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PILOT'S BIOLOGICAL-PSYCHIC STATE ASSESSOR

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Abstract: *The paper deals with the approach to synthesis of the bio-psychic-state assessor of pilot. The presented example of pilot's bio-state model is a part of intelligent man-machine interface intended for modern adaptable cockpit of military airplane. The pilot assessor is represented as a knowledge system in form of production rules.*

Keywords: *intelligent control, man-machine interface, knowledge-based systems.*

1 INTRODUCTION

The interface between man and technical system is very important for providing maximum effectiveness of the whole man-machine system. The modern man-machine interface (MMI) is synthetized as an adaptive system, using principles, approaches and methods typical for cybernetic branch – intelligent control. To provide the adaptation law the situation of whole system must be recognized. For this purpose the system situation recognizer (SSR) is used. The important part of the SSR is pilot assessor (PA) that provided variables characterizing the bio-psycho-state (BPS) of man in process of his activity.

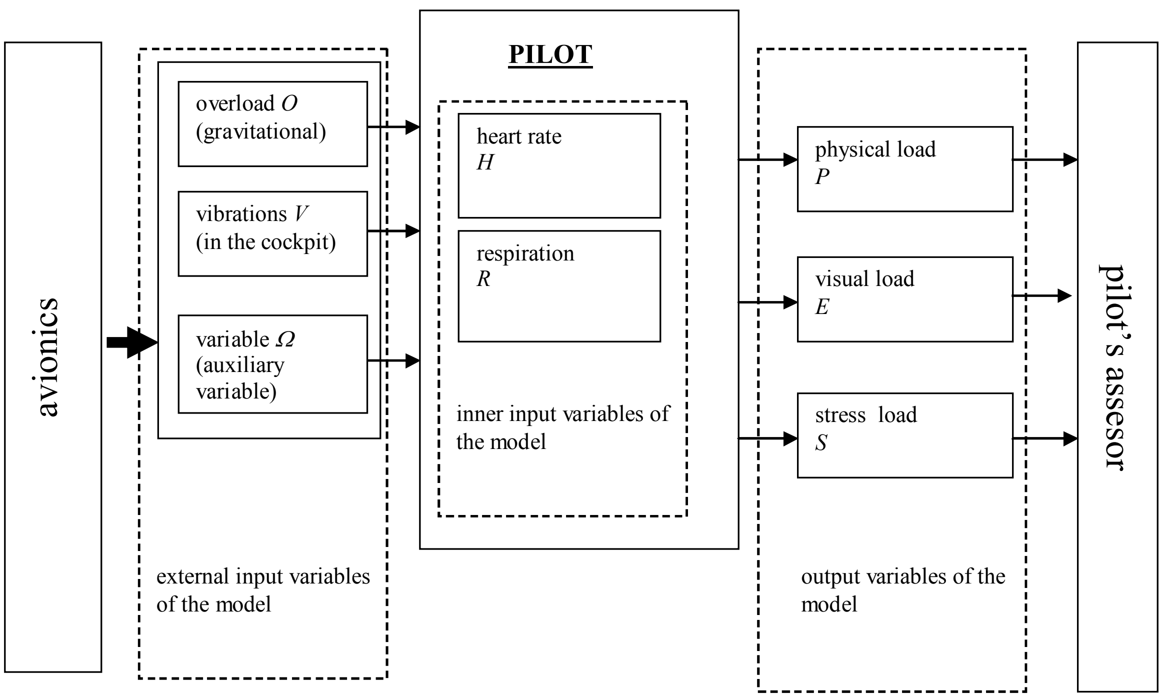

Fig.1: Pilot assessor (part)

In Fig. 1 The pilot assessor is presented. The used BPS variables are physical load P, visual load V and stress load S. Variables of BPS are mostly determined from variables directly measured on man, in this example such variables as heart rate H, respiration R are used.

