UDK: 621.45.07, 621.45
COSATI: 01-03, 19-01

Development of the pilot seat rocket motor propulsive charge of improved performances

Vladimir Kapor, MSc (Eng)[1)]
Miloš Filipović, PhD (Eng)[1)]
Milorad Savković, PhD (Eng)[1)]
Ljupka Nenadović, BSc (Eng)[1)]

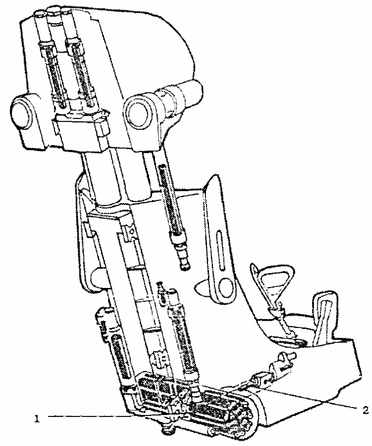
The research and development results of a new double base propulsive charge of the pilot seat rocket motor with improved performances is presented in this paper. The comparative analysis of performances pointed out the significant advantages of this new propulsive charge with respect to the reference one. The realized ballistic performances of the new propulsive charge allow a steadier and safer operating phase with higher degree of security of the pilot seat rocket motor in the considered temperature interval.

Key words: **pilot seat, catapult seat, rocket motor, propulsive charge, double base rocket propellant.**

Introduction

THE ejection pilot seat (Fig.1) is designed for the pilot to sit on inside the airplane cabin and abandon the airplane by ejection. The pilot can safely abandon the airplane in case of a single seater or a crew member at two-seater by ejection seats with combined ejection mechanism at wide diapason of speeds and flight altitudes of airplane and during its take-off and landing. It is used along with protection gear. Ejection is performed by lugging center-pull ejection handle, after which all seat devices and the airplane device for emergency rejection of roof cabin are activated automatically until the parachute is triggered to separate the pilot, or a crew member from the seat [1].

- Combined mechanism for seat ejection contains [2]:
- Double-barreled mechanism (first level) consists of external and internal barrel and pyrotechnic actuator full cartridge, with an electrical safety lock, with electrical pyrocartridge. Mechanism is being activated by a command of the system for steerage. First level works for 0.2 s and gives the seat starting a velocity larger than 13.6 m/s.
- The rocket motor (second level) with the nozzle and pyrocartridge. It is activated as seat moves on steered tracks out of the airplane cabin. The housing of the second level rocket motor contains propulsive charge and an igniter containing pyrocartridge. The second level works for 0.4 s and develops a thrust over 2000 daN.
- Mechanism for activating a parachute, which provides rejection of the back part when the parachute is activated. It consists of right and left frame for housing the pyrocartridges with mechanical safety locks.



1 - propulsive charge
2 - pyrocartridge

Figure 1. The ejection pilot seat

The pilot seat is activated by lugging a center-pull ejection handle. Ejection managing System is realized through mechanisms for managing and blocking.

The ejection pilot seat of rocket motor (Fig.2) consists of a rocket motor casing with two chambers in which is placed propulsive charge (Fig.3) and igniter for antipersonnel mine with pyrocartridge. The rocket motor propulsive charge consists of 2 x 25 pieces of cylindrical dual-channel propellant grain with external diameter (D) 17.7±0.3 mm, internal diameter (d) 4.2±0.2 mm, distance between two interior channels (A) 6.3±0.3 mm, overall external diameter (B) 28.4±0.3 mm, wall thickness (W) 6.85±0.2 mm and length (L) 117.5±0.5 mm, which cross-sectional area is shown in Fig.4.

