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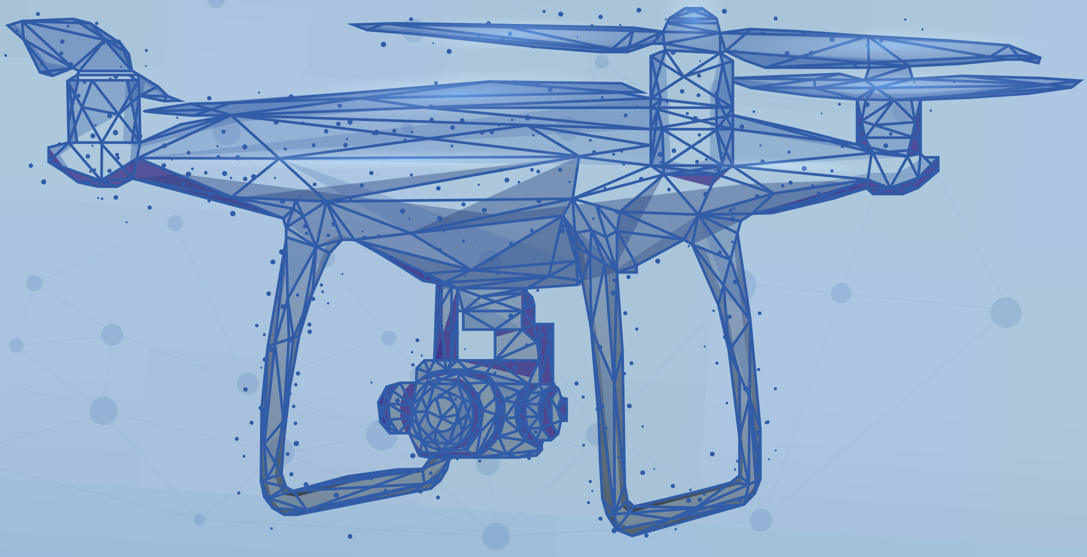

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Research Article

Air Quality Studies at Ukrainian Airports

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Abstract

Sustainability of aviation must be provided to limit the harmful influence and protect public health and the environment. As a rule, national and international regulations aim to reduce ambient air pollution from the aviation sector. Ukraine and other countries have historically adopted international regulations concerning air quality to protect public health and the natural environment. Local regulations also regulate it. However, these documents cover mainly stationary emission sources. In contrast, mobile sources, especially aircraft, are not considered, although, unlike most transportation modes, aircraft travel great distances at various altitudes, generating emissions that potentially impact air quality. This paper was aimed to study the principles and methods to monitor air pollution from aircraft engines at main airports of Europe, North America, and Asia. Based on measurement campaign analysis at some airports of the world and modelling results by complex model PolEmiCa (Pollution and Emission Calculation), the method and technical characteristics for measurement system detect the aircraft engine emissions. The developed practical recommendations were realised at Ukrainian airports and used for validation of model PolEmiCa. Thus, the modelling results for each engine are in good agreement with the results of measurements by the AC32M Nitrogen Oxides (NO_X) analyser system due to considering the jet and plume-regime during an experimental investigation at Boryspol airport. Analysis of measured instantaneous concentration demonstrates a high correlation with the runway movements and take-off at Zhulyany airport.

Keywords

Aircraft engine emission
Air pollution
Local air quality
Monitoring of air pollution
Emission index

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1. Introduction

The Advisory Council for Aeronautics Research in Europe (ACARE) goals intend that in 2050 technologies and procedures available allow a 75% reduction in carbon dioxide (CO_2) emissions per passenger-kilometre and a 90% reduction in NO_X emissions. In addition, the perceived noise emission of flying aircraft is reduced by 65%. These are relative to the capabilities of typical new aircraft in 2000 (ACARE Goals, 2008).

The number of flights has increased by 8% between 2014 and 2017 and is forecast to grow by a further 42% between 2017 and 2040. As a result, the carbon monoxide emissions (CO) and NO_X are predicted to increase by at least 21% and 16 %. At 2040 by the European Aviation Safety Agency figures (EASA, 2019). According to the State Aviation Service of Ukraine, the total passenger traffic of Ukrainian airports in 2018 increased by 25% compared to 2017. Consequently, the future growth in

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the European aviation sector will be inextricably linked to its environmental sustainability.

