You may sure in future development …..

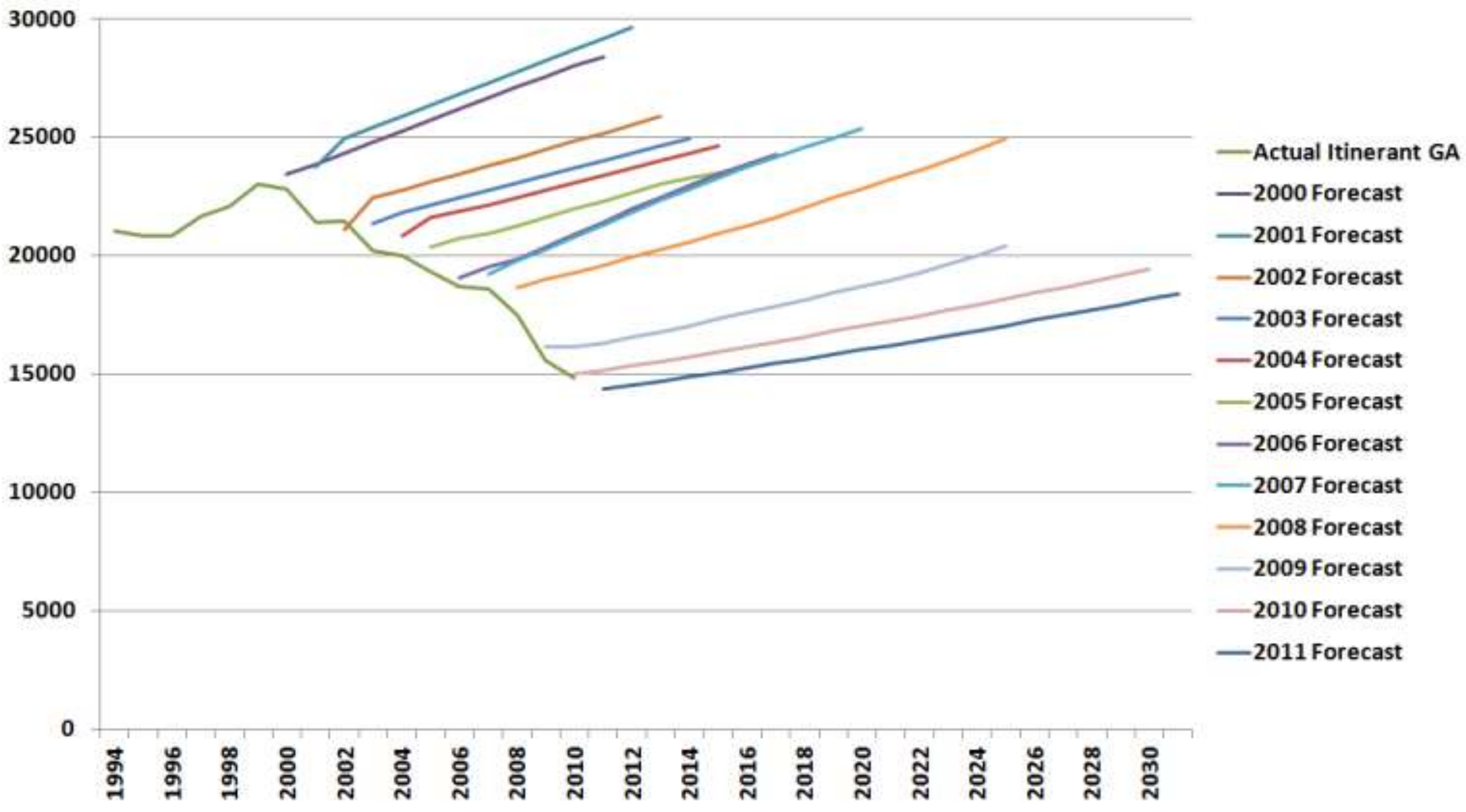
SAT /PATS

- ✓ New market
- ✓ Electric – hybrid propulsion
- ✓ Distributed propulsion

- ✓ Unconventional forms
- ✓ Morphing
- ✓ Etc.

You may sure in future development …..

Itinerant General Aviation Operations at All Towered Airports



FAA publication cited by Shetty, K. I., Hansman, J. Current and historical trends in general aviation in the United States, MIT, International Center for Air Transportation (ICAT), Report No. ICAT-2012-6, August 2012

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Supporting the Less-Skilled Pilots

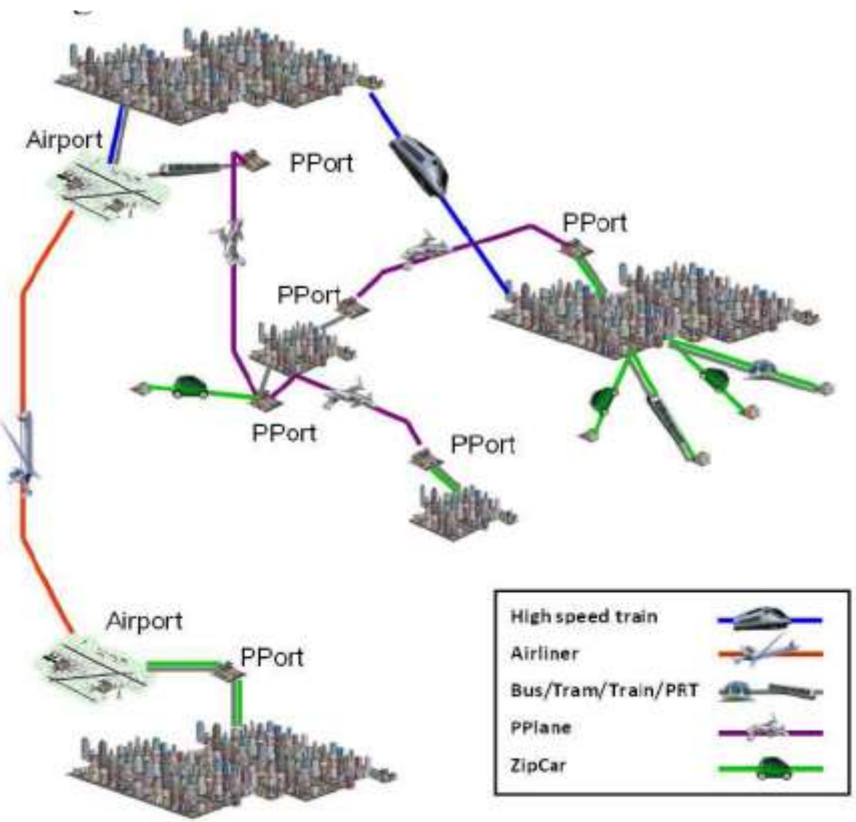
Introduction

1. Accident statistics investigation
2. Safety and security aspects of the small / personal aircraft
3. Safety philosophy for small aircraft development
4. Control system for personal aircraft
5. Pilots' subjective decision
6. Pilot load model monitoring
7. Pilot decision support system

Conclusions

Introduction

- Latest results of sciences and technologies allow to develop
  - cost effective
  - sustainable
  - small / personal aircraft.
- There are mane projects developing the new aircraft (EPATS, PPLANE, SATS-Rdmp, ESPOSA, or NASA SATS)
- The new airplanes will be controlled by les-skilled pilots
  - having the required licences (knowledge), but
  - limited practice and
  - they uses very subjective decision making.

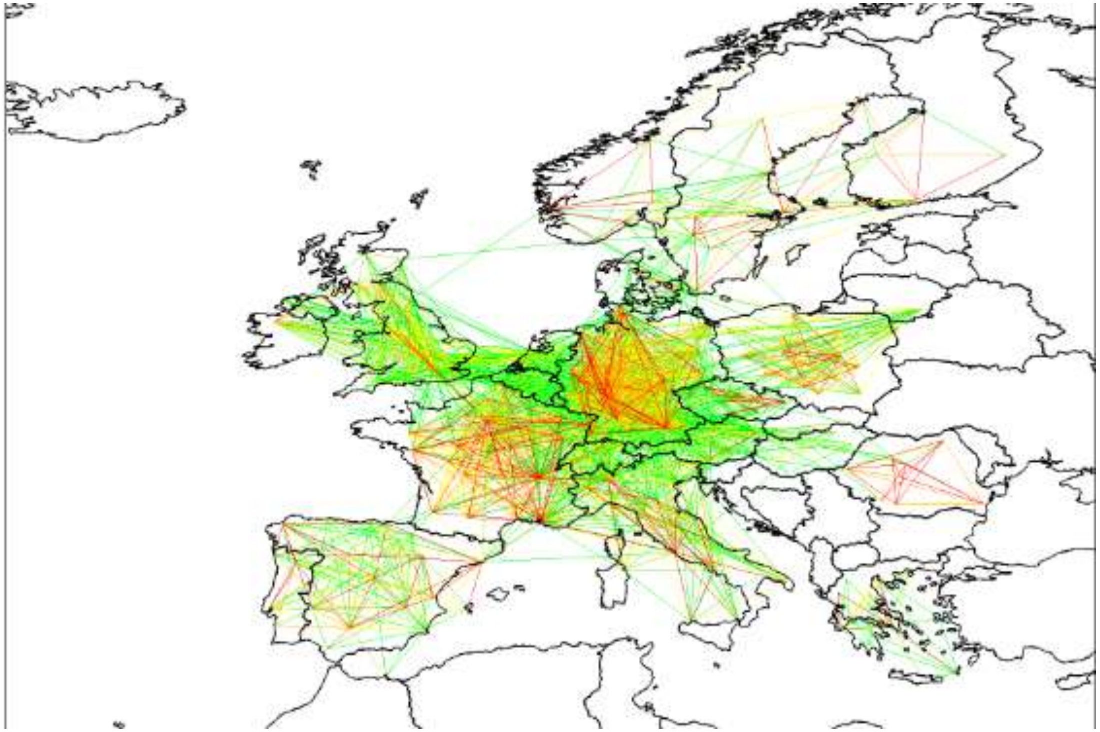


PPLANE vision

Introduction

- **Major problem: safety of personal aircraft**
- **controlled by less-skilled pilots,**
- **needing supporting systems.**
- **Overview of the results.**

