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Abstract: Parabolic flights are one of the most important pillars for research, development, and applications in space. Accordingly, we developed the world's first non-governmental parabolic flight program using Novespace's Airbus A310 ZERO-G. Through the flexible combination of academic research with industrial experiments, as well as with the support of private persons and low administrative efforts, we achieved a highly cost-efficient small-scale campaign concept, which is located at the Air Base Dübendorf in Switzerland. The program was very successful, and it resulted in 31 experiments and tests conducted by Universities and organizations in the industry in microgravity, culminating in many scientific publications and in larger subsequent projects for all users. We describe here how we designed, developed, tested, and built up this program. We also discuss the difficulties, problems, and success factors of a project that—for the first time—was successfully built from the "bottom-up", and which was a large-scale flight research platform by scientists for scientists on a voluntary, non-governmental, and non-commercial basis.

Keywords: microgravity; parabolic flight; space environment; research flights

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1. Introduction: Parabolic Flights as Test and Research Platform

During the past 70 years, aircrafts flying parabolic trajectories have provided an important milestone in space exploration and research [1–4]. Parabolic flights are the only manned research platform in which weightlessness can be generated without leaving the atmosphere of Earth. Since they are aircraft-based, they are basically easily accessible, can be deployed very frequently, provide a very large test area, and require less complex payload preparation when compared to suborbital and orbital platforms. After many thousands of experiments and tests in the last decades, parabolic flights are an important backbone of microgravity, spaceflight research, and technology developments. During a parabolic maneuver, an aircraft is weightless due to flying on a Keplerian trajectory (which is described as an unpropelled body in an ideally frictionless space that is subjected to a

centrally symmetric gravitational field [1]). During this type of free fall trajectory, the result from all the forces acting on the aircraft other than gravity is nullified.

It is highly probable that weightlessness maneuvers have been performed since the beginning of aviation but were not reported and not conducted on a systematic basis. The first known official reports of weightlessness maneuvers were from Heinz von Diringshofen, an aeronautical medical doctor, who performed nose-down maneuvers to study the physiological effects of hypergravity and microgravity in 1936. In 1950, Fritz and Heinz Haber (Air Force School of Aviation Medicine at Brooks Air Force Base in Texas) first described the possibility of studying the effects of weightlessness using aircrafts flying parabolas [5]. In summer 1951, NACA (the National Advisory Committee for Aeronautics) pilot Scott Crossfield and Air Force pilot Charles E. Yeager flew a number of Keplerian trajectories at Edwards Air Force Base in California and at Wright Field in Ohio and generated up to 20 s of weightlessness [6]. In 1953, a regular parabolic flight program began at Holloman Air Force Base, first with T-33 and F-89 jet aircraft, then with the F-94C as the standard, thereby achieving 30 to 40 s of weightlessness [7]. During this period, parabolic flights were also performed with the F-100F and the F-104A, resulting in 50 s weightless periods [1]. Based on these beginnings, parabolic flights later became an integral part of the Mercury program.

The European Space Agency (ESA) did not begin a parabolic flight program in Europe until 1984, whereby the first six parabolic flight campaigns conducted with the NASA (National Aeronautics and Space Administration) KC-135 aircraft in Houston [8]. In 1989, the ESA and CNES (Centre national d'études spatiales, French Space Agency) launched a parabolic flight program with a Caravelle under the leadership of the French astronaut Jean-François Clervoy (who was assisted by the French astronaut Jean-Pierre Haigneré). The company Novespace, a subsidiary of CNES, was entrusted with the organization and execution of the flights from the Bordeaux-Mérignac airport (France). During this period, microgravity experimentation in parabolic flights evolved significantly, thus showing the importance of this tool for microgravity research [8]. In 1997, the Caravelle was replaced by an Airbus A300, the largest aircraft in the world with the largest experimental area, to perform parabolic flight campaigns. In 2015, the Airbus 310 was used for the first time (F-WNOV, MSN 498). It was built in 1989 and flew from June 1989 to August 1991 for the Interflug, the state airline of the German Democratic Republic GDR (registration DDR-ABA until 3 October 1990, and afterwards with the registration D-AOAA), and then under the military registration 10 + 21 for the German Air Force as the governmental aircraft "Konrad Adenauer." Since 2015, the completely converted A310 has been in operation under the nickname "ZERO-G" as a European research aircraft for generating weightlessness and partial gravity.

The Airbus A310 ZERO-G aircraft (Figure 1) generally executes 15 to 31 parabolic maneuvers during one flight day. A parabolic maneuver starts from a steady horizontal flight; then, the aircraft gradually pulls up and climbs to an angle of approximately 50 degrees (Figure 2), during which the aircraft experiences an acceleration of around 1.8 g for 20 s. The engine thrust is then strongly reduced to the minimum required to compensate for the aerodynamic drag, and the aircraft then follows a free fall trajectory of approximately 22 s microgravity between $+/- 2.10^{-2}$ g in the z (vertical) axis, and between $+/- 10^{-2}$ g in the x (longitudinal) and y (transverse) axes. Then, it performs a pull-out maneuver of an approximately 20 s duration at 1.8 g (Figure 2) before returning to a normal level flight attitude.

Parabolic flights have been one of the most important pillars for research and development for astronautics for more than 70 years. Research and technology testing on Swiss parabolic flights could thus strengthen the technical and scientific competitiveness of science and industry in Switzerland, thereby promoting the participation of new research groups from Switzerland in the scientific application of microgravity, as well as contributing to the visibility and strengthening of Swiss space research. Of course, in principle, Switzerland has access to the "large scale" parabolic flight campaigns of ESA,

for which users from Switzerland can apply to ESA. Moreover, a faster, simpler, and local parabolic flight platform does not exist. The German Aerospace Center (DLR) is conducting its own governmental parabolic flight program and had used the Cologne-Bonn Airport for this purpose until 2007, but after that, all German parabolic flight campaigns were conducted exclusively in Bordeaux, France. Also the French Space Agency (CNES) has been conducting a national parabolic flight program in parallel with the ESA program.

Figure 1. The Novespace Airbus 310 ZERO-G (F-WNOV, MSN 498) at Air Base Dünendorf during the 4th Swiss Parabolic Flight campaign (Picture: VBS/Swiss Air Force).

Figure 2. Induction and termination of the Keplerian free fall trajectory with the Airbus A310 ZERO-G. Left: Pull-up maneuver with an angle of approximately 50 degrees and an acceleration of around 1.8 g for 20 s. The engine thrust is then reduced to the minimum required to compensate for aerodynamic drag. The aircraft then follows a free fall trajectory of approximately 22 s, as well as between +/− 2.10^{-2} g in the z axis and between +/− 10^{-2} g in the x and y axes. Right: Pull-out maneuver of approximately 20 s and 1.8g for a return to normal level flight attitude (Pictures: Novespace/R. Sablotny).

First beginnings with the Northrop F-5E "Tiger II": The first beginnings of a Swiss parabolic flight program started in 2010, when Marc Studer and Oliver Ullrich developed the concept of a research platform onboard the military fighter jet aircraft Northrop F-5E "Tiger II" [9]. The experimental system consisted of a programmable and automatically

operated system that was composed of six individual experiment modules, which were placed in the front compartment and worked completely independently from the aircraft systems. The system was designed specifically for cell biological experiments and included fluid exchange, temperature control, and were operated in an autonomous pre-programmed operation mode. The parabolic maneuver started at 13,000 ft and at a Mach 0.99 airspeed; moreover, it followed a free fall ballistic Keplerian trajectory that lasted 45 s with an apogee of 27,000 ft at a Mach 0.4 airspeed. The parabolic flight profile allowed up to 45 s of microgravity at a quality of 0.05 g in all axes. A very late access time and early retrieval time (30 min) were further features of a valuable tool for frequent and repeated cell culture experiments and thus for state-of-the art methods of biomedical research. This concept also aroused interest in countries outside of Switzerland, such as the U.S., Saudi Arabia, and Malaysia, but it was not finalized there ultimately. With the stepwise decommissioning of the Northrop F-5E "Tiger II" fleet, the program had to be terminated in Switzerland before it could develop.

