REVIEW OF EQUIPMENT OF FLIGHT ANALYSIS AND DEVELOPMENT OF INTERACTIVE AERONAUTICAL CHART USING GOOGLE EARTH'S SOFTWARE

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Abstract. While carrying out pilot-student flight analysis, it was observed that there is a scarcity of means designed to allow fast and convenient analysis and evaluation of pilot-student flights in airspace. Most of the free navigation tools available are more adapted for on-ground navigation analysis (height and vertical speed information are not always displayed). Various software programmes can display different flight information; however, it is difficult to relate the different data parameters and compare them. Thus, the aim of the study is to resolve these problems by offering to pilots-instructors a convenient interactive aeronautical chart.

Keywords: aviation; training flight assessment; flight assessment methodology; *Google Earth*; *OziExplorer*; *IGC Flight*; software.

Introduction

When the circumstances are favourable for flights, there is a huge increase in the workload of pilot-instructors. This leads to the situation, when without any additional equipment it is hard for the pilot-instructors to review the solo flights carried out by pilot-students and to assess, whether the planned trajectories were carried out well.

Researchers across the world are continuously working towards the development of new means to improve flight safety, and some studies have focused on improving pilot flight trajectories and the means for assessing them. Savičienė (2012) carried out research on pilot support systems, in which certain flight corridors were projected so as to ease the pilot's orientation in flight. In the current study, however, the focus is not on pilot support systems but on means that would aid in the assessment of pilot-students. In a work by Gruszecki *et al.* (2007), the relationship between a pilot's knowledge and skills was explored. Taking this relationship into consideration, a theoretical model for the possible assessment of a pilot was developed. Experimental research was made using an AL200MCC flight simulator and WOMBAT situational awareness and stress tolerance test. The assessment was made by setting predetermined

values for important flight parameters and calculating deviations from those values in a simulated flight. Such a model would require a determination of certain ranges for the deviations in order to assess a flight on a certain scale. Shub *et al.* (1994) presented an autonomous Pilot Evaluation System (PES) used for the evaluation of candidates to become fighter jet pilots. The system evaluates the performance of the candidates in simulated flight conditions. The evaluated skills are correlated with a set of required skills, determined by the experts. The candidate carries out a flight scenario; the system gathers parameters needed to assess performance and, afterwards, provides an evaluation. However, the system was only used in a simulator and is only projecting what the performance of the candidate would be, if he was a pilot. So, it cannot be adequately used to assess a pilot's flight in real conditions. The literature review revealed that there is a lack of means for flight assessment as well as studies that specifically focus on it using experimental data. It has been observed that there is a lack of appropriate and convenient equipment for analysing flights available to pilot-instructors, and if there are some means, they are not usually applicable to pilot-student flights, for which quick and accessible means for reviewing flight trajectories are needed. The use of such not fully adapted equip-

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ment creates certain disadvantages, that lead to the fact that its application is inconvenient for the user. A more detailed analysis of possible flight analysis equipment will be presented in the following section.

1. Review of Flight Data Analysis Equipment

In this section the most prominent (and more appropriate for flight analysis) Global Navigation Satellite System (GNSS) data visualisation software is reviewed, taking into consideration their advantages and disadvantages. The main thing that is lacking in most of these software packages is the possibility of comparing various flight data (e.g. coordinates, altitude, speed, heading, etc.).

When using *IGC Flight Replay* (Fig. 1), the whole pilot-student flight trajectory is observed from the point of view of the cockpit, although it is also possible to view the whole flight trajectory as well. One disadvantage is the fact that it is not possible to conveniently draw the planned flight trajectory when reviewing the flight. In order to assess a flight by a pilot-student, the pilot-instructor must know the terrain features well, to be able to see whether the pilot-student is carrying out the planned trajectory.

Without a good flight visualisation, the *IGC Flight Replay* allows to view the graphs of main flight parameters. The following figures represent the graphs of an ex-

perimental circuit flight: altitude (Fig. 2), speed (Fig. 3), vertical speed (Fig. 4) and lift-to-drag ratio (Fig. 5).

The graph in Fig. 5 is more appropriate for analysing glider flight parameters. Without the flight parameter graphs, if there are additional sensors, *IGC Flight Replay* software can also provide the level of engine noise and thermalling. Similarly to other flight parameter analysis software, the visualisation of these parameters in a single timeframe is not possible, which prevents a convenient comparison of these parameters.

