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OPTIMAL PROBABILISTIC TRAJECTORY DESIGN OF NONLINEAR SYSTEM

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Abstract. *A stochastic problem of optimal launcher trajectory design is considered. The solid propellant launcher motor has uncontrollable thrust deviations. Both a thrust and initial state vector variations are random. It is necessary to minimize a criterion connected with dispersion of terminal state vector components. New numerical algorithm for the problem solution is proposed. This algorithm is based on Monte-Carlo method modification. It is possible to obtain the optimal stochastic control program in pitch and yaw channels and to reduce the criterion using this program.*

1. INTRODUCTION

This paper considers the problem of optimal stochastic program design for a penultimate stage of four-stage solid-propellant launcher.

The necessity of this problem solution is connected with inadmissible dispersions of terminal state vector components due to random disturbances. The initial state vector components and uncontrollable solid propellant motor thrust deviations are random. Such random disturbances were out of consideration during the nominal control program design. We'll try to reduce the dispersion of terminal state vector components using the stochastic control program. Such program design is the purpose of this paper.

The problem of terminal dispersion minimization was traditionally solved on the base of simplified or linear models of motion. Only approximate solution could be received in this case.

It is necessary to use a full nonlinear mathematical model for the exact problem solution.

Such problem solution is possible using Monte-Carlo method [1], results to inadmissible computational expenditures.

Therefore, a new accelerated method of stochastic control program design will be developed in this paper. A so-called confidential approach [2, 3] is the base of the new

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method. It will be possible to reduce computational expenditures for stochastic control program design in this case in comparison with a method, based on the Monte-Carlo simulation.

2. Problem statement

Let's involve a discrete model of launcher center mass motion [4]:

$$\left.\begin{aligned} z_{i+1}^1 &= z_i^1 + (W(t_i,\omega_1)\cos\vartheta(t_i)\cos\psi(t_i) + G_x)\tau, \\ z_{i+1}^2 &= z_i^2 + (W(t_i,\omega_1)\sin\psi(t_i) + G_y)\tau, \\ z_{i+1}^3 &= z_i^3 + (-W(t_i,\omega_1)\sin\vartheta(t_i)\cos\psi(t_i) + G_z)\tau, \\ z_{i+1}^4 &= z_i^4 + z_i^1\tau, \\ z_{i+1}^5 &= z_i^5 + z_i^2\tau, \\ z_{i+1}^6 &= z_i^6 + z_i^3\tau, \end{aligned}\right\} \quad (1)$$

here $z_i = col\,(z_i^1,...,\,z_i^6)$ – a state vector,

$z_i^1 = V_x$, $z_i^2 = V_y$, $z_i^3 = V_z$ – a velocities,

$z_i^4 = X$, $z_i^5 = Y$, $z_i^6 = Z$ – a coordinates,

$W(t_i,\omega_1)$ – a thrust acceleration, $\omega_1 \in N(0,1)$ – a random parameter,

G_x, G_y, G_z – a gravity accelerations, $\vartheta(t_i)$ – a pitch program,

$\psi(t_i)$ – a yaw program, τ – a discretization step, $t_i = i\tau$ – a time.

The initial launcher state vector is described by a mean value vector m_z and a covariance matrix K_z. In this case, it is possible to represent initial state vector as a linear function of random parameters $\omega_i \in N(0,1), i = \overline{2,7}$.

Let's represent the launcher motion model (1) in the most general form, i.e. as a discrete stochastic system:

$$z_{i+1} = f_i(z_i, u_i, x_i),\ i = \overline{1,N}, \quad (2)$$

here $z_i = col(z_i^1,...,z_i^m)$ - state vector in instant i;

$f_i(\cdot)$ - a continuous and differentiable vector function;

$u_i = col(u_i^1,...,u_i^s) = col(\vartheta(t_i),\psi(t_i)) = col(\vartheta_i,\psi_i)$ - a control vector parameters in instant i;

$x_i = col(x_i^1,...,x_i^n)$ - a vector of random disturbances in instant i;

$x_i = x_i(\omega), i = \overline{1,N}, \omega = col(\omega_1,...,\omega_7)$,

N – steps number.