Toward the Airbus A310 ZERO-G: The unique advantages of parabolic flights using the Airbus A310 ZERO-G are (1) the very large experimental area (100 m^2), (2) the possibility for the teams of scientists to perform the experiments themselves, (3) the very broad and flexible possibilities for integrating a wide variety of experimental requirements, and (4) regularity and reliability. Furthermore, highly standardized and well-rehearsed procedures, as well as the support provided by Novespace with their more than 30 years of experience and the relatively low costs compared to space experiments, enable frequent and successful utilizations. A typical parabolic flight research campaign consisting of 3 flights with 30 parabolic maneuvers each costs about EUR 1.5 million [3], which corresponds to an average of about a EUR 125 thousand flight cost per experiment (with 12 experiments on board) per campaign [3]. Experiments on parabolic flights are not only preliminary stage experiments, pilot experiments, or technology tests, but they also make a significant independent contribution to research.

Situation of the airfield Dübendorf at the beginning of the Swiss Parabolic Flight Campaign: The Dübendorf Air Base (AFB Dübendorf, LSMD) (Figure 3) is a military airfield of the Swiss Air Force in Dübendorf, Switzerland. It is located east of Zurich with a runway length of 2355 m (runway 11/29). Flight operations with Super Puma, Cougar and EC635 helicopters take place daily. In addition, it is the air base of several federal air transport services and swisstopo's special survey aircraft.The Swiss Air Force regularly flies search and rescue (SAR) missions out of Dübendorf using SAR helicopters. The Dübendorf Air Base is also used for parascout training on Pilatus PC-6 aircraft, and is a training site of the PC-7 TEAM. The Military Police, the Armed Forces Logistics Organisation, the Armed Forces Command Support Organisation, the Command Support Training Unit and the Air Reconnaissance Technical Service are all stationed on the premises. External partners include skyguide, the Federal Office of Topography swisstopo, RUAG, the Zurich police force, REGA and the Air Force Centre. On 22 October 1910, flight operations began with the first Zurich Flight Week in Dübendorf. In 1914, the airfield became a federal military airfield. Between 1919 and 1948, Dübendorf was also used as a civilian airport, which included Swissair. During the Cold War and until 2005, Dübendorf was home to various fighter aircraft squadrons. The Federal Council's decision on 3 September 2014 on the future use of the Dübendorf military airfield envisaged its long-term use as a civilian airfield with a helicopter base and the establishment of an innovation park by the Canton of Zurich. In this way, the Federal Council is following the goal of pursuing all three interests of the Confederation (military aviation, civil aviation, innovation park) in parallel. The Dübendorf airfield site is an ideal location for an innovation park due to its location, its accessibility, and its embedding in one of the country's most important economic regions.

Figure 3. Air Base Dübendorf (LSMD): located east of Zurich with a runway length of 2355 m (runway 11/29). Switzerland Innovation Park Zurich will be built on the west side, and civil research and factory flight operations will take place on the south side (Picture: VBS/Swiss Air Force).

2. Basic Concept of the Swiss Parabolic Flights

In the context of the federal and cantonal utilization concept, research flights represent an ideal interface between aviation and the innovation park, as well as provide a high added value with only a few flight movements. As an airfield without commercial flight operations and with an excellent infrastructure for the local preparation and implementation of scientific and technological experiments and tests, Air Base Dübendorf already provides the possibility of experiment preparation, as well as sample processing and analysis, with the most advanced scientific methods and technologies in the immediate vicinity of the Irchel Campus of the University of Zurich. In the case of Swiss experiments, the additional advantage is the completely national execution of the research flight (no customs, no complex logistics required, as well as an unrestricted validity for all Swiss permits for research equipment and procedures). Furthermore, the concept of Swiss Parabolic Flights as a "small campaign" with only one or two flight days and 15 parabolas per flight (Figure 4) offers a significant cost reduction compared to the regular "large" campaign configuration of ESA, DLR, and CNES that conduct three flight days and 30 parabolas each day.

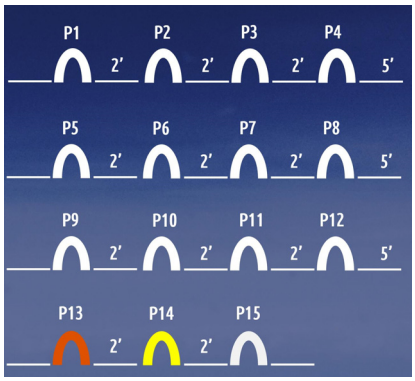

Figure 4. Parabolic sequence of the small-scale parabolic flight campaign in the Swiss Parabolic Flight Program: a sequence of 12 microgravity parabolas (white) is followed by a parabola with Mars gravity (red) and a parabola with Moon gravity (yellow). This is followed by another microgravity parabola (white). After every four parabolas there is a longer pause of at least 5 min to allow a turn of the aircraft (Picture: Novespace).

Through a flexible combination with industrial experiments, support by private persons, and low administrative efforts, a high cost efficiency for the academic experiments is achieved, thus complementing the regular "large" campaign format in a meaningful way. Furthermore, we see access to microgravity as a regular research tool that should be available to all researchers in the spirit of the freedom of research (article 20 of the Federal Constitution of the Swiss Confederation), and that it should not be subject to governmental control. The smaller campaign format means that research under microgravity can now be made available to a much larger group of scientific teams than before. The per-experiment flight costs of about CHF 8500 per person (flight costs plus costs for hardware design, construction, and implementation) are in a range of regular consumption costs in funded research projects. The participation of private individuals allows for the full utilization of the cabin (maximum 40 participants) as cabin space that is not used by scientific or industrial experiments can be fully occupied. Full cabin utilization significantly reduces the cost per scientific experiment. The lower costs of the small-scale campaign are also mainly due to the lower number of parabolas since the flight costs of the Airbus A310 ZERO-G depend less on the flight hours and much more on the number of parabolas flown. Lower flight costs mean that the parabolic flight research platform can be made available to many more scientific and industrial users than in the past, insofar as a "large" campaign format is not required for the experiment. Due to these special features, research flights in Switzerland from Air Base Dübendorf could be a very useful complement to the ESA-funded flights from Bordeaux-Merignac. The research flight operations are carried out based on Art. 38 of the Federal Aviation Act (LFG). We organized a strong and close collaboration with our partners in Dübendorf to make the parabolic flights possible (Table 1).

Table 1. Swiss Parabolic Flight program: responsibility and competencies.

Entity	Responsibility
Swiss SkyLab Foundation	Overall coordination, financing, logistics, ground support, and science implementation
Novespace	ACMI (Aircraft, Crew, Maintenance and Insurance) charter of A310 ZERO-G
Swiss Air Force	Military Air Base Dübendorf
Skyguide	Airspace coordination
Air Force Center	Aircraft handling and ground infrastructure
Swissport	Aircraft handling
Federal Office of Civil Aviation (FOCA)	Permission to use the Swiss airspace
Federal customs	Customs clearance aircraft and crew
Cantonal police	Immigration foreign crew and scientists
Military police	Air base security
Custodio	Flight security
Dovespace	Private participants

The following projects in particular would be considered for implementation on a parabolic flight from Dübendorf: (1) projects that require only a small number of parabolas and can therefore be implemented in a reduced campaign format (1 flight with 15 parabolas) compared to a "large campaign" (3 flight days with 30 parabolas), (2) projects that cannot be carried out in Novespace's ground laboratories and workspaces in Bordeaux-Merignac or can only be carried out at a disproportionate cost (for example, highly sensitive and complex life science experiments with extensive ground infrastructure requirements, experiments with the requirements of elaborate immediate sample processing and/or analysis after landing, or experiments with the requirements of using materials or work processes

not approved in Novespace's laboratories in Bordeaux-Merignac), (3) experiments that can only be performed in Switzerland due to legal or ethical regulations, and (4) scientific and technical pilot studies in preparation for a full-scale project prior to application to the regular ESA funding schemes. The concept of parabolic flight campaigns from Dübendorf allows, for the first time, a flexible combination of scientific or technical experiments from universities or other public research institutions with industrial experiments and supporting private persons. Industrial experiments benefit from a fast integration time, high flexibility, and minimization of administrative procedures. Administrative procedures applied here mainly concern the safety approval of the experiment, which is performed according to a rigorous but standardized and highly efficient procedure, in part due to Novespace [4,10]. A very high degree of confidentiality can also be guaranteed. Private individuals reduce the flight costs for research through their participation and thus directly support science. Novespace has already been offering parabolic flights for private individuals from Bordeaux-Merignac airport under the "Air Zero G" brand since 2013. The revenue from these so-called "Discovery Flights" supports the scientific use of the Airbus A310 ZERO-G. With the "Swiss Parabolic Flights", private individuals have the additional opportunity to directly experience the research conducted on board. They take part in the same program, briefings, and events as the scientists, and thus experience directly and through personal observation and contact with the researchers how science is conducted in microgravity. The Swiss Parabolic Flights shall contribute to the advancement of Swiss capabilities and, in particular, it shall allow for increasing key technological competencies and the building up of knowledge in Switzerland with regard to microgravity experiments. The Swiss Parabolic Flight program has been classified as in the public interest of Switzerland according to Art. 38 of the Federal Aviation Act by the Swiss Air Force, which has been explicitly confirmed by the Federal Council's response to interpellation 16.3100 on 11 May 2016.

