

¹Anna Polanecka

Determination of Laser Attack Risk Zones Under Aircraft Flight Path



Abstract: - This paper introduces a method of determination of zones around and beneath an aircraft's flight path where it is reasonable to believe that a laser attack would be successful, i.e. from where a laser beam pointed towards an aircraft can reach the eye of the pilot and lead to a potential safety risk. The method is based on the determination of lines of sight led from the ideal pilot eye position as recommended by the aircraft's manufacturer and a simplified model of aircraft windows derived from aircraft technical drawings published by the manufacturer. The paper demonstrates the change of the shape of these zones and the distance between the aircraft and the emitter as a function of the aircraft's pitch, allowing the zones to be adjusted according to the targeted area to be protected such as the final approach path or the intermediate approach segment. The use of such a method is demonstrated on a sample application of determination of such zones at 2500 ft above terrain, a height representing the transition from the intermediate approach segment to the final approach descent.

Keywords: Aircraft footprint, flight path, laser attack, laser risk zones.

I. INTRODUCTION

Laser attacks on aircraft are a serious hazard to air operations safety and pilot's health. When the human eye is struck by a laser beam, the consequences may range from temporary dazzling to permanent damage to or loss of sight, depending on the power of the used laser and the distance between the emitter and the target. However, in the context of air operations, even the temporary effects are potentially fatal if a pilot becomes disoriented or unable to properly see flight instruments, even for a short time.

The increasing number of laser attack safety reports in air operations indicates that measures to control the distribution of powerful laser devices and mandatory warnings displayed on the packaging or in user's manuals are effective only to a limited extent and people use such devices to target aircraft in flight. While some research focuses on the development of a mitigation strategy in form of windscreen or eyewear filters to limit the dazzling and harmful effects of the attack once it has happened, a preventive approach calls for the reduction of laser attacks as such, primarily by making them prosecutable. Although endangering the safety of an aircraft is a criminal offence in most countries, the identification of attackers and the collection of evidence against them is very difficult.

Project APALER aims at developing a method of reliable and precise detection of the location of a laser beam source using optical equipment and advanced algorithms to determine the position of the source. One key aspect of the project is to be able to define an area to be monitored by the equipment so that resources can be concentrated to a territory where the probability of an attack is highest. Flight paths of aircraft subject to laser attacks can be determined from surveillance data acquired from Automatic Dependent Surveillance – Broadcast (ADS-B). An analysis of such reports has shown that aircraft in the vicinity of an airport, and in particular those on the final approach track to a runway are targeted more frequently than aircraft in cruise flight. From the design of an aircraft and the layout of cockpit windows, it is obvious that there is a limited area from which an aircraft can be targeted, relative to its flight path, because the beam has to pass through the window at an angle capable of hitting the pilot's eye. This paper discusses a method of determining an aircraft's footprint on the ground, i.e. those places on the ground from which a laser attack will not pose a hazard to the flight, in order to define a useful area of operation of the laser source detection equipment.

¹ Department of Air Transport, Faculty of Transportation, Czech Technical University in Prague

polanann@fd.cvut.cz

Copyright © JES 2024 on-line : journal.esrgroups.org

II. METHODOLOGY

Previous stages of the project identified increased occurrence of laser attacks at low altitudes in the approach phase [1].

The area from which a potentially dangerous laser beam can be emitted depends on two principal factors. The first one is the size and shape of the cockpit windows in combination with the seating position of the pilot, which in turn affects the position of the eye with respect to the windows, i.e. the geometry of the cockpit. The second one is a combination of the power of the transmitting device and the distance of the aircraft from the laser source, which determines to what extent the emitted light will be dangerous or dazzling. Therefore, it is necessary to determine areas of potential laser sources and their distance from the aircraft to assess the harmfulness of the beam emitted from there.