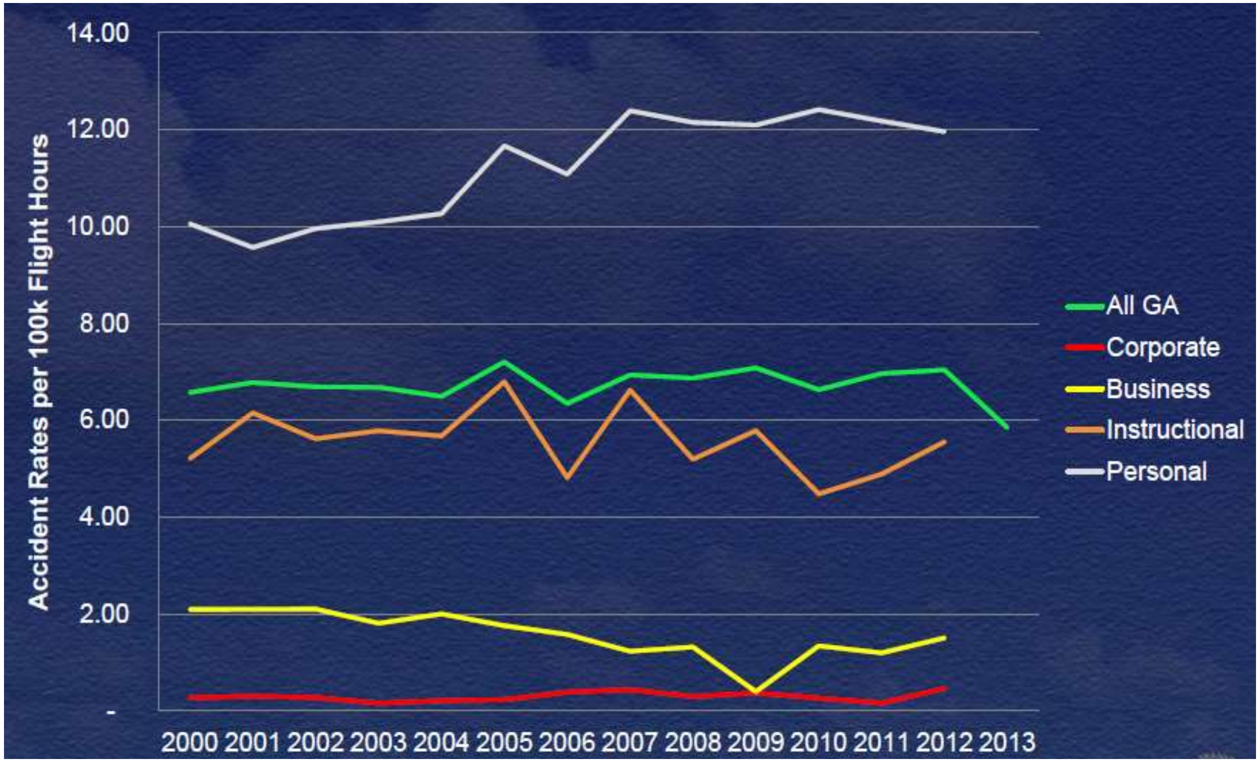
Prediction of the small air transport flights routes in 2035, coloured by number of daily flights (Green stands for 5-20, yellow for 20-50, orange for 50-100, while red for 100+ movements a day respectively)



1. Accident statistics investigation

- ***safety***: avoiding emergency situation caused by unwanted system uncertainties, errors or failures appearing randomly.
- ***security***: avoiding the emergency situations caused by unlawful acts (of unauthorized persons) – threats.

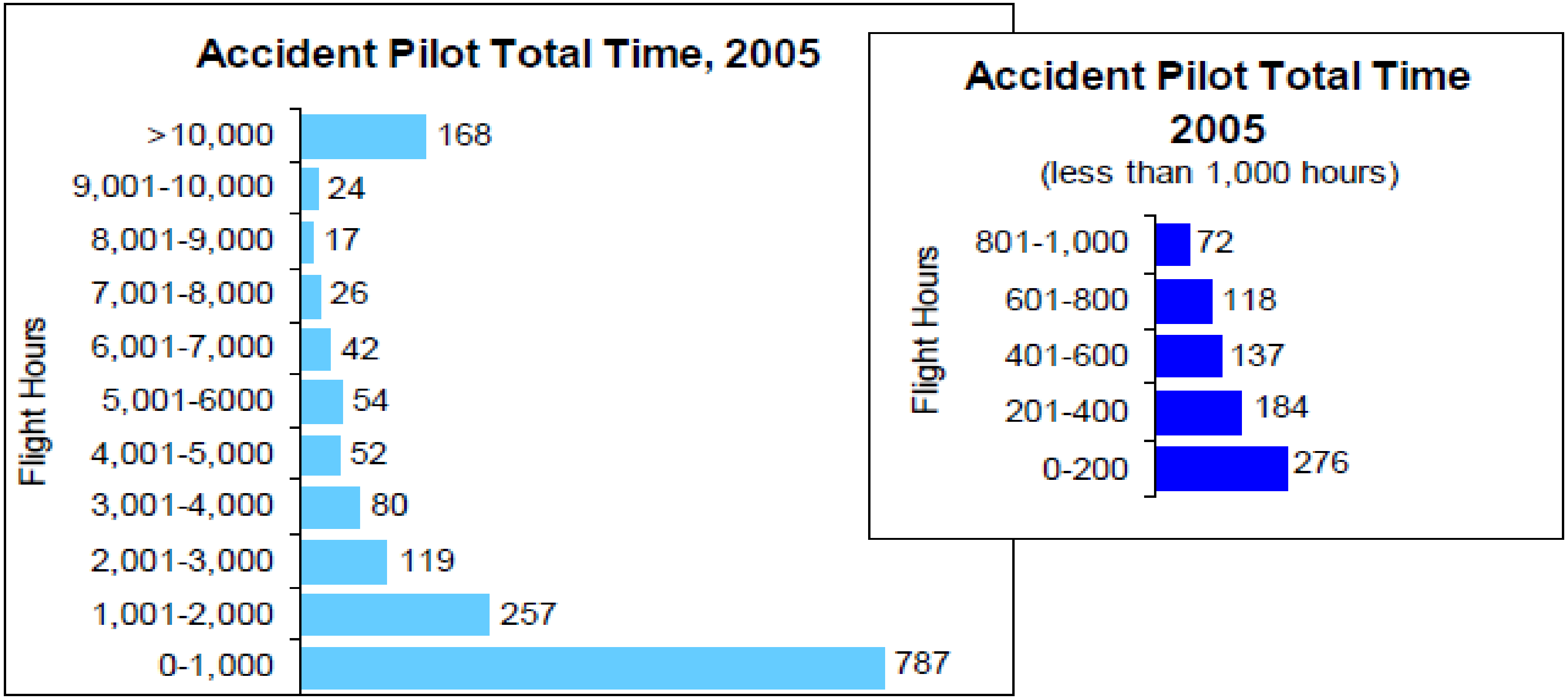
- Classification of safety:
  (i) physical,
  (ii) technical,
  (iii) non-technical safety



https://www.ntsb.gov/news/speeches/EWeener/Documents/weener_20150425.pdf

1. Accident statistics investigation

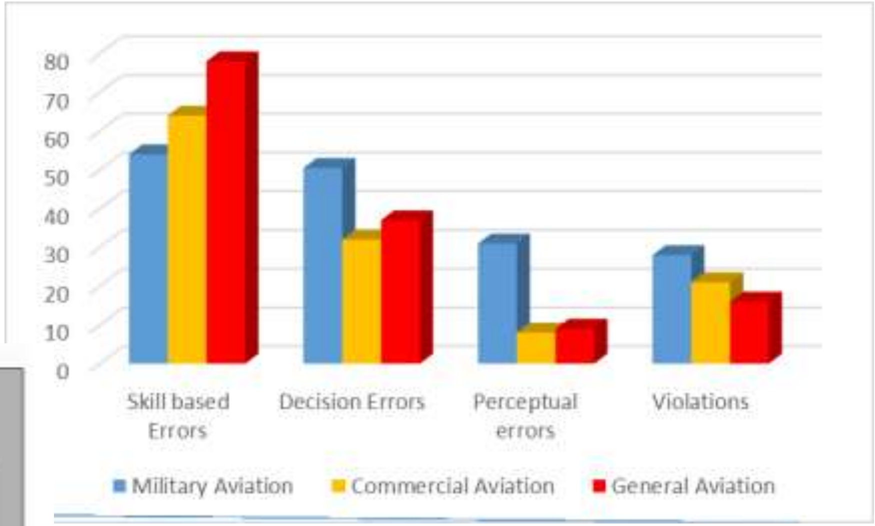
The distribution of experience among accident pilots

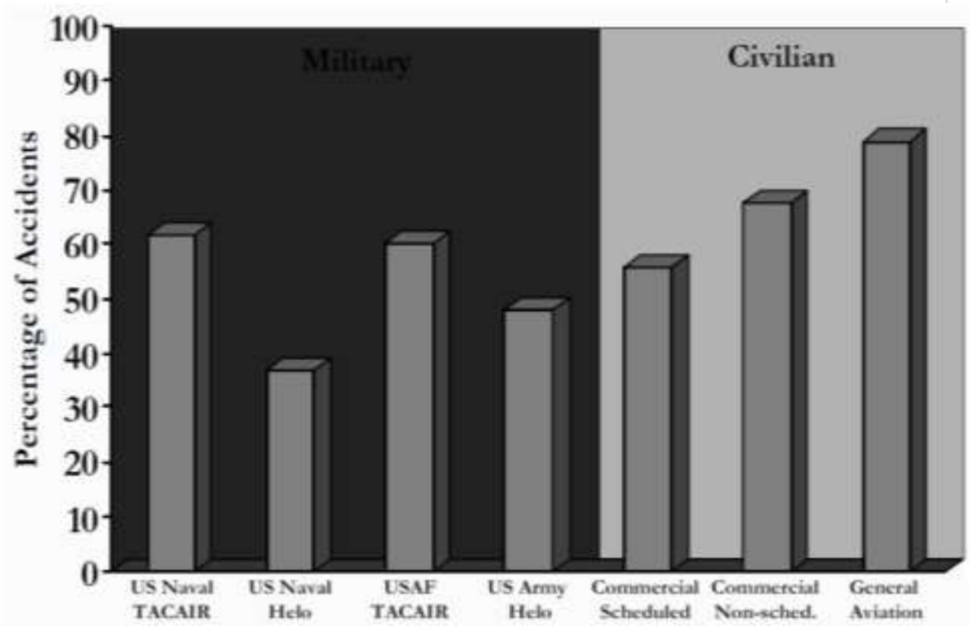


http://www.docstoc.com/docs/9058675/Annual-Review-of-Aircraft-Accident-Data-US-General-Aviation

