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Influence of Mass Parameters Modification on Manoeuvrability of 9K33 „OSA" Set 9M33M3 Missile

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Abstract. This paper discusses analytical method for realization of preliminary missile stability design calculations. Action has been taken to estimate influence of replacing massive blocks of analogue electronics with compact solutions of digital electronics in missiles remaining in operation. On an example of a short-range 9M33M3 missile from 9K33 „OSA" set and its previously analysed aerodynamic characteristics, the analysis of the centre of gravity location impact was carried out to determine maximum loads occurring in the two most interesting phases of flight: after booster engine burnout and directly after cruise engine burnout. The suggestion for modification suggestion of flight parameters' optimization is presented which defines stability and its critical impact of these parameters on aeronautical engineering. For the tested missile, the methodology suggestions for the modification is discussed with the comparison of serially produced copies to define the ability of improving the flight parameters.

The paper includes visualizations and quantity analysis of: maximal loads on the fuselage, minimal turn radius, and control wing inclination angle as missile's angle of attack function.
Keywords: flight mechanics, short-range missile, missile stability

1. INTRODUCTION

Stability is a basic issue during preliminary design of flying objects. Statically stable systems have the ability to self-reduce the deflections from the equilibrium. On the other hand, statically unstable systems tend to continue diverging from the neutral position. It is crucial, especially in rocket dynamics due to all the rapidly changing conditions and the need to counteract them with an autopilot installation. Most of the modern units are developed with almost none static margin, what makes the exact prediction of the amount in conceptual design hard task. Even minor changes in the centre of gravity location may result in huge rocket properties deviation. Moving the centre of gravity, by changing internal modules with different densities placement, does not affect the geometrical parameters and we can linearly adapt the margin along the roll axis. It directly modifies the maximal available angle of attack and in addition to the mass lose increase in critical overloads occurs.

Analytical semi-empirical correlations for aerodynamics are taken from 'slender body', 'linear wing', and 'body cross flow' theory. Basing on them for the geometrical parameters of 9M33M3 missile from Table 1, the calculations of aerodynamic coefficients for the surfaces have been done and the moments hinged in the centre of gravity have been balanced. They are not the substantive part of the article, hence certain of the exact values were omitted.

In the 9K33 „OSA" set 9M33M3 missile, put into operation in 1971, the massive, analogue, electronical executive system is used and both internal and external waveguides for the communication purposes with overall weight of 7.3 kg. Nowadays, fully functional system can be replaced with on-board computer with mass not exceeding 200 g. In case of reconfiguration of the location of a warhead system onto the place of executive system, it is possible to improve missile stability and its manoeuvrability. Effects of an exchange without movement have been also discussed. Two main states of missile's flight have been investigated – booster engine burnout and the flight right after cruise engine burnout with maximal velocity for Mach number equal to 1.5. Table 2 presents the values changing during such a movement. The maximal velocity is considered for standard atmosphere conditions.

Table 1. Geometrical parameters of the missile

Missile length	3.158		m
Diameter	0.208		m
Nose length	0.818		m
Nose bluntness	6%		-
	Wing	Tail	
Surface	0.021	0.096	m^2
Mean aerodynamic chord	0.136	0.244	m
Leading edge sweep	46	45	deg
Aspect ratio	0.969	1.365	-
Taper ratio	0.461	0.385	-
Station from the nose	0.495	2.78	m
Root chord	0.178	0.33	m
Maximal surface deflection	13	-	deg

Table 2. Mass decrease and change in the centre of gravity location before and after

	Original unit	Moved warhead	Without mass centres movement
After booster burnout	109.3 kg	101.8 kg	101.8 kg
	1805 mm	1791 mm	1843 mm
After cruise burnout	69.6 kg	62.1 kg	62.1 kg
	1652 mm	1609 mm	1695 mm

2. EQUATIONS

Static margin has been defined as a difference between the location of the centre of pressure of surfaces and the centre of gravity of the missile related to the full missile length, according to equation (1).

$$SM = \frac{x_{AC} - x_{CG}}{L} \cdot 100\% \tag{1}$$

The centre of pressure is a point, where drag and lift do not create a moment forcing the change in an angle of attack. Total value is calculated as the weighted average of a product of a normal force and the centre of pressure for every aerodynamic surface taken into account.

$$x_{AC} = \frac{\sum C_{N\,i}\, x_{CP\,i}}{\sum C_{N\,i}} \tag{2}$$

In case of control surfaces, the centre of pressure is constant for different angles of attack. For Mach number of 1.5, it is equal to 529 mm from the nose for wing and to 2841 mm for the tail. However, it does not apply for the body considerations. Figure 1 presents a change in the centre of pressure on the body according to equation (3)

$$(X_{CP})_B = 0.63\, l_N\, (1 - \sin^2 \alpha) + 0.5\, l_B \sin^2 \alpha \tag{3}$$

where l_N is the nose length and l_B is the total body length.

