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THE ROLE OF FLIGHT LABORATORIES IN AVIATION EDUCATION AND TEACHING METHODOLOGY DEVELOPMENT: CASE STUDIES FROM POLAND AND GEORGIA

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Abstract: Aviation is one of the fastest-developing areas of transportation, and a strong aviation sector is important for a country's economic growth and competitiveness. As global flight activity increases, aviation authorities and international organizations must address new challenges to maintain high safety standards. This often means introducing new technologies and updating operational practices. The changes needed to meet these requirements will require adjustments to the skill sets that aviation professionals will be expected to have (on the ground and in the air). Therefore, having sufficient numbers of adequately trained aviation professionals is necessary, and hence, practical, experience-based training is essential in aviation education today.
This study examines the current needs of aviation training and the limitations of traditional classroom-based teaching. Using a qualitative, comparative case-study approach, it analyses how flight laboratories are applied at two universities in Poland and Georgia, and how they provide students with direct experience with real aircraft and operational tasks. The results show flight labs enhance student projects, practical skills, and teaching methods in aviation.
Keywords: aviation education, flight laboratories, teaching methodology, innovative technologies

1. INTRODUCTION

The human element is one of the most crucial factors in aviation, both in development of systems and technologies as well as their implementation at every stage. Since human error can pose serious safety risks, it’s essential for regulatory agencies, service providers, and aircraft operators to collaborate closely in efforts to minimize those risks. Many scientific studies have examined the role of human error in the number of aviation accidents and incidents.
Some of these errors may happen during:

- Initial training of personnel and their adaptation to the new technological environment of aviation.
- Formation of new knowledge, skills, and duties necessary for a safe aviation operation system.
- Changes related to the increasing level of automation (Saniuk et al., 2024).

As aviation technologies advance, educational approaches must also change to ensure graduates acquire the necessary competencies and practical skills nowadays. Flying laboratories and in-flight tests in student projects offer a hands-on, innovative way to enhance traditional teaching (Lewis and Harrap, 2009; Tomczyk, 2010; Trainelli et al., 2014). While modern engineering education increasingly relies on advanced virtual training platforms and AI algorithms (Gąbka & Przybyś, 2025), flying laboratories provide a unique, irreplaceable value by exposing students to the real, physical aviation environment that simulations cannot fully replicate.
Aeronautical science is a multidisciplinary field and brings together physics, mathematics, engineering, and human sciences.

Fig. 1. Progression from myth to modern aviation education

From the earliest stages of aviation, scientific research has played an essential role in developing new ideas and integrating them into operational aviation systems. Before the first flight in 1903, aviation itself was often viewed as a myth rather than a technology (Fig. 1). It is now understood that learning occurred throughout this time frame, and the relationship between scientific investigation and experimental testing would be beneficial to both aviation education and the practical application of teaching programs. Flying laboratories today represent a vital tool in supporting the educational process of aviation students.
At present, a wide range of flying laboratories is used in scientific and educational activities worldwide (Daniels, 2023). Different types of aerial vehicles serve as platforms for such laboratories, including aircraft, balloons, rockets, and helicopters, providing practical examples and case studies that support the development of modern teaching methodologies (Fig. 2).

Fig. 2. Flying laboratories examples

Examples of institutions that employ flying laboratories in science and education include Cranfield University, Delft University of Technology, the Technical University of Munich, and the University of Pennsylvania (Lewis and Harrap, 2009). This paper presents case studies from Poland and Georgia to illustrate the integration and implementation of flying laboratories into the educational programs of Rzeszów University of Technology and Georgian Aviation University.
Flying laboratories can be used across different fields and sub-fields of aviation, such as flight dynamics and stability, aircraft performance, control systems and avionics, air traffic management and procedures, as well as human factors and crew resource management (Fig. 3).

