Identification of Major Safety Issues for Futuristic Personal Plane Concept

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Abstract:

The paper describes activities related to safety assessment of futuristic personal plane concept, done by researchers at Institute of Aerospace Engineering (IAE), Brno University of Technology as a part of FP7 PPlane research project. Activities under PPlane project were done in joint cooperation with international research team led by ONERA (France). The 7.FP EU project PPlane is aimed to identify potential new concepts and technologies for future air transport – namely to create future Personal Air Transport System (PATS). The personal air vehicle is understood as to be analogous to private car in terms of accessibility and ease of operation. Such new transportation system can help to reduce congestion on roads and enable more efficient transportation of passengers to their destinations. Introduction of PATS is a long-term goal which requires considerable progress beyond the current state-of-the-art in technology, as well as in related areas. The major enabling technology is believed to be high level of automation in new air vehicles, requiring no or small piloting skills of passengers.

Key words: aircraft systems, avionics, FHA, PATS, PPlane, safety.

1. Introduction

Recent increasing congestion on roads and constantly growing demand for fast and comfortable transportation to final destinations leads to research of new alternative means of personal transportation. One of possible solutions is seen in utilization of small personal aircraft able to transport small number of passengers close to their final destinations. For example in the USA, NASA has launched the Small Aircraft Transportation System (SATS) initiative aimed at showing that emerging aviation technologies can be integrated into operations in a small airport environment. In Europe, European Commission (EC) supports several research projects dedicated to use of small aircraft for personal transportation. New term Personal Air Transportation System (PATS) becomes standard in the field. Most recent activity supported by EC is PPlane project (Personal Plane) joining 13 international partners from 11 European countries. The project, under the coordination of French aerospace research institute ONERA, is focused on definition of operational concepts leading to implementation of PATS. The personal air vehicle is understood as to be analogous to private car in terms of accessibility and ease of operation. Major difference compared to existing small aircraft is seen in the level of automation. PPlane vehicles are expected to be fully automated, therefore enabling transportation of passengers (users) without significant piloting skills. Attention is given to several critical areas, where most significant progress is expected. These areas include: “Security and Safety”, “Automation and Control”, “Human Factors” and “Environment”. **PPlane project should build first operational concepts with expected implementation at 2030 and beyond timescale.** Recommendations for implementation and most critical areas are expected to be outputs from the project. These will help EC find most efficient way for implementation of PATS as alternative transportation means. PPlane consortium includes partners from whole Europe and Israel, namely ONERA, IAI, AirNet, Bologna university, Brno university, CIRA, Intergram, Warsaw university, DLR, INTA, NLR, Patras university and REA-TECH.

Researchers of Institute of Aerospace Engineering (IAE), Brno University of Technology (BUT) **are involved in** several key areas of **PPlane project.** Most IAE activities are connected with safety assessment of proposed PATS concept. Safety assessment performed in PPlane is based on recent practices used for safety and reliability analyses of current aircraft. In addition, also results of research done on reliability of different aircraft systems in Czech Aerospace Research Centre helped to better analyse critical elements of proposed PATS.

Fig. 1.1 – VUT100 Cobra: Example of existing small aircraft that can be used as PATS vehicle

Methodology selected for PPlane safety assessment uses at the first stage surveys of typical systems and equipment used on existing aircraft (more details are given in chapter 2). Based on the study, identification of most perspective systems for future PATS was possible.

