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IAC-19-A2.5.4x50685

Glide, without g – a systematic quantification of gliders 0-g flight capabilities

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Abstract

With the ever democratizing access to Space, easier access to microgravity before launch is becoming critical as more and more space systems are being developed and require testing. On the other hand, science and research continuously benefit from experiments conducted in reduced gravity environments.

Conventional solutions to reach weightlessness are today well established: sounding rockets, parabolic flights and drop towers, all provide an opportunity to reach weightlessness. The cost of that access to microgravity often scales up with the duration of the test window and the quality of the microgravity environment. Moreover, because of the increasing demand for microgravity solutions, long lead times are often to be expected. Recently, there has been some interest in the possible development of affordable microgravity solutions based on general aviation platforms, which could significantly increase the supply of microgravity test platforms and would create a new market opportunity. The team behind this paper, hereinafter referred to as LIDE, is a recent Belgian initiative which looks into the suitability of sailplanes to recreate quasi-microgravity conditions for research and technology development tests.

This work further investigates the potential of sailplane-operated parabolic flights. Based on preliminary data collected during LIDE's on-going flight test campaign, the characteristics of the parabolas are described with a focus on the segments of microgravity. The quality and repeatability of the weightlessness are characterized using statistics of the flights, showing that a quasi-0-g acceleration can be maintained for 5.5 seconds on average, with a measured standard deviation smaller than 0.1g. Operational considerations associated with glider parabolic flights are also discussed. Finally, sailplane and piston-engine flight data are compared to illustrate the negative effect of the engine-induced vibrations on the experienced acceleration. Sailplanes are only sensitive to atmospheric turbulence, and thus provide a good quality environment to support microgravity.

Keywords: microgravity experiments, gliders, parabolic flights

1. Introduction

Experiments in a reduced-weight environment are a fundamental part of many branches of applied sciences: material science, fundamental physics, fluid dynamics, physiology and space medicine, plant and cellular biology, combustion physics, all require to conduct experiments in zero gravity [1]. Additionally, the space industry produces a continuously growing number of systems that often require to be tested in weightlessness before they can actually be deployed. Yet, the number of solutions able to reproduce microgravity on Earth is limited and they all have their limitations. Sounding rockets, parabolic flights and drop towers are today's most valued microgravity platforms. However, they all suffer from low availability, low affordability and long lead times. [2]

Considering the continuous increase in the demand for microgravity solutions and the relatively constant supply of test opportunities, there has been some recent interest in alternative, less costly solutions for microgravity testing. For instance, parabolic flights can be performed with light single-engine piston aircraft, as was demonstrated by flight test campaigns operated with a Cessna 206 [3] and a CAP 10 [4,5]. Microgravity was achieved for 8 seconds during each parabola.

Sailplanes are also potentially favourable platforms for reaching weightlessness. A first quantification of gliders 0-g flight capabilities has been realized [6,7] using a Grob G-103 Twin II. The results showed that:

- Weightlessness can be achieved continuously for up to 6 seconds per parabola;
- A typical 20 to 25-minute flight allows to perform between 3 and 21 parabolas, depending on the pilot's experience;
- The estimated level of achieved weightlessness ranges between 10-2 and 10-1g.

The goal of the present study is to refine these results and to provide a more complete and systematic quantification of gliders 0-g flight capabilities. We present the preliminary results of an ongoing flight test campaign of parabolic flights realized with an ASK-21 (which has similar characteristics to the G-103). Data were collected using custom made recorders and accelerometers which allow us to precisely identify the

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level of 0-g achieved during parabolas, and their duration.

In this article, we first expose the context of research and tests in microgravity, and we elaborate on the potential benefits of the development of low-cost sailplane-based microgravity platforms. In section 3, we introduce the flight test campaign that aims to better quantify the capabilities of sailplane-operated parabolic flights. We describe the sensors that are used to collect data, and the additional systems involved. Section 4 is dedicated to a first analysis of the preliminary flight test results, with a specific focus on the microgravity phase. Additional considerations specific to glider flights are also discussed, including the comparison between the vibration levels measured in a glider and in a light airplane.

2. Technical and economic context

1.1 Applications of 0-g environments on Earth

The range of scientific fields that are related to reduced-weight environment is extremely large. We will focus on three main examples of experiments that currently exist and are being run on ISS or other platforms to illustrate how access to zero gravity is fundamental to modern science.

