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COMPARISON OF PLATFORMS USED IN SIMULATED SESSION AS A LEARNING TOOL FOR INSTRUMENT PROCEDURES TRAINING

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Abstract. Authors aim to analyze the requirements for the use of simulation technologies for the Air Traffic Pilot License Theory and, based on the selected, measured, and interpreted parameters, to compare the platforms used by the Czech Air Force. At the University of Defence, the simulation center is used as a support instrument. The objective of this paper is to determine the most appropriate flying platform for student-pilots when employing basic radionavigation theory. To verify the analysis, simulated student flights were carried out. The first group of approaches was performed on the simulated platform of the Zlin Z142 aircraft, and the second group on the L39 Albatros aircraft. Individual flights were statistically evaluated and compared. The parameters for comparison were the deviation of the flight altitude compared to the recommended approach altitude and the deviation of the heading compared to the final approach course. Statistical evaluation of the performed simulated flights was made by F-test and verified confirmed that to teach the theoretical subject of Radionavigation, a slower-flying Zlin Z-142 is more suitable. According to the results, the Z142 platform gives the student more time to observe a pilotage error and correct it before starting the final approach phase.

Keywords: simulation, platform selection, pilot training, instrument approach, radionavigation, F-test.

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Introduction

Future Czech Armed Forces pilots are educated at the University of Defence (UoD) in five years master's degree study program of military technology, in specialization military pilot. In the first stage of the study, they complete scholarly and professional subjects at the Private Pilot Licensing Theory level. In terms of navigation, pilotage under Visual Flight Rules (VFR) is emphasized. After passing the element training program, students continue to the next theoretical level based on the Air Traffic Pilot License Theory Course (ATPL). The ATPL course structure is defined by the Civil Aviation Authority. Although the UoD educates only military pilots, the program is based on these civilian theoretical courses and follows them. The reason for this is the legal framework for aviation in the Czech Republic, specifically Act no. 49/1997 Sb. that defines the applicable range of "military aviation." For flights conducted in the same flight area, the same rules for military, police, and civil aviation shall be used (Act no. 49/1997 Sb.). Exceptions only apply to air defence missions or missions in support of state security. The subject of radionavigation is a vital part of the ATPL course and, according to experience, it is appropriate to support the theory by simulated training beyond the minimum prescribed requirements.

The subject of radionavigation is included in the pilot's curriculum of study. Computer-based exercises on flight simulators are also included in addition to aircraft hours for greater clarity, attractiveness, and effectiveness of teaching. An important decision is to choose the platforms on which the students will complete these exercises. The selection of the platform must be supported by the evidence from the analysis of radionavigation in-flight procedures. Based on this comparison, the selection of a suitable platform can be performed. The selected platform will be used for computer-based exercises on flight simulators during the course of study so that the greatest possible added value is achieved, and students are not overloaded with too much stimuli during the flight, which could hamper learning and lead to the adoption of bad habits.

Air Force Department uses as a simulation training tool a simulation center based on a fixed cabin with overhanging hardware instrument panel where the simulation works on commercial aviation software Prepar3D by Lockheed Martin, shown in Figure 1. The center consists of four pilot cabins, and air traffic controller stations for the tower and approach, and the whole simulation is controlled by the instructor station that can monitor each simulation parameter such as flight path or weather.

In the system, the workplace of the pilot is represented by an airplane actively controlled by the student. In theory, the workplace can be reconfigured to any MFS-X-compatible simulated aircraft.

The following aircraft are used as the basic default types:

- a generic propeller single-engine aircraft, equipped with a piston engine and retractable landing gear;
- a genetic subsonic single-engine jet aircraft with the retractable landing gear.

In the basic configuration, both airplanes are equipped with an extended autopilot and full equipment for instrument navigation. Airplanes can be supplemented with additional navigation devices such as Global Positioning System (GPS) or Flight Management System (FMS) if such a need.

One of the objectives of the simulation centre at the UoD is to finalize the construction of a universal simulator for student-pilot training. The selected device will simulate an appropriate military aircraft in which the students will carry out a wide spectrum of tasks (Korecki et al., 2022). The appropriate simulator should enable the initial delivery of practical air training planned for student-pilots of all aviation branches in the Czech Air Force (Univerzity of Defence News Portal, 2019).

All the simulators correspond to Flight and Navigation Procedures Trainers (FNPT) requirements for in-flight procedures training that is sufficient for education within the Radionavigation area (European Union Aviation Safety Agency [EASA], 2021). The advantages of simulation usage can be described in these points (Boril et al., 2015):

- availability – a flight simulator is dependent neither on environmental conditions, e.g. weather, nor the availability of aviation assets;
- repeatability – simulation does not need to go through the complete course of the flight, but enables the learner to repeat targeted tasks (e.g. landing);
- absence of danger to life – feasibility of practicing all conceivable situations, including emergencies, without exposing the crew to real-world risks;
- operating costs – in comparison with a real airplane, the operating costs of a flight simulator are considerably lower.

Disadvantages can be concealed at these points (Boril et al., 2015):

- no stress of danger to life – in a simulated emergency situation we can hardly expect the same level of stress as in a real situation;
- predictability – pilots' ability to anticipate some conditions, situations, and emergencies in repeated training;
- fatigue – short flight cycles are incapable of accurately demonstrating the effects of fatigue or routine piloting (decreased attention) on the crew.