Identified systems are subject to detailed Functional Hazard Assessment (FHA) with aim to identify most critical items. FHA is described in chapter 3. All activities are closely connected to the work of other partner organizations on PPlane project. For example, safe design of selected critical systems is a subject of activities of multiple partners. **The paper is limited to the activities done mainly by BUT- IAE researchers.**

Description of proposed PPlane system:

Based on extensive studies, as a need to ensure practical operations, **PPlane consortium partners defined basic PPlane system concept that is fully automated. PPlane vehicles are operated from small airports close to urban areas.** Users/passengers onboard the aircraft are able to perform only high-level tasks like decision on destination change. Operations of PPlane vehicles are supported by ground infrastructure (ground segment) that includes *remote pilot stations (RPS)*, *air traffic control* (ATC) and *PPlane system operation management centre (PSOMC)*. In case of an emergency situation (failure, health problems onboard, etc.), pilot at *ground pilot station* takes over the control and brings the PPlane vehicle to the nearest airport. Ground pilot can also be contacted by users/passengers onboard. In normal situation, ground pilot supervises multiple aircraft – he takes over only in emergency situations. Even in emergency situation, ground pilot can only change aircraft trajectory and has general control over aircraft systems – direct handling and control of aircraft is not supposed.

Such PPlane system needs development of highly reliable components and systems. Many of them can be based on existing UAVs (Unmanned Aerial Vehicles). Even if we consider existence of systems necessary for realization of PPlane concept, **practical realization cannot be expected before the year 2030**. This aviation vision should be understood similar to increasing level of automation in automotive industry or railways.

Graphical presentation of basic PPlane concept is shown on fig. 1.2.

