PROBLEMS OF MECHATRONICS
ARMAMENT, AVIATION, SAFETY ENGINEERING

ISSN 2081-5891 12, 3(45), 2021, 111-122

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Strength Analysis of the MSBS-5.56B Rifle Handguard Assembly Loaded with an Under-Barrel Grenade Launcher

Michał GRĄZKA*, Ryszard WOŹNIAK, Mirosław ZAHOR

Military University of Technology,
Faculty of Mechatronics, Armament and Aerospace
2 Sylwestra Kaliskiego Str., 00-908 Warsaw, Poland
Corresponding author's e-mail address and ORCID:
michal.grazka@wat.edu.pl; https://orcid.org/0000-0003-0639-5755

Received: March 9, 2021 / Revised: April 12, 2021 / Accepted: May 11, 2021 / Published: September 30, 2021

DOI 10.5604/01.3001.0015.2431

Abstract. This paper presents the results of FEM (finite element method) numerical testing of the handguard of the MSBS-5.56B 5.56 mm calibre rifle complete with a 40 mm calibre under-barrel grenade launcher. The FEM calculations and the analysis of the calculations were intended to provide verification of the strength of the handguard subjected to the forces generated by the interaction with the grenade launcher during the launch of a grenade round. The results of the tests allowed the designers and process engineers to design the optimal shape of a handguard that will guarantee its safety during the operation of the rifle with the under-barrel grenade launcher.
Keywords: structural mechanics, FEM numerical analysis, armament

1. INTRODUCTION

The modern personal loadout of a soldier includes a great number of components (including firearm(s), magazine carriers/pouches, a bulletproof vest, a helmet, and impact resistans protectors) intended to enable operation in various combat theatre conditions, also beyond enemy lines. The most important part of the personal loadout, which demands utmost dependence, is the primary personal firearm, most often a rifle/carbine. Currently, the primary personal firearms in service for the Polish Army include 5.56 mm-calibre BERYL rifles and MINI BERYL SMGs (carbines), and the latest Polish 5.56 mm-calibre rifles, MSBS GROT (Photo 1) developed by the Military University of Technology (MUT) in Warsaw (Poland) and Fabryka Broni Łucznik Radom Sp. z o.o. (FB Radom, Poland) and introduced into service in late 2017 (with more than 35,000 of the MSBS GROT rifle manufactured by mid-2020).

Currently, MUT and FB Radom, under development project No. O ROB 0034 03 001 (Codename RAWAT) titled "Development, Production, and Structural and Technology Testing of the 5.56 mm-calibre Modular Small Arms System (MSBS-5.56)" co-funded by the Polish National Centre for Research and Development are researching and developing the 5.56 mm standard bullpup rifle, the MSBS-5.56B (Photo 2). Not unlike the MSBS GROT standard rifle, the MSBS-5.56B rifle can be provided with various accessories (including flashlights, optical scopes, laser sights, extra hand grips, etc.), which include a 40 mm under-barrel grenade launcher (Photo 2).

Photo 1. MSBS GROT 5.56 mm standard rifle version A0 (FB Radom)

Photo 2. MSBS-5.56B bullpup rifle prototype without a grenade launcher (top) and with the 40 mm calibre under-barrel grenade launcher (bottom) (FB Radom)

The installation of optional accessories exposes the firearm structure to additional forces, which may cause strain during operation. While static accessories, such as flashlights, sights, scopes or hand grips, only increase the mass of the carbine and shift its centre of gravity, dynamic-action accessories, such as a grenade launcher, exert additional stress on the strength of the firearm's structure during use. Firing a round from the grenade launcher, underslung below the carbine's centreline, generates multiple forces acting both on the handguard (to which the grenade launcher is attached) and the rifle structure.

This paper presents the results of a strength analysis of the critical components of the rifle, especially its handguard (an intermediate component providing an interface between the rifle and the grenade launcher), during firing from a grenade launcher, focused on the reliable interaction of the firearm with the underslung grenade launcher. Numerical calculations were performed to verify if the proposed design of the handguard and other bearing components of the rifle can ensure safe operation of the rifle and grenade launcher combination. This type of result obtained from computer-aided analysis could be applied in the future optimisation of the handguard design.

2. ANALYSIS OF THE MSBS-5.56B RIFLE STRUCTURAL DESIGN WITH THE UNDER-BARREL GRENADE LAUNCHER

The MSBS-5.56B standard bullpup rifle with and without a 40 mm calibre under-barrel grenade launcher is shown in Photo 3.