The resolution of the current published Lithuania's aeronautical charts (Fig. 6) is not very high. This is particularly clear when analysing circuit flights. *OziExplorer* software application (Fig. 7), requires high resolution scanned *jpg*- or *bmp*-format graphical maps. In Fig. 8 it is evident that traffic circuits (trajectories in red) are on a rather small scale, and the resolution of the map is low as well. Under such conditions, it is difficult to accurately assess flight accuracy and quality. Route flights can only be carried out within the coordinates of the map or aeronautical charts of neighbouring countries must be used.

It is possible to obtain graphs for flight altitude (Fig. 9) and flight speed (Fig. 10) in both *IGC Flight Replay* and *OziExplorer*. With *OziExplorer* it is also possible to use the *Zoom* function to widen the graph (Fig. 11), and view separate sections by choosing the required widened part of the graph using the *Pan* function. The Zoom feature is also possible in the flight speed graph (the Zoom is not illustrated).

However, both *IGC Flight Replay* and *OziExporer* are not capable of visualising the data of several parameters in one timeframe. The *X*-axis, represents upon choice either time or distance.

GPS TrackMaker (GTM) (Fig. 12) software is more adapted to the Brazilian market, and it is also compatible with *Google* maps. The GTM can visualise the altitude graph, which can also be zoomed in and viewed in separate sections. The GTM allows to draw various figures on the map to some extent and is also able to handle various flight data formats.

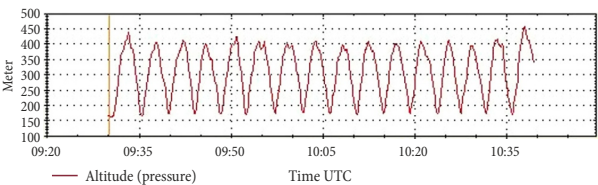Fig. 1. *IGC Flight Replay* flight analysis software window view
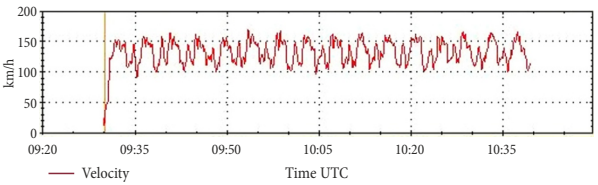

Fig. 2. Circuit flight altitude graph
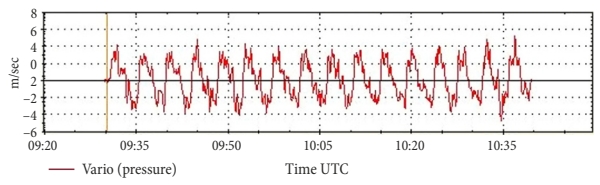

Fig. 3. Circuit flight speed graph

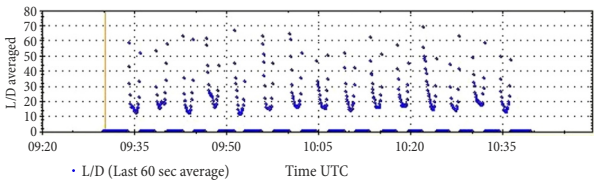Fig. 4. Circuit flight vertical speed graph

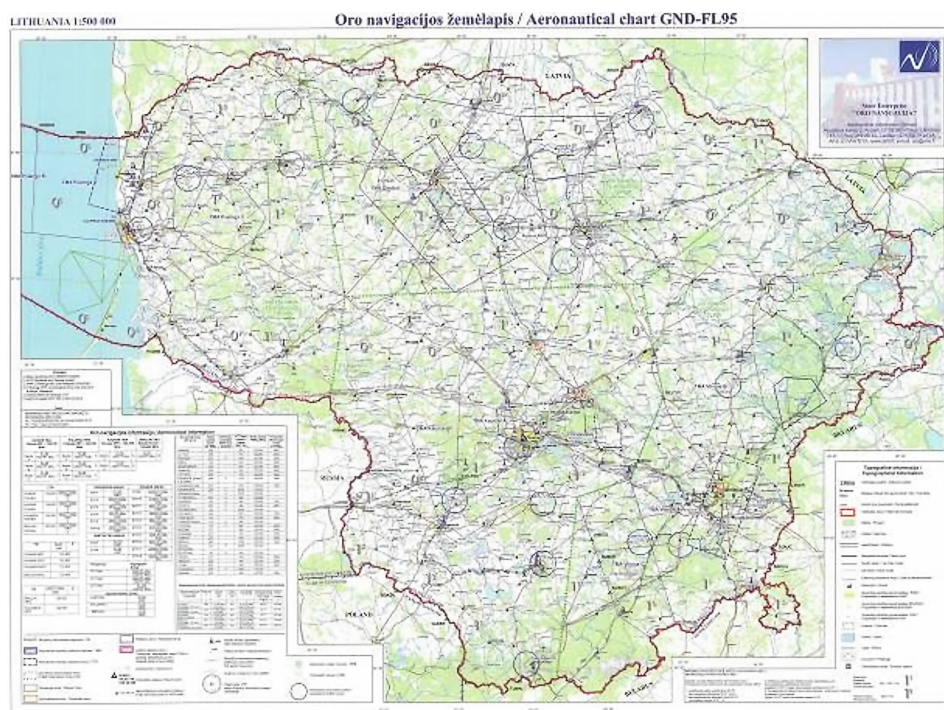Fig. 5. Circuit flight lift-to-drag ratio

