SAFETY ASPECTS AND SYSTEM IMPROVEMENTS FOR PERSONAL AIR TRANSPORTATION SYSTEM

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Abstract: The paper aims to identify the safety aspects / safety problems of the developing PATS (Personal Air Transportation System) and to name their possible solution. Personal aircraft systems need to be considerably redefined and improved relative to the general aviation aircraft. The philosophical approach to flight safety of personal air transportation system could be characterized by the application of the automatic adjustment system, the simplified control system, the pilot assessment system and the ride control.

Keywords: PATS (Personal Air Transportation System), safety, aircraft systems

1 Introduction

Several EU supported projects e.g. EPATS (European Personal Air Transportation System), PPLANE (Personal Plane) and some other Hungarian national projects e.g. SafeFly aiming to develop a novel, so-called personal air transportation system. In this system, the personal flights would be basically operated by the aircraft owners or renters having a license, but with limited practice. Such operators are often called as less-skilled pilots.

As of 2010, the technology and ready to develop a new, economic [1], and environmental friendly aircraft for the less-skilled pilots [2,3]. In the view of this, the EU EPATS (European personal air transportation system) project [4] predicts that in 2020 about 50 million flights pro year will be performed by small aircraft. Such rapid development would call for about 150 000 - 180 000 new small aircraft in Europe [4]. Seeing that the envisioned number of aircraft is considerably high, it is expected that small aircraft operations would cause safety problems, which would therefore require a new safety philosophy [3]. The new air transportation system would also call for a change in the current general aviation systems, like airport development [3], or air traffic management [5].

The European commission has recognized the important future of the new small aircraft transportation system and call up the attention on its required development [6].

Small aircraft operational concepts might generally range from free flight in uncontrolled airspace to fully automated operations performed by professional pilots on the ground (remote control). Safety aspects might be defined form these operational concepts. In any case, personal planes are expected to be piloted by the less-skilled individual pilots or by professionals (from ground) that might show soft skills. Therefore, the solutions of the safety problems require new and original ideas, and the development of new technologies.

This paper aims to identify the safety aspects / safety problems related to the coming PATS and to develop their possible solution. This paper is focusing on the aircraft systems that are expected to require considerable modifications and enhancements compared to those of the “traditional” general aviation aircraft. The philosophical approach to the flight safety of PATS based on the idea that personal aircraft will be operated by less-skilled pilots or by professional having soft skills. This would also mean that the cockpit instruments and the aircraft control are expected to be radically changed. The solution of the major safety problems might result to the:

- application of an automatic adjustment system to automatically set up the ideal flying configuration (for example centre of gravity adjustment)
- simplification of the control system to the level of an ordinary car (computer assisted control system with automatic limitations on critical regimes, integrated engine and aircraft control, connected roll and yaw control into one channel),
- pilot assessment system (including automatic voice checklist, pilot load condition estimation, work-load monitoring, etc.),
- ride control system for increasing the passengers' comfort (as personal aircraft are expected to be operated at relatively low altitude that is more turbulent).

2 Some thoughts on aircraft accident statistics

Flight safety investigation could be made by the analysis of the accident statistics. These records lead to the conclusions defined below.

The aircraft accident statistics clear indicate the well-known facts [7, 8, 9]: the longest part of the flight (with about 50 - 80 % of flight time) is the cruise phase, which only accounts for 5 - 8 % of the total accidents and 6 - 10 % of the total fatal accidents. The most dangerous phases of flight are the take-off and landing.

This fact results to an interesting and important conclusion: the different air transportation modes (e.g. commercial, general aviation) should have approximately the same flight risk; or at least the same accident rate for the number of flights.

On the other hand, the investigation of the accident causes demonstrates that about 70 - 80 percent of the accidents are caused by human factor and nearly 50 % of them are initiated by the pilots.

More generally speaking, the investigation of the accident statistics shows that [9, 10, 11]

- aircraft accidents are generated by the complex effects of structure features, peculiarities of the pilot, air traffic and the surroundings;
- as usually the accidents are initiated by 3 - 6 different major failures or errors;
- *the probabilities of the second, third and the following errors are depending on the previous errors and might even be 30 - 80 times higher;*
- the special distribution at the left or right hand side (tails) of the empirical density functions related to the system characteristics plays a deterministic role in the accidents;
- the inaccurate calculation and modelling of the common failures (principally independent failures or errors appearing at the same time) might result in the under evaluation of the risks.

Another interesting conclusion: the human factor is the most important contributing factor to flight accidents. Therefore, the flight risk of small and personal air transport must be nearly the same as the risk of the commercial flights. The difference might be caused by less training, or less practice.

Finally another interesting fact published by the EASA: in Europe, the fatal accident rate, as fatalities per 10 million flights, has increased since 2003, but the reason of this was not explained so far.

Nowadays, general aviation (GA) is a large part of civil aviation. For example in 2005, 215 837 aircraft, about 91 % of the US operated civil aircraft belonged to GA [12]. 211 940 GA aircraft were so-called active, as it is presented in the Figure 1.

According the the statistical records of 2001 [13]:

- more than 18 000 landing facilities served the US GA, including heliports, lakes, dirt landing strips in remote areas as well as general airports near urban regions and even large airports used by commercial air carriers,
- GA operations ranged from one-person "ultralights" or powered parachutes with extremely limited range and payload capabilities to helicopters, seaplanes, antiques, fabric-and-wood biplanes,

"homebuilt" experimental airplanes, the ubiquitous four-seat single-engine airplane, twin turboprops, and large or small business jets,

- GA aircraft were operated by 600 000 certified pilots and served 77 % of all air traffic with transporting approximately 180 million passengers in different aircraft sizes for business and personal reasons,

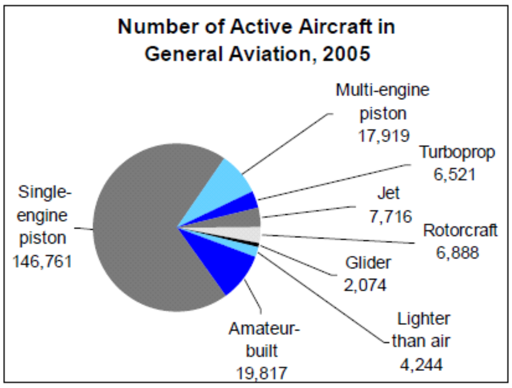

Figure 1. Distribution of US GA per aircraft type [16]

- US GA accounted for over 637,000 jobs, with nearly $20 billion in annual earns, while its direct and indirect economical impact is exceeded to be $102 billion in different aircraft sizes for business and personal reasons,
- 65% of all general aviation flights were conducted for business and corporate travel,
- commercial, non-scheduled flights (charters) as a component of GA, with more than 22,000 pilots flew some 14,700 aircraft for this industry segment.