FLUIDICS: Fluid dynamics are notoriously difficult to model in zero gravity, which is a major impediment to spacecraft control efficiency. Indeed, sloshing in tanks of liquid propellants rockets or satellites leads to disturbing torques that are hardly predictable and controllable. The FLUIDICS (Fluid Dynamics in Space) experiment, run on board the ISS, is an attempt to better understand liquid sloshing and wave turbulence phenomena. [8]

ICE: The equivalence principle can be measured by comparing the accelerations of two atoms having different masses and structures using a two-species atomic interferometer. On Earth, measured atoms are subject to gravity and ultimately fall off the recording area, while weightlessness allows for longer, and thus more precise, recordings. The ICE (Coherent Source Interferometry for space) is an experimental set-up onboard Novespace's 0-g Airbus, defined as « a first step towards a spatializable system » [9].

SHS Capsule: The Material Science in Variable Gravity Group of the University of Bremen [10,11] is especially interested in seeing how reduced or high gravity levels impact material synthesis and properties. To this end, they developed the Self-Propagating High-Temperature Combustion Synthesis Capsule (SHS) meant to be tested within the ZARM drop tower. It is equipped with two monitored reaction chambers, and allows to study how material structures are affected by weightlessness.

Besides fundamental research, weightlessness is also used to test future equipment for the International Space Station and other space systems. For instance, heat dissipation systems and water supply systems, which optimal operation envelope depends on applied accelerations, are tested during numerous parabolic flights campaigns before being installed (e.g. on the ISS). With the additional and ever-growing interest in CubeSat, and in space exploration in LEO and beyond in general, there is nowadays a clear rise in the demand for conducting experiments and testing components in microgravity.

Finally, new fields are also looking into the potential benefits of microgravity such as 3D printing, medicine, etc.

Overall, this rise in demand comes mainly from smaller research organisations or privately funded commercial entities which are much more sensitive to the cost and lead time of access to traditional platforms.

1.2 Existing solutions for ground-based microgravity platforms and their limitations

Access to microgravity research is notoriously expensive and complicated. The average cost and lead time for the most popular solutions are summarized in [6].

Only few laboratories and research organizations can afford parabolic or suborbital flights, not to mention the cost of sending an experiment to the ISS [12]. Parabolic Flights are often used to conduct experiments and train astronauts in microgravity. For example, ESA and CNES conduct one campaign per year with up to 30 experiments. Generally, parabolic flights are performed with large aircraft, such as the A-310 operated by Novespace or the B-727 operated by the Zero Gravity Corporation.

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

Among ground based solutions, drop-towers are used around the world (USA, Europe and Japan) to achieve up to 9s of free fall, but these are often overbooked. The highest in Europe is the ZARM tower located in Bremen, Germany. In theory, the tower can be used every day, but it requires the creation of vacuum inside the whole tower to remove the impact of aerodynamic drag.

To a lesser extent, clinostats, and random position machines can be used to reproduce microgravity from a statistical perspective, but these are limited to niche research (e.g. to study cellular biology and plant growth). [13]

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In Europe, all these platforms are being currently used by laboratories and by the industry.

Students can also access some of these facilities through ESA-financed program (*Fly your thesis, Drop your thesis, Spin your thesis*). But these programs are limited in scope and capacity and the lead times to get access to one of the test slots are relatively long. While these initiatives are very beneficial for microgravity research in Europe, they also epitomize the demand for more accessible test opportunities in microgravity conditions.

1.3 Potential market benefits of sailplane-operated parabolic flights

Sailplanes are commonly operated in many places of the world. Moreover, a majority of the training glider currently in use are suitable for parabolic flights, as the structural loads endured during the parabola are compatible with most of today's glider flight envelopes (see section 4). Besides, the cost of operation of a glider are relatively small. These are all advantages to the use of gliders for microgravity experiments.

In order to guarantee the safety and the quality of the parabolic flight, one should however ensure that:

- pilots are properly trained for the maneuvers in all phases of a parabolic flight;
- the subject of the experiment/test is correctly installed and fastened in the glider.

For the latter, we propose the use of a standardized container (still to be developed), which could adapt to several types of gliders, and which could potentially provide power supply and telemetry to the experiment. Such a standard container could be sent to a gliding club close to the customer, such that the experiments can be performed there (with a qualified pilot). It therefore offers less painful logistics to the customer by reducing the cost and time of transporting payloads, in addition to lowering the administrative burden.

