Moscow aviation institute

Pilot – aircraft system design provided the necessary level of flight safety

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International seminar: “Flight safety: vehicle, pilot, environment – 2012”

«Since the controlled motion of airplane is a combination of airplane and pilot characteristics it is necessary to know something about both airplane and pilot characteristics before a satisfactory job of airplane design can be done».

Koppen, O.C., 1940

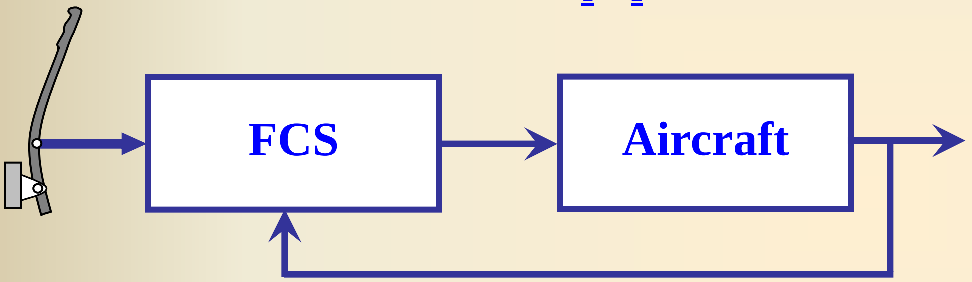
The design of modern flight control systems defined the controlled motion of airplane, doesn’t take into account the human factor practically.

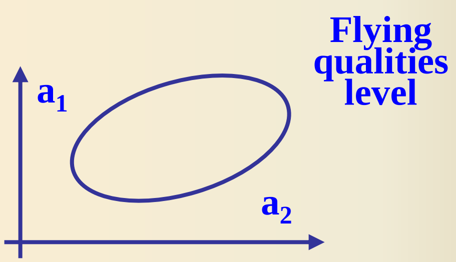
Requirements in flight control systems (FCS) design

CRITERIA:
- effectiveness in fulfillment of piloting tasks (accuracy)
- flight safety

Criteria used now for flight control system design suppose that

a. Effectiveness is provided by flying qualities corresponding to the specific boundary of Aircraft + Flight Control System parameters f(a_1, a_2, …)

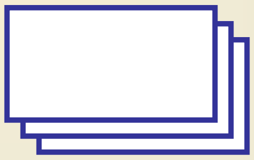




в. Flight safety is provided by fixed reliability of aircraft subsystem

1. probability of accident for passenger airplanes $p = 10^{-9}$

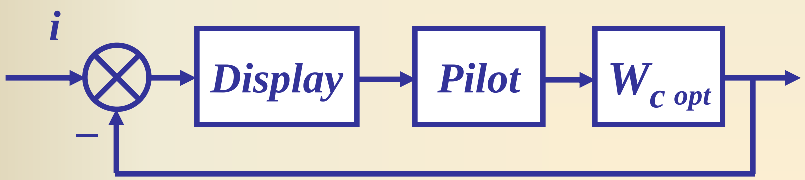
aircraft subsystems

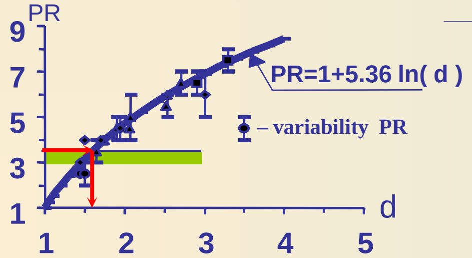


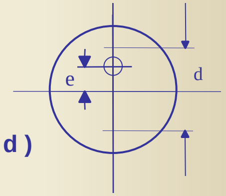
2. Accepted probability of subsystem (p_1) leading to transmit from 1 flying qualities level to the second has to be $p_1 \leq 10^{-2}$

IS IT IMPORTANT TO TAKE INTO ACCOUNT THE HUMAN FACTOR IN FCS DESIGN?

1. Flying qualities optimization with taking into account human factor







Flying qualities optimization:

- ***improves accuracy***
- ***decreases pilot work load considerably***

2. Pilot’s errors are the reasons of – 60 – 80 % accidents

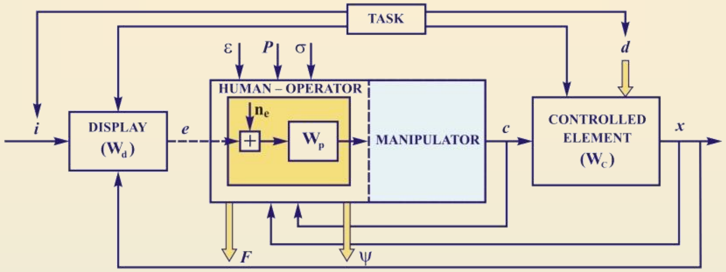
- **errors due to abnormal pilot actions not provoked by piloting conditions**
- **errors due to conditions provoking their appearance**