3. Results

3.1. First Swiss Parabolic Flight: Feasibility Test

The goal of the first Swiss Parabolic Flight in autumn 2015 was to test the operational, scientific, technical, and administrative feasibility of a scientific parabolic flight platform with the A310 ZERO-G from Air Base Dübendorf in Switzerland. The financial, operational, and legal preparation of the first test flight proved to be extraordinarily difficult.

The operational challenges were high, but solvable: since the Dübendorf Air Base was not designed for such large aircraft as an Airbus A310 in routine operations, all heavy ground equipment such as towing, stairs, and loading trucks had to be procured from Zurich Airport and transported to Dübendorf. Ground Power Unit (GPU) and fueling (Jet A1) could be provided on site. All ground procedures could be worked out very quickly and efficiently together with the Swiss Air Force and the Air Force Center, including the handling of the experiments and of all involved people on-site, which, in total, was about 100. The administrative procedures (i.e., the permission to use Air Base Dübendorf by the Air Force Commander, flight permission from FOCA (the Federal Office of Civil Aviation), customs permission for aircraft import/export from the EU to Switzerland, temporary authorization of the Air Base Dübendorf as a customs airport, customs handling procedures, authorization from the Cantonal Police Zurich, and flight security authorizations) were extensive but trouble-free due to the excellent, transparent, and proactive cooperation of all involved agencies.

Since the flight must be completely financed by the contributions of the participants, while the costs for campaign preparation and execution in addition to the ACMI charter (aircraft, crew, maintenance, and insurance) were only known theoretically, many uncertainties remained. Potential sponsors were reluctant whether the project could be realized at all. In parallel to our project, the back then existing company "Swiss Space Systems (S3)" offered the same type of parabolic flight for private participants from the airfield of Payerne in Switzerland. It was part of a "world tour" with over 100 flights in 20 destinations in the

year 2015 with costs starting from 2500 CHF per participant [11], which was less than 1/3 of our non-profit price when calculated with 40 participants on board. S3 planned to be able to achieve a significantly lower price per person with a significantly higher number of people in the cabin of the proposed Airbus A340. At that time, S3 had partnerships with the École Polytechnique Fédérale de Lausanne (EPFL), Dassault Aviation, and the Swiss luxury watchmaker Breitling. In particular for the partnership with S3, Breitling had issued the "Breitling S3 ZeroG Chronograph", which is exclusively available to the participants of the S3 parabolic flights as part of a "boarding pass". In contrast, our Swiss Parabolic Flight project had no public supporters. However, S3 could not realize any parabolic flight and was declared bankrupt in December 2016. Further unplanned time resources had to be spent because many of the teams that had registered for research experiments did not have any operational and technical experience in experiments on a parabolic flight; as such, a great deal of time-consuming support was required.

Furthermore, the legal framework proved to be a particular challenge. The organization of this test flight was based on the assumption that an ACMI charter of a large research aircraft could be implemented in the standard legal and financial operational procedures of the University of Zurich. While this was indeed the case, the special nature of this flight triggered extraordinary in-depth liability clarifications and approval procedures. On the one hand, it was an experimental flight with unusual flight maneuvers; on the other hand, it was an aircraft that had only a temporary permit to fly that was delivered by the French Directorate General of Civil Aviation, and this differed from the standard Certificate of Airworthiness (CofA) that was issued for public transportation aircraft, which does not comply with the safety standards defined for public air transportation. The University of Zurich, an external expert lawyer for aviation law, and the Canton of Zurich were involved in many clarifications and safeguarding measures. It was only thanks to the coordinated interaction of all parties involved that the liability issues could be resolved. The university management finally approved the parabolic flight on 17 September 2015, only five days before the planned flight campaign. Since this was a discretionary decision, it was completely unclear until this point whether the flight could take place at all.

The organization of the maiden flight with the A310 ZERO-G at Dübendorf proved to be very challenging not only operationally, logistically, and legally, but also due to the provocation of some political resistance. After all, a research flight of this size from Air Base Dübendorf would represent a widely visible and very real signal for the meaningfulness of the continued aviation use of the Dübendorf airfield, which—at that time—was the focus of political disputes. There were major political disagreements between the federal government, the canton, and the municipalities about the future of aviation at the Dübendorf airfield, all while other political forces at the municipal and federal level were politically fighting against the planned innovation park. Since the parabolic flights from Dübendorf are a clear and visible link between aviation and innovative research and development, the opposition was strong from both sides. Thus, this case of a first Swiss Parabolic Flight, which was in preparation and was intended as a test flight, reached the National Council and the Swiss Federal Parliament with a parliamentary interpellation in September 2015 (Interpellation No 15.3993), which was followed by a second interpellation in 2016 (Interpellation No. 16.3100). The Swiss Federal Council and the Swiss government confirmed the decision of the Swiss Air Force to classify the parabolic flights conducted from Dübendorf as being in the public interest.

After all, on 22 September 2015, the University of Zurich conducted a parabolic flight with Novespace's A310 ZERO-G from the Dübendorf military airfield to test the feasibility of a scientific parabolic flight platform in Switzerland. Here, the University of Zurich worked closely with Novespace, the Swiss Air Force, and the Air Force Center in Dübendorf. The Swiss astronaut and scientist Prof. Claude Nicollier was a patron of the University of Zurich's first parabolic flight. The flight from the military airfield in Dübendorf lasted 3 h and went into a reserved special airspace above the northern Mediterranean. Fifteen parabolas were flown. The test project was completely privately

financed by sponsors. The University of Zurich did not claim any resources from the canton or the federal government for this purpose.

The following five experiments and tests were on conducted on board:

- Cavitation bubbles in variable gravity (EPFL École Polytechnique Fédérale de Lausanne, Switzerland);
- The cellular response to hypoxia during microgravity (HYPOXIA) (Institute of Veterinary Physiology, University of Zurich);
- Primary macrophages in microgravity (Institute of Anatomy, University of Zurich);
- Primary endothelial cells in microgravity (UPM University Putra Malaysia);
- Mechanical watches in altered gravity conditions (H. Moser & Cie, Neuhausen am Rheinfall, Switzerland).

The University of Zurich conducted cell biological experiments with macrophages and endothelial cells, as well as with cells exposed to oxygen deprivation during microgravity. A team from the EPFL in Lausanne studied the surface tension of so-called cavitation bubbles in microgravity, a topic of basic physics research with great application relevance for turbines, pumps, and hydraulics. An industrial experiment conducted by the watch manufacturer H. Moser in Neuhausen am Rheinfall examined how clockworks operated in microgravity in order to obtain important data for improving computer simulations for the design of clockworks by eliminating gravity-associated mechanical effects.

The overall flight mission was successful and received positive national press coverage. Twenty-one print articles and one lengthy TV report were produced. All reports were very positive. Among others, SRF (Swiss Radio and Television) reported the flight in a special TV series "Switzerland in Space". The calculated reach of all of the media reports was 15.8 million people. The public interest in this research platform was underlined by the visit of the Parliamentary Aerospace Group of the Swiss National Council to Dübendorf on the day of the first parabolic flight.

In just 10 months, the project succeeded in demonstrating, from idea to real-life implementation, that parabolic flight campaigns with Novespace's A310 ZERO-G from Dübendorf Air Base are operationally, scientifically, technically, and administratively feasible [12]. This first flight was recorded in a remembrance video [13], and the corresponding web page of the first flight was not deleted so as to keep the history of the first Swiss parabolic flight alive [14]. Thus, on 22 September 2015, the University of Zurich (UZH) successfully conducted the first parabolic flight with the A310 ZERO-G (Novespace/French Space Agency CNES) from Air Base Dübendorf to test the feasibility of a scientific parabolic flight platform in Switzerland.