Provided that these two above conditions are filled, sailplane parabolic flights could be used to endorse a large number of microgravity experiments for research, academic, and industrial purposes, provided that the constraints on the quality of the weightlessness required for the envisioned test is not too stringent.

Among potential beneficiaries, let us mention universities and student projects, and laboratories looking for preliminary results without discouraging access fees, delays, experimental constraints, or application procedures.

It is to be noted that the authors of [6] also assessed the possibility to use a sailplane to generate a high gravity environment (by flying high-bank turns) or quickly changing g-loads (by flying aerobatics maneuvers like chandelles). Results show that gliders can achieve a g-load between 1.5 and 2g for 20 to 40s, and to quickly vary the g-load between 0g and 4g. These maneuvers are not within the scope of the present study, but show that sailplanes may also be used to perform high-g experiments.

3. Description of the experiments and collection of data

Data presented hereafter were collected during the first phase of a flight test campaign which consisted of 7 flights, totalling 74 parabolas, conducted between September 2018 and September 2019. All flights were performed in smooth air conditions in order to minimize the perturbations due to atmospheric turbulence. Recordings were obtained onboard a Schleicher ASK-21 two-seat glider (see Fig.1). The manufacturer specifies a g-limit of +6.5g and -4.0g for structural reasons. This flight envelope largely covers the needs of parabolic flights, and is similar to the limitations of other two-seat plastic-made training gliders (e.g. DG-505, DG-1000, G-103).

Fig. 1. The ASK-21 used for the flight test campaign

3.1 Data collection: sensors and means of measurement

During the flight tests, we used three independent devices in order to record data for the quantification of the parabolas.

The first flight data recorder (FDR-1) is based on an Arduino-YUN rev2 board, equipped with a microcontroller for data acquisition and processing, and a Linux microprocessor which was used here for real-time data display (see next section). The FDR-1 was fitted with a DP0107 GNSS module for geo-localization and with a MPU-9250 IMU providing measurements of the acceleration, the rotation rate and the magnetic field intensity in 3-D. Initially, we aimed at a data acquisition rate of 10 Hz, which is the largest allowed by the GNSS module. In practice, because of the high workload demanded from the processing of both sensors data, and also accounting for the communication between the

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microcontroller and the Linux processor, the actual sampling rate varies between 3 and 5 Hz.

The second data recorder uses a Raspberry Pi 3 microcomputer, wired with a Bosch BNO055 absolute orientation sensor.

The BNO055 is a smart 9-DOF which processes data from an internal IMU (accelerometer, gyroscope and magnetometer) and outputs the accelerations and orientation of the sensor. Turning the IMU sensor data into actual aircraft absolute orientation is difficult to implement on low cost real-time systems [14]. This BNO055 sensor was selected as the included high speed ARM Cortex-M0 based processor automatically digests all the sensors data and sends out directly usable information in the form of quaternions, Euler angles or vectors.

This abstraction level removed away concerns about sensor fusion and real time requirements and the bespoke algorithm developed by the authors could focus on combining the orientation and acceleration data to get meaningful insights for the pilots during post-flights reviews. Overall, FDR-2 has a sampling and writing frequency of about 25Hz.

Finally, the built-in accelerometer sensor of a smartphone was used as a back-up sensor. Advantageously, the sampling frequency could be increased to 100Hz.

All sensors were installed in the backseat of the glider, as shown in Fig.2, in order to minimize their distance to the center of gravity (CG) of the sailplane. Tape was used as the easiest and most efficient solution to attach the recorders.

Notice that the distance between the sensor and the CG have a small, but non negligible influence on the recorded data. Indeed, during the parabola, the glider pitch rate is of the order of 0.26 rad/s (as it goes from a +45° to a -45° pitch angle in approximately 6s). If the sensor is located e.g. 2m in front of the CG (ahead of the front seat), the corresponding acceleration would be of the order of 0.014g. In the backseat, the distance is closer to 0.5m, and the spurious acceleration is down to less than $3.4 \cdot 10^{-3} g$.

Fig. 2. Mounting of the sensors in the backseat of the glider (FDR-1 on the right, FDR-2 on the left).

