The research of ballistic properties of ejection seats rocket motors

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Abstract

Combat aircrafts are obligatory equipped with ejection seats in order to safe pilots when emergency situation occurs. Evacuation of the pilot from a damaged aircraft should take place as soon as possible – regarding human body limitations, and rocket motors are commonly used to perform such a fast work. Propellant charges supplying the energy to eject a seat with a pilot, should characterise of precisely ballistic parameters at wide range of temperature. In the paper the results of research on ballistic properties of different propelling charges designed by leading manufacturers in the world are described. Propelling charges have been developed and manufactured in Polish enterprises. Following technical data of rocket propulsion were compared: shape, mass and quantity of propelling charges; thrust, pressure in combustion chamber and time of burning; heat of combustion and wide range of temperature exploitation. Tests concerning the ability of different propelling charges to detonation have been conducted.

Key words: ejection seat, rocket motor thrust, propelling charge, ability to detonation

1. Introduction

An ejection system for saving the lives of crew in emergency situations is a mandatory component of military aircraft equipment. The ejection systems are constructed primarily of mechanical systems which accurately perform their functions in a strictly defined time sequence, in a wide range of operating conditions (temperature, pressure and cinematic parameters of the aircraft). The most advanced ejection seats are H0V0 class, which indicates they can effectively rescue the pilot, even under conditions of the aircraft standing on the airfield. Evacuation of the pilot from a damaged aircraft should take place as soon as possible, but without compromising the pilot's health. Based on many years of physiological experiments [1] it is understood that an overload affecting a healthy human body for a time of 0,1-0,2 second should not exceed 20 (with acceleration of gravity relationship).

The primary sources of energy for the automatic execution of programmed operations involving the dynamic movements of different weight components are the charges of explosive propellant materials, the so-called propelling charges. The largest weight (2-4 kg) is that of rocket propellant where the function of the rocket motor is to launch the seat, along with the pilot to a height of approximately 100 m, which enables secure landing of the pilot using a parachute. Manufacturers of ejection seats have used a variety of technical solutions to design rocket engines and the shape and properties of ballistic propelling charges. In this paper, the author have presented the results of his own long-term research on the properties of ballistic propelling charges used by leading companies worldwide and the practical results of technological effort made to improve the ballistic properties of those charges.

2. Propelling charge technology upgrade and ballistic research

The propelling charges used on ejection seats are manufactured from nitroglycerine double-base propellants of various chemical compositions and different heat of combustion. They are characterized by a variety of geometrical shapes and weight of a single charge. Each manufacturer of ejection seats has designed its characteristic solution. Any attempt to reconstruct a specific propelling charge involves research work from scratch ended with field ballistic tests of complete sets of charges in a combat or equivalent testing rocket motors. Fig. 1 shows the cross-section shapes of transverse propelling charges from various ejection seats that were subject of ballistic research and technological efforts aimed at upgrading them [2-4].

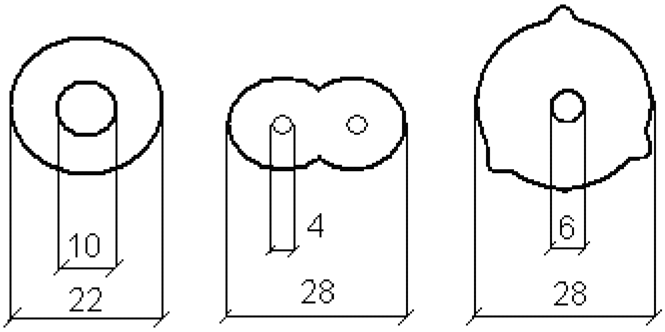

Fig. 1. Cross-sections of propelling charges used in rocket motors of ejection seats: KM1M, K36DM and SC-HV-00 correspondingly

The model and prototype lots of propelling charges were manufactured at the industrial plant drawing on the experience and knowledge accumulated during the execution of earlier research projects. The production lots of the propelling charges were ordered by a foreign buyer on whose request ballistic tests of motors with manufactured propelling charges were run. At Fig. 2 pictures of propelling charges tested in rocket motors of chosen ejection seats are shown.

