A Fighter Arms and Flight Complex Onboard Control System: Tasks, Pattern, Algorithms

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Introduction. Modes and tasks of a fighter combat control

The modern and perspective fighters have high aerodynamic, maneuverable, tactical-technical and battle data, for they are designed to strike a counteracting enemy under the complicated combat operation circumstances. The only way to make these characteristics effective is to organize high efficient many-stage control of an aircraft [1].

There are variant groups of a fighter control modes, correspondent to the certain combat circumstances and instrumental in realization of the every stage of control tasks: transport-navigation modes; transport-homing modes; modes for attacking targets in distant air missile battle; modes for attacking targets in close-in air maneuverable battle.

Here are described functional tasks of constructing onboard management system for an interceptor. The control process of interception of air targets is divided into several flight stages and stages of control actions [2]. Taking into consideration the time-graph of a battle task fulfillment, we can list the following stages of interception:

- The long-range guidance, which is meant to bring an aircraft into conditions of detecting and capturing air targets, according to the information from external guidance and control systems (ground-level or air based);
- Homing, which is carried out after capturing and appointing the targets attack, according to the data of onboard aim – information systems, with fulfillment of the task of bringing a fighter into the area of missiles probable launching, and also with the provision for missiles launching within this area, as well as with the provision for missile attack safety, conversion into a short-range combat or escaping an attack.

There are certain flight stages, according to which there are described the groups of control modes, which are to execute the control tasks at each stage: transport-navigation modes, transport-aiming modes and air targets attacking. The former two groups of modes, named transport, consist of the route control mode, command aiming mode, single and sectional onboard aiming, autonomous and semi-autonomous search, coordinated aiming. The third group includes the mode of a single distant combat on aiming at the maneuvering target, multi-target mode on attacking several targets, duel situation mode, attack at the situation of incomplete information mode, etc. According to the purposes put at each stage of interception flight and realized through the modes and submodes (fig. 1), it is possible to mark a number of special control tasks, associated in groups (problematic tasks), each of which deals with individual tasks:

1. Program control on commands of external systems, which provides: processing signals coming from external guidance systems; creation of a flight optimal profile; logical coordination with external systems; optimization of control by altitude, speed and