The operation of GA and commercial airliners' aircraft were made according to different practices, which resulted in different accident rates. [14].

The GA has about 10 - 35 times greater accident rate (accident per 100 000 flight hours) than the commercial flights [15]. However, the fatal accident rate of GA is only about 2,5 - 3 times greater than the same rate for the commercial carriers.

The GA accident rates are highly depending on the type of operation. The corporate and executive aircraft operated by professional pilots are not more often involved into accidents than the airlines' aircraft. The AOPA (Aircraft Owners and Pilot Association) Air Safety statistics shows that *more than 70 % of GA accidents and fatal accidents are caused by personal pilots, while they flew less than 50 % of total flight time.*

When the developers are targeting the less-skilled pilots, they should be aware that the skills are not only depending on their practice. Pilot skills could be basically divided into two different classes: hard and soft skills. Hard skills means that the pilots know all the regulations, rules, technologies required for a safe operation, they have enough information on the theory of flight, performance and system characteristics of the given aircraft, operational conditions including the airport, weather, etc. limitations, rules / technologies of using the airspace and they can perform a flight safely (e.g. define the flight plan, use the flight procedures, control the aircraft, use communication and information systems). On the other hand, soft skills are mainly defined by human personal characteristics. This means that the pilots know everything that is required to have hard skills (evaluated during flight tests - examination for licensing), but due to their actual psychophysical or mental conditions, as well as their own habits, they are not flying as it would be required. They do it because they have limited practice / knowledge about the risks and emergency situations, or they believe more in their ability than it would be reasonable.

Less-skilled pilots are pilots with a license, but (i) having less practice or less information about the flight conditions, (ii) making false decisions, (iii) overestimating their own ability or, (iv) just being negligent.

Real accident statistics as shown in the Figure 2., demonstrates the complex role of soft skills. For example, it might surprise experts, but *each tenth GA accidents are caused by pilots having a total flight time of more than 10 000 hours*. According to the investigations of the NTSB [12], from the 1626 accident pilots whom total flight experience data was available, 48% had 1,000 or less total flight hours [12]. Furthermore, *pilots having less than 200 flight hours are took part in 17 % of the accidents. 88 % of these accidents were made with a single piston engine aircraft.*

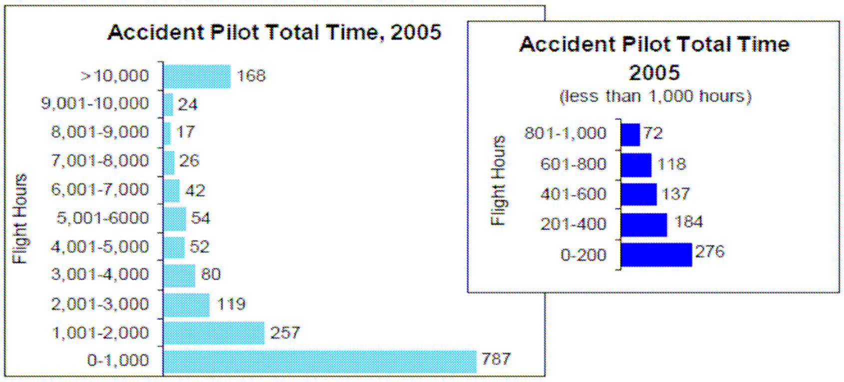

Fig. 2. The distribution of experience among accident pilots

Another interesting point is that the commercial pilots are 3 times less involved in the accidents and fatal accidents than the GA pilots. It is also observed that the accidents per 1000 pilots are decreasing, while the fatal accident per 1000 pilots are scattering around the nearly same values.

The detailed investigation of the curves of the Figure 3. leaded to two interesting hypotheses:

- the fatal accidents per 1000 pilots – partly characterizing the role of pilots (because the human factors) in the fatal accidents – are nearly the same for GA and airlines, by considering that airlines' aircraft are piloted by two pilots, while the GA aircraft are rather operated by one. In addition, airlines' pilots are also more supported with different services (e.g. air traffic control).

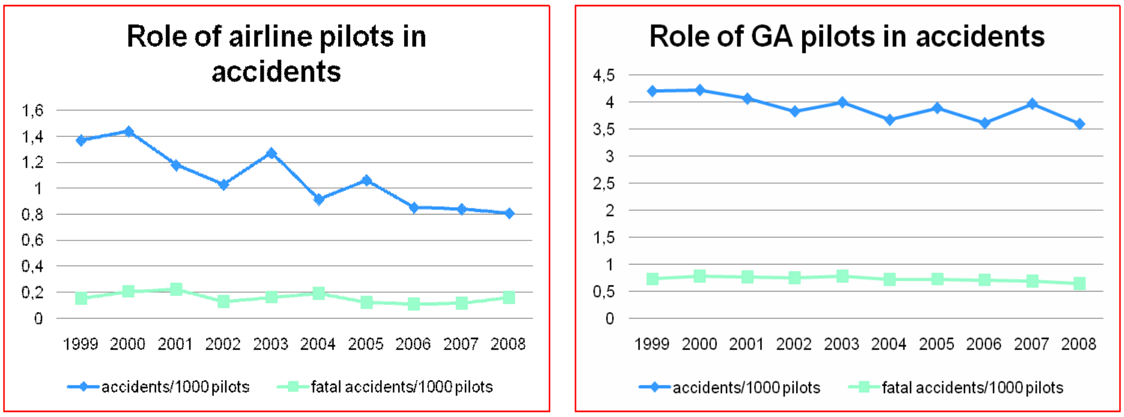

Fig. 3. Accidents and fatal accidents for 1000 cetified pilots

- the number of fatal accidents per 1000 pilots - as a function of calendar time - is slowly decreasing because of slowly increasing human intelligence, which has a positive influence on the human situation awareness and reaction time.

The accident statistics related to different type of aircraft shows that the accident rate of private pilots is "only" twice higher compared to airlines' pilots, while GA commercial pilots are nearly four times more often involved into different accidents. As for the accident rate per 1000 active pilots, the safest flights are statistically made by student pilots [16].

Finally, there is an another hypothesis guided from the accident statistics [15]: air transportation system (including training, regulations, research and developing, production, infrastructure, monitoring and control - ATM, maintenance, services, etc.) was developed, organized and managed on the risk level accepted by the society.

3 PATS safety aspects

PATS is a complex system including:
- new small and smart aircraft developed especially for personal use,
- new net of small airports including improved existing GA airports, adapted conventional airports, and newly developed airport laced close to the city center,
- net of service providers e.g. ATM, rent a plane system, technical workshops, supporting units, etc.