3.2. The 2nd Swiss Parabolic Flight: Full-Scale Research Flight

From the experiences of the 1st Swiss Parabolic Flight, the following results of three "lessons learned" were obtained: (1) the operational, technical, scientific, and administrative feasibility was given and could be carried out with the procedures developed and tested for the 1st Swiss Parabolic Flight, (2) the liability issues of the ACMI Charter by the University of Zurich were and currently remain a problem, and (3) the acquisition, support, and implementation of the private participants should be professionalized. To solve these problems, the following measures were taken: (1) The ACMI charter of the Airbus A310 ZERO-G from Novespace is to be carried out by a newly established non-profit foundation. This foundation will fully bear the entrepreneurial risk and liability of the flight execution. Thus, we established the Swiss SkyLab Foundation [15] on 12 June 2016. According to its statutes, the Swiss SkyLab Foundation supports scientific, technological, and academic utilization of research flight platforms in Switzerland to promote education, professional training, and development. The Swiss SkyLab Foundation is a non-commercial and non-profit scientific foundation according to federal law, and it is supervised by the Swiss Federal Supervisory Board for foundations. The team of the Swiss Parabolic Flight program is the foundation board of the Swiss SkyLab Foundation, which consists of experienced experts in the fields of microgravity sciences; life sciences and medicine; extreme environments; civil

and military aviation; economics; and education [15]. It is supported by the experts from the innovation cluster space and aviation of the University of Zurich [16], the military Air Base Dübendorf, and the Air Force Center. (2) To professionalize the acquisition, support, and implementation of the private participants, the brand "Dovespace" of the travel agency Nussbaumer Reisen AG was founded [17,18]. On 25 November 2020, the independent company "Dovespace GmbH" was spun off from the brand "Dovespace". Thus, it was no longer the University of Zurich but a company that bears the full entrepreneurial risk for the acquisition, support, and implementation of the private participants.

Following the first feasibility test flight conducted by the University of Zurich ("1st Swiss Parabolic Flight" on 22 September 2015), the "2nd Swiss Parabolic Flight" research flight was conducted on 22 October 2016 by the Swiss SkyLab Foundation from Air Base Dübendorf (Figure 5). The Swiss Space Office (SSO) of the State Secretariat for Education, Research, and Innovation (SERI) supported the research flight with a "Call for Experiments 2016: Parabolic Flight Campaign in Switzerland". Five scientific experiments of the Universities of Basel, Zurich, and Lucerne, as well as the ETH Zurich were selected by a review panel of the Swiss Space Center (SSC); in addition, they were awarded by the SSO in the form of a grant for the scientific–technical preparations. The costs for the flight campaign itself were provided by the Swiss SkyLab Foundation based on the flight fees charged to the science teams and private participants in the amount of 8500 CHF per participant. The participating research teams had about five months for the technical–operational preparation until the flight, including the design, construction, and testing of the research technology, as well as before the planning and testing of all procedures up to the final flight certification. The entire scientific–technical preparations were accompanied and supported by members of the Swiss SkyLab Foundation Board. The flight campaign was organized and carried out by all members of the Foundation Board with the participation of volunteers. All work was performed voluntarily without remuneration or other forms of compensation.

The 2nd Swiss Parabolic Flight was successfully performed on 22 October 2016, with ten scientific research projects and test experiments being conducted on board:

- The impact of reduced oxygenation on human cells during microgravity (Institute of Veterinary Physiology, University of Zurich);
- Zero-g experiments to understand how phytoplankton respond to turbulence in oceans and lakes (Department of Civil, Environmental and Geomatic Engineering, ETH Zurich);
- Spinal stiffness in microgravity (Interdisciplinary Spinal Research (ISR), Balgrist University Hospital Zurich);
- The Mars Sedimentation Experiment (Environmental Sciences, University of Basel);
- Involvement of calcium in mechano-sensitive processes of muscle cells (Competence Center in Biomedical Space Research and Medical Engineering, Lucerne School of Engineering and Architecture, HSLU);
- Are calcium dependent Ion channels also sensitive to gravity? (Competence Center in Biomedical Space Research and Medical Engineering, Lucerne School of Engineering and Architecture, HSLU);
- Virtual Reality in altered gravity (ICEBERG/Orbital Views, Paris, France);
- The conducting of three experiments in a miniaturized laboratory for microgravity platforms (SpacePharma, Courgenay, Switzerland).

The team from the University of Zurich investigated how human cells react to the lack of oxygen in weightlessness—an important question for outboard missions in space. The Lucerne University of Applied Sciences and Arts (HSLU) used electrophysiological tests to elucidate the mechanisms of gravity perception in cells. A team from the Department of Chiropractic Medicine, University Hospital Balgrist, examined functional relationships in the development of diseases of the spine. An experiment from the ETH Zurich was devoted to the role of gravity in the behavior of phytoplankton and will thus contribute to the understanding of one of the most important oceanic microorganisms on Earth. And the University of Basel tested sedimentation behavior under the conditions of Martian gravity,

thus providing important data for calibrating mathematical models to reconstruct the planet's environmental history. An experiment by the Swiss-Israeli company SpacePharma tested scientific hardware that will be used on small satellites.

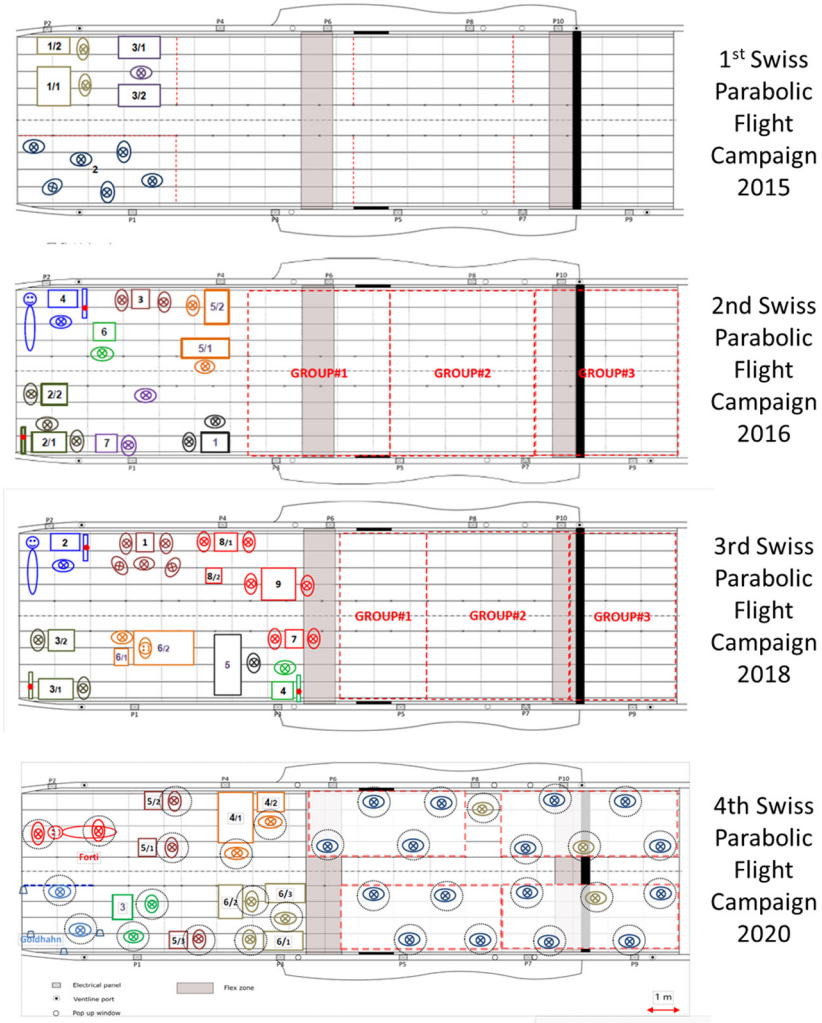

Figure 5. Airbus A310 ZERO-G cabin configurations during the four Swiss Parabolic Fight campaigns: The experimental area is 20 m long, 5 m wide, and 2.25 m high at the highest point of the cabin. In the front part of the cabin is the separate part for the scientific equipment and experiments, and the zone for the private participants is in the rear part of the cabin. The ovals indicate the position of an operator, and the angular structures are scientific equipment. The whole cabin has a maximum capacity of 40 persons, which is divided into scientific operators in the front part and private persons in different sub-zones in the rear part. On the 4th Swiss Parabolic Flight, due to COVID-19 measures, there were only 35 people on board and no private participants. Remark: Different colors were used for better visibility of the experiment zones.