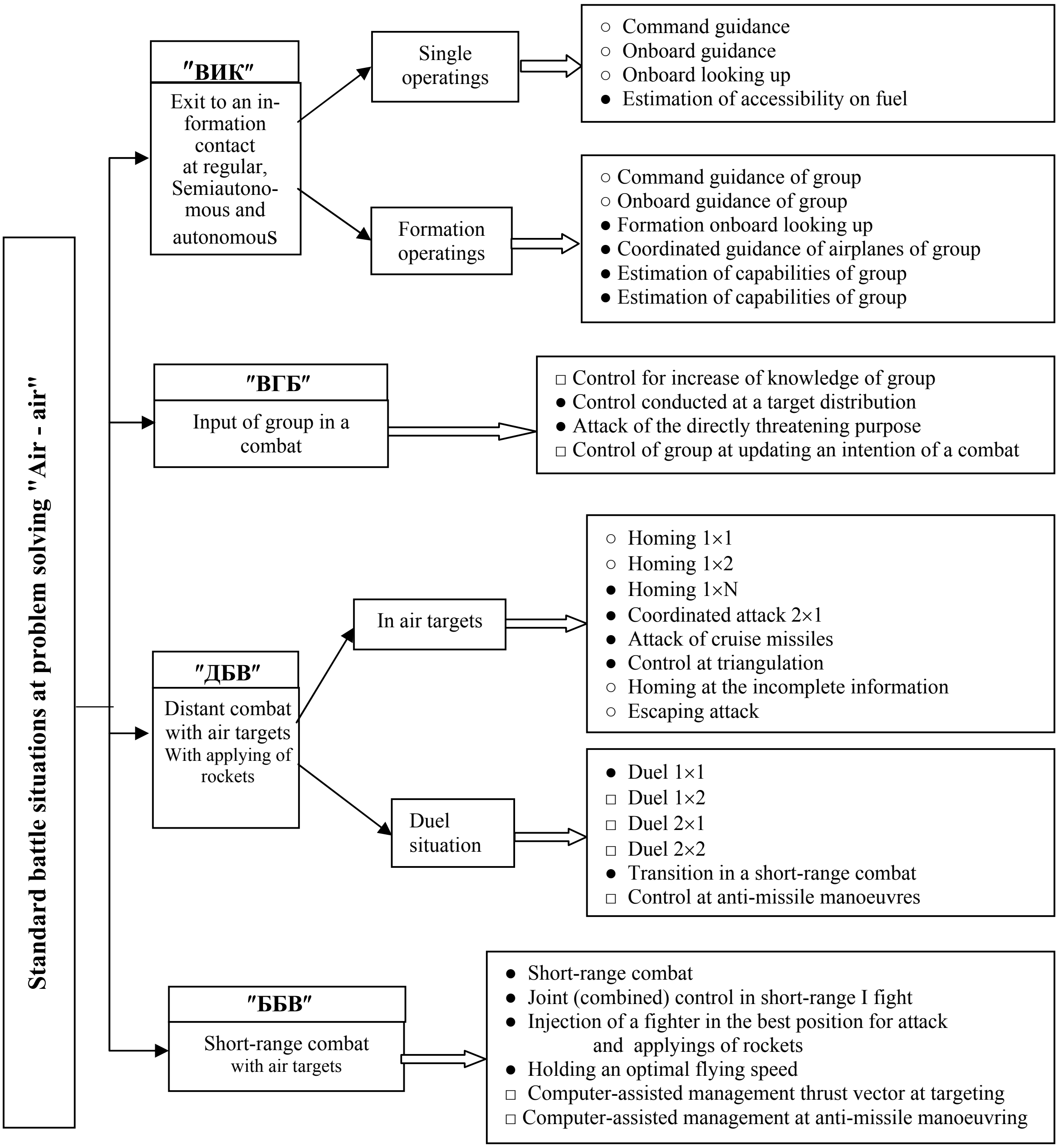

Fig. 1. Standard battle situations and control modes

course index; programs for climb and decrease tasks execution; traction engines control; dangerous flight phases limit.

2. Control on transport modes, which includes: strategic change of a route; control by a route and by navigational points; routing with dangerous zones escape; entry to a given point according to a given direction; time control of arrival at final and via points; calculation of a flight radius of and accessibility according to fuel amount; the fulfillment of applied task with the creation of a flight profile; semiautonomous actions (including sectional ones) control; onboard control planning the trajectory of aiming; traction engines control.

3. A homing fighter control, which consists of: developing methods of aiming at a single target; planning the trajectory at multi-target attack; altitude and attacking speed control with the usage of optimal profiles and special control laws; missile attack safety control; creation of control signals in accordance with limitations; traction engines control.

Certainly, the above list does not comprise all control tasks, appearing on interception. At the same time, the practice of algorithmic support and development of onboard control systems of modern interceptors at variant combat stages allows us to conclude, that the above listed control tasks and applicable to them individual tasks form a unified complex of tasks, and the fulfillment of these tasks will provide a high quality performance of interception.

The complex of control tasks, as well as onboard systems for these tasks fulfillment, has a multistage structure; for the observed groups of modes and algorithmic support for an onboard control system there are described the following levels of control tasks:

- on the *intellectual level*, with participation of a crew and with the help of intellectual support systems, there are realized the tasks of finding solutions on assigning this or that mode and settings in accordance with combat conditions and a task general statement;

- on the *level of tracking a trajectory* there are realized the tasks of the upper trajectory level for a flight transport stages (selection of operational modes, tracking a route and a long-range homing trajectory, selection of a trajectory parameters and control instructions, defining a flight profile), as well as for air targets attack (tracking a trajectory of a flight while performing attack modes and ending attack trajectory);

- on the *level of control according to the trajectory* (lower trajectory level) there are executed the tasks of realization of the tracked trajectory (program control in a vertical plane and control according to a selected route; forming control signals and commands);

- on the *autopilot level* there are executed the tasks of improvement of the control signals on given overload, given roll and traction engines control.