The organization structure, working conditions and harmomnisation of the operational processes of the system elements are defined and developed from the PATS operational concept. The operational concept is a document defining the characteristics of a proposed or developing system from the user point of view. More generally speaking, the operational concept defines how to develop, implement and use the proposed system with user (costumer) high complacence. In our case, the users of PATS (private persons) require an aircraft, an airport and different services including for example a rent a plane system, an adapted ATM, as well as safe and secure assistances. Therefore, the operational concept defines a proposed system being cost effective, safe, secure and affordable for the users.

The operational concept can be developed by different methods but generally it contains the followings:
- goals and objectives of the system,
- strategies, tactics, policies, jurisdictions and constraints affecting the system,
- organizations, activities, and interactions among participants and all the stakeholders,
- clear statement of responsibilities and authorities delegated including the monitoring and regulations and actions in emergency situations,
- methods of using the system (including e.g. renting, service, flying, ATM),
- specific operational processes for fielding the system,
- processes for initiating, developing, maintaining, and retiring the system.

The specification of the system elements (e.g. geometric, aerodynamic characteristics, flight performance of the new small aircraft, behaviors of the special airports) might not directly derive from the operational concept. The user needs could determine a series of the system elements, for example the class of aircraft (fix or rotary wing), the type of propulsion system (piston, turboprop, jet), the desired cockpit instruments / features (e.g. ILS, unpressurized or pressurized cabin), or the category of the airport (e.g. special small aircraft dedicated to PPlane, adapted traditional). However, the operational concept should define the basic rules of using the system elements mentioned above, and the relationships between the stakeholders. For example the rules of shared ownership, renting, training, pilot licensing, integration into the global air transportation system should ideally be define and built up on the same basis, defined by the operational concept. This could be performed similarly to the NASA SATS (Small Aircraft Transportation System) [17], which developed a general basic operational concept, on which several “partial” operational concepts were defined and tested separately for e.g. the ATM, airport operation, financial support.

The starting point of PATS operation is the personal travel demand. Once there is a demand, real PATS operations would be a function of e.g. cost, door-to-door time, affordability, safety and security. These driving factors would determine the major characteristics of the system (e.g. the type of aircraft, airport, ATM related services), since for example a high door-to-door time would require airports to be placed closer to the city centers, where land is more expensive, and environmental impact is more in focus, which therefore would lead to small and low cost operations. In this specific case, airports would not require control towers, neither expensive primary surveillance systems. On the other hand, to limit the environmental impact, special flight procedures, traffic rules, and flight operational technologies could be needed.

Such system should be developed with original solutions using the latest technological achievements, as PATS – as indicated above – is a complex and large system composed from several elements that might have thousands of errors, failures and deviations in its system parameters. PATS has many safety aspects, which could be classified into the following groups: (i) general (e.g. innovation system, innovation process management, certification, society acceptation), (ii) development (e.g. operational concept, development philosophy, knowledge, technology), (iii) airport (e.g. geographical position, size), (iv) aircraft, (v) airspace, (vi) maintenance (e.g. airspace design, flight plan, surveillance, air traffic control, air traffic rules), (vii) support (e.g. training, ownership, rent a plane), (viii) additional safety aspects (e.g. system integration, sustainability, solution for the security problems).

The aircraft major safety problems are defined by the table 1. There are some examples demonstrating the safety aspects related to the given area, and their possible solution. Seeing the high number of safety aspects, the table contains many different information as for example auto healing materials, MEMS technology, care-free control. Due to the page limitations, this document is not describing each of these aspects with their solutions, neither the full list of the relevant references. (note – we appreciate the support from our partners in the SafeFly, EPATS and PPLANE projects contributing to the given classification of the PATS safety aspects)

Table 1.

PPLANE safety aspects					
No.	**Area**	**Major problem**	**Description**	**Examples**	**Possible solution**
	Aircraft				
1.	Aerodynamics	New aerodynamic design method is required.	Traditionally the small aircraft are designed for the practiced professional pilots flying in relatively clear air, however the new aircraft designing for the PATS will be piloted by less-skilled and less disciplinary pilots in most turbuilised airspace (in regions of 2 - 4 km altitude) and in "all weather" condition. So, there is a needs in development of the aerodynamic design and calculation methods for developing new forms, new lift generation system, drag reductions, etc.	risk of accident because the flow separation near the critical flight situations or in bad weather conditions, risk of using the passive and active adaptive structures, shapes, and so on.	Developing new software for support the small aircraft development implementing the new ideas, new technologies, developing methods for investigation of the flow control by MEMS, effects of the adaptive structure on the changes in aerodynamic characteristics, etc.
2.	Propulsion system	The new small aircraft need new smart and green engines.	Because the strong requirements on the efficiency and environmental impact the new small aircraft must applied new smart (and probable single) engines.	risk associated with reliability of the quickly developing new engines, using radically new technologies for reducing the noise and emission, etc.	Developing, testing and certification of the new propulsion systems are very expensive that unacceptable increase the primary cost of aircraft. Initiating special international project for developing a new small, reliable and green engines for the small aircraft. Testing of the possible new method, rules, technologies and certification must be organized on the international cooperation level.

No.	Area	Major problem	Description	Examples	Possible solution
3.	Flight performance	The required flight performance must be defined from the operational concept(s)	Because the door - to - door speed one of the most important indicator for PATS, the airports must be small and close to city centres, and these facts will be define the flight performance (and flight procedures) of the developing aircraft.	risks of errors in choosing the flight performance and in definitions the limits for them, for example choosing the maximum landing speed, or changes in the descent angle for making quicker approach, etc.	Determining the required flight performance and limitation on its from the operational concept, airport and ATM conditions.
4.	Aircraft stability	Stability of the unconventional form and stability depending on the loading.	Several new and unconventional form of aircraft will be developed that need further investigation of the vehicle stability. The same problem in case of loading of aircraft with more then six seats.	risks of loosing the stability because the any disturbances, exceeding the limits for centre of gravity and loosing the stability	At first, the stability of the unconventional vehicles must be studied, near the critical and critical regimes (as spinning) must be investigated specially. At second, a special centre of gravity adjustment system must be developed.
5.	Aircraft control	Use of aircraft control system by the less skilled pilots	The coordination of the different control channel inputs may cause difficulties for the less-skilled pilots.	accident because of the errors in choosing and realising the controls, for example unwanted reduction in altitude during reducing the speed, using the uncorrected banked turns.	Developing the coordination between the control channels with using the computerised control: the longitudinal motion and engine controls as well as the lateral and directional controls must be harmonised. In case of using the simplified control, the alternative control technology like voice control can be implemented more easily. There is a question about the reducing the stick forces and making hinge moment adjustable for changing the manoeuvrability of the aircraft from the unmanoeuverable to the semi manoeuvrable (not up to acrobatic one). Developing the car-free or H-methaform types of control systems avoiding departures to the critical regimes. Development of the pilots load monitoring systems, and in emergency situation switch out the pilots from the control loops.