1. Accident statistics investigation

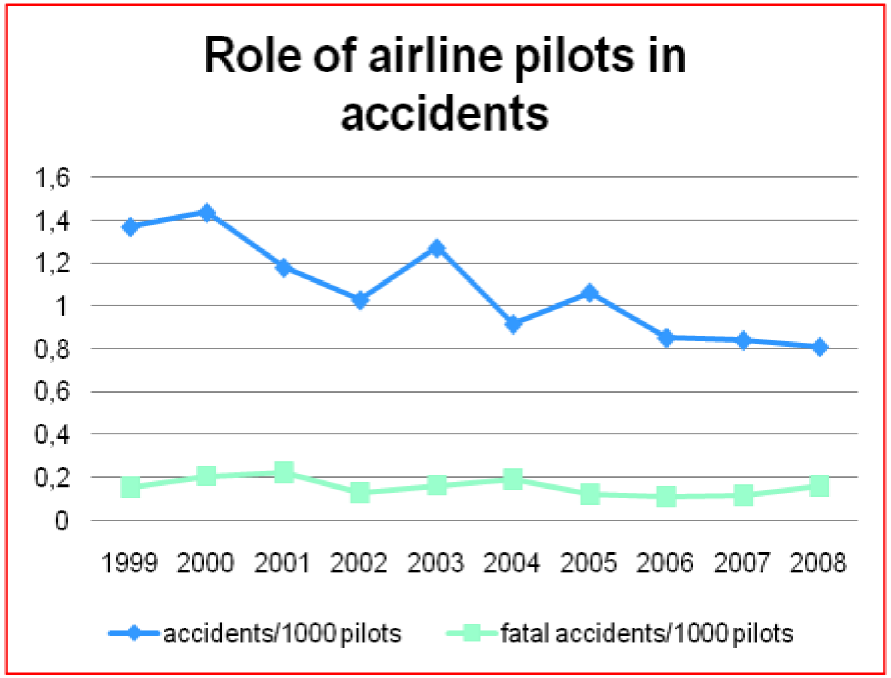
Skill-based and decision errors

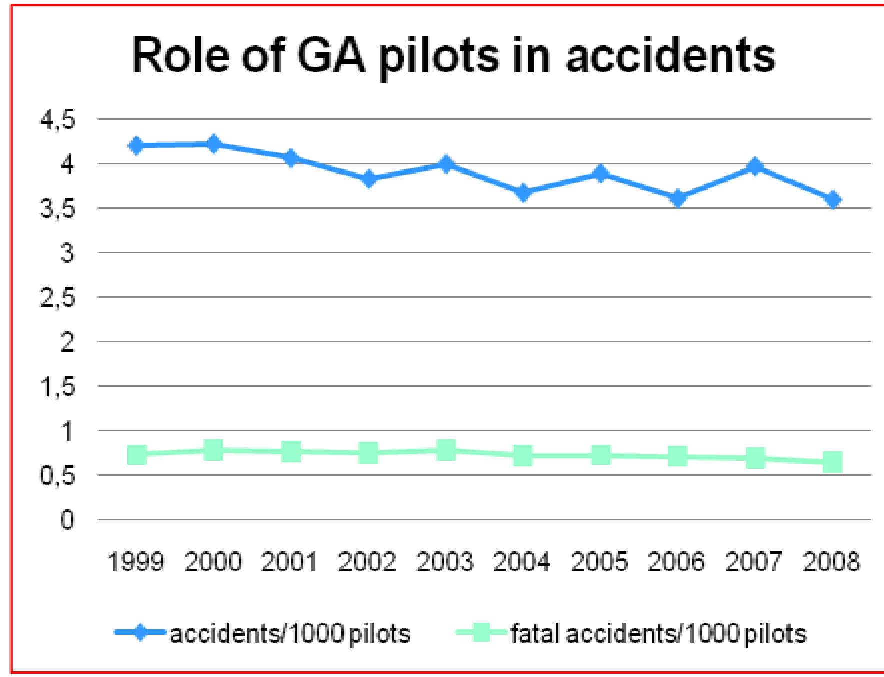




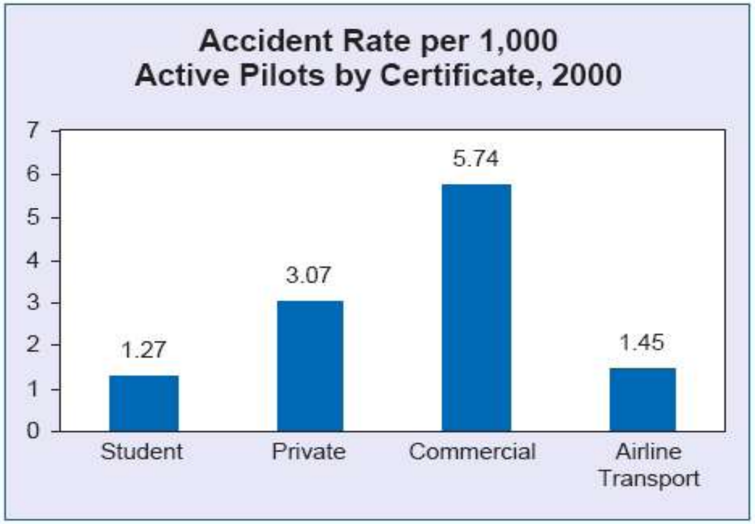
1. Accident statistics investigation

Accidents and fatal accidents for 1000 certified pilots





1. Accident statistics investigation



Accidents per different classes of pilots

http://cafefoundation.org/v2/pdf_tech/NASA.Aeronautics/NasaPavTech.pdf

An original way to compare airliner and GA accident statistics

2. Safety and security aspects of the small / personal aircraft

There were analysed all types of major safety aspects

No.	Area	Major problems	Description	Examples	Possible solution
1.			General		
1.1.	Innova-tion system	Lack of an innovation system that may support the SATS develop-ments	Development of the radically new technologies as SATS are supported in very limited forms by EU and safety seems as a particular problem.	Errors in the definition of the safety problems, underestimation of the safety aspects, developing and using low reliable or unsafe technology	Initiating new projects (as the deployment of a radically new aircraft control system, low cost on-board instruments to support less-skilled personal pilots or the development a special low cost surveillance, traffic monitoring and control system)
1.2.	Certifi-cation	Certifica-tion rules for the personal air transpor-tation system are unclear	EASA's opinion on the development of the new personal aircraft and SATS, as well as the airworthiness requirements, the certification rules, applicable technologies are not clear. The European general aviation is slightly out of the direct focus of the EASA.	errors in the identification of the requirements, in the development of the test programs, and also in testing and certification	Discussions with the policy makers and stakeholders. Improving the existing rules, developing new regulations. Many ideas, rules and requirements could be based on the FAA and US SATS, PAV and NextGen projects. The personal aircraft controlled by less-skilled pilots might be developed as a non-acrobatic aircraft, but with enhanced load and g limitations. Certification, in case of remote controlled aircraft might fall in the UAS category.

2. Safety and security aspects of the sm / personal aircraft

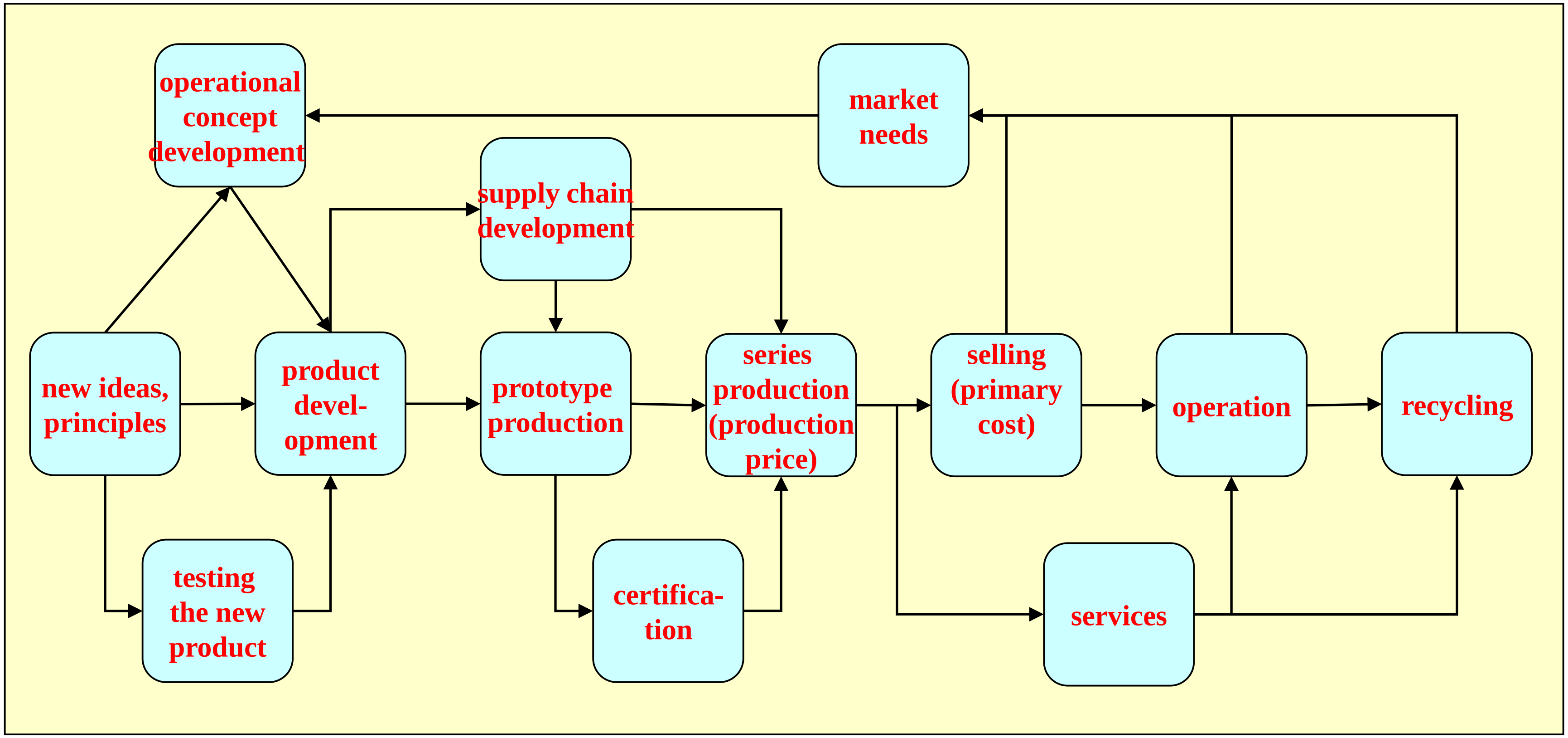
4.			Aircraft		
4.2.	Propul-sion system	The new small aircraft requires new, smart and green engines.	Because of the strict requirements on the efficiency and environmental impact, small aircraft must apply a new, smart engine.	Risks associated with the reliability of the accelerated developing new engines based on radically new technologies to reduce noise and emission.	The development, the test, and the certification of the new propulsion systems are very expensive that unacceptably increase the primary cost of small aircraft. One solution is to initiate a special international project to develop a new small, reliable and green engines for small aircraft applications. Testing of the possible new methods, rules, technologies and even the certification should be organized on the international cooperation level.
4.5.	Aircraft control	The use of the aircraft's control system by less-skilled pilots or remote pilots	The unconventional control system of PPlane may cause difficulties for the remote pilots. Automated systems are also needed to avoid the departure to critical regimes and also to perform remote control recovery from critical flight regimes.	Accidents due to poorly completed control, for example unwanted deviation in the altitude during flight speed reduction	Developed the improved car-free or H - methaform types and /or coordinated controls (see point 5.) Develop a pilot and remote pilot load monitoring system, which in emergency situation might even forbid the pilot to control the aircraft. Develop a management rules to perform control in emergency situations.

2. Safety and security aspects of the small / personal aircraft

4.			Aircraft		
4.10.	Pilot decision support system	Problems of pilot decision making.	Personal and remote (ground) pilots having more soft skill require a sophisticated decision support system.	Risks due to the reduced decision time, errors in the subjective analysis, in the evaluation of the situations, in the selected decisions, errors made by pilots loosing their orientation, etc.	Develop new methods to understand and model the decision making process of the pilots, based on the stochastic hypothesis analysis (minimization of the Baye's risk) and on the application of subjective analysis technology. Decision making should be supported with correct information on conflict detection and resolution. Orientation of remote pilots could be supported with synthetic vision systems.
4.13.	Passenger (ride) comfort	Passengers and even pilots could have problems in case of low ride control	Personal aircraft will be operated at the most turbulent altitude. Under such conditions, the aircraft's oscillation motion and the extra g load initiated by the air turbulences might be uncomfortable for the pilots and the passengers.	Risks of wrong decisions and errors made by pilots having health problem, risks of wrong passenger actions by the passengers having health problems.	Develop a manoeuvring limitation, gust effect elimination system, including (i) advanced design processes (resulting for example in smaller wing and higher wing load to have better ride comfort), and (ii) passive and active technologies (e.g. distributed system of micro sensors and actuators for flow control to reduce the aerodynamic effects from air turbulences).