A development control algorithm is mainly focused on a combat task execution quality, as well as on the dynamics of targeting errors improvement and on the usage of maneuverable and flight-technical abilities of an aircraft, safety issues of maneuvers performance.

1. Construction of a complex onboard control system

The analysis of combat tasks faced by the air complex, estimation of an aircraft battle control requirements, experience of algorithmic coordination of control modes of modern and developing fighters prove the necessity to elaborate a special complex control system of a fighter arms and flight (onboard control system). The system represents a complex of algorithmic support, hierarchically structured and consisting of subsystems, groups algorithms units and indicated here as battle modes onboard control system ("BMCS"). Battle control tasks fulfillment is based on the algorithmic and information interaction of “BMCS” components and other algorithmic units and systems, integrated in the structure of functional control software for onboard equipment.

Elaboration of onboard systems of tactical aircrafts in the USA also has the tendency to combine separate functional systems, which is characterized, particularly, by complex linking of auto flight control system (САУ) and Management system of an aircraft armament (СУВ) in a unified system. Thus the high level of targeting and piloting processes automation is provided, including critical time modes of attack, during which the operating load exceeds physical and physiological capabilities of the pilot. The high-priory aim of the automation is the organization of control on flight trajectory and on the position of an aircraft at battle maneuver during targeting.

It is just with the use of onboard control system that realization of the integrated control of weapon delivery, fire and maneuver is possible onboard a perspective complex. The system synthesizing of algorithms ″BMCS″ has allowed to create structure of both control actions distribution and information exchange (fig. 2), providing high level of control quality dynamic, fidelity and combat indications.

The integration of partial algorithms, groups and systems of algorithms in an onboard control system ″BMCS″ gives efficient solution to the control tasks, full realization an air complex and onboard systems potential, contribute to the interaction between different elements and units of algorithmic support, exempting a pilot from non-creative operations [3].

The introduced general scheme of battle modes control system includes a number of algorithms subsystems, which are structural components and are expected to serve the following tasks:

- Subsystem "УпрВИК" – to provide control modes for establishing an information contact with air targets.
- Subsystem "УпрВГБ" – to provide control modes at a stage of a group's entering air combat.
- Subsystem "УпрДБВ" – to provide control modes at a stage of a distant missile combat with air targets.
- Subsystem "УпрББВ" – to provide control modes at a stage of a short-range air combat.
- Subsystem "АФУСБ" – to establish control signals and to provide safety control at all stages of battle deploy.

Battle modes integrated onboard control system allows:

- To automate semiautonomous actions,
- To decide boundary, route and temporary problems,
- To realize combined and tactically flexible ways of attack control,
- To execute battle modes' traction control,
- To coordinate actions according to a trajectory and time,
- To attack several targets on proper conditions of tracking and launch,
- To follow limitations and conditions of security at battle deploy.

2. Safety control of a computer-assisted fighter at battle maneuvering

Cooperation onboard control system of arms use ("СУВ") and the auto flight control systems ("САУ") for the first time made it possible to apply different limitations and safety conditions at battle tasks fulfillment.

According to the research, the present algorithmic system is characterized by a number of features, concerning the automated performance of battle vertical maneuvers at the stages of homing and air target attack.

In case of serious misalignments between required and current flying speeds (for example, in case of picking up maximum speed), at descent/pick up an airplane gets in large negative angles of piqueing and it is possible to break permissible descent velocity ($V_{у\ доп}$) limit.

Serious restriction of a control signal of vertical overload $n_{Взад}$, top and lower levels of which are smaller than figures permissible for a particular airplane, provides smoothness of transitions between trajectory segments in a vertical plane and improvement of quality of the mission plans realization.