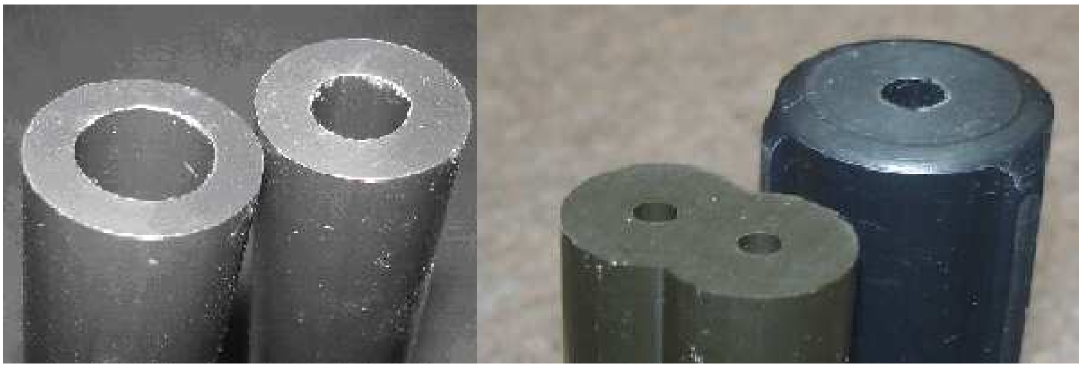

Fig. 2. Pictures of front surfaces of propelling charges (from left): PZM, PZMM, PZAM, C

3. Rocket motor of KM1M ejection seat

The design of the MiG-21 interceptor dates back to mid-twentieth century, but upgrades of this aircraft are still in service. It is estimated that more than ten thousands of the aircraft were produced for the Air Forces of more than 50 countries. The KM1 ejection seat has in the meantime been subject of a major modernization while preserving its main design features.

The propelling charges (PZM) of the rocket motor of the KM1M ejection seat come in the form of tubes with a cross-section of Φ = 24/14 mm and a length of 410 mm (Fig. 1). The charge weight is about 200 g. The combustion chamber of the rocket motor accommodates 11 charges with a total weight of 2.2 kg, arranged concentrically. The gases generated during the fast burning process is discharged through two symmetrical nozzles of a 33 mm diameter. The designers of that rescue system assumed a shorter rocket motor operation time (below 0.2 sec) compared to the Martin-Baker system discussed in paper [2]. Given the reduced effective time, it is possible to accept a greater overload on the pilot's body without any harmful side effects. The ballistic requirements for PZM charges are collected in Table 1.

Based on the experience from the research works on solid rocket propellants, it was assumed that an improvement of the ballistic properties of the PZM charges made from catalyzed double-base propellant could be obtained by changing the geometry of the charge [3] while maintaining its current weight, which is about 200 g. The potential energy needed to perform the responsible work of ejecting the pilot together with his seat must remain unchanged but a modification of the dynamics of this process is allowed within reasonable limits. An analysis of the geometric shape of the PZM charge shows that a modification of the geometric dimensions of the PZM charge cross-section from Φ=24/14 mm to Φ=22/10 mm, while maintaining a length of 410 mm, does not practically change the weight of the charge. However, the initial combustion surface is reduced by about 18% which is going to decrease the yield of the combustion products with a consequent drop of pressure in the rocket motor chamber. The combustible layer of the geometrically modified charge (PZMM) will be thicker (6 mm) compared to the PZM charge (5 mm). This factor, just like the pressure drop in the rocket chamber, will also affect the combustion time. It should be noted that these modifications relate only to charge dimensions while the remaining parameters of the ballistic motor (the ignition pulse and the critical cross-section of a nozzle) remained unchanged. At Fig. 2 the front surfaces of the PZM and PZMM charge are shown.

Fig. 3 presents the thrust vs. time record of the KM1M seat rocket motor which contains a set (11 pieces) of upgraded propelling charges (PZMM). The ballistic tests were run after the motors with charges had been conditioned in a thermostat for 6 hours at extreme operating temperatures of -35ºC and +60ºC. Compared with traditional charges (PZM), a significant reduction of thrust was observed at the test temperature of +60ºC [4], which is a particularly advantageous feature of the upgraded charge, made from a new rocket propellant, because it reduces the acceleration that affects the pilots body.

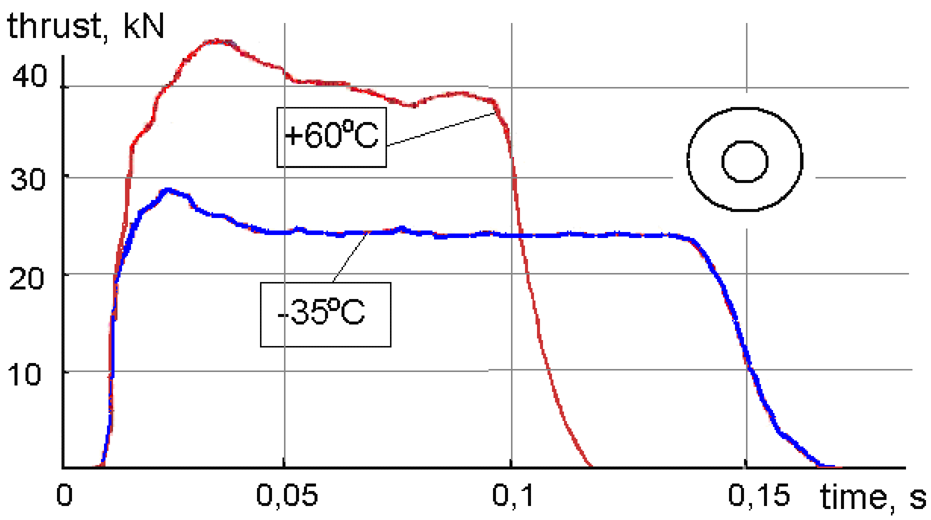

Fig. 3. Thrust vs. time diagram recorded in full-scale test of KM1M ejection seat loaded with charges of modernized shape (PZMM) at temperature +60ºC and -35ºC. The mark at top right corner indicates the shape of a propelling charge cross-section

