Towards a Scalable and Financially Viable Test Platform for Microgravity Research

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Abstract

Access to microgravity on Earth is a key component of scientific experiments and for testing and demonstrating future aerospace technologies, both for space research and industry. Unfortunately, the best quality solutions are the most expensive, and the alternatives are rare or difficult to book. In addition, the providers of microgravity platforms are centralised in only a few places which can be geographically very far from their customers – forcing them to deal with the complex logistical and regulatory challenges involved in the international shipping of scientific payloads. Thus, availability, affordability and long lead times are the main issues with existing microgravity platforms. However, few people have been looking at designing and bringing to market a new and innovative alternative microgravity platform.

With the demise of the ISS closing in, several institutions have conducted market analyses in order to assess the commercial potential of privately-owned suborbital vehicles or space stations. These reports seem to indicate that some applications of microgravity do not need to be performed in space and could be performed by alternative means. Furthermore, recent test campaigns across Europe show that sailplane gliders can provide, to some extent, the microgravity environment sought after by many customers.

The present work focuses on assessing the financial viability of microgravity glider flights and finding out if there is a sustainable business model for this new microgravity platform. Commercial applications of microgravity are identified and in each case their requirements in terms of maximum allowed accelerations, variability and duration are listed. These are then compared with what a glider could provide to identify potential markets.

Based on that analysis, we present a glider-based microgravity testing platform and standardised interface that permits microgravity testing in a scalable, distributed and financially viable manner, and thereby enables cost-effective prototype testing, anytime and anywhere, for commercial NewSpace companies as well as research laboratories. The potential impact of such platforms on reducing cost and risk associated to developing new technologies for space exploration is also discussed.

Keywords: Microgravity, Research, Glider, Sailplane, Market Analysis, Technology

Acronyms/Abbreviations

ISS	International Space Station
LEO	Low Earth Orbit
TRL	Technology Readiness Level
SRV	Suborbital Reusable Vehicle

1. Introduction

Access to microgravity research is notoriously expensive and complicated. Only few laboratories and research organisations can afford parabolic or suborbital flights, not to mention the cost of sending an experiment to the ISS. Some ground-based solutions (i.e. drop towers, clinostats, and Random Position Machines) do exist but they are often either limited to niche research or overbooked (all slots for the ZARM drop tower are booked for the next 18 months). Availability, affordability and long lead times are the main issues with existing microgravity platforms.

On the other hand, with the ever-growing interest in CubeSat and space exploration in LEO and beyond in general, there is a clear rise in the demand for conducting experiments and testing components in microgravity. New fields are also looking into the potential benefits of microgravity such as 3D printing, medicine, etc. Fortunately, this increasing demand has pushed towards the standardization of microgravity experiments: CubeSat, KIWI [1], ICE cubes [2], ... All these initiatives provide a framework that we propose to exploit in a new type of platform: gliders.

LIDE.space proposes a solution based on gliders as a platform for parabolic flights, thus providing affordable and simple access to a relatively high-quality microgravity environment, anywhere in the world. Space enthusiasts, universities, and laboratories looking for preliminary results without discouraging access fees, delays, experimental constraints, or application procedures, will be the main beneficiaries of LIDE's solution.

While the aforementioned advantages for the innovative glider platform make it an interesting alternative, the market has to be analysed and the potential customers identified. The goal of this paper is to assess the financial viability of the concept in order to pave the way to a solid business model that will be used to access grants, incubation or investors. In that respect, Section 2 will introduce the topics by conducting a short literature survey of the existing microgravity platforms, summarizing the potential applications identified and showcasing the new offered solution in more details. The applications and their requirements will be compared with the restrictions inherent to glider flights in section 3 in order to narrow down the field applications that could in practice be conducted on that platform. Section 4 will then be devoted to providing an insight into the market size and estimating the potential revenues. Results are then shared in section 5, compiling the potential customers and the estimated market size. Finally, some discussions are made in section 6 on the other merits that are not easily quantified but could be seen as additional financial advantages for the glider platform.

This paper focuses on the European space environment and, in particular, on pondering how LIDE's activities in this sector could be made economically sustainable (with less or no institutional support).

2. Background of microgravity

2.1 Existing Platforms

After a short description, platforms are compared in more details in Tables 1 and 2.