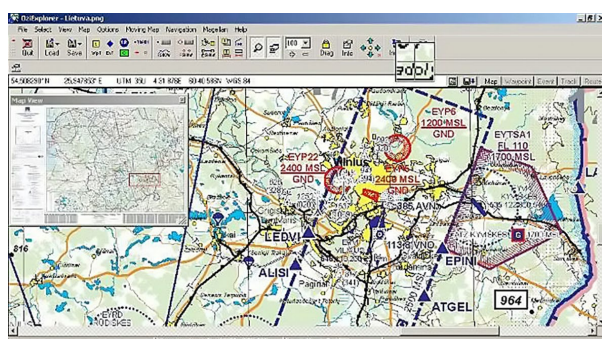Fig. 6. View of static aeronautical chart of Lithuania (VĮ Oro navigacija 2015)

Fig. 7. General view of use of bitmap and graphical aeronautical charts in *OziExplorer* software

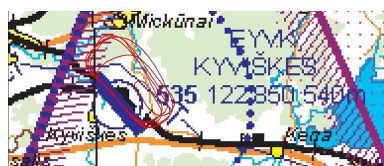Fig. 8. Possible closest view of aeronautical chart of Lithuania in *OziExplorer*
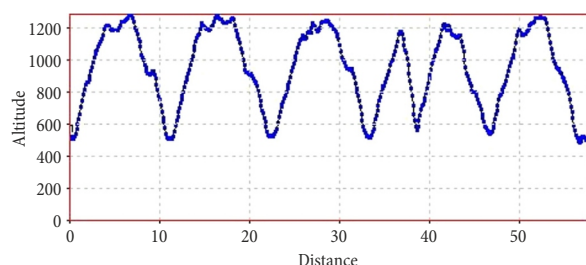

Fig. 9. *OziExplorer* all flight circuit altitude graph (altitude [ft], distance [km])
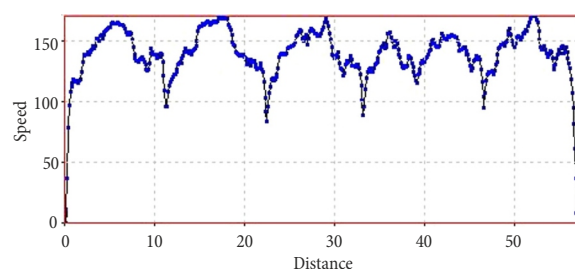

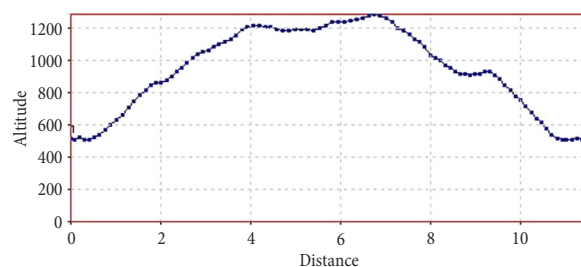Fig. 10. *OziExplorer* all flight circuit speed graph (speed [km/h], distance [km])

Fig. 11. *OziExplorer* detailed first circuit flight altitude graph from Fig. 9 (altitude [ft], distance [km])
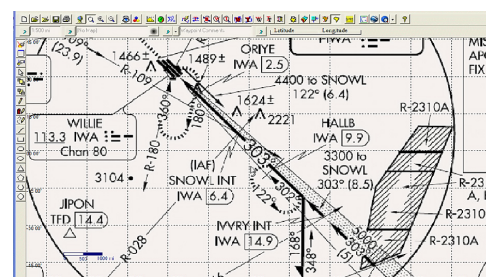