THE CONDITIONS PROVOKING PILOT'S ERRORS

- variability of pilot actions
- unsatisfactory aircraft flying qualities
- flight control subsystems failure leading to deterioration of flying qualities
- sudden change of pilot's motivation
- sharp change of atmosphere turbulence
- quick change of task variable or piloting task …

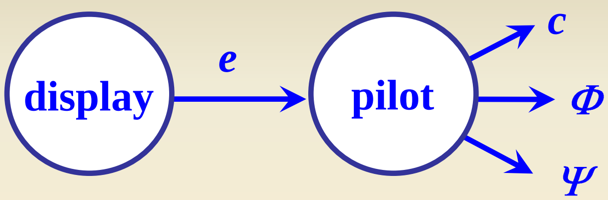
CONSEQUENCE:

- conflict between pilot's action and task variables in pilot–aircraft closed–loop system



- deterioration of flying qualities
- degradation of flight safety

PILOT RESPONSES AND THEIR CHARACTERISTICS

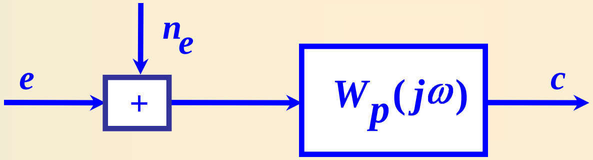


$c = f(e)$ – control

Ψ – psychophysiological

Φ – phisiological

Control response characteristics



$W_p(j\omega)$ – pilot describing function

$n_e(S_{n_e n_e})$ – remnant, (spectral density of remnant)

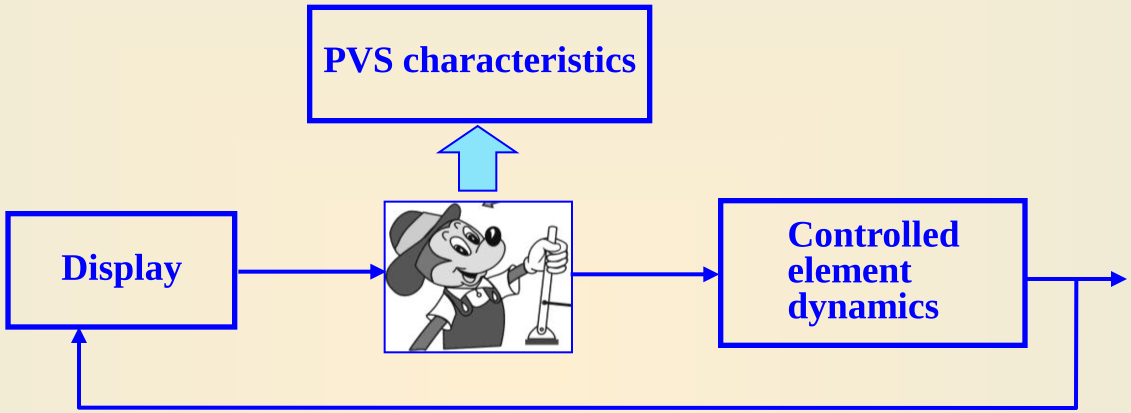
PSYCHOPHYSIOLOGICAL CHARACTERISTICS

- Pilot rating scales (CHPR, PIOR)

- Pilot workload

Pilot control response characteristics investigation

- mathematical modeling;
- experimental investigation.



Math modeling

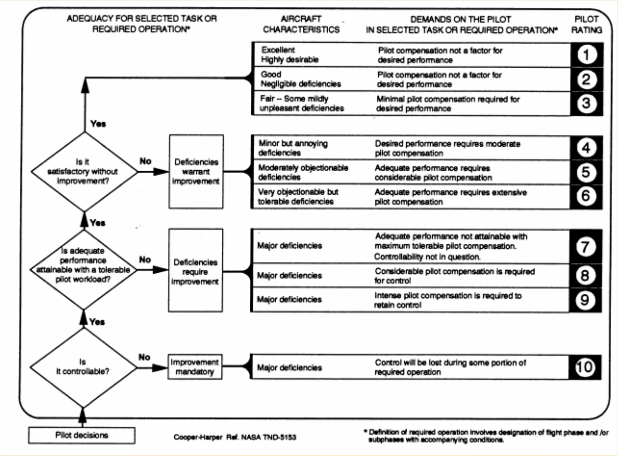
- Structural model
- OCM
- Neural network model