Maximal angle of attack for the centre of pressure consideration has been set to value of 60 deg to produce data for examination of more than an original rocket build is capable of and determine the limits of allowable improvements. Further calculations are defined by the static stability's supremum and infimum.

3. RESULTS

By limiting observation only to one airfoil panel it is easy to define the impact of the surface on the stability. When the centre of pressure moves towards the tail with the fixed centre of gravity, it will positively affect the margin. It means that OSA's wings negatively impact the system, but their relatively small size is countered by the huge surface of the tail.

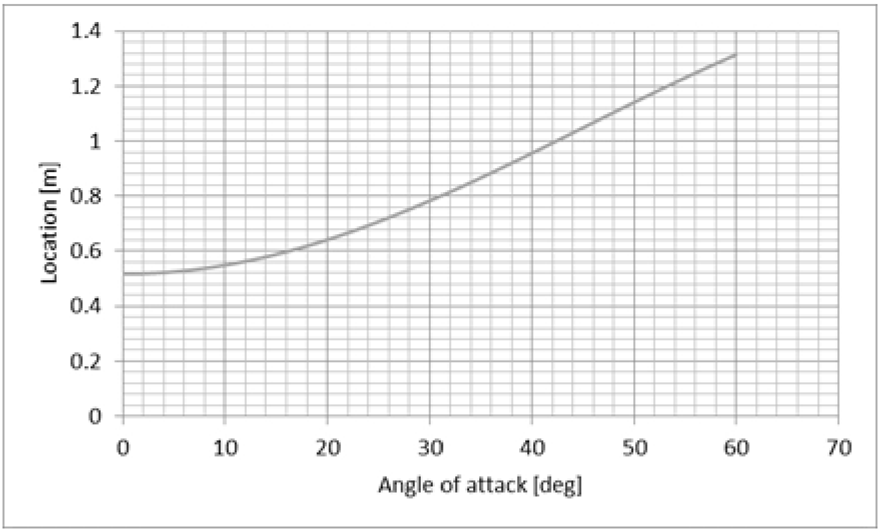

Fig. 1. Centre of pressure location from the nose

Static margin for the discussed states is shown in Fig. 2 and Fig. 3.

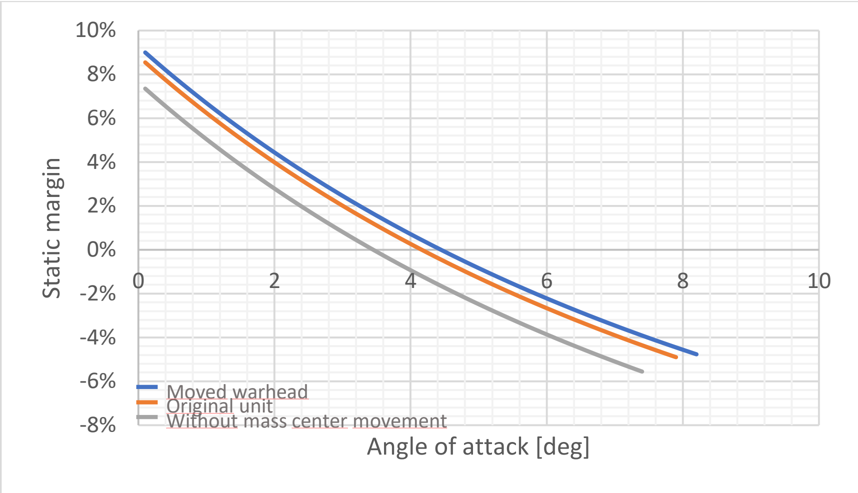

Fig. 2. Static stability margin as a function of angle of attack for the rocket after booster engine burnout