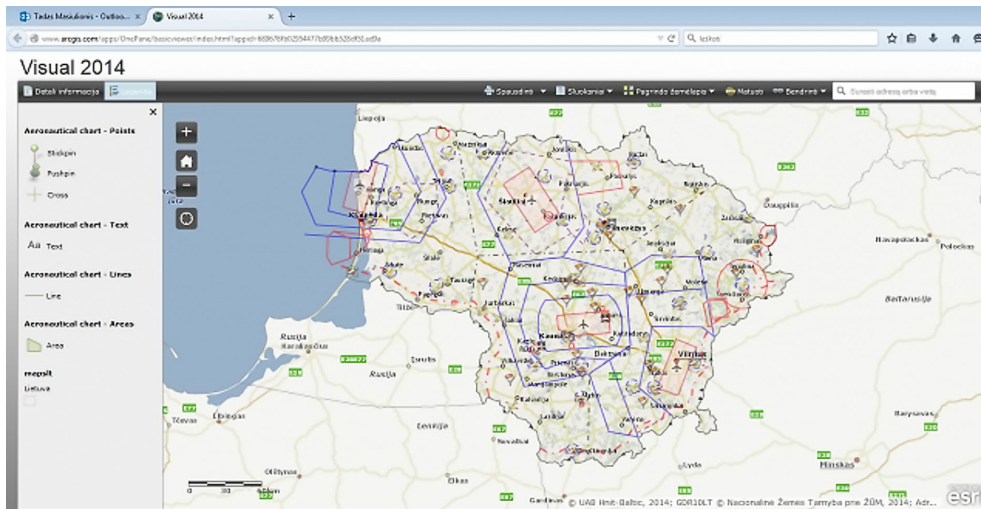Fig. 12. View of *GPS TrackMaker* software window

Fig. 13. Online ArcGIS aeronautical chart of Lithuania (ArcGIS Visual 2014; VĮ Oro navigacija 2014b)

Fig. 13 represents an online *ArcGIS* aeronautical chart of Lithuania (ArcGIS Visual 2014), which shows various zones that are distinguished: Flight Information Region (FIR), Controlled Traffic Region (CTR), Terminal Manoeuvring Area (TMA), etc. It is not possible to access any other functions using it. A similar aeronautical chart can also be accessed on *SkyVector* website (SkyVector 2016).

Fig. 14 shows the graph of a flight trajectory of a circuit and a holding pattern generated using *Matlab* software.

Standard *Matlab* configuration does not include any objects or terrain features. All the required objects
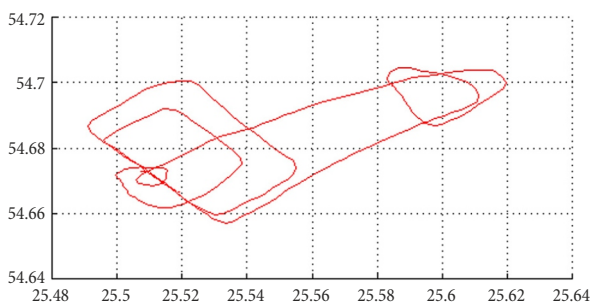

Fig. 14. Visualisation of student-pilot circuit flight and holding pattern trajectories in *Matlab* software
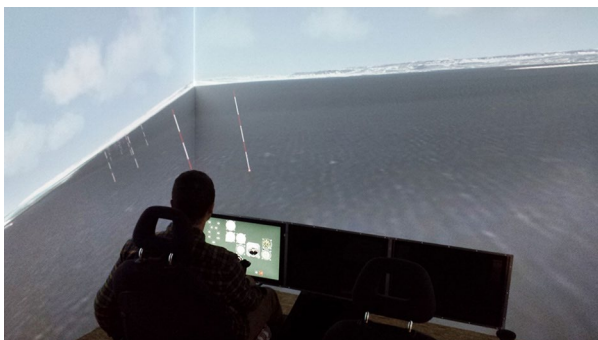

Fig. 15. Helicopter pilot slalom task in a flight simulator

and supporting data must be developed separately. However, *Matlab* is a good platform for analysis that permits to carry out calculations and assess some elements of a pilot-student flight, including deviations from the planned flight trajectory.

For the experiment, a flight simulator adjusted for the experiment (Fig. 15), with an integrated AIRBUS EC225 kinematic and aerodynamic programming model was used. The slalom was designed (columns were placed) above Lake *Etang de Berre*, so that additional objects would not divert the pilot's attention. Three gates of different width (10, 24.5, 34.5 m) were designed. Based on the helicopter pilot training manual ADS-33 (Crews *et al.* 2000), a flight experiment involving a slalom for a helicopter pilot was carried out in ONERA aeronautics laboratory, France (Salon-de-Provence) (Fig. 16). Four Brazilian helicopter pilots participated in the experiment; they performed the flights in the flight simulator at 3-difficulty levels (different gate width).After designing a programme in *Matlab* for processing the data, the following results were obtained (Fig. 17).