3.2 Real time display

In 2018, a first series of exploratory flights were conducted. From this early experience, it became clear that specific training for the pilot was required to guarantee the good quality of the parabolas. Meanwhile, the pilots also identified the need for a real-time feedback of the g-force experienced by the payload in order to fine-tune the sailplane trajectory. Indeed, aviation accelerometers exists but are not part of the mandatory instruments for gliders (there were none in the glider which was used for the present study).

In order to allow for real-time acceleration display, the Arduino-based FDR hosts a HTTP server embarking a Javascript runtime environment. The server has access to the measurements and is programmed to pack them inside a graphical user interface and return them on HTTP requests. We use the Arduino's capability of creating a Wi-Fi hotspot for handling wireless connections between the FDR and external devices. As a result, a smartphone with a standard internet browser can be used as a monitor for our digital accelerometer. Fig.3 shows an example of the view displayed to the pilot.

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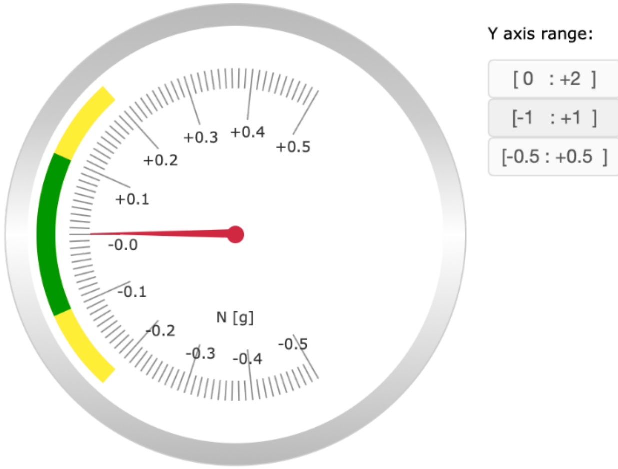

Fig. 3. Example view of the pilot display generated by FDR-1, showing the current load factor.

A satisfactory latency of less than 0.25s is observed between the time of measurement and the time of display, and the refresh rate of the display is close to the sampling rate of FDR-1. This shows that the entire data processing and communication chain only introduces a moderate lag. However, feedback from the pilots indicates that a higher refresh rate would allow them to refine the parabolic trajectory and smoothen their actions on the glider flight controls. For the second part of the flight tests, a software solution is envisioned to improve the performances of FDR-1, but this might eventually also require hardware changes.

4. Systematic quantification of gliders 0-g flight capabilities

4.1 Parabola from an instantaneous perspective

Unpowered aircraft can hardly reach the same quality of weightlessness as conventional aircraft used for parabolic flights, nor will they be able to sustain parabolas nearly as long. Indeed, at first order, the duration of the parabola is proportional to the injection velocity (i.e. the velocity at which the parabolic trajectory is initiated), which gives a clear advantage to fast flying airplanes for maximizing the duration of the free fall. Nevertheless, some aspects of the 0-g flight capabilities of a sailplane are here further investigated.

The precision of the trajectory is quantified, also attesting the reproducibility of microgravity conditions. The influence of the aerodynamic drag and the environmental noise are also assessed.

In practice, the flight procedure consists in performing several parabolas in sequence, starting from an initial dive used to build up speed and reach the initial velocity. In order to maximize the duration of the parabolas, the injection velocity should be as high as possible. However, in addition to the *never exceed velocity* (VNE = 250 km/h for the ASK-21), an even more restrictive constraint stems from the flight envelope.

One must verify that the initial velocity will not lead to load factors exceeding the threshold during the pull-up between two parabolas. In this case, we intentionally set this limit to 4g in order to reduce the loads on the glider, and therefore, we selected a target initial velocity of 200km/h which gives an injection velocity of 150km/h.

In this document, all accelerations are given in the body axis frame, with the x-axis pointing forward out of the nose (i.e. in the axial direction), the z-axis pointing downward (i.e. in the vertical direction) and the y-axis to form an orthonormal frame, as illustrated in Fig.4.

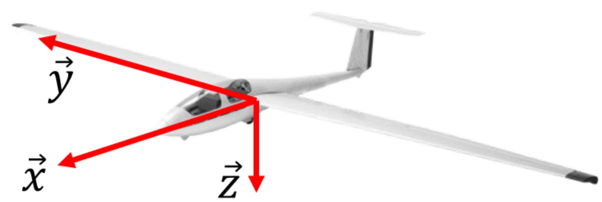

Fig. 4. Body frame axes.