1) Military Technical Institute (VTI), Ratka Resanovića 1, 11132 Belgrade

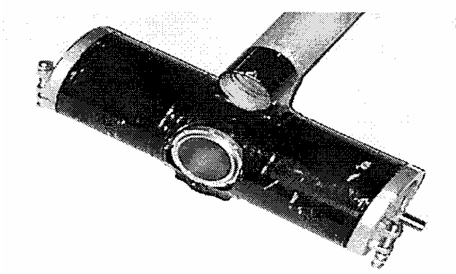


Figure 2. Rocket motor of the ejection pilot seat

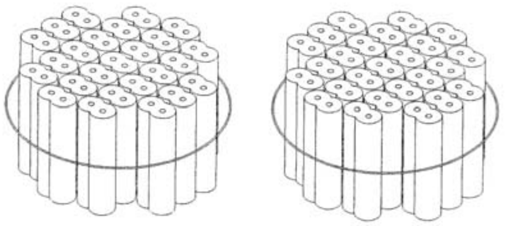


Figure 3. Propulsive charge

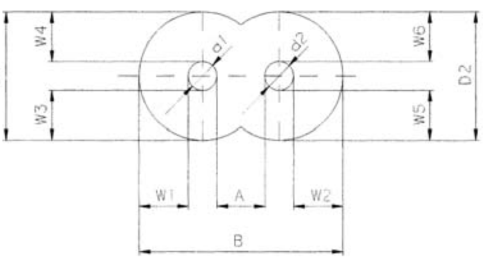


Figure 4. Cross-section the propellant grain

Due to the conditions in which propulsive charge is being used (take-off, flying and landing the aircraft) require it to be changed after five years. The basic goal of new propulsive charge research, accomplished through pattern explorations and production and testing of the prototype part, was to develop the same exploitive and protective characteristics as in the referent solution [3,4].

Definition and production of the propulsive charge

Technical problem, whose resolving was the object of this research and development, consists of the following questions: how to produce double-based propulsive charge of the pilot seat rocket motor by using available raw materials and extrusion treatment, so the mass, shape and dimensions fit the referent solution. The physical-chemical, mechanical, energetic and kinetic characteristics must supply the required ballistic performances of the defined rocket motor. The production process must be safe and the product obtained (propulsive charge) has to include quality and reproducibility aimed at. If the problem is expressed in this way it is necessary to define the technical demands for propulsive charge, i.e. ballistic performances of the pilot seat rocket motor. These performances were determined from static tests propulsive charge results in experimental rocket motors at test temperatures –30°C and +50°C (temperature interval in which rocket motor is able to operate in real conditions) [5]. Experimental results are illustrated in Figures 5-7.

The temperature sensitivity of the burning rate, $\left(\pi_p\right)_{KN}$, at constant motor geometry $\left(K_N\right)$ is defined:

$$(\pi_p)_{K_N} = \frac{1}{p_c}\left(\frac{dp_c}{dT_i}\right)_{K_N}$$

The calculated value of temperature sensitivity of burning rate for double-base rocket propellant in referent propulsive charge is 0,37% K^{-1}.

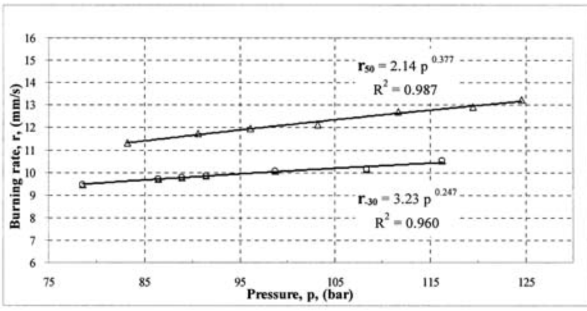


Figure 5. The burning rate laws of the referent double base propellant

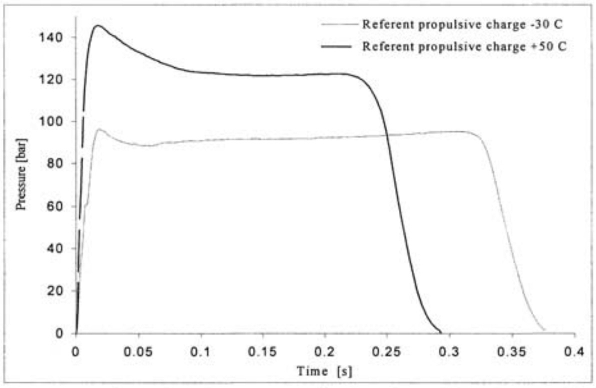


Figure 6. The pressure of gases in rocket motor as a function of propulsive charge combustion time