2 PILOT ASSESSOR DESIGN

The pilot assessor is knowledge system representing the mapping from group of measured input variables to BSP variables. Because of the SSR is realized as rule based system, the pilot assessor is represented by group of simple rules as well. In step of analysis the auxiliary algebraic model is constructed. Then the division of variable ranges is suggested. Then the algebraic model is converted into a set of rules that is then part of the SSR knowledge base.

In paper the synthesis of three relative independent submodels of PA are presented. They are the Model of Physical load, Model of actual visual load E and Model of the instant stress load S

2.1 Physical load model

The variable actual physical load P offers objective information about pilots actual physical load. The pilots physical load has a variable character through performance assault mission by demand of the mission pursue. For example: If the pilot realizes standard flight and he does not make hard flight maneuver, then the pilots physical load has a standard value. In the case of air combat mission, when the pilot is in proximal contact with enemy and when he does hard flight maneuver, then his physical load will be high.

On the basis of the pilot medical physiology knowledge was determined the variable P as the function of two quantifiable variables: the variable H, cardiac frequency (heartbeat) and the variable R, breathing intensity.

The main reason for the choice of variables H and R is their relatively easy measurability not only in quiescent condition in strict laboratory terms, but in the life cycle of fighting mission with ballast and intrusive influences. The next reason is their massive notice value in the relation to pilots physical load. The measuring devices of variables, heart rate and breathing intensity are accurate, little bulky and not energy demanding. The computational relations for the variable P are:

$$P = f(H(t), R(t), \mu_1, \mu_2, t)\,, \tag{1}$$

$$P = H(t) \cdot \mu_1 + R(t) \cdot \mu_2\,, \tag{2}$$

$$P \in \langle 0,1 \rangle,\ H \in \langle 0,1 \rangle,\ R \in \langle 0,1 \rangle, \tag{3}$$

$$\mu 1 + \mu 2 = 1, \tag{4}$$

where: H(t) is the heart rate (heart beat), R(t) is the breathing intensity, $\mu 1$ express the rate of the influence of the variable H (the value is adjusted by expert), μ express the rate of the influence of the variable R (the value is adjusted by expert), t time.

Quantification of the variable P

The model output variable P assumes the value from the interval $\langle 0,1 \rangle$. This interval is divided into four subintervals, which are responsible for appropriate linguistics expression, Tab.3.3.

The number of the subinterval	Intervals of the variable P	Linguistic expression
1	$\langle 0, 0.4)$	Normal load
2	$\langle 0.4, 0.6)$	Increased load
3	$\langle 0.6, 0.8)$	High load
4	$\langle 0.8, 1)$	Very high load

Tab. 1. Subintervals and their linguistic expression

Computation of the variable P

The necessary variables for the computation of the variable P are in the Tab.2. The short descriptions of input variables (H,R) like factors, indications, type and dimension with equivalent linguistic expression and its rate of the influence for every variable is presented here. The reason for the creating this table is to imagine to the reader the way of the calculation of the model output variable P, i.e it gives the algebraic model of P.

<table>
<tr><td>Variable</td><td>Factors</td><td>Indication</td><td>Type and dimension</td><td>R_i</td><td>Linguistic expression</td><td>Influence rate μi ⟨0,1⟩</td></tr>
<tr><td rowspan="8">Instant physical load
P
[Physical load]
Type: metric
⟨0,1⟩</td><td rowspan="4">Heart rate
The variable:
H</td><td rowspan="4">Measuring of the heart rate</td><td rowspan="4">Number (4)
R_{HR} = ⟨50,150⟩
[Pulse / min]</td><td>R4 = ⟨120,150)</td><td>Very high, H=1</td><td rowspan="4">μ_1=0.6</td></tr>
<tr><td>R3 = ⟨100,120)</td><td>High, H=0,7</td></tr>
<tr><td>R2 = ⟨80,100)</td><td>Increased, H=0,4</td></tr>
<tr><td>R1 = ⟨50,80)</td><td>Normal, H=0,2</td></tr>
<tr><td rowspan="4">Respiration
The variable
R</td><td rowspan="4">Measuring of the respiration</td><td rowspan="4">Number (4)
R_{RE} = ⟨10,30⟩
[Tinge, expiration/min]</td><td>R4 = ⟨25,30⟩</td><td>Very high, R=1</td><td rowspan="4">μ_2=0.4</td></tr>
<tr><td>R3 = ⟨20, 25)</td><td>High, R=0,7</td></tr>
<tr><td>R2 = ⟨15,20)</td><td>Increased, R=0,4</td></tr>
<tr><td>R1 = ⟨10,15)</td><td>Normal, R=0,2</td></tr>
</table>