A. Aircraft footprint

Aircraft certification specifications such as the European CS 25 for large aeroplanes do not prescribe any minimum or maximum angles of view from the cockpit. They only prescribe sufficiently extensive, clear, and undistorted view to safely manoeuvre the aircraft [2], and the primary concern is not to obstruct the view from the cockpit outside, as opposed to the inherent requirement for protection from laser attacks to actually minimize the view or the size of the windows. As a consequence of this lack of specific window dimensions or angles of view, aircraft design regulations could not be used to determine what part of ground can be seen from the cockpit, and, in the opposite direction, from where the pilot's eye can be hit by a laser beam. It was therefore necessary to develop a mathematical model of the aircraft's footprint, or an area obstructed by the aircraft's fuselage, which is invisible from the cockpit and where a perpetrator is unlikely to endanger the aircraft from. This area could subsequently be excluded from the coverage of the laser detection system. The determination of the footprint was based on a drawing of a Boeing 737-800, however, the same method can be applied to any aircraft provided its drawing is available. Boeing releases 2D drawings of all of its currently operating models for airport planning purposes [3]. These drawings contain front, side and planar views of the aircraft including principal dimensions such as fuselage length, aircraft height or wing span. From there, the dimensions and the position of the cockpit windows was measured.

To determine the position, an origin had to be selected for the reference system to be further used in the calculations. As the ultimate goal of the measurement was to determine the footprint of the aircraft relative to its flight path, a single point representing the aircraft's position had to be chosen. The aircraft's altitude is derived from the pitot-static system. The static ports are, for most aircraft, located on both front sides of the fuselage approximately below or slightly behind the cockpit windows. However, the altitude data are only used to determine the vertical position of the aircraft before intercepting the final approach segment, after which the altitude of the aircraft is governed by the glide slope, provided an instrument landing system is available at the airport. During other types of approaches, the vertical position could be derived from the barometric altimeter or from global navigation satellite system (GNSS) vertical data depending on the type of approach. The glide slope antenna is usually located in the radome, i.e. the nose of the aircraft. The GNSS antennas are usually located on the upper fuselage or tail. As a consequence, the aircraft's vertical position is actually determined with respect to a number of different locations on the fuselage and it changes during different phases of flight. To create a model generally useable for airport planners without the need to consider specific aircraft types and the phase of flight, the forwardmost point of the nose of the aircraft was selected as the origin of the reference system, and the position of the aircraft consisting of the recorded 2D flight path and altitude is considered to be associated with this point in this model.

AutoCAD software was used to determine the positions of the points of interest for this method. There are generally two possible methods of determining the position of various points in the drawing from the selected origin of the reference system. The MEASURE command can be used to measure the slant, vertical and horizontal distance between any two points. If the first point is the selected origin (nose of the aircraft), the relative

coordinates of the other points can be read off directly. The ID POINT command can be used to read off the coordinates of any selected point directly, however, with reference to the origin of the drawing instead of the nose of the aircraft. This command was used due to need to select only one point rather than two for each measurement. The coordinates of each measured point with reference to the nose were then calculated using (1) and (2).

$$x_P = x_{P0} - x_{N0} \quad (1)$$

$$y_P = y_{P0} - y_{N0} \quad (2)$$

Where:

x_P, y_P are the x- and y-coordinates of point P with respect to the aircraft origin (nose);

x_{P0}, y_{P0} are the x- and y-coordinates of point P with respect to the drawing origin; and

x_{N0}, y_{N0} are the x- and y-coordinates of the aircraft nose N with respect to the drawing origin in the side view.

To obtain z-coordinates, the planar view was used, z-coordinates of the real aircraft being y-coordinates of the drawing. The drawings were in 1:1 scale in inches, therefore the values obtained from (1) and (2) were converted to cm using the factor of 1 inch equaling 2.54 cm.

This established an aircraft reference system with the x-axis being defined from the origin at the tip of the radome along the fuselage, y-axis from the origin upwards and z-axis from the origin to the left side of the fuselage.

The windows of the aircraft are generally of irregular shape. In the examined Boeing 737-800, their sides were straight, i.e. could be described with a straight line, however, the corners were rounded and of irregular shape. For the purpose of this model, the window corners were replaced with single points made of intersections of the lines forming their sides. In all cases, the points representative of the model windows penetrated further in the solid and obstructive structure of the aircraft than the actual window, slightly increasing the angles from which a laser beam could penetrate the cockpit.