The research campaign was carried out smoothly and without any major problems. The 2nd Swiss Parabolic Flight Campaign resulted in 80 press reports with a total coverage of 15.3 million people. Of the 80 reports, 13 were rather positive, 3 rather negative, and 64 neutral. The media reach has not yet been determined. With the second successful research flight and an extensive research program, the Swiss Parabolic Flight Program was firmly established. The flexible combination of research from universities, industrial experiments, and private individuals enables the costs of the flight to be minimized for science.

3.3. The 3rd Swiss Parabolic Flight Campaign: Two Flight Days

Due to the high demand for a parabolic flight research platform, the Swiss SkyLab Foundation was already able to offer and conduct two flight days at the 3rd Swiss Parabolic Flight Campaign from 11–13 June 2018. The responsibility, the mode of execution, and the procedures and processes corresponded to the 2nd Swiss Parabolic Flight Campaign.

During the 3rd Swiss Parabolic Flight Campaign, eight experiments in the fields of physical science, life sciences and medicine, and manufacturing in space and psychology were conducted by researchers from the ETH, the EAWAG, the University of Zurich, the Balgrist University Hospital, the HSLU, the University of St. Gallen, the Chinese Academy of Sciences (CAS), and the Swiss-Israeli company SpacePharma (Figure 5).

The following eight research projects and tests were conducted:

- Microgravity turns soils anoxic (Subsurface Environmental Processes Group, EAWAG-ETH Zurich, Switzerland);
- The effect of changing gravity on spinal stiffness (Department of Chiropractic Medicine, Balgrist University Hospital, Zurich Switzerland);
- Effects of microgravity on membrane potential in cartilage cells (Institute of Medical Engineering, Lucerne School of Engineering and Architecture, Lucerne University of Applied Sciences and Arts, HSLU, Switzerland);
- Oxygen-shortage and manned space flights (Institute of Veterinary Physiology, Vetsuisse Faculty, University of Zurich);
- Structural and molecular dynamics of cellular adaptation to microgravity (Institute of Anatomy, University of Zurich);
- Crystallization in microgravity (SpacePharma SA, Courgenay, Switzerland);
- The Space Manufacturing Experiment (Technology and Engineering Center for Space Utilization CSU, Chinese Academy of Sciences CAS);
- An exploratory study for measure and genesis of We-Consciousness: Induction through weightlessness in parabolic flights (Research Institute for International Management, Competence Center for High Performance Teams, University of St. Gallen).

The 3rd Swiss Parabolic Flight campaign was conducted without any major problems. The press reports were explicitly positive and particularly emphasized the following: (1) the independence of this large research campaign from governmental funding and organization (which is unique in Europe [19]), and (2) the excellent fit with the Zurich Innovation Park on the Dübendorf airfield site [20]. The calculated reach of all media reports was 2.3 million people.

3.4. Preliminary Conclusion after the First Three Parabolic Flight Campaigns

The utilization concept of the Swiss Parabolic Flights—shared use by universities, companies, and private individuals—was unique in the whole of Europe to date and offered a significant competitive advantage for Switzerland: the parabolic flight campaigns provided science and industry with cost-effective access to research and development projects in microgravity. Three parabolic flight campaigns with a total of 23 research projects have already been successfully carried out with the A310 ZERO-G, which was operated from Dübendorf Military Airport.

The Swiss SkyLab foundation—as a non-commercial and non-profit scientific foundation according to federal law, which works in the frame of the innovation cluster space and aviation of the University of Zurich (UZH Space Hub)—has introduced a unique funding model for microgravity research flights: the costs are not covered by major space agencies, but shared by industry, academia, and private persons. This has succeeded in significantly reducing the costs for academia. The Swiss Parabolic Flights were not in competition to the already existing ESA platforms in Bordeaux with "large scale" flight campaigns, but rather filled a strategic gap at the level of "small scale" parabolic flights with low costs, simple access, and rapid integration times; moreover, they were conducted in the scientific and technical environment of the facilities at Dübendorf airport and the University labs nearby. Scientists from Switzerland were using the parabolic flight platform in Dübendorf

for initial, first, and preliminary experiments, often before they were applied in large scale projects at ESA, Horizon 2020, or the Swiss National Science Foundation (SNF). Thanks to the results and experience generated through their participation in the Swiss Parabolic Flight campaigns in the past, scientists from Switzerland have applied successfully for competitive ESA funds. Furthermore, the results from parabolic flight experiments have advanced product development and testing for various Swiss companies. Finally, parabolic flights are a unique educational and outreach tool to inspire students and young scientists, as well as the public, for the space sciences.

3.5. The 4th Swiss Parabolic Flight Campaign: The World's First Parabolic Flight Campaign under SARS-CoV-2 Pandemic Measures

3.5.1. Preparations

In October 2019, and based on the success of 23 flown experiments and broad support and interest in science and industry in Switzerland, the preparations for the 4th Swiss Parabolic Flight Campaign that was scheduled for June 2020 began. Seven scientific experiments were planned for the 4th Swiss Parabolic Flight Campaign over two flight days. Of these seven experiments, six were from Switzerland, including a NASA-funded joint project between UZH and NASA, a NCCR PlanetS project, and an independent student project from ETH Zurich. It was planned to include 15 scientists and 25 private participants per flight day. The flight price was, as usual, 8500 CHF/person/day with no price differences between the scientists or private participants. The flight fee for participation in the Swiss Parabolic Flights was still cost covering and non-profit, consisted of about 80% of the ACMI charter of the Novespace Airbus A310 ZERO-G, as well as about 20% of additional costs such as experiment safety reviews, engineering services, ground equipment (towing truck, stairs, loader, etc.), rentals, fees, etc.

The following experiments were prepared for implementation:

- TEMPus VoLA: The Timed Epstein Multi-Pressure Vessel at Low Accelerations (Experiment of NCCR PlanetS, University of Zurich, Institute for Computational Science and University of Bern, Physics Institute, Switzerland);
- The Computational Sedimentation Modeling Calibration Experiment (CompSedMod-Cal) (Physical Geography and Environmental Change, Department of Environmental Sciences, University of Basel, Switzerland);
- Effect of altered gravity on the nucleus (NASA Kennedy Space Center, USA, and University of Zurich, Institute of Anatomy, Switzerland);
- Mechanical Chest Compression in microgravity condition (Eurac Research, Institute of Mountain Emergency Medicine, Centrale SUEM, Italy and Helios Klinikum Bad Saarow, Germany);
- Integrative analyses of nuclear gravitational force transduction mechanisms and their role in gene expression homeostasis in immune and muscle cells (University of Zurich, Institute of Anatomy, Switzerland);
- The impact of hyper- and microgravity on expression of hypoxia-inducible factors alpha (HIFα's) and their oxygen-dependent sub-cellular distribution (Institute of Veterinary Physiology, Vetsuisse Faculty, University of Zurich, Switzerland);
- Influence of different gravitational forces on the measurement of body functions using IMU based sensor systems (Institute of Translational Medicine, D-HEST, ETH Zurich).

According to the planned experiments during the 4th Swiss Parabolic Flight campaign, the following results could be expected:

- To better understand the gravitational force transduction in muscle cells, and to, therefore, identify new therapeutic targets for musculoskeletal degeneration during mechanical unloading.
- To better understand gravitational force transduction into the chromatin in human T cells, and to, therefore, identify the fundamental principles of cellular adaption to different gravity environments.

- To explore the processes that are important for planetesimal formation and evolution, as well as to reconcile classical physical principles that have mostly been tested under Earth-like flow conditions with modern astrophysical theory and simulations.
- To investigate cardiopulmonary resuscitation (CPR) in microgravity, which is one of the fundamental tasks in clinical space medicine.
- To better understand the role of gravity in the cellular response to hypoxia.
- To better understand the role of gravity on the cell nucleus.
- To study the speed of sensory–motor adaptability to altered gravity.
- To develop model systems of the sedimentation processes on Mars.
- To develop new scientific instruments.

3.5.2. The Situation under SARS-CoV-2 Pandemic Measures

When the operational planning of the 4th Swiss Parabolic Flight Campaign had already been largely completed in March 2020, the measures used to contain the SARS-CoV-2 pandemic massively restricted public life three months before the start of the research flight campaign. Since 16 March 2020, the "extraordinary situation" imposed by the Swiss Federal Council with massive restrictions on public life was in force. It was the first time since World War II that the Federal Council ruled with emergency law for a long period. Switzerland closed its borders with neighboring countries, introduced border controls, and entry restrictions, as well as mobilized parts of the army. Until June 15, all borders were closed for entry for non-absolutely-necessary purposes. Universities and research institutions closed their in-person teaching and research operations. SWISS International Air Lines, beginning from 18 March 2020, reduced their flight operations to a minimum and stationed up to 24 unused aircraft at Air Base Dübendorf (Figures 6 and 7). However, a curfew with the deployment of police against staying in public spaces, as ordered in various German states, cities, and municipalities, was never implemented in Switzerland.

