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A Concept for Striking Range Improvement of the GROM/PIORUN Man-Portable Air-Defence System

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Abstract. This paper presents a concept for striking distance performance improvement of the GROM/PIORUN Man-Portable Air-Defence System rocket missiles by increasing the rated diameter of the rocket missile propulsion system and its fuel charge weight. A mathematical and physical model of the GROM rocket missile was designed and its enhanced propulsion system was simulated in a computer environment. The computer simulation results were displayed on plot charts.
Keywords: mechanics, rocket missile, rocket engine, mathematical model.

This work has been compiled from the paper presented during the Conference on Ammunition & Rocket Missile Ordinance Industry for the Technical Upgrade of Polish Armed Forces, Chlewiska, Poland, 12 May 2016

1. INTRODUCTION

The GROM Man-Portable Air-Defence System (MPADS) is a VSHORAD platform which has been manufactured by the Polish defence industry since 1998. By mastering the manufacturing technologies of this armament type, Poland has become one of the world's very few producers of VSHORADs. Table 1 lists other manufacturers of man-portable air defence systems.

Table 1. Manufacturers of man-portable air-defence systems

Country	Product launch year	Rocket missile system
USSR / Russia	1966	Striela-2 (SA-7a, Grail)
	1971	Striela-2M (SA-7b, Grail)
	1974	Striela-2M1 (SA-7c, Grail)
	1976	Striela-3 (SA-14, Gremlin)
	1982	Igla SA-16 (Gimlet)
	2011	Vierba (Pussy Willow)
USA	1965	Redeye FIM-43A
	1978	Stinger FIM-92A
	1983	Stinger Post FIM-92B
	1989	Stinger RMP FIM-92C
United Kingdom	1972	Blowpipe
	1985	Javelin
	1986	Starstreak
	1989	Starburst
Sweden	1977	Ray Rider RBS 70
	1993	Ray Rider RBS 90
France	1987	Mistral SATCP
Poland	**1998**	**Grom**

Between the years 2010 and 2015, the GROM MPADS evolved into the GROM-M/PIORUN version (see Fig. 1). The evolution has improved the homing rocket missile warhead performance through enhanced target detection, thus increasing the target detection range; the GROM-M/PIORUN also boasts a higher interference resistance, increased striking radius, proximity detonator, access control authorization system, and night-time operating capability.

Fig. 1. GROM-M/PIORUN MPADS (courtesy of MESKO S.A.)

This paper proposes a concept of a further upgrade of the GROM/PIORUN MANPADS missile to provide it with enhanced range ratings. For the purpose of this concept, theoretical feasibility of applying an enhanced propulsion system was studied with the current potential and experience of the Polish defence industry.

2. SIMULATION TEST OBJECT: GROM MANPADS ROCKET MISSILE

The GROM MANPADS is intended for engagement of low-altitude aircraft (air planes and helicopters) in presence of natural and artificial thermal interference and on interception or pursuit trajectories within an identified striking zone. The GROM MANPADS performance ranks among similar air defence systems from leading global manufacturers. See Table 2 for specific technical and tactical performance ratings of the GROM MANPADS.

Table 2. GROM MANPADS technical & tactical performance [10, 14]

GROM MPADS technical & tactical performance	**Value**
System weight [kg]	16.5
Missile weight [kg]	10.25
Warhead weight [kg]	1.82
Launch system weight [kg]	1.85
Power supply system weight [kg]	1.35
Propellant charge weight [kg]	4.5
Missile length [mm]	1596
System length [mm]	1686
Rocket missile O.D. [mm]	72
Maximum flight velocity [m/s]	650
Average flight velocity [m/s]	580
Time to combat readiness [s]	13
Time from activation to launch readiness [s]	5
Time to self-destruction [s]	14 to 17
Minimum interception altitude [m]	10
Maximum flight altitude on intercept course [m]	2000 to 3000
Maximum striking ceiling on pursuit course [m]	2500 to 3500
Horizontal striking zone [m]	500 to 5000
Maximum target velocity receding [m/s]	360
Maximum target velocity on pursuit [m/s]	320
Jet aircraft heading [m]	2000
Piston engine aircraft / helicopter heading [m]	2500
Maximum target angular velocity [°/s]	12
Hit probability without interference	0.6
Hit probability with interference	0.4
Operating temperature range [°C]	-35^{o} to $+50^{o}$

3. MODELLING THE GROM MANPADS ROCKET MISSILE FLIGHT

The feasibility of an enhanced propulsion system application in the GROM MPADS missile was subjected to a theoretical analysis by using a numerical model built for this purpose. The development procedure of the numerical model had several stages (see Fig. 2) [1, 2, 3].