Let's involve a terminal criterion describing successful launcher mission implementation as a random event:

$$J = F(z_{N+1}) \quad (3)$$

This criterion is continuous and differentiable with respect to argument z_{N+1}.

According to model (2), the terminal state vector z_{N+1} property depends on both random vector $x = col(x_1,...x_N)$ and random vector ω, and also on control vector $u = col(u_1,...u_N)$. Then the primary criterion (3) can be represented as follows:

$$J = F(z_{N+1}(u,\omega)) = \Phi(u,\omega). \quad (4)$$

The criterion $\Phi(u,x)$ is a random value. It is impossible to use such criterion directly in optimization problem.

Consider quantile [2]:

$$\Phi_\alpha(u) = \min\{\varphi : P_\varphi(u) \geq \alpha\}, \quad (5)$$

where

$$P_\varphi(u) = \mathrm{P}\{\omega : \Phi(u,\omega) \leq \varphi\}. \quad (6)$$

The problem is to minimize quantile $\Phi_\alpha(u)$ by $u_i, i = \overline{1,N}$:

$$\Phi_\alpha = \inf_{u_i, i=\overline{1,N}} \Phi_\alpha(u), \quad (7)$$

where control vector components $u_i, i = \overline{1,N}$ are the functions of step number only.

3. Equivalent optimization problem

We will use the so-called confidential approach for the problem (5), (6) solution [2, 3]. On the base of this approach the initial problem (5), (6) can be replaced to equivalent problem:

$$\Phi_\alpha = \inf_{u_i, i=\overline{1,N}} \inf_{E\in \overline{\mathrm{E}}_\alpha} \sup_{\omega\in E} \Phi(u,\omega), \quad (8)$$

here $E \in \overline{\mathrm{E}}_\alpha$ - a confidential set with a probabilistic measure α, specific in space of vector ω, and also replaced to equivalent problem:

$$\Phi_\alpha = \inf_{u_i,\ i=\overline{1,N}} \sup_{D\in \overline{\mathrm{E}}^{1-\alpha}} \inf_{\omega\in D} \Phi(u,\omega). \quad (9)$$

here $D \in \overline{\mathrm{E}}^{1-\alpha}$ - a confidential set with a probabilistic measure $1-\alpha$.

It is convenient to use equivalent optimization problems by a pair:

$$\left.\begin{aligned} \Phi_\alpha &= \inf_{E\in \overline{\mathrm{E}}_\alpha} \inf_{u_i, i=\overline{1,N}} \sup_{\omega\in E} \Phi(u,\omega) \\ \Phi_\alpha(u^*) &= \sup_{D\in \overline{\mathrm{E}}^{1-\alpha}} \inf_{\omega\in D} \Phi(u^*,\omega) \end{aligned}\right\}. \quad (10)$$

Both optimal control vector u^* and optimal confidential set E^* will be calculated on the base of first equation, and optimum confidential set D^* will be calculated on the base of second equation. It is possible to check values of both upper and lover quantile estimations simultaneously.

4. Algorithm of control program optimization

The algorithm of control program optimization based on the equivalent problems of probabilistic optimization is as follows:

1. The required probability magnitude α should be given in advance.
2. The initial approximation of control vector magnitude u^0 is set. The series of fixed directions r^i, $i=\overline{1,p}$ purposed for control program optimization is set also.
3. The initial confidential set E_0, $P(E_0)=\alpha$, is set as sphere, and the set $D_0=R^7\backslash E_0$ is set also.
4. The random point network A_0, consisting points ω^i, $i=\overline{1,K}$, is created in space R^7.
5. The function $\Phi(u,\omega)$ is calculated in all specific points $\omega^i, i=\overline{1,K}$ of network A_0 in a case of specific vector u^0 as $\Phi(u^0,\omega^i), i=\overline{1,K}$.
6. A set of the following points is determined on E_0:

$$\omega^{*j}=\arg\max_{i=\overline{1,K}}\Phi(u^0,\omega^i),\ j=\overline{1,s}\,. \tag{11}$$