Tab. 2. Computation of the variable P

Rules used in the knowledge base for the variable P

The Tab. 2 is presents the knowledge base in the pilot's biological-psychic model. The list of rules is given in the next text above this table where FP is the consequent of the rule and AP is the antecedent. These rules are insert in to created program, which is the main part of the biologic-physic model.

FP1	AP21	AP22	AP23	AP24
AP11	1	1	2	3
AP12	1	2	2	3
AP13	2	2	3	4
AP14	2	3	4	4

Tab. 3. Knowledge base rules for variable P determination

The model presented in table could be expressed in for of rule, e.g.

FP11: Rule AP11 & AP21, Rule AP12 & AP21, Rule AP11& AP22,

FP12: Rule AP13 & AP21, Rule AP14 & AP21, Rule AP12 & AP22, Rule AP13 & AP22, Rule AP11 & AP23, Rule AP12 & AP23, and so on.

The record of the variable P during the combat flight

The Fig. 2 represents the time record of variables R, H and P. Slopes of variables R and H was measured during a simulation in pilots combat training. It takes 360 sec. There was a 150 sec scramble with an opponent on the interval 200-300sec. The increase of the physical load is easy to see during this phase there. The scanning sample period is 10s, it makes a small records degeneracy unfortunately.

2.2 Actual visual load E

The variable instant visual load E offers information about pilot's instant visual load due to external influence. These external influences act on pilot through the fly by overload and mechanical vibration in aircraft's cockpit. Both of them have a negative influence to the optical sensor's function. In case of normal flight, vibrations of pilot's cockpit participate on visual load. In cases of pilot's difficult manoeuvring (air combat, antimissile manoeuvres, etc.) overloads applied to the pilot participate on visual loads. Positive overload values cause "blackout" – visual field gets grey till black. Negative overload values cause "redout" – visual field gets red, displeasing filling in the eyes, etc.. The overload values, which act on the pilot's body we can get by accelerometers located in cockpit. Effective vibration value we can get by the similar way by means of special accelerometers. The instant visual load is the function of the positive overload (O^+), of the negative overload (O^-) and of vibrations in the cockpit (V).