Photo 3. MSBS-5.56B rifle with the under-barrel grenade launcher: (1) – rifle; (2) – under-barrel grenade launcher; (3) – under-barrel grenade launcher sight; (4) – handguard (FB Radom)

The analysis revealed that the grenade launcher (2) attached to the rifle (1) and the grenade launcher sight (3) significantly changed the mass, size and inertial characteristics of the rifle-grenade launcher combination compared to the rifle alone. The centre of gravity of the firearm configuration was also changed (and displaced by approximately 30 mm forward, Photo 3). Firing the grenade launcher generates additional forces and moments, applied directly to the handguard – and subsequently to the rifle – which comprised a recoil force, a bending moment and a torsional moment (Photo 4), which significantly affected the durability and reliability of the handguard, used to provide the interface between the rifle and the grenade launcher.

For the analysis of the types of load acting on the grenade launcher body, the handguard, and the MSBS-5.56B rifle as a whole, it was necessary to perform FEM (finite element method) numerical calculations. This method helped reflect the stresses and strains in the rifle and grenade launcher structure generated upon firing the grenade launcher.

Photo 4. Forces and moments acting on the carbine-grenade launcher configuration when firing a grenade launcher round (courtesy: FB Radom): (1) direction of bending moment; (2) direction of torsional moment; (3) grenade launcher centreline; (4) direction of recoil forces; (5) rifle centreline

Before the FEM numerical calculations could be carried out, a suitable model had to be developed. The calculation model developed was a 3D model, based on previously prepared solid models applied during the design engineering work on the rifle and grenade launcher structures.

2.1. Numerical model of the MSBS-5.56B rifle with under-barrel grenade launcher

The CAD model developed at the design stage of the MSBS-5.56B rifle was tested with the 40 mm under-barrel grenade launcher (Fig. 1) but proved to be too accurate and detailed in terms of structure.

Fig. 1. CAD model of the rifle and the under-barrel grenade launcher before optimisation

Therefore, for the sake of the calculation process, the model was optimised (by simplification), eliminating those parts which did not significantly affect the accuracy of the numerical calculations but did increase the computing load and protracting the calculation time. The model developed for the numerical calculation had the following components removed: magazine with accessories, sights and parts of the trigger mechanism which do not directly transfer stresses and only actuate the process of firing a round. In addition, obsolete embossing, edge chamfers and rounding were removed. The geometry of the individual parts was simplified so that during the finite element mesh digitisation process the mesh did not generate numerical errors. The simplified CAD model of the rifle and grenade launcher is shown in Fig. 2.

(a) (b) (c)

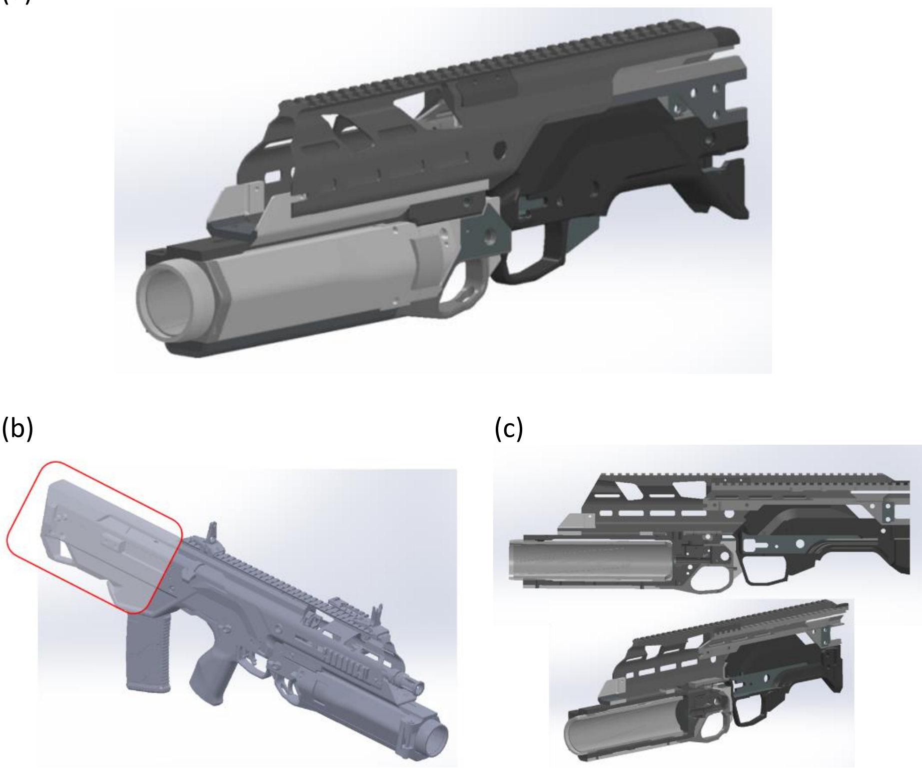

Fig. 2. Numerical calculation-optimised CAD model of the rifle with its under-barrel grenade launcher: (a) post-simplification model overview; (b) removed portion of the rifle; (c) cross-sectional view of the simplified model

The CAD model thus optimised was digitised with 4 mm single-node tetragonal elements (Fig. 3).