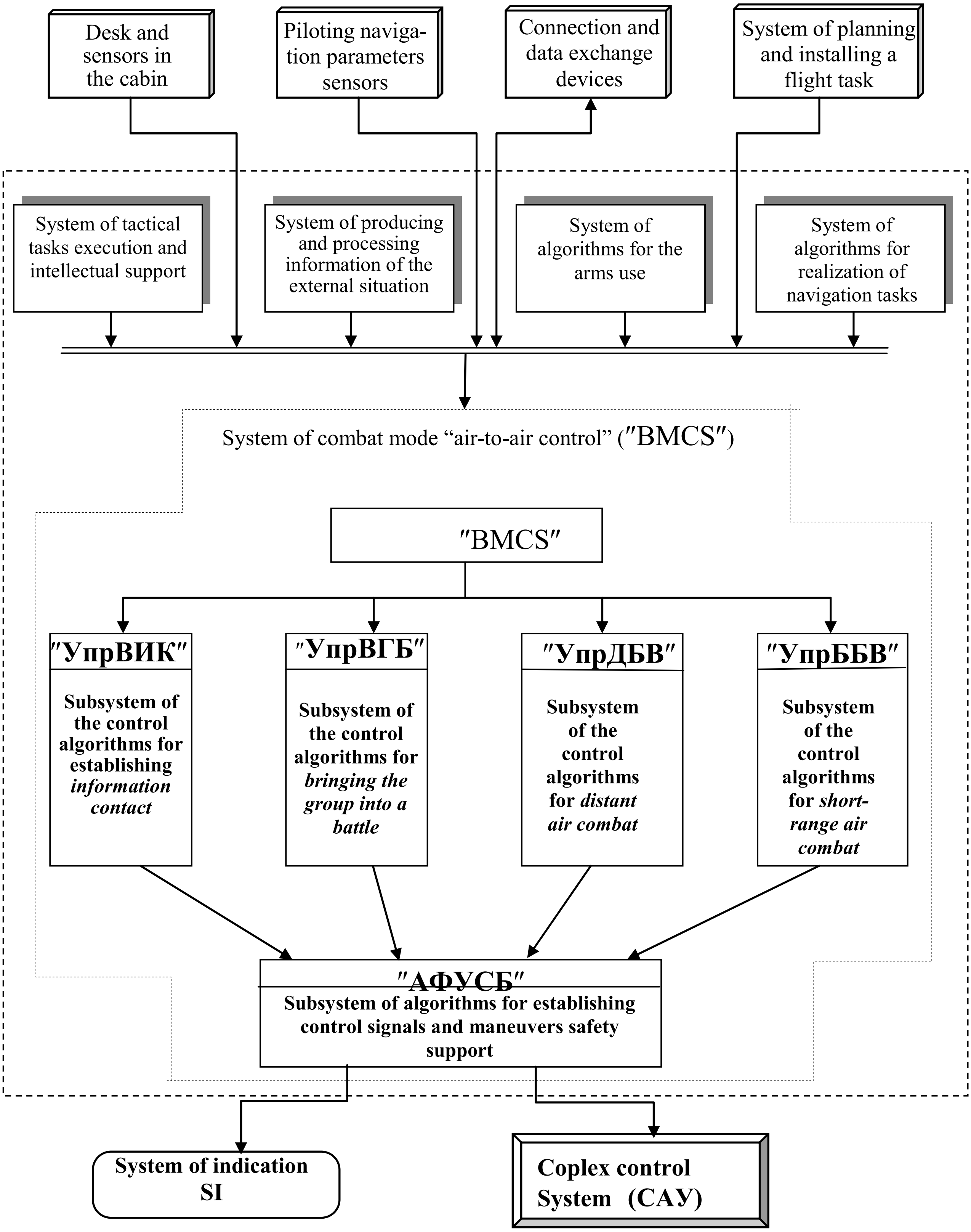

Fig. 2. Functional structure of combat modes control system, comprised into onboard information-control system

In these conditions the maneuver of picking up maximum speed with a decrease or stopping maneuver in climb can be performed with impermissible re-operation of $V_{пр\ max}$, H_{min}, $V_{пр\ min}$ values.