Aviation must be environmentally sustainable, operating harmoniously within the constraints imposed by the need for clean air and water, limited noise impacts, and climate change, as Federal Aviation Authority declares (FAA, 2015). Air transport is committed to meeting its responsibilities for sustainable development, maximising its support for economic development, reducing its impact on the environment, and consolidating its social benefits. International Civil Aviation Organisation (ICAO) policies implement environmental policy within the two separate parts at least –globally as climate change and - locally as general provisions, noise, and local air quality. In a subject of climate change control, the recorded total CO_2 aviation emissions are approximately 2% of the global greenhouse gas (GHG) emissions (international aviation accounts for about 1.3% of total global CO_2 emissions) with an expected growth of around 3-4% per year due to traffic and proper fuel consumption growth (ICAO, 2015). There are many studies that also emphasise incredibly high concentrations of toxic compounds, including NO_X, particulate matter (PM), unburned hydrocarbons (UHC), the volatile organic compound (VOC) and CO due to airport-related emissions and their significant impact on the air quality and sufficient contribution to the public health concerns within neighbouring. Some of these primary pollutants undergo chemical and physical transformations in the atmosphere, producing other pollutants such as secondary PM and O_3. Additionally, NO_X and fine PM emissions from aircraft engine emissions can be initiators of photochemical smog and regional haze, directly impacting human health.

The problem of local/regional air pollution of airports is crucial for Ukraine in the increase of air traffic and the trend of approximation of residential areas to airports (for airports Boryspyl, Kyiv (Zhulyany), Lviv, Odessa, Kharkiv, Zaporizhzhia). By 2035, in the absence of constant efforts, it is expected that Ukrainian airports will meet environmental restrictions on the growth of air traffic. Air quality degradation in the locality of airports poses a public health hazard. The ability to quantitatively predict airport operations' air quality impacts is important for assessing airports' air quality and public health impacts today, of future developments, and for evaluating approaches for mitigating these impacts.

Criteria of civil aviation impact on air quality are determined by the requirements and recommendations of the national legislative framework (Ministry of Health of Ukraine, 2019; Air Code of Ukraine, 2011) EU requirements (art.137, 138 of Ukraine-EU Association Agreement), ICAO norms (ICAO, 1993; ICAO, 2011; ICAO, 2002).

Aircraft emissions and air pollution levels in the vicinity of the airport can be assessed through the organisation of permanent ambient air monitoring or computer modelling (or a combination of both for increased accuracy). ICAO's Airport Air Quality Guidance Manual contains advice for the assessment of airport-related air quality (ICAO, 2011).

2. Method

2.1. Monitoring of Airport Air Pollution

The national legislative framework does not include any norms and methods for monitoring air pollution at the civil airport in Ukraine. Nevertheless, the participation of Ukraine at the EU association supposes harmonisation of existing and implementation of new normative for environmental regulation. So, the overview of methods and basic principles was conducted to monitor air pollution at main airports of the world to accumulate best practices in this field.

Thus, permanent monitoring of aircraft engine emissions is realised John Kennedy Airport (Herndon, 2008). Spectrometry methods are used to detect the instantaneous concentration of NO_X and CO_2 in the plume from aircraft engines during both idle and take-off conditions. Thus, Tuneable Diode Laser Differential Absorption Spectroscopy (TILDAS) was used to measure NO_X and the non-dispersive infrared absorption method (LICOR). The monitoring station is positioned close to the in-use taxiway (within 300m) and the runway due to the prevailing wind. During take-off, the wind carried exhaust plumes from aircraft to the monitoring station when the aircraft had travelled approximately 300 m or the first tenth of the runway distance. Determination of NO_X concentration in aircraft emissions is based on the clear correlations between peak NO_X concentrations and aircraft's movements (Herndon, 2008).

Analysing continuous values of measured concentrations and aircraft movements, it was discovered that peaks of NO_X concentrations are correlated with aircraft take-offs at the runway, minimum values of NO_X concentrations and peaks of CO_2 concentrations have observed during aircraft taxing (fig.1).

A permanent monitoring of the extended list of the contaminants (NO_X, CO and CO_2, UHC, PM, and soot) in aircraft engine exhausts were conducted at Harts-Field-Jackson Atlanta International Airport (Herndon, 2008b). Most of the sampled plumes by TILDAS and LICOR methods during this measurement campaign were emitted from engines at maximum (take-off activity) and idle operation modes (taxing activity). The monitoring station is positioned close to the in-use taxiway (within 216 m) and the runway due to the prevailing wind.

Results of routine measurement highlight correlations between peak measured concentrations and aircraft's operation modes. The plot also expresses dependence emission index of PM on aircraft engine mode and ant correlation with black carbon emissions. So, PM emission is more significant at idle operation mode and minimum – at full operation mode. Opposite dependence is observed for black carbon.

