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Investigation of the Basic Parameters for Alternative Solid Rocket Propellant Engines for Research and Civilian Use

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ABSTRACT

Investigation of the basic parameters for new generation of alternative solid rocket propellant engines for research and civilian use was implemented. This was caused from needs for substitution of the widely used construction materials of the aircraft units based on polymers and of petroleum composites. Numerous fire tests, both static and flight, in a real working environment of a new generation of environmentally friendly solid rocket propellant engines that are completely degradable in the nature were carried out. The obtained results after burning of rocket fuel for internal engine ballistics and thermo-mechanical coupled characteristics of composite materials are presented.

Keywords: rocket motors, fuselage, biodegradable composites, ecology.

INTRODUCTION

Solid propellant rocket engines are a closed combustion chamber made of high-melting material, in which combustible structure of a certain shape and pre-operating parameters are burned and simultaneously creating a large amount of gases. This gas mixture is under pressure in the engine chamber and exiting through the engine nozzle; it expands and creates the drive thrust of the racket. The operating pressure is a determining parameter for the stable work of the engine and is a function of the geometry of the solid fuel charge, its combustion surface and the critical diameter of the nozzle outlet.

The most used structural materials for making engine fuselage are the various types of steel, alloys of relatively light and high-melting metals, composite materials based on carbon and glass fibre and fabrics, in matrices of polyester and epoxy resins. For the production of nozzle blocks, many different heat-resistant materials with high strength are used - high-melting metals and alloys, graphite, high-temperature ceramics, composite of the carbon-carbon type, etc. In the civil sector, economic sector variants of nozzles are preferred - they are made of pressed clay and minerals, phenolic presses, or suitable combinations of metal and graphite [1].

The main groups of solid propellants used for rockets are gunpowder, ballistic and composite. The choice between them for a particular type of rocket engine is determined by the requirements for optimal specific impulse, operating conditions

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in the engine, reliability and safety in use, cost of components and manufacturing technology, physical and mechanical properties, durability and storage requirements, toxicity and problems during their disposal.

The serious problems caused by the mass use of rockets in the civil and military sectors are related to the toxicity and explosiveness of many components of their fuel, as well as the structural materials used in them.

The missile technology in the research and civilian sector has been based on existing military products that have been modified for their non-military application. This automatically transfers their shortcomings from the military sphere, where they were developed, to the civilian sector, where their new functions are assigned. This approach is clearly no longer relevant with today's high demands for a committed attitude towards the protection of human health and a clean environment, and requires a radically new philosophy in the design of missiles for research and civilian use [1]. An important element of this new approach is to use a highly differentiated mode in the design of each specific type of product, in which to precisely define the priority requirements for it and to comply with all the rules and norms related to its production and future operation.

The development of new prototypes and carry out tests of rocket engines, constructed entirely of innovative degradable materials intended for a specific research and civilian application are object of the present investigation. The other aim is creation of a new ecologically friendly formula for the composition of solid rocket propellant in the experimental engines.

EXPERIMENTAL

Two specific types of prototypes of engines were developed - one a model engine for amateur rockets with a theoretical full impulse in the range up to 40 N.s and an outer diameter of 30 mm, and other - a larger solid-fuel engine for experimental rockets with a theoretical full impulse in the range of up to 500 N.s and outer diameter 55 mm. Static and flight tests were conducted with these prototypes to prove their operability and to verify the theoretically assumed their parameters, obtained through software simulation [1].

The construction of both types of prototypes was made entirely of new created degradable materials [2, 3]. Their fuselage was made of multi-layered coiled tubes of natural fabrics in a matrix of gelatin, corn starch and technological additives, and the nozzle block and the front closing wall were made of alkali-activated materials (AAM) based on a combination of high-melting oxides, sodium silicate and sodium hydroxide [4 - 7]. The advantages of the material used in this way are related to the possibility of fast and cheap cold forming, the high heat resistance of the obtained parts and the easy mechanical processing to reach the final overall dimensions. The attachment of the nozzle block and the front wall of the engines to the fuselage are by means of a unique innovative system that was developed by the research team.

The solid fuels of the experimental engines are executed according to a formula created by members of the research group and are a variety of the so-called caramel fuels widely used by hobbyists around the world [8, 9]. The fuel element in it is a specific combination of natural fructose, obtained from fruits, in combination with the natural sweetener, obtained from sugar beets. As a result, a solid rocket propellant with a specific impulse sufficient for the purposes of its application, of natural origin, non-toxic, non-explosive, low-cost and extremely simple technology for molding by casting at a temperature of 145°C was obtained.

A series of ground static tests were conducted in order to determine the possible allowable operating pressure, thermal resistance, nozzle erosion and take internal ballistic characteristics of the prototype engines. The following parameters were being reached [1]:


(a)


(b)

Fig. 1. The static (a) and flight (b) tests.