A software extension was purchased for the instructor station in order to increase productivity of simulator training. The software extension allows for the following added capabilities (Boril et al., 2017):

- capability of recording selected flight parameters for their future evaluation;

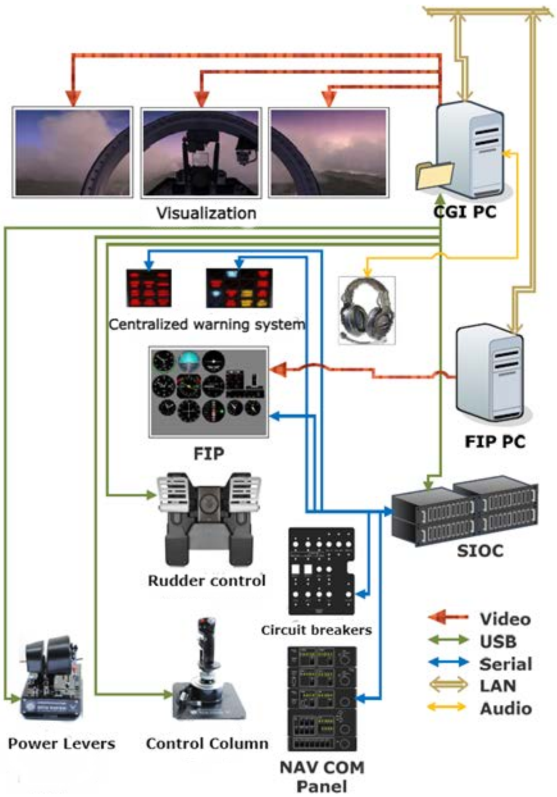

Figure 1. Pilot station. Left side scheme, right side real arrangement (source: own elaboration)

- capability of changing selected parameters in flight (e.g. simulation of faults);
- capability of controlling the simulation environment, mainly weather.

In terms of simulators categorization the reference publication for the European region is ED Decision 2012/010/R Certification Specifications for Aeroplane Flight Simulation Training Devices which provides these definitions of flight simulation training device (FSTD) categories:

- "Full flight simulator (FFS)" a full-size replica of a specific type or make, model, and series aircraft flight deck/cockpit, including the assemblage of all equipment and computer programs necessary to represent the airplane in ground and flight operations, a visual system providing an out of the flight deck/cockpit view, and a force cueing motion system. It complies with the minimum standards for FFS qualification;
- "Flight training device (FTD)" a full-size replica of a specific aircraft type's instruments, equipment, panels, and controls in an open flight deck/cockpit area or an enclosed aircraft flight deck/cockpit, including the assemblage of equipment and computer software programs necessary to represent the aircraft in ground and flight conditions to the extent of the systems installed in the device. It does not require a force-cueing motion or visual system. It complies with the minimum standards for a specific FTD level of qualification;
- "Flight and navigation procedures trainer (FNPT)" a training device that represents the flight deck/cockpit environment including the assemblage of equipment and computer programs necessary to represent an aircraft or class of airplane in flight operations to the extent that the systems appear to function as in an aircraft. It complies with the minimum standards for a specific FNPT level of qualification;
- "Basic instrument training device (BITD)" a ground-based training device that represents the student pilot's station of a class of airplanes. It may use screen-based instrument panels and spring-loaded flight controls, providing a training platform for at least the procedural aspects of instrument flight;
- "Other training device (OTD)" means a training aid other than an FSTD which provides training where a complete flight deck/cockpit environment is not necessary.

Specific requirements for FSTDs are defined worldwide by the International Civil Aviation Organization (ICAO) in Doc 9625 Manual of Criteria for the Qualification of Flight Simulation Training Devices (ICAO, 2015). The value of the training performed using FSTDs is recognized within the EASA regulation (and more widely, internationally) by the ability to replace or complement actual flight training hours with instruction hours on flight training devices. The amount of training hours that may be performed on the FSTD towards the minimum hours required for the issue of a license, rating, or certificate is known as "Training Credit" (Commission Regulation (EU) No 1178/2011, 2011). The current regulatory base does not address the appropriate and effective use of FSTDs in the theoretical training phase of pilot candidates. It only establishes the categorization and requirements for individual categories.

1. Training platforms

Education in terms of radionavigation is focused on basic principles of interpretation of individual navigation devices, pilot input, and possible limitations. The theory of radionavigation should be understood as a manner of establishing an aircraft's position in space in relation to land-based, sea-based, or space-based radionavigation equipment. Common navigational aids used in aviation include the Very High Frequency Omni-Directional Range (VOR), Distance Measuring Equipment (DME), or Instrument Landing System (ILS).

The importance of a pilot's ability to fly precisely according to flight instruments could be illustrated by the increased number of flights at airports. As Żak et al. (2021) mentions, as air transportation expands and the number of flight operations increases, the desired structure/architecture of airports is changing. The appearance of current airports has evolved from modestly equipped field airstrips to intercontinental hubs with dozens of flight operations per hour. With modern navigation equipment, procedures, knowledge, and skills of aviation service personnel, and modern aircraft designs, today's airports are increasingly independent of weather conditions (Hošková-Mayerová et al., 2022).