No.	Area	Major problem	Description	Examples	Possible solution
6.	Automatic and distance (remote) control	Full support of the less-skilled pilots	With automation of the aircraft control or using the remote control may switch out the less-skilled pilots from the aircraft control system. Automatic systems need for avoiding the departure to the critical flight and automatic or remote controlled recovery from the critical flight regimes.	risk or errors in automatic systems, bugs appearing at the critical regimes only, viruses' attacks, soft skills of remote pilots, dissipation of attention of remote pilots, etc.	Definition the requirements and specification for automatic control development, developing the small aircraft iron bird for testing then new software, developing the system auto monitoring and diagnostic systems, development of the communication system (datalink) for distance control, development of the supporting system (for example with using the synthetic vision) for remote control pilots, development of the rule for control in emergency situations as limitation of number of controlled aircraft, switch to control more practiced pilots), development of the technologies and system for the recovery from the critical flight regimes, etc.
7.	Aircraft structure	Using new structural solutions	Using the unconventional forms and new materials, new technologies as well as the changes in the operational characteristics, flight performances (like increasing the vertical component of the touch down velocity because the landing by les-skilled pilots or flying in mostly in areas of higher turbulences in region of altitude 2 - 4 km re turbulence) need new structural solutions, changes in design and stress analysis methods.	risk of increased fatigue damage processes, risks of structural damage because the using radically new technologies that are not tested for the newly developing structural solutions, accident because the flight performances out of the conventional limits, etc.	developing the methods for testing and evaluation of the unconventional and new structural solutions, developing safe and damage tolerance constructions, using the health monitoring, auto diagnostics and auto healing technologies, specification of the requirements for the load limits and conditions, developing new methods for design and stress analysis, etc.

No.	Area	Major problem	Description	Examples	Possible solution
8.	Cockpit	Redesigning the cockpit for less-skilled pilots.	The cockpit and its instrumentation must be considerable redesigned with using the latest technologies (as synthetic vision of full airspace around the aircraft, or color weather information) as well as with implementation of the developed pilot decision support for less-skilled pilots	errors in communication, characteristics measurement and displaying, wrong solution for information displaying, errors in support the pilots with information about the aircraft position, situation awareness, etc.	Development and redesigning the cockpit and its instrumentation system, testing the new system as the ergotic system (system in which the pilot is an important but only the one of the elements), developing low cost (GPS based) positioning system, passive and active situation awareness system, conflict detection and resolution system, and well developed decision support system. Principally the personal aircraft may have single pilot - decision, but the instrumentation, communication, pilot decision support must be developed for this condition, even the best solution is the development of the virtual co-pilot system (see safety aspect number 4.12. of this list).
9.	Communication System	New communication system is required (as specially for remote control)	The non-professional, less-skilled pilots are less-skilled in communication, too. They may have a problem with English phonetics, using the radio, etc. On the other hand the PATS will use the distance (remote) control at least in emergency situations that needs wide bandwidth, high speed communication, datalink.	Errors in communication, understanding the transferred information, noise, accuracy of information transferred may generate risk, and risk associated with the a lack of information transferred in time to the distance controller.	Developing datalink system between the boards and board and ground, supporting the "distance" pilot by the right, reliable and required information about the aircraft position, traffic information, situation awareness, conflict detection, etc.

No.	Area	Major problem	Description	Examples	Possible solution
10.	Pilot decision support system	Problems of pilot decision making.	The less skilled private pilots and the remote controllers, pilots may have more soft skill need a sophisticated decision support systems.	risks associated with the shorting the time for decision, errors in subjective analysis and evaluation of situations, errors in chosen decisions, errors made by pilots loosing their orientation, etc.	Developing the new methods for understanding and modelling the pilots decision making that may based on the stochastic hypothesis analysis (minimisation of the Bayes risk) and applying the subjective analysis technology. The decision making must be supported by the required and correct information, traffic situation displaying, using the automated conflict detection and conflict resolution, etc. One another very interesting question how to support the right decision of pilots may lost their orientation, or may have wrong decision because the illusion. Such problem must be defined for less-skilled pilots, and for the pilots controlling the aircraft from distance on the basis of displayed information, only, For remote controllers the using the 3D synthetic vision can be a solution, too.
11.	Aircraft systems	Developing the simplified and low cost solutions for aircraft systems	The personal air transportation system will be developed for flying a limited range up to 500 - 700 km (except developing the micro jets) , therefore the systems (like control, fuel, electric, cabin air condition, etc.) must be realised in very simple and low cost solutions, while several systems, like hydraulic systems for servo actuating, or cabin pressurizing can be avoided.	problem appearing as errors in system simplification, using regimes out of the operational conditions, etc.	Study the possible simplifications, development of the requirements for design and operation, testing the new solutions, etc. (See the aircraft control system - safety aspect 4.5. in this list - as the system may have most radical changes.)

No.	Area	Major problem	Description	Examples	Possible solution
12.	Flight operation	Supporting the less-skilled pilots in flight operation	Flight operation starts with development a flight plan (see safety aspect number 5.2 of this list) and depends on the aircraft performance, flight rules, traffic situations, etc.	errors in designing the flight plan, errors in choosing the flight operational modes, errors in applying the traffic rules and errors in evaluation of the traffic situations, errors in following the flight operational manuals, etc.	Developing the service or support (software) for flight operation for example developing the virtual co-pilot, that can read check-list, giving warning signal in case of situation changes, flying on regimes close to the critical ones, etc.
13.	Passenger (ride) comfort	Passengers and even pilots may have problems in case of low ride control	The personal aircraft will be operated at altitude 2 - 4 km which is characterised with the maximum air turbulences. Therefore a oscillation motion of aircraft initiated by the air turbulences and extra manoeuvre loads may cause health problems of pilots and or passengers.	risk of wrong decisions and errors made by pilots having health problem, risks of wring actions of the passengers having health problems.	Developing the manoeuvring limitation, gust effect elimination systems including the design process (for example making smaller wing and higher wing load for having greater ride comfort), passive and active technologies (for example distributed system of micro sensors and actuators for flow control and reducing the aerodynamic effects from air turbulences) for elimination of the air turbulence effects.
14.	Aircraft design and production	There is a lack in good designer and producer organisation.	The new small aircraft for the PATS will be designed and produced by a lot of small and newly established companies having limited practice (the older companies increased their activities up to the cooperation with the larger aircraft producers, therefore they can not design and produce the new small aircraft on the acceptable cost level).	errors in designing, error in engineering (using the new technologies, new materials), errors in production because the less-skilled workers.	Development of the air worthiness and requirements with accordance to development and production of the small aircraft, development of the testing and certification technologies, development of the quality control, etc. There is a need in European institute for developing the design and production technology, investigating the emerging technologies, studying the technical life of new technologies, new structural solutions, their maintenability and repairability. Such European institution may have responsibility on the certification of the designers (designer companies), production, maintenance and repair organisations from the quality control point (supporting the authority).