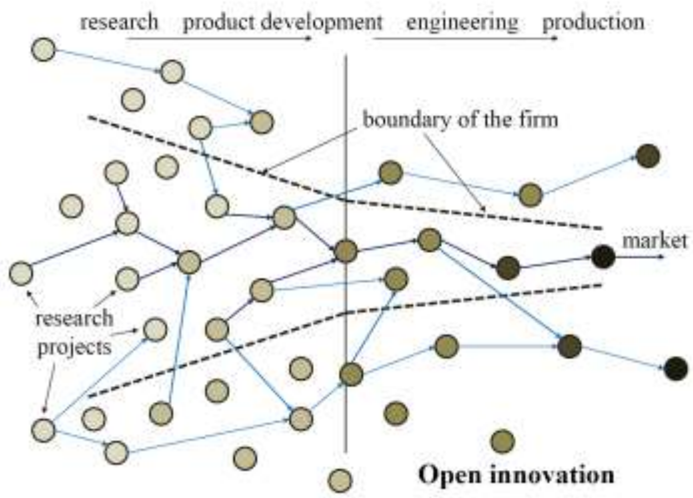
3. Safety philosophy for small aircraft development

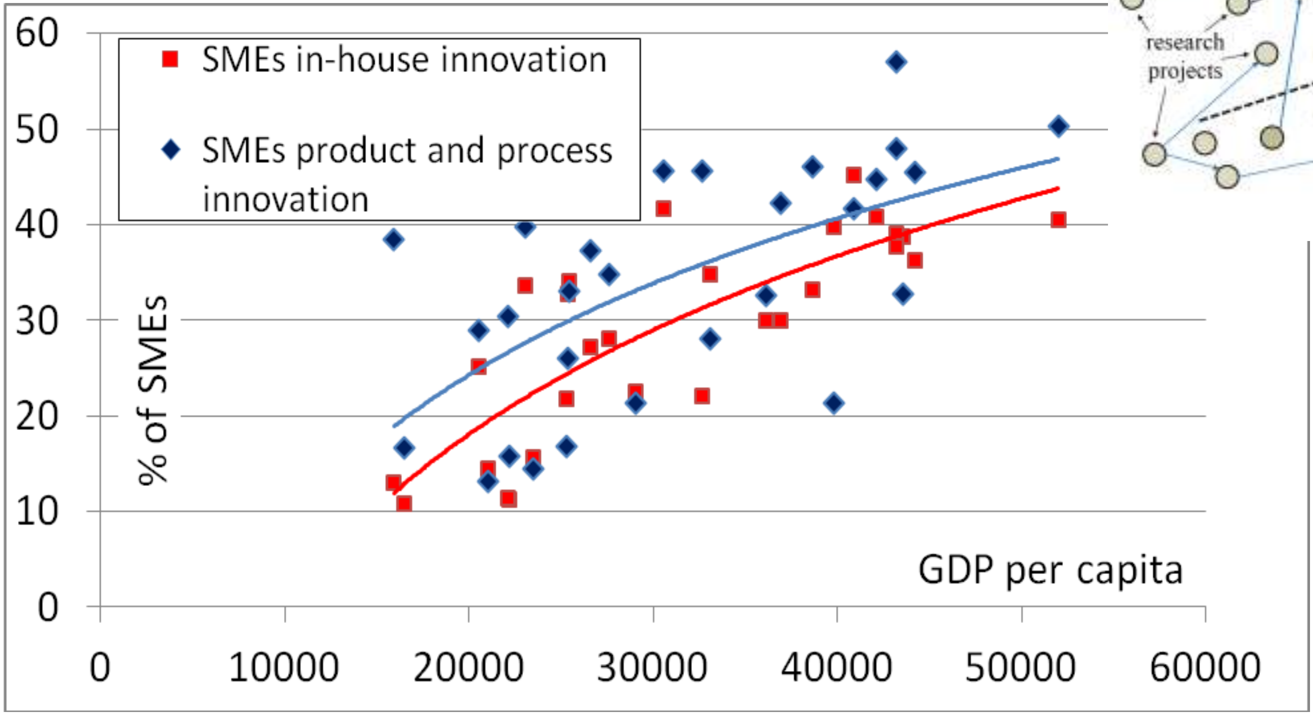
- The project defined three major key-elements:
  - set of safety requirements,
  - description of the aircraft development process and
  - introducing the outside innovation process.



3. Safety philosophy for small aircraft development

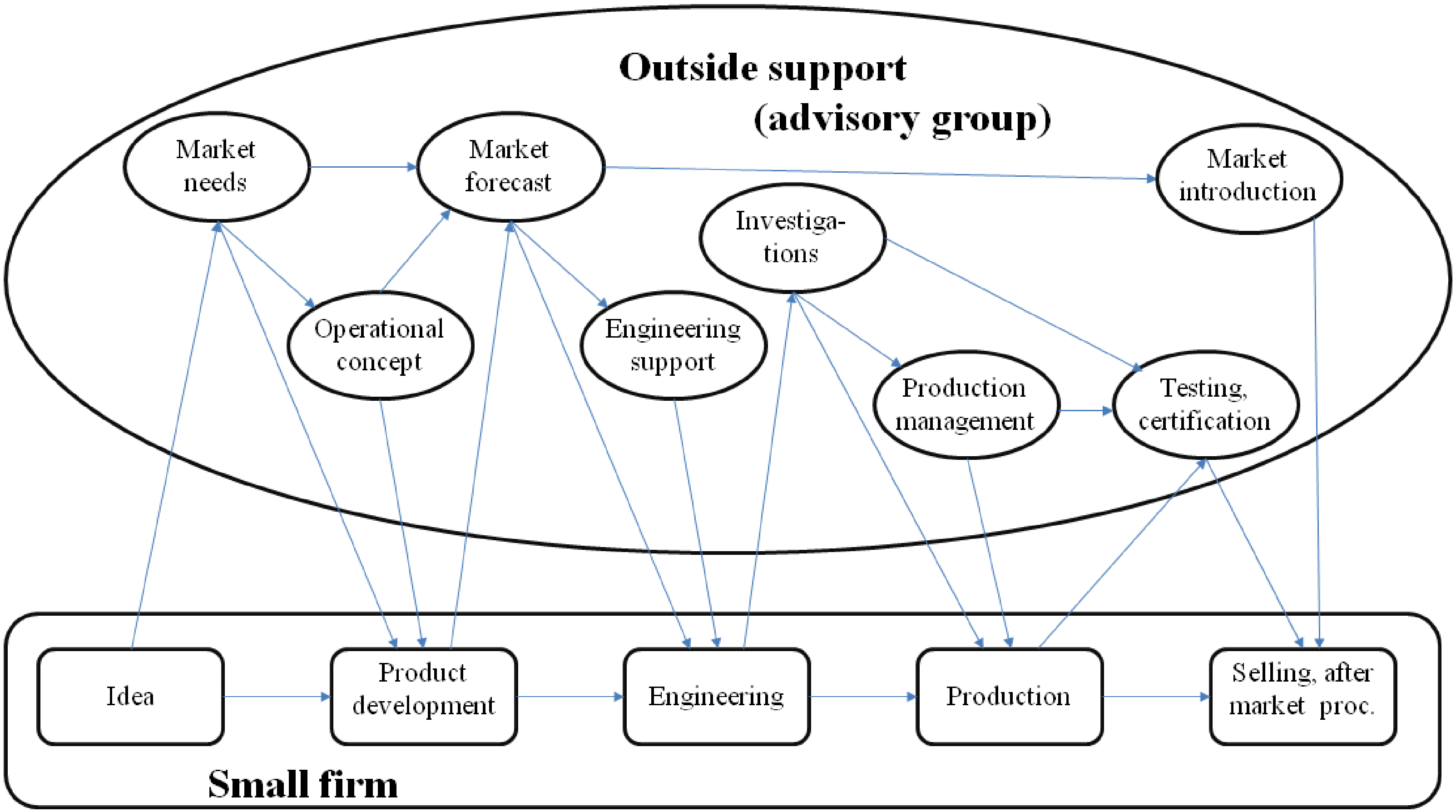
- Innovation. closed – open
- Use closed system for success!
  (EU practice)





3. Safety philosophy for small aircraft development

Outside innovation: contracted advisory team



4. Control system for personal aircraft

- The philosophical approach results to four possible solutions
  - considerable improving and automation of the control system,
  - car-free technology (originally developed for the military aircraft),
  - H-metaphor, as analogy with horse driving and
  - analogy to car driving as accepted level of technical system controlled by common persons.

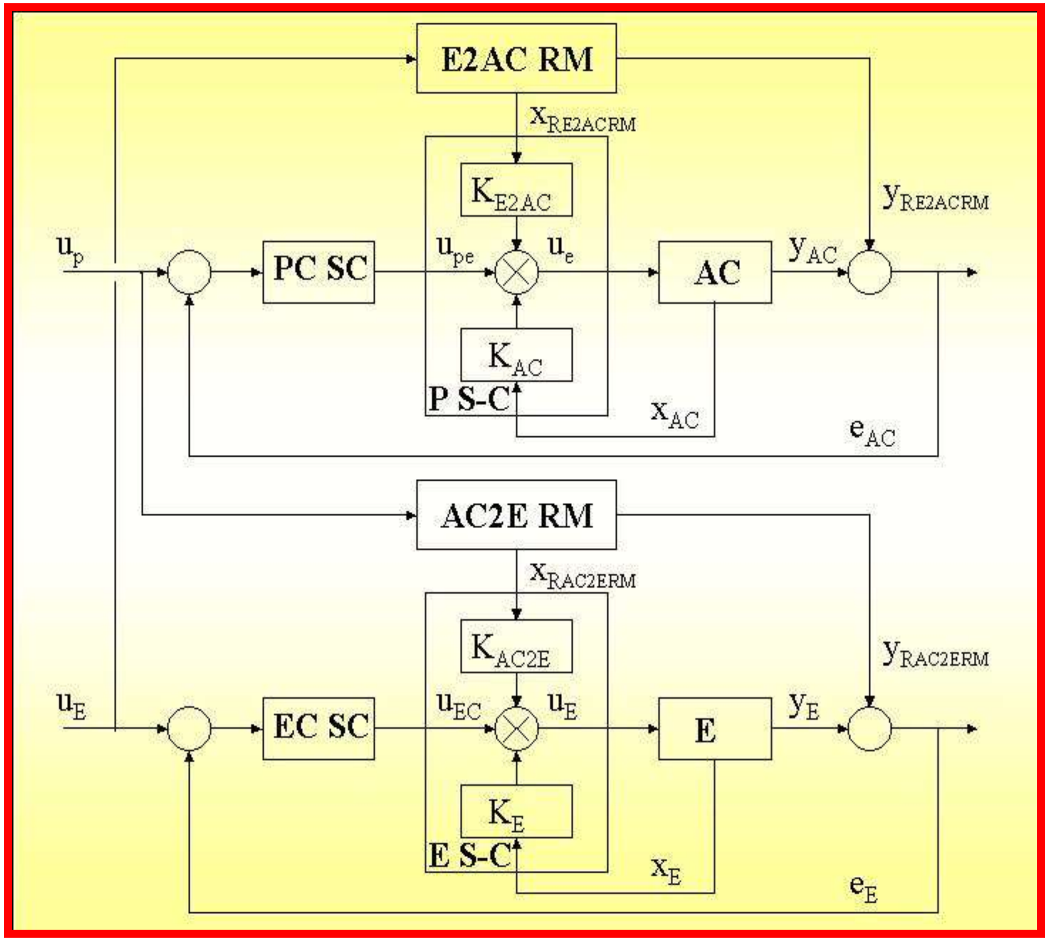
4. Control system for personal aircraft

New technologies:

- automatic adjustment of the control system
- improving the information support (a weather channel, all around vision by use of artificial screens, night vision system, 3D flight path tunnel prediction vision),
- automatic digital voice checklist (virtual co-pilot),
- pilot load condition estimation, overload detection,
- automatic detection of pilot failures,
- overtaking on pilot decision in emergency situation with leading to stabilized horizontal flight,
- switch on the distance control system, e.g. control from ground for land the aircraft in out of pilot control case,
- advanced cockpit instrumentation with developed advisory system for safe piloting,
- specially equipped airport net (with use of radically new systems even),
- radically new air traffic control system or better to say, development of the air traffic rules for personal air transportation system, etc.