Today, Performance Based Navigation is the most dynamically developed concept of navigation that combines all of the above in combination with Global Navigation Satellite Systems (GNSS). The navigation computer automatically chooses the most suitable and most accurate navigation information (Korecki & Adámková, 2018; Smrz et al., 2017). All of these manners of radionavigation can be simulated at the Air Force Department simulation center.

It is necessary to choose the most suitable environment for the students to create appropriate reactions in relation to the presentation of the onboard instrument. It is required for pilots to know a large number of procedures, augmentation, and navigation systems. This will not be possible without the appropriate training process. It is very important because theoretical knowledge, practical skills, and other acquired habits will be used in the workplace (Kozuba et al., 2016).

It is crucial to conduct simulated parts of flights on similar platforms to those where the future pilot candidates will undergo their advanced flight training after graduating from the UoD. Therefore, only two variants come into play in the Czech Air Force environment. The first is the basic propeller trainer ZLIN Z-142 and the second is the jet plane L-39 ALBATROS, shown in Figure 2. For a comparison of both types, see Table 1.

Table 1. Aircraft flight characteristics (source: Avialogs: Aviation Library, 1989, 1991)

Aircraft type	Cruising speed [kts]	Service ceiling	Endurance [hrs]	Normal Rate of climb [ft/min]
Z-142	100	FL 110	3:30	1000
L-39	220	FL 360	2:30	3000

Figure 2. Real pictures of simulated platforms. Left side ZLIN Z-142, right side L-39 ALBATROS (source: own elaboration)

At first sight, the main differences occur which are mostly given by the different types of propulsion, propeller, and jet.

For radionavigation purposes, the cruising speed respectively the approach speed during the approach phase is vital. The main reason for the simulated events in UoD is not the pilotage itself. The events are profiled to educate and train the elementary phase of flight in connection with the theoretical base. Therefore, it is not necessary to train the flare during landing, etc. It is important to analyze the exact VOR radial interception procedure, ILS glide path interception, etc. For this part of the flight, the cruising speed or approach speed is determining because the velocity is an indirect function of navigation instrument indication.

In a further comparison, the way of navigation instrument presentation is described in conjunction with different cruising or approach speeds.

The consistent approach to the selection of the platform implies the student´s reaction to an error that can occur during the early training of instrument flight procedures.

The instrument procedures are normally done during the approach phase of flight where a certain level of hazard exists. This phase is critical because of the lower flight profile during the approach and the greater impact of meteorological conditions on safety of flight.

2. Instrument Landing System

ILS is one of the most widely used instrument landing systems. ILS is usually used in limited weather conditions when visibility is low (clouds or fog). The ILS informs the pilot during the instrument approach of the position of the aircraft in two axes, horizontal and vertical (Mori & Fujita, 2020).

The first ILS testing began in early 1929 in North America. This testing was initiated in the background of the need to ensure the regularity of post-flight flights. Several systems were tested as a part of the testing. The Boeing 247-D, on the Washington, D.C. – Pittsburgh route was the first to perform an approach and landing with the help of the ILS system on January 28, 1938, due to a severe storm. Subsequently, in 1941, the Federal Aviation Administration (FAA) approved the installation of the ILS system at six selected airports. In 1945, ILS was already installed at nine airports, and a gradual installation of the ILS systems was carried out at other airports. ILS has been ordered for fifty military airports across the United States (Imrich, 2007).

Subsequently, new standards known as the United States Standard for Terminal Instrument Procedures (TERPS) were adopted. The International Civil Aviation Organization (ICAO) adopted the ILS military system as the standard precision instrument approach system for all member states in 1949. The Procedures for Air Navigation Service – aircraft operation (PAN-OPS) are based on the TERPS standard, which ICAO has adopted. Following the new procedures, new terms were created, that are known today as decision altitude (DA) or minimum descent altitude (MDA). It was also necessary to accurately adjust and define the weather conditions under which it is still possible to land safely. Today's instrument approach minimums include visibility (VIS), runway visibility (RVR), and the height of the lowest cloud base (CIG) (Imrich, 2007).

A summary of instrument approach landings is provided in the "Notice of Proposed Amendment 2018-06 (C)".

The precision approach (PA) procedure is the instrument approach procedure based on navigation systems (ILS, Microwave Landing System (MLS), Ground Based Augmentation System Landing System (GLS), and Satellite Based Augmentation System (SBAS) Category I), designed for 3D approach by type A or B instruments. Instrument approach procedure using directional and descent information provided by "ILS or Precision Approach Radar (PAR)" (AIM, 2020).