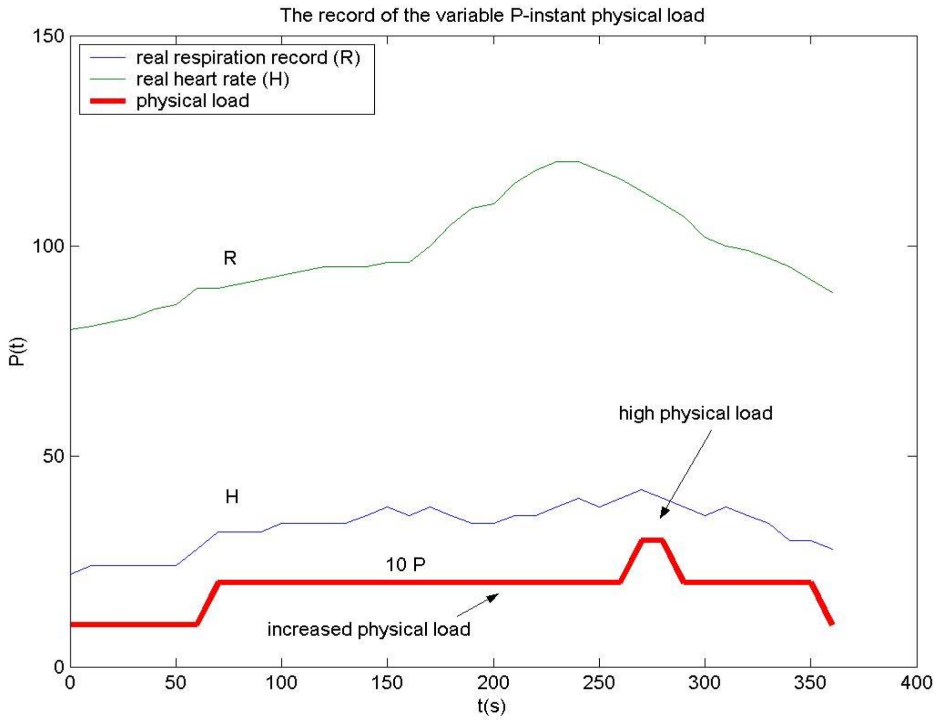

Fig. 2: Physical load

The calculation of the variable E is performed by means of following relations:

$$E = f(O^+(t), O^-(t), V(t), \xi_1, \xi_2, \xi_3, t)\,, \tag{5}$$

$$E = O^+(t)\cdot\xi_1 + O^-(t)\cdot\xi_2 + V(t)\cdot\xi_3\,, \tag{6}$$

$$O+ \in \langle 0,1\rangle,\ O- \in \langle 0,1\rangle,\ V \in \langle 0,1\rangle\,, \tag{7}$$

$$\xi 1 + \xi 2 + \xi 3 = 1, \tag{8}$$

where: O+(t) is the influence of a positive overload , O−(t) isthe influence of a negative overload, V (t) is the influence of vibrations in the cockpit , ξ1is s the rate of the influence of the variable O+(t), ξ2 is the rate of the influence of the variable O−(t), ξ1= ξ2, ξ3 is the rate of influence of the variable V, t is time.

Quantification of the variable E

The model output variable E assumes the value from the interval $\langle 0,1\rangle$. This interval is divided into four subintervals, which are responsible for appropriate linguistics expression, Tab.4.

The number of the subinterval	Subintervals of the variable E	Linguistic expression
1	$\langle 0, 0.4)$	Normal load of a visual sensor
2	$\langle 0.4, 0.6)$	Increased load of a visual sensor
3	$\langle 0.6, 0.8)$	High load of a visual sensor
4	$\langle 0.8, 1)$	Very high load of a visual sensor

Tab. 4. Subintervals and their linguistic expression

Computation of the variable E

The necessary variables for the computation of the variable E are in the Tab. 5. There is short description of these variables (O+,O−,V) like factors, indications, type and dimension with equivalent linguistic expression and its rate of the influence for every variable there

Variable	Factors	Indication	Type and size	R_i	Linguistic expression	Influence rate ξi ⟨0,1⟩
Visual load E [visual load] Type : metric ⟨0,1⟩	Negative overload Variable: O^+	Size of the negative overloading scanned by accelerometer	Number (4) RO+ = ⟨0,-3⟩ [G]	R4 =⟨-2,-3), O+=1	Very high	ξ_1=0.7
				R3=⟨-1,-2), O+=0,7	High	
				R2=⟨-0.5,-1), O+=0,4	Increased	
				R1=⟨0,-0.5), O+=0,2	Normal	
	Positive overload Variable: O−	Size of the positive overloading scanned by accelerometer	Number (4) RO− = ⟨0, 9⟩ [G]	R4 = ⟨5,9⟩, O−=1	Very high	
				R3=⟨3, 5), O−=0,7	High	
				R2= ⟨1,1), O−=0,4	Increased	
				R1= ⟨0,3), O−=0,2	Normal	
	Vibrations variable: V (0,40Hz)	Measure vibration scanned by accelerometer	Number (4) RV = ⟨0, 2⟩ [Real value G]	R4= ⟨1.5, 2⟩, V=1	Very high	ξ2=0.3
				R3=⟨1,1.5), V=0,7	High	
				R2=⟨0.5,1), V=0,4	Increased	
				R1=⟨0, 0.5), V=0,2	Normal	

Tab.5. Computation of the variable E

Rules used in the knowledge base for the variable E

The presented Tab.6 is used for the knowledge base in the pilots biological-psychic model. The list of rules is given in the next text above this table, where FP is the consequent of the rule and AP is the antecedent. These rules are inserted in to created program, which is the main part of the biological-physic model.

