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Development of the ILR-33 "Amber" sounding rocket for microgravity experimentation

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A B S T R A C T

This paper gives an overview of the development of the ILR-33 "Amber" sounding rocket designated for microgravity experiments, that is under development at Institute of Aviation in Warsaw, Poland. The lack of an easily accessible and affordable platform for this kind of research was one of the key reasons for this work. The proposed design enables performing experiments in microgravity for almost 150 seconds with an apogee over 100 km. Combining these results with a relatively low price per launch and short deployment time gives a possibility to establish a firm position on the dynamic market. This article describes also the rocket structure and the vehicle's capabilities. The proposed design utilizes a hybrid rocket motor with High Test Peroxide as an oxidizer along with two reusable solid rocket boosters. The early phase analysis of the rocket configuration and propellant considerations are also presented in the paper. Furthermore, there have been already several on-ground test performed such as: wind tunnel research and motor firings. The proposed design is considered as an introduction to small launch vehicle technology.

1. Introduction

Microgravity research is a significant field of engineering that supports development in areas ranging from material to life sciences. Limited duration tests can be conducted on Earth, while many companies and space agencies are looking into long-duration microgravity research supporting both: terrestrial and exploration needs. There are four main platforms for microgravity research:

- Drop towers
- ZeroG airplanes (parabolic flights)
- International Space Station infrastructure
- Sounding rockets

The first two provide short durations of μG that is not sufficient for all types of experiments. In case of the International Space Station, the main advantage is that the duration of the experiment is almost infinite. The problem is that costs (mainly transport to orbit) and safety regulations are the main barrier for researchers. Thus, the rocket platform in many ways appears to be the most attractive solution. It provides relatively long time of μG (even up to 20 min) [1], ease of deployment and relatively low costs. The problem is that most existing solutions are limited in terms of availability or are based on sub-optimal, for the given mission, stacks of post-military rocket motors or are simply too expensive [2–5].

Taking these factors into account and having the goal of maturing technologies necessary for developing small launch vehicles [6], several small projects including development and testing [7–9] and theoretical optimisation activities [10,11] considering sounding rockets were carried out at the Institute of Aviation in recent years. Work on a new sounding rocket was initiated in 2014 as a professional continuation of the Polish Small Sounding Rocket Program. IoA has been developing green propellant solutions based on high purity, high concentrations of hydrogen peroxide as the oxidizer [12–14] and its use was one of the baseline requirements due to its performance and benign environmental impact. The technology of preparation of High Test Peroxide is covered by an European patent of Institute of Aviation.

Recently, hybrid rocket motors are becoming more and more popular and are considered as a promising technology [15–17].

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Abbreviations

μG	Microgravity	LEO	Low Earth Orbit
HTP	High Test Peroxide	SRM	Solid Rocket Motor
HTPB	Hydroxyl-terminated polybutadiene	SSRP	Small Sounding Rocket Program
IoA	Institute of Aviation		

They enable obtaining relatively high performance, low development and operational costs. Additionally, they do not require complicated feeding systems, while the thrust level can be controlled and reliable restarts are possible for more demanding missions. Development of hybrid rocket motors is ongoing in several countries worldwide. Notable projects include 87.5% HTP/HTPB motors from Nammo, Norway [18] and American developments using Nitrous Oxide as oxidiser [19,20]. A review of historic applications of hybrid rocket technology is provided in [21].