A set of the following points is determined on D_0:

$$\omega_*{}^j=\arg\min_{i=\overline{1,K}}\Phi(u^0,\omega^i),\ j=\overline{1,q}. \tag{12}$$

7. The following integrated system is calculated in inverse time for everyone ω^{*j}, $j=\overline{1,s}$:

$$\Psi_i=\frac{\partial f_i(z_i,u_i,\omega^{*j})}{\partial z_i}\Psi_{i+1},\ \Psi_{N+1}=\frac{\partial F(z_{N+1})}{\partial z_{N+1}} \tag{13}$$

The expression for the partial derivatives $\frac{\partial f_i(z_i,u_i,\omega^{*j})}{\partial z_i}, i=\overline{1,N}$ should be obtained analytically before. Note, that magnitudes of vectors $z_i, i=\overline{1,N}$ were calculated before (item 5). The following magnitudes are calculated simultaneously:

$$\frac{\partial\Phi(u,\omega^{*j})}{\partial u_i}=\frac{\partial f_i(z_i,u_i,\omega^{*j})}{\partial u_i}\Psi_{i+1},\ i=\overline{1,N}, \tag{14}$$

where the expressions for the partial derivatives $\frac{\partial f_i(z_i,u_i,\omega^{*j})}{\partial u_i}, i=\overline{1,N}$ should be obtained analytically before.

8. The following condition fulfillment is checked up:

$$\min_{r^i,i=\overline{1,p}}\frac{\partial F^*(E,u)}{\partial r^i}\geq 0, \tag{15}$$

here

$$\frac{\partial F^*(E,u)}{\partial r^i}=\max_{\omega^{*j},j=\overline{1,s}}\left(\frac{\partial\Phi(u,\omega^{*j})}{\partial u}r^i\right) \tag{16}$$

Let's assume that the control program is optimal $u^*(E_0)$ in a case of condition (16) fulfillment. The transition to item 11 implements.

Otherwise, the motion direction is selected as:

$$r^{*0} = \arg \min_{r^i, i=\overline{1,p}} \frac{\partial F^*(E,u)}{\partial r^i} . \quad (17)$$

9. The following approximation of control vector is calculated as:

$$u^1 = u^0 + h^0 r^{*0} . \quad (18)$$

10. The following condition fulfillment is checked up:

$$\left| \frac{\partial F^*(E_0, u^0)}{\partial r^*} \right| < \varepsilon_f , \quad (19)$$

where $\varepsilon_f > 0$ - a specific number. Let's assume that the control program is optimal $u^*(E_0)$ in a case of condition (19) fulfillment. The transition to item 11 implements.

Otherwise, transition to item 5 implements, taking into account a substitution u^1 instead u^0.

11. The function $\Phi(u,\omega)$ is calculated in all specific points $\omega^i, i = \overline{1,K}$ of network A_0 in a case of specific vector $u^*(E_0)$ as $\Phi(u^*(E_0), \omega^i), i = \overline{1,K}$.

12. The set of points ω^{*j} , $j = \overline{1,s}$ is determined by expression (11). The set of points $\omega_*{}^j$, $j = \overline{1,q}$ is determined by expression (12).

13. The following condition fulfillment is checked up:

$$\Phi(u^*(D_0), \omega_*{}^1) \geq \Phi(u^*(E_0), \omega^{*1}) . \quad (20)$$

Assume that the both sets are optimal (E^* and D^*) in a case of condition (20) fulfillment. The transition to item 16 implements. Otherwise, transition to item 14 implements.

14. One point $\omega_*{}^j$ is transmitted from the set D_0 to the set E_0.

15. One point ω^{*j} is transmitted from the set E_0 to the set D_0.

Finally we will obtain both a new sets E_1 and D_1.