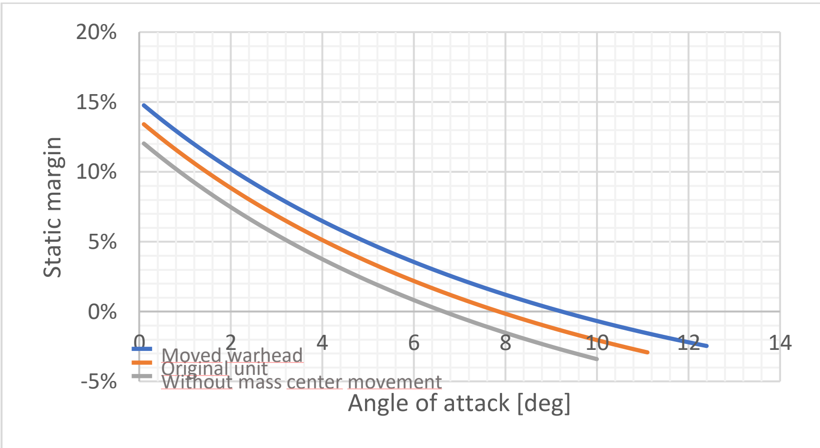

Fig. 3. Static stability margin as a function of angle of attack for the rocket after cruise engine burnout

Cross point on OX-axis is the position, where deflection of control surfaces changes to negative one. In case of not changing masses location of internal elements and reduction of mass by the replacement of an analogue system with a digital one, an angle of attack for the positive stability margin is 3.4°, for the original – 4.1° and with the movement of a warhead and the change for digital system it is equal to 4.4°.

After full burnout it is: 6.6º, 7.9º, and 9.2º. The parameters are getting worse with the modification of mass and without moving the warhead. In flight without fuel, stability increases for the full set of changes.

Control wing panel position has been determined for maintaining moment balance on all of the aerodynamic surfaces due to the acquired normal force coefficients for the wings on equation (4).

$$M_{tail}(\alpha) - M_{body}(\alpha) = M_{wing}(\delta_w) \quad (4)$$

where α is the angle of attack and δ_w is the control surface's deflection angle.

Fig. 4. Control wing panel position for maintaining the stability after booster engine burnout

Fig. 5. Control wing panel position for maintaining the stability after cruise engine burnout

Turn radius is the value to maintain the equilibrium during a sustained turn with control wings in a position of steady state flight for a given angle of attack, Eq. (5).

$$R(\alpha) = \frac{mV^2}{qC_{N\,total}(\alpha)S_{REF} + F_T sin\alpha} \tag{5}$$

where m is the mass of rocket, V is the velocity, q is the dynamic pressure, C_N is the total normal force perpendicular to the rocket body axis, S_{REF} is the reference area, and F_T is the thrust force.

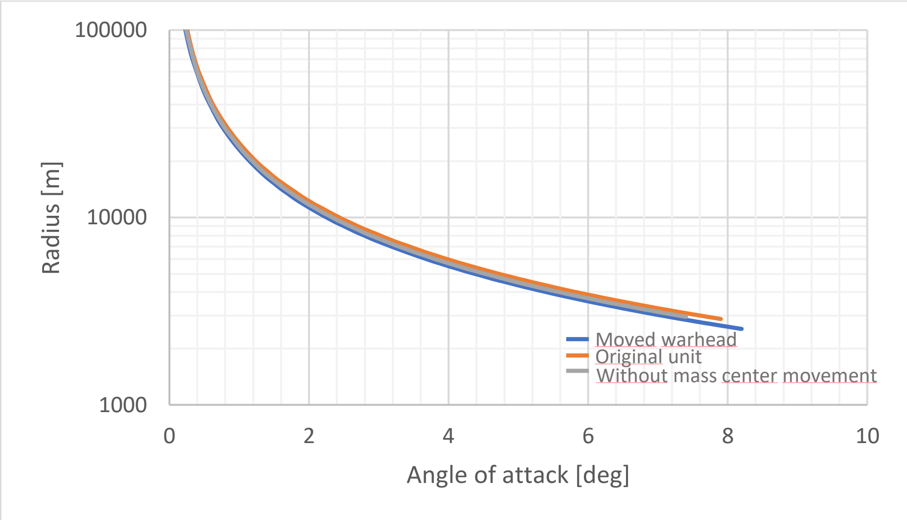

Fig. 6. Turn radius for constant velocity as a function of angle of attack for the rocket after booster engine burnout