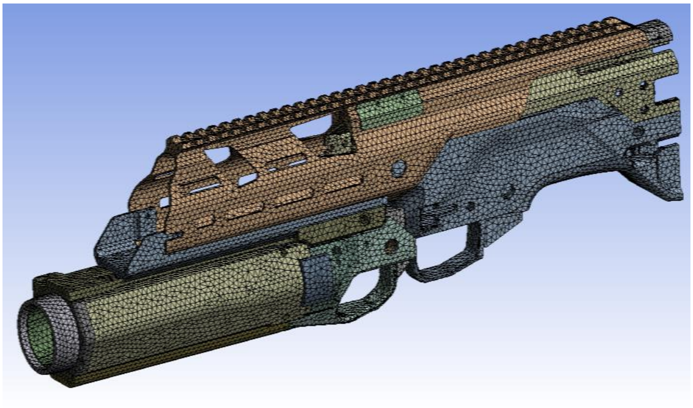

Fig. 3. CAD model divided with the finite element mesh

The digital model was loaded with an input (with application of initial-boundary conditions) the value of which was derived from the solution of the thermodynamic interior ballistics model for the 40 mm calibre under-barrel grenade launcher. The model was constrained in three axes on surfaces where the CAD model optimisation was performed (Fig. 4).

Fig. 4. The method of constraint and input loading applied in the calculation model: (1) input by forces acting to the barrel grooves; (2) input by the pressure behind the projectile in the barrel; (3) constraint of the calculation model in directions x, y, and z

The force and pressure inputs were applied to the surfaces of the grenade launcher. The pressure applied to the bottom of the grenade launcher breech chamber was 20 MPa. Another type of load adopted in the calculation model was that resulting from the effort of the grenade launcher projectile inside the barrel bore. The load was 4.3 kN, which resulted from the interaction between the projectile surface and barrel surface. The force value was calculated from a dynamic analysis of the grenade launcher projectile, which, in accelerating to a muzzle velocity of 80 m/s, applies the calculated force to the barrel bore. The calculated value of the force was applied to the surface of the barrel grooves, thus generating a force that pulled the barrel bore forward while a round was fired and produced a torsional moment.

2.2. Results of the handguard strain level calculations

The finished model was applied in the numerical calculations using an implicit static loading mode method. FEM was used as the calculation method. The results of the calculations allowed verification of the level of strain of the carbine handguard and of the grenade launcher under the maximum input load.

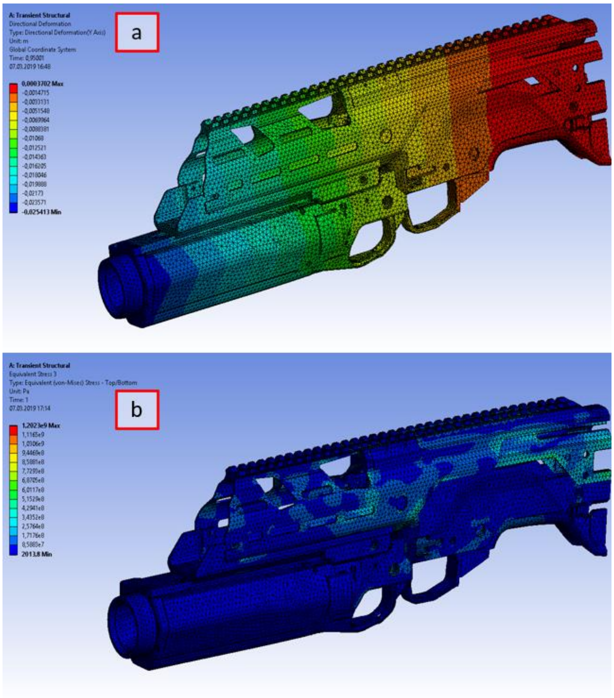

Fig. 5. View of the distribution maps for: (a) the H-M-H reduced strain level per the H-M-H hypothesis; (b) the H-M-H reduced stresses in the rifle-grenade launcher configuration

Figure 5 shows the level of strain of the structure at the moment of maximum load action and the distribution of the H-M-H reduced stresses on the surface of the handguard, the grenade launcher and the rifle.