FP2	AP31	AP32	AP33	AP34	AP35	AP36	AP37	AP38
AP41	1	1	2	3	1	1	2	3
AP42	1	2	3	4	1	2	3	4
AP43	1	2	3	4	1	2	3	4
AP44	2	2	3	4	2	2	3	4

Tab .6. Rules of the variable E for the knowledge base

The record of the variable E during the combat flight

The Fig.3 represents the time record of the overloading applied to pilot's body through anti-missile maneuver and corresponding duration of value V, effective value measure vibration and value E, eye load, which is simultaneously output of pilot's biological-psychic model.

From run of the variable E we can see, that on pilot is acting great overload in anti-missile maneuver, which loads his eyes. It is the same result, which is well known from practically experience of combat pilots in real mission situations. The scanning sample period is 0,1s

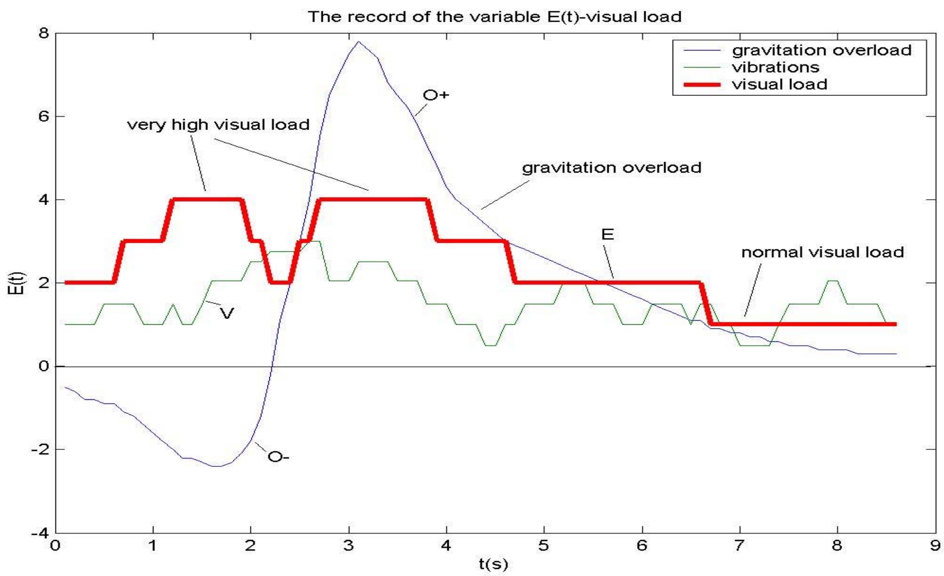

Fig. 3 The record of the variable E

2.3 The variable-instant stress load S

There are many critical situations in combat conditions, which pilots must solve till border of pilot's resistance. Pilot reacts by stereotyped reactions, which is marked as the stress. There are many factors that influence pilot's stress loading through combat flight. These factors are fear of death, danger as anti-air missiles, enemies' fighters, stress experience from previous missions, etc. There is value instantly stress loading to represent pilot's stress. This value providing information about instantly stress, which have negative influence in mostly incident.

The variable-instant stress load S is like physical overload, negative influence of overload during the flight and negative vibration in the cockpit and on the value Ω. The negative influence of the overload through the flight and the negative influence of vibration is in value E. The physical loading is involved in the value P. The size of the value Ω equals answering the seriousness of flight tasks and the influence of conflict situations. This value has dominant influence to pilot's stress load. Expert adjusts this value. Values of the variable Ω , ($\Omega \in \langle 0,1 \rangle$) and flight tasks are shown in the Tab.7.