16. Assume that a sphere of maximum volume is entered in the set E^* as the subset $\Omega_1 \subset E^*$. Let's assume also that a sphere of minimum volume is circumscribed rather the set E^*, i.e. the subset $\overline{\Omega}_3 \subset E^*$. The subset Ω_3 complements subset $\overline{\Omega}_3$ till the whole space R^7, $\Omega_3 = R^7 \setminus \overline{\Omega}_3$. The subset Ω_2 complements subset ($\Omega_1 \cup \Omega_3$) till the whole space R^7, $\Omega_2 = R^7 \setminus \Omega_1 \setminus \Omega_3$.

17. Assume, that we have obtained new K realizations ω_i , $i = \overline{K+1, 2K}$ of random vector ω with the probability density $p_1(\omega)$ in the space R^7. The random point network A_1, consisting both the old points $\omega^i, i = \overline{1,K}$ and the new points ω_i, $i = \overline{K+1, 2K}$, is created in space R^7.

18. The function $\Phi(u,\omega)$ is calculated in all new specific points ω_i , $i = \overline{K+1, 2K}$ of

network A_1 in a case of specific vector $u^*(E^*)$ as $\Phi(u^*(E^*),\omega^i), i=\overline{K+1,2K}$. The optimal control vector $u^*(E^*)$ is considered as initial approximation u^0. The transition to item 6 implements.

5. THE PROCEDURE OF RANDOM POINTS NETWORK CREATION

The procedure of the random points network creation could be presented as following steps:

1. Assume that we have obtain K realizations ω_i, $i=\overline{1,K}$ of random vector ω with the initial probability density $p(\omega)$ in the space R^7. The points ω_i, $i=\overline{1,K}$ are considered as points of network A. The each point ω_i belongs to a set $\theta_i(x_i)=\theta_i \in R^7$, $i=\overline{1,K}$ with a probabilistic measure $\mathrm{P}(\theta_i)=1/K$, $i=\overline{1,K}$, $\bigcup_{i=1}^{K}\theta_i = R^7$, $\sum_{i=1}^{K}\mathrm{P}(\theta_i)=1$.

2. The initial set E_0, which is the sphere of r_0 radius with the probabilistic measure $\mathrm{P}(E_0)$, is set in R^7 space. The set D_0 complements the set E_0 till to space R^7: $D_0=\overline{E}_0=R^7 \setminus E_0$, and it has a probabilistic measure $\mathrm{P}(D_0)=1-\mathrm{P}(E_0)$.

3. Assume that the set E_0 includes the sets θ_i , $i=\overline{1,l}$: $E_0=\bigcup_{i=1}^{l}\theta_i$, $\omega_i \in E_0$, $i=\overline{1,l}$, and set D_0 includes the sets θ_i , $i=\overline{l+1,K}$: $D_0=\bigcup_{i=l+1}^{K}\theta_i$, $\omega_i \in D_0$, $i=\overline{l+1,K}$. Then

$$\mathrm{P}(E_0) \approx \sum_{i=1}^{l}\mathrm{P}(\theta_i(\omega_i \in E_0)) , \ \mathrm{P}(D_0) \approx \sum_{i=l+1}^{K}\mathrm{P}(\theta_i(\omega_i \in D_0)) . \tag{21}$$

4. Suppose that some set $\theta_i(\omega_j \in E_0)$ is transferred from the set E_0 to the set D_0, and some set $\theta_k(\omega_k \in D_0)$ is transferred from the set D_0 to the set E_0. Then the set E_0 will obtain both: a negative volume increment $\delta E_0^- = \theta_j$ and a positive volume increment $\delta E_0^+ = \theta_k$. The set D_0 will obtain also both: the negative volume increment $\delta E_0^+ = \delta D_0^-$ and the positive volume increment $\delta E_0^- = \delta D_0^+$.