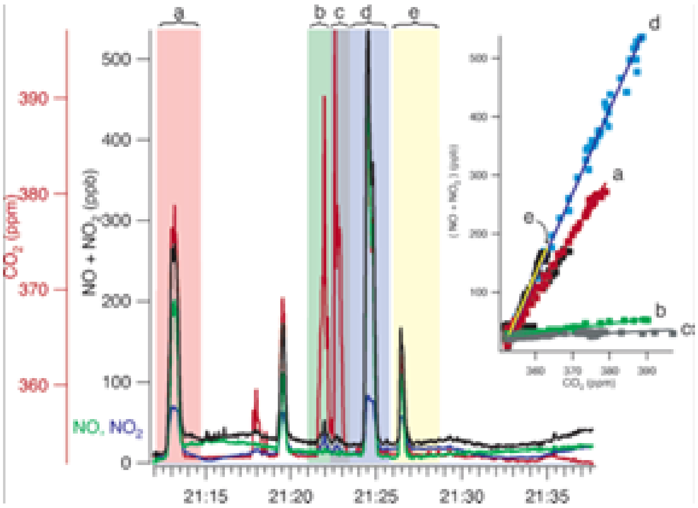


Fig. 1. Results of routine measurements of NO_X and CO_2 in aircraft engine exhaust emissions by TILDAS method (a, d, e correspond to aircraft take-off; b and c to aircraft taxi).

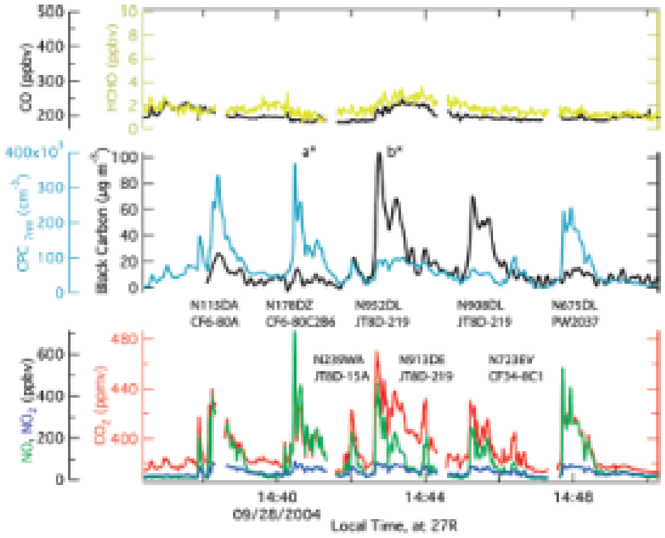
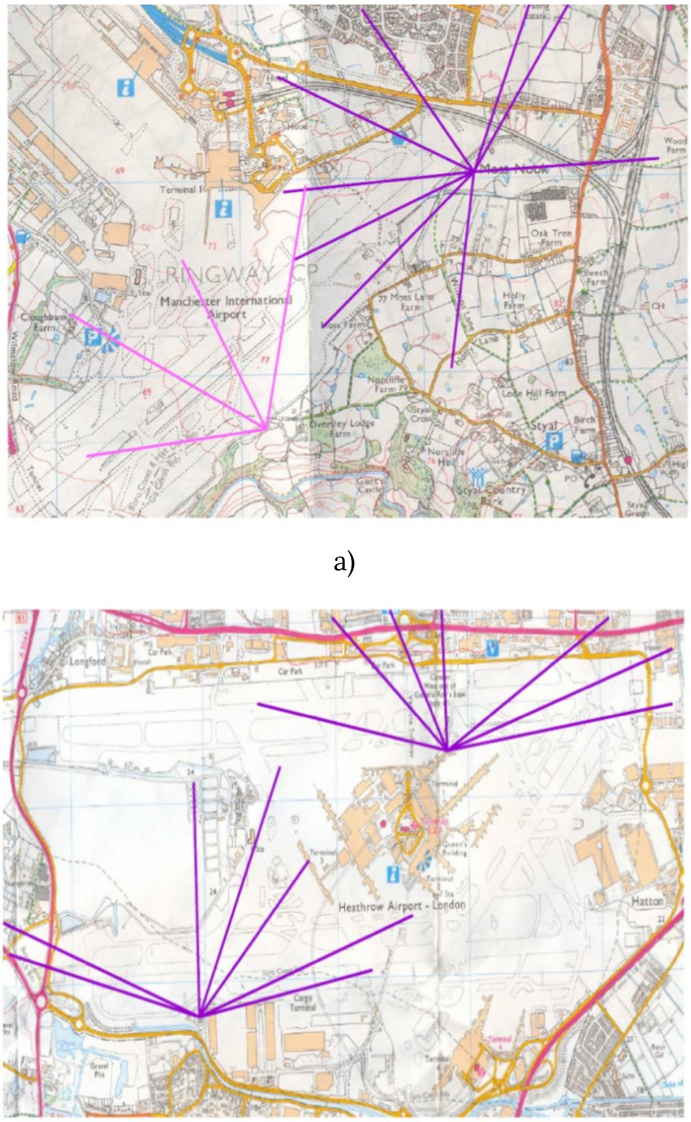