Fig.5 shows the time history of the vertical acceleration a_z divided by the gravitational acceleration g (i.e., the load factor $n = a_z/g$) and the altitude during a sequence of parabolas.

The sequence of parabola is made of several periods, and it can be clearly seen from the acceleration profile that each period can be decomposed in three phases. Starting when the initial velocity is reached, the first phase is the pull-up where the glider transitions from a dive to a pitch angle of +45° (yellow shaded area). The second phase starts at the injection: the pilot promptly pushes the stick forward until the 0g is reached, and by doing so he initiates the parabola. This phase lasts for about 6s (green shaded area) and will be further analyzed here after. In the third phase which lasts for about 3s, the glider is maintained in a nose down attitude in order to recover the initial velocity required for the next period in the sequence (blue shaded area).

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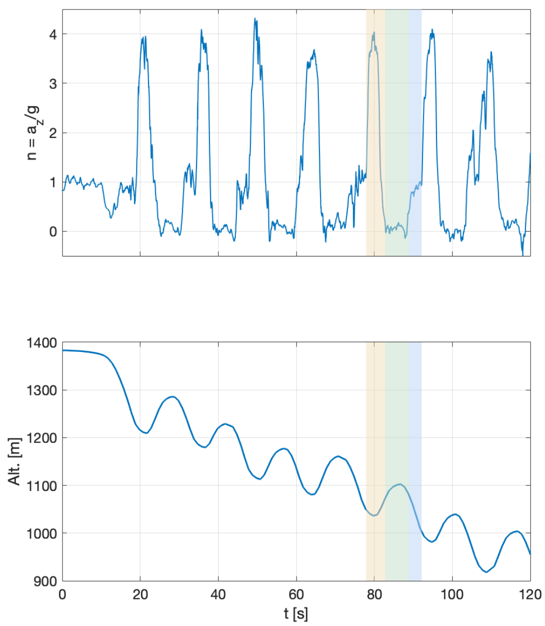

Fig. 5. Time history of the vertical acceleration (load factor) and the altitude during a portion of flight #3, with the initial dive and seven subsequent parabolas.

4.2 Parabola from a statistical perspective

In order to better characterize the 0-g phase, the accelerations measured by the back-up high frequency sensor was used to derive statistics over a set of 30 parabolas. The results are shown on Fig.6. We stress that, because of the small number of parabolas involved, the statistics are not fully converged for this preliminary study. However, the ensemble size should be sufficient to identify the main trends.

The average vertical acceleration shows that the pilot is indeed able to maintain the glider in a fairly constant reduced gravity environment. The microgravity phase, which is here arbitrarily defined as the portion of the parabola with $a_z/g < 0.2$, is 5.5s long on average, with a standard deviation of about 1s.

Because it is quite short as compared to conventional parabolic flights, it is hard to further decompose the microgravity phase as was proposed in [15].

Importantly, the standard deviation of the vertical acceleration is lower than 0.1 g. This mainly characterizes the repeatability of the maneuver and the level of smoothness acquired in piloting the trajectory of the glider. Those two characteristics are mostly dependent on the pilot and on his experience. Notice that the cause of the standard deviation is not to be found in measurement noise or vibrations, as will be shown in section 4.4.

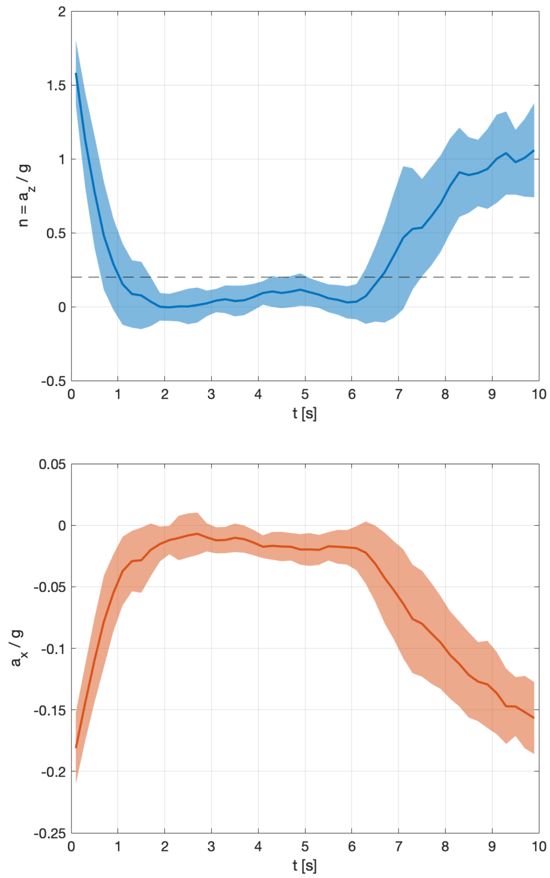

Fig. 6. Average vertical (top) and axial (bottom) acceleration measured during a parabola, and their standard deviations (shaded areas).