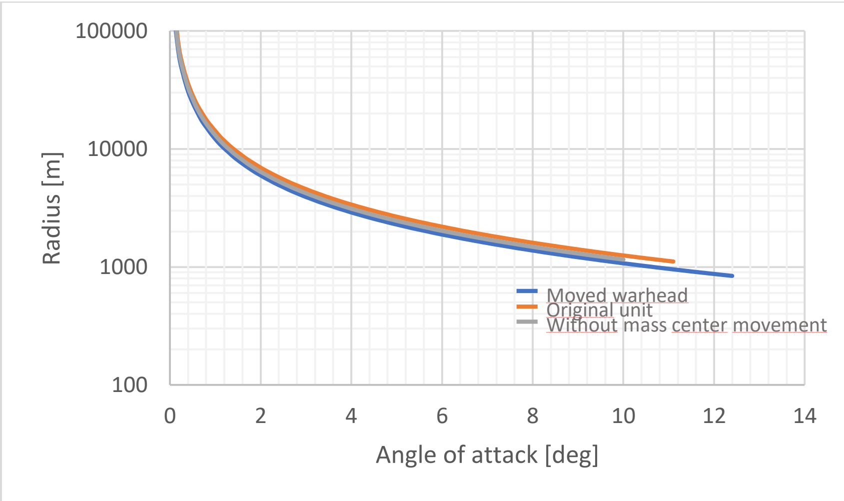

Fig. 7. Turn radius for constant velocity as a function of angle of attack for the rocket after cruise engine burnout.

Overloads' values come directly from turn radius values, Eq. (6).

$$g(\alpha) = \frac{V^2}{R(\alpha)} \tag{6}$$

Critical deflection of 13º is fixed. Figures 8 and 9 present maximal values of overloads for the modified missiles and original ones.

Fig. 8. Overloads comparison for maximal available angles of attack for the rocket after booster engine burnout

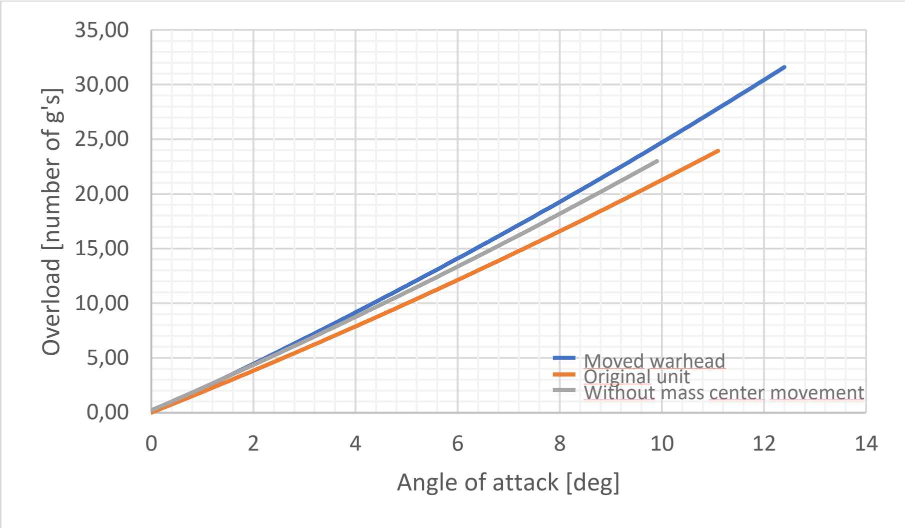

Fig. 9. Overloads comparison for maximal available angles of attack for the rocket after cruise engine burnout

Visible increase is caused by the mass decrease and rise of range of available missile angles of attack. Stability is limitation for even further growth of overloads, while the unit reaches maximal deflection angle faster, according to Fig. 6. and Fig. 7, which presents the convergence to lowering the radius. This means that the best results are provided by the missile with the lowered mass and moved warhead. Values of minimal turn radiuses are shown in Table 3., while maximal overloads are in Table 4.

Table 3. Minimal turn radius for maximal overloads' comparison

	Original unit	Moved warhead	Without mass centres movement
After booster burnout	2876 m	2545 m	2959 m
After cruise burnout	1110 m	840 m	1155 m

Table 4. Comparison of maximal overloads for the rocket in flight

	After booster burnout			After cruise burnout		
State	Original unit	Moved warhead	Without mass centres movement	Original unit	Moved warhead	Without mass centres movement
Maximal overload [g]	9.2	10.4	9.0	23.9	31.6	23.0
Difference	-	13%	-2%	-	32%	-4%

4. SUMMARY

Valuable changes are especially visible in the final phase of the flight – actually, the most important considering the need for critical overloads’ range availability due to attempt to take the most efficient path to reach the target. Substantial improvement is also noticed in an earlier phase. Nowadays, digital electronics devices almost ousted analogue devices, because of their compact sizes and mass. Analytically computed data are viable sources of information of the object, not only in a preliminary design, but also when defining the impact of certain improvements in actual units. The proposed modification significantly adjusts the serviceableness of the missile making it cheaper alternative for modern, and costly systems that are and not always available for customer.

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