No.	Area	Major problem	Description	Examples	Possible solution
15.	Line up service	Line up service and maintenance	The personal aircraft owned by private persons or rented by common persons will be used in case of quick travelling when they will have less or limited time for preparing their aircraft for flights.	Errors in preparation of aircraft for flight, errors in line up maintenance because the limited practice of service providers, etc.	Development the line up maintenance technology can be used generally for family of aircraft, establishing a set of service providers, net renting system , when the rent office will have responsibility on the technical condition and maintenances.
16.	Aircraft maintenance	Maintenance manuals and technologies for PATS	There is a lack of information and realisation about the maintenance of the PATS, generally.	Flight risks because the errors in designing and realisation of the maintenance technologies, manuals, using the wrong technologies, materials, a lack of knowledge about the maintenability of the new structural solutions, etc.	The aircraft and the other elements of PATS must be developed for low maintenance needed, or even for maintenance-free condition. The maintenance manuals and technologies must be redesigned and establishing for the PATS specially.
17.	Aircraft repairing and modernisation	Overhaul (repair) technologies and ways of possible modernisation of the PATS.	There is a lack of information about the overhaul of the PATS because too much original and even radically new technologies will be applied, overhaul and modernisation technologies for which have not clearly developed yet.	Flight risks due to errors in repairing technologies, applying wrong methods, technologies, a lack in knowledge in diagnostics, failure detection, damage evaluation, etc.	The new small aircraft must be developed with using the methods resulting to the good maintenability, repairability, developing new NDT methods and technologies, ground and flight tests, etc.

4 PATS safety philosophy

The philosophical approach to solve the safety problems of PATS could be based on the

- car-free technology (originally developed for the military aircraft),
- H-metaphor[18], as analogy with horse driving and
- analogy to car driving as accepted level of technical system controlled by common persons.

The control of civil and military aircraft (especially the fighters) is considerably different. For the civil aircraft, the handling qualities, the avoidance of the critical regimes and the optimizations are the most important tasks. On the other hand, for the military aircraft, the maneuver characteristics, the flight mode optimization, the enhanced flight and load envelopes, the control on critical regimes, and the solution for the departure / recovery problems are also essential. Therefore, for the military aircraft control design, a new term, the so-called “carefree handling” was introduced. It means the reliable limitation of commands from a trained pilot to keep the aircraft within the allowed envelope, to avoid departure, and to prevent aircraft overloading leading to pilot unconsciousness [3].

The carefree handling technology initiated with simple autopilots through stick shakers/pushers. In autopilot mode, pilots have limited command authority, “the computer flies the aircraft”. The modern technology can provide fully automatic control, including recovery from dangerous situations. Therefore, today the control also deals with the coordinated motion of the centre of gravity of aircraft, while the 20-year-old control makes the co-ordination for the rotation around the centre of gravity. In the carefree mode, the computer is only monitoring and limiting how the pilot flies the aircraft. Because the high complexity of the fully automated control, an aircraft is often only carefree with respect to some critical parameters.

Generally, the maximum controllable areas of the flight and load envelopes are highly depending on the flight condition and configuration. Therefore, many input parameters are needed to guarantee the reliable limitations.

Depending on the applied control philosophy, the control of characteristics could be made by two different ways [3]:

- Passive, with no control law change: a pure warning system (mostly acoustic) giving information about the distance to the actual boundaries of the flight envelope, in order to enable the pilot to control the aircraft closer and safer along these boundaries. Even this passive, and relatively simple systems can highly support the pilot, however, in many accidents such warnings were simply ignored.
- Active, with control law changes: an active limitation system is more complex and therefore considered to be more risky, but it offers better performance and increased safety. Naturally, carefree handling always requires active systems.

The effective carefree handling characteristics could enable for example (i) a higher success of the mission, (ii) a full concentration of the pilot on the target, (iii) a more aggressive command inputs, while using the full flight performance, (iv) a reduction of the risk in human – machine interaction, or (v) a reduction of structural load factors. On the other hand, the development of carefree handling is more complex due to the additional software, the testing, and confusion in the pilots who prefer to have the full control in their hands.

The carefree control philosophy – the limiting the pilot actions – might also be applied for personal aircraft piloted by less-skilled pilots. The approach can be further improved and the limitation can be adapted to the actual pilot’s level of expertise.

Another appealing and useful philosophy is given by Moore [16]: "the sentience of a horse in that it is an intelligent vehicle that “sees” the environment, shares its intent with neighboring vehicles, “feels” the flow over its wings, senses its internal health, and communicates with its user. Instead of a user being required to instruct the horse along a specific path, the user is able to provide the ‘intent’ while performing higher level tasks that the horse could never perform effectively. From these perceptions, the sentient vehicle develops an integrated awareness of its situation and autonomously plans and executes a course of action that appropriately satisfies the user’s directives. The resulting vehicle's capabilities will enable at least automobile levels of safety and convenience, while providing a balance between user control and security."

The H-metaphor [18] may go back to far. Safety philosophy of personal aircraft can be based on a simple idea: the aircraft control should be simplified to the level of driving a personal car. Such supporting system might include the following features: voice check-list, automatic situation awareness, flight path prediction, automatic recovery, or even switch to full automatic / distance control.

Finally the third approach is directed to develop a system can be operated by the common persons on level that is accepted and used by them everyday. As it had been introduced that is a road transport known an used by everybody.

As mentioned, PPlane or personal aircraft is expected to be used by less-skilled, common persons in different ownership or rent-a-plane operations in the uncontrolled or unmanaged airspace, between small airports placed close to the city center that provides limited services. Under these conditions, there are several solutions for the control system.