5. The volume increment $\delta E_0^+ = \delta D_0^-$ corresponds to a probabilistic measure increment $\mathrm{P}(\delta E_0^+)=\mathrm{P}(\delta D_0^-)=\mathrm{P}(\theta_j)$. The volume increment $\delta E_0^- = \delta D_0^+$ corresponds to the probabilistic measure increment $\mathrm{P}(\delta E_0^-)=\mathrm{P}(\delta D_0^+)=\mathrm{P}(\theta_k)$.

6. The both new set E_1 and D_1 will be obtained as two sets θ_j and θ_k transfer result:

$$E_1=(E_0 \setminus \delta E_0^-) \cup \delta E_0^+ , \tag{22}$$

$$D_1=(D_0 \setminus \delta D_0^-) \cup \delta D_0^+ , \tag{23}$$

with the probabilistic measures

$$\mathrm{P}(E_1)=\mathrm{P}(E_0)+\mathrm{P}(\delta E_0^+)-\mathrm{P}(\delta E_0^-) , \tag{24}$$

$$\mathrm{P}(D_1)=\mathrm{P}(D_0)+\mathrm{P}(\delta D_0^+)-\mathrm{P}(\delta D_0^-)=1-\mathrm{P}(E_1). \tag{25}$$

We will remark, that the previous expressions are formally correct in a case if only one set - θ_j or θ_k is transferred.

7. Assume that the space R^7 is subdivided on three not intersected subsets Ω_1, Ω_2 and Ω_3 with probabilistic measures $P(\Omega_1)$, $P(\Omega_2)$ and $P(\Omega_3)$ correspondingly, $R^7 = \Omega_1 \cup \Omega_2 \cup \Omega_3$, $\sum_{i=1}^{3} P(\Omega_i) = 1$. The first subset Ω_1 we'll accepted as a sphere with the radius r_1. The subset $\overline{\Omega}_3$ we'll accepted as a sphere by a radius $r_2 > r_1$. The third subset Ω_3 complements subset $\overline{\Omega}_3$ till the whole space R^7, $\Omega_3 = R^7 \setminus \overline{\Omega}_3$. The second subset Ω_2 we'll accepted as a ring with internal radius r_1 and external radius r_2. The subset Ω_2 complements subset $(\Omega_1 \cup \Omega_3)$ till the whole space R^7, $\Omega_2 = R^7 \setminus \Omega_1 \setminus \Omega_3$.

8. Involve a new probability density as:

$$p_1(\omega) = k_1 p(\omega), \begin{cases} k_1 < 1, \omega \in \Omega_1 \\ k_1 > 1, \omega \in \Omega_2 \\ k_1 < 1, \omega \in \Omega_3 \end{cases}. \tag{26}$$

Assume that we have obtain K_1 realizations ω_i, $i = \overline{1, K_1}$ of random vector ω with the probability density $p_1(\omega)$ on the subset Ω_1, K_2 realizations ω_i, $i = \overline{1, K_2}$ with the probability density $p_1(\omega)$ on the subset Ω_2, K_3 realizations ω_i, $i = \overline{1, K_3}$ of random vector ω with the probability density $p_1(\omega)$ on the subset Ω_3, $K_1 + K_2 + K_3 = K$. The points ω_i, $i = \overline{1, K}$ are considered as a new points of network A. The total number of points (taking into account the first realization series) is equal to $2K$. The each point ω_i belongs to a set $\theta_i(x_i) = \theta_i \in R^7$, $i = \overline{1, 2K}$ with the probabilistic measure $P(\theta_i) = P(\Omega_1)/K_{1\Sigma}$ in a case $\omega_i \in \Omega_1$, or with the probabilistic measure $P(\theta_i) = P(\Omega_2)/K_{2\Sigma}$ in a case $\omega_i \in \Omega_2$, or with a probabilistic measure $P(\theta_i) = P(\Omega_3)/K_{3\Sigma}$ in case $\omega_i \in \Omega_3$.

9. Now it is possible to repeat items 2–8 taking into account new probabilistic measures $P(\theta_i)$ of the sets θ_i, $i = \overline{1, 2K}$.

6. Numerical results

The control program optimization technique consists in utilization the specific numerical algorithm described above.