Experimental investigations

- $W_p(j\omega), S_{n_e n_e}(\omega)$
- $W_{OL}, W_{CL}, \ldots$

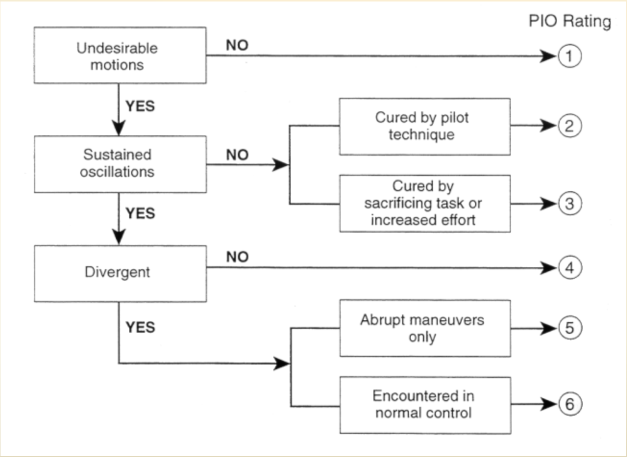
PILOT OPINION SCALES

Cooper – Harper scale



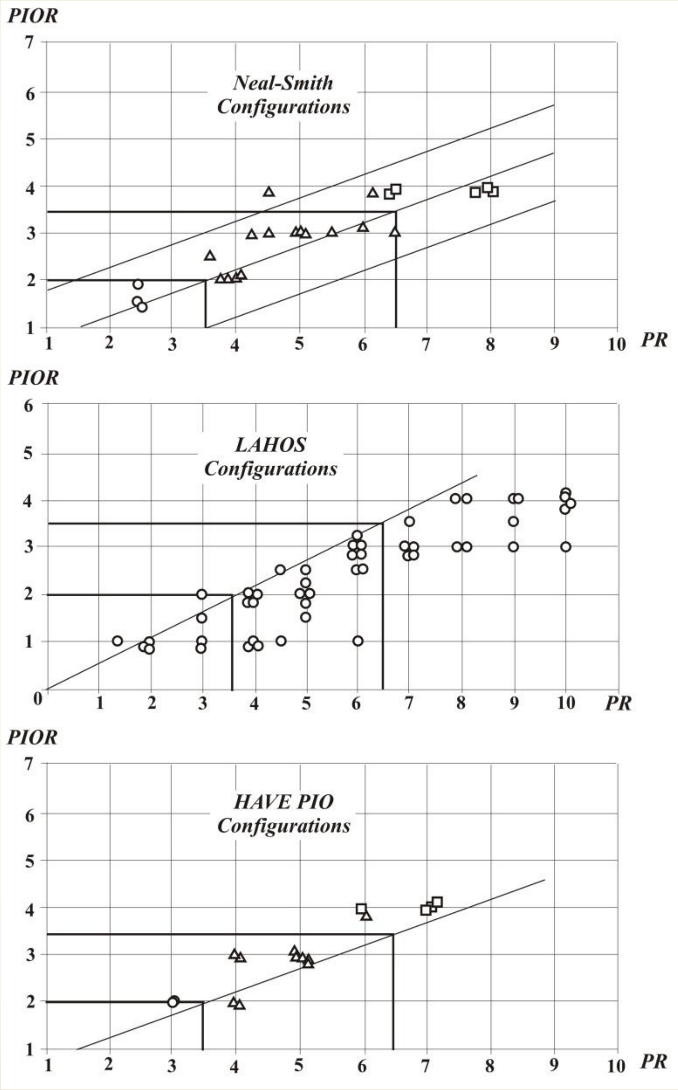
10 (accident)

Pilot–induced oscillation scale



6 (accident)