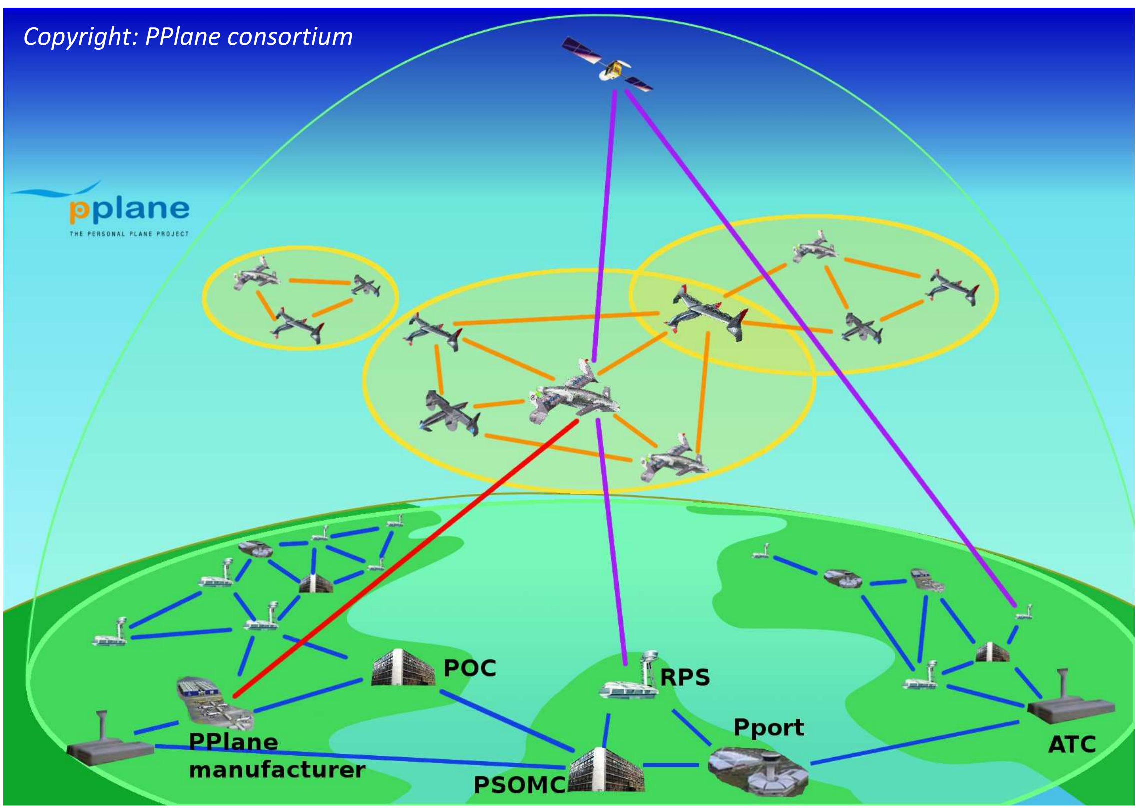


Fig. 1.2 – PPlane system architecture definition

2. Study on existing aircraft systems in general aviation aircraft

Significant decision factor for definition of future PPlane concept is current state-of-the-art in aircraft categories close to defined PPlane aircraft. Therefore, extensive study of existing aircraft was done with particular attention on typical systems and equipment. Outcome of the study was the database of aircraft representing current situation in different categories of aircraft. Special attention was given to typical avionic equipment and aircraft systems. Full database included 59 aircraft in 5 categories. Although aircraft in the database did not cover all existing aircraft, they represent majority of used aircraft in given categories. This was secured by careful selection of aircraft types based on their importance for current general aviation – considering number of build airplanes and year of development. Major sources for the study were [1] and [2]. Table 2.1 shows a fragment of created aircraft database.

Table 2.1: Example summarizing form of the database (small fragment of the database) – 4 seats fixed wing aircraft (showing all items taken into consideration)

Type	GENERAL					
	Seats Configuration	Flight Rules	Configuration	Propulsion	Construction	Pressurized Cabin
4-seats						
Summary (most typical configuration)	4-seats	100% IFR	fixed wing	81% single engine, 19% two engines	37,5% composite 62,5% metal	non-pressurized

Type	PARAMETERS					PERFORMANCE	
	Wingspan [m]	Wing Area [m²]	MTOW [kg]	W/S [kg/m²]	W/T [kg/kW]	Cruising Speed [km/h]	Range [km]/ Endurance [h]
4-seats							
Summary (most typical configuration)	9,5 ÷ 13,5 m	13 ÷ 17 m^2	1100 ÷ 1785 kg	70 ÷ 117 kg/m^2	6,5 ÷ 11,5 kg/kW	210 ÷ 350 km/h	800 ÷ 1600 km

Type	AIRCRAFT SYSTEMS				
	Flight Control System	Electrical System (Power Supply)	Mechanical Systems	Electrical Systems	Hydraulic Systems
4-seats					
Summary (most typical configuration)	mechanical	44% dual electric system	aileron, rudder, elevator	69% flaps, 56% trim	69% brakes, 12,5% propeller, 12,5% landing gear

Type	AIRCRAFT EQUIPMENT							
	Flight Environment Data	ADI/HSI	Navigation	Communication	Autopilot	Transponders	Collision Avoidance Systems	Weather Radar/ Stormscope	Anti / De - Icing System
4-seats									
Summary (most typical configuration)	12,5% BASIC "T", 87,5% EFIS	12,5% mechanical, 87,5% EFIS	1 or 2 Nav. panel + 1 back-up VOR	2 or 3 Comm receivers/ transmitters	87,5% of aircraft has autopilot (2-axis type)	yes	81% yes	81% yes	19% yes

2.1 Example of today's typical "Personal Plane"

The aircraft included in the study were divided into several categories. The first main category is fixed wing aircraft. The fixed wing aircraft are divided according to seats configuration to 2-seats, 4-seats and 5-6 seats. The next main category is rotary wing aircraft as previously subdivided into 2seats, 3-4 seats and 5-7 seats. All of aircraft in these categories were factory built in small or large aviation manufacture. The last category of aircraft consists of homebuilt aircraft or kit planes. Those aircraft usually have 2-4 seats.