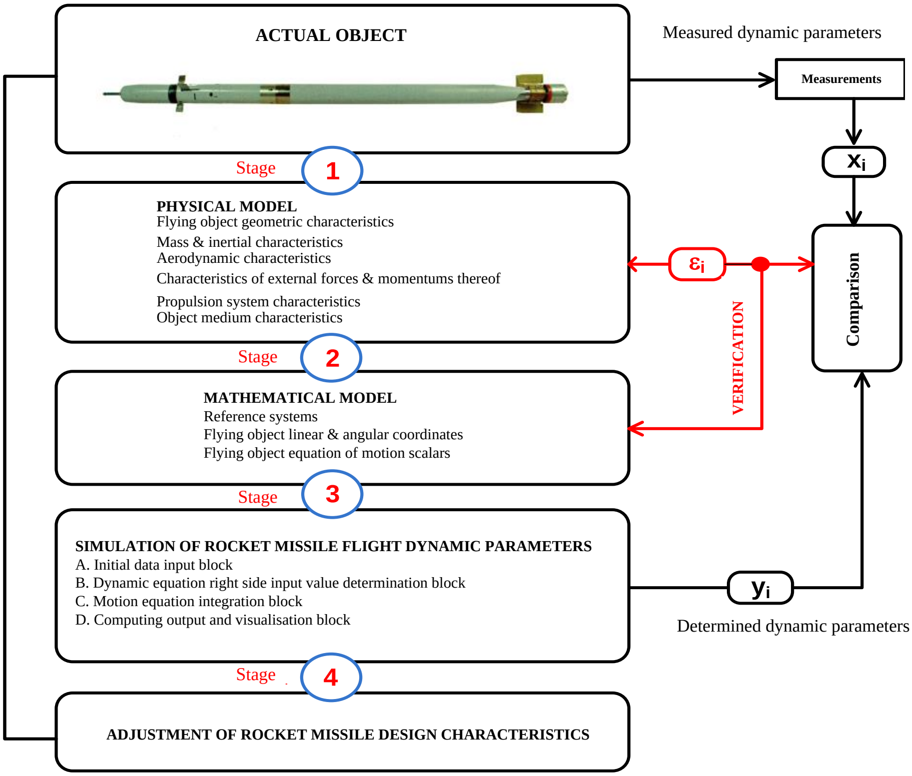

Fig. 2. Modelling procedure of the GROM MANPADS missile flight

Stage one was to idealize the actual object, i.e. the GROM MANPADS missile. The idealization deliverable was an abstract physical model, which was not a material model. The model included characteristics of geometry, mass and inertia, aerodynamics, the propulsion system, the motion and force centre, and the moments acting on the rocket missile in flight. Stage two involved mathematical modelling.

The deliverable was a model formed by a system of non-linear first-order differential equations. Stage three consisted in implementing these equations in Matlab (or MathCAD) to develop a numerical model.

Thus, the simulation model includes an initial data input block, a dynamic equation right side input value determination block, a motion equation integration block, as well as a computing output and visualisation block. Stage four included the verification of the simulation model. It was best to verify the simulation model by means of proving ground experimental results.

The verification permitted adjustment of the design characteristics of the contemplated rocket missile [4, 5].

3.1. Geometric & mass and inertial characteristics of the GROM MANPADS missile

The geometric characteristics shown in Fig. 3 and Table 3 included the length, diameter, control fin span, destabilizer span, and stabilizer span of the rocket missile. The accuracy of geometric parameters affected the accuracy of the numerical model.