Drop Tower are used around the world (USA, Europe and Japan) to achieve up to 9s of free fall. The highest in Europe is the ZARM tower located in Bremen, Germany. While the tower can in theory be used every day, they require the creation of a vacuum inside the whole tower to remove the air drag impact.

Parabolic Flights are often used to conduct experiment and train astronauts in microgravity. ESA and CNES conduct one campaign per year with up to 30 experiments, on board of the Novespace's A310.

For **Sounding Rockets**, REXUS in Europe is the leading initiative, conducting one campaign per year, only for students.

The International Space Station (ISS) is of course a good platform for conducting long-term microgravity research but is costly and requires long lead times and high Technology Readiness Level (TRL) which can only be achieved through expensive testing beforehand. Moreover, its end-of-life is currently planned for 2024 or 2028.

Clinostats and Random Position Machine (RPM) are accessible but only relevant to niche research (mainly to study cellular biology and plant growth).

Suborbital Reusable Vehicles (SRVs) or Shuttle-like orbital vehicles. Concepts like the X-37B or the Dream Chaser in the USA are also considered in Europe (SpaceRider and DC4EU) and could provide a platform for long-term experiments that could come back to Earth to be analysed.

Table 1. Comparison of existing microgravity platforms in terms of characteristics [3,4]

Platform	g	Duration	Volume [m^3]	Interaction
Drop Tower	10^{-3}-10^{-5}	4-9 s	<1	TC
Parabolic Flights	10^{-2}-10^{-3}	22 s	>10	Hum
Sounding Rockets	10^{-4}-10^{-5}	6 min	<1	TC
ISS	10^{-2}-10^{-5}	Years	>1	Hum
Glider Flights	**10^{-1}-10^{-2} ***	**6 s**	**<1**	**Hum/TC**
SRVs	10^{-2}-10^{-5}	Months	>1	TC

* Potentially improved by flight recorder and pilot training.

Table 2. Comparison of existing microgravity platforms in terms of logistics and cost [3,4]

Platform	Waiting Time	Cost	Cost per exp.
Drop Tower	Months	> 10k	5k
Parabolic Flights	Months	1.5M	135k
Sounding Rockets	> 2 years	>2M	>400k
ISS	> 5 years	>10M	1-5M
Glider Flights	**Weeks***	**<5k****	**<3k****

* Dependence on the weather but could be days in summer.
** Precise numbers not shared. Rough estimate.

In Europe, all these platforms are being currently used by laboratories and students through ESA-financed program (*Fly your thesis*, *Drop your thesis*, *Spin your thesis*), with long lead times and few flight opportunities. While these initiatives are very beneficial, they artificially raise the number of institutions being able to conduct such research and developments. The question remains whether this sector can be made economically sustainable with less or no institutional support.

2.2 Applications

2.2.1 Basic and Applied Research - Biological and Physical Research.

Gravity having such a big effect on any processes on Earth, the lack of it makes it possible to investigate other parameters or processes that are difficult to study otherwise. That is why basic and applied research in a number of disciplines can be done by leveraging the unique properties of and access to microgravity. The fields interested includes: Fundamental Physics, Atmospheric and Environmental research, Materials Sciences, Physics of Fluids and Combustion, Astrobiology, Biology and Human Physiology and Performance. Many examples of such research can be found in the papers published for the bi-annual European Low Gravity Research Association (ELGRA) Symposium.

Even less obvious fields like medicine or the pharmaceutical industry have been shown to benefit from research conducted in weightlessness, [6] [7].

2.2.2 Aerospace Technology Test and Demonstration

Another application of the microgravity environment is to advance technology maturity or achieve space demonstration, qualification or certification. Space hardware has to be tested in a multitude of environments (vacuum, vibrations, microgravity, etc.) and while each test is meant to increase the Technology Readiness Level (TRL) of the solution, it is also used to reiterate on some design flaws or misconceptions.

Another possibility is to test technological solutions that are taking advantages of properties and abilities that also valid in weightlessness, like capillarity for example. Overall, there has been a constant increase in the number of technological patents linked to microgravity, as shown in [8].

2.2.3 Manufacturing products and services

As described in [10], some manufacturing markets have been studied. Some products and materials are proven to be way better if produced in space, or more accurately in microgravity, for instance, high-grade silicon carbide and exotic fibre optic cable. While assumptions can be made on the required duration and level of acceleration, it is difficult to foresee the volume needed to manufacture and the potential customers looking to produce this on a bigger scale.