Each category includes very detailed additional information about general parameters, performance, aircraft systems and equipment. Dimensions and performance correspond to each individual category and fulfil PPlane requirements. These requirements were determined in first period of PPlane project. Structure is either composite or all-metal (but it can also be combined). All-composite construction prevails only at kitbuilt aircraft. Only a few aircraft are designed with pressurized cabin for flying in high altitude. **No revolutionary changes related to the airframe structure are expected in the future PPlanes, except of continuous improvements i.e. use of fail-safe structural concepts.**

Fixed wing aircraft are mostly powered by single piston engine driven by two-blade or three-blade constant-speed propeller. Typical construction of small aircraft engine is flat piston engine with four or six pistons. While more powerful fixed wing aircraft are powered by turbo-diesel engine, turboshaft engine is the typical propulsion for 5-6 seated rotorcraft. **New propulsion (engine) types are expected to be available in the timeframe supposed for the PPlane. Current engine types will lead to the need for multi-engine PPlanes, see chapter 4.**

Aircraft systems used in the aircraft evolved into reliable products, often with back-up. New generation aircraft rely heavily on electric power because of the wide use of aircraft instrument systems. The usual electrical power system is 28 VDC with one alternator and one battery. Modern trend is to use dual electric system with two alternators and two batteries. Small two-seater fixed wing aircraft and rotorcraft usually use 12 VDC electrical power systems with one back-up battery. This power is for them sufficient. **Future PPlane vehicles will need more sophisticated highly redundant electric systems.**

Flight control system in most current GA aircraft is conventional and manual mechanical. The main control surfaces of a fixed wing aircraft (e.g. ailerons, rudder, and elevator) are mechanically controlled via cables and pushrods. Secondary and other control surfaces, especially flaps and trims, are controlled electrically by the actuator in most of new modern aircraft. Hydraulic system is mostly used for brakes and retractable landing gear. Rotorcraft have the different flight controls. Cyclic and collective controls achieve steady aerodynamic flight. Both are controlled by mechanical or hydraulic system (electro-hydraulic system in minimum cases). **Major technological breakthrough is needed in flight control systems in given aircraft category to enable PPlane concept – transition to fly-by-wire (FBW) system.**

There are two arrangements of avionic systems. The first is traditional "T" configuration, where basic flight instruments (HSI, ADI, airspeed indicator, altimeter) are exactly arranged to shape of letter "T" together with turn-coordinator and vertical-speed indicator. The second arrangement is an electronic flight instrument system (EFIS). EFIS is an aircraft cockpit that features electronic instrument displays rather than electromechanical. Usually includes primary flight display (PFD), multi-function display (MFD) and Engine Indicating and Crew Alerting System (EICAS). These display units are the most obvious parts of an EFIS, because of this fact is commonly known as "Glass cockpit". The PFD displays all information critical to flight, including calibrated airspeed, altitude, heading, attitude, vertical speed and yaw. MFD displays navigational and weather information from multiple systems. MFDs can also display status of aircraft systems. The small 2-seats rotorcraft still use an old Basic Six configuration, also known as "six pack". This panel arrangement includes a set of six essential flight instruments (altimeter, airspeed indicator, turn and bank indicator, vertical speed indicator, artificial horizon, directional gyroscope or heading indicator). **Future PPlane vehicles will have totally different presentation of data in the cabin (absence of the pilot on-board), and probably also at remote pilot stations. New technology has to be developed.**

The small aircraft are standardly equipped with one navigation panel and one mechanical back-up navigation system if necessary, one or two communication receivers and transmitters and one mode S transponder. The bigger and more powerful aircraft have in most cases these avionics equipment doubled. The most of the new modern aircraft are also equipped with the autopilot. The autopilot is usually two-axis or three-axis type. In kitbuilt aircraft is the autopilot optional. Engine instruments and indications are standalone devices or a part of Electronic Flight Instrument System (EFIS). If EFIS is built in the cockpit, the information taken from weather radar, stormscope and collision avoidance system, are displayed on MFD. If EFIS is not installed, such information is not available. **Future PPlane vehicles need to have integrated "*flight control-navigation-communication*" system. New technology has to be developed.**

Outputs from the database helped to define existing systems and necessary extension to new systems adopted within created PPlane concept. Definition of systems for future PPlane (based on abovementioned study) was performed by partner organization, one of the big aviation producers – Israeli Aerospace Industries. **Special focus was given to high level of automation necessary for practical realization of PATS. Use of PATS vehicles by individuals with low or no piloting skills creates safety and security related problems in several areas.**

3. Functional hazard assessment

Detailed safety assessment was performed to ensure safety of perspective PATS vehicle. Safety assessment was based on current modern methods. Furthermore, it was done in accordance with requirements in recent regulations CS-23 [3] and AC 23.1309-1D [4]. According to the requirements for identification of critical aircraft functions, **Functional Hazard Assessment** (FHA) was selected as a base for the assessment.