Relationship between CHPR and PIOR



PIOR = 0,5PR + 0,25

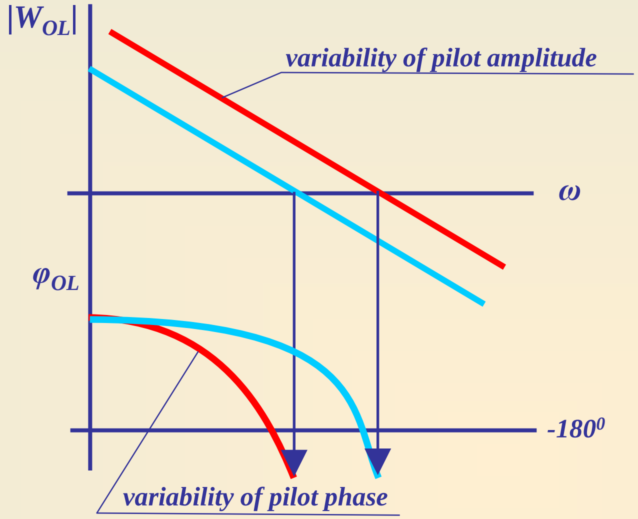
PR = 3,5 ⇨ ***PIOR = 2***

PR = 6,5 ⇨ ***PIOR = 3,5***

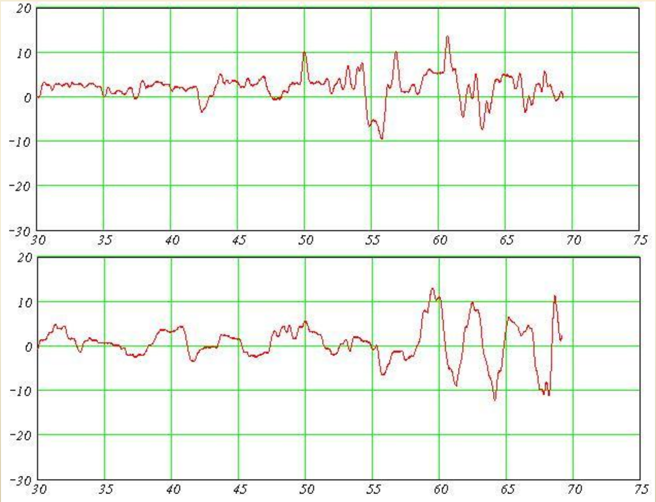
PR = 9,5 ⇨ ***PIOR = 5,0***

PILOT ACTION VARIABILITY

1. Probability of temporary loss of stability



2. Pilot actions variability → pilot rating variability

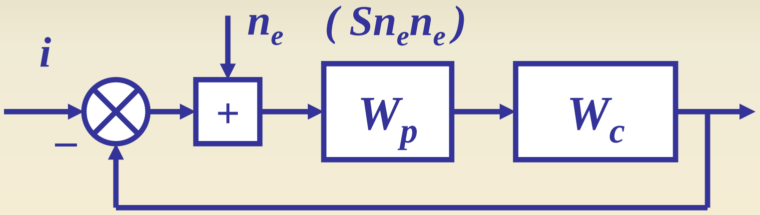


PR **= 6**

Experiments with the same dynamic configuration

PR **= 9**

Influence of flying qualities on PILOT VEHICLE SYSTEM characteristics



1. Stationary task, $W_c \neq f(t)$

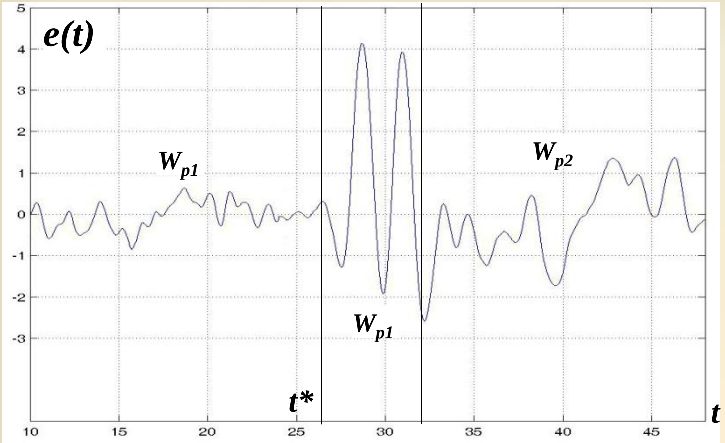
$$W_{c_1} \Rightarrow W_{c_2} \quad PR_1 < PR_2$$

- **increase of pilot compensation ($T_L \uparrow$)**
- **decrease of amplitude (phase) margin (*s*) of open–loop system ($(\Delta\varphi, \Delta L)\downarrow$)**
- **increase of resonance peak ($r \uparrow$)**
- **increase of remnant ($Sn_en_e \uparrow$)**

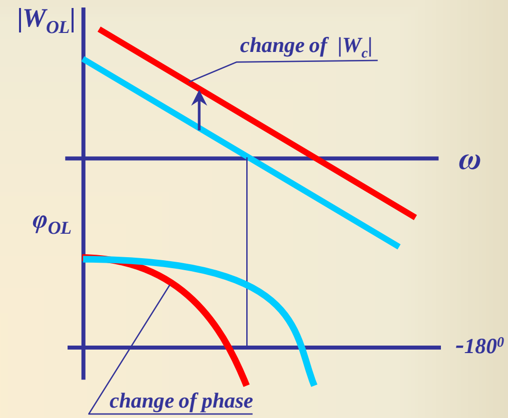
Probability of temporary loss of stability increases

2. Unstationary task, $W_c = f(t)$

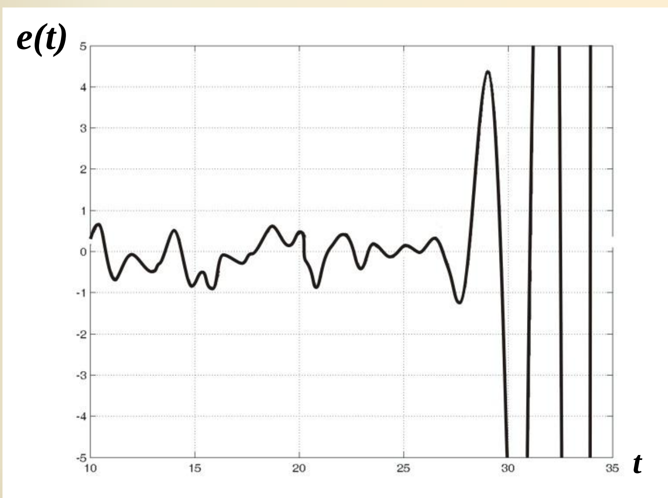
a. Failure not leading to exposition of nonlinear features of FCS