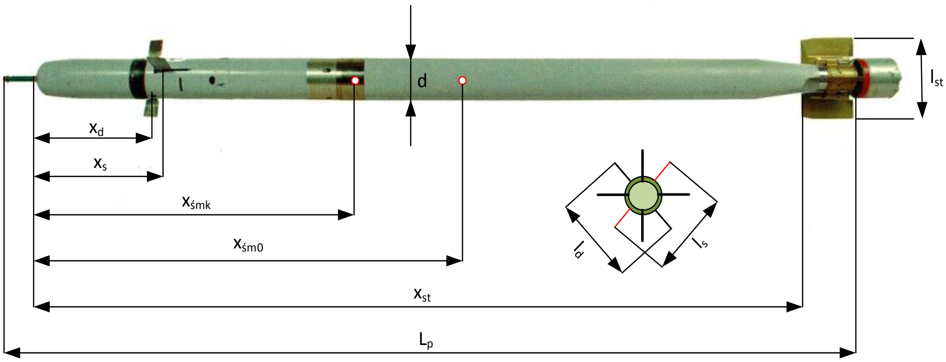

Fig. 3. Geometric characteristics of the GROM MANPADS missile

Due to the fuel charge burn during the flight of the GROM MANPADS missile, its overall weight, moments of inertia and the mass centre location changed by approximately 50% each. Table 4 shows the mass and inertial parameters of the GROM MANPADS missile.

Table 3. Geometric characteristics of the GROM MANPADS missile [11]

Parameter	**Designation**	**Value**
Missile length	L_p	1.5960 m
Missile diameter	d	0.072 m
Destabilizer attack edge coordinate	x_d	0.271 m
Control fin attack edge coordinate	x_s	0.295 m
Stabilizer attack edge coordinate	x_{st}	1.409 m
Destabilizer span	l_d	0.142 m
Control fin span	l_s	0.166 m
Stabilizer span	l_{st}	0.145 m

Table 4. Mass & inertial characteristics of the GROM MANPADS missile [11]

Parameter	**Designation**	**Value**
Missile initial weight	m_0	10.25 kg
Missile weight after fuel outburning	m_k	5.75 kg
Missile mass centre initial location	$x_{śmo}$	0.750 m
Missile mass centre location after fuel outburning	$x_{śmk}$	0.574 m
Stabilizer attack edge coordinate	x_{st}	1.409 m
Missile initial moment of inertia relative to transverse axis z	I_{z0}	1.6736 kg m^2
Missile moment of inertia relative to transverse axis z after fuel outburning	I_{zk}	1.0212 kg m^2

3.2. Propulsion system of the GROM MPADS rocket missile

The GROM missile had a two-stage 72 mm diameter propulsion system. Table 5 lists the basic parameters of this rocket engine under normal operating conditions (+15 deg. C). The total engine burn time was 6.9 s with a total impulse of 8.58 kNs.

Table 5. Propulsion system characteristics of the GROM MANPADS missile [13]

GROM MANPADS missile propulsion system parameters	Value
Rocket motor chamber casing O.D.	0.072 m
First stage thrust, average	3.2 kN
Second stage thrust, average	0.7 kN
First stage burning time, average	1.5 s
Second stage burning time, average	5.4 s
First stage total impulse	4.80 kNs
Second stage total impulse	3.78 kNs
Rocket motor total impulse	8.58 kNs

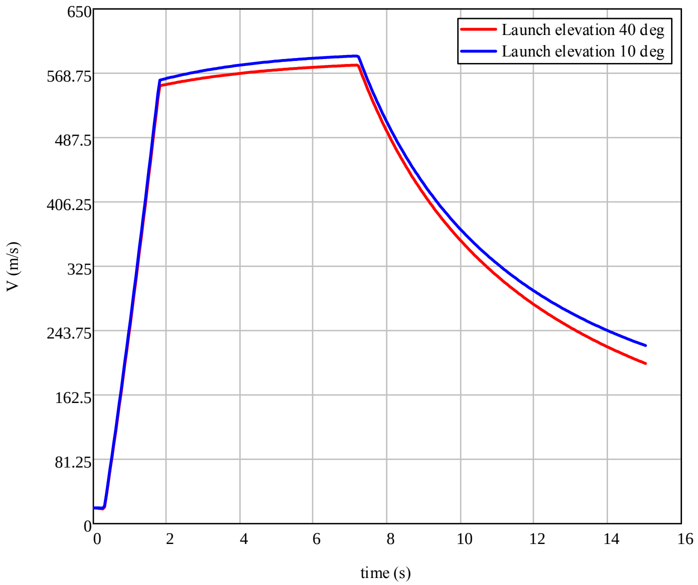

Fig. 4. Velocity of the GROM MANPADS missile launched at an angle of 10° and 40°

The rocket engine's first burn stage at a total impulse of 4.8 kNs exhibited a relatively large thrust, 3,2 kN, and a burn time of 1.5 s. At the end of the first stage burn, the GROM MANPADS missile reaches a velocity of 552 m/s.