To determine the position of the pilot's eye, the drawing of the ideal seating position as published by the aircraft manufacturer in the flight crew operating manual [4] was used. The relative position of the ideal eye was measured with reference to the windows illustrated in the same picture and then converted into the aircraft reference system with respect to the nose using (3) and (4).

$$x_E = \frac{2.54 \times d_{W0}}{d_{We}} \times (x_{Ee} - x_{We}) + x_W \quad (3)$$

$$y_E = \frac{2.54 \times d_{W0}}{d_{We}} \times (y_{Ee} - y_{We}) + y_W \quad (4)$$

Where:

x_E, y_E are the calculated coordinates of the eye in the aircraft's reference system;

d_{W0} is the change of x-coordinates between the side window's forward upper corner and the aft upper corner in the side view of the manufacturer's drawing;

d_{We} is the change of x-coordinates between the same window corners in the ideal eye position diagram;

x_{Ee} , y_{Ee} are the coordinates of the eye measured as the intersection of the upper and lower sight lines in the diagram;

x_{We} , y_{We} are the coordinates of the forward upper corner of the side window in the eye diagram; and

x_W , y_W are the coordinates of the forward upper corner of the side window in the aircraft reference system.

To calculate the z-coordinate of the eye position, the centre of the pilot seat in a planar view of the cockpit and cabin taken from the flight crew operations manual's emergency equipment layout [4] was measured with reference to the centre of the fuselage, and scaled using the ratio of the fuselage width in the original manufacturer's drawing and the cabin an cockpit drawing measured in the same place along the fuselage (at the leading edge) using (5).

$$z_E = 2.54 \times \frac{w_{F0}}{w_{Fc}} \times |y_{Sc} - y_{Cc}| \quad (5)$$

Where:

z_E is the z-coordinate of the eye in the aircraft reference system;

w_{F0} is the width of the fuselage in the manufacturer's drawing;

w_{Fc} is the width of the fuselage in the cockpit and cabin layout drawing;

y_{Sc} is the y-coordinate of the seat centre position in the cockpit and cabin layout drawing; and

y_{Cc} is the y-coordinate of the centre of the fuselage in the cockpit and cabin layout drawing.

Cockpit windows typically reach beyond the position of the pilot seat. Furthermore, it was assumed that during the flight, the pilot monitors instruments, therefore the angle from which a laser beam can usually hit the eye is further restricted by the normal peripheral vision. A commonly used field of peripheral vision is 100° either side from the centre of the face [5]. The planar view, i.e. the windows' and pilot eye's x- and z-coordinates were used to calculate the intersection of the peripheral vision limit with the lower window side to determine the aftmost point from which a laser beam would be perceivable by the pilot. The line passing through the pilot's eye position can be described with (6).

$$x = \tan \beta \times z + x_{E0} \quad (6)$$

Where:

β is the angle of the peripheral vision beyond 90° (i.e. beyond the direction of the z-axis measured at the position of the eye); and

x_{E0} is a point where the line passing through the pilot's eye at angle β intersects the x-axis, i.e. the centreline of the fuselage.

Similarly, a two-dimensional representation of any window side in the planar view can be described with (7) using the measured coordinates of its respective forward and aft corners 1 and 2.

$$x = \frac{x_{W1} - x_{W2}}{z_{W1} - z_{W2}} \times z + x_{W0} \quad (7)$$

Where:

x_{W1} , x_{W2} , z_{W1} , z_{W2} are the respective coordinates of corners 1 and 2 of a window side; and

x_{W0} is the x-coordinate of the point where the line of the window side would theoretically intersect the aircraft's x-axis.

As (7) is only defined on an interval bound by the measured window corners, line (6) intersects only one window, in the case of the examined Boeing 737-800 only the forward side window and determines the most rearward angle from which a laser beam can hit the eye.

The purpose of the aircraft footprint is to determine areas on the ground obscured by the fuselage. Therefore, the lower window sides are a limiting factor. In this model, they are approximated by line segments, and, correspondingly, their projection from a single point in the ideal pilot's eye onto the ground will be linear. Therefore, the footprint can be best described by a set of lines of sight from the pilot's eye through each of the lower corners of the windows. The coordinates of the eye and the coordinates of each of the corners of the windows from the front one rearward up to the coordinates of the point limited by peripheral vision including this point were used to calculate parameters l , m and n of a general line (8) representing the reciprocal of a harmful laser beam, i.e. a line of sight from the eye through the window corner or the point limited by peripheral vision down from the aircraft onto the ground.

$$\frac{x - x_E}{l} = \frac{y - y_E}{m} = \frac{z - z_E}{n} \quad (8)$$

In (8), if the y-coordinate is selected to be the distance below the aircraft, i.e. the negative value of the aircraft's height above terrain, the z-coordinate is the minimum lateral distance from the aircraft at which a laser beam can be shone through one of the windows and the x-coordinate is the place in front of the aircraft's position from which the laser would hit the pilot's eye.