4. The rocket motor of the SC-HV-00 ejection seat

The SC-HV-00 ejection seat made in Romania is used on the training and combat IAR-93 and IAR-99 aircrafts. The seat design is based on the solution applied in the Mk-10 system of Martin-Baker. The seat's rocket motor has no single combustion chamber to hold all the propelling charges as in other designs. The charges of three different lengths and an identical cross-section are shown in Fig. 1 and 2 (C type) are placed in separate chambers located in the rear part of the seat and linked via shared collectors of propellant gas with two main and two auxiliary nozzle distributed in the lower part of the seat. Fig. 4 shows the thrust vs. time diagram of the SC-HV-00 ejection seat rocket motor measured in AEROFINA, Bucharest after conditioning loaded motors for at least 6 hours in extreme exploitation temperature. Combustion chamber were filled with type C charges manufactured in Poland under author's supervision.

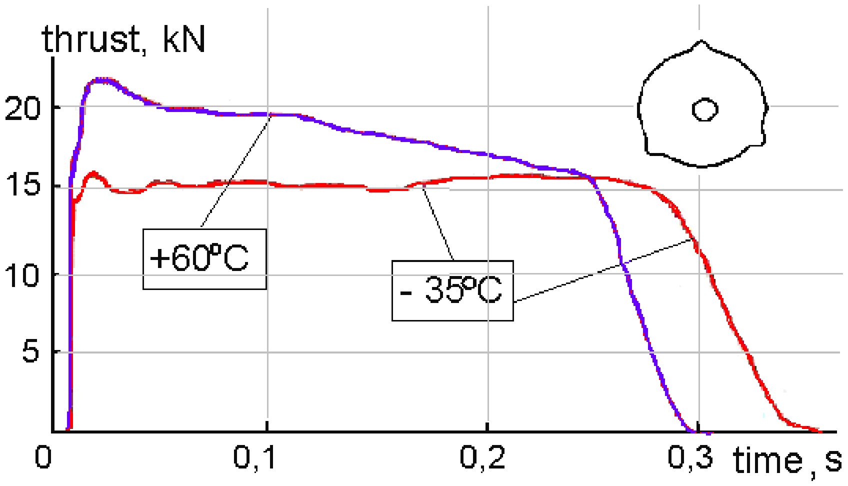

Fig. 4. Thrust vs. time diagram recorded in full-scale test of SC-H0-V0 ejection seat loaded with type C charges, at temperature +60ºC and -35ºC. The mark at top right corner indicates the shape of a propelling charge cross-section

5. The rocket motor of the K36DM ejection seat

The K36DM ejection seat is a modern system that has proven itself in many critical cases. It is used on Russian combat aircraft, inter alia Mig-29, Mig-31, Su-22 and Su-25. The K36DM ejection seat has a cylindrical rocket motor installed under pilot's seat with a single nozzle located symmetrically on the cylindrical surface of combustion chamber. Clusters of 25 pieces of PZAM propelling charges are inserted from each side through bottom screw-on covers.

Ballistic tests were run after the rocket motors with charges had been conditioned in a thermostat for 6 hours at different temperatures: -40ºC, +10ºC and +50ºC. Fig. 5 shows a field ballistic test station with an installed rocket motor dismantled from the K36DM ejection seat [5,6].

Fig. 5. View of the ballistic stand with a rocket motor of K36DM ejection seat prepared to test. Coaxial cable seen at right is connected with a pressure gauge fixed to the right bottom. Gauge of the thrust is placed behind the rocket motor, along with the axis of the nozzle, seen at the center of the picture.