As part of the tests, strength analysis was performed on the geometry of the handguard that accommodates the mounting of the grenade launcher to the rifle assembly. Figure 6 shows the distribution and level of the maximum strain which can occur in the structure of the handguard in each direction.

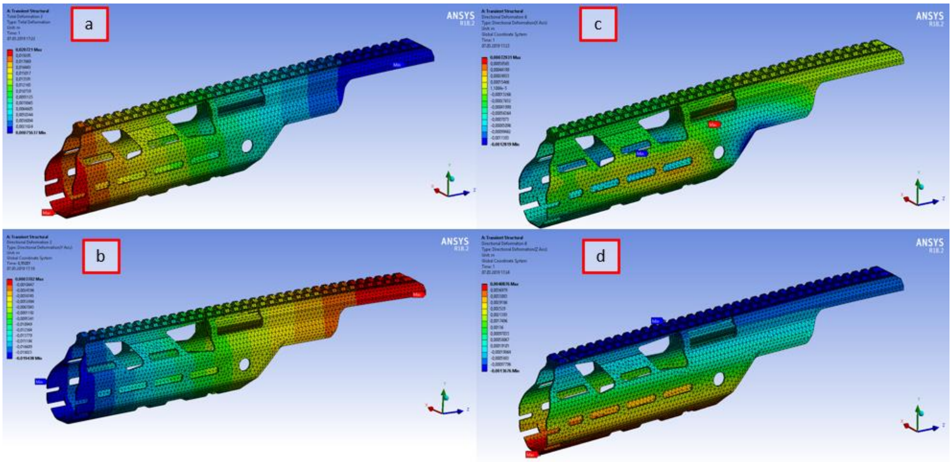

Fig. 6. Strain level distribution: (a) per the H-M-H hypothesis; (b) in the OY direction; (c) in the OX direction; (d) in the OZ direction

The results of the completed calculations showed that the proposed handguard structure underwent a strain of approximately 1.9 mm when exposed to the maximum permissible load imposed by the grenade launcher action. This was the maximum strain on the handguard in the along the OY axis and caused the handrail to bend. Since this strain achieved a value above 1 mm, it was necessary to verify that the handguard structure does not exceed the permissible elastic stresses, which might cause permanent deformation of the handguard, leading to its failure.

Figure 6 shows the distribution of the H-M-H reduced stress level on the surface of the handguard with the proposed geometry. The maximum value of the reduced stress calculated with FEM exceeded the yield point of the handguard material. However, the area in which this yield stress occurred suggests that it was the result of an error in the finite element mesh applied for the digitisation, and the finite element mesh was characterised by a numerical notch from the presence of a single node for three elements at the boundary of the model. An analysis of the range of stresses recorded on the remaining structure of the handguard showed no evident increase in stress above the yield point.

To confirm that the handguard structure was safe, the value of the safety factor k_t was determined. Figure 8 shows the distribution of the safety factor values for the handguard structure, which varied from 0.3 to 15. As the safety factor did not reach 0 or even a negative value at any point of the handguard, this indicated that the yield point was not exceeded.

