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Feasibility of a low-cost sounding rockoon platform

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ABSTRACT

This paper presents the results of analyses and simulations for the design of a small sounding platform, dedicated to conducting scientific atmospheric research and capable of reaching the von Kármán line by means of a rocket launched from it. While recent private initiatives have opted for the air launch concept to send small payloads to Low Earth Orbit, several historical projects considered the use of balloons as the first stage of orbital and suborbital platforms, known as rockoons. Both of these approaches enable the minimization of drag losses. This paper addresses the issue of utilizing stratospheric balloons as launch platforms to conduct sub-orbital rocket flights. Research and simulations have been conducted to demonstrate these capabilities and feasibility. A small sounding solid propulsion rocket using commercially-off-the-shelf hardware is proposed. Its configuration and design are analyzed with special attention given to the propulsion system and its possible mission-orientated optimization. The cost effectiveness of this approach is discussed. Performance calculation outcomes are shown. Additionally, sensitivity study results for different design parameters are given. Minimum mass rocket configurations for various payload requirements are presented. The ultimate aim is to enhance low-cost experimentation maintaining high mobility of the system and simplicity of operations. An easier and more affordable access to a space-like environment can be achieved with this system, thus allowing for widespread outreach of space science and technology knowledge. This project is based on earlier experience of the authors in LEEM Association of the Technical University of Madrid and the Polish Small Sounding Rocket Program developed at the Institute of Aviation and Warsaw University of Technology in Poland.

1. Introduction

Suborbital flight experimentation has proved to be a significant mean of validating new technologies and conducting scientific research during the last 70 years [1]. Low altitude atmospheric sounding was done even earlier using meteorological balloons. However, the workhorses of high performance missions are rocket vehicles. With over one hundred suborbital flights conducted annually since World War II, a wide range of experimentation has been ongoing using sounding rockets. Sounding rockets have had an especially significant share of the space vehicle market till the late 1960s when launcher technology remained inaccessible for most nations and atmospheric research programs took place in over 20 countries worldwide [2]. However, nowadays, some sources forecast a downturn of sounding rockets. This is due to intensive space transportation commercialization, which is undertaken by numerous private entities through the use of cost-driven design philosophy. One of the most common approaches is the development of reusable vehicles, what may enable reducing operating costs by over an order. Many expect this rapidly growing segment to hasten the demise of classic sounding rockets. However, reusable suborbital vehicles full introduction is still yet to come and most of the companies postpone their official introduction. Moreover, there is a wide range of missions that require high altitude, high acceleration experimentation. Therefore, also in the field of sounding rockets new commercial players are emerging. Unlike in space tourism vehicles, new modules including large exterior hatches and serious modifications from flight to flight can be easily used. Therefore, sounding rockets serving as simple, reliable test and microgravity experimentation platforms will remain attractive for many entities.

A specific type of sounding mission involves the use of a balloon to lift a rocket launch platform to the stratosphere. By doing this, higher altitudes can be achieved because the launch path enables the avoidance of high density lower layers of the

Abbreviations: AP, Ammonium Perchlorate; CFRP, Carbon Fiber Reinforced Plastic; COTS, Commercially-of-the-Shelf; DLR, Deutsches Zentrum für Luft- und Raumfahrt (English: German Aerospace Center); HTPB, Hydroxyl-Terminated Polybutadiene; LEEM, Laboratory for Space and Microgravity Research; SL, Sea Level; SRM, Solid Rocket Motor; SSRP, Small Sounding Rocket Program; WUT, Warsaw University of Technology.

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atmosphere. Such system is called a rockoon, combination of words “rocket” and “balloon”.

The original concept dates back to 1949, by Lee Lewis, G. Halvorson, S. Singer and J. Van Allen, with the first attempts to use such device made during the fifties by the US Office of Naval Research. Many rockoons were fired during the following decade from vessels in the sea between Greenland and the US, others from the Equator, reaching more than 100 km in altitude and helping Van Allen make important discoveries on high altitude radiation and Earth magnetic fields [3,4]. Records show that both Australia [5] and Japan [6] made tests with this technology, but with no progress past the testing phase. The concept was soon discarded as more powerful sounding rockets appeared, and it offered, at that time, no clear advantages compared to other systems, and neither in the next decade in comparison to space launchers and the possibilities offered by satellites. The post-cold war era has seen the attempt to recover this technology, in an effort to achieve low cost access to space. Great examples of this are the L5 Society from Alabama, an amateur team who successfully launched a rockoon with a camera to an estimated altitude between 55 and 65 km [3] and the US based company JP Aerospace [7] with a simple design, proven to work at lower altitudes. Notable is also the Romanian-based ARCA project aiming to win the Google XPrize. Although not going far in terms of the original plans, a successful in-air ignition of the rocket propulsion system was demonstrated and 40 km of altitude were reached. Most recently the Spanish Zero2Infinity company announced its innovative concept to lift small payloads to Low Earth Orbit using a rockoon launch vehicle architecture. Other air-to-space launch systems involve aircraft. This is the case of the Virgin Galactic proposal and a number of similar smaller launch vehicles that are under development worldwide. However, up-to-date data from the Pegasus launch vehicle program show that such systems may be less cost-effective as it would be desired and significant durations of the pre-launch operations are experienced.