4. Control system for personal aircraft

Integrated engine and elevator control



(E – engine, AC –aircraft, E2AC RM – engine to aircraft reference model, AC2E RM – aircraft to engine reference model, PC SC – pitch control servo compensator, EC SC engine control servo compensator, P S-C – pitch servo-controller, E S-C – engine servo-controller, K - feed forward and feedback x – state vector, y – output vector, u control vector, e – different vector, extra indexes: p - pitch, pe - pitch – elevator, e – elevator, EC engine compensated)

4. Control system for personal aircraft

- Simple longitudinal flight model

$$\dot{\mathbf{x}} = \mathbf{A}\mathbf{x} + \mathbf{B}\mathbf{u}$$

$$\mathbf{y} = \mathbf{C}\mathbf{x} + \mathbf{D}\mathbf{u}$$

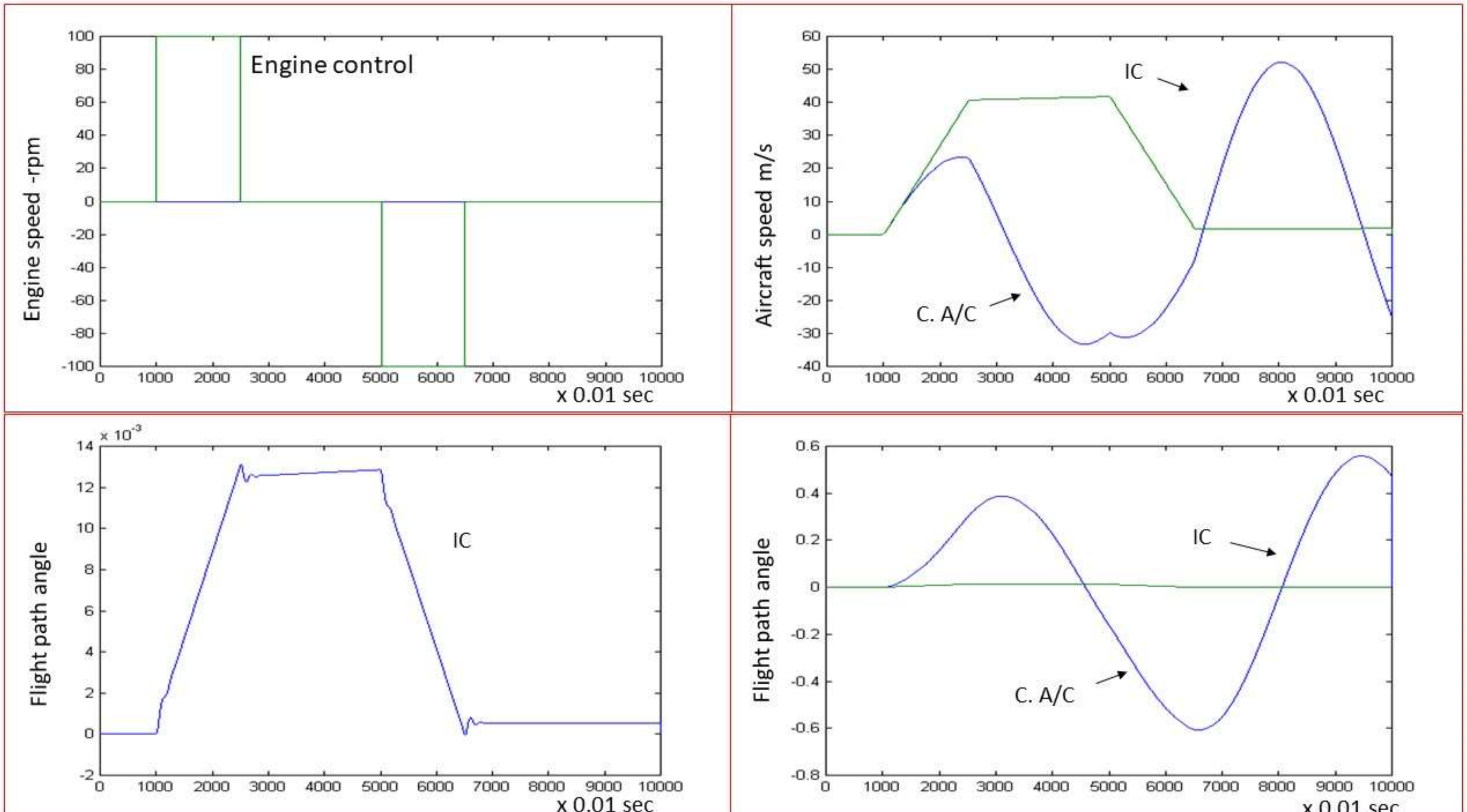
$$\underline{x} = \begin{bmatrix} \Delta V \\ \Delta \alpha \\ \Delta q \\ \Delta \vartheta \end{bmatrix} \qquad \underline{u} = \begin{bmatrix} \Delta \delta_E \\ \Delta n \end{bmatrix}$$

$$\underline{\dot{x}} = \begin{bmatrix} -0.017938 & 1.779147 & 0 & -9.81 \\ -0.006883 & -2.029455 & 0.944587 & 0 \\ 0.022188 & -5.154428 & -5.890203 & 0.010374 \\ 0 & 0 & 1 & 0 \end{bmatrix} \cdot \underline{x} + \begin{bmatrix} 0 & 17.93356 \\ -0.160444 & -0.00893 \\ -11.675895 & -1.36058 \\ 0 & 0 \end{bmatrix} \cdot \underline{u}$$

$$\underline{y} = \underline{\underline{C}} \cdot \underline{x} + \underline{\underline{D}} \cdot \underline{u} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & -1 & 0 & 1 \end{bmatrix} \cdot \begin{bmatrix} \Delta V \\ \Delta \alpha \\ \Delta q \\ \Delta \vartheta \end{bmatrix} + \begin{bmatrix} 0 & 0 \\ 0 & 0 \end{bmatrix} \cdot \begin{bmatrix} \Delta \delta_E \\ \Delta n \end{bmatrix} = \begin{bmatrix} \Delta V \\ \Delta \theta \end{bmatrix}$$

4. Control system for personal aircraft

Comparison of the integrated (IC) and conventional control (C. A/C) in case of change in engine speed,

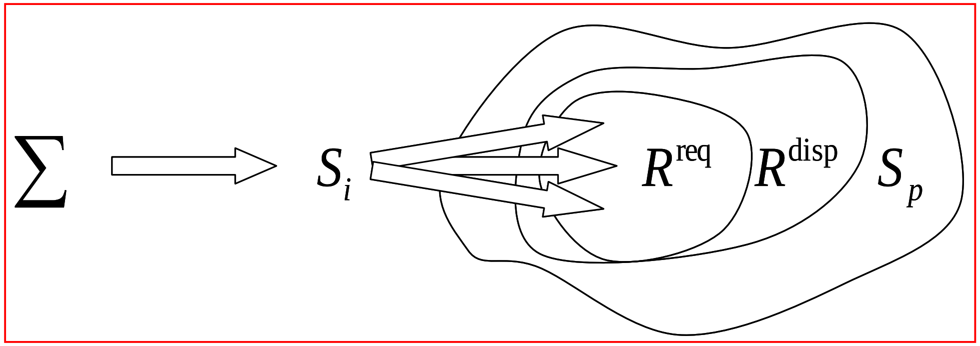


4. Control system for personal aircraft

Using the simplified control system by myCopter project

5. Pilots' subjective decision

- **The aircraft motion depends on**
  - **its (aerodynamic and flying) characteristics,**
  - **disturbances and**
  - **applied control.**



- **The pilot as subject, Σ,**
- **must identify and understand the problem (situation), S_i, then**
- **from the set of accessible or possible devices, methods and factors, S_p ,**
- **must choose the disposable resources, R^{disp},**
- **available for possible solving the identified problems, and finally**
- **must decide and apply the required resources, R^{req} .**

5. Pilots' subjective decision

- **The active resources are defined by pilot decision which and how will the passive resources be used that can be characterized by**

$$R_{\mathrm{a}}^{\mathrm{req}} = f\left(R_{\mathrm{p}}^{\mathrm{req}}\right)$$

- **or velocity transferring the passive resources into the active**

$$v_{\mathrm{a}}^{\mathrm{req}} = f_v\left(v_{\mathrm{a}}^{\mathrm{req}}\right)$$

where

$$v_{\mathrm{a}}^{\mathrm{req}} = \frac{dR_{\mathrm{a}}^{\mathrm{req}}}{dt}, \qquad v_{\mathrm{p}}^{\mathrm{req}} = \frac{dR_{\mathrm{p}}^{\mathrm{req}}}{dt},$$

and in simple case

$$f_v = \frac{\partial R_{\mathrm{a}}^{\mathrm{req}}}{\partial R_{\mathrm{p}}^{\mathrm{req}}}$$

5. Pilots' subjective decision

- **The situation chain process can be given by the following mathematical representation:**

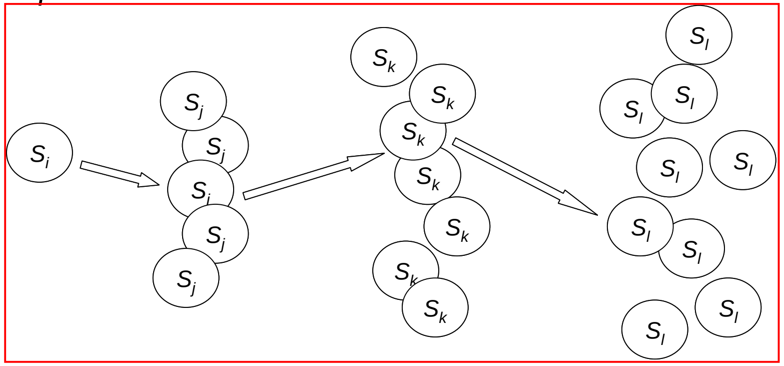
$$c(t): \quad \left(x_0, t_0, \omega\left(t_f \in [t_0, t_0+\tau]\right); R^{disp}(t_0), R^{req}(t_0), \ldots\right)$$

- **or with using the more general approach:**

$$c(t): \quad \left(P: \sigma_0(t_0) \rightarrow \sigma_j\left(t_f \in [t_0, t_0+\tau]\right) \in S_f \subset S_a, R^{disp}(t_0), R^{req}(t_0), \ldots\right)$$

where x_0 is the vector of parameters at the initial (actually starting) state at t_0 time; σ is the state of the system in the given time; τ is the available time that is enough for transition of state vector into the set of ω not later then $[t_0, t_0+\tau]$; *P* are the problems how to transit the system from the initial state into the one of the possible state $S_f \subset S_a$ not later then τ .

- **This is a situation chain process**



5. Pilots' subjective decision

- **Required time for decision**

$$t^{req} = t_{ue}^{req}(\sigma_k) + t_{dec}^{req}(S_a) + t_{react}^{req}(\sigma_k, S_a)$$

σ_k **possible situations**

- **The subjective factor of pilots can be assumed by introduction the ratio of the required and disposable resources:**

$$\bar{r}_k = \frac{R^{req}(\sigma_k)}{R^{disp}(\sigma_k)} = \frac{t^{req}(\sigma_k)}{t^{disp}(\sigma_k)}$$

- **with using of this factor an endogenous index can be defined as**

$$\varepsilon_k(\sigma_k) = \frac{\bar{r}_k}{1-\bar{r}_k} = \frac{\tau^{req}(\sigma_k)}{\tau^{disp}(\sigma_k) - \tau^{req}(\sigma_k)}$$

5. Pilots' subjective decision

- **If the subjective probability of situation, $P(\sigma_k)$, then the distribution of the best alternatives from the negative point of view ,**

$$p(\sigma_k)=\frac{P^{-\alpha}(\sigma_k)e^{-\beta\varepsilon_k(\sigma_k)}}{\sum_{q=1}^{2}P^{-\alpha}(\sigma_q)e^{-\beta\varepsilon_k(\sigma_q)}}$$

- **can be derived as a solution of the functional:**

$$\Phi_p=-\sum_{k=1}^{N}p(\sigma_k)\ln p(\sigma_k)-\beta\sum_{k=1}^{N}p(\sigma_k)\varepsilon_k(\sigma_k)-\alpha\sum_{k=1}^{N}p(\sigma_k)\ln P(\sigma_k)+\gamma\sum_{k=1}^{N}p(\sigma_k)$$

- **which includes the logarithm of the subjective probability in to the structure of the efficiency function:**

$$\eta_p=-\sum_{k=1}^{N}(\alpha\ln P(\sigma_k)+\beta\varepsilon(\sigma_k))p(\sigma_k)$$

- **If** $\bar{t}_k=\frac{t^{req}(\sigma_k)}{t^{disp}(\sigma_k)}\rightarrow 0$ **then** $P(\sigma_k)$ **, only, and if** $\bar{t}_k\rightarrow 1$ **the 0**

5. Pilots' subjective decision

- **A modified Lorenz attractor:**

$$\frac{dX}{dt} = aY - bZ - hX^2 + f(t);$$

$$\frac{dY}{dt} = -Y - XZ + cX - mY^2;$$

$$\frac{dZ}{dt} = XY - dZ - nZ^2.$$

where *a*, *b*, *c*, *d*, *h*, *m*, *n* are the constants and *f* takes into account the disturbance. (In case of *h*=*m*=*n*=0 and *f(t)*=0 the model turns into the classic form of Lorenz attractor.)