FHA is usually used at early design stages, during concept evolution and before more detailed design of particular systems. The main purpose is to find and accurately identify critical aircraft systems and parts using comprehensive structured assessment (leaving no or small space for omission of important element). As a consequence, identified critical systems should have more robust design (i.e. redundancy, over strengthen…). All the identified functions are further classified by type of failure conditions and by severity level on whole aircraft. No safety effect, minor, major, hazardous and catastrophic is primary classification of failure conditions. Aircraft functions are sorted by ATA Spec 100. The ATA Chapter numbers provide a common referencing standard for all commercial aircraft documentation. In other words, ATA Chapters is instruction on how to divide the whole aircraft and its functions into groups, systems and subsystems. Fragment of created FHA can be seen on Table 3.1.

Aircraft Function		Classification of Failure Conditions			Functional Category	Phase of Flight	Analysis Consideration
Function Signification (ATA 100)	Function Name	Total Loss of Function	Loss of Primary Means of Providing Function	Misleading and/or Malfunction Without Warning			
27	**FLIGHT CONTROLS**						**Functions are closely connected to autopilot.** Fly-by-wire system is considered with redundant channels (enabling single failures without catastrophic consequences). It is supposed that there is no possibility to override the system from passenger (user) cabin. There is also no possibility to directly take controls from remote pilot station - operator at remote pilot station can only define changes in the flightpath as a result of emergency situations.
27-10-F01	**Aileron control (Roll control)**	HAZ	R	CAT	F	ALL	
27-20-F01	**Rudder control (Yaw control)**	HAZ	R	CAT	F	ALL	
27-30-F01	**Elevator control (Pitch control)**	CAT	MAJ	CAT	F	ALL	
27-30-F02	**Elevator trim tab position control**	MAJ	R	MAJ (sometimes HAZ during TOF)	F	ALL	
27-50-F01	**Flap control**	MAJ	R	CAT	F	TOFI CLAP RLD G	

Table 3.1: Fragment of FHA – Function of Flight Controls

FHA created for PPlane describes failure conditions for 100 functions including respective classifications. In terms of worst classification, total of 40 functions with CATASTROPHIC classification were revealed, 22 functions with HAZARDOUS classification, 18 functions with MAJOR classification and 16 functions with MINOR classification. To simplify understanding, the functions are joined into 7 major functional categories, as shown in Figures 3.1 and 3.2.