To increase a level of safety and to escape breaking of $V_{пр\ max}$ limits, the following measures are taken:

a) Limitation of required angle of incline by value $\theta_в^{Vпрmax}$

$$\theta_в^{Vпрmax} = \lambda_1\ [\kappa_{\Delta M}\ (M - M_{max}(H)) + \kappa_{пx}\ n_{xп}],$$
$$\lambda_1 = \lambda_{10} + \lambda_{11}\ H + \lambda_{12}\ H^2\ ,$$

with the realization of ***quasiprogrammed catching-up control***, according to $M_{max}(H)$ programme, correspondent to $V_{пр\ max}$.

б) Applying the extension of limitation index n_{Bmax} up to the index $n_{y\ max}^{расп}$. The working logic of such a limit is this:

$$n_{Bmax} = n_B^+ = \begin{cases} n_o & \text{at } \Delta n < n_o \\ n_1 + n_o + \Delta n & \text{at } n_o \le \Delta n \le 0 \\ n_1 + n_o & \text{at } \Delta n > 0\ , \end{cases}$$

where $\Delta n = \max\ [\kappa_1\ (H_{min} - H);\ \kappa_2\ (M - M_{max})]$,
$n_o, n_1, \kappa_1, \kappa_2 = \text{const} > 0$.

When close to minimum permissible speeds, it is expedient to provide a flight safety by several steps, using a number of restraining measures:

1) In long-range homing modes, according to the from external systems information, there is used the program of a descent, optimized by a minimum of fuel consumption $M_{прог}^{сн}(H)$ and correspondent to the transport modes minimum speed $V_{пр\ min1}$. Keeping to the speed $V_{пр\ min1}$ is possible through the logic described in [2], with the use of programmed flight control laws.

2) At an air attack in distant missile fight (including the performance of the maneuver “hill up”) there is stated the value of speed permissible in this mode $V_{пр\ min2}$, which can change together with an altitude, that is the value $M_{min} = f\ (H)$. Picking up to this speed and keeping up to it at high target attack (with switching an aircraft control laws) is realized through logic [2].

3) At any maneuvers of an airplane, including control by a pilot, there is realized the mode of keeping up to minimum permissible speed $V_{пр\ min3}$, close to $V_{эв}$. In this case it is possible to go into the maximum angle of attack α_{max}; there is a special stop in the "САУ" subsystem to limit the angle’s enlargement.

This mode is realized with the use of:

- Picking up control with limitation of required angle of incline $\theta_в$ by the value $\theta_в^{эв}$; with the realization of quasiprogrammed control $M_{min3} = f\ (H)$;

- Extension of minimum limitation of the required exuberant overload $n_{взад}$ up to the minimum value for this airplane $n_{y\ min}$ (while $V_{пр} \le V_{пр\ min2}$).

The specific feature of this last measure is to keep an airplane from overload close to 0 (the requirement, induced by a fuel system operation). It is realized through the hysteresis logic:

$$n_{Bзад}^{вых}\ (i) = \begin{cases} n_{Bзад}\ (i) & \text{at } |n_{Bзад}\ (i) + 1| \ge \Delta_1 \\ \Delta_1 - 1 & \text{at } n_{Bзад}\ (i) + 1 < \Delta_1 \\ & \text{and } n_{Bзад}\ (i-1) + 1 \ge \Delta_1 \\ -\Delta_1 + 1 & \text{at } n_{Bзад}\ (i) + 1 > -\Delta_1 \\ & \text{and } n_{Bзад}\ (i-1) + 1 \le -\Delta_1 \end{cases}$$

$$n_{Bзад}^{вых} \ge n_{Bmin}\ .$$

The complex of all-level limitations of control parameters in a vertical plane can be presented as follows:

1-st level – limitation of errors of control:

$$\Delta M_{з\ min} \le \Delta M_з \le \Delta M_{з\ max},\ \Delta H_{з\ min} \le \Delta H_з \le \Delta H_{з\ max}.$$