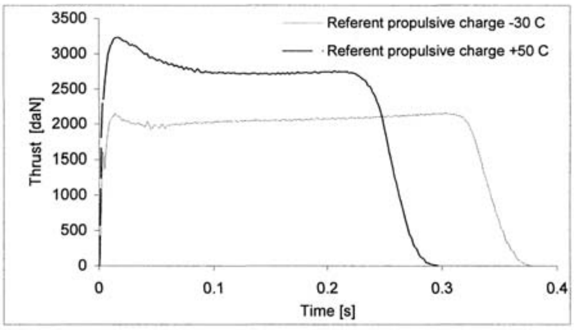


Figure 7. The thrust of a rocket motor as a function of propulsive charge combustion time

Table 1. Technical demands for propulsive charge

Characteristic	Technical demands
CHEMICAL COMPOSITION	
Nitrocellulose	Amount and ratio of energetic components must provide the necessary energetic and mechanical characteristics, as well as possibility for manufacturing
Nitroglycerin	
Stabilizer	Must provide chemical stability
Ballistic modifier	Must provide the required burning rate law

ENERGETIC CHARACTERISTICS	
Heat of explosion	Must provide necessary total impulse
MECHANICAL CHARACTERISTICS	
Compression strength	Must provide propulsion charge mechanical durable in all exploitation conditions
Compression critical strength	
RATE AND BURNING RATE LAW	
Rate and burning rate laws at interval from –30 to +50°C	Must provide necessary internal ballistic characteristics
INTERNAL BALLISTIC CHARACTERISTICS	
Interval of temperature, ° C	-30 to +50
Maximum pressure, bar	Must provide safe operation of rocket motor
Average effective combustion time, s	Must provide acceleration of the pilot seat not bigger than allowed
Pressure integral ratio, bar s	Must provide the energy of rocket motor
Total impulse, N s	Must provide additional rate of seat with pilot in it and also the conditions for opening the parachute

Models and prototype parts of the new double-base propulsive charge are constructed by extrusion procedure [6]. The new double-base propulsive charge with lower pressure exponent in the burning rate law in a wide range of pressures and lower temperature sensitivity of burning rate in a temperature interval from –30 to +50°C [7] was developed.

Results and discussion

Chemical stability of the new double-base rocket propellant [3,4,7] which is used for new propellant charge production completely corresponds to the chemical stability for this type of rocket propellant.

The physical and mechanical properties of propellant tubes provide structural integrity of the propellant charge at all exploitation conditions [3,4,7].

Lower pressure exponent of double-base propellant combustion and lower temperature-sensitivity of developed propulsive charge in regard to the original charge enable uniform and safe running of the pilot seat rocket motor at temperature interval from –30°C to +50°C [3,4,7,8].

A simultaneous verification and final testing of the new and the referent propulsive charges had been performed according to the program shown in Table 2.

Table 2. The final testing program of new propulsive charge

Class of test	Sample size	Execution manner	Measurements
Testing of propulsive charges in rocket motors by vibration	4 sets	SNO 0514-1A [9]	Dismantling and inspection of propulsive charges
Artificial aging of the propulsive charges in rocket motors	4 sets	SNO 0187 [10], regime B, 14 days and SNO 0188 [11], regime B, 14 days	Dismantling and inspection of propulsive charges
Static test of original propulsive charges in experimental rocket motors	8 sets	3 sets at – 30° C 2 sets at + 20° C 3 sets at + 50° C	Pressure and thrust in function of time
Thermal cycling of original propulsive charges in experimental rocket motors	3 sets	SNO 0186 [12], regime B, three cycles per 8 hours	Temperature and duration
Static test of original propulsive charges in experimental rocket motors	5+5+15 sets	5 sets at – 30° C 5 sets at + 50° C 15 sets at + 20° C	Pressure and thrust in function of time

When vibration tests were finished, no changes were noticed.