Number	Stress situation	Values of the variable Ω
1	Normal flight	0.2
2	Air refueling	0.4
3	Identified monitoring by anti-aircraft	0.5
4	Flight in a low flight level (under 200m)	0.6
5	Strike to an enemy target (ground, air)	0.7
6	Identified fire of anti-aircraft missile	0.8
7	Flight combat with enemy aircraft	0.9

Tab.7 Values of the variable Ω , which correspond with stress situation

Following relations performs the calculation of the variable S:

$$S = f(P_T(t), E_T(t), \Omega(t), \sigma_1, \sigma_2, \sigma_3, t) , \quad (9)$$

$$S = \left(P_T(t) \cdot \sigma_1 + E_T(t) \cdot \sigma_2 + \Omega(t) \cdot \sigma_3\right) \quad (10)$$

$$PT \in \langle 0,1 \rangle,\ ET \in \langle 0,1 \rangle,\ \Omega \in \langle 0,1 \rangle \quad , \quad (11)$$

$$\sigma 1 + \sigma 2 + \sigma 3 = 1, \quad (12)$$

where: PT (t) is the instant physical load, ET (t) is the instant eyes load, Ω (t) is the auxiliary variable, σ1 is the coefficient express the rate of influence of the variable P(t), σ2 is the coefficient express the rate of influence of the variable E(t), σ3 is the coefficient express the rate of influence of the variable Ω(t), t is time.

Quantification of the variable S

The model output variable S assumes the value from the interval $\langle 0,1 \rangle$. This interval is divided into four subintervals, which are responsible for appropriate linguistics expression Tab. 8.

The number of the subinterval	Subintervals of the variable S	Linguistic expression
1	$\langle 0, 0.2)$	Normal stress load
2	$\langle 0.2, 0.5)$	Increased stress load
3	$\langle 0.5, 0.8)$	High level of the stress load
4	$\langle 0.8, 1)$	Very high stress load

Tab. 8. Subintervals of the variable S with their linguistic expression

Computation of the variable S

We can see input values for the computation of the variable S on the following Tab. 9. There are short descriptions of these variables (P, E,Ω) like factors, indications, type and dimension with equivalent linguistic expression and its rate of the influence for every variable. The reason for the creating this table is to imagine to the reader the calculation of the variable S.

Variable	Factors	Indication	Type and size	Values	Linguistic expression and intervals	Rate of influence σi ⟨0,1⟩
Stress load S [stress load] Type: metric ⟨0,1⟩	Transform physical load the variable: PT	The first output variable of the biological-psychic state model	Number (4)	PT=1	Very high, $P \in \langle 0, 0.4)$	σ1=0,25
				PT=0,7	High, $P \in \langle 0.4, 0.6)$	
				PT=0,4	Increased, $P \in \langle 0.6, 0.8)$	
				PT=0,2	Normal, $P \in \langle 0.8, 1)$	
	Transform visual load the variable ET	The second output variable of the biological-psychic state model	Number (4)	ET=1	Very high, $E \in \langle 0, 0.4)$	σ2=0,25
				ET=0,7	High, $E \in \langle 0.4, 0.6)$	
				ET=0,4	Increased, $E \in \langle 0.6, 0.8)$	
				ET=0,2	Normal, $E \in \langle 0.8, 1)$	
	Ω(t)…the auxiliary variable	The identification of just realized task (pilots behavior)	Number (7)	The table 5		σ3=0,5

Table 9. Computation of the variable S

Rules used in the knowledge base for the variable S

In Tab. 10 the rules of knowledge base in the pilot's biological-psychic model are presented.

FP3		AP51	AP52	AP53	AP54	AP55	AP56	AP57	AP58	AP59
		0,1	0,15	0,2	0,225	0,275	0,3	0,35	0,425	0,5
AP61	0,2	1	2	2	2	2	2	2	3	3
AP62	0,4	2	2	2	2	2	3	3	3	3
AP63	0,5	2	2	2	2	3	3	3	3	3
AP64	0,6	2	2	3	3	3	3	3	3	4
AP65	0,7	2	3	3	3	3	3	3	3	4
AP66	0,8	3	3	3	3	3	3	3	4	4
AP67	0,9	3	3	3	3	3	3	4	4	4

Tab. 10. Rules of the variable S

The record of the variable S during the part of the combat flight

The Fig. 4 represents the record of the variable S during the time interval 150s. This record has three phases. The first phase was the flight phase in the duration 0÷50 s, the second phase was the phase in the duration 50÷100s, the third phase was the phase in the duration 100÷150s.

