated the average distance (depending on aircraft performance and airport SIDs: Standard Instrumental Departure routes, STARs: Standard Terminal Arrival Routes [9]) that might be required for a traditional flight to reach FL 190. That gave us 130 km [9]. Finally, by tracing a circle with this radius around big European airports we had the figure 5.3. Surprisingly, the circles cover an exceptionally large geographic area, which can not be deviated without the serious impacts on flight plan and contradictions with target objectives of small aircraft.

Thus other solutions have to take into consideration, such as defining corridors within the airspace that might enable small aircraft to pass by crowded areas. Anyhow, a major conclusion is that flexible or optimal usage of airspace capabilities that replies on dynamic requirements could become important. Nevertheless that could create an increased pilot/controller workload and high requirements on cockpit instrumentation, which calls for an increased automation.

VI. SMALL AIRCRAFT INTERACTION MODELING: A GENERAL SYSTEM OVERVIEW

After an overview has been gained on small aircraft traffic attributes, further investigations are focused on its impact modeling on ATM. This might affirm the conclusions of the traffic analysis, and support the identification of the domains and areas that influence - form a small aircraft point of view - the future state of aviation, which might be focused during our future works.

Our system overview could be defined as follows: the ATM could be considered from a complex system modeling view at the macroscopic level, where the whole system is decomposed into the following three subsystems:

- Society Subsystem: that contains the society constraints and drives for growth including passengers and airlines,
- Technical Subsystem: that includes all technical infrastructures supporting the functioning of the ATM system,
- Human Subsystem that takes into consideration all human components of the whole system, from flow managers to supervisors, pilots and controllers.

From such a point of view, the impact of small aircraft on ATM could be modeled in terms of sets of components of different subsystems and sets of interactivities between them, to accomplish the mission of simultaneously maintaining safety and sustaining growth.

VII. INITIAL INTERACTION MODEL

The input data analysis clarified, that the initial problem with interaction modeling is that, the generally used solutions can not give a suitable result, since small aircraft transportation does not exist in Europe, hence no relevant information could be used. This lack of input data, and the aim to have an advanced model that could reply to our specific requirements, forced us to come up with an initial model, which might identify the elements that weight the level of SA’s impact. Such an initial model could also represent the interactions, and help to understand their functionality. Moreover, the right balance between these elements should be
found and applied in order to eliminate unforeseen complexities and side effects (such as increased costs due to a high level of cockpit instruments), while trying to bring into play the most possible benefits. This balance also calls for initial modeling that might be used for the enhanced mathematic model.

As preliminary analysis show [10], GDP, population density, and other characteristics could seriously influence the demand of small aircraft, thus it has to make a part of our investigation. That finally gives a general interaction model that is visible in the figure 6.1. . Our approach to small aircraft impact modeling is that GDP might describe the mobility of passengers otherwise the study would become too complex. Anyhow, the effects of regulations and technological development have been added to (what we call here) market attributes, since it might influence the demand or impact of small aircraft in any future scenario (for example noise restrictions).

As the figure 7.1. shows, that market attributes drives the characteristics of small aircraft (SA) and traditional air traffic.

As for small aircraft group, it is mainly consist of the future number of aircraft, the fulfill of market requirements (such as freedom, traveling on-demand, point-to-point, etc.), and costs. For our purposes, “traditional traffic” data is only used to feed (with “SA traffic” together) the group called “interaction on ATM”. This final element of the model is made up of the most important air traffic management domains, and some supplementary areas that might be interesting to analyze, and which is mainly the outcome of the air traffic, and future perspectives in ATM analysis, from a small aircraft point of view. For instance, avionics means cockpit instruments and navigation tolls (such as TCAS, GPS, ADS-B, and others). Moreover, separation responsibility is defined by its importance, without taking into consideration whether pilots or controllers should deal with it. Similarly, the domain of “automation” means more its significance, without underlining, that it might range from automation of controllers’ routine tasks to autonomous operation, with advanced airborne system application (such as Airborne Separation Assurance Systems) and even free flight.

VIII. MATHEMATICAL MODEL INVESTIGATION FOR INITIAL INTERACTION MODEL

In order to set up a mathematical model - that replies to the needs posed by the complex interactions - we could define a matrix with the same number of columns and rows, with the domains of the interaction model, placed on the diagonal. With its help, all of the relationships could be easily defined, and the investigation of the outcome could become possible, while remaining nearly the same four groups, as previously described (figure 7.1.). In that case, $a_{ij}$ (where $i \neq j$) are the coefficients, that describe the interaction between the key elements $a_{ii}$ and $a_{ij}$. (such as the impact of separation responsibility on the number of small aircraft). By defining a vector $\mathbf{x}$ that contains the elements of the general interaction model such as

$$\mathbf{x} = \begin{bmatrix}
S\text{need} \\
S\text{mark}_{\text{req}} \\
S\text{need} \\
T\text{need} \\
T \cos t \\
\text{avionics} \\
\text{ASM} \\
\text{sep}_{\text{resp}} \\
\text{automation}
\end{bmatrix}$$

the following equation holds:

$$\mathbf{x}[k + 1] = \mathbf{A} \cdot \mathbf{x}[k] + \mathbf{B} \cdot \mathbf{u}[k]$$

(8.1.)

to predict the variables of $\mathbf{x}$, where $k \in \mathbb{N}$ is the time in years, and $\mathbf{B}$ similarly to $\mathbf{A}$ describes the relationships between the input data $\mathbf{u}[k]$ ($\mathbf{u} = [\text{GDP}\ \text{regulation}\ \text{techn}\ \text{development}]$) and $\mathbf{x}$, such as the effect of GDP increase on the number of small aircraft.