After vibration tests propulsive charges were loaded in rocket motors and statically tested at +20° C.

Having performed artificial aging, dismantling and inspection of propulsive charges and no changes were noticed, these propulsive charges loading were performed by static tests at +20°C.

After thermal cycling of propulsive charges in rocket motors, static tests were performed at 20° C.

The propulsive charges were not treated and those which were subjected to the tests mentioned above manifested uniform and reproductive values measured of the internal ballistic parameters, so there are no differences between the two.

The thrust integral average values of referent propulsive charge and the same values of the new one are overlapping. It means that the rocket motor with new propulsive charge provides the required extra rate of the pilot seat with the pilot in it.

Through static tests of the new propulsive charge at temperatures +50, +20 and –30°C the reproductive values of measured ballistic characteristics were obtained. Deviations of some internal ballistic values, for some groups at certain temperature, are within the allowed measuring error (about 1%).

Characteristic diagrams of the burning rate laws and the pressure and rocket motor thrust as a function of combustion time are shown in Figures 8-10.

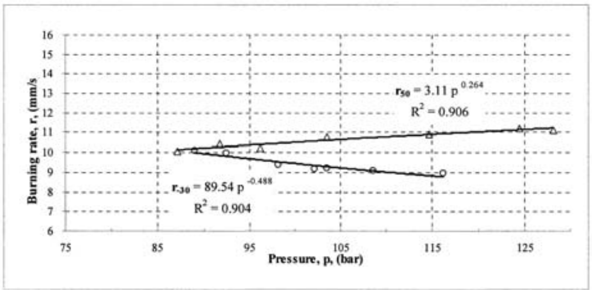


Figure 8. The burning rate laws of the new double base propellant

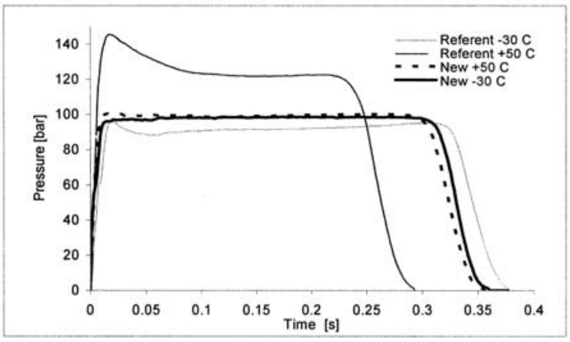


Figure 9. The pressure in rocket motor as a function of combustion time of a new and referent propulsive charge

Analyzing the values of the effective time of combustion, t_{ef} and the effective force of thrust, F_{ef} for rocket motors with referent and new propulsive charges at +50°C, it has been concluded that the obtained average value of t_{ef} of the rocket motors with new propulsive charges are greater for about 23% and the F_{ef} is proportionally smaller, because the total impulse differs only about 0.7% from the corresponding values of the referent propulsive charge rocket motor. The results satisfied the requirements for the accelerations of the pilot seat to be less than permitted.

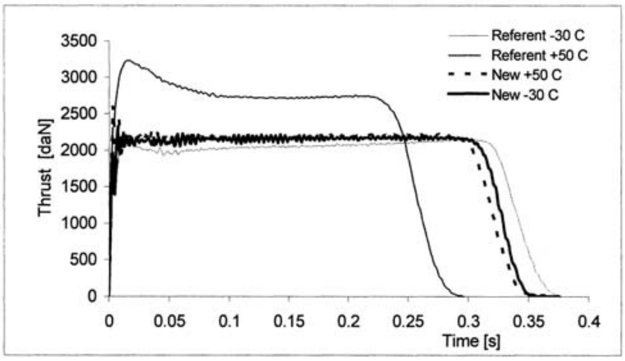


Figure 10. The thrust of rocket motor as a function of combustion time of a referent and new propulsive charge