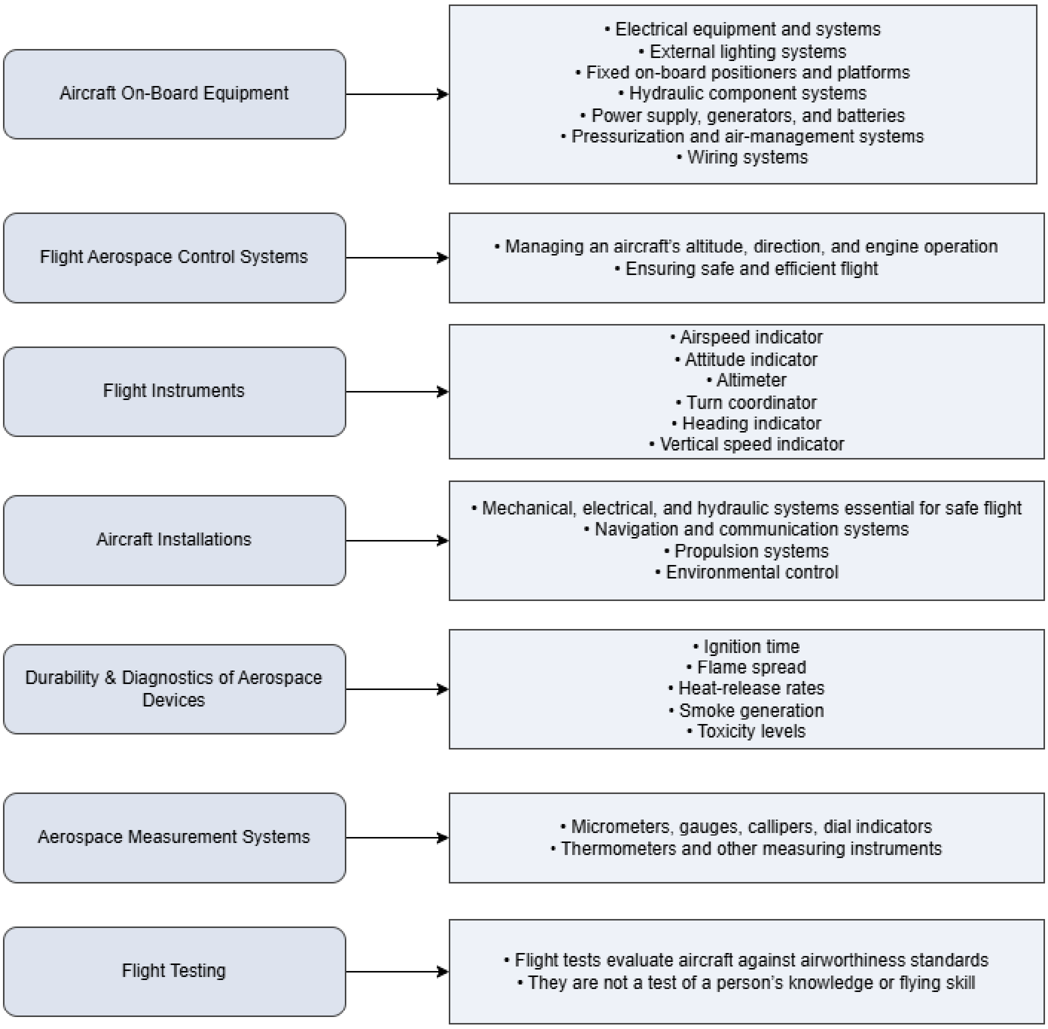

Fig. 3. Taxonomy of flying laboratory types and their practical applications in aviation education and research

They can be integrated at multiple educational levels, including regular student lessons, semester projects, diploma or capstone projects, doctoral research, and extracurricular student activities and competitions.

For students, the flying laboratory will connect classroom theory to reality in an operational environment. The students can observe how the aircraft behaves during flight, validate their theoretical models through real-flight experiments, and build the skills and knowledge they need to work in aviation. Flying laboratories also allow students to understand performance, stability, control, and procedures by engaging in structured, hands-on activities involving flight data. For these reasons, flying laboratories play an essential role in modern aviation education (Trainelli et al., 2014).

2. METHODOLOGY OF RESEARCH

To fulfil the objectives of this study, the research is based on analysis, synthesis, qualitative assessment, and comparison methods. The approach follows the general practice used in studies on flight-test education and flying laboratories. The work mainly describes how two universities organize and apply different types of flying laboratories, and compares their educational roles in real training conditions.