Fig. 2. Time series results of concentration measurements of NO_X, CO, CO_2, PM and soot in sampled plumes from 8 aircraft engines (CF6, CF-34, JT8D-19, PW-2037)

Permanent monitoring of air pollution during take-off and landing aircraft activities is implemented by LIDAR (Light Detection and Ranging) system at Manchester and Heathrow airports (Graham, 2008). This system operates in the optical spectral range, where intense laser pulses interact with particles and molecules of the atmosphere. From the backscattered intensity and travel time, LIDAR provides detailed information on aerosols and clouds, water vapour, atmospheric trace gases, and wind speed and direction can be directly obtained with high spatial and temporal resolution.

LIDAR scanning directions of air contamination producing by aircraft engine emissions inside Manchester and Heathrow airports are shown on fig.3, and 4. (Graham, 2008; Wayson, 2002) Results of LIDAR measurements allow to investigate aircraft plume behaviour (fig. 4), namely height plume rise and plume standard deviations. This data set provides accurate initial data for modelling systems of air pollution produced by aircraft engine activities. Participation of Ukraine at EU association supposes harmonisation of existing and implementation of new normative for regulation of civil aviation.



a)

b)

Fig.3. Scheme of scanning directions of Manchester (a) and Heathrow (b) Airport by LIDAR

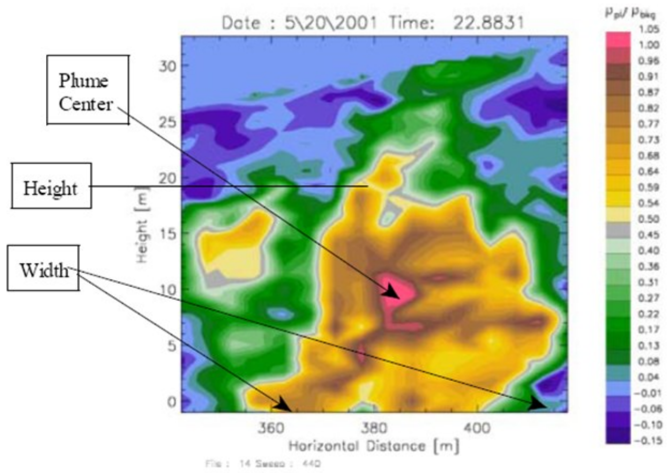


Fig.4. Example of computer enhanced LIDAR image

Most countries in Asia and the Pacific do not have air monitoring systems at airports at all. The only document that allows estimating emissions from sources of pollution is the inventory of emission sources required per ICAO policies. As instrumental monitoring is advisory, most airports ignore this issue (IQ Air, 2018). In 2018 in Southeast Asia, Jakarta registered the most polluted air in the sub-region last year. However, there are no real-time data from monitoring posts in the city. In contrast, at the Soekarno Hatta Airport, which serves Jakarta and the neighbouring cities, there are no monitoring posts.

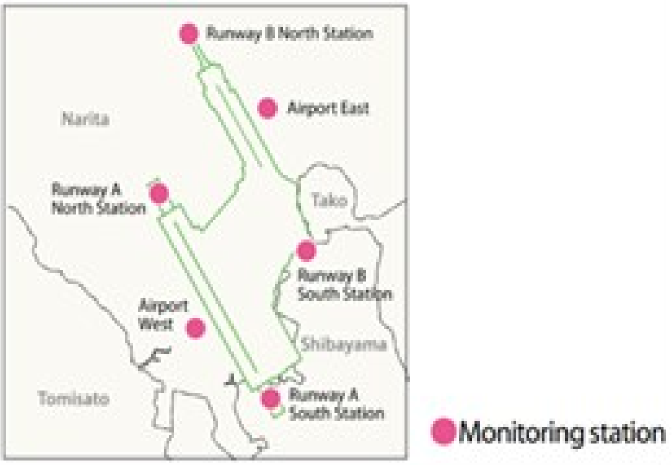


Fig.5. Scheme of monitoring sites within Tokyo Narita International Airport and the adjacent territories.

One of the most