Approach Procedure with Vertical Guidance (APV) is "the instrument approach based on Performance-Based

Performance-Based Approach Classification Summary						
Domain	Document	ICAO Panel	Operations			
Approach Operations	Annex 6	FLTOPSP	Classification	Type A	Type B	
				(>=250')	(200<=DA/H<250')	(<200')
				2D or 3D	3D	3D
				MDA/H or DA/H	DA/H	DA/H
Approach Minima Runway Requirements	Annex 14	ADOP	MDA/H or DA/H >= VCM	Non-instrument RWY		
			M(DA/H) >=250' Visibility >=1 000 m	Non-precision RWY		
			DA/H >= 200' RVR >=550 m	Precision RWY, Category I		
			DA/H >=100' RVR >=300 m	Precision RWY, Category II		
			DA/H >=0' RVR >= 0 m	Precision RWY, Category III (A, B, C)		
System Performance Procedures	Annex 10, PANS-OPS, Volume II, PBN Manual	NSP IFPP PBNSG	N/A	VOR, NDB, LOC and LDA w/ GS		ILS, MLS, GBAS
				PBN (including SBAS), ILS, MLS, GBAS		

Figure 3. Performance-based approach classification (source: Aeronautical Information Management [AIM], 2020)

Navigation (PBN), designed for a 3D approach to Type A instruments" (AIM, 2020), detailed in Figure 3.

Non-precision approach procedure (NPA) is "the instrument approach procedure designed for a 2D type A instrument approach" (AIM, 2020).

As part of the research, this article is focused on the ILS system, which contains the following two basic components for the safe guidance of the aircraft relative to vertical and horizontal planes:

1. Airport ground equipment
   - Very High Frequency (VHF) Localizer (LOC, or LLZ according to ICAO standardization)
   - Ultra High Frequency (UHF) Glide slope transmitter (G/S)
   - Distance Measuring Equipment (DME)
   - Marker Beacons;
2. On-board aircraft equipment.

The system may be divided by functionality into three parts:

1. Guidance information: LOC, G/S;
2. Range information: marker beacon, DME;
3. Visual glide path information: approach lights, touchdown and centreline lights, and runway lights.

The localizer transmitter operates on one of 40 ILS channels within the frequency range of 108.10 to 111.95 MHz. The signals provide the pilot with course guidance relative to the runway centerline (ICAO, 2021).

The approach course of the localizer is called the front course and is used with other functional parts, e.g. glide slope, marker beacons, etc. The localizer signal is transmitted at the far end of the runway. It is adjusted for a course width of (full-scale fly-left to a full-scale fly-right) of 700 feet at the runway threshold. The coverage area of both signals is illustrated in Figure 4. The course line along the extended centerline of a runway, in the opposite direction

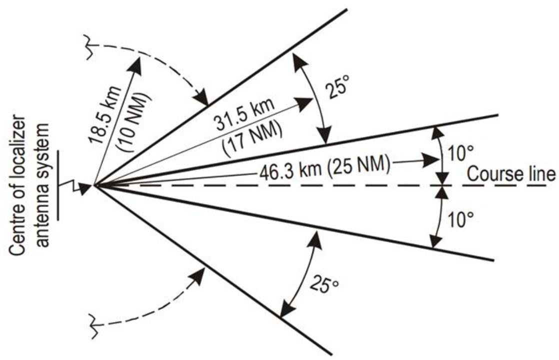

Figure 4. Localizer and glide path signal coverage (source: ICAO, 2018)

to the front course, is called the back course (Federal Aviation Administration, 2021).

Aircraft on-board equipment includes:

- VHF Localizer receiver;
- UHF Glide slope receiver;
- DME receiver with indication;
- antennas;
- ILS display device.

Segments of instrument approach:

- arrival Segment;
- initial Segment;
- intermediate Segment;
- final Segment;
- missed Approach Segment.

In procedural instrument flying, it was counted on turns with a 15° bank angle after take-off and 25° in other cases, but only aplied a 25° bank angle to aircraft with a flight speed greater than 167 knots. At these speeds, it was no longer possible to reach a standard rate turn with a lower bank angle. By definition, a rate one or standard rate turn is accomplished at 3°/second resulting in a course reversal in one minute or a 360° turn in two minutes. A rate one half turn is flown at 1.5°/second and a rate two turn at 6°/second (F-AIR, 2020; SKYbrary Aviation Safety, 2021).

The bank angle (BA) for a certain speed can be determined using a simplified Equation (1):

$$BA = \frac{TAS}{10} + 7{,}5\,. \tag{1}$$

The bank angle required to conduct a turn at a specific rate is directly proportional to true airspeed (TAS) in knots