- maximum working pressure in the combustion chamber 7.4 MPa;
- working temperature in the combustion chamber 1320°C;
- erosion in the critical diameter of the nozzle 11 %;
- comparison with pre-simulated ballistic characteristics 87 %.

After the static experiments, a series of flights tests were made with model rockets specially designed for the two types of tested engines, (Fig. 1).

The rockets were also constructed from degradable materials, which, in the event of a malfunction of the model and its loss, can be decomposed in a natural environment for a period of several months. These degradation times have been proven by experiments carried out with the construction materials in previous projects of the research group.

Additionally a planned experiment was conducted to determine the objective function, evaluate the coefficients and the adequacy of a proposed model describing the relationships between two independent input variables - the initial launch mass and the outer diameter of an assembled rocket model and the output - flight height at a vertical launch of 90°. For the implementation of the task, the change limits of the input variables are defined:

- initial launch mass of the assembled rocket model (fuselage) – X1 = [0.300 - 0.600 kg];
- outer diameter of the assembled rocket model (fuselage) – X2 = [40 - 80 mm].

Two software products generated results for flight altitude reached (the other parameters were being equal):

- software online platform: Thrustcurve.org / Motor performance data online – Y1;
- open source software program LAUNCH – Y2;
- real flight data – Y3.

Simulation and experimental data for flight height of experimental rockets are shown in Table 1.

The variables are the launch mass X1 (kg) and the outer diameter X2 (mm). The constants are the mass of the fuel and the full engine impulse, respectively. The engine for all tests is an F-36 class solid propellant with a full impulse of 40 N.s and a run time of 1.1s.

A planned experiment was carried out in order to determine the coefficients in the regression model and create an objective function with the following form (Eqs. 1 and 2):

$$\hat{Y} = 238 - 76{,}75.X1 - 69{,}67.X2 + \\ + 48{,}75.X1.X2 + 15{,}5.(X2).(X2) \quad (1)$$

where X1 and X2 are coded variables or:

$$Y = 1129{,}967 - 1486{,}667.\tilde{X}1 - 6{,}1397.\tilde{X}2 + $$
$$+ 16{,}25.\tilde{X}1.\tilde{X}2 + 0{,}0388.(\tilde{X}2).(\tilde{X}2) \qquad (2)$$

where $\tilde{X}1$ and $\tilde{X}2$ are natural variables.

An assessment of the adequacy of the model after excluding the insignificant coefficients was made and it was proved that the model is adequate and can be optimized. On this basis, a 2D optimization with area restrictions of the input variables was made. The goal is to obtain the maximum value of Y ($\hat{Y}$), i. e. at what launch mass X1 and outer diameter X2 of the assembled rocket model will the maximum flight height Y be reached, (Fig. 5) [1].

As a result, it was obtained that the maximum flight height is reached at the limit of the permissible area, namely at a launch mass of the assembled rocket model of 0.300 kg and an outer diameter of ø 40 mm.

Table 1. Simulation and experimental data for flight height [1].

(X1)	Results from:	(X2)		
kg	-	ø 40 mm	ø 60 mm	ø 80 mm
0.300	(Y1)	454 m	294 m	209 m
0.300	(Y2)	471 m	313 m	226 m
0.300	(Y3)	482 m	305 m	194 m
0.400	(Y1)	315 m	240 m	187 m
0.400	(Y2)	311 m	244 m	193 m
0.400	(Y3)	325 m	216 m	176 m
0.500	(Y1)	201 m	173 m	147 m
0.500	(Y2)	198 m	175 m	152 m
0.500	(Y3)	226 m	181 m	166 m

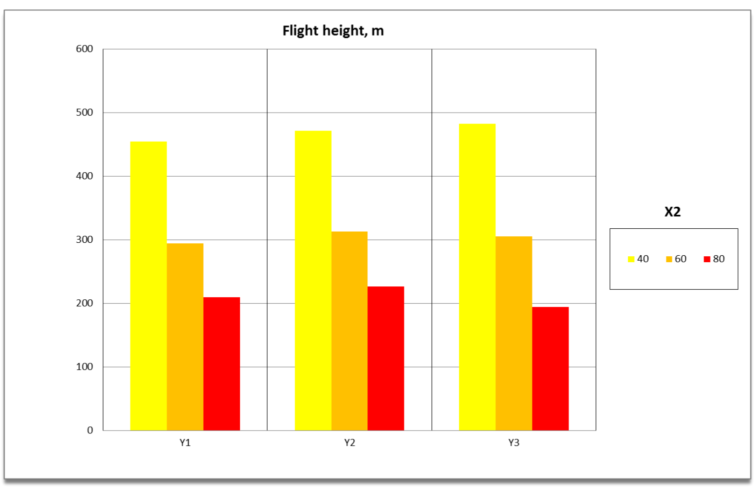

Fig. 2. Simulation and experimental data for flight height at initial mass 0.300 kg and variation of outer diameter.