Conservation of stable process with worse flying qualities is possible

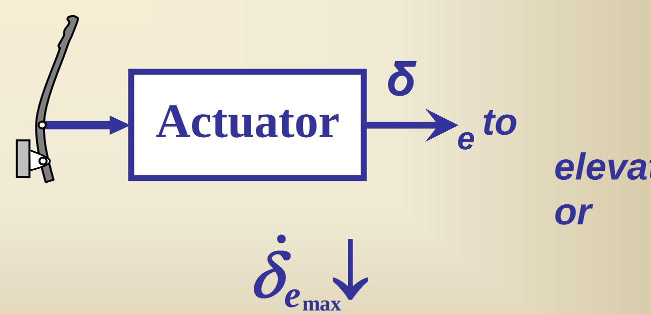


b. Failure leading to exposition of nonlinear features of FCS



Development of unstable process in pilot–vehicle system

Experiments for statically unstable aircraft



TAKING INTO ACCOUNT PILOT'S ERRORS IN EVALUATION OF FLYING QUALITIES AND FLIGHT CONTROL SYSTEM DESIGH

Postulates:

- **Accident is defined in terms of probability of subsystem failure leading to accident for one flight hour**
- **Pilot is an element (subsystem) of pilot–aircraft system**

Suggestion:

To apply to a pilot the same requirements which are used for reliability of flight control system

Failure of flight control system elements

Pilot errors

Increase of probability of accident

RELATIONSHIP BETWEEN AIRCRAFT FQ AND FLIGHT SAFETY

Variability of pilot action → variability of *PR*

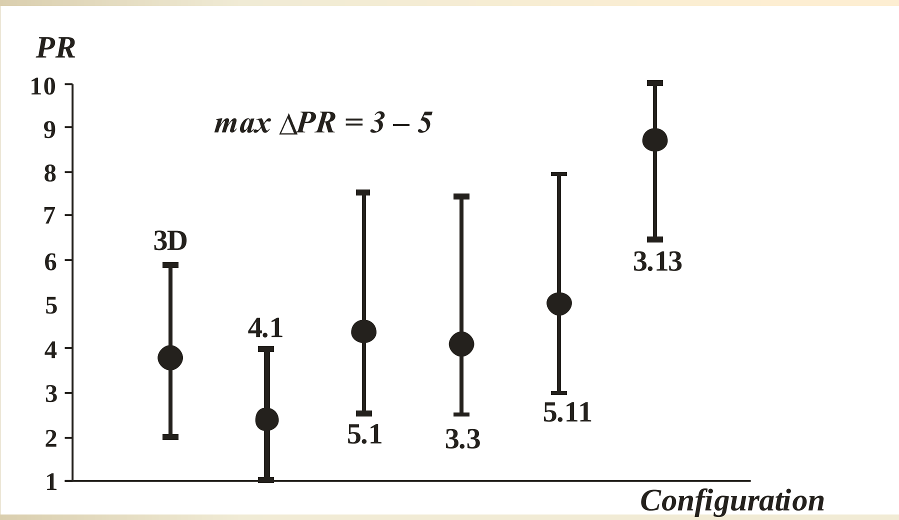
Cooper–Harper scale

Catastrophic (accident) case. Control is impossible

1 — **Deterioration of flying qualities** → **10**

Probability of accident is low

Probability of accident is high



<u>*PR* – random value</u>

Peculiarities of random value *PR*:

- ***PR*** **– whole number**
- ***PR*** **– a number contained in the limit set of numbers**

Conclusion: Random value *PR* has to be characterized by binomial law

THE TECHNIQUE ON FLYING QUALITIES DEFINITION WITH TAKING INTO ACCOUNT THE PROBABILITY OF ACCIDENT

Binomial law

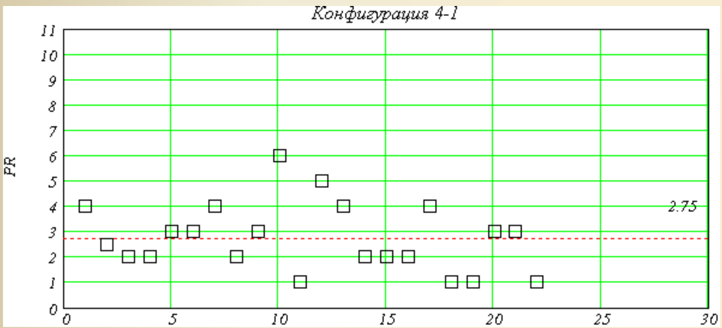
$$p(\overline{PR}) = C_9^{PR-1} p^{PR-1} (1-p)^{10-PR}$$