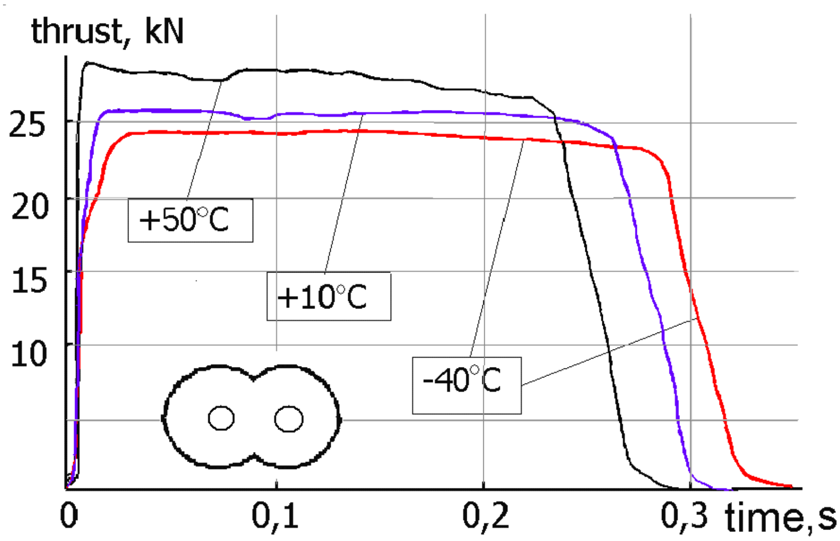

Fig. 6. Thrust vs. time diagram recorded in full-scale test of K36DM ejection seat loaded with PZAM charges, at temperature +50℃, +10℃ and -40℃. The mark at left bottom right corner indicates the shape of a propelling charge cross-section

6. Detonation ability of propelling charges

An important feature of explosives and propelling charges used in combat aircraft ammunition is their reduced sensitivity to initiation by various stimuli and to detonation. In consideration of the safety of aircraft crew and ground personnel as well as the safety of ammunition in transport and storage, this feature is becoming an obligatory requirement.

In order to assess the susceptibility of the propelling charges under research to detonation transition, tests were run to assess that feature in conditions most conducive to the development and propagation of detonation. Picture (Fig. 7) shows a method of testing propelling charges for detonation ability.

A charge or cluster of charges of approx. 200 g total weight, placed on a steel plate 5 mm thick (so called witness), was initiated using a 10 g explosive plastic detonator. The effects of initiating propelling charges from various rocket motors are shown in the photograph (Fig. 8). In each case, the steel plate was perforated by the detonation, which proves that the propelling charges do not meet the highest insensitive munitions (IM) criteria.

Fig. 7. Picture of propelling charge ready to test of the ability to detonation (left) and other propelling charges tested in the work: PZM, C and PZAM

Fig. 7. Picture of steel plates perforated by detonation of propelling charges under study

7. SUMMARY

Table 1 provides the technical and ballistic parameters of three types of ejection seats studied in the paper. The ballistic data come from the research made within the framework of this work and the other data come from manufacturers of aircrafts rescue systems.

Table 1. Technical and ballistic data of ejection seats

Type of seats	**KM1M**	**K-36DM**	**SC-HV-00**
Weight of a seat kg	135	145	90
Weight of a charge, kg	**2,1**	**3,75**	**2,8**
Heat of combustion, kJ/kg	**4600**	**3600**	**4600**
Impulse total, kNs	4,0	7,0	5,0
Thrust max., kN	45	30	26
Thrust aver., at temp. 15°C, kN	32	25	18
Overload max. a/g	**19**	**12,5**	**13,5**
Pressure max. MPa	26	25	30
Pressure aver. MPa	16	10	14
Time of motor work, s	0,10 – 0,18	0,25 - 0,35	0,22 – 0,32
Exploitation temperature, °C	-35 ÷ +60	-50 ÷ +50	-35 ÷ +60

The oldest design is that of the KM1M seat which exposed the pilot to a high but brief overload. In consideration of the physiological limitations of the human body, the subsequent generation of ejection seats, both Russian and those based on the British design, is marked by a higher degree of safety in an emergency. By comparison, the newer designs of ejection seats, K-36DM and SC-HV-00, reduce the overload on the pilot's body, which does not exceed an average value of 10 and lasts a bit longer, about 0.3 sec. Both designs belong to the H0V0 class and are dominant on the world market.

The nature of the specific role played by the propelling charges of an ejection seat rocket motor, whose function is to provide a velocity of about 30m/s within a fraction of a second to a system incorporating a human, imposes strict restraints on the scattering of the ballistic characteristics of propelling charges within a wide temperature range, usually from -40ºC up till +65ºC. The theoretical and practical experience accumulated by the author in the rocket propellants technology was utilized to implement the production of the propelling charges under the research at ZPS Gamrat Sp. z o.o. in Jasło on the order of a foreign buyer.

The propelling charges developed and produced in Poland have successfully undergone qualification tests at AEROFINA S.A. in Bucharest and at Instytut Techniczny Wojsk Lotniczych (Air Force Technical Institute) in Warsaw.

The tests of charges resistance to detonation initiation, conducted in the strictest of conditions, revealed that the nitroglycerine propellants used to manufacture the charges do not meet the requirement of IM products. This is a guideline for further research with other types of propellant, e.g. composite propellants, in order to develop more safe propelling charges.

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