In this model the coordinates of the attractors can be defined as X - is a inner endogenous parameter, and

5. Pilots' subjective decision

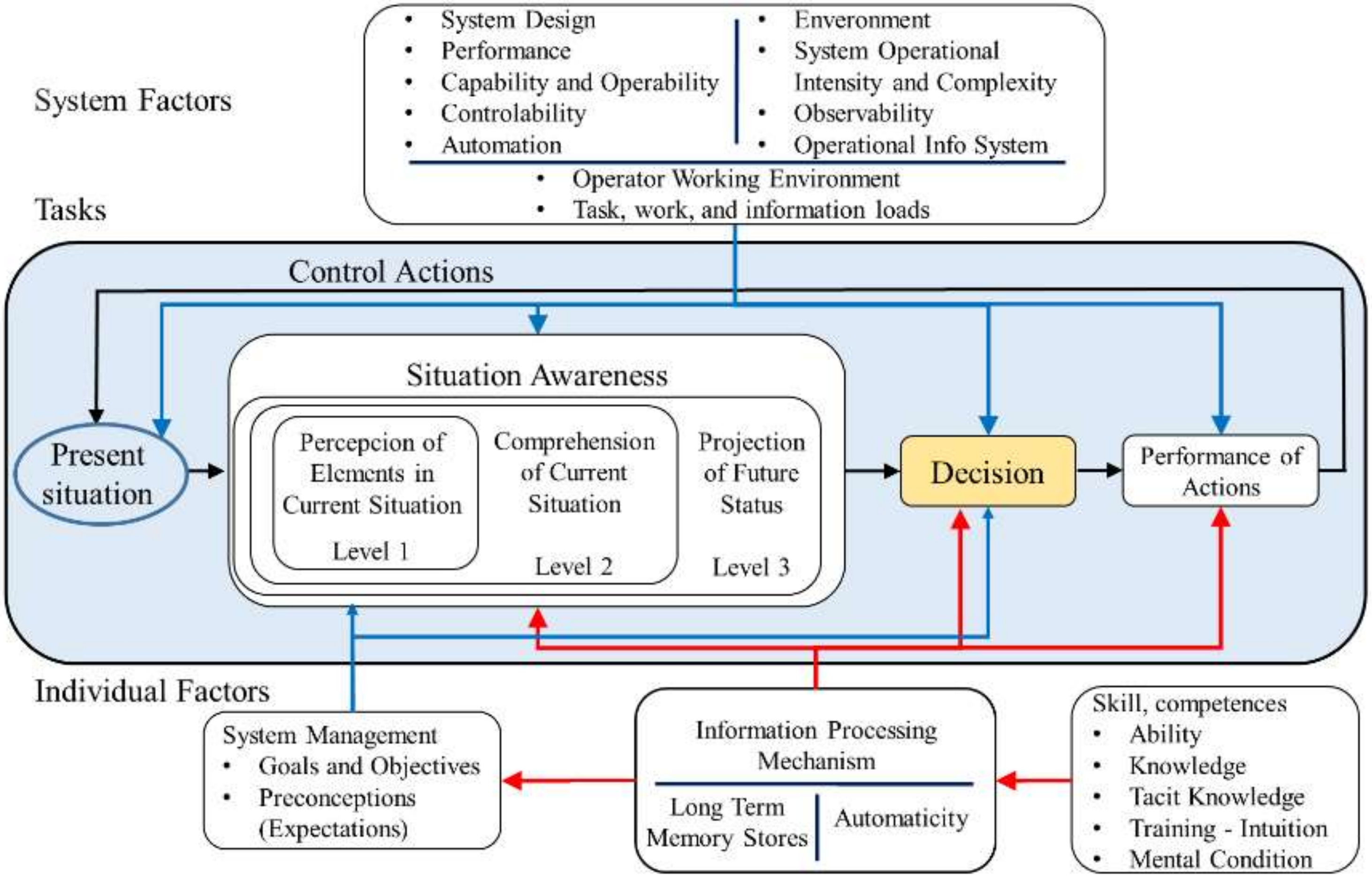
➢ From the results of the using the developed model, we can make an interesting conclusion, in case of appearing any problem at the final part of descent, the common airliner pilots need time for decision about three times more then the well practice.

➢ The developed model can be applied to the small aircraft and
➢ to cases when the aircraft are controlled by the less-skilled pilots.

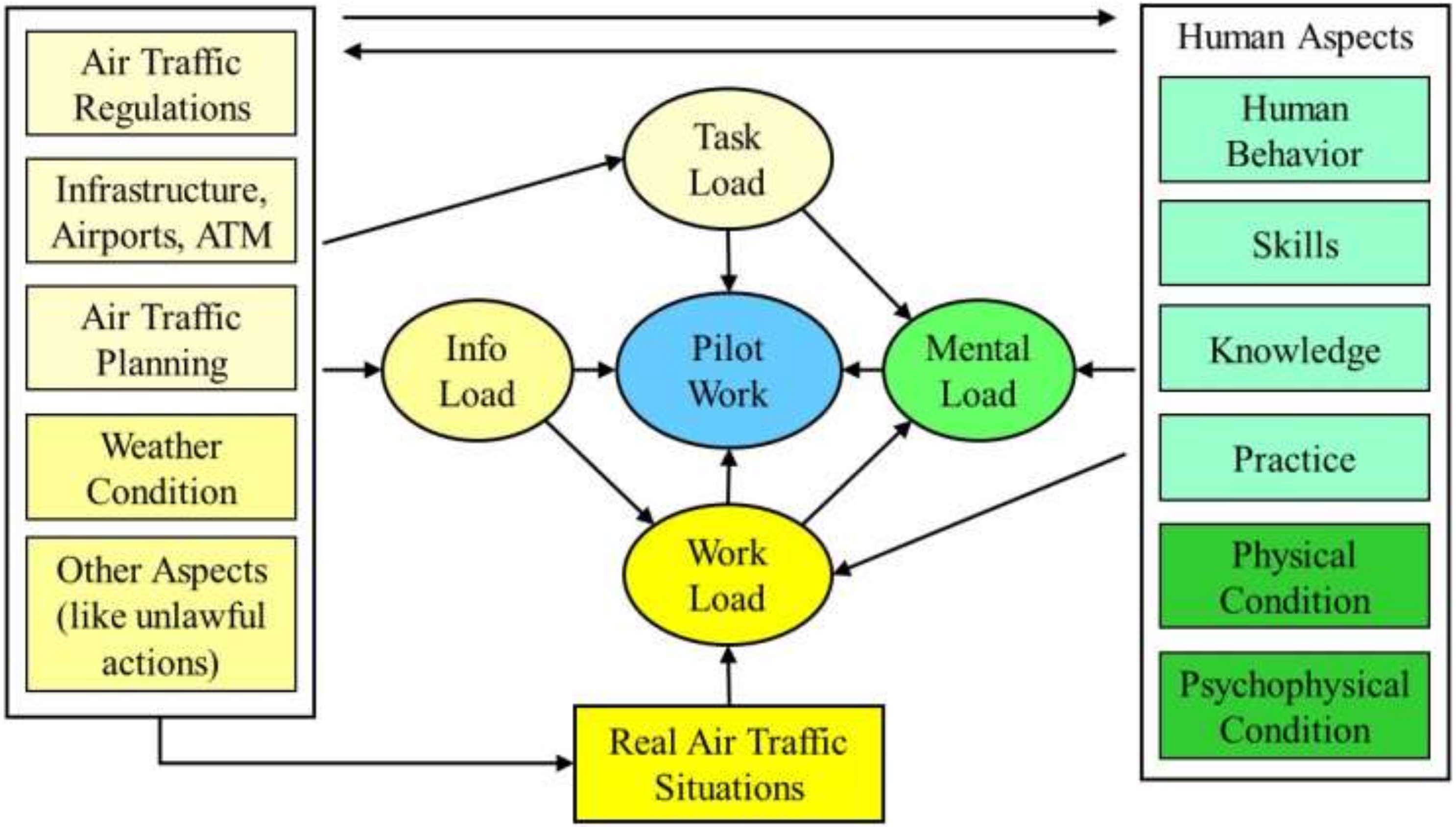
➢ From the Figures, the descent velocity for the small aircraft can be calculated as about 100 km/h for the pilots as airliner common pilots
➢ and in case, if the pilots are less-skilled (accepting the differences between the less-skilled and common pilots equals to the difference between the common and well-trained pilots) the descent velocity of the small airc raft can not be greater then 75 Km/h.

6. Pilot load model monitoring

➢ Situation awareness process



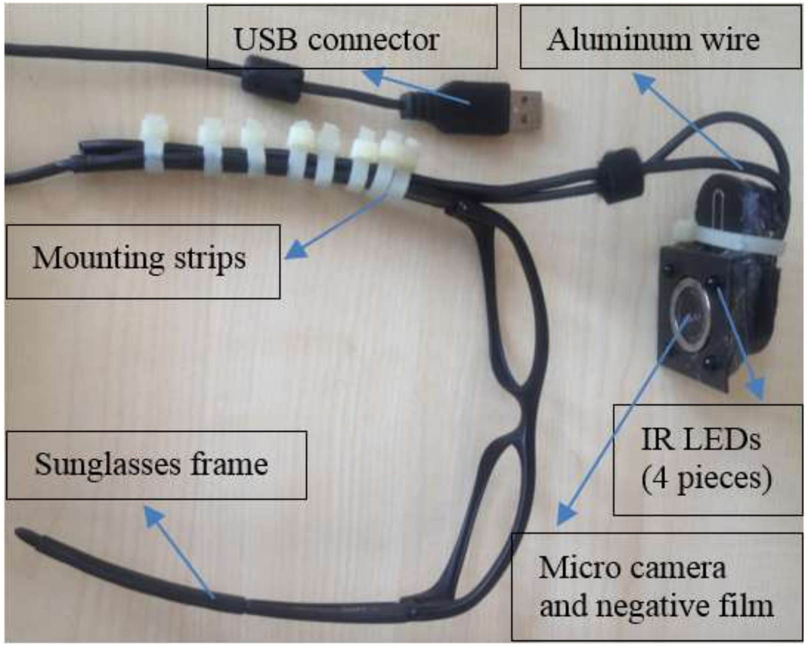
6. Pilot load model monitoring



6. Pilot load model monitoring

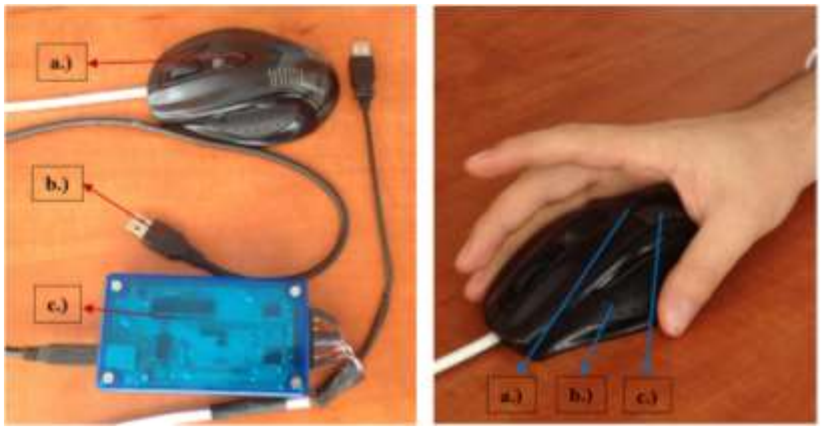
Applicability:

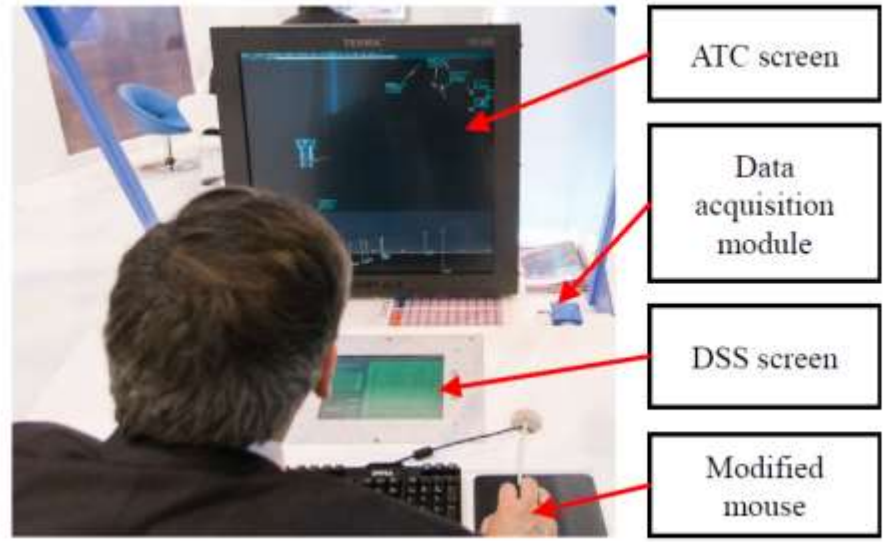
- training the pilots (operators),
- monitoring the pilot's loads
- using in control

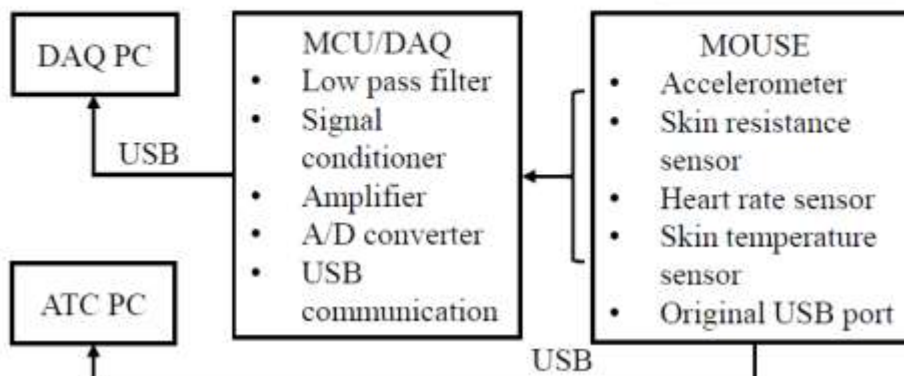


6. Pilot load model monitoring

- Developing new sensors (as skin resistance) and
- their integration into the working environment







Bio-electric measurements

- electromyography (EMG),
- electroencephalography (EEG),
- electrocardiography (ECG or EKG) and
- heart period variance (HPV).

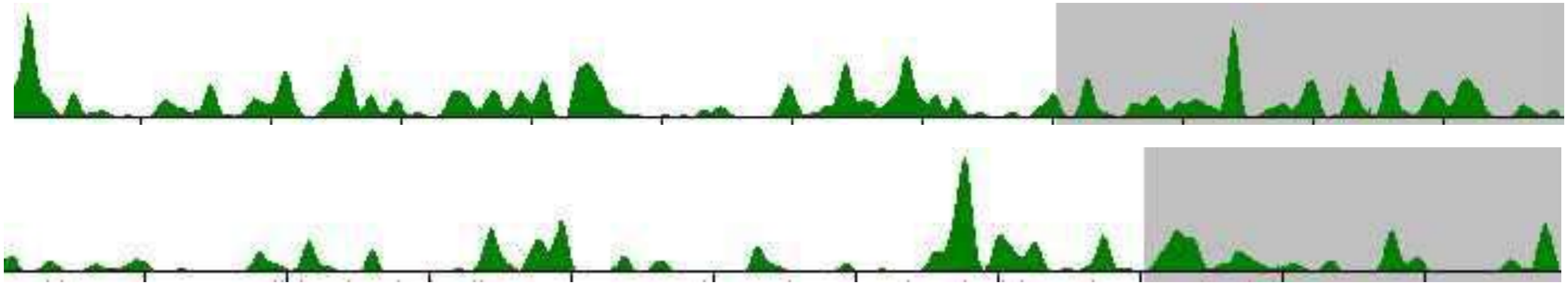
placement of the electrodes

measurements in the flight simulator

6. Pilot load model monitoring

placement of the EKG electrodes

preparing the flight simulator for measurement



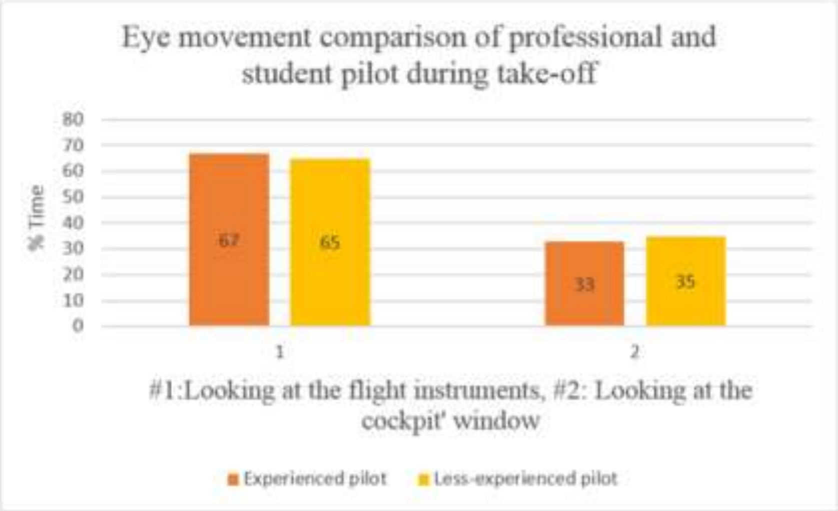
The HPV record of a pilot: upper fig. in case of using side stick, lower fig. in case of using control yoke