2.2.4 Education

All aforementioned platforms provide excellent opportunities to schools, colleges, universities, and graduate programs to increase access to and awareness of space. Some are even used to train astronaut and prepare the future of space exploration.

2.2.5 Media, advertising

The idea is to use weightlessness to promote products, increase brand awareness, or film space-related content.

2.3 New Alternative Platform: Sailplane and Glider

Previous studies have considered the opportunity of flying parabolas with regular gliders or aerobatics planes, for educational purposes [3][4][5]. While very useful and inspirational, these studies did not provide any insight from an economics perspective.

Technically, any conventional glider can sustain the load factors inherent to parabolic flights, with flight envelopes usually extending from -3g to +5g at least.

The first tests conducted at LIDE, and backed by literature, hint at 6s parabolas and with an acceleration below 0.1g. Besides, gliders are very popular, quite flexible in transport and operation, and they offer very smooth rides in the proper atmospheric conditions as there is no vibration coming from the engine, as on light aeroplanes.

Our objective is to mount the rear seat of a couple of conventional two-seated gliders with a Payload Box that will be flown into microgravity and will provide a standard interface for payloads. The so-called LIDE Box can be adapted on customer demand or can be outfitted with several standard cube slots. The maximum payload mass (container + content) is 100kg, based on the glider Maximum Take-Off Weight (MTOW). The glider would also be equipped with a Flight Recorder designed to accurately monitor the position, velocity and acceleration of the on-board experimental sample. A specific display for the pilot is provided, in order to facilitate the execution of the flight and reach high quality microgravity environment. This Flight Recorder contains an off-the-shelve microcontroller connected to a GPS receiver, an accelerometer and a gyroscope.

Operationally, the LIDE team will build a network of supported gliders with the objective to limit the number of gliders owned by LIDE and reduce the cost and exploitation. LIDE provides the pilot and the Payload Box and the Flight Recorder while the customer sends the experiment to the chosen airfield on the scheduled date. LIDE then performs the experiments during one or several flights, to guarantee the quality of the results.

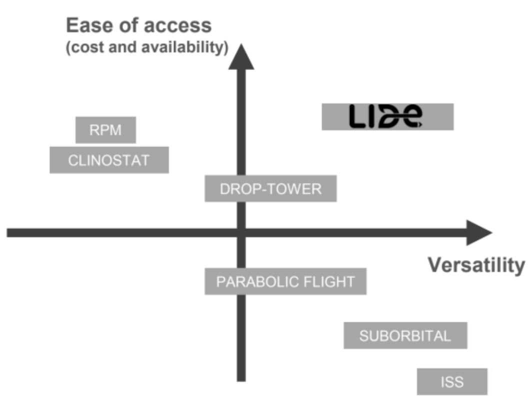

Fig. 1. Qualitative comparison of LIDE solution with other existing platforms

While this alternative solution still needs to be further tested in other to better qualify the solution space in terms of microgravity quality, duration of flights and volume, the platform can already be compared with the others (cf. Fig.1).

3. Comparison and identification of potential markets

Commercial applications of microgravity have been identified in section 2.2. In this section, in each case the microgravity requirements are listed (in terms of maximum allowed accelerations, variability and duration). These are then compared with what a glider could provide to identify potential markets. See in Annex for the full table of results. See herein below for summary of findings.

Since ISS operations are soon coming to an end, several market analyses have been conducted for SRVs [9] or privately-owned space stations [10]. Those studies focused on seeking applications of the microgravity environment which would have requirements fitting the restrictions of such platforms. All applications will have different requirements regarding duration, size, acceleration levels, etc. while all platforms have different restrictions and advantages. In order to apply this method to the glider platform, the characteristics that such flights can offer have to be identified and quantified.

- Duration of flight: 6s
- Level of microgravity reached: 0.1-0.01 g
- Type of human interaction/operation: human can be operator but that reduces the available volume or telecommand
- Volume available for payload: 0.24 m^3

The following fields of application have been assessed through relevant examples in order to identify if they could provide some applications that could or would definitely work within the characteristics offered by glider flights. For each field, some examples are provided in order to identify better what are the potential actors.