The study uses an explanatory, case study method, which is based upon the experiences of the authors as they have conducted their own flying laboratories in both Poland and Georgia. The study describes the overall laboratory design (Fig. 4) and provides information on the various forms of exercises that are implemented and the practical skills or competencies students develop as a result of this form of training. These insights help the authors explain the educational value of the two laboratory approaches and compare their main features.

Several questions are important for the development of flying laboratories:

- What is the optimal structure and configuration of a flying laboratory for educational purposes?
- What development processes, procedures, and safety requirements should be followed?
- How, when, and by whom should flying laboratories be designed, implemented, and maintained?

To support answers to these questions, the study includes:

- Examples of how flying laboratories and in-flight tests are used in university education.
- A presentation of possible applications depending on aircraft type, equipment, and learning objectives.
- A review of how students and staff become familiar with laboratory procedures and research tasks.

In addition to the challenges previously mentioned with using a flying laboratory, there are many misconceptions about its use. The most common misconception among aviation professionals is that in-flight testing is usually very expensive, requires advanced or specialized equipment, and cannot be incorporated into an average university course. However, early studies (Daniels, 2023; O'Donoghue, 1994) show that educational flying laboratories may only need standard training aircraft and relatively simple onboard systems. Sharing information on how to implement these labs, creating specific guidelines, and gradually introducing hands-on experiences can help integrate them into curricula and evaluate their impact on student learning.

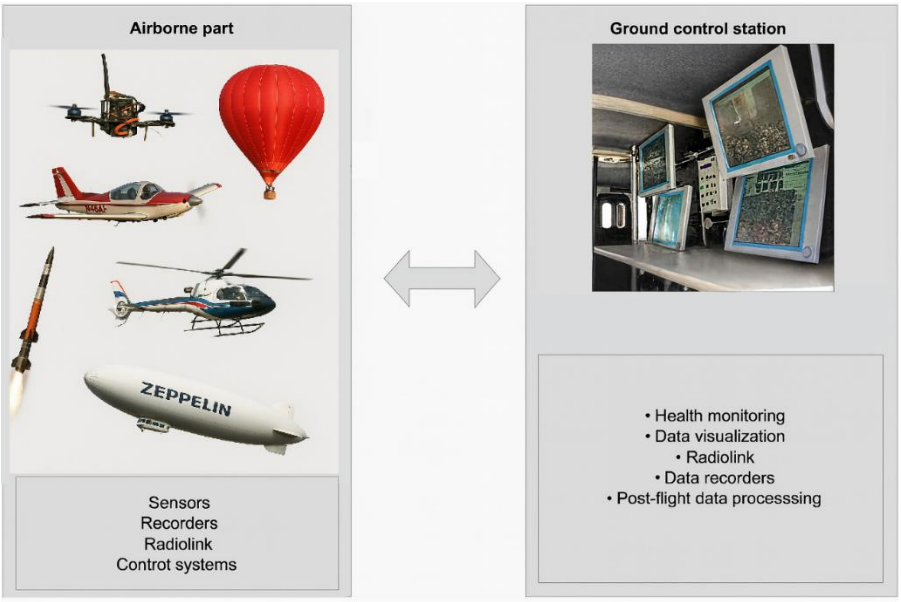

Fig. 4. General structure of flying laboratories operation

3. RESULTS

The results of the study are based on an analysis of how flying laboratories are implemented at Rzeszów University of Technology and Georgian Aviation University. Case studies show that despite different aircraft and training methods, in-flight exercises share features in aiding aviation education, comparing laboratory structures and activities outcomes.

3.1. Case Study: Rzeszów University of Technology (Poland)

Optionally Piloted Vehicle

The flying laboratory's optionally piloted vehicle is built on the MP-02 Czajka (Fig. 5), a Polish ultralight experimental aircraft.

Fig. 5. Optionally Piloted Vehicle (MTOW 495kg, Max. Airspeed 270 km/h,

Research and education:

- Flight tests of control laws for ultralight aircraft.
- Experiments with onboard equipment and avionics.

- Tasks involving both cockpit crew and ground station operators (Fig. 6).
- Relatively low operating costs enabling repeated student exercises.

Objectives of the research:

- Handling-qualities assessment.
- Preparation and execution of flight-test manoeuvres.
- Stability and performance testing.
- Evaluation of landing characteristics with different flaps settings.