The rocket engine’s second burn stage at a total impulse of 3.78 kNs had 0,7 kN of thrust during a burn time of 5.4 s. This thrust value ensured that the velocity developed during the first stage burn was maintained, and with a slight further increase to 610 m/s without sharp manoeuvring.

The plotted velocity vs. time of the GROM MPADS missile (see Fig. 4) at launch elevation angles of 10° and 40° was determined with the numerical model, which was consistent with the proving ground experimental results.

4. FEASIBILITY ANALYSIS OF EXTENDING THE GROM MANPADS RANGE

The range parameters of the GROM MPADS rocket missile could be enhanced by increasing the overall total impulse of its engine, which would require increasing the fuel charge quantity from the current 5 kg (approx. value). This would be feasible by increasing the propulsion compartment volume of the rocket missile, and without modifying the overall length of the latter. This concept was the subject of a numerical analysis with two variants shown in Figs. 5 and 6 and Table 6.

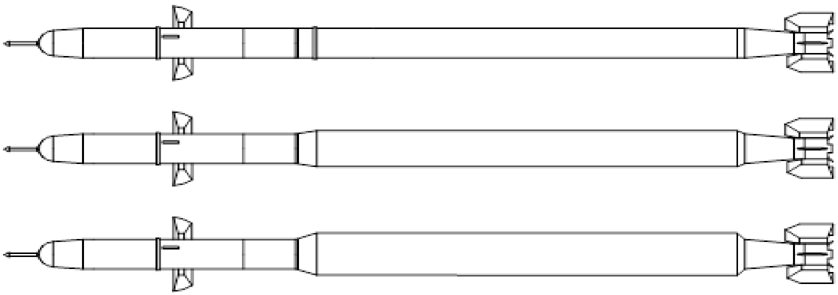

Fig. 5. Proposal for increasing the propulsion system diameter of the GROM MPADS missile

Table 6. Mass characteristics of the proposed new propulsion system for the GROM MPADS

Mass parameters	GROM	GROM-W1	GROM-W2
Missile initial weight	10.25 kg	13.5 kg	16 kg
Propellant charge weight	4.5 kg	7.2 kg	9 kg

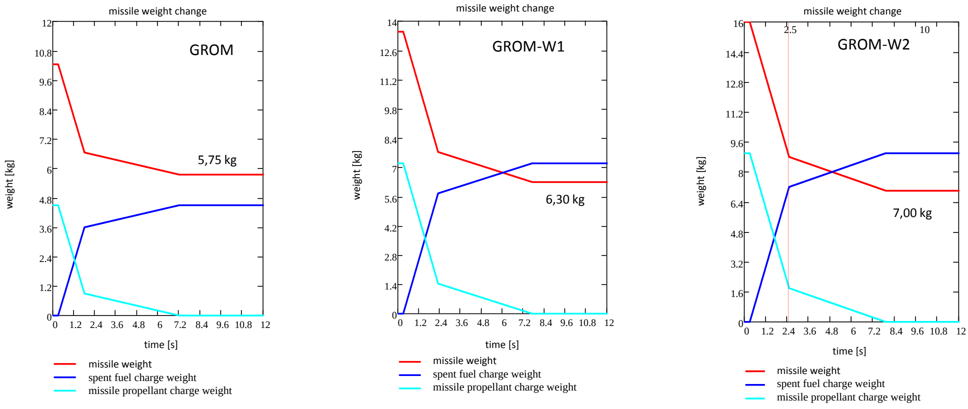

Fig. 6. Mass & inertial characteristics of the GROM MANPADS missile with the new propulsion system