The pilot realized normal flight during the time 0÷50 s. The stress is approximately normal in this phase. The pilot realized the flight on the low flight level during the time interval 50÷100s in the next. It is know from praxis, that such flight way gives on the pilots psychic high demands. The increase of the variable S responds that.

The pilot began in the time interval 100÷150s an attack on a ground target. The pilot was exposed to the danger of enemies air defense during this phase especially and he perceived it. The pilots stress load is extreme in this time, the high value of the variable S responds it. The scanning sample period is 5s.

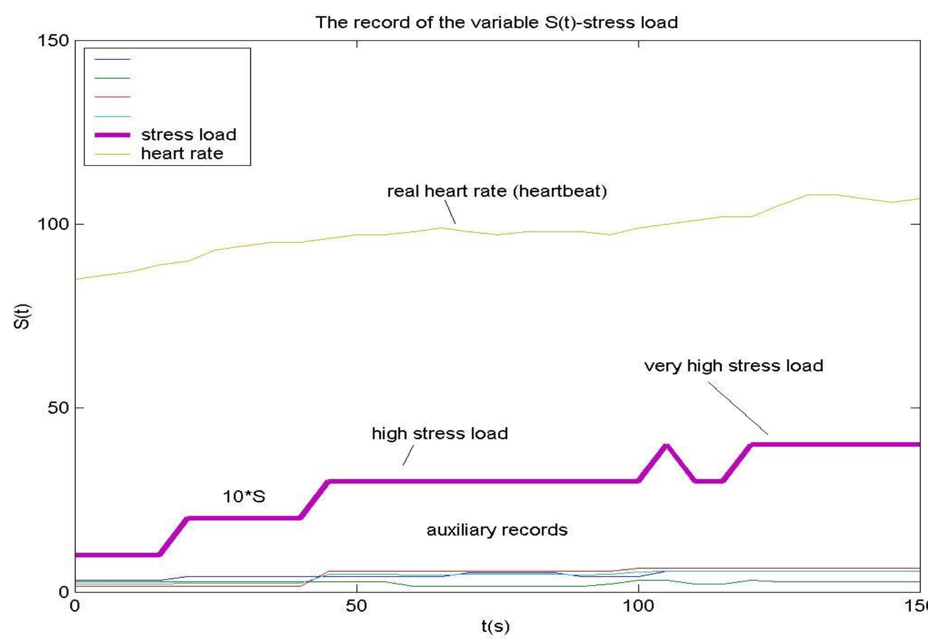

Fig. 4 The record of the variable S characterized the pilots stress load during the flight

3 CONCLUSIONS

In paper the simple pilot assessor is presented For description of the biological-psychic pilots state three variables are used: P-physical load, E-visual load, S-stress load is for the using in the adaptive flight control possible. Values of coefficients in algebraic model are given by experts. It is supposed they will adjusted for every pilot especially. Records of input variables of the model like heartbeat, respiration, vibrations, gravitational overload were obtained from special workstation in our country [CVUT Prague]. These records were used for design this biological-psychic state model. The advantage of used input variables of the biological-psychic model is their good measurability. Relatively simply electronic devices could measure the heart rate and respiration. Gravitation overload is measured by device on the pilot's cockpit and is visualized on the board device. Vibrations could be measured by special accelerometers, which could be placed on the cockpit. The auxiliary variable Ω , which is used by expression pilot's stress load could be adapted for needs of mission goals, conditions, etc. It is obvious that the relations used in model's calculations could be changed or completed in the future. The plausibility of the created model must be verified in real mission conditions especially.

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