As illustrated by Fig. 17, the flight trajectory of the slalom resembles a sinusoid. Based on this, the mathematical model of the flight corridor of the slalom task was developed (1) and its true view is presented in Fig. 18:

$$y(x) = \left(A \cdot \sin\left(\frac{2 \cdot \pi \cdot y_0}{T} + \varphi \right) \right) \pm d \pm x_0, \qquad (1)$$

where A – sinusoid amplitude; φ – sinusoid initial phase; T – sinusoid period (distance between maximum si-
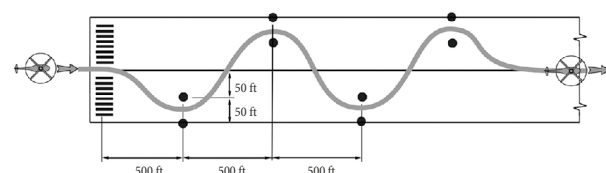
Fig. 16. Helicopter slalom task flight trajectory (ADS-33)
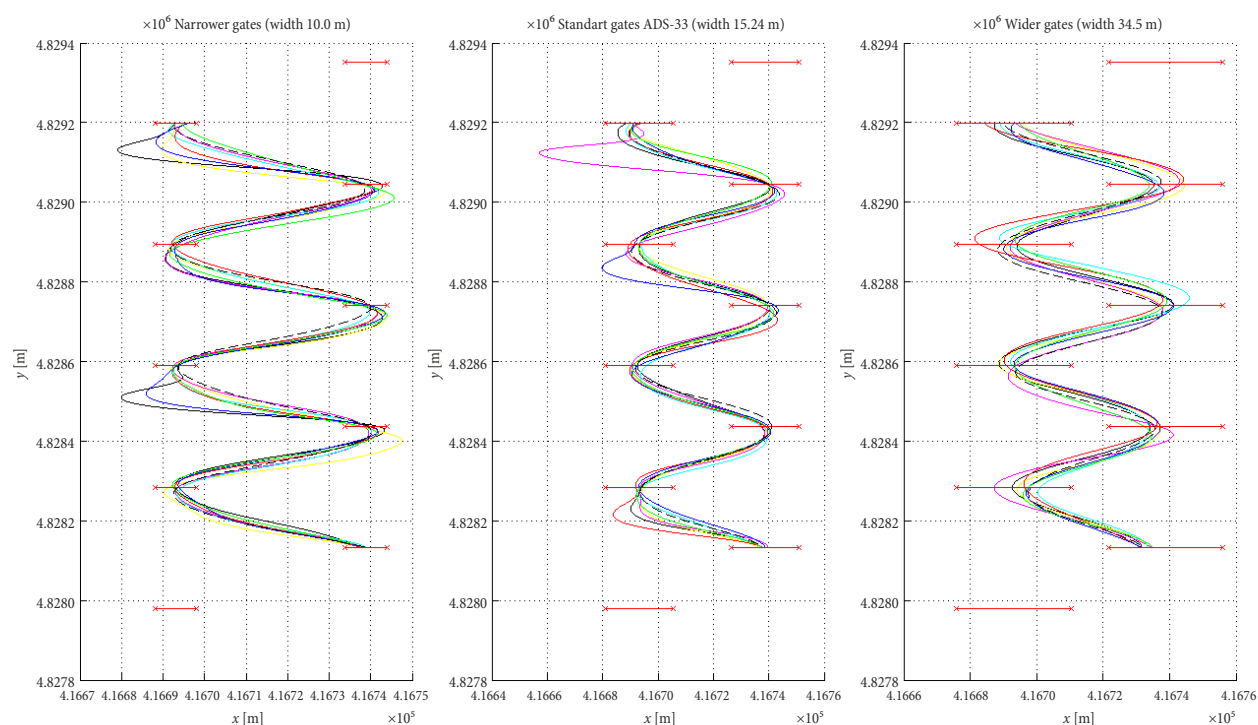
Fig. 17. Results obtained from the helicopter slalom experiment at 3-difficulty levels

nusoid values); d – amplitude shift; π – mathematical constant; x_0 – initial longitude coordinate; y_0 – initial latitude coordinate.

A similar mathematical model in *Matlab* has been generated for aircraft traffic circuit flights (Masiulionis, Stankūnas 2016). A prototype of a flight corridor for traffic circuit flights in Kyviškės aerodrome (VĮ Oro navigacija 2014a; VGTU 2016) is provided in Fig. 19. The parameters for such a flight corridor model can be easily modified by changing values in the mathematical model.