Table 7. New propulsion system characteristics of the GROM MANPADS missile

Propulsion system parameters	**GROM**	**GROM-W1**	**GROM-W2**
Engine chamber casing O.D.	0.072 m	0.090 m	0.100 m
Stage one thrust	3.2 kN	3.8 kN	4.5 kN
Stage two thrust	0.7 kN	1.1 kN	1.3 kN
Stage one burn time	1.5 s	2 s	2.2 s
Stage two burn time	5.4 s	5.4 s	5.4 s
Stage one total impulse	4.80 kNs	7.60 kNs	9.90 kNs
Stage two total impulse	3.78 kNs	5.94 kNs	7.02 kNs
Overall total impulse	8.58 kNs	13.5 kNs	16.90 kNs

The change of the propulsion compartment O.D., resulting in a higher volume of fuel charge, would provide the characteristics of the new rocket engines as shown in Table 7 and Fig. 7. The rocket engine stage one burn times would be extended to the values shown below: GROM-W1: 2 s, GROM-W2: 2.2 s. However, the second stage burn time would remain unchanged from 5.4 s.

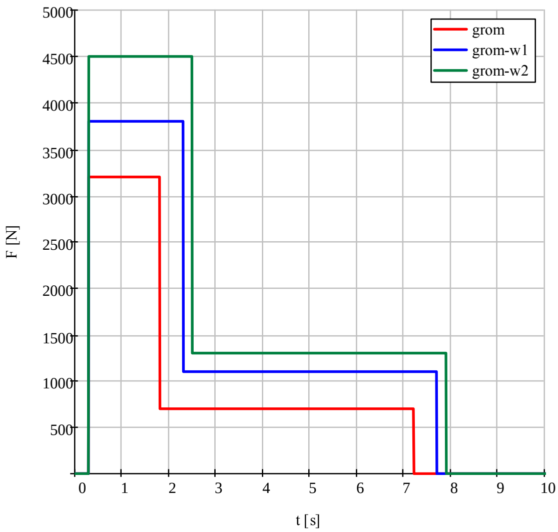

Fig. 7. Thrust vs. time burning for the proposed new propulsion systems of the GROM MANPADS missile

5. COMPUTER SIMULATION RESULTS

The delivered data on the enhanced rocket missile engines (i.e. the variants) were analysed with the numerical model developed for the GROM rocket missiles. The computer simulation initial conditions were: launching system elevation: 40°, rocket missile initial velocity: 20 m/s.

A selection of the computer simulation results are shown on range and velocity plot charts. The chart in Fig. 8 shows the velocity change of the GROM MPADS rocket missile in time. The simulation duration was 15 s. This was imposed by the self-termination time of the rocket missile which occurs between 14 and 17 seconds from launch. The computer simulation results were as follows:

– GROM-W1: maximum velocity 660 m/s, reduced to 630 m/s during the stage two burn, and reduced to 240 m/s at the 15th second from launch.
– GROM-W2: maximum velocity 728 m/s, reduced to 687 m/s during the second stage rocket motor operation, and reduced to 220 m/s at the 15th second from launch.

Note that the velocity changes slightly differ between the proposed new propulsion system variants and the current GROM MPADS engine evolution (see Figs. 4 and 8), especially during the second stage burning.

This is because of the characteristics assumed for the second stage burning of the enhanced propulsion systems.

The chart in Fig. 9 shows the missile flight trajectory (i.e. the GROM MPADS missile striking range). The vertical axis is the flight altitude, and the horizontal axis is the horizontal plane range.

The specific plots show the missile flight time down to the second. This helped study the missile flight trajectory to understand what distance it covers each second. Hence, the results were as follows:

– Current GROM evolution: range 5167 m and altitude 3853 m at the 15th second.
– GROM-W1: the 15th second range and altitude would increase by +30 m and +127 m, respectively.
– GROM-W2: the 15th second range and altitude would increase by 566 m and 569 m, respectively.

The results of this analysis applied to a zero-manoeuvre flight; as manoeuvring generally increases the aerodynamic drag and reduces the flight velocity. Hence, the simulated range and altitude of the missile were maximum values.