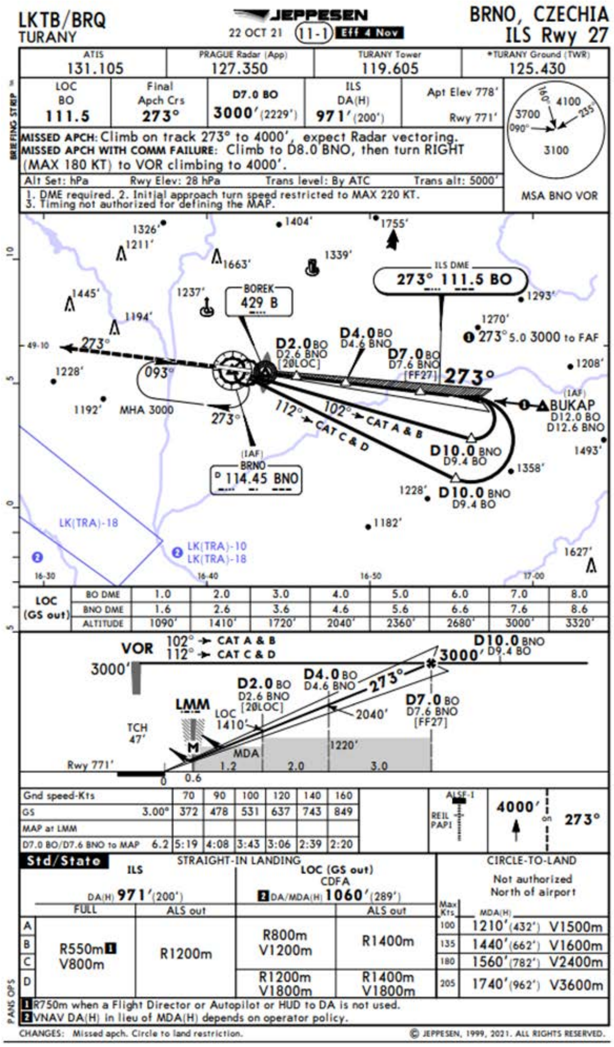

Figure 5. Jeppesen approach chart for Brno Tuřany airport (source: Jeppesen, 2022)

and BA is the bank angle in degrees (F-AIR, 2020; SKYbrary Aviation Safety, 2021).

Using this formula, an aircraft flying at 80 knots would require 15° of bank for a rate of one turn whereas at 160 knots, 23° would be required and at 240 knots a bank angle of 31° would be required to achieve the same rate of turn. As a high bank angle is undesirable, especially under Instrument Meteorological Conditions (IMC), the ICAO guidance for holding procedures states that "all turns in nil wind should be at a bank angle of 25 degrees or Rate One, whichever requires the lesser bank". The protected airspace is then based on the turn radius for the maximum allowable holding speed at 25° of bank (SKYbrary Aviation Safety, 2021).

3. Flightpath discussion

From the facts mentioned above, the prerequisites for comparison results:

- the faster the airplane flies, the faster the localizer bar moves;
- the faster the bar moves, the less time the student has for reaction;
- when the student has little time, the probability of a wrong reaction increases, and the disruption of the protected airspace can occur.

When the airplane follows the proper pattern for localizer interception then the Horizontal Situation Indicator (HSI) starts to indicate approaching the axis at a three-degree angular deviation. The real simulation center indication of the yellow localizer bar is presented in Figure 6. The length of the path from the indicated margin to the ideal centerline is a function of the distance from the runway. The study considers the approach made at Brno Tuřany airport LKTB (the approach scheme is illustrated in Figure 5).

The final turn to the approach course is drawn as a continuous turn in instrument charts, but in fact, according to the fly procedures the final segment is intercepted at level flight at an angle of 30 degrees or less. During level flight, the pilot waits for bar movement into the center, typically called as "localizer alive". At this precise moment, the difference between platforms becomes important. The enumeration of level flight time comes out of the geometry illustrated in Figure 7.

full scale fly-right half scale fly-right centerline position

Figure 6. HSI indication as presented at the simulation center (source: own elaboration)

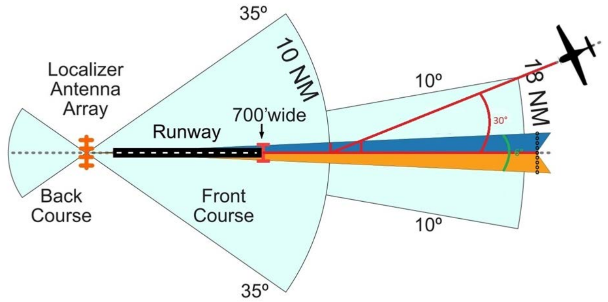

Figure 7. Geometry situation for the 30-degree level flight phase (source: own elaboration)

Distance of level flight (D) is defined by the Equation (2):

$$D=\frac{tg3°\times 10NM}{\cos 30°}=0{,}6\ NM\,. \quad (2)$$

This distance D is covered in 22 seconds at a speed of 100 knots. Compared to that, the distance is covered in 10 seconds at a speed of 220 knots. It is needed to account for the time of the final segment turn at an angle of 30 degrees, therefore, it is necessary to subtract 10 seconds for rate one turn, respectively, 5 seconds for rate two turn that is used by some jet planes, L-39 for example. The remaining time is labeled as reaction space. The comparison of Z-142 and L-39 is made in Table 2 by reaction time as the crucial factor for student pilots.

Table 2. Comparison of time factors for two platforms (source: own elaboration)

Type of aircraft	Level flight time [s]	Turn time [s]	Reaction space [s]
Z-142	22	10	12
L-39	10	5	5

The assumptions mentioned above were tested during simulated flights. The test was designed by conducting 5 flights on the Z-142 platform by five students with only basic PPL flying experience (50 flying hours in total). Then the same five students performed the same flight on the L-39 platform. All flights were performed under the same conditions:

- start point over BNO VOR;
- start altitude 3000 ft AMSL;
- identical weather conditions.

The flight path according to the platform is illustrated in Figure 8 in the horizontal direction and Figure 9 in the vertical direction.

The statistical evaluation of these two groups is illustrated on the Box-and-Whisker plot listed below. In Figure 10 altitude was chosen as a parameter. The value of altitude between the distance of 10 NM to 7 NM from the touchdown zone was the most important phase before the Final Approach Fix. The altitude according to the approach scheme for the LKTB airport during this phase is 3000 feet. In Figure 11 the difference from a prescribed final heading of 273 degrees was a parameter.