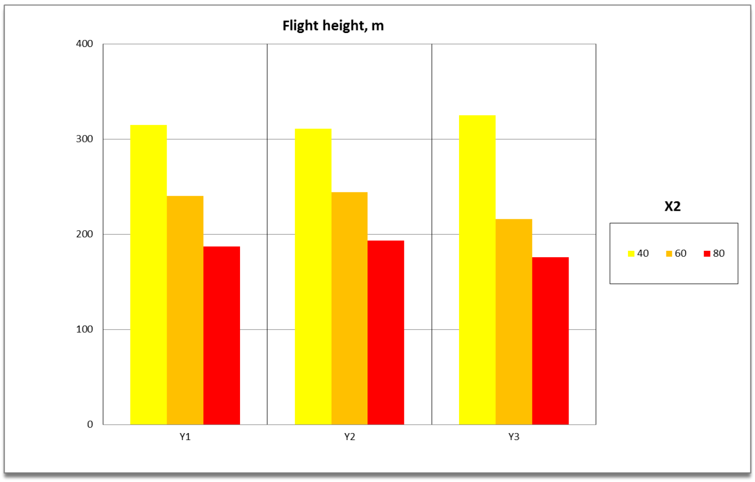

Fig. 3. Simulation and experimental data for flight height at initial mass 0.400 kg and variation of outer diameter.

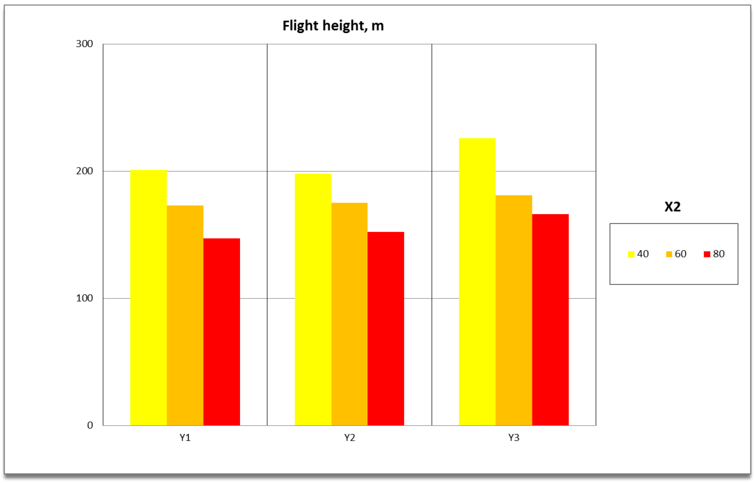

Fig. 4. Simulation and experimental data for flight height at initial mass 0.500 kg and variation of outer diameter.

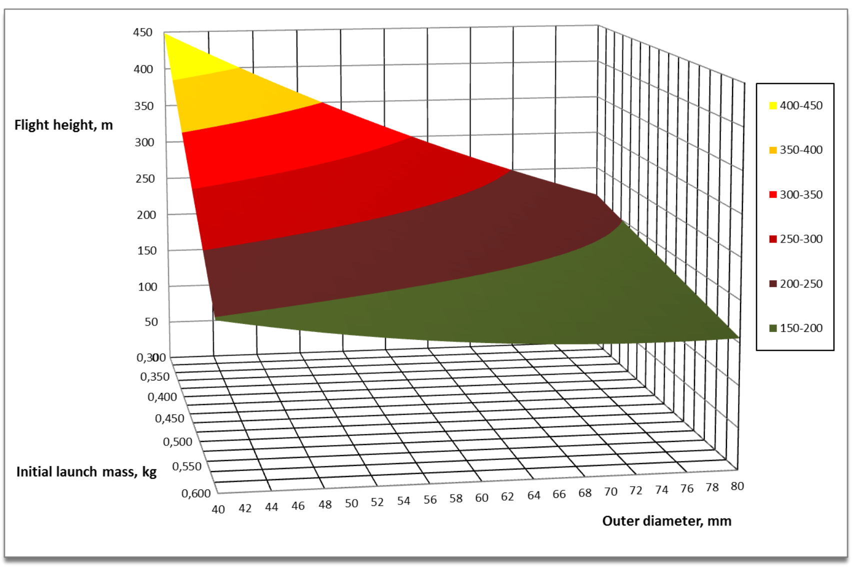

Fig. 5. The maximum flight height obtained by variation of initial launch mass and the outer diameter of the fuselage.

CONCLUSIONS

Prototypes of rocket engines for two types of application both for research and civilian use were created - model engines for amateur and racing purposes with a full impulse of 40 N.s and a starter motor for experimental rockets with a full impulse of 500 N.s. The main characteristic of these innovative and up-to-date alternative rocket engines is that they are embedded in building components and composites that are completely degradable in the natural environment. Thus, they are an ecological substitute for most existing technological solutions made of polymers, metals, glass composites and carbon composites. During the conducted ground and flight tests, the good performance of the prototypes and the possibility of their serial production with the aim of their improvement and subsequent implementation in mass production for their specific use in practice have been proven.

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