B. Aircraft Rotation

The above presented relationships were derived from a technical drawing in which the x-axis was selected parallel to the lower side of the aircraft's fuselage, i.e. zero pitch. However, an aircraft in flight is pitched up, and it rotates about its centre of gravity (CG). The vertical position of the centre of gravity, i.e. its y-coordinate, is not normally measured or calculated and is not limited by the manufacturer because the design of the aircraft and the location of cargo and passenger compartments assures that the aircraft will not be unstable about its longitudinal axis. As this value could not be determined, the y-coordinate of the CG was arbitrarily assigned to be 0 for simplification of the model.

The lateral position, i.e. the z-coordinate of the CG, was also assigned a value of 0. Although it is commonly determined for helicopters, airplanes are not laterally limited because, as in the case of the vertical position, the layout of the fuselage ensures that variable load is concentrated near the centre of the fuselage and the wings and the possible fuel contained within is, under normal circumstances, symmetrical about the longitudinal axis.

Therefore, the only variable coordinate of the CG is the x-coordinate. The model assumes that all aircraft in flight are within their CG limits, so the forward and aft limits as published in the airplane flight manual [6] were used to define the point about which the airplane is rotated.

The pitch of an aircraft depends on the flight phase, i.e. whether the aircraft is flying horizontal, climbing or descending, its mass, its speed and configuration of lift devices. Thus, it is variable even during one phase of flight, such as in the intermediate approach when the aircraft may be maintaining a single altitude, but the speed is reduced, and configuration changes take place. Pitch values recommended by the manufacturer for flight with

unreliable airspeed, i.e. a situation when the pilot cannot control the aircraft using the speed indicator and uses a pre-defined combinations of power or thrust and pitch setting, were used to approximate the typical angles during terminal area operations at 5000 ft with flaps 1, 5 and 15 and during final approach with flaps 15 and 30. The respective pitch attitudes varied between 0.5 and 6.5° [7] for the Boeing 737-800, but the recommended flap settings and pitch attitudes may differ for other aircraft types.

The aircraft's rotation changes the position of the aircraft's reference system with respect to the ground. While in the initial model, the aircraft's x-axis was parallel to the bottom of the fuselage of an aircraft stationary on the ground and the y-axis was thus vertical to the ground, only the z-axis remains parallel to the ground when the aircraft is pitched up. It is therefore necessary to develop a transformation of the rotated aircraft coordinate system in the ground reference system. In this model, coordinates of the measured points were transformed from cartesian to polar ones, the rotation was applied and the transformation between the two coordinate systems was reversed to obtain the cartesian coordinates of the rotated points with respect to the original reference system with the x-axis being parallel to the ground and the y-axis being vertical. After that, the parameters of line (8) were calculated to determine the footprint as a function of height for the various pitch attitudes.

C. Distance from Aircraft

The effects of a laser of a particular transmitting power depend on the distance between the emitter and the eye. The further the eye is, the more dispersed the transmitted energy is and therefore the damage to the eye is lower. At a certain distance, the laser is not harmful anymore. However, it may still be dangerous to air traffic as it is perceived as a very bright, dazzling light. At a greater distance, it becomes a bright light, but does not cause any problems to the pilot. For a green-coloured laser of a given power, the distance has to increase approximately 4.5 times to change from the Nominal Ocular Hazard Distance, at which the laser causes permanent damage, to the Sensitive Zone Exposure Distance where a person may feel flash-blinded. Another increase in distance by a factor of approximately 4.5 results in the observer being in the Critical Zone Exposure Distance at which glare may still influence pilot's ability to correctly read instruments and control the aircraft, and another increase by a factor of 10 results in the laser light appearing only as a bright light with no adverse effects [1].

Therefore, the dimensions of the footprint on the ground must be evaluated together with the distance between the possible source of the laser and the aircraft. Considering the aircraft's nose as its reported position and at the same time the origin of the reference system, the distance of a point on the ground from the eye can be determined by (9).

$$d_L = \sqrt{(x_L - x_E)^2 + (y_L - y_E)^2 + (z_L - z_E)^2} \quad (9)$$

Where:

d_L is the distance between the laser and the aircraft's position; and

x_L, y_L, z_L are the coordinates of a selected point on the ground.