Thus, at least the minimal prerequisites appeared to be present to conduct a research flight campaign based on the SARS-CoV-2 protection concepts developed by the Federal Office of Public Health (FOPH), which were communicated by the Federal Council. Rapid administrative clarifications showed that, provided the protective regulations were observed, there were no objections to the implementation of the research campaign either on the part of the Air Force or on the part of the cantonal or federal authorities (e.g., the Federal Office of Civil Aviation, FOCA). The entry of participants from France, Italy, Germany, and the USA was possible on the basis of exceptional permits issued to the border control authorities in accordance with paragraph 1.5.5 (entry in the public interest) of Directive 323.7-5040/3 (entry restrictions within the framework of the COVID-19 regulation). In regard to the accompanying private passengers, we also recorded no withdrawals. Thus, on March 21, five days after the emergency law came into force, all Swiss institutions involved were able to confirm that the 4th Swiss Parabolic Flight Campaign could be carried out.

Nevertheless, political pressure was initiated outside the immediate partners of the Swiss Parabolic Flight program, mostly from abroad, to cancel or to postpone to a time "after the pandemic". On 22 April 2020, Novespace, the owner and operator of the A310 ZERO-G and subsidiary of the French space agency CNES, informed us that, due to the SARS-CoV-2 pandemic, CNES had banned all private participants aboard the A310 ZERO-G. This meant that 60% of the total funding was abruptly lost seven weeks before the research campaign. In addition, Novespace reduced the maximum number of people allowed in the 100 m^2 experiment zone of the A310 ZERO-G, as well as imposed a mask requirement on board and prohibited free flying during microgravity.

At the same time, we were advised to cancel the research campaign and to try and fly in 2021 instead. By the time the cancellation of the research campaign was imminent, we were already "ready to fly" and all major milestones had been reached: all permits from the Air Force, the Federal Office of Civil Aviation, the Customs Administration, and the Cantonal Police had been obtained; the aircraft handling (stairs, towing, fuel, GPU, and

loading) and ground infrastructure to support the experiments had been organized; and the sophisticated safety and security concepts required had been developed and tested.

Figure 6. During the COVID-19 measures, SWISS International Air Lines, beginning from 18 March 2020, reduced their flight operations to a minimum and stationed up to 24 unused aircraft at Air Base Dübendorf three months before the planned 4th Swiss Parabolic Flight Campaign (picture: VBS).

Figure 7. The A310 ZERO-G parking site: Due to the aircraft parked on the taxiway during the COVID-19 measures, the taxiway with the "Mirage-Stübli" were not available for the A310 ZERO-G ground operations (upper picture: regular A310 ZERO-G parking site, VBS/Swiss Air Force). During the COVID-19 measures, the A310 had to be parked at the end of the taxiway, and all persons, service vehicles, and experiments had to pass the long row of SWISS and Edelweiss aircrafts that were temporarily out of service (lower picture: VBS/Swiss Air Force).

At that time, no parabolic flight campaigns of the major space agencies in Europe took place or were postponed to 2021 due to the SARS-CoV-2 pandemic. However, in the USA, the parabolic flight campaigns of the ZERO-G Corporation (operator of the Boeing 727 "G-Force One") had been cancelled indefinitely. Finding a suitable alternative date in 2021 was therefore not unproblematic and there was no guarantee of an improved pandemic situation in the future. Furthermore, a postponement would have caused great damage to the research projects of our participating scientists. Many projects are time-sensitive, research grants are not easily renewable, and most of the job positions of the involved scientists were temporary. Importantly, the Swiss Parabolic Flights were classified as being in the public interest. Therefore, from the very beginning, our goal was to carry out this research campaign, even when under all manner of difficult conditions and high pressures.

Giving up was not an option, even if it would have been the easier solution (and had we given up then the teams of scientists would have had to bear the damage). After several discussions and with the presentation of COVID-19-protection concepts, a joint agreement was reached with Novespace to carry out the parabolic flight.

3.5.3. Organization of a Scientific Parabolic Flight under Pandemic Measures

As a first measure and in close consultation with the science teams, we were able to merge most of the experiments planned for Flight Day 2 into one flight day by reorganizing the experiments and cabin schedule, such that only one flight day had to be funded and organized. Moreover, the Swiss SkyLab Foundation was prepared to privately bear the massive funding shortfall that was expected. Thankfully, our decision to stick to the research flight campaign led to a show of great solidarity and support: individuals were willing to support the flight campaign through donations or their labor due to the critical situation, and many partners reduced the cost of their services. At the same time, intensive negotiations and discussions took place with Novespace to reach an agreement on the protection concepts to be implemented, which had to comply not only with Swiss regulations, but also with the stricter French requirements. In the first weeks of May, this agreement was reached, and two complementary and harmonized protection concepts were put into force. These were based on the Swiss COVID-19 Regulation 2 (818.101.24), the Swiss Labor Code (SR 822. 11), and the "Protection Concept for the 4th Swiss Parabolic Flight Campaign" of the State Secretariat for Economic Affairs (SECO) and the Federal Office of Public Health (FOPH) (which were based on its regulations and the "Rules to Fight Against Spread of SARS-CoV-2 During Parabolic Flights" of Novespace that were, in turn, based on the French rules).

On May 18, we submitted an application for subsidiary support to the Swiss Space Office (SSO) from the State Secretariat for Education, Research and Innovation (SERI) for the amount of the expected funding gap. The request was approved by order of 10 June 2020, one day before the A310 ZERO-G landed at the Dübendorf military airfield. Thanks to the support of private individuals, campaign partners, and the SSO, the 4th Swiss Parabolic Flight Campaign was able to cover its costs.

In addition to the considerable administrative preparation required, however, the greatest challenges to be solved arose in a completely different area: the unpredictability of the situation and the national, as well as local, measures against the pandemic, which led to profound disruptions in the ability to work through entry restrictions; the slowed or disrupted movement of goods, work, and access bans; disruptions in logistics; and even the collapse of entire supply chains. A research flight campaign is a high-precision system based on the free and undisturbed movement of people and goods.

3.5.4. Operational Procedure of the Parabolic Flight Campaign

Novespace was responsible for the parabolic flight operation with the A310 ZERO-G, as well for the technical safety, i.e., the safety tests and safe installation and operation of the scientific experiments. The Swiss SkyLab and the UZH Space Hub were responsible for flight-associated operations, such as aircraft handling, the interface to the military airfield operations, and the parking site of the A310 ZERO-G. These included infrastructure (towing, GPUs, stairs, transport trucks, supply bases, mechanical support points, shuttle bus operations, and security); airfield security; the support and coordination of science teams; registration; logistics; transportation; occupational safety; SARS-CoV-2 protection; photos/videos; aerospace medicine; and communication. All services, except those of external service providers, were contributed to by the Swiss SkyLab on a voluntary basis.

The parking position of the A310 ZERO-G was connected via a continuous personal and material shuttle transport with Hangar 9 (the ground support infrastructure). Hangar 9 at the Air Force Center offers an area of 1500 m^2 (Figure 8) so that those with a distance rule of 2 m up to 93 persons and those with a distance rule of 1.5 m up to 166 persons can work simultaneously. The hangar has the necessary equipment (electricity, high voltage, water,

WCs, storage rooms, offices, and washable floor surfaces) and size to be able to operate even under pandemic conditions in a safe and comfortable way. The fact that Hangar 9 is connected to the land side and airfield side in parallel and a movable fence allows airside, as well as landside, safety operations. Thus, operations during the 4th Swiss Parabolic Flight Campaign were conducted landside during the setup and testing of the experiments on the ground, and these were switched to airside after the landing and connection of the A310 ZERO-G to the hangar. In agreement with the Swiss Air Force, the Swiss SkyLab personnel carried out a special security concept with the support of professional security personnel in an efficient and unobtrusive way, and this did not interfere with the research operations. No security relevant events occurred.

Figure 8. Upper picture (O. Ullrich): Hangar 9 at the Air Force Center offers an area of 1500 m^2 so that even during COVID-19 distance rules up to 166 persons can work simultaneously. Hangar 9 has all the necessary equipment and size to be able to operate even under pandemic conditions in a safe and comfortable way. Lower picture (VBS/Swiss Air Force). Thus, the 4th Swiss Parabolic Flight Campaign was able to be executed, and the parabolic flight took off on 11 June 2020.