Let's consider basic expressions used.

We will involve an addition variable $z_i^7 = \omega_1$ and an appropriate equation for z_i^7 as:

$$z_{i+1}^7 = z_i^7 . \tag{27}$$

Consider a joint system (1), (27). The initial state vector $z_1 = col(z_1^1, ..., z_1^7)$ of joint system we'll describe as:

$$z_1 = A\overline{\omega} + B , \tag{28}$$

where a matrix $A = \begin{Vmatrix} A_1 & 0 \\ 0 & 1 \end{Vmatrix}$, a vector $B = \begin{Vmatrix} B_1 \\ 0 \end{Vmatrix}$,

a vector $\overline{\omega} = col(\omega_2, \omega_3, \omega_4, \omega_5, \omega_6, \omega_7, \omega_1)$, the mean values vector $m_z = B_1$ and the covariance matrix $K_z = A_1 A_1^T$.

Consider the partial derivatives matrix $\dfrac{\partial f(z_i, u_i)}{\partial z_i}$ of the joint system as:

$$\begin{pmatrix} 1 & 0 & 0 & -\mu\tau(\frac{r^2 - 3(z_i^4 + r_0)^2}{r^5}) & \mu\tau(\frac{3(z_i^4 + r_0)z_i^5}{r^5}) & \mu\tau(\frac{3(z_i^4 + r_0)z_i^6}{r^5}) & \frac{\partial f_1}{\partial z^7} \\ 0 & 1 & 0 & \mu\tau(\frac{3z_i^4 z_i^5}{r^5}) & -\mu\tau(\frac{r^2 - 3(z_i^5)^2}{r^5}) & \mu\tau(\frac{3z_i^4 z_i^6}{r^5}) & \frac{\partial f_2}{\partial z^7} \\ 0 & 0 & 1 & \mu\tau(\frac{3z_i^4 z_i^6}{r^5}) & \mu\tau(\frac{3z_i^5 z_i^6}{r^5}) & -\mu\tau(\frac{r^2 - 3(z_i^6)^2}{r^5}) & \frac{\partial f_3}{\partial z^7} \\ \tau & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & \tau & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & \tau & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 \end{pmatrix} \quad (29)$$

here μ – a gravity constant; r_0 – the Earth radius,
r – a range from the Earth center up to the launcher mass center,

$$r = \sqrt{(X + r_0)^2 + Y^2 + Z^2}; \quad (30)$$

$$\begin{aligned} \frac{\partial f_1}{\partial z^7} &= \frac{\partial W(t_i, z_i^7)}{\partial z^7} \cos\vartheta(t_i)\cos\psi(t_i)\tau, \\ \frac{\partial f_2}{\partial z^7} &= \frac{\partial W(t_i, z_i^7)}{\partial z^7} \sin\psi(t_i)\tau, \\ \frac{\partial f_3}{\partial z^7} &= -\frac{\partial W(t_i, z_i^7)}{\partial z^7} \sin\vartheta(t_i)\cos\psi(t_i)\tau. \end{aligned} \quad (31)$$

Also, consider the partial derivatives matrix $\dfrac{\partial f(z_i, u_i)}{\partial u_i}$ of the joint system as:

$$\begin{pmatrix} -W(t_i, z_i^7)\tau\sin\vartheta(t_i)\cos\psi(t_i) & W(t_i, z_i^7)\tau\cos\vartheta(t_i)\sin\psi(t_i) \\ 0 & W(t_i, z_i^7)\tau\cos\psi(t_i) \\ -W(t_i, z_i^7)\tau\cos\vartheta(t_i)\cos\psi(t_i) & W(t_i, z_i^7)\tau\sin\vartheta(t_i)\sin\psi(t_i) \\ 0 & 0 \\ 0 & 0 \\ 0 & 0 \\ 0 & 0 \end{pmatrix}. \quad (32)$$

We will substitute the obtained expressions in the numerical algorithm of control program optimization, described above.