2-th level – limitation of required angle of lean of a pathway:

$$\theta_{в\ min} \le \theta_{в\ потр} \le \theta_{в\ max};$$
$$\theta_{в\ max} = \min\ (\theta_в^{Mmin};\ \theta_в^{Vпр\ min};\ \theta_{в\ max1};\ \theta_{в\ max2};\ \theta_{в\ max3});$$
$$\theta_{в\ max1} = f(H, M);\ \theta_{в\ max2} = f(H, n_{xп});$$
$$\theta_{в\ max3} = \text{const};$$
$$\theta_{в\ min} = \max\ (\theta_в^{Mmax};\ \theta_в^{Vy\ max};\ \theta_в^{Vпр\ max};\ \theta_в^{Hmin};\ \theta_{в\ min1};\ \theta_{в\ min2});$$
$$\theta_{в\ min1} = f(H, M);\ \ \theta_{в\ min2} = \text{const}.$$

3-rd level – limitation of an error of guidance (targeting):

$$|\Delta B| \le \Delta B_{max}.$$

4-th level – limitation of required vertical overload:

$$n_{Bmin} \le n_{Bзад} \le n_{Bmax}.$$

$$n_{Bmax} = f(H, M);\ \ n_{Bmin}. = f(H, M) = f(H, M);$$

$$n_{Bmin} = f(H, M);$$

the values n_{Bmax}, n_{Bmin} are reamed at nearing to boundaries on $V_{пр\ max}$, M_{max}, $V_{пр\ min}$, H_{min}; at calculation n_{Bmin} the values $n_{Bmin} = -1 \pm \Delta n_{min}$ are carved.

5-th level – limitation of increment of required overload on each step of the score:

$$\Delta n_{Bз}(i) = n_{Bзад}(i+1) - n_{Bзад}(i);$$

$$|\Delta n_{Bз}(i)| \le к_{\Delta nB}.$$

6-th level – limitation to full given overload:

$$n_{y\ min} \le n_{y\ зад}^{абс} \le n_{y\ max};$$

$$n_{y\ max} = к_{no} + к_{n1}\, q_{\ сж};\ \ \ к_{пун} \le n_{y\ max} \le к_{пув};$$

$$n_{y\ min} = к_{n\ min}.$$

The introducing of limitations 1-st, 3-rd, 4-th levels provide of reasonable dynamic processes of holding of the programs of motion on an altitude and speed, and also smoothness of transitions between segments of the programs.

The limitation of 5-th level eliminates unexpected drops of a control signal caused by some fluctuations and gaps in the flight parameters.

A limitation of 2-th and 6-th levels is called by necessity of holding of flight limitations of an airplane and safety of fulfilment of vertical manoeuvres. Pursuant to the tendered concept at a level 2 will be realised квазипрограммное flight control with holding of limitations on $V_{пр\ max}$, M_{max}, $V_{пр\ min}$, H_{min}, $V_{у\ доп}$.

Shortly we shall mark a series of the positive parties of usage of picking up restraining control on modes of an air-to-air attack in distant rocket I fight (fig. 3).

At manual or director control of a throttle lever by the pilot is improved safety of flight on large and low speeds, for in random errors of a piloting or delay of moving of control handle by the engine (ORES) the airplane does not fall outside the limits $V_{пр\ max}$, $V_{пр\ min}$. The pilot with the help of ORES changes only vertical velocity V_y, the airplane executes motion with speeds, close to limiting. Without implementation of such mode the pilot, for example, at manoeuvre “A zoom downwards” during target homing should closely keep track of by a flying speed to not exceed $V_{пр\ max}$ and in time to switch off “An afterburning” engines.