- Basic and Applied Research - Biological and Physical Research

As identified in [6], one challenge to conducting microgravity research on SRVs is designing experiments that can effectively use one to five minutes of microgravity and cannot be effectively scaled for much shorter periods of microgravity in drop towers and parabolic flights.

This report based on interviews with experts from different sectors, hint at the fact that many experiments can be scaled down for shorter periods of time and be conducted in parabolic flights.

Due to the novelty of gliders as alternative platforms for weightlessness experiments, and to the scarcity of information on microgravity funding, it is rather difficult to precisely determine the size of the expected market. It is however possible to extrapolate an order or magnitude from available data. Firstly, it is to be noted that users of glider-based weightlessness solutions are expected to form an entirely new market. Indeed, current customers of microgravity platforms (namely top-notch laboratories, universities, and space agencies) are likely to stick to existing solutions (drop towers, suborbital flights, parabolic engine-based flights), which they can afford and comply with their requirements. On the other hand, smaller research institutes, which are our main target market, do not have access to current microgravity platforms. The market share that could be gained from current users is thus expected to be negligible.

- Aerospace Technology Test and Demonstration

Payloads can be at any level of maturity but are most likely to be at the higher TRLs of 5, 6, and 7, which require test or demonstration in relevant environments. In addition, SRVs provide opportunities to train new members of the workforce with hands-on management experience with flight systems.

Glider flights could be used to increase the TRL of technologies before they can actually be tested in all relevant environments. Multiple tests are required before being allowed to launch on-board the ISS or even in space. In practice, glider flights campaign can be done to validate the microgravity functioning of the technology but also to conduct cheap and fast preliminary testing before the actual validation occurs.

With the growing interest in lunar or Martian exploration, it is important to mention that parabolas can be tuned to achieve low-gravity levels such as those on the Moon or on Mars.

- Manufacturing products and services

Manufacturing fibre optics in microgravity is a known potential market that is currently tested by Made in Space and FOMS. Reproducing the methodology of [7] regarding the production of fibre optics using ZBLAN, we can infer that 6 seconds of microgravity could produce up to 60 cm of fibre optics which could still be sufficient for some biomedical applications. The feasibility, levels of attenuation reached, or shortest needed length are not confirmed.

- Education

Due to the low cost and accessibility of the glider platform, this category could lead to a lot of opportunities.

- Media, advertising and public relations

It seems unlikely that such applications can be scaled down in terms of required volume.

4. Size of Market Estimation

Comparing the overall NASA budget with the sole budget of its Microgravity Research Program [11] for fiscal years from 1995 to 1999 (pre-ISS area, and last NASA budget reports for which the microgravity budget is detailed [7]) shows that the share of space-related public spending dedicated to microgravity ranges from 0.7% to 1.22%, with a mean of 0.93%. It is to be noted that these figures represent the share of total public funding (and not only of science budget, which amounts to 28.48% of the total NASA budget as of 2015 [12] and to 9.2% of the total ESA budget as of 2019 [13]).

Even if only 1% of this share is invested into glider-based microgravity research and given that the total public spending in space programs reached $62 billion in 2016 [14], the total market size of glider-based research would represent up to $5.8 million.

In Europe, the size of the current market can also be roughly estimated based on known and published numbers, as presented in Table 2. In order to estimate, the assumption is made that the major actors are Novespace with its parabolic flights, ZARM and its drop tower and Rexus's sound rocket. Six parabolic flights would amount to 9 million €, one Rexus campaign amounts to 2 million € and an estimated 300 ZARM drop per year give 3 million €. It is therefore safe to assume that the current spending in microgravity research, is clearly above 15 million € per year.

While the operational cost of the proposed glider flights is still under assessment, it is clear that the total cost per experience can be significantly lower than that of other platforms. The final offered price will have to cover the cost of the glider rental or acquisition, pilot, and any other operational fees while as well amortizing the development of the required Flight Recorder and Payload Box.

However, it is not only foreseen to take some parts of the market but more importantly, LIDE.Space is aiming at creating a new market by giving access to institutions who can currently not afford to do those kinds of research and testing.