The average vertical acceleration during the parabola is almost zero. The small residual offset, together with the standard deviation itself, could be both further decreased with an improved real-time display system (or a standard instrument), and will be also reduced with the increasing experience and practice of the pilots.

It is worth mentioning that the targeted mean level of weightlessness can also be adapted to simulate Moon (0.165g) or Mars (0.374g) surface gravities, just as in traditional parabolic flights [4].

Strictly speaking, because the glider has no engine, perfect zero-gravity conditions cannot be reached as opposed to propelled aircraft, for which the residual drag force can be compensated by the engine thrust. The parasitic drag experienced by the glider on the parabolic trajectory results in an axial acceleration which cannot be zero. It is here measured to be smaller than 0.02g on average (see Fig.6), which is compatible with a rough estimation based on the glider technical specifications.

Indeed, if one considers that the parasitic drag is 50% of the total drag at the best glide angle *bga* (assumption stemming from the Prandtl Lifting Line

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theory), and based on the technical specifications of the glider, we find a drag coefficient of

$$C_{D_0} = \frac{1}{2}\,\frac{1}{bga}\,\frac{Mg}{\frac{1}{2}\,\rho\, V_{bga}{}^{2}\, S} = 0.012$$

with S the reference surface, V_{bga} the optimal velocity and ρ the air density.

With a glider mass M=550kg, this should correspond to an acceleration on the order of 0.025g under the conditions of our flight tests.

This axial acceleration is however small compared to the variations in vertical acceleration shown above.

4.3 Number of parabolas per flight/day/year

In this section, we determine the average number of parabolas achievable over one flight which obviously depends on the release altitude of the glider. Using the characteristics of every flight of the flight test campaign, we have determined that the average altitude loss per parabola is 50m. This is confirmed by the altitude profile obtained from GNSS data.

Operationally speaking, the glider is preferably towed up to a height of about 1000m. Accounting for a reserve height of 300m necessary for maneuvering and for the execution of the standard landing pattern, the remaining 700m can be used for parabolic flight. Therefore, one can expect to perform 14 to 15 parabolas per flight. Obviously, several flights can be performed in a row to increase the number of parabolas performed in a day, as the duration of one of these typical flights is around 20 minutes.

Generally, the operation of sailplanes and general aviation aircraft is more dependent on weather conditions than standard commercial aircraft. Rain, strong winds, low ceiling or reduced visibility typically prevent them from taking off.

It is difficult to assess the number of days per year where flying is possible, especially because the go/no go threshold can be subjective and because there are many criteria to take into account: the local weather, the type of flight envisioned, the airspace, the safety margins... Within Europe, there are regions where the conditions make it possible to fly gliders all year long and even in less favorable locations, there are always several “good” days per month. It must be stressed that, for the type of parabolic flights described above, the weather minima are simply the same as in VMC (allowing for VFR flights). This is way less stringent than the weather conditions awaited by the sport sailplane pilot, in which the formation of thermals and cumulus clouds are expected to enable long duration or long distance flights.

Therefore, while it cannot be guaranteed that sailplane parabolic flights can happen on any day, it can be postulated that the waiting time before the next flying opportunity is shorter than the typical lead time of current microgravity platforms.

4.4 Jitter analysis and comparison with aircraft capabilities

Gliders do not suffer from the increased level of vibrations generated by piston engines, which had previously been identified as one of the main drawbacks of using light aircraft for weightlessness studies [3,4]. In order to verify this assertion, we compare the high frequency acceleration data collected during our glider flights with that measured in a General Aviation (GA) aircraft. The latter recordings were obtained on board a Diamond DA40-TDI, a four-seat single-engine piston light aircraft equipped with a 135Hp Thierlet Centurion Diesel-injected engine.