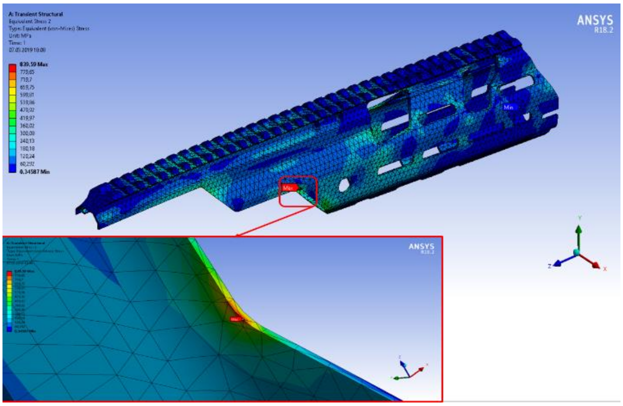

Fig. 7. H-M-H stress level distribution on the handguard structure

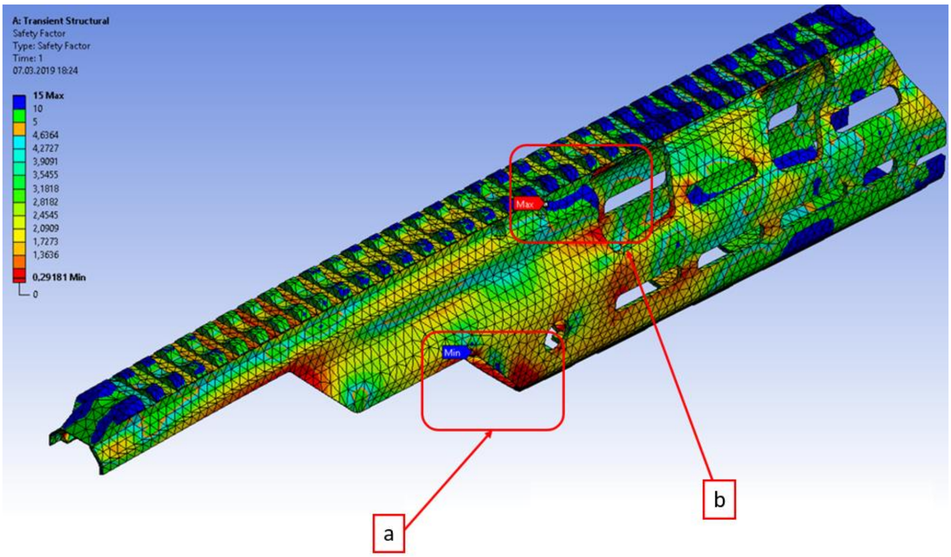

Fig. 8. Distribution of the safety factor *k*t values for the handguard: (a) the marked area had the lowest safety factor value; (b) this area had the highest safety factor value.

3. CONCLUSIONS

This paper presented the design of the MSBS GROT rifle. This firearm design is novel to the market of defence service armament in Poland. The effect of loads generated by firing an under-barrel grenade launcher on the carbine structure was tested numerically (by application of FEM analysis). The developed numerical calculation methodology demonstrated how the structure of a complex technical object such as this rifle can be simplified for use in engineering calculations. A number of simplifications were proposed in the design, based on the removal of elements not involved in the transfer of the loads generated by the grenade launcher action. The elements included the automatic firing gearing of the rifle, the sight system, and elements of the stock. All these elements increased the complexity of the tested system without significantly affecting the strength parameters of the rifle. Therefore, the system presented in this paper was optimal in terms of the size and number of elements necessary to test the structure of a rifle loaded with forces generated by an under-barrel grenade launcher.

The key element of the analysed structure was the handguard, providing the attachment/mounting point for the grenade launcher to the rifle structure. This component was responsible for transferring all the forces generated by firing the grenade launcher on the bearing structure of the rifle, followed by its operator. A hollow steel profile design with a wall thickness of 1 mm was used in this test. The average H-M-H stress value was approximately 180 MPa and below the yield point of 720 MPa for the material adopted for the calculations. The handguard structure proposed in these analyses was characterised by a high stiffness of 21,500,000 N/m, which allowed a minimum strain of approximately 1 mm at the moment of firing the grenade launcher. It should also be noted that the conditions that were assumed during the analysis were the most unfavourable that could occur in this type of construction. The applied load of 4.3 kN was the highest value of force that could occur at the moment of firing the grenade launcher. The method of analysis (the full restraint of one of the surfaces of the rifle) also caused the rifle structure to deform more than it would in real-life conditions, where the grenade round would be fired by a human operator the body mass of whom would absorb a part of the inertia forces generated by the grenade launcher and the rifle.

The developed mathematical model of the rifle and grenade launcher will also permit future optimisation of the mass of the handguard structure, which may have a positive impact on the mass of the entire rifle which is now in military service.

FUNDING

The paper contains the results of the R&D Project No O ROB 0034 03 001 financed by the Polish National Centre of Research and Development,

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Analiza wytrzymałościowa zespołu łoża karabinka MSBS-5,56B obciążonego granatnikiem podwieszanym

Michał GRĄZKA, Ryszard WOŹNIAK, Mirosław ZAHOR

Wojskowa Akademia Techniczna
ul. gen. Sylwestra Kaliskiego 2, 00-908 Warszawa

Streszczenie. Artykuł przedstawia wyniki badań numerycznych zespołu łoża 5,56 mm karabinka MSBS-5,56B zawierającego granatnik podwieszany kalibru 40 mm przeprowadzonych z wykorzystaniem metody elementów skończonych. Przeprowadzone obliczenia, a następnie analiza uzyskanych wyników miały na celu sprawdzenie wytrzymałości łoża, poddanego działaniu sił powstałych wskutek współpracy z granatnikiem podczas strzału. Wyniki badań pozwoliły konstruktorom i technologom zaprojektowanie optymalnego kształtu łoża, które będzie gwarantowało jego bezpieczeństwo podczas eksploatacji karabinka i granatnika.

Słowa kluczowe: mechanika konstrukcji, analiza numeryczna MES, uzbrojenie.