3.5.5. SARS-CoV-2 Protective Measures

Rigorous protective measures were implemented for each segment of the flight mission in addition to meeting the legal conditions, and this extended to not only the FOPH guidelines, but also the protection conditions of the French state. There was an organizational separation of functional and working areas; the removal of unnecessary objects; a definition of movement zones, room divisions, and the limitation of the number of people (1 person per 10 m^2); hygiene masks (surgical masks/OR masks); hand hygiene stations; regular and sufficient air exchange; a regular cleaning of surfaces and objects; gloves; the use of only packaged food; and special safety officers to control the measures. We worked with as few people as possible in the 1500 m^2 Hangar 9 of the Air Force Center, as well as with only 35 people plus crew and mandatory masks, on board the A310 ZERO-G. In addition, free floating in microgravity was prohibited to avoid uncontrolled collisions and contacts.

3.5.6. Outcome

On 11 June 2020, the 4th Swiss Parabolic Flight (Figure 5) could be carried out without any problems and without off-nominals. The entire process was exceptionally smooth and

free of complications. Based on the knowledge gained from the experiences of previous parabolic flight campaigns, planned reserves and contingency plans did not have to be used, and there were no off-nominals or major problems despite the fact that most of the people worked together for the very first time on this complex research mission, including senior leaders. SARS-CoV-2 infections did not occur. All experiments were successfully performed [21]. The press coverage was very positive. In particular, it was emphasized that, despite the pandemic conditions and the constant "encouragement to quit", the research flight mission was nevertheless carried out with great success [22,23]. The calculated reach of all media reports was 43.5 million people. Due to the special nature of the 4th Swiss Parabolic Flight Campaign, a documentation video was produced [24].

3.5.7. Large Research Flight Missions Possible under Pandemic Conditions

Despite the scope of the protective measures, the difficulty was never in planning, implementing, and monitoring these protective measures, and this success can be assigned to the realm of successful professional routines. Rather, the difficulty was in the enormous impact of the pandemic measures on everyday work. Key success factors were the pragmatic and solution-oriented cooperation with the Air Force, FOCA, Swiss federal customs, and the Cantonal Police, as well as the many years of experience of the Novespace crew—which all enabled routine and efficient work. The flexible campaign concept even allowed the program to implement an additional COVID-19 relevant experiment two months before the parabolic flight. The experiment "pharmacologically induced immune control in human macrophages to prevent severe courses of COVID-19", conducted by the Institute of Anatomy of the University of Zurich, tested a new therapeutic strategy against COVID-19 based on the knowledge gained from space medicine.

The 4th Swiss Parabolic Flight Campaign was the world's first parabolic flight during the SARS-CoV-2 pandemic. It showed, in practice, that large-scale research missions are also possible in a pandemic situation. In particular, Air Base Dübendorf is well suited for providing the necessary infrastructure and logistics for pandemic protection measures even during large-scale research flight missions. Additionally, even under severe pandemic measures, professional research and development can be conducted on large flight campaigns.

Based on the very good experience of the first parabolic flight campaign under pandemic conditions, we offered—in coordination with the Swiss Air Force—to conduct the ESA parabolic flight campaigns from Dübendorf Air Base as they could not be operationally performed due to the pandemic measures in Bordeaux. The UZH Space Hub and the Swiss SkyLab Foundation, together with the Swiss Air Force, were prepared to provide the necessary logistics and infrastructure, coordinate the ground segment, and provide facilities for experiment implementation, including biolabs. They were able to provide this on the experience gained from the four parabolic flight campaigns conducted from Air Base Dübendorf, one of which was conducted under the full restrictions of pandemic conditions. However, ESA decided to conduct the 73rd and 74th ESA parabolic flight campaign in November/December 2020 from the German regional airport of Paderborn-Lippstadt, where DLR already conducted its 35th DLR parabolic flight campaign in September 2020 as an alternate airport. The reason given was the low infection numbers in the Paderborn district and that most of the scientists in these campaigns were from Germany. In principle, however, Air Base Dübendorf is also suitable as a venue for European parabolic flight campaigns.

4. Discussion

4.1. Successful Concept for Small-Scale Parabolic Flights

Parabolic flights are suitable platforms for all research and development projects in which microgravity or partial gravity plays a role, such as in new procedures in medicine, pharmacology, material sciences, geology, astrophysics, and in the testing of technologies for space. The parabolic flight research platform has been an integral and indispensable part of any research in microgravity worldwide for decades.

The concept of Swiss parabolic flights—i.e., the shared use by universities, companies and private individuals—was unique in Europe and offered a significant competitive advantage: the program filled a strategic gap at the level of "small" parabolic flight experiments with low costs, easy access, and fast integration times, as well as being operated in the scientific and technical environment of Air Base Dübendorf and nearby universities and research institutes. Based on the research conducted and the experience acquired during the Swiss Parabolic Flight program, scientists from Switzerland have successfully applied for larger projects (e.g., with ESA or the Swiss National Science Foundation SNSF). The Swiss Parabolic Flights generated high added value, strengthened the competitiveness of research and technology from Switzerland, as well as were used within the framework of Swiss research alliances (e.g., the NCCR PlanetS) and in international research collaborations, including joint operations with the NASA Kennedy Space Center under a NASA–University of Zurich–Space Act Agreement. Parabolic flight experiments in Dübendorf have also driven product development and testing for various Swiss companies (e.g., Moser & Cie or SpacePharma). Furthermore, new scientific instruments have also been developed, as well as new technological concepts for generating physical microgravity through flight or drop maneuvers. Finally, the Swiss Parabolic flights were also a unique tool through which to attract talented students and young researchers to space science. In this context, two projects by students from ETH and UZH were carried out on the flight campaign. In addition, it served as the basis for a practical course at the Ernst Abbe University of Applied Sciences in Jena, Germany.

A total of 31 experiments/tests were carried out in four parabolic flight campaigns (Table 2). Of the 31 experiments/tests, 25 (=80%) were from academia and 6 (=20%) from industry (Table 3), and these were conducted in the fields of astrophysics, geology, space manufacturing, sensor technology, aerospace medicine, gravitational biology, pharmacology, and psychology. Until July 2023, 13 publications have been published in international journals, and another 8 are in revision or in immediate preparation. Thus, in the end, an average of one publication in a scientific journal per academic experiment can be expected, which corresponds approximately to the number of publications per experiment in the DLR parabolic flight program [4] in which the experiments are up to six times larger with 3 flight days and 31 parabolas per flight day. Of course, a statistically valid comparison is not possible, but the tendency shows that the Swiss Parabolic Flights have already led to a considerable number of scientific publications—although the concept of the Swiss Parabolic Flights focuses mainly on first and preliminary experiments, which is where scientific publications are not necessarily to be expected.

Table 2. The number of experiments/tests and publications in international journals.

Parabolic Flight Campaign	Experiments/Test Total	Scientific	Industrial	International Journal Articles (Published)	International Journal Articles (under Review/ Final Preparation)	References
1st	5	4	1	2	0	[25,26]
2nd	10	6	4	2	1	[27,28]
3rd	8	7	1	3	1	[29–31]
4th	8	8	0	6	6	[32–37]
Total	**31**	**25**	**6**	**13**	**8**	

The Swiss Parabolic Flights program was classified by the Swiss Air Force as being in the public interest of Switzerland according to Art. 38 of the Swiss Aviation Act, which was explicitly confirmed by the Swiss Federal Council in a response to Interpellation 16.3100 of 11 May 2016. The Swiss Parabolic Flights are also part of the activities of the National Innovation Park in Zurich. Unlike the large governmental programs of space agencies, the costs of the Swiss Parabolic Flights were shared by industry, science, and private individuals—i.e., taxpayer money was not used. Parabolic flight campaigns are organized, coordinated, and financed by the non-profit foundation Swiss SkyLab.

Table 3. The experiments/tests on board the Swiss Parabolic Flight Campaigns using the Airbus A310 ZERO-G.