Fig. 6. Rzeszów OPV aircraft and the accompanying mobile ground station used during flight-laboratory activities

Use of the MP-02 platform has enabled students to gain practical experience in test preparation, real-time monitoring, and post-flight data interpretation (Fig. 7). Activities conducted through the ground station improve teamwork between the flight crew and technical support personnel.

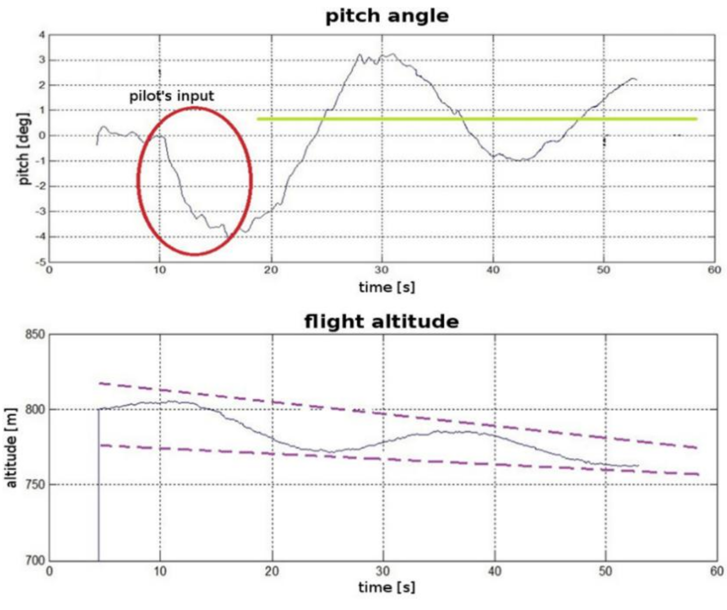

Fig. 7. Longitudinal stability test results

Previous research confirming the suitability of the MP-02 for experimental work (Rzucidło et al., 2021, Nowak et al., 2022) is consistent with observations made during exercises, where the aircraft proved flexible and adaptable to a variety of test scenarios.

Piper Seneca V

Research and education:

- Testing control laws for general aviation aircraft.
- Performance and stall investigations.
- Activities for small student groups (up to six onboard).

Objectives of the research:

- Performance verification in real flight.
- Determination of climb and stall characteristics.
- Execution of structured manoeuvres for data collection.

Exercises conducted on the Piper Seneca V demonstrate that multi-engine aircraft enable students to perform more advanced performance testing and gain experience managing complex aircraft systems. The ability to host several students at once also increases exposure to real cockpit procedures. An example of a test exercise could be calculating climbing speed (Fig. 8) at multiple altitudes and comparing the results to the manual (Table 1).

Table 1

Climb rate test results

Time [min.]	Height [ft]	RPM [1/min]	Manifold Pressure [in. Hg]	Engine temperature [°F]	OAT [°F]
0	3000	2500	32	1311	32
1/2	3340	2500	32	1283	32
1	4060	2495	32	1301	26.6
1 1/2	4620	2500	31.5	1280	24.8
2	5080	2500	31.5	1278	24.8
2 1/2	5520	2505	31.5	1264	24.8
3	6000	2505	32	1261	24.8
3 1/2	6480	2510	32	1264	24.8
4	6980	2510	32	1258	21.2
4 1/2	7520	2510	32	1254	21.2
5	8360	2505	31.5	1263	19.4
6 1/2	9040	2510	32	1251	19.4