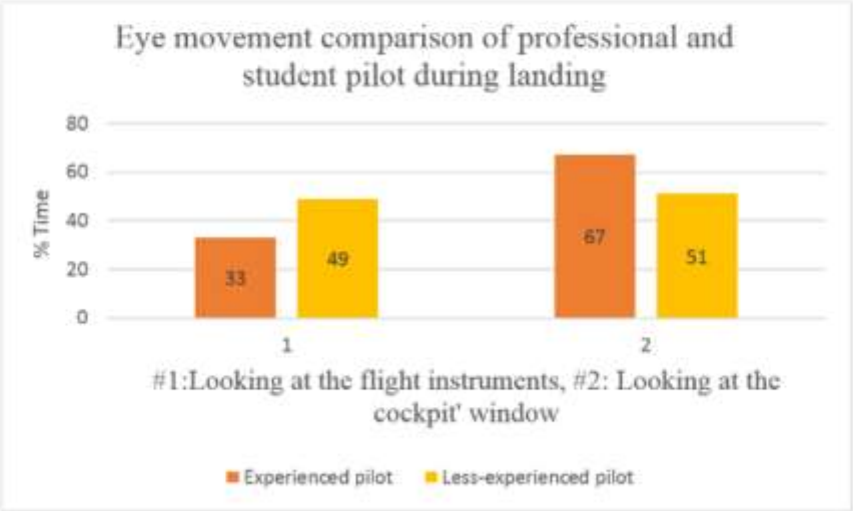
6. Pilot load model monitoring

- Eye movement, attention target measurements

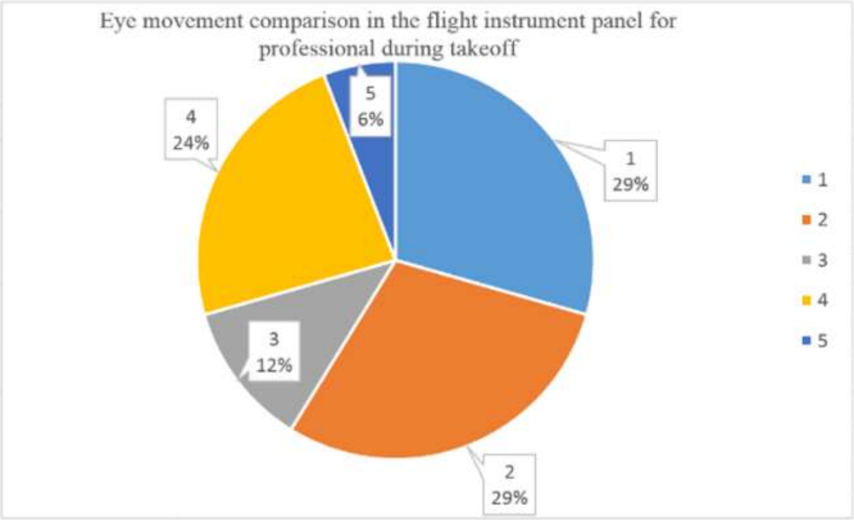
take-off

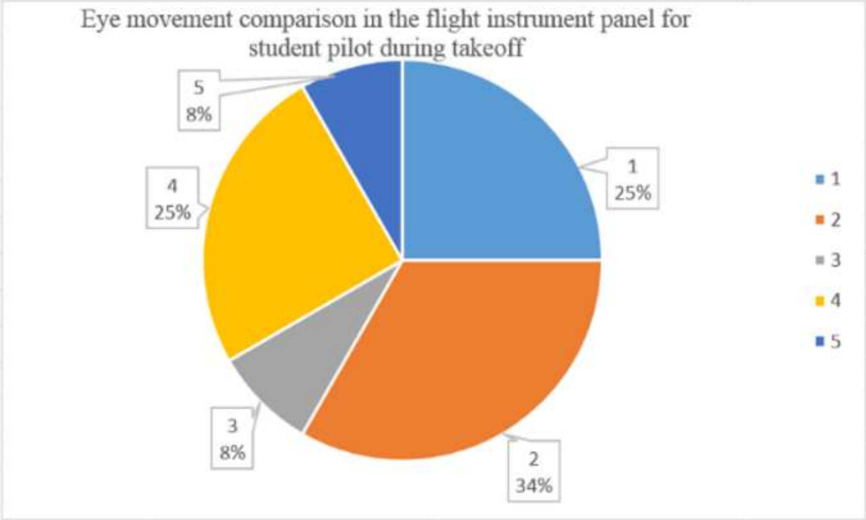
final approach

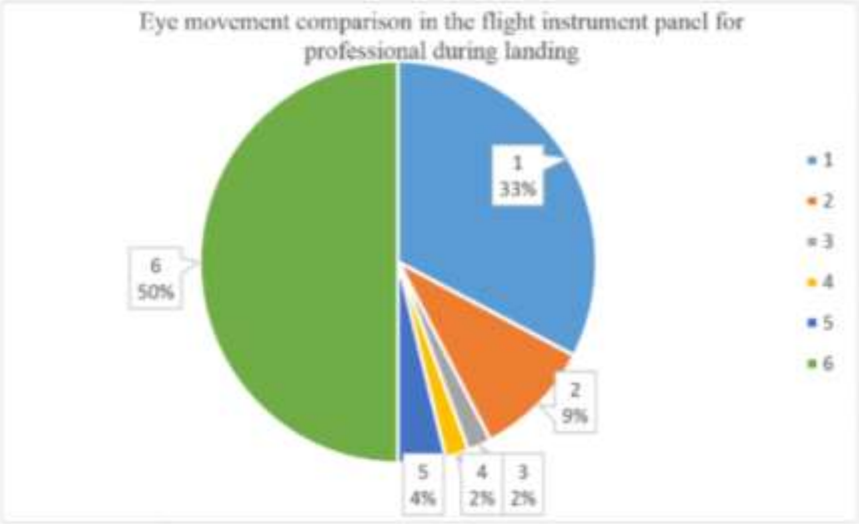


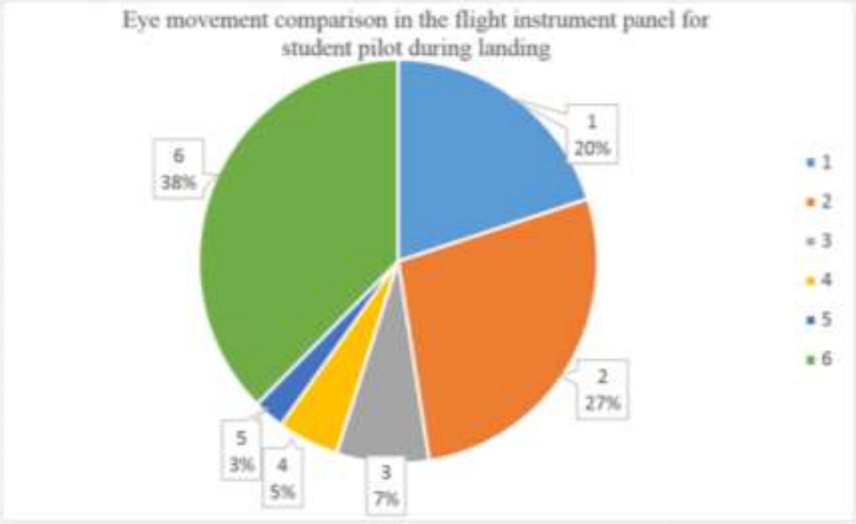


6. Pilot load model monitoring









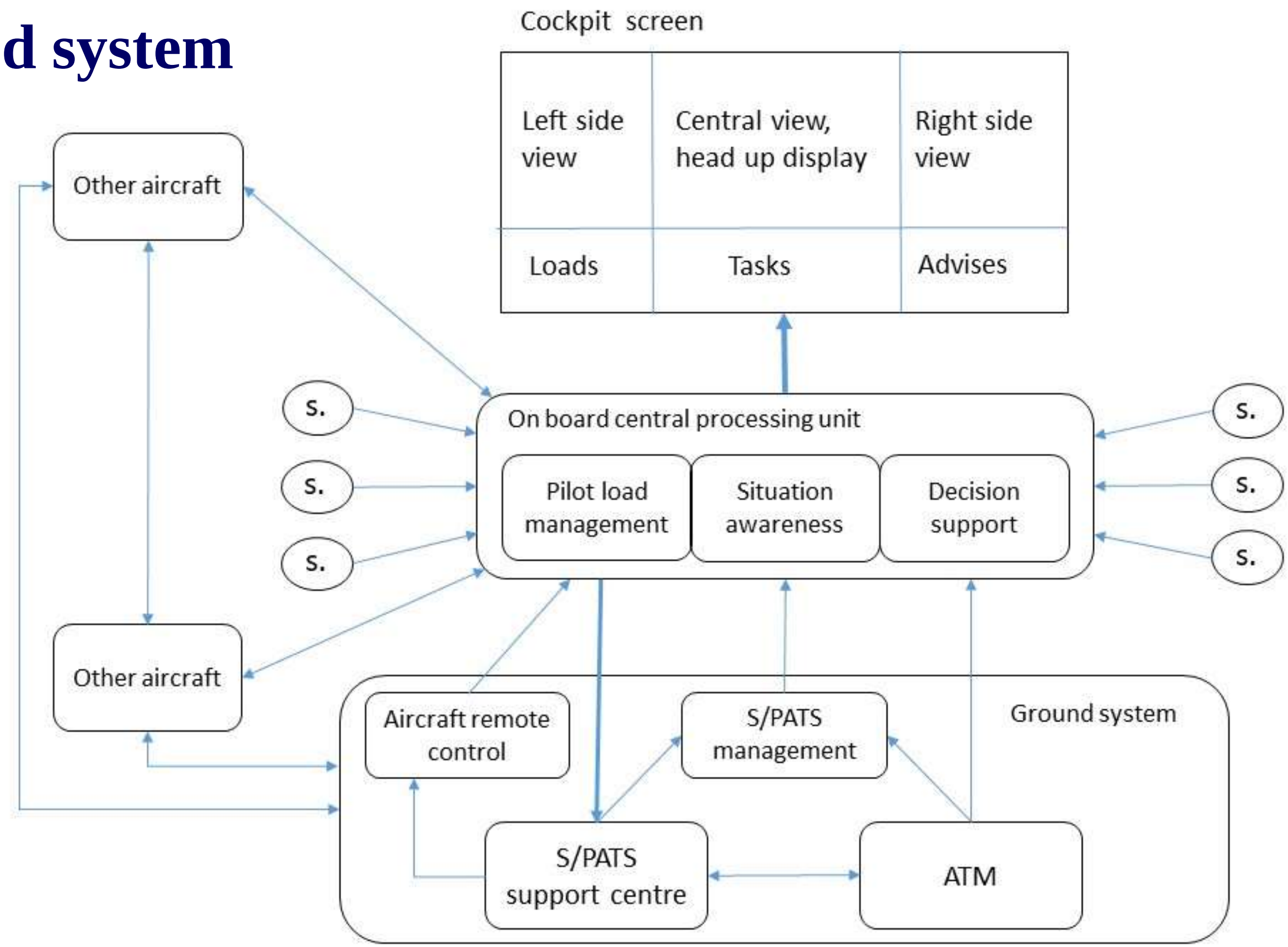
7. Pilot decision support system

Many different technologies might be applied

For example the future cockpit for pilot supporting system:

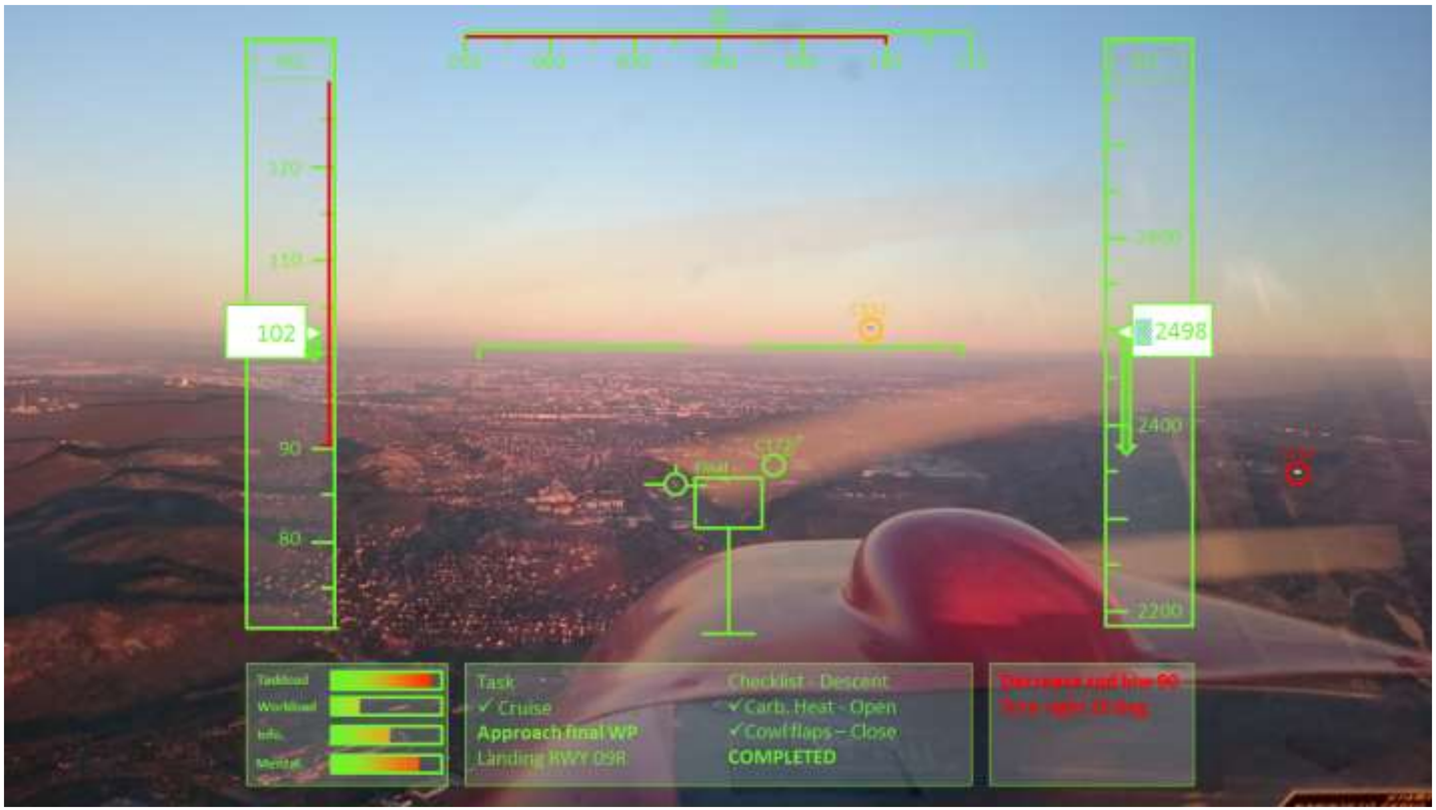
- the developed cockpit could contain up to 6 colour displays for the following tasks :
  - digital reproduction of the basic flight instruments,
  - coloured macro and micro weather visualization, 3d all around vision with location of wind-shear, lightning or storm cells, etc.;
- flight advisory system with
  - day – night visualization of the aircraft surroundings,
  - artificial vision generated by advanced sensors, digital terrain databases, accurate geo-positioning, all around 3D picture of terrain, obstacles, runway, etc.
  - 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 like information about the traffic situation

Functional model of the recommended system



7. Pilot decision support system

Possible screen of the decision support system



Conclusions

- This paper overviewed the actions and summarize the results of
  - (i) safety aspects analysis of the small / personal aircraft, air transport system,
  - (ii) introduced the methods of subjective analysis to investigation and modelling the pilot decision process,
  - (iii) created an improved pilot load model and load management, and
  - (iv) defined the developing (less-skilled) pilot supporting system.

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Original and simplified solution of control for personal aircraft

Take-off

Landing

Sex on the board

Call to system engineer