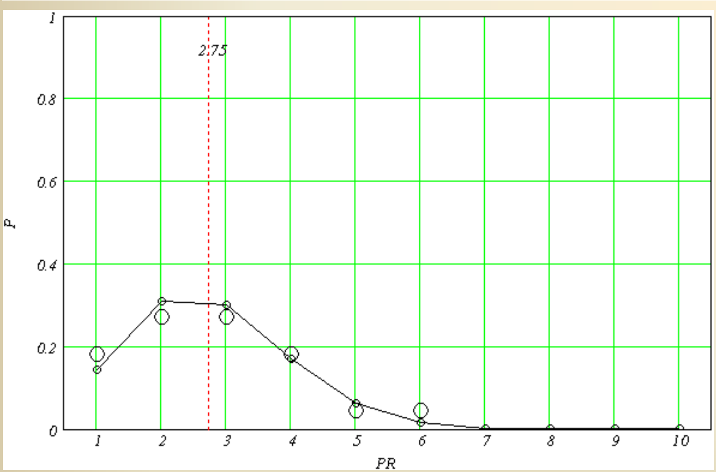
$$C_9^{PR-1} = \frac{9\,!}{(PR-1)\,!\,(10-PR)\,!} \qquad p = \frac{\overline{PR}-1}{9}$$

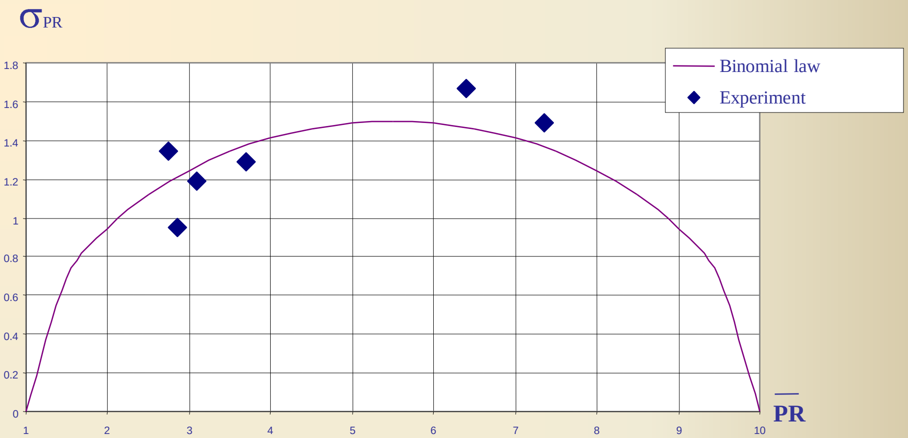
$$\sigma_{PR} = \sqrt{\frac{(\overline{PR}-1)(10-\overline{PR})}{9}}$$

ERIMENTAL TEST ON POSSIBILITY TO USE BINOMIAL LAW FOR DESCRIPTION OF PILOT RATING *P(PR)*

Configurations	2.1	4.1	3.8	3.8	3.12	5.10	всего
Number of experiments	22	22	24	20	19	17	124
$\overline{PR}$	2.86	2.75	3.1	3.7	6.4	7.35	





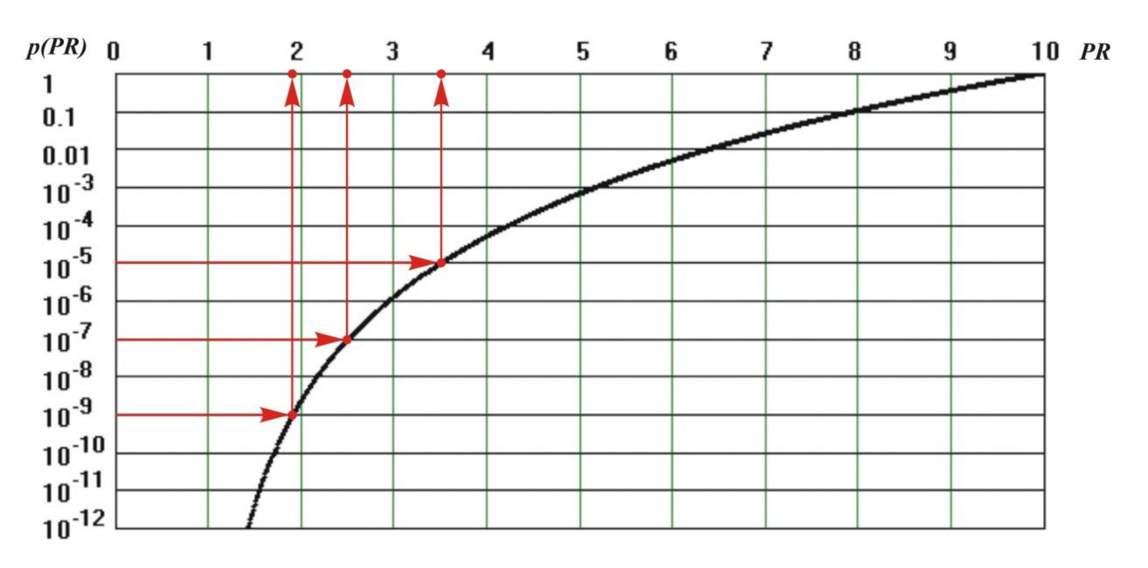


TASK: To define probability $p(\overline{PR})$ of catastrophic (accident) case (PR = 10) for aircraft with flying qualities characterized by $PR = \overline{PR}$ by use of binomial law

AGREEMENT BETWEEN REQUIREMENTS TO FLYING QUALITIES AND GUARANTEED LEVEL OF FLIGHT SAFETY

1. Definition of the first level of flying qualities

Requirements: probability $p(PR_1)$ of catastrophic situation (PR=10) for aircraft with flying qualities characterized PR_1 has to be less $p^*(PR)$.