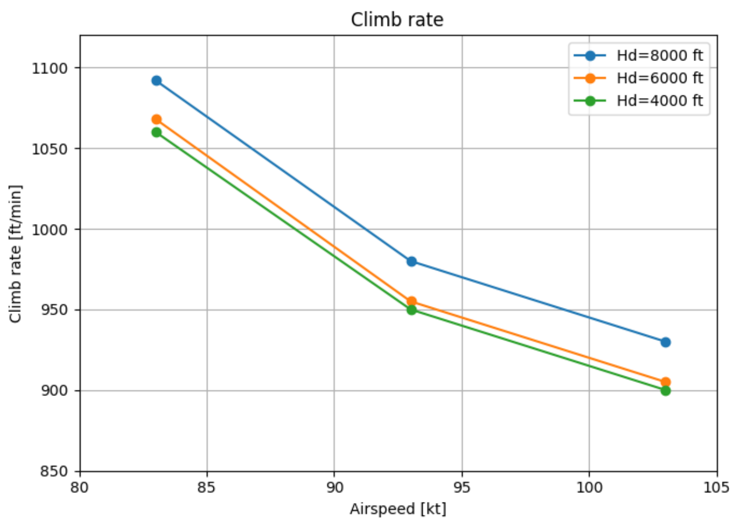

Fig. 8. Climb rate test results

Source: Authors' own work

3.2. Case Study: Georgian Aviation University (Georgia)

Tecnam P2008JC

Fig. 9. Tecnam P2008JC (MTOW 650 kg, Max cruise speed 215 km/h)

Research and education:

- Flight-parameter testing.
- Take-off performance comparison with different aircraft loads.

Objectives of the research:

- Analysis of performance under varying conditions.
- Execution and interpretation of simple in-flight experiments.

Exercises from P2008JC (Fig. 9) show that even simple performance tests help students feel how weight, distance, and climbing ability are related. These activities help build a practical understanding of operational performance calculations, which are often only talked about in theory (Table 2).

Table 2
Tecnam P2008JC take-off performance comparison for MTOW

Pressure Altitude (ft)	**Condition**	**-25°C**	**0°C**	**25°C**	**50°C**	**ISA**
S.L.	Ground Roll	157	198	244	296	225
S.L.	At 50 ft AGL	265	331	406	490	375
1000	Ground Roll	172	216	267	323	242
1000	At 50 ft AGL	289	361	442	533	402
2000	Ground Roll	187	236	291	353	259
2000	At 50 ft AGL	314	392	481	580	430
3000	Ground Roll	205	258	318	386	279
3000	At 50 ft AGL	342	427	524	631	461
4000	Ground Roll	224	281	347	421	299
4000	At 50 ft AGL	373	466	571	688	494
5000	Ground Roll	244	308	380	461	322
5000	At 50 ft AGL	406	508	622	750	530
6000	Ground Roll	268	337	416	504	346
6000	At 50 ft AGL	443	554	679	819	569
7000	Ground Roll	293	369	455	552	373
7000	At 50 ft AGL	484	605	741	894	611
8000	Ground Roll	321	404	499	605	401

8000	At 50 ft AGL	529	661	810	977	656
9000	Ground Roll	352	443	547	663	432
9000	At 50 ft AGL	578	722	885	1068	705
10000	Ground Roll	386	486	600	728	466
10000	At 50 ft AGL	632	790	969	1168	758

Source: Tecnam P2008JC Operating Manual (Costruzioni Aeronautiche TECNAM S.r.l., 2013a)

Tecnam P2006T

Fig. 10. Tecnam P2006T (MTOW 1230 kg, Max cruise speed 269 km/h)

Research and education:

- Flight-parameter testing.
- Single-engine instrument approach procedure exercises.

Objectives of the research:

- Understanding twin-engine aircraft performance.
- Development of the student's ability to fly an instrument approach with one engine inoperative.

Observed typical student errors (Tikanashvili, 2019):

- Difficulty maintaining heading and aircraft control.
- Deviation from the glide slope and localizer.
- Uncertainty in following the correct instrument-approach procedures.

These results highlight how single-engine exercises can uncover gaps in students' procedural knowledge and situation awareness. That's why the P2006T (Fig. 10) lab is so helpful for teaching human factors skills.

3.3. Observed Benefits for Students

In both case studies, flying laboratories offered educational benefits. Students participating in actual flight tasks deepened their understanding of how theoretical concepts connect to aircraft behavior, especially in stability, performance, and control. Engaging in flight preparation, communication, and data analysis also nurtured professionalism and a hands-on approach. These experiences show that safe human performance relies on resilience, motivation, and good health and safety practices. (Putra et al., 2024).

In the Polish OPV laboratory, students can play different roles - as onboard crew and ground-station operators. That gives them a chance to experience the same flight exercise from multiple perspectives. In Georgia, exercises like single-engine approaches show common challenges in workload management and instrument scanning. This feedback helps instructors refine their training methods.