The data post-processing is similar to what is proposed in [16], and involves the following on the norm of the measured acceleration vector:

- Data segmentation. As we are interested in the vibration level in both aircraft types, we compare data collected during similar flight conditions: constant speed straight flight for the glider, versus cruise condition flight for the GA plane. Data of interest was selected prior to the analysis based on the pilot’s flight log.
- Filtering. A high-pass filter is applied on data to remove the low frequency component from the jitter analysis (see Fig.7). A 5th order digital Butterworth filter with a cutoff frequency of 1Hz was designed using the Scipy Signal Processing toolbox in Python [17] and applied to data forwards and backwards.
- Sigma computation. The variable of interest to be compared among recordings is finally the standard deviation of the filtered data.
- Power Spectral Density computation. For further analysis, the PSD of recordings are computed plotted using the Matplotlib library [18], see Fig.8. The number of data points used in each block for the Fast Fourier Transform is NFFT = 512.

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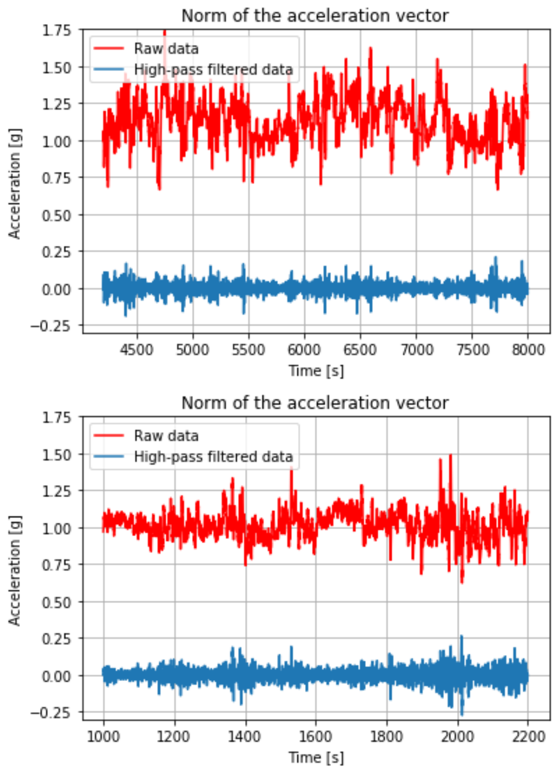

Fig. 7. Measured and filtered accelerations for glider (top) and GA aircraft (bottom).

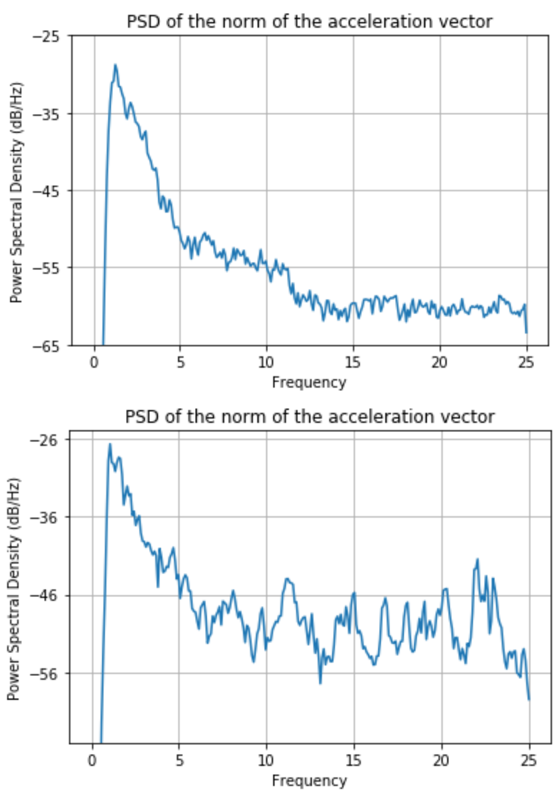

Fig. 8. Power spectral density of the filtered acceleration for glider (top) and GA aircraft (bottom).

The standard deviation of the filtered acceleration is finally 0.0358g for the glider, and 0.0452g for the aircraft. As seen on the plots of Power Spectral Densities (Fig.8), no striking frequency appears in the recordings. We would however expect that the engine induces peaks associated to the engine operation. They are not visible here because the nominal regime for a light aircraft engine is typically above 2000 RPM (i.e. approximately 33Hz), higher than the Nyquist frequency for our recorder (50/2 = 25Hz).