- fully automatic intelligent control system, leaving the pilot out of the control (while it is technologically feasible and in the personal aircraft community it is often considered to be the best solution, the society does not ready to accept fully automatic systems. In addition, such operations might even lead to juridical problems once an accident occurs),
- distance control performed by well trained pilots from the ground (it would mean less human problems, but still, the majority of the accidents are expected to be caused by the humans),
- on-board control by less-skilled pilots (with the development of a supporting system to facilitate the duties of the pilot),
- combination of the third solution with the second or the first (with automatic monitoring of the pilot's work-load / condition with the possibility to switch – if needed – to distance or automatic control).

This last scenario seems more realistic, since it is expected that personal aircraft owners or renters would like to pilot their plane.

The difference between the less-skilled pilot and experienced remote pilot is not as much as it seems, since by not sitting on the plane, the attention of the remote pilot could be diverted. Therefore, both operational scenarios require advanced supports, for example info-communication, situation awareness, decision making, and simplified control.

The previously identified safety aspects are leading to the formulation of the PATS safety philosophy, or strategic plan for the future developments and tasks to be solved. PATS safety philosophy could therefore be given in the following form:

- development of a safe personal air transportation system using limited technological background (at tower-less small airports close to the city centre without conventional primary surveillance system, and flights mostly performed in uncontrolled / unmanaged airspace) by less-skilled pilots,
- decreased technological level that is comparable to road transportation and to the difficulty of driving a personal car,
- advanced info-communication system, automated situation awareness and decision support,
- possibility to switch to fully automatic system in case of emergency.

PATS needs new, revolutionary solutions [19, 20, 21], in which all the system elements are radically improved, or even redesigned.

In this paper, only the aircraft system improvements will be discussed.

5 System improvements

The application of the above mentioned psychological approach to the personal air transportation system leads to the following system improvements.

5.1 Certification:

Personal aircraft are not acrobatic aircraft, however they are recommended to be certified in the utility category (which is the highest certification level of non-acrobatic aircraft) to be capable of withstanding higher load limits and G forces.

5.2 Design and engineering:

There is no a special design and certification requirements for the personal aircraft. However, the elements and the systems are recommended to fit FAR 23 and JAR 23 requirements. This might be seen too strong, but the personal aircraft might have higher loads due to the complex operational conditions. Safety is a factor of the applied design philosophy and must be „built“ into the structural solutions over the design and engineering processes. Therefore, the structure must have damage tolerance and the system should have fault tolerance. Presently, the airframe could be full composite using damage tolerance design technique, nano and auto health technologies. Generally, the carbon-fibers are nowadays about three times stronger then aluminum based alloys. The metal–composite and the full metal structure might be based on frame solution for the fuselage, and on light way technology for the wings and the tails.

The main spar and joint elements as well as the systems must be very simple and redundant. With the dual philosophy, each spar must be apple to support the entire load alone. The redundancy in the electric system and in the avionics is especially important to support the less-skilled pilots with relevant information.

To further enhance safety and indicate the extreme situations, personal aircraft are also expected to have a load measuring and data recording system, which alerts the operator in extreme loads, and estimates the equivalent operational time.

Personal aircraft are expected to be used in all or in nearly all weather conditions, by pilots having less knowledge of flying in bad weather. In the view of this, and especially the lightning meteorological conditions, personal aircraft are recommended to be certified as all-metallic aircraft.

5.3 Production

The production of personal aircraft should be as simple as possible, seeing that these aircraft would have a lower total operational cost and they are expected to be produced by new small companies, having less practice in the domain. Some developers are thinking about the simplification of the aircraft surface, completing the lifting body from the plan panels even if the aerodynamic goodness factor (lift over drag ratio) will be reduced for 20 – 25 %.

The production time and cost can be reduced with the use of lean technology.

5.4 Cabin safety and ride control

Generally, the life of passengers in the emergency situations are saved, if the aircraft or at least the cabin stands the hard landing (with higher vertical touch-down velocity), the roll-over situations (with up to 3 G), the seats are strong enough, and the special active safety systems (as air bags in the cabin, emergency parachutes for all the aircraft or the entire cabin) are applied. Other influencing factors include the protection of the door to be opened in flight, the application of fire resistant materials that might decrease the risks for injuries and fatalities.

Another important problem is the ride control, as personal aircraft are expected to be operated at relatively low altitude, which is the most turbulence region of the airspace. To avoid its negative effects, personal aircraft could apply (i) passive (using the highly loaded wing), (ii) semi-active (control by limiting the pilots' sudden actions) and (iii) active methods (like a special system reducing the effects of turbulence by active lift – lift distribution – control system.

5.5 Cockpit instrumentation

After revising the current projects, programs and tools concerning cockpit development (e.g. NASA cockpit vision for SATS [22], Capstone [23]) the following main points can be concluded:

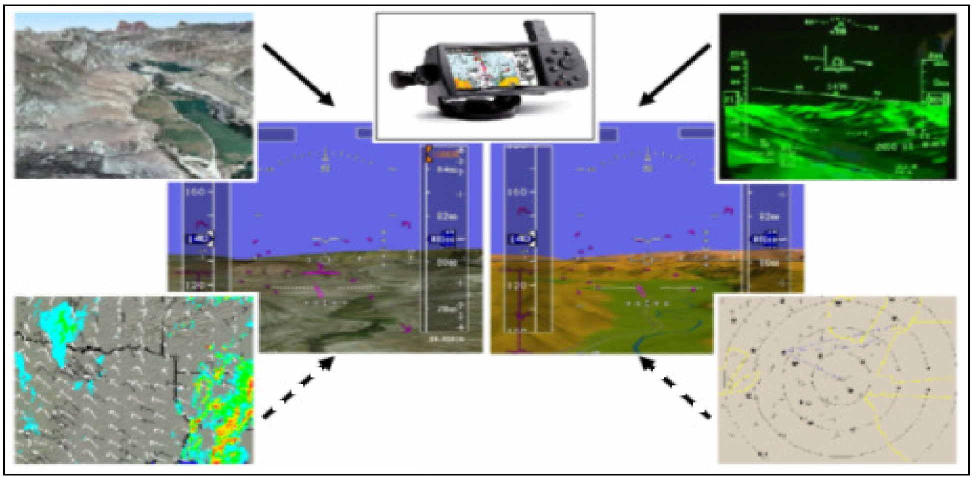

Figure 4. Possibilities of weather and synthetic vision systems for enhanced visualization of aircraft surroundings.