2. Rocket overview

The ILR-33 Amber is the unguided sounding rocket. It consists of two parallel stages: the main stage (core) and two solid rocket boosters [22,23]. The main stage utilizes an innovative hybrid rocket motor with a composite combustion chamber operating in a pressure-fed cycle. The propellants applied are high grade hydrogen peroxide with concentration exceeding 98% and polyethylene as a multiport grain. The mission of the rocket assumes recovery of the payload section using a parachute recovery system. Table 1 contains basic parameters of the ILR-33 rocket. These are present values of key design parameters, while chapter 3 of this paper presents some earlier design iterations and examples of conducted analyses. The majority of the components of the rocket were designed from scratch by employees of Institute of Aviation, frequently utilizing solutions not present in other project of this type. Simplicity, reliability, low costs and adaptability of the performance and mission profile are the main characteristics of the ILR-33. The main goals of the project are the evaluation of the developed technologies and the possibility to gain specialized capabilities in rocket design. New knowledge will be adopted during foreseen projects related to launch vehicles. For the purposes of the ILR-33 project the Avionics Division of IoA designed a new on-board flight computer [24]. The hybrid rocket motor, feeding system, recovery system and pyrotechnic separation device are also fully new developments. Extensive tests of particular subsystems are being conducted at Institute of Aviation. Advanced computational techniques were utilized with the use of specialized commercial software (ANSYS Fluent) [25], as well as in-house codes. All main components of the rocket are presented in Fig. 1.

Table 1
Main parameters of the rocket.

Parameter	Value	Unit
Total mass	156	kg
Empty (core) mass	52	kg
Payload mass	5	kg
Length	5.00	m
Diameter	0.23	m
Maximum altitude	~100	km
Maximum velocity	1300	m/s
Maximum acceleration	115	m/s^2
Time to max altitude	170	s
Microgravity duration	~150	s

3. Preliminary design

During the early phase of the design two propulsion systems were taken into consideration: a liquid rocket engine and a hybrid rocket motor. Experience with High Test Peroxide combined with Jet-A (liquid rocket engine) [26,27] and HTPB (hybrid rocket motor) [28,29] already existed at IoA. Theoretical performance obtained for hybrid rocket motors using storable propellants is nearly identical to that of liquid rocket engines using non-cryogenic propellants. While combustion efficiency is lower for hybrid rocket motors than for the bipropellants, additives such as aluminium powder or aluminium hydrate can increase performance beyond the one obtained from typical bipropellant engines while using the same oxidizer. Fig. 2 presents results of chemical equilibrium calculations using NASA Chemical Equilibrium with Applications software [30] for an in-orbit propulsion system under consideration at IoA within a parallel activity. P_c is combustion chamber pressure and p_e is nozzle exit pressure.

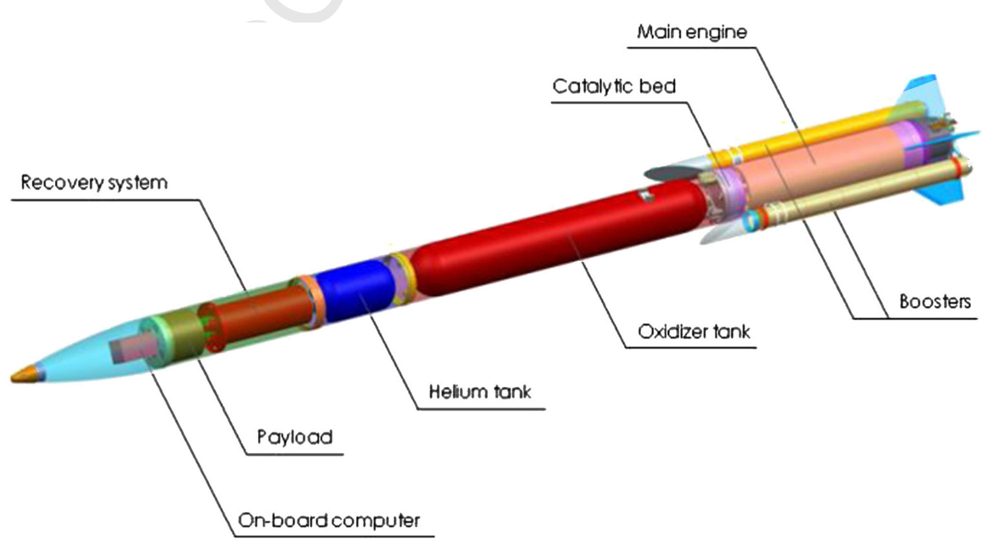

Fig. 1. CAD model of the rocket.

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