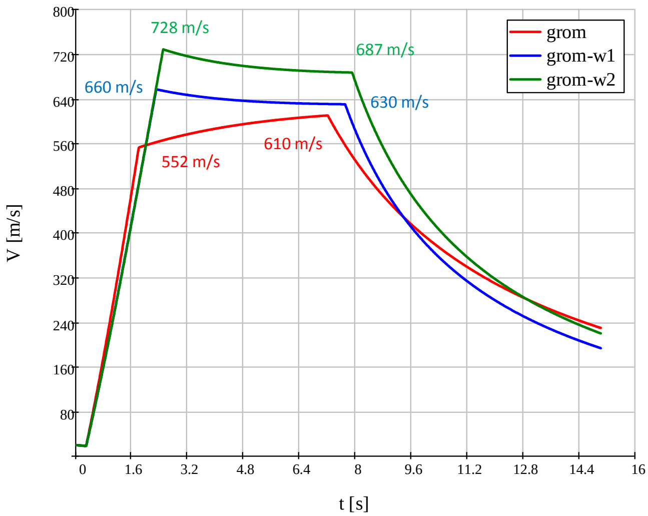

Fig. 8. GROM MANPADS missile velocity changes vs. time at the launch elevation of 40° with the simulated enhanced propulsion system variants

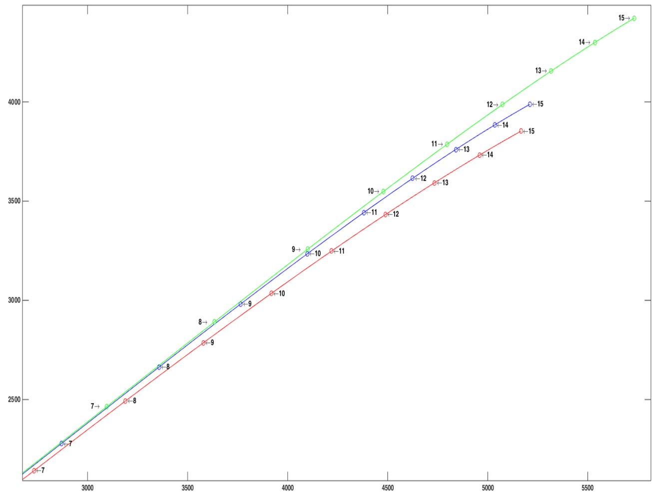

Fig. 9. GROM MANPADS missile flight trajectory from the launch at elevation of 40° with the simulated enhanced propulsion system variants (shown from the 7th second of the flight)

6. SUMMARY

1. The kinematic performance (range and velocity) of the current GROM propulsion system evolution is the possible maximum. An increase of the two parameters without redesigning the GROM MANPADS missile design could be achieved by replacing the fuel charge with a higher energy yielding material (e.g. as used in the VIERBA missile system) [12].
2. The proposed change of the propulsion engine compartment size (resulting in an increase of the fuel charge weight), without modifying the missile or the launching system length, would, by forecast, increase the combat performance by 10%. Hence, this approach to retrofitting the GROM MANPADS missile rocket motor is deemed not to be significantly effective.
3. A higher potential for combat performance enhancement could be gained by combining the increase of the propulsion motor chamber diameter and length. This, however, would increase the weight of the entire GROM MANPADS unit by over 25 kg. The contemplated evolution would render the GROM MANPADS no longer man-portable and more approximate in characteristics to mobile air defence systems, such as the POPRAD, BIALA, KUSZA, and similar.
4. However, the Polish defence industry is perfectly capable of evolving the GROM MPADS according to the concept discussed herein.

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Koncepcja zwiększenia zasięgu Przenośnego Przeciwlotniczego Zestawu Rakietowego GROM/PIORUN

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Streszczenie. W pracy przedstawiono koncepcję poprawy parametrów zasięgowych rakiety GROM/PIORUN poprzez zwiększenie średnicy układu napędowego i zwiększenie masy ładunku napędowego. Zbudowano model matematyczno-fizyczny pocisku GROM i przeprowadzono symulacje komputerowe z zastosowaniem wzmocnionego układu napędowego. Wyniki badań symulacyjnych przedstawiono w formie wykresów.

Słowa kluczowe: mechanika, pocisk rakietowy, silnik rakietowy, model matematyczny