5. Results

In a first part, applications that could benefit from a low-cost, more available platform are clearly identified:

Scaling down the experiment to fit within the restrictions of glider flights seem feasible for a series of disciplines. The ranges of requirements for the experiments belonging to each application fields are deemed very wide. Within each category, one can find experiments that could indeed be scaled down in terms of duration, volume and weight but also identify several which could definitely not be conducted in a glider. Besides, it is believed that given a cheap and accessible solution will spur new opportunities in research, even in disciplines that are traditionally not looking to experiment in weightlessness. Therefore, basic and applied research is definitely a potential market, but specific attention has to be given to the requirement and the possibility of downscaling.

Testing and validating experiments and parts that will eventually be flown in space is very costly. Reliability and safety are required by all institutions and stakeholder involved in the ISS and other space exploration endeavours. The community benefits from experiments and satellites that are well tested beforehand instead of sending useless or dead components, especially given the current cost to send a certain mass up there and time it takes to prepare and get a launch slot. Proper testing and training also improve the teaching and inspiring experience for universities or school as it would increase the success rate of CubeSats and nanosats.

The design technique of trial and error can barely be envisaged as for the ground testing, the costs are high, and the opportunities spare. This results in laboratories and companies having to spend a considerable amount of money and time in testing their components or experiments. With this in mind, the new proposed solution has the goal to improve the overall success rate and considerably reduce the costs, delays and hassles related to conducting microgravity experiments testing.

Glider flights are also an exciting opportunity to simply conduct experiments designed by students and universities with the purpose of education. Ways to finance these kinds of activities will have to be found with states and other educational programmes but it is clear that space enthusiasts, universities, and students looking for preliminary results without discouraging access fees, delays, experimental constraints, or application procedures, will be beneficiaries of LIDE's solution.

Potentially, products could eventually be manufactured in the microgravity environment aboard a glider, but this would have to be properly assessed on a case-by-case basis. Moreover, the technology is not yet matured and the market somewhat restricted.

Even though it is difficult to make an accurate prediction of the market potential for all these categories, we can conclude that the demand for microgravity and low-gravity glider flights will be dominated by research experiments and components test applications. Advantageously, the costs per experience for glider flights, which have been here estimated and discussed, would allow for significant margins for the provider. Even so, it is clear that this solution would be the cheapest available for many potential customers.

6. Discussion

Other merits of the glider platforms have been identified but are not easily quantified even though they could be seen as additional financial advantage for the glider platform.

First, a major benefit of our solution is the ease of access since it can be deployed in any airfield in the world. The payload container and the recorder will be designed to fit several types of gliders. This presents a major advantage compared to existing solutions, which usually impose stricter limitations on the size or event shape of the experiment. Conveniently, they can thus be sent to a partner gliding club close to the customer, such that the experiments can be performed on the spot. It is therefore a very attractive solution for customers who do not have to deal with the administrative pain and cost of shipping a scientific payload internationally. The unanswered question is how much money is saved by not shipping abroad and or far from the customer premises?

As previously mentioned, a cheap and accessible platform can be used to run preliminary test to iterate on a solution and to train and prepare for a more serious validation on a parabolic flight or on board of an orbital vehicle. The claim is that much money can be saved on the testing and training.

Moreover, the potential impact of such platform on reducing cost and risk associated to developing new technologies for space exploration can also discussed.

7. Conclusions

Entering the 2020's, ISS operations are soon coming to an end. While several other solutions are being assessed in Europe and in the world and that many endeavours beyond LEO are foreseen, there might be an opportunity to revolutionize the field by offering an alternative lost-cost platform to conduct microgravity research and testing.

Given the preliminary results presented in this paper, a market exists for the proposed innovative platform. Therefore, this new solution would primarily focus on industrial actors active in any field related to space and research institutions from multiple disciplines, with a need for fast and cheap access to microgravity. Thanks to the flexibility of the platform, repeated test windows can be offered within short delays, with high value for the customer as it allows them to shorten their process and facilitate their developments.

In addition, LIDE gliders will open the door for a whole new segment of the market by enabling educational parabolic flight activities to promote Science in schools. The affordability of the service and the limited number of requirements and procedural constraints will also allow many enthusiasts to experience microgravity for fun and artist to express their art in microgravity.

While the technical details are currently being tested and validated, the next step would be to assess the financial viability and come up with a realistic business model that will be leveraged as a selling argument with investors and incubators.

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