The accepted requirement to the first level of flying qualities ($PR \leq 3.5$) does not agree with accepted requirement to the level of safety

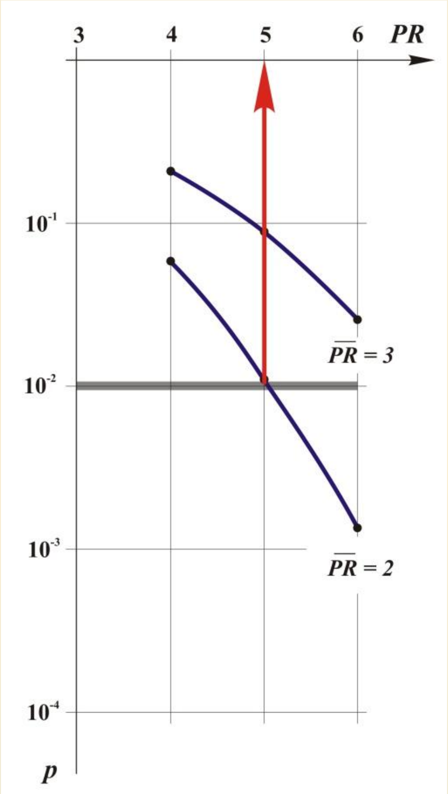
CONCLUSION: **IF THE REQUIREMENT TO ACCEPTED LEVEL OF FLIGHT SAFETY ($p \leq 10^{-9}$) APPLY TO A PILOT (AS A AIRCRAFT SYSTEM) THEN THE REQUIREMENT TO THE FIRST LEVEL OF FLYING QUALITIES HAS TO BE CHANGED:**

1) **REQUIREMENT TO THE FIRST LEVEL OF FLYING QUALITIES FOR II CLASS AIRCRAFT – $PR \leq 2.5$**

2) **REQUIREMENT TO THE FIRST LEVEL OF FLYING QUALITIES FOR TRANSPORT AND PASSANGER AIRCRAFT – $PR \sim 2$**

2. Agreement between requirement to flying qualities with probability of transform from one to another level of FQ

It is accepted that Flying qualities might transform from the first to the second level with probability $p \leq 10^{-2}$