If there is a need, a similar flight corridor can be developed in *Google Earth* software (Google 2015; Earth Point 2015). However, it would be static then. In order to change the parameters of the circuit, all the lines should be re-drawn. For a lower or higher number of aircraft in the circuit, only in advance prepared air traffic circuit patterns with appropriate parameters (certain circuit perimeter) could be chosen. To dynamically change the circuit parameters, traffic circuit design principles based on mathematical models using *Matlab* software must be used, as it was done for Fig. 18.

Fig. 18. View of helicopter slalom task flight corridor model

Fig. 19. Prototype of Kyviškės aerodrome traffic circuit corridor (Masiulionis, Stankūnas 2013)

2. Features of the Interactive Aeronautical Chart Developed in *Google Earth* Software

It is difficult to create an informative and all-inclusive aeronautical chart. On one hand, a lot of compiled information is needed, on the othe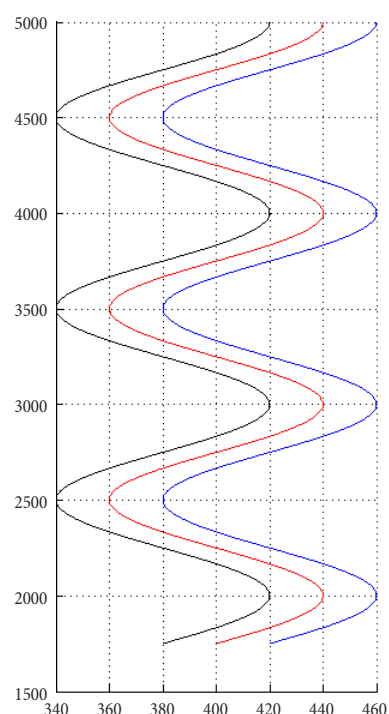r – the map can easily become overcrowded with information some items start overshadowing others, which leads to some information becoming invisible.

One of the possibilities for solving this problem in order to show all navigation information is to use layered maps (Fig. 20). A smart layered map allows to choose the layers that will be displayed and to hide those that are not currently necessary. In this way, the most necessary navigation information for a certain period can be obtained.

Usually, the user chooses the type of information presented in a layered map, e.g. coordinates, roads, rivers, lakes, limits of countries and regions, landmarks, etc. In aeronautical charts, navigation zones can be displayed in addition to terrain features and navigation equipment: FIR, CTR, TMA, etc. A general view of such an aeronautical chart that was designed is provided in Fig. 21.
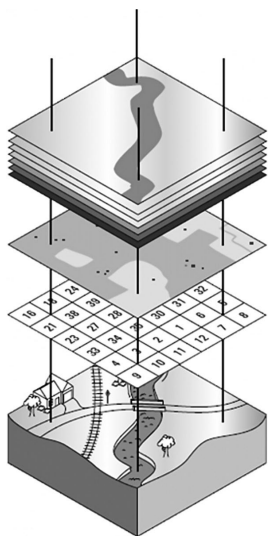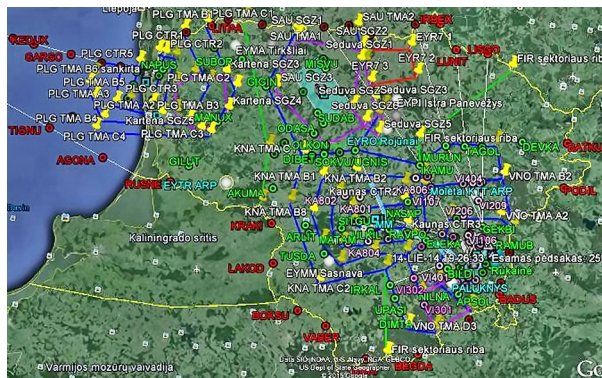
The advantages if such an interactive map in comparison with other maps are:

- the chart is not overcrowded with unnecessary information. The pilot-instructor can view the necessary and block the unnecessary information layers. So, a lot of information used for flight assessment can be included in one chart;
- all coordinates are linked not only to terrain features of the map, but also with high resolution satellite images of the map that can be accessed by the pilot-instructor (compare with the static aeronautical chart of Lithuania provided in Fig. 6);
- in addition to all the navigation elements included in the chart, pilot-student flight trajectories can be directly uploaded, compared and assessed according to terrain and additional elements;
- zoom in or out of the map functions without the loss of resolution are possible, in order to see the whole flight trajectory or a detailed view of some part of it;
- the pilot-instructor is able to view not only the flight trajectory, but also altitude and speed graphs for the student-pilot flight on one axis;
- it can be used to introduce pilot-students to the distribution of radionavigation equipment and its coverage within Lithuania (Fig. 22).

The location of radionavigation equipment (VOR, DME, TACAN, NDB, ILS) (Fig. 23) and their coverage zones (Fig. 22) were included in the interactive aeronautical chart of Lithuania in *Google Earth,* according to the information gathered from various documents providing the operational parameters for this equipment.