Based on the first evaluation, students achieved more accurate pilotage when flying on the Z142 platform. The results are evaluated in Box-and-Whisker plots in Figure 12 and Figure 13. The exact statistical values are shown in Table 3, where:

- Sample mean

$$\bar{X}=\frac{1}{n}\sum_{i=1}^{n}X_i\,, \quad (3)$$

- Standard deviation

$$S=\sqrt{\frac{\sum_{i=1}^{n}\left(x_i-\bar{x}\right)^2}{n-1}}\,. \quad (4)$$

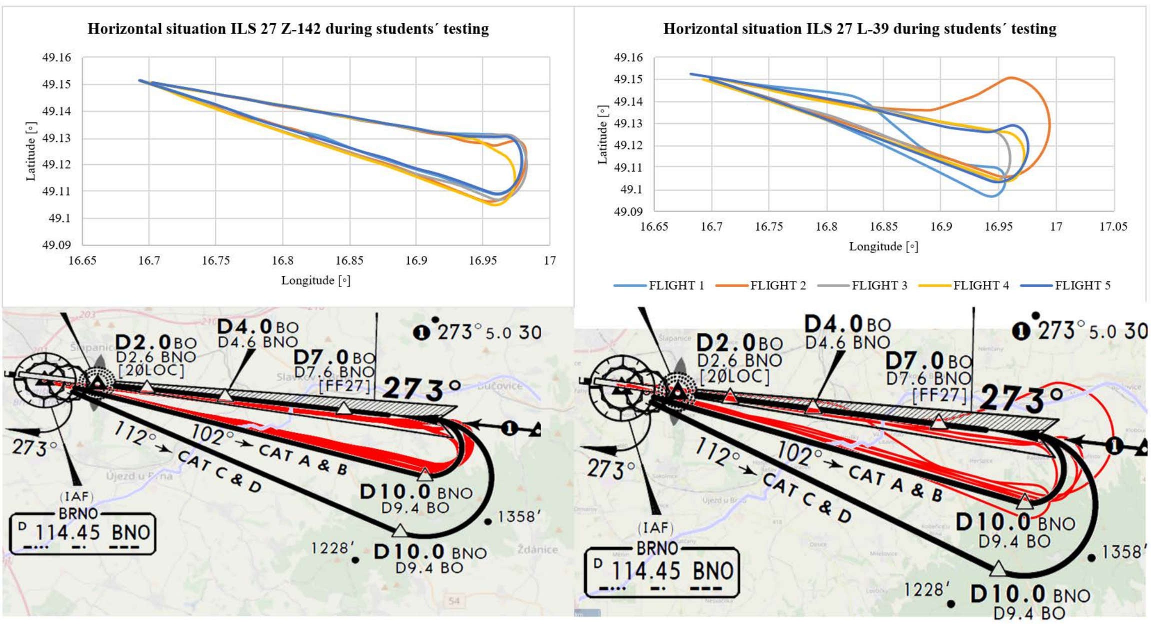

Figure 8. The horizontal situation during students' testing (source: own elaboration)

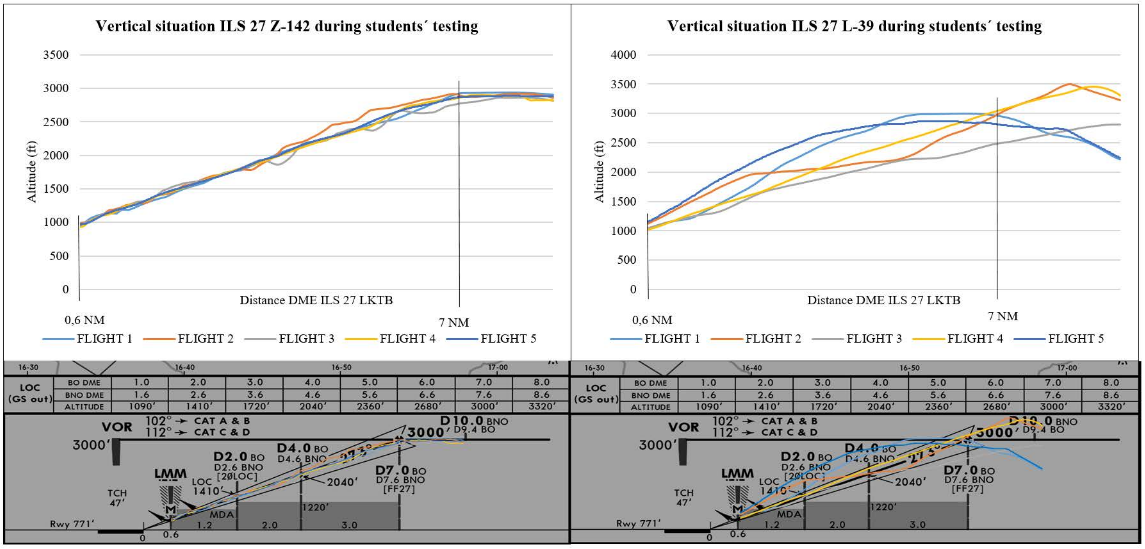

Figure 9. The vertical situation during students' testing (source: own elaboration)