A very-early development rockoon-like system has been developed in Madrid by LEEM, successfully achieving motor ignition at low altitude [8]. It is however a small step as it involves subscale, non-space components, while new launch attempts involve improved technology and larger rockets. The goal of this project is to demonstrate that access to space (both in the form of orbital or sub-orbital flight) can be done at very low cost, satisfying the needs of some portions of the market.

In Poland near-space activities consist of both rocket and ballooning missions. With the first large scale balloon (127,000 m^3) built as early as in 1938 [9], plans to reach the 30,000 m altitude had to be abandoned due to World-War-2. Nowadays several ongoing university-based and outreach sounding ballooning activates take place in Poland reaching altitudes in excess of 35,000 m, with some interest in the field of rockoons declared. However, large scale developments are based on ground-launched sounding rockets utilizing solid and hybrid propulsion systems [10–13]. First launches to altitudes above the Von Kármán took place in Poland in the early 70' [2,14] and recent efforts may lead to the development of a small liquid-propelled [15] satellite launcher [16,17].

Recent theoretical research in the field of rockoons focuses on possible orbital performance [18]. However, most air-launch studies consider the use of aircraft [19–23]. Due to the lack of previously published analyses of optimization concerning balloon-launched low-altitude sounding rockets, this paper has the aim of showing such a close-to-optimal rockoon configuration in terms of commercial use. The study conducted focused on selecting a baseline for the potential development of a system enabling sub-orbital flights of a 1 kg payload above the Von Kármán line. Being defined as 100 km above sea level, this altitude is commonly referred as the beginning of space. Since depending on the launch site location and atmospheric conditions, different performance of the rocket can be expected, an “altitude margin” of 20% is considered. This means that configurations giving flight apogees of 120 km are searched for.

2. Rockoon platform

The proposed rockoon system is conceived as a combination of a lifting segment (one or several balloons), a launching platform, anti-torsion tethers connecting both of them, and the rocket with the payload itself. It has been studied that a better solution involves the use of more than one balloon, as a simple way to achieve higher altitudes still using COTS balloons. Regarding the launching platform and the tethers, it must be done in the lightest possible way, including only essential elements, as it is a dead mass with no use for the final mission. A more detailed description of the selected platform is exposed in the following chapters.

2.1. Pros

A rockoon system attempts to add to the offer of current technologies the possibility to reach space for a short time frame and at a low cost. The fact that it is an aerial platform allows for world-wide all-year-round launches, with flexibility that no other launching system can achieve. This is because the system can be used from any point in the planet, taking advantage of better climatic conditions in different areas. This ability with launch occurring at high altitude, prevent direct pollution of the lowest layers of the atmosphere and near natural reserves, reducing the impact a small payload sent to space would have on the environment in comparison to a piggybacked launch using a common rocket. While this is not critical for the mission, it is of some importance for the public to accept this system as an improvement over the existing ones. Ignition in the stratosphere implies that nozzles can be optimized for near-vacuum conditions, resulting in higher propulsion system performance. The small payload market could benefit from flexibility at a very competitive cost, most likely creating a whole new industry to cater the needs of educational centers, government institutions, certification of hardware made by the space industry and a whole plethora of other options either current or yet to come.

2.2. Cons

While it has many benefits, there are some obvious disadvantages like the impracticality to launch heavier payloads, or the difficulty of precise attitude control, due to the fact that it is a mobile platform that moves along with the air in its ascent to the stratosphere. Strong winds or precipitation may cause launch delays since stable conditions are required for the correct inflation and the whole structure set-up.

While not being the only gas used to lift a balloon, helium is considered the most adequate one as it is safe to use, unlike hydrogen which suffers from explosion risk. However, it is scarce and its price is increasing in time. Feasibility of other gas alternatives should be considered in the future as to assure a continuity of this kind of activities.

3. Balloons and main structure

3.1. Single balloon configuration

Initially, a single balloon system is considered. Due to the heavier than usual payload, low-cost classic balloons currently