D. Maximum Limits of Risk Zone

The footprint of the aircraft determines the zone that does not have to be monitored because the pilot's sight is protected by the fuselage of the aircraft. The maximum distance from which the aircraft can be targeted is theoretically the tangent to the Earth's surface from the position of the aircraft. However, this model assumes that such a distance would generally require a very powerful laser, the sale of which is regulated and the size of which makes it difficult to move or manipulate to place it in a location close to the flight path and to point it to the aircraft. Therefore, the practical maximum limit has been arbitrarily decided to be that at which the slant range

increases 45 times – modelling a distance at which a laser just at the higher limit of the Sensitive Zone Exposure becomes a laser at the Risk-Free Exposure Distance. To increase the slant distance 45 times at a given aircraft height, the angle of the eye-to-ground line of sight measured from the y-axis, γ , has to be increased as given by (10).

$$\gamma_{max} = \cos^{-1} \frac{\cos \gamma_{min}}{45} \tag{10}$$

Alternatively, if a smaller monitored area is desired, e.g. due to economic reasons, the factor can be decreased, for example, to 10 to represent the change in distance from the Critical Zone Exposure Distance to the Risk-Free Zone distance.

III. RESULTS

A sample footprint for an aircraft at 2500 ft above the ground, which approximates the final approach fix or point at which the aircraft typically transitions from level flight to descent has been calculated using the above-described method. Table 1 summarizes the lateral (z) and forward (x) distances of the footprint lines and the respective slant distance (d) between the point of intersection with the ground and the pilot eye in metres for a Boeing 737-800 for selected pitch angles of 0.5° (flaps 30, descent, light mass), 2.5° (flaps 15, descent, heavy mass) and 6° (flap 1 or 5, level flight, medium to heavy mass). Negative values indicate a position in front of the aircraft or on the right side of the aircraft.

TABLE I – MINIMUM RISK ZONE DISTANCES FROM AIRCRAFT POSITION

x – meters			
Pitch	0.5°	2.5°	6.0°
Windscreen, right corner	-2956	-3450	-4834
Windscreen, left corner	-1446	-1577	-1859
Forward side window, forward corner	-1214	-1314	-1521
Aft limit of peripheral view	207	232	250
z – meters			
Windscreen, right corner	-1498	-1733	-2401
Windscreen, left corner	892	956	1096
Forward side window, forward corner	1045	1107	1239
Aft limit of peripheral view	1051	876	679
d min – metres			
Windscreen, right corner	3317	3864	5401
Windscreen, left corner	1701	1847	2161
Forward side window, forward corner	1604	1720	1964
Aft limit of peripheral vision	1071	905	723

Table 1 shows that the forward corner of the forward side window is, for any pitch, critical in determining the smallest footprint and hence the largest exposure area in front of the aircraft, while outward corner of the windscreen (i.e. the left corner for the left windscreen) is critical in determining the smallest footprint laterally from the flight path. The shortest distance between the emitter and the eye leading to the highest level of laser beam power and most harmful effects can be achieved from behind through the peripheral vision.

The effect of pitch is favourable for the forward footprint limits, increasing the obscured area and slant range for the forward window and the forward corner of the side window, but it is negative for the aft limit of the peripheral vision.

Table 2 shows the maximum lateral limit of the monitored laser-risk zone derived from the minimum limit (aft limit of peripheral vision) for the various pitch angles.

TABLE II - MAXIMUM RISK ZONE DISTANCE FROM AIRCRAFT POSITION

x max – meters			
Pitch	0.5	2.5°	6.0°
Aft limit of peripheral vision	47300	41131	30569