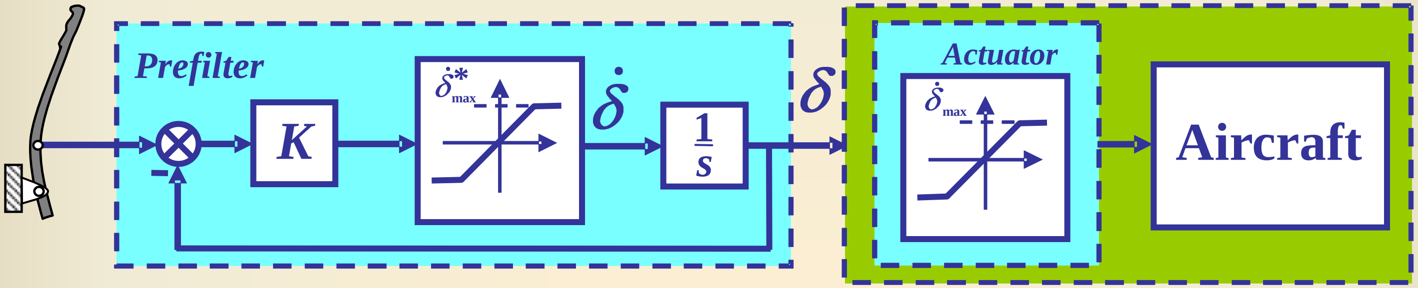


FOR EXCEPTED PROBABILITY REQUIREMENT ($p \leq 10^{-2}$) THE SECOND LEVEL OF FLYING QUALITIES CORRESPONDS TO *PR* = 5

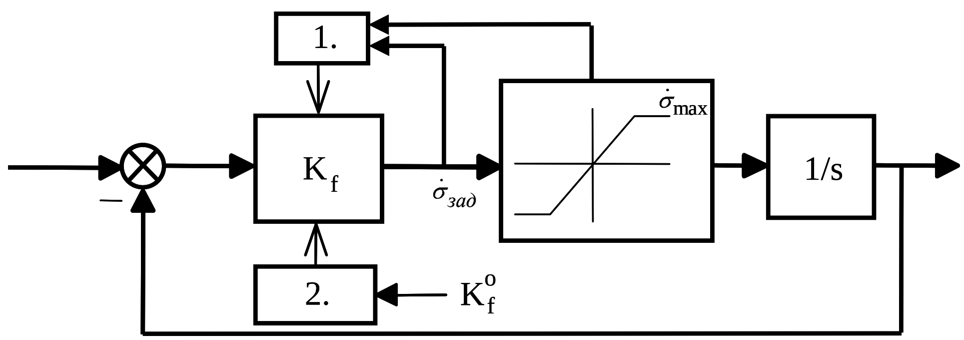
FLIGHT SAFETY EVALUATION FOR DIFFERENT FCS PREFILTERS

ACCEPTED LOGIC USED FOR NONLINEAR PREFILTERS

– TO LIMIT PILOT OUTPUT SIGNAL δ



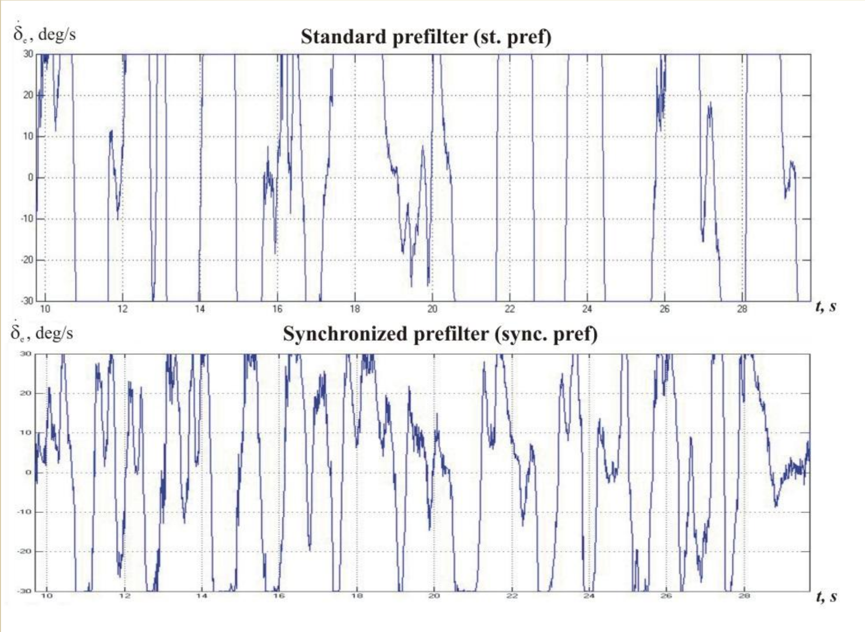
LOGIC OF SYNCHRONYZED PREFILTER – TO SYNCHRONIZE PILOT ACTION AND FLIGHT CONTROL WITH LIMITED POTENTIALITIES BY LINEARIZATION OF PILOT–AIRCRAFT SYSTEM CHARACTERISTICS



law 1: quick change of K_f $\qquad K_f = K_f \left|\frac{\dot{\sigma}_{max}}{\dot{\sigma}_{зад}}\right|$

law 2: restoration of initial gain coefficient K_f^o $\qquad K_f^o \Rightarrow \frac{1}{(Tp+1)} \Rightarrow K_f$

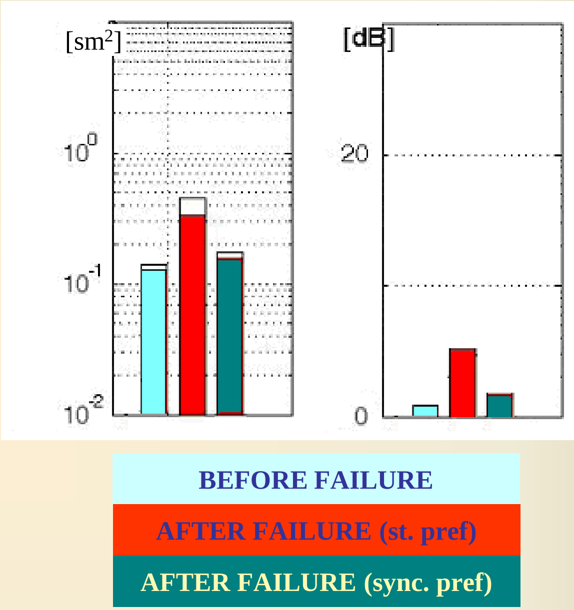
FAILURE OF HYDRAULIC SYSTEM ($\dot{\delta}_{max}$ = 80 → 30 deg/s)



PILOT–AIRCRAFT SYSTEM CHARACTERISTICS

σ_e^2 – error

r – resonance peak



Basic prefilter

without failure

$PR_{\text{normal}} = 3 \div 4$

PROBABILITY OF ACCIDENT

$p = 10^{-6} \quad 5 \cdot 10^{-5}$

Basic prefilter

with failure

$PR_{\text{st. pref}} = 9$

PROBABILITY OF ACCIDENT

$p = 0.35$

Synchronize prefilter

with failure

$PR_{\text{sync. pref}} = 4 \div 5$

PROBABILITY OF ACCIDENT

$p = 5 \cdot 10^{-5} \quad 8 \cdot 10^{-4}$

THANK YOU FOR ATTENTION!