The developed cockpit could contain up to 6 color displays for the following tasks :

- digital reproduction of the basic flight instruments,
- colored macro and micro weather visualization (around the aircraft on the flight path) with 3-D depiction of complex weather patterns that clearly identify the location of e.g. wind-shear, lightning or storm cells. A good example for such an instrument is the NASA Aviation Weather Information System [19]. The AWIN project is developing enabling technologies and coordinated practices for using near real-time aviation weather information in the cockpit (figure 4) in order to reduce accidents where weather is a contributing factor.
- flight advisory system with
  - day – night visualization of the aircraft surroundings: artificial vision generated by advanced sensors, digital terrain databases, accurate geo-positioning, and digital processing to provide a perfectly clear 3-D picture of terrain, obstacles, or runway. An advanced tool for such visualization is the NASA's Synthetic Vision System [20]. This targets to eliminate one of the most important contributing factor to aviation accidents, the Controlled Flight Into Terrain (CFIT). It provides a clear electronic 3-D perspective of the airplane surroundings (figure 3.), no matter what the weather or time of day. The database is given by the combination of Global Positioning System satellite signals and an onboard photo-realistic record to give a terrain picture for the crew. Accuracy can also be checked by sensors comparing the real world with the generated pictures,
  - automatic identification and alerts to threats, regardless of weather, nature or human built obstacles,
  - recommended flight path (for example with 3D-tunnel/predictor) visualization,
- flight navigational display to represent the flight routes on the general moving map based on macro data,
- condition monitoring and diagnostic system display,
- other supplementary displays for further goals not mentioned here such as the visualization of the back or side surroundings, or the information in emergency situations.

By using the new technological achievements described above (and others not mentioned), the difference between the existing and the developed cockpit is remarkable.

5.6 Communication

Cockpit development could pose new requirements and obligations in several domains, such as accuracy and availability of data. Thus, communication and information sharing (like those of the GPS) between airspace users and ground stations is also a domain to be ensured. Aviation uses radio signals to carry the data. Virtually everybody use these datalinks, so their usage is increasing day after day.

As aviation radio communications are limited to a number of dedicated channels in their allocated part of the radio spectrum, pilots are complaining about overload in high density airspace. But experts prove that further channel splitting is technically not possible, and around 2012 a communication jam is possible [24].

The problem here is that voice massages have to be transmitted and acknowledged by the recipient, even if theses massages are briefs. But circumstances (in general) are not so ideals because of poor reception conditions, which make massages to be repeated. That consumes too much time on today's crowded radio channels.

One solution for that problem is a kind of datalink, where even complex massages can be passed with high reliability. One of the solutions is EUROCONTROL's controller / pilot datalink communications (CPDLC) program [24, 25] where voice transmissions can be replaced by messages displayed on controllers' and pilots' screen, which can be accepted and acknowledged by a simple press of key.

Even if CPDLC could be a good solution, there are other concepts as well, which are mentioned at the followings in the aim to have a wider view of the existing technological achievements, and possible utilization. An ideal solution might also be an internet based IC^3 (information, communication, commend, control) system combined with positioning and secondary surveillance systems (using GPS records for air traffic monitoring).

5.7 Aircraft control system (in general)

Control system is a crucial element of personal air transportation. Due to the size of the aircraft, control system might be made in mechanical form. In case of fully electric aircraft solution, the control system can be fly by wire, or even wire-less, but this would require the system to be duplicated. The control system for such small (up to 9 seats) aircraft must be developed for

- automatic adjustment of the aircraft centre of gravity (that can be important for the 4+ seats aircraft),
- position control of aircraft elements (under carriage system) and mechanical systems (like flaps deflections) as well as the active system elements (like lift or drag control by MEMS based active elements),
- control of the propulsion system (engine speed, propeller blade position, thrust vectoring),
- control of power distribution (including the electric power distribution) and
- control of aircraft position with aerodynamic control surfaces, and
- use of other possible control elements.

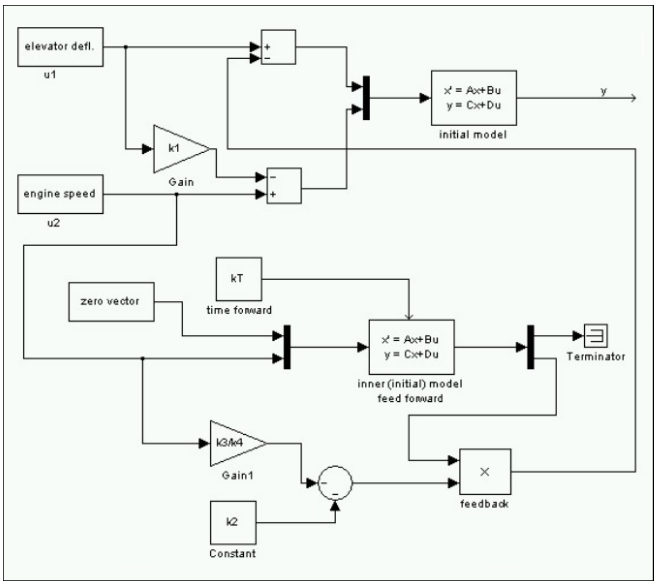

Figure 5. Automation connecting the engine control and the elevator to facilitate the control of a small aircraft.

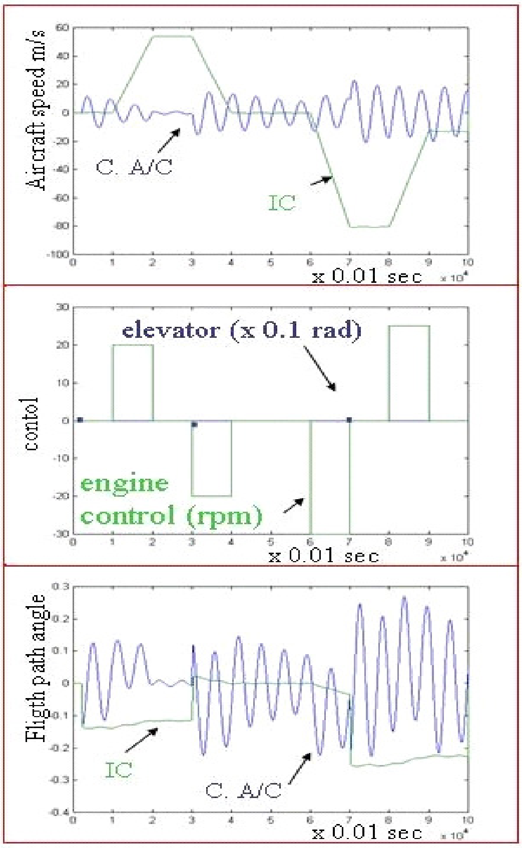

Figure 6. Automation performing engine and longitudinal control (C. A/C: conventional aircraft control, IC: integrated control).