The combustion effective time values, t_{ef} and effective force of thrust, F_{ef} have been analyzed for the rocket motors with referent and new propulsive charges at –30°C. These results are contrary to experimental results at +50°C. The obtained average value of a t_{ef} for rocket motors with new propulsive charges are about 6% smaller but the F_{ef} values are proportionally greater, because the total impulse differs only 0.7% from the corresponding values of the referent propulsive charge. The results satisfied the demands for the stability of rocket motor running at this temperature.

The thrust integral average values of new rocket motors propulsive charge correspond to the values of the referent propulsive charge at all temperatures. Therefore the demanded pilot seat rate will be obtained in the temperature range from –30°C to +50°C.

The new propulsive charge has about 43% smaller values of maximum pressure compared to the referent propulsive charge at +50°C. This result satisfied the demands for greater safety of rocket motor running at this temperature.

Maximum pressure of the new propulsive charge is about 0.4% greater and the effective time is about 1.8% smaller at – 30°C.

The relative deviation (in %) values of some internal ballistic parameters between new and referent propulsive charge at different temperatures are given in Table 3.

Table 3. The relative deviations of internal ballistic parameters, %

Temperature °C	Effective time, s	Integral of pressure bar s	Thrust integral daN s	Specific impulse m/s
-30	-6,2	0,3	0,7	-0,3
+20	12,0	0,5	-0,5	-1,4
+50	23,1	-2,1	-0,7	-1,6

Comparing the difference of t_{ef} at temperatures –30°C and +50°C ($t_{ef}^{-30°C}$ - $t_{ef}^{+50°C}$) for the new propulsive charge and the difference of t_{ef} ($t_{ef}^{-30°C}$ - $t_{ef}^{+50°C}$) for the referent propulsive charge [5], it is evident that the difference for the new propulsive charge is five time less (15 ms) than for the referent one (81 ms), which contributes to a more balanced working of the rocket motor pilot seat when temperatures changes.

Conclusion

Based on the research results presented above it can be concluded that:

The new propulsive charge production procedure, the quality of initial raw materials and the method of their application, the quantity and the dosage of ballistic modifier and processing conditions of the propellant mass (gelatinization, extrusion, cutting propellant tubes), are completely defined.

The new propulsive charge mass, shape and dimensions correspond to the referent solution. The physical-chemical, mechanical, energetic and kinetic properties of the propulsive charge provide the required ballistic performances of the defined rocket motor. Furthermore, the production procedure is safe and the product (propulsive charge) has the required quality and reproducibility.

Chemical stability of the new double-base rocket propellant, used for new propellant charge production, completely corresponds to chemical stability for this type of rocket propellant.

The mechanical properties of propellant tubes provide strength of propulsive charge in all exploitation conditions.

Tactical-technical requirements are completely satisfied by the developed propulsive charges and these can be used for loading the rocket motor pilot seat.

Lower pressure exponent of double-base propellant and lower temperature sensitivity of the developed propulsive charge with regard to the referent charge enable a more uniform and safer running of the pilot seat rocket motor in the temperature interval from –30°C to +50°C.

References

[1] WINN,A., *Fast Exit*, FLIGHT Internacional, 1997, pp.56-60

[2] *Izbacivo pilotsko sedište druge serije*, PVO-03.VTUP. 010.

[3] KAPOR,V., FILIPOVIĆ,M., SAVKOVIĆ,M., NENADOVIĆ,LJ., *Raketni motor pilotskog sedišta*, Razvoj modela novog pogonskog punjenja, Elaborat VTI-04-01-0287, Beograd, 2003.