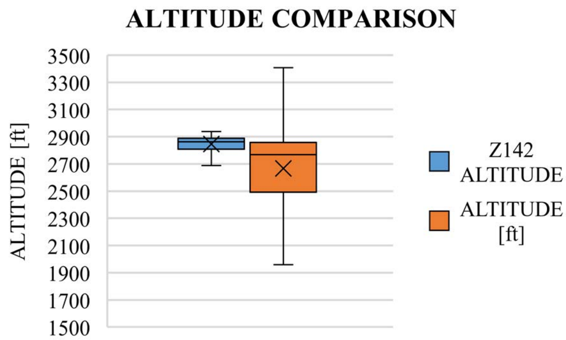

Figure 10. Altitude comparison during students' testing (source: own elaboration)

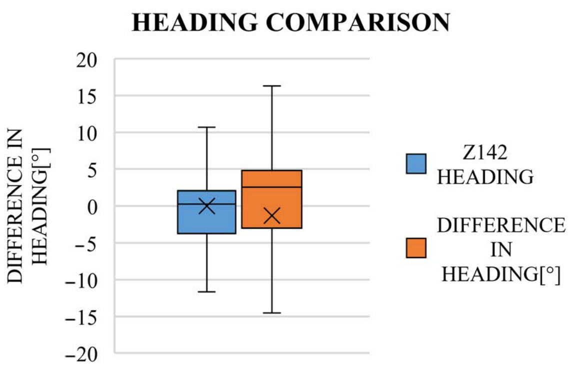

Figure 11. Heading comparison during students' testing (source: own elaboration)

Table 3. Statistical characteristics of heading and altitude measurements (source: own elaboration)

		Sample mean	Standard deviation
ALTITUDE	Z-142	2847 ft	62 ft
	L-39	2666 ft	312 ft
HEADING	Z-142	–0.003°	5.003°
	L-39	–1.279°	11.292°

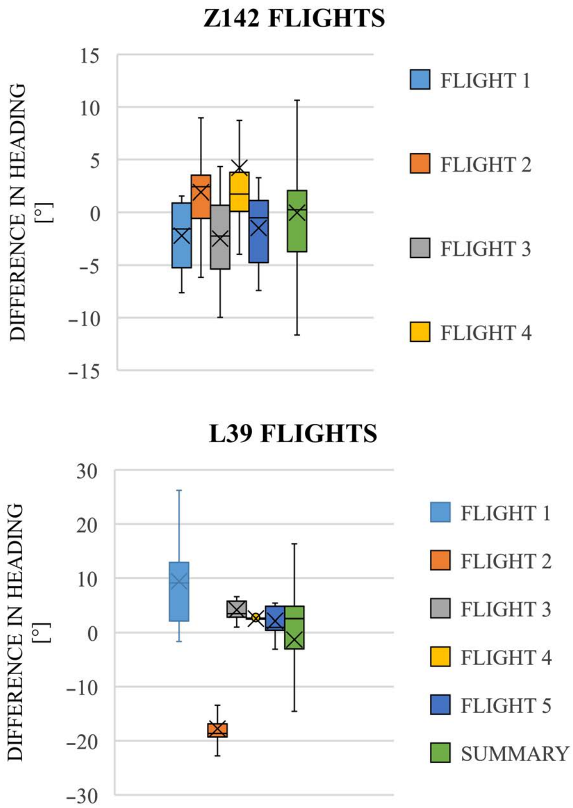

Figure 12. Statistical comparison of heading during students' testing (source: own elaboration)

The statistical evaluation of the flight altitude and heading was performed by the F-test (King & Eckersley, 2019). Flights conducted on the L-39 platform are considered an independent group X_1 and flights conducted on the Z-142 platform are considered an independent group Y_1.

The null hypothesis is defined by the Equation (5):

$$H_0 : \sigma_1^2 = \sigma_2^2. \quad (5)$$

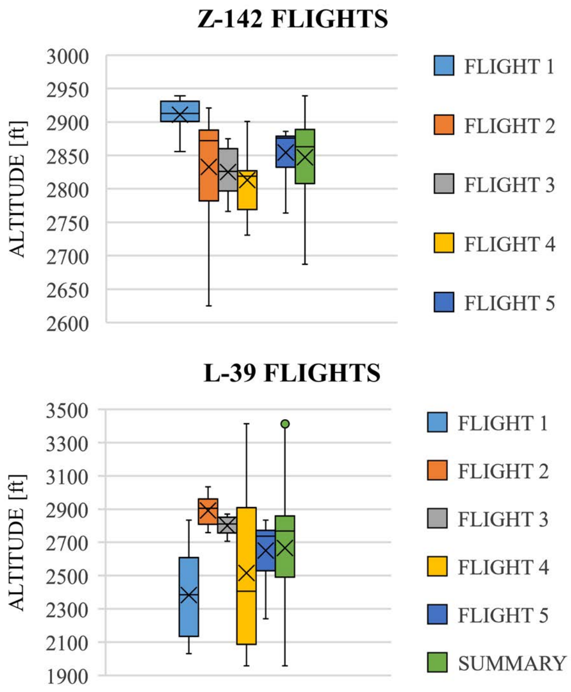

Figure 13. Statistical comparison of altitude during students' testing (source: own elaboration)

The alternative hypothesis is defined by the Equation (6):

$$H_A : \sigma_1^2 \neq \sigma_2^2 . \quad (6)$$

For the test flights, the F parameter comes out to be 25.55 for the altitude test, and the F parameter 5.09 for the heading test. Thus rejecting the null hypothesis, it can be declared that the given samples are statistically different. More detailed information on the F test is summarized in Tables 4–7.

Table 4. Population parameters of altitude difference from 3000 feet (source: own elaboration)

Summary altitude flight L-39		Summary altitude flight Z-142	
n =	1374	n =	3070
Suma	–458457	Suma	–469056
Minimum	–1042	Minimum	–407
Maximum	413	Maximum	–61
Difference max-min	1455	Difference max-min	346
Median	–231,5	Median	–137
Modus	–130	Modus	–124
μ =	–333,666	μ =	–152,787
s =	312,700	s =	61,855
σ =	312,587	σ =	61,845
s2 =	97781,583	s2 =	3826,032
σ2 =	97710,418	σ2 =	3824,785

Table 5. F-test for altitude measurements (source: own elaboration)

Null hypothesis
$\sigma_1^2 = \sigma_2^2$

Alternate hypothesis
$\sigma_1^2 \neq \sigma_2^2$

$F_p(v_1, v_2)$

$v_1 = n_1 - 1$	$v_2 = n_2 - 1$	–	
1373	3069	–	
$F_{\alpha/2}(v_1,v2)$	$F\alpha(v_1,v_2)$	$F_{1-\alpha}(v_1,v_2)$	$F_{1-\alpha/2}(v_1,v_2)$
0,913	0,927	1,078	1,093

α	The level of significance	F_p	$F_p \in W_\alpha$	Critical value		p-Value	Null hypothesis	Alternate hypothesis
0,05	95%	25,557	yes	0,913	1,093	0,000	rejected	accepted

Table 6. Population parameters of heading difference from final approach course 273° (source: own elaboration)

Summary altitude flight L-39		Summary altitude flight Z-142	
n =	1374	n =	3070
Suma	–1802,931	Suma	–11,261
Minimum	–27,957	Minimum	–11,665
Maximum	26,193	Maximum	17,143
Difference max-min	54,150	Difference max-min	28,809
Median	2,525	Median	0,261
Modus	–1,149	Modus	–6,147
μ =	–1,312	μ =	–0,004
s =	11,311	s =	5,003
σ =	11,307	σ =	5,002
s2 =	127,940	s2 =	25,032
σ2 =	127,847	σ2 =	25,024

Table 7. F-test for heading measurements (source: own elaboration)

Null hypothesis
$\sigma_1^2 = \sigma_2^2$

Alternate hypothesis
$\sigma_1^2 \neq \sigma_2^2$

$F_p(v_1, v_2)$

$v_1 = n_1 - 1$	$v_2 = n_2 - 1$		
1373	3069		
$F_{\alpha/2}(v_1,v_2)$	$F_\alpha(v_1,v_2)$	$F_{1-\alpha}v_1,v_2)$	$F_{1-\alpha/2}(v_1,v_2)$
0,913	0,927	1,078	1,093

α	The level of significance	F_p	$F_p \in W_\alpha$	Critical value		p-Value	Null hypothesis	Alternate hypothesis
0,05	95%	5,094	yes	0,913	1,093	0,000	rejected	accepted

Conclusions

Summarizing the above facts, the conclusion is that the platform based on ZLIN Z-142 is preferable for student pilots undergoing elementary flight training, including the practical application of radionavigation theory. The slower airspeed of the Z-142 allows more time for the student pilot to perceive deviations during the approach and apply the appropriate input. This hypothesis was confirmed by the analysis of the measurements taken during the simulated flights of the students during the instrument approach to the LKTB Turany Brno airport (Figure 5). The students on the Z142 platform followed the altitude and heading during the approach more accurately (Figures 10, 11). This fact was confirmed by the statistical F-test (Tables 4–7).

In the evaluated flights on the L-39, deviations can be observed from the specified height of more than 300 ft, which would result in the violation of the protected areas for the given type of instrument approach. This error could have fatal consequences in a real-world approach. It follows from what was observed that the use of this platform is inappropriate at the given stage of training and could lead to undesirable flying habits.

An analytical approach to the problem of selecting an appropriate aircraft platform for flight simulation training provided an objective result. Selecting the objectively superior aircraft platform for initial radionavigation training should therefore contribute to a positive learning outcome for student-pilots. The relationship between simulator training and the degree of skill transferred to practical flying may be explored by future research.

The hypothesis that using a slower aircraft for basic flight training with a focus on instrument flying was verified by data collected during actual simulator flights with UoD students. Based on this data, the Z-142 platform is the preferred platform for student-pilots in the initial application of radionavigation at the University of Defence.

The transition to a high performance platform such as the L-39 should be done after mastering the final manoeuvre without time pressure. This transition occurs with students who have sufficient practical skills and can safely operate the aircraft at higher speeds.

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Author contributions

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