As mentioned above, the aircraft control needs simplifications, which might be the most challenging, revolutionary new and interesting task. Automation might be applied in several areas, but this paper only presents the problem related to the parasite, unwanted effect of altitude deviation. In the present small aircraft, one might use both the engine control and the elevator to change altitude at a constant speed. By not doing so, the aircraft starts a parasite motion by modifying both altitude and speed (Figure 6.). However, pilots without a normal training and expertise will probably not be able to handle and to get familiar with such a situation. Furthermore, personal pilots might not be interested in aerodynamic and parasite effects. They just would like to change one flight characteristic (e.g. the speed) while keeping all the remaining characteristics constant, as made in a car. To reach the requested simplicity in aircraft control, the lack of automation becomes clear very quickly. Engine and elevator control could be connected on a feed-forward technique. A global solution could be a computer assisted control system with automatic limitations on critical regimes which integrates engine and aircraft control, and connects roll and yaw control into one channel [26] (Figure 6.). The result of automation relative to a conventional small aircraft are clear in the Figure 6.

The same principle could be used for several other goals, such as ride control applications to increase passenger comfort.

5.8 Operation and support

Aircraft operation and maintenance (line up maintenance- services, on condition maintenance and repairing) should also be strongly supported. The support of the private pilots could be made at three different levels:

- economical support (credit to purchase an aircraft, establishing the rent a plane system),
- technical support (providing full services, maintenance and overhaul programs),
- personal support (including the flight plan development services, on board decision support system and even the virtual co-pilots),
- other supports (e.g. pilot training schools, weather information services).

The virtual co-pilots could even have a voice check-list function.

5.9 ATM

The personal air transportation is a new air transportation system, with less-experienced non-professional, or remote controlled pilots. In any case, it is expected that the air traffic control of these personal flight should be based on radically new ideas. The main features of the envisioned the envisioned ATC are the followings:

- control is composed from en-route and airport control, areas
- during en-route, personal flights could be controlled by GPS positioning and transponder information,

– based on GPS optional records, the system will automatically keep the aircraft on the designed flight route otherwise it will alert the operator,
– surrounding aircraft (within a 15 km range) will be located by communication between the on-board transponders, and presented on a small color cockpit display,

➢ airport control might be solved with GPS based ATC info – system,
  – all aircraft will transfer their GPS position to the airport control information centers,
  – the airport information centers will represent all received positions on their display,
  – the information center will determine the flight routes of each aircraft (by respecting the flight rules and safety instructions),
  – the determined information will be visualized on the same display,
  – the images of the general and calculated situations will be transferred back to each aircraft,
  – each aircraft has to follow its flight as described by control center,

ATC might integrate all the available information through a wire-less datalink system. One of the solutions is the UAT ADS-B [27], developed and applied in Alaska (Figure 7.). UAT is a radio datalink system, supporting broadcast services such as Automatic Dependent Surveillance Broadcast (ADS-B), Traffic Information Service (TIS-B) and Flight Information Service (FIS-B). UAT can allow two types of messages. Firstly, broadcast transmissions from aircraft, supporting aircraft-to-aircraft and / or aircraft-to-ground surveillance applications that allows to see other ADS-B equipped plane. The second type of transmission supported by UAT is the uplink broadcast of information from fixed ground stations. Such a capability could be used by the followings:

➢ Flight Information Services – Broadcast (FIS-B) to broadcast weather and aeronautical information such as status information on airports, or special airspaces,
➢ Traffic Information Services - Broadcast mode (TIS-B) that can provide traffic information broadcasts using ground-based radar systems.

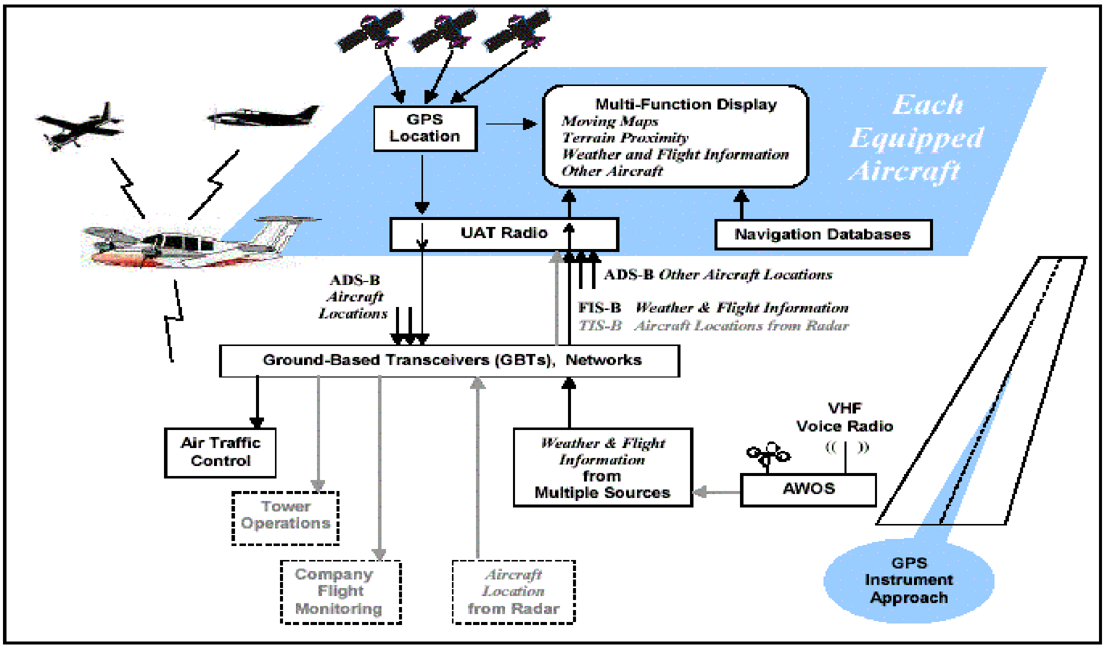

Figure 7. Capstone Datalink System Architecture.

Comparing to the GPS itself, ADS-B opportunities help to develop a more complex system using both technologies. Its more a ”usable” infrastructure that can propose communication, navigation, and surveillance possibilities, both in IFR and VFR service by a complex system architecture with several tools like GPS, Terrain Awareness and Warning System, Automatic Dependent Surveillance Broadcast, Flight Information Service Broadcast, or Traffic Information Service Broadcast.

6 Conclusions

Personal air transportation system opens a new and large market. Such system will be operated by less-skilled pilots in areas maybe of the control, but close to the city centre. Therefore, PATS safety is an important problem that must be solved. This paper analyzed and summarized the safety aspects, safety problems and gave recommendations for possible solutions. Some recommendations are discussed and defined for further investigations in the area of aircraft and aircraft system improvements.

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