Google Earth software does not have a function for drawing circles. Therefore, for marking radionavigation equipment coverage zones a special *Free Map Tools* website was used (Free Map Tools 2015). After the input of appropriate coordinates and radius, it automatically

Fig. 20. Structure of a multi-layered map (McNamara 2008)

Fig. 21. General view of interactive aeronautical chart of Lithuania in *Google Earth* software
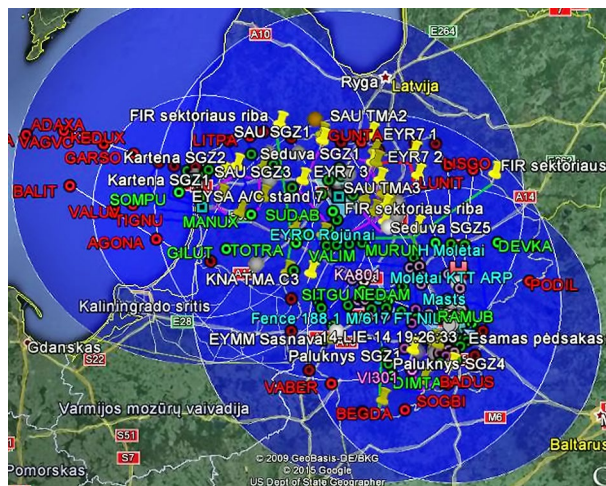

Fig. 22. Coverage zones of Lithuania's radionavigation equipment (blue circles)

creates a file, where the points of the circle are marked within similar distances from the designated coordinate.

While analysing flights near the runway at Kyviškės aerodrome, it was observed that real coordinates of Kyviškės runway (measured by a GPS) do not correspond exactly to *Google Earth's* coordinate system (have been shifted for safety). In order to accurately assess pilot-student flights near the runway, the real limits of the runway and taxiways are necessary. Using a GPS, the real limits of the runway, taxiways and parking areas of Kyviškės aerodrome were determined (Fig. 24).

It is evident from the measurement results (Fig. 25) that the real side boundary (western) of Kyviškės runway almost corresponds to the runway centreline in *Google Earth* map. It seems that the map is shifted to the side with regard to the runway by a distance of 11.5 m according to the following equation:

$$\frac{Runway\,width}{2} = \frac{23}{2} = 11.5 \text{ m.} \tag{2}$$

Runway parameters of Kyviškės aerodrome are: altitude above Mean Sea Level (MSL) is 152 m; direction – 13/31; length – 540 m; width – 23 m; paved with asphalt (Vikipedija 2016).

The black rectangle in Fig. 26 represents the real boundaries of the runway, so now the accurate and inaccurate take-offs and landings on the runway by pilots-student are more clearly seen. Pilot-student flight trajectories are marked in the illustration in blue.

Google Earth software allows to compare the flight trajectory with the terrain in 3D mode, by extending lines from the flight trajectory to the ground (Fig. 27). This provides a better visual picture of the trajectory for analysis.

In Fig. 28 airway entry and departure points are visible. Flight altitude and speed changes at a certain way point can be viewed as well. When the entry and departure points were not marked, it was not clear, why the pilot-student changed the flight altitude at certain points. However, after the inclusion of entry and departure points, as seen in Fig. 28, the pilot-student only changed the altitude at waypoint ELEKA. The flight was carried out along the same route both ways (to and back). In the altitude graph the arrows indicate a change in altitude over waypoint ELEKA. Flying towards Kaunas, over ELEKA the aircraft lowers its altitude (red arrow), while returning back to Vilnius, over ELEKA the aircraft increases the altitude (blue arrow). If there were no other waypoints with a planned altitude change, the ability of the pilot-student to maintain flight altitude could be assessed.

The blue dots in Fig. 29 indicate the holding areas of Kyviškės aerodrome. The Aerodrome Traffic Zone (ATZ) is indicated by yellow lines whereas the. TMA is indicated in red, the blue line corresponds to Vilnius International Airport CTR. This allows observing, how the pilot-student is able to circle in the holding area, whether performing the flight in TMA he does not enter the CTR, etc.