[4] KAPOR,V., FILIPOVIĆ,M., SAVKOVIĆ,M., NENADOVIĆ,LJ., *Raketni motor pilotskog sedišta*, Razvoj prototipske partije pogonskog punjenja NGR-121, Elaborat VTI-04-01-0334, Beograd, 2003.

[5] KAPOR,V., SAVKOVIĆ,M., NENADOVIĆ,LJ., *Rezultati identifikacionih ispitivanja originalnog pogonskog punjenja raketnog motora pilotskog sedišta*, Elaborat VTI-04-01-0191, Beograd, 2000.

[6] STOJANOVIĆ,R.*Opšti tehnološki postupak proizvodnje dvobaznih raketnih goriva i pogonskih punjenja*, TP 5000, Elaborat VTI-004-01-0109, Beograd, 1994.

[7] KAPOR,V., *Dvobazno raketno gorivo*, SNO 8758, Vojnotehnički institut, Beograd, 2003.

[8] KAPOR,V., FILIPOVIĆ,M., SAVKOVIĆ,M., NENADOVIĆ,Lj., *Pogonsko punjenje*, SNO 8759, Vojnotehnički institut, Beograd, 2003.

[9] SNO 0514-1A, *Vibracije – Uslovi ispitivanja vazduhoplovne opreme i naoružanja u uslovima primene*

[10] SNO 0187, *Ispitivanje spoljnih uticaja na sredstva naoružanja i vojne opreme – povišena temperatura – Metoda 102*

[11] SNO 0188, *Ispitivanje spoljnih uticaja na sredstva naoružanja i vojne opreme – snižena temperatura – Metoda 103*

[12] SNO 0186, Ispitivanje spoljnih uticaja na sredstva naoružanja i vojne opreme – nagle promene temperature – Metoda 101

Received: 15.01.2005.

Razvoj pogonskog punjenja poboljšanih performansi raketnog motora pilotskog sedišta

Prikazani su rezultati istraživanja i razvoja novog dvobaznog pogonskog punjenja poboljšanih performansi raketnog motora izbacivog pilotskog sedišta. Uporedna analiza performansi ukazala je na značajne prednosti novog u odnosu na referentno rešenje. Ostvarene balističke performanse novog pogonskog punjenja u odnosu na referentno rešenje omogućavaju ujednačeniji i bezbedniji rad i veći stepen sigurnosti raketnog motora pilotskog sedišta u temperaturskom intervalu upotrebe.

Ključne reči: **pilotsko sedište, sedište za katapultiranje, raketni motor, pogonsko punjenje, dvobazno raketno gorivo**

Le developpement de la charge propulsive aux performances ameliorees du moteur-fusee du siege de pilote

On a présenté les résultats de la recherche et du développement d'une nouvelle double base charge propulsive aux performances améliorées du moteur-fusée du siège de pilote. L'analyse comparative des performances a démontré les avantages significatifs de cette charge propulsive par rapport de la solution de référence. Les performances balistiques réalisées de cette nouvelle charge propulsive permettent les meilleure stationnarité et confiance de la phase opérationnelle avec le plus grand niveau de sécurité du moteur-fusée du siège de pilote dans de l'intervalle de la température considéré.

Mots-clés: **siège de pilote, catapulte siège, moteur-fusée, charge propulsive, propergol double base.**

Развитие маршевой заправки топливом улучшеных технических характеристик ракетного двигателя сидения летчика

Здесь показаны результаты исследований и развития новой двуосновной маршевой заправки топливом улучшеных технических характеристик ракетного двигателя катапультируемого сидения летчика. Сравнительный анализ характеристик указал на значительные преимущества нового по отношению к главному решению. Осуществленные баллистические характеристики новой маршевой заправки топливом по отношению к главному решению обеспечивают более одинаковую и эксплуатационную надежность и большую ступень эксплуатационной безопасности ракетного двигателя сидения летчика в использованном температурном интервале.

Ключевые слова: сидение летчика, катапультируемое сидение летчика, ракетный двигатель, маршевая заправка топливом, двуосновное ракетное топливо.