The advantage of such an approach is that, it could be used for any interaction modeling even with different small aircraft characteristics.

However, the challenge is to find the coefficients for both $\mathbf{A}$ and $\mathbf{B}$ matrices. For our small aircraft purposes, they are partially based on statistics, and on estimations (for example as it is said, approximately 3% of the aircraft is taken away from the traffic each year, hence the coefficient of the matrix $\mathbf{B}$, $a_{11}$ - that describes the relationship between the "number of SA" and "number of SA" - would be 0.97).

Finally, the outcome of the equation (8.1.) could give us an initial prediction of the elements of the vector $\mathbf{x}$, that might help us understand the role of the key elements presented in the general interaction model, and to foresee, what could be a relevant domain to focused on for our future works.
IX. SIMULATION

To have the prediction of the key elements (vector x), in this paper, only a example of a simulation is presented, where the input data is defined such as follows (Figure 9.1.): the annual GDP growth vary between 1.5 and 3 percent, the technological development from 1 to 3 percent, and even the effect of regulation is visible, since it might be interesting to analyze in any future scenario. Note that here the regulation is considered as an increasing factor, and all the input data are based on assumptions.

By running a simulation with these input data, the model gives the outcome of each key elements (vector x), however, this paper only presents the “number of small aircraft” and the domain of “automation”. By focusing on the first outcome, it predicts nearly four times more small aircraft that is today. A break point of the curve is also observable, which is the effect of regulation. Surprisingly, the model is not as sensitive for other input data change; hence the effect of GDP and technological development could not be easily tracked.

As for the curve automation, it has to be underlined again, that this analyze does not aim to point out one of the automation capabilities, since it only represents its importance to achieve the future air transportation of small aircraft. Anyhow, in the figure 9.1., its increasing role might be observed, that could be even be twice more important, that is today. This result might correspond to any future scenario, since automation capabilities should become a major factor in the future, where aviation should face with an increased number of small aircraft that might significantly impact the conventional air traffic (as it was already foreseen in the small aircraft resembling traffic analysis). Moreover, if these small aircraft are handled by pilots with limited experiments who would not be able – or just do not willing to – deal with high separation responsibilities and difficult procedures, automation might become even more important.

As for the effects of GDP and technological development, the same observation could be made than in the previous case, which might call for further analysis, with the enhanced mathematical model, that replies on the complex system approach.

X. FUTURE WORKS

Further investigations should focus on the enhanced mathematical model from a complex system approach. Its result should be analyzed and compared with the initial model, in order to name the differences (if any), and to define the level of accuracy of the matrix coefficients defined in the initial model.

Finally, with the use of scenarios, we could provide simulation based recommendations and proposals for further Air Traffic Management research areas.

XI. CONCLUSION

The increasing economy and air traffic volume might allow the future of small aircraft transportation. In that scenario, traveling habits will change. Maximum satisfaction of market requirements will take over the lead, which could enhance people’s quality of life and ensures their freedom.

Such a shift in air traffic attributes, and the increased number of flights could call for a change or demand enhancement is several areas of the current ATM, thus it has to be analyzed. The identification of the bottleneck among these ATM domains could be imagined by the results coming from a mathematical model that describes the impact and interaction of small aircraft on ATM.

In the face of this model calls for relevant information and the knowledge on small aircraft transportation attributes, in Europe, the availability of these data is extremely limited. This forced us to accomplish the initial objectives, namely the small aircraft resembling flights’ attributes analysis. This partial result allowed us to place small aircraft flights in the airspace, and to use arguments on flight level, flight distance, propulsion technology preference, that is mainly impacts the conventional air traffic at airport surroundings.

With these clarified main characteristics, and the restricted area that should be focused on, the definition of the mathematical model became possible. The initial model showed the complexity of the work ahead of us, and gave
some preliminary results on the number of small aircraft, and
the characteristic of some of the ATM fields that might be
focused on.

Anyhow, the mathematical model could enable the
definition of the bottleneck for our future work, where new
technologies, and ideas - enabling such modifications in air
transportation – could be applied to the entire system
intelligently and in an integrated fashion, in the aim of having
a new, effective, more safe and accessible way of
transportation to any users.

REFERENCES

December 2003

[2] Dr. Bruce J. Holmes, NASA; John Scott, Icosystems :
Transportation Network Topolo-gies, April 27, 2003
http://spacecom.grc.nasa.gov/icsnconf/docs/
2004/01_plenary/PS-06-Holmes.pdf

Hungary, reports I - III, BUTE - Budapest, Dornier -
München, RHTW - Aachen, 1991-93.

automatique pour de petits avions, 2004 July, INSA de
Lyon & BUTE.

Las Vegas, October 2004
Available:
http://www.rollsroyce.com/civil_aerospace/
overview/market/outlook/downloads/busjet04.pdf

Transportation, Oklahoma – CASI, November 14, 2003
OK_CASI_11-14-03.ppt

[7] Rohacs, J.: PATS, personal Air Transportation System,
ICAS Congress, Toronto, Canada, CD-ROM, 2002,
ICAS. 2002.7.7.4.1 -7. 7.4.11.


[9] Italian vACC.
Available:
http://www.vatita.net/?dir=download&pagina=planning/
charts

[10] Rohacs, D. Analysis of the impact of small aircraft on
ATM in Europe. In Proceedings of the 9th Air Transport
Research Society world conference (ATRS), Rio de
Janeiro, Brazil, June 2005.