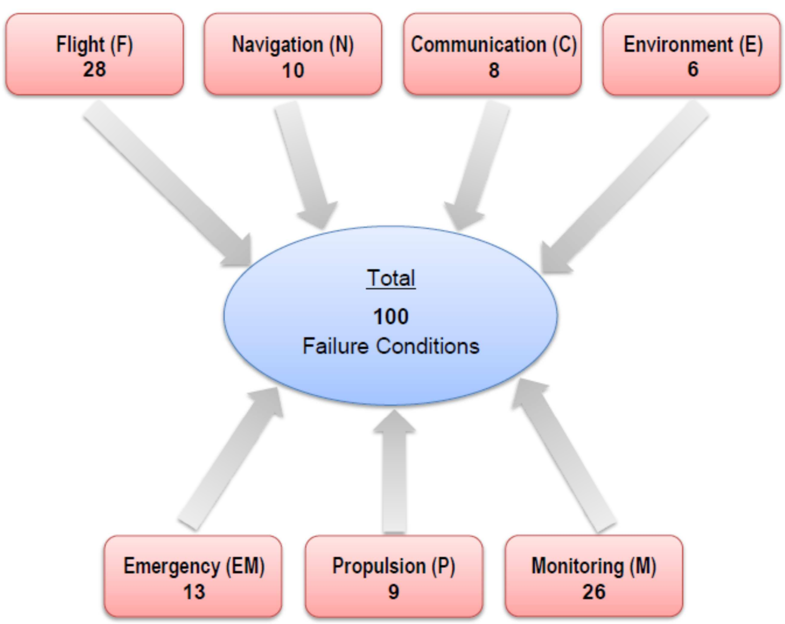
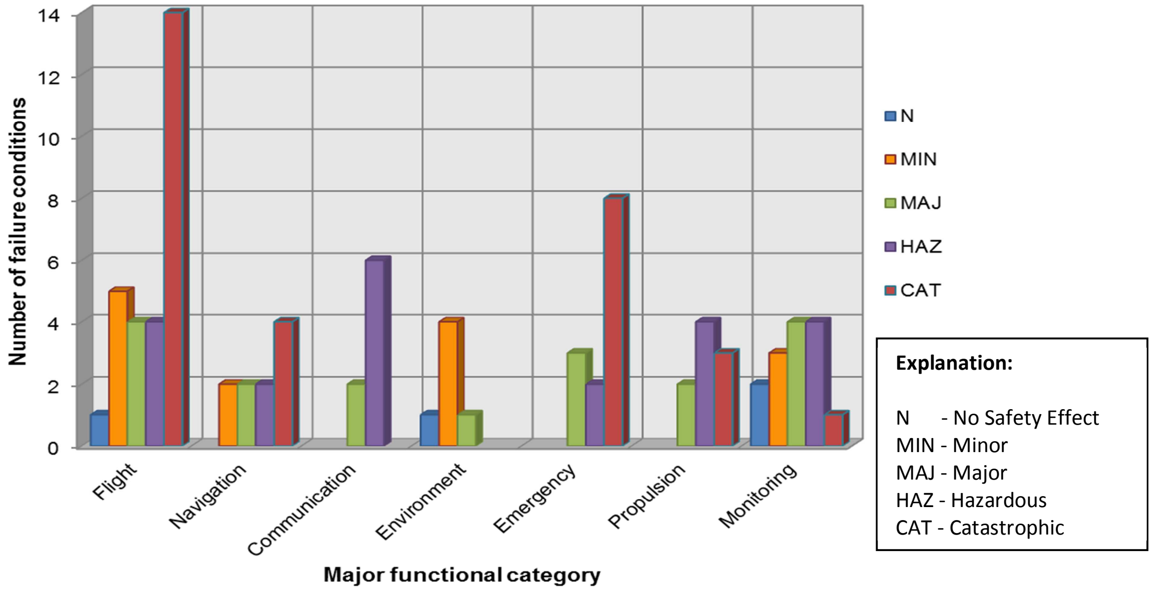


Figure 3.1: Summary of FHA results – functions/failure conditions related to 7 different functional categories

Figure 3.2: Summary of FHA results – Failure conditions severities by major functional category



Outputs from FHA had further shown that, apart from same critical systems as on current aircraft, great attention should be paid to several new systems. These include especially:

- Flight and Flight Control Systems
- Emergency
- Monitoring
- Electrical Power and engine systems

Failure / loss of some functions of these systems has critical consequences, and therefore needs to be assessed carefully and implemented the necessary precaution.

4. Recommendations for future PATS

4.1 Recommendations on future regulations for PATS vehicles

Existing regulation requirements impose reduced safety and reliability requirements on small aircraft. This is a result of historic development, where application of some of the most advanced redundant systems was not possible in small aircraft. Also accident rate due to human factors (especially pilot failures) were significantly more frequent than in case of transport aircraft.