3.3. Challenges and Limitations

Both universities have experienced multiple issues with the lab sessions involving the flight laboratory. The weather and aircraft availability will determine how many times the university can schedule a flight session during the semester. Organizing each flight session requires significant time and effort to ensure all students receive sufficient experience, since flights can be provided for only a limited number of students at a time. Additionally, there is a variety of technological and regulatory issues associated with using modified or optionally piloted aircraft, which creates a number of procedural and safety issues that instructors must follow when conducting the experiments. Furthermore, instructors need to utilize their real-world operational experience to assist the students through the learning process, while continuing to participate in the required training and professional development.

4. DISCUSSION

The combination of a flying lab and classroom-based instruction is an effective learning strategy for students. The flying lab allows students to apply classroom instruction by actually using the aircraft to execute the tasks. As such, the flying lab provides students with first-hand experience, allowing them to see how classroom theories are applied to actual aircraft performance. This is accomplished through student participation in pre-flight planning, execution of specific aircraft maneuvers, and analysis of flight data.

4.1. Interpretation of Case-Study Findings

The two universities use different types of flying laboratories, but both approaches have proved helpful for educational purposes. At Rzeszów University of Technology, the MP-02 Czajka OPV and the Piper Seneca V enable students to participate in activities related to control testing, stability, and performance measurements. The involvement of a ground station also gives students the chance to focus on monitoring, telemetry, and analysis during the flight. Georgian Aviation University uses standard training aircraft and practical exercises that reflect real-world situations. The take-off performance test, as well as the single-engine approach procedure, assist students to identify typical challenge areas related to workload and maintaining appropriate flight parameters. Although the aircraft used and the types of practical exercises may vary, both demonstrate that hands-on flight experience enables students to understand aviation topics better and identify areas for improvement in their required skills.

The most important aspect is how these two types of flying laboratories contribute to aviation system safety. These two types of flying laboratories allow students to observe real aircraft behavior, handle unusual events, and make data-based decisions; therefore, they enhance the students' understanding of how operations work, improve their accuracy in making technical decisions, and both of these factors are likely to reduce incidents caused by human error. The opportunity to experience realistic flight scenarios will also enable students to identify potential dangers quickly, respond effectively under stress, and perform safe practices more accurately. As a result, students graduating from the Aviation program and entering the industry will have better training, improved competence, and increased reliability. Consequently, this will lead to a measurable improvement in the overall safety and resilience of the aviation industry.

4.2. Strategic Recommendations for Universities

Based on observations from both institutions, several practical steps can support the effective use of flying laboratories:

- Have flight lab assignments included as part of course material so each flight has a defined objective related to what is being learned.
- Synchronize the teaching process and flight scheduling process to ensure that student flight assignments are in line with both the course schedule and safety standards.
- Gradually introduce students to flight lab work by having them begin observing flights and then progress to participating in lab assignments which increase their level of responsibility.
- Work with outside organizations to provide students with access to a variety of different types of aircraft and equipment.
- Maintain current flying lab activities through instructor training, maintaining equipment and updating methods for collecting and processing data.

4.3. Future Research Directions

Further research is needed to identify which type of flight exercise most effectively enhances students' hands-on skills and to determine the best way to incorporate actual flight data into the learning experience. Future studies would need to examine ways that advanced technology can be used to objectively measure and compare students' attention and scan of the instruments while participating in flight lab activities (Gomolka et al., 2020), as well as monitor when and where pilots are focusing their attention; this information will assist with identifying critical competencies and improve teaching techniques. Additionally, comparing practices across institutions will help identify shared approaches and significant differences to develop a comprehensive set of standards for flight laboratories in aviation education.

5. CONCLUSION

Case studies from Poland and Georgia show that flight laboratories greatly improve aviation education. These laboratories allow students to interact directly with aircraft, collect flight data, and apply theoretical knowledge in areas such as control systems, data analysis, radio systems, aerodynamics, and in-flight testing.

Flying laboratories provide students with an opportunity to gain hands-on experience and increase their motivation by allowing them to work directly with the aircraft and related devices. Even a basic aircraft can provide substantial educational value when equipped with sufficient measurement tools to enable students to develop practical skills. The results of both universities demonstrate that this type of experience can be successfully integrated into their curricula and therefore challenge the idea that flight-based experiences are too complicated to include routinely in an academic environment.

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