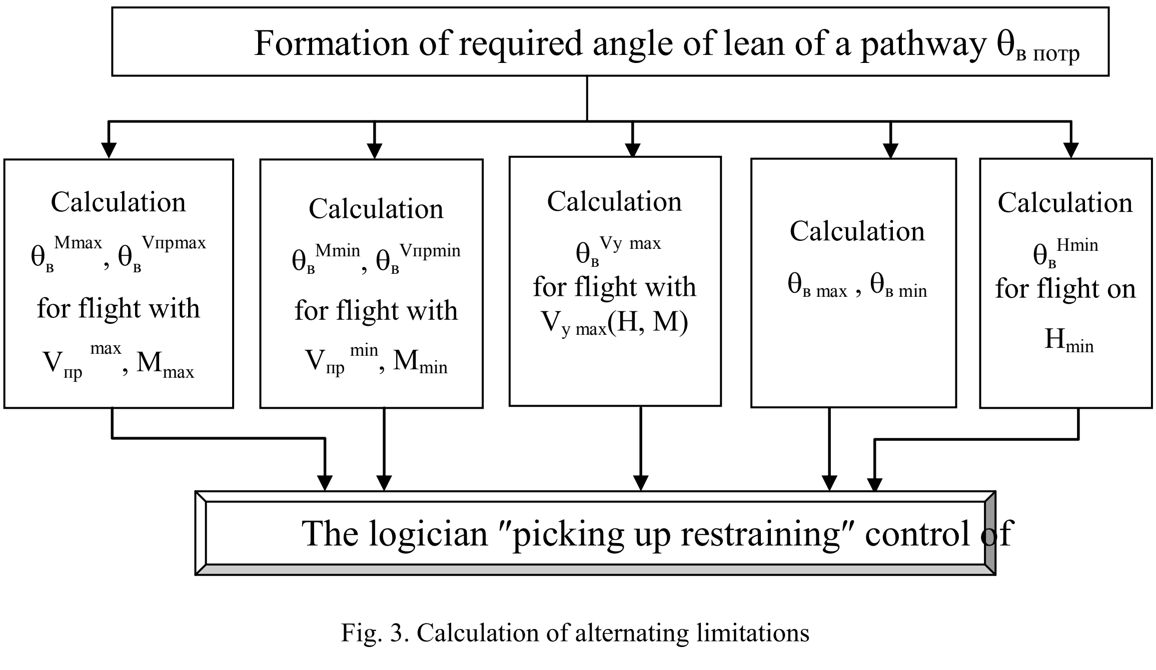

Fig. 3. Calculation of alternating limitations

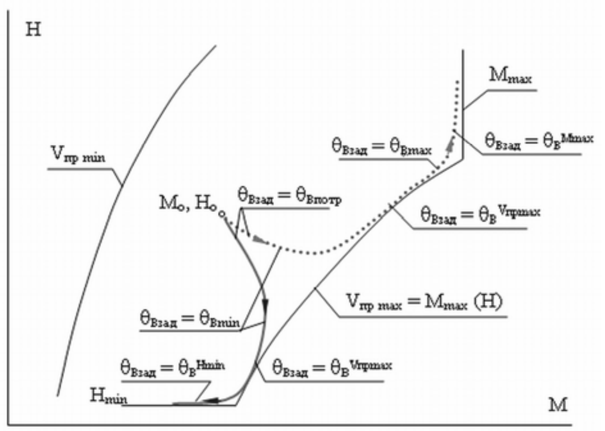

Fig. 4. Pathways of motion of a fighter on limitations

There is also provided a smooth transition to the altitude H_{min}. In a number of nowadays on-board systems the process of going down to H_{min} after intensive airplane descent is characterized by drops in the altitude to the values much lower then H_{min}, since in such systems there exists a sated zone of control laws changeover.

On fig. 4 there are shown possible flight trajectories of a fighter at attacking highly and low-altitude targets close to maximum speeds.

Overall use of flight and maneuvering data of a particular airplane allows improving combat capabilities of an air complex.

With the use of the above described logic and restraining algorithms it becomes possible to:

– to keep up to the limitations on a vertical speed and angle of trajectory incline at a descent with picking up to maximum speeds and with braking down to minimum speeds;
– while picking up the speed, to eliminate a decrease of a below calculated minimum altitude of the flight, realizing smooth transition to this altitude at the approach to H_{min};
– to provide the performance of intensive maneuver of going up to ultimate values $V_{пр\ max}$, $V_{пр\ min}$ or H_{min} with the extension of a limiting level of the stated normal overload control signal.

All these measures contribute to the improvement of vertical maneuvers characteristics, exempting a pilot from waste of attention to the control and from interference with the automated control mode. Thus is also increased a level of automation of an aircraft secure piloting.

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