This seems to be un-acceptable for future PATS, where users/passengers (and also aviation authorities) will require similar level of safety as in transport aircraft. Detailed analysis of current situation was done within PPlane project and described in project report D2.1 "Safety and Security" [7]. Results indicate that currently **1,01 fatal accidents per 100 000 flight hours** (approx. $1{\cdot}10^{-5}$ per flight hour) occur for general aviation aircraft (both, single-engine and multi-engine), see ref. [6]. However, only approx. 15% of fatal accidents are related to mechanical/maintenance problems (0,155 fatal accidents per 100 000 flight hours). At the same time, accident rate of large air carriers is 0,01 fatal accidents per 100 000 flight hours ($1{\cdot}10^{-7}$ per flight hour) for Northern America region, see ref. [6]. Worldwide, 0,049 fatal accidents per 100 000 flown hours ($4{,}9{\cdot}10^{-7}$ per flight hour) were tracked in the period 1997-2006. **<u>Compared to other transportation means, target safety statistics should be comparable (i.e. close to 0,05 per 100 000 flight hours).</u>** Although major source for safety data were US databases, situation can be considered similar in Europe (and whole developed world).

Tab.4.1– Risks associated to transportation systems competitive to PPlane (source: ref. [7])

	Fatality rates per 100 million miles	Fatality rates per 100 000 hours of exposure*	Note
Road vehicles 2008	1,25	0,06	USA, ref. [8]
Road vehicles 2009	1,13	0,05	USA, ref. [9]
Trains 2010 (all fatalities connected to train operations**)	104,76	5,24	USA, ref. [10]
Trains 2010 (trains only)	1,14	0,06	USA, ref. [10]
		Fatal accident rates per 100 000 flight hours	**Note**
Airliners 2006		0,01	NTSB 2006
Small general aviation aircraft similar to PPlane 2010 (excluding agricultural, experimental, homebuilt, old timer aircraft)		1,01 (0,155 without pilot-related accidents)	NTSB 2010 (total number of flight hours estimates based on 2009 data)

* An average speed of 50 mph (80km/h) is considered for the calculation

** Including highway-rail passes and trespassers

Furthermore, lessons learned from UAVs lead to application of more strict requirements on aircraft with high level of automation.

Graphical interpretation of author's recommendations for regulation requirements on PATS are shown in **fig.4.1**.

Classification of Failure Conditions	**Current** Allowable Quantitative Probabilities (per 1 flight hour)	**Recommended Future** Allowable Quantitative Probabilities (per 1 flight hour)
No safety effect (No effect on operational capabilities or safety, inconvenience for passengers)	No Probability Requirement	No Probability Requirement
Minor (Slight reduction in functional capabilities or safety margins, physical discomfort for passengers)	$< 10^{-3}$	$< 10^{-3}$
Major (Significant reduction in functional capabilities or safety margins, physical distress to passengers, possibly including injuries)	$< 10^{-4}$	$< 10^{-5}$
Hazardous (Large reduction in functional capabilities or safety margins, Serious or fatal injury to an occupant)	$< 10^{-5}$	$< 10^{-7}$
Catastrophic (Normally with hull loss, multiple fatalities)	$< 10^{-6}$	$< 10^{-8}$ * $< 10^{-9}$ **

* If PPlane systems are significantly less complex than systems of current large air carriers

** If PPlane systems have similar complexity as systems of current large air carriers

Fig. 4.1 – Author's recommendation on regulation requirements on future PATS (proposed figures are based on analysis of current transportation systems and experience with requirements imposed on FAA FAR-23 / EASA CS-23 aircraft defined at AC 23.13009-1E [4])

4.2 Recommendations on future PATS vehicles systems

Performed safety assessment revealed **critical functions** (and systems) of proposed PPlane system. These include especially:

- ***Flight*** and ***Flight Control System (FCS)*** – functions related to maintaining of flight parameters (attitude, speed, altitude, etc.) and direct control of the vehicle. Loss of such functions is highly critical and should be subject of major design focus.
  Higher criticality of functions at PPlane (compared to existing aircraft) leads to the need to develop new type of highly reliable flight control system and autopilot, if possible integrated in the single system. Totally different design of FCS is expected (FBW instead of mechanical system). Higher degree of redundancy compared to existing autopilots in similar aircraft categories is required.
  Design of FCS system could be based on existing designs for higher category aircraft. **Some elements could be based on existing technology.**

- ***Emergency*** – second most critical group of functions is related to emergency systems (performing emergency procedures). Since some of today's existing and commonly used procedures would be difficult to adopt in PPlane system (i.e. emergency landing out of airstrips, sense and avoid), new systems and procedures have to be developed. Important element in proposed emergency equipment is ballistic recovery system (BRS) utilizing emergency parachute.

- ***Monitoring*** *(Central Maintenance System)* – High degree of automation in PPlane system (and especially in vehicle operation) leads to dependency on CMS (Central Maintenance Monitoring) and especially on on-board monitoring. This system is therefore highly critical and misleading indications can lead to the loss of critical systems.

In addition:

- **PPlane system (PATS) needs improvement in design compared to current aircraft**
  Currently **1,01 fatal accidents per 100 000 flight hours** (approx. $1{\cdot}10^{-5}$ per flight hour) occur for general aviation aircraft (both, single-engine and multi-engine). However, only approx. 15% is related to mechanical/maintenance problems (0,155 fatal accidents per 100 000 flight hours). **Compared to other transportation means, target safety statistics should be comparable (i.e. close to 0,05 per 100 000 flight hours).** More details are given in chapter 4.1.

- **Increased reliance on electronic/avionic systems should not itself constitute a hazard**
  The PPlane study indicated also relatively low percentage of accidents caused by instruments and electrical systems (0,11% of all accidents, and 0,67% of fatal accidents). **Therefore, higher level of automation may eventually lead to lower accident rate.** This conclusion is also supported by operational experience with recent Technologically Advanced Aircraft (TAA).

- **PPlane system (PATS) can be single engine aircraft**
  After careful analysis, an important conclusion for PPlane project is that number of engines is not decisive factor for safety of current PPlane sized aircraft. More decisive is use of additional emergency equipment. **It is recommended to enable design of single-engine PPlane vehicles, if more strict safety goals are met (see chapter 4.1).** However, **more strict regulation requirements today lead to multi-engine vehicles (no single-engines able to meet requirements mentioned at 4.1 exist today)**. Also operations over urban areas may lead to the need to have multi-engine PPlane vehicles.

- **It is highly recommended to use BRS (Ballistic Recovery System) for PPlane vehicles**
  The study indicated that for current aircraft **BRS increases survailability rate by approx. 33%** (current rate of initiation is $6{,}98{\cdot}10^{-6}$ per flight hour for the aircraft equiped with this system). Additionally, lack of skilled pilot on board even increases this percentage, because handling of emergency situation after failures by automated systems leads to more complex systems with high number of functions (prone to fail). Therefore, it is highly recommended to use BRS for PPlanes system. However, BRS initiation should be limited to the areas, where PPlane vehicle

performs emergency landing without inflicting damages to material assests or injuries to population on the ground.

5. Summary and Conclusions

The paper describes effort to define future Personal Air Transport System (PATS). Within dedicated PPlane project, supported by European Commission under contract no. 233805, studies of different aspects were realized with the aim to help with introduction of PATS (in form of PPlane system). IAE took part in studies dedicated to safety of PPlane system. The paper provides details on FHA done for PPlane system (see chapter 3) and summarizes recommendations for future PATS (see chapter 4). FHA analysis revealed critical systems (including systems fundamental for PPlane concept) and provided recommendations for their future design. Study also revealed that some of those systems and elements could be based on existing technology. The new modern technologies and high level automation have potential to decrease accident rate of small transport aircraft.

If all legislative and technical challenges are successfully solved, personal air transport may become one of the most important and broadly used parts of whole transportation system.

Acknowledgment

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