Campaign	Experiment/Test	Institution/Company
1st Swiss Parabolic Flight Campaign	Cavitation bubbles in variable gravity	EPFL
	The cellular response to hypoxia during microgravity (HYPOXIA)	University of Zurich
	Primary macrophages in microgravity	University of Zurich
	Primary endothelial cells in microgravity	University Putra Malaysia
	Mechanical watches in altered gravity conditions	H. Moser & Cie
2nd Swiss Parabolic Flight Campaign	The impact of hyper- and microgravity on expression of hypoxia-inducible factors alpha (HIFα's) and their oxygen-dependent sub-cellular distribution	University of Zurich
	Gravity as a cue for plankton migrations	ETH Zürich
	Involvement of calcium in mechanosensitive processes of muscle cells	Lucerne University of Applied Sciences and Arts (HSLU)
	Are calcium dependent Ion channels also sensitive to gravity?	Lucerne University of Applied Sciences and Arts (HSLU)
	Change in spinal stiffness in upright and prone position during microgravity induced by parabolic flights: A pilot study	Balgrist University Hospital, Zurich
	Mars Sedimentation Experiment Settling Tube Photometer Rack (MarsSedEx-STP Rack)	University of Basel
	Virtual Reality in altered gravity	ICEBERG/Orbital Views
	Experiment in the SPmgLab system (customer 1)	SpacePharma, Courgenay
	Experiment in the SPmgLab system (customer 2)	SpacePharma, Courgenay
	Experiment in the SPump system (customer 3)	SpacePharma, Courgenay
3rd Swiss Parabolic Flight Campaign	Microgravity turns soils anoxic	EAWAG, ETH Zurich
	The effect of changing gravity on spinal stiffness	Balgrist University Hospital, Zurich
	Effects of microgravity on membrane potential in cartilage cells	Lucerne University of Applied Sciences and Arts (HSLU)
	Oxygen shortage and manned space flights	University of Zurich
	Structural and molecular dynamics of cellular adaptation to microgravity	University of Zurich, National Aeronautics and Space Administration (NASA)
	Crystallization in microgravity	SpacePharma, Courgenay
	Space Manufacturing Experiment	Technology and Engineering Center for Space Utilization (CSU), Chinese Academy of Sciences (CAS)
	An exploratory study for measure and genesis of We-Consciousness: Induction through weightlessness in parabolic flights	University of St. Gallen (HSG)
4th Swiss Parabolic Flight Campaign	TEMPus VoLA: The Timed Epstein Multi-Pressure Vessel at Low Accelerations	University of Zurich, University of Bern
	Computational Sedimentation Modeling Calibration Experiment (CompSedModCal)	University of Basel
	Effect of altered gravity on the nucleus	University of Zurich, National Aeronautics and Space Administration (NASA)
	Mechanical Chest Compression in microgravity condition	Eurac Research, Institute of Mountain Emergency Medicine, Helios Klinikum Bad Saarow
	Integrative analyses of nuclear gravitational force transduction mechanisms and their role in gene expression homeostasis in immune and muscle cells	University of Zurich
	The impact of hyper- and microgravity on expression of hypoxia-inducible factors alpha (HIFα's) and their oxygen-dependent sub-cellular distribution	University of Zurich
	Pharmacologically induced immune control in human macrophages to prevent severe courses of COVID-19 with transfer of results from Space Medicine	University of Zurich
	Influence of different gravitational forces on the measurement of body functions using IMU based sensor systems	ETH Zurich

The preparation time is usually one year, but can be as little as six months. This includes the design, construction, and testing of the research technology, as well as the planning and testing of all procedures up to the final flight certification directly after final installation in the A310 ZERO-G. A parabolic flight mission is a large-scale research mission that requires long and careful preparation.

4.2. End of the Swiss Parabolic Flight Program with the A310 ZERO-G

Following the CNES directive from 2020, it is now prohibited to bring private persons and scientific hardware on board the Airbus A310 ZERO-G at the same time. There was no specific reason for this ban on the side of the Swiss Parabolic Flight program as all flights were carried out without any incidents. Due to the spatial separation of the cabin sections during the flight, the private participants did not interfere in any way with the scientific experiments. On the contrary, a joint flight with private participants and scientists, as well as the possibility to experience the preparation, installation, and execution of the experiments had very positive consequences for the public understanding of research under microgravity conditions. On the Swiss parabolic flights, the A310 ZERO-G was not only a research aircraft, but also a "flying classroom". The flight was always introduced by short presentations of the experiments on the evening before the flight, where science teams and private participants participated jointly in the safety and flight briefing. Various coordinated outreach activities could also be carried out to increase the awareness of research in space, such as an awareness campaign of the UZH Space Hub for the ESA astronaut selection, the participation of students from various Swiss universities in the parabolic flights, the participation of a TV team from Swiss television, and a contribution to a Swiss children's book [38]. As a non-governmental program, the ban—imposed by the French Space Agency CNES—against private participants on a board of flights loaded with scientific instruments has completely deprived the Swiss Parabolic Flight programs with the A310 ZERO-G of its funding basis. Without full cabin utilization due to additional paying private participants, it is not possible to achieve a full flight, and it also requires a lowering of the flight costs per experiment to an affordable level for early stage tests and for experiments in science and industry without governmental funding. Thus, the entire program could not be continued with even after the end of the pandemic measures.

The two flights with private participants that were not permitted by CNES during the 4th Swiss Parabolic Flight were repeated on 17 September 2021 from Dübendorf Air Base, and on 11 May 2023 from Basel Airport (LFSB). In total, 196 private participants experienced a scientific parabolic flight and microgravity through the Swiss Parabolic Flight program. Thus, nearly 200 people from many professions, including many entrepreneurs from different industries and company CEOs, were able to experience extraterrestrial gravitational sensations of microgravity, as well as Moon and Mars gravity. Moreover, these were combined with a hands-on insight into current research and the newly developing space economy under the program title "Astronauts for one day". The feedback from private participants was always very positive, with some even flying multiple times on different campaigns. Dovespace GmbH plans to continue the Discovery Flights of the Swiss Parabolic Flight program with private participants using the A310 ZERO-G and operating from Basel (LFSB) airport. It is planned that the Discovery Flight program will continue to present the research conducted on parabolic flights, in particular the Swiss Parabolic Flights. However, due to the imposed separation of these flights, the direct and vivid experience of the research and development activities on board of a parabolic flight is no longer possible for private participants, and the idea of this "immersive" science experience can no longer be realized.

4.3. Re-Orientation of the Swiss Parabolic Flight Program

Due to an enforced separation of private participants and research experiments, the previous program concept could no longer be continued. For this reason, the Airbus A310 ZERO-G can now only be made available for research flights where the entire cabin is utilized or where a full financing of aircraft charter and ancillary costs is possible without additional paying private participants (which is difficult without a major client and/or governmental funding). Further use of the A310 ZERO-G in the Swiss Parabolic Flight program is therefore still possible, but the frequency of use will probably be rather low.

For this reason, we switched the Swiss Parabolic Flight concept to a purely scientific and technological program without the outreach generated by private participants. We

now implement the Cessna Citation II research aircraft, operated by the Royal Netherlands Aerospace Centre (NLR), as the new main research aircraft for parabolic flights. We conducted the first research flight campaign between October 3rd and October 7th, 2022, with six parabolic flights in total. Using the Cessna Citation II research aircraft, the researchers can determine the parabolas and flight profile individually, thus making microgravity even more accessible. However, the achievable duration of microgravity with the Cessna Citation II is max. 15 s instead of the 22 s possible with the Airbus A310. The 6th Swiss Parabolic Flight Campaign included tests for the "Akademische Raumfahrt Initiative Schweiz (ARIS)" to develop a nanosatellite, an experiment involving autonomous drones for future Mars missions, an experiment on human tissue production in microgravity, and a basic research experiment to study the "genomic code" of gravity [39]. All scientific users were very satisfied with the flight platform and the interaction between crew, organizers, and the Air Force. In summary, the new concept means that the NLR Cessna Citation II is to be used for frequent early-stage experiments and tests, and the Novespace A310 ZERO-G is to be used for large-scale projects that require the entire cabin. Thus, in principle, a scalable access to microgravity is available through these two research aircrafts.

Thanks to the Swiss Parabolic Flight program presented here, parabolic flights could be established strategically and in the long term in Switzerland. The Swiss SkyLab Foundation will continue the Swiss Parabolic Flight program from Dübendorf Air Base. On 31 August 2021, the Swiss federal government, the canton of Zurich, and the local municipalities signed a joint "synthesis report" [40] for the transformation of the airfield area in Dübendorf, which lists parabolic flights as one of the key research platforms of the airfield's use. Thus, in Switzerland, parabolic flights were not established "top-down" by a governmental agency but "bottom-up " by the scientists themselves. However, this is no more and no less a further step in the New Space Economy, in which governmental actors are gradually being replaced by decentralized companies and institutions.

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