IV. DISCUSSION

The footprint was determined for a stationary aircraft at a single point. Assuming a continuous movement towards the runway, any point forward of the aircraft's position until landing will become obscured by the fuselage at a later stage. While it is not excluded that an attacker would be standing below the flight path, the relatively fast movement of the aircraft towards him or her provides only a limited time of aiming the laser at the aircraft and actually hitting it. On the other hand, an attacker standing sideways of the flight path experiences a comparatively slower movement and a larger time during which the aircraft is close enough to be visible, targetable and during which the laser is potentially dangerous. Therefore, the lowest lateral limit of the aft peripheral view at the largest expected pitch angle outlines the zone around the flight path where visual detection of perpetrators is expected to be most effective. The outmost lateral limit is determined above all by the power of the laser at which it becomes harmless. An analysis of aircraft occurrences [1] did not reveal any damage to the health of the pilot, therefore it is assumed that all occurrences were at the Sensitive Zone Exposure or Critical Zone Exposure level. Provided that the most critical attack happened just at the minimum lateral distance from the aircraft's flight path, the zone within which the laser can still retain its dazzling or glare-causing properties can be up to 47300 m from the flight path for the lowest modelled pitch. At that distance, the laser appears only as a bright light and will likely not be considered a laser attack by the pilot. Such a large area is currently out of the scope of the project, monitoring it would require significant resources consisting of a large number of detection devices (cameras), image processing capacity as well as manpower ensuring response to the detected laser emissions.

V. LIMITATIONS

The current model has been tested using the data of the Boeing 737-800 as one of the commonly used types. While Airbus, the other major aircraft manufacturer, provides equivalent data, it has not been verified that similar aircraft data can be obtained for less common types or general aviation aircraft, limiting the use of the model to larger airports.

The view out of the aircraft windows is based on simplified quadrilateral window shapes giving a slightly larger window opening compared to the actual aircraft. The substitution of a single window corner point with the actual curved profile would increase the precision of the model, but it would lead to an increased processing time, making it impractical to calculate the footprints of multiple aircraft types for a given airport.

It must be recognized that this model is based on a single pilot eye position based on the ideal or recommended position by the manufacturer. Actual seating positions of pilots may differ. They might not always look straight ahead, for example when viewing a window-mounted electronic flight bag device, therefore they may occasionally be targeted by a beam that is emitted from the area covered by the aircraft's footprint or from an angle behind the normal peripheral vision.

REFERENCES

- [1] A. Polanecka and J. Hospodka, "Analysis of Reported Aviation Safety Occurrences Related to Laser Attacks," 2022 New Trends in Civil Aviation (NTCA), 2022.
- [2] European Union Aviation Safety Agency, "CS-25 Initial Issue," EASA. [Online] 10 2018. [Cited: 20 09 2023.] <https://www.easa.europa.eu/en/document-library/certification-specifications/cs-25-initial-issue>.
- [3] Boeing, "Airport Operations," [Online] 1995-2023. [Cited: 24 09 2023.] https://www.boeing.com/commercial/airports/3_view.page.
- [4] Boeing Commercial Airplane Group, "Flight Crew Operations Manual Boeing 737-600/700/800," The Boeing Company, 2018.
- [5] H. K. Walker, W. D. Hall and J. W. Hurst, "Clinical Methods: The History, Physical, and Laboratory Examinations," Boston, Butterworth-Heinemann, 1990. 978-0409900774.
- [6] Boeing Commercial Airplane Group, "737-800 Airplane Flight Manual," The Boeing Company, 2010.
- [7] Boeing Commercial Airplane Group, "737 Quick Reference Handbook," The Boeing Company, 2015.

ACKNOWLEDGMENT

This research was supported by TAČR DOPRAVA 2020+ CK 3000036 "Ochrana letectví před nízkooenergetickými lasery" APALER.

AUTHORS PROFILE



Anna Polanecka is an assistant lecturer at the Department of Air Transport at the Faculty of Transportation of the Czech Technical University in Prague. She obtained her master's and Ph.D. degree at this university and since then she has been teaching aviation subjects, specializing in the education of future professional pilots, among all performance, mass and balance and more recently flight planning. As part of her doctoral degree, she did research on fuel savings and environmental aspects of continuous descent approach operations, proposing higher than standard final approach descent angles for aircraft with favourable drag characteristics to sustain a steeper descent. She also contributed to a proposal of changes to the requirements on theoretical pilot instruction in the area of global navigation satellite system operations. Among her more recent research is a project dedicated to the analysis of safety reports related to laser attacks on aircraft and the development of a detection method of laser beams to effectively monitor areas susceptible to these occurrences. Ms Polanecka is also an active professional pilot and has extensive work experience in aviation safety and compliance management, having worked in related positions in a major airline, for a national aviation authority and at various flights schools.