Both the nominal and the optimal pitch programs are shown on Fig. 1.

Let's discuss the numerical results of control program optimization.

The quantile magnitude, correspond to initial nominal control program in pitch and yaw channels, is equal to 0,862.

The quantile magnitude, correspond to optimal control program in pitch and yaw channels, is equal to 0,811.

The obtained result shows that it is possible to reduce the quantile magnitude on 5,9%.

It is connected with a solid propellant motor thrust singularity. The "maximal" thrust corresponds to "minimal" motor burnout time and the "minimal" thrust correspond to "maximal" motor burnout time. Moreover, the "maximal" and the "minimal" thrust results to different terminal state vector deviations.

The described thrust singularity was out of consideration during the nominal control program design. The nominal thrust was taken into account only.

The optimal control program was design on the base of the random thrust properties. The first part of optimal program partially compensate the "maximal" thrust, the second part partially compensate the "minimal" thrust.

The obtained results also show the high efficiency of offered optimization algorithm in comparison with optimization algorithm, based on standard Monte-Carlo simulation. It is possible to reduce the computation expenditures in two times totally.

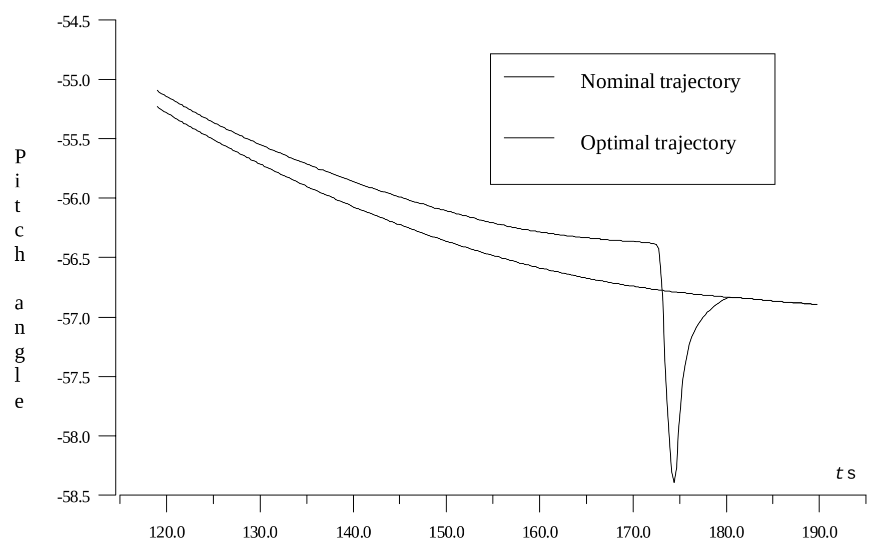

Fig. 1. Both the nominal and the optimal pitch programs

7. CONCLUSION

The following results was obtained in this paper:

1. The new numerical algorithm of stochastic control program optimization is offered. This algorithm has high efficiency level in comparison with optimization algorithm, based on standard Monte-Carlo simulation.

2. The stochastic problem of launcher control program optimization was solved. It is possible to reduce the terminal criterion on 5,9% in comparison with the deterministic nominal control program.

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KONSTRUISANJE OPTIMALNE VEROVATNOSNE TRAJEKTORIJE NELINEARNOG SISTEMA

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Razmatra se stohastički problem konstruisanja optimalne trajektorije lansera. Lansirni motor sa čvrstim pogonskim gorivom ima odstupanja potiska koja se ne mogu kontrolisati. Varijacije potiska, kao i vektora početnog stanja su slučajne. Neophodno je da se minimizuje kriterijum povezan sa disperzijom komponenti vektora graničnog stanja. Predložen je novi numerički algoritam za rešavanje problema. Ovaj algoritam je zasnovan na modifikaciji Monte-Carlo metoda. Moguće je da se dobije program optimalne stohastičke kontrole u kanalima "pitch" i "yaw" i da se redukuje ovaj kriterijum korišćenjem ovog programa.