In order to systematically compare the level of jitter for sailplanes and engine aircraft, and their capacities in terms of achieved weightlessness, we should not only have used data collected during similar flight conditions (constant speed straight flight for the sailplane, and cruise condition flight for the engine aircraft, both operated in a stable atmosphere), but also data recorded during parabolas, which are the phases of flight during which the level of jitter is critical. However, there are several risks associated with sustained 0-gravity with Single Engine Piston aircraft. Often, the oil system of GA engines relies on gravity for the proper feeding of the lubrication pump. Prolonged microgravity could thus lead to oil starvation of the engine, causing the risk of engine damage due to the absence of lubrication. Depending on the engine design, this remark could also apply to the fuel system.

4.5 Additional comments: payload size and weight

The backseat of the glider should offer to accommodate a large range of experiments, without imposing too severe constraints on their mass and their volume. Indeed, the ASK-21 empty mass and MTOW are respectively 360kg and 600kg, which yields a total useful mass of 240kg for the pilot in the front seat and the payload. The maximum mass specified by the constructor for the back seat is 110kg, which will be the maximum mass of our payload (and can be used as a rule of thumb for other types of sailplanes).

Payload limits, in terms of size and weight, are thus of the same order of magnitude as for a Cessna 206 previously studied for weightlessness purposes (1000L in volume and 150 kg in mass) [3].

5. Conclusions

5.1 Why gliders are good for 0-g, and what we did to show it

In this work, we showed that using gliders to reach weightlessness would represent a step further in the evolution towards providing more accessible and flexible microgravity platforms. A microgravity platform based

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on sailplane gliders would be especially suitable for compact experiments and equipment that do not require a long-lasting microgravity test conditions and which do not require the very large payload capacities of conventional aircraft.

Many experiments could therefore benefit greatly from the use of a glider, provided that they can fit in the backseat volume and that they comply with the maximum 100kg mass limit requirement.

Typically, a single sailplane parabolic flight will provide approximately 15 test windows of 6s duration each. Several flights can easily be performed in a row allowing similar or longer combined total test flight time in quasi microgravity than zero-g flights performed by wide-body aircraft.

From the preliminary results of our ongoing flight test campaign, we measured that the excursion on the acceleration during the microgravity phase remains below 0.1g. We showed that these low excursion levels are reproduced from one flight to another, and thus that the operation is well repeatable. These variations, together with the absolute level of acceleration reached, are highly dependent on the pilot experience. Better controlled parabolas will be obtained when a visual feedback on the acceleration is provided to the pilot, and the hardware solution that was presented here is currently being improved to eventually compensate for the potential absence of an approved g-meter in the cockpit.

Alternatively, general aviation aircraft have also been proposed as microgravity platform in the past, and could provide even longer duration parabolas. However, because of the piston engine, the level of vibration is higher in a light aircraft than in a glider, as confirmed by the measurements that were here presented and compared. The augmented risk inherent to the operation of internal combustion engine in microgravity also hampers the development of such solutions.

5.2 Further technical developments

Our approach encompasses the three main trends that drive the design of microgravity experiments, as defined in [4]: miniaturization, automation, and interface standardization.

While the glider solution requires a pilot and proper training, one alternative solution would be to use Unmanned Aircraft Systems (UAS) for longer test campaigns thus increasing safety and robustness of test results. These Autonomous fixed-wing drones could fly at higher altitudes. The higher altitude (and higher velocity) would provide two more additional benefits: an increase in the duration of the ballistic segment of the flight path as well as a decrease of aerodynamic jitter due to less turbulent atmosphere at higher altitudes. The avionics of such glider UAS could be partly based on the IP and algorithms already developed for FDR-1 and FDR-2.

In the long term, this solution would also potentially reduce the operational costs.

5.3 Economic perspectives

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 endeavors 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.

An independent study that we conducted has shown that a market exists for the proposed innovative platform. 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, gliders might 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.

Acknowledgements

The authors thank Dr. V. Pletser for his decisive role in the instigation of the present project and for insightful discussions. They acknowledge the contribution of N. Frischauf, P. Billuart and H. Delattre in collecting valuable flight test data, and the collaboration with *Aeroclub Universitaire de Louvain* through which the airframe was made available. They also express their gratitude to the personnel of *UCLouvain-iMMC* for technical advising and sharing of resources.

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