As seen in Fig. 30 the flight circuits do not correspond to each other. The greatest accuracy is reached near the runway boundary and when taking-off and landing. The flight circuit length also depends on the change in the number of aircraft in the pattern. If there are fewer planes in the circuit, it is not practical to fly a bigger circuit, which leads to higher fuel expenditures and a longer time to cover the circuit. Thus, during the flight, it is more important to manage as many take-offs and landings as possible. When the number of aircraft in the traffic circuit increases, the circuit must be widened to maintain a safe distance between aircraft.
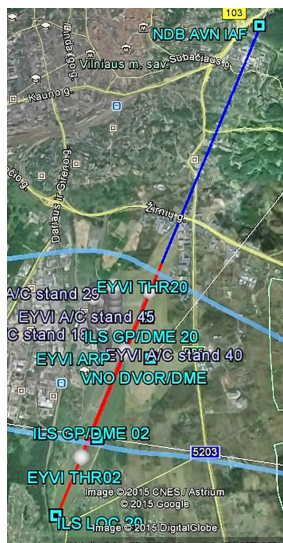

Fig. 23. Distribution of radionavigation equipment around Vilnius airport (VĮ Oro navigacija 2010)

Fig. 24. Mismatch of Kyviškės aerodrome coordinates between GNSS measurement and *Google Earth* software

Fig. 25. Mismatch of Kyviškės runway coordinates with *GPS* data

Fig. 26. Revised boundaries of Kyviškės runway (black rectangle) and student-pilot flight trajectories (blue)

Fig. 27. Circuit flight trajectory analysis near the runway with extended vertical lines

Fig. 28. Flight altitude assessment according to entry/departure points

Fig. 29. Holding areas of Kyviškės aerodrome and waypoints

In addition, *Google Earth* has a special function for measurements that allows approximately measuring the distances between objects or the flight trajectory. Fig. 30 shows a real pilot-student flight trajectory (wide blue line) and the trajectory between two waypoints that was given as a task (narrow white line). The pilot-instructor is able to measure the deviation from the task at any point in the flight trajectory using the measurement function in *Google Earth* (yellow line on the map; the distance is visible in the pop up window) and using this to assess the pilot-student's skills to maintain a given trajectory.

Despite all the advantages, *Google Earth* software also has some disadvantages for analysing circuit flights. Generally, approximately 1 hour is allocated to the student to perform circuit flights, during which it is possible to make 10 circuits. As seen in Fig. 31, the altitude and speed graphs are rather compressed, but *Google Earth* does not include a function for widening them. Therefore, in order to view a respective altitude or speed graph in detail, data on other circuits must be deleted from the recorded flight file.

The developed interactive aeronautical chart of Lithuania in *Google Earth* is an additional means for flight assessment for pilot-instructors. When assessing pilot-student flights, the pilot-instructor makes all

Fig. 30. *Google Earth* distance measurement function

Fig. 31. Circuit flight trajectory, and altitude and speed graphs

decisions himself. The map was demonstrated to pilot-instructors at Antanas Gustaitis Aviation Institute of the Vilnius Gediminas Technical University. They had the opportunity to get acquainted with the map and its functions, and have positively commented that this chart will allow making the pre-flight briefing of the task to the pilot-students and a post-flight briefing easier, especially when providing specific comments on the flight task. In addition, with the use of this chart, it will be possible to assess the operation of a developed automatic system for pilot flight assessment. The map could be used for real time flight monitoring on the ground, using GNSS and mobile internet technologies. The delay of the flight trajectory representation in the map will depend on the data rate and response time of the mobile internet. Real time data transfer possibilities have been discussed in more detail in the paper by Masiulionis and Jakučionis (2013).

For the development of the aeronautical chart, various documents were used: aeronautical chart of Lithuania, Lithuanian airspace chart (VĮ Oro navigacija 2015), and flight instructions of various Lithuania's airports and aerodromes.

Conclusions

1. During this study various flight analysis equipment was reviewed, and it was determined that they differ greatly in the functions that they provide concerning flight assessment possibilities. If all the possible functions used for flight data presentation could be consolidated into a single programme, a good tool for flight assessment could be developed.
2. The developed aeronautical chart was offered for the use of pilot-instructors at Antanas Gustaitis Aviation Institute of the Vilnius Gediminas Technical University and received positive comments. Previously, no similar flight data analysis means were used.
3. The aeronautical chart of Lithuania developed within *Google Earth* allows presenting flight data required for assessment faster and in various visual formats. The flight analysis is thus more detailed, than in cases when only an aeronautical chart is used. Earlier, separate flight instructions for different airports and aerodromes had to be used as well.
4. Nevertheless, the interactive aeronautical chart of Lithuania developed within *Google Earth* is not entirely without limitations. If State Enterprise 'Air Navigation' (*VĮ Oro navigacija*) would publish a new aeronautical chart with changes, they would have to be manually included in the interactive aeronautical chart.
5. The aeronautical chart of Lithuania developed within *Google Earth* will be used as an additional means for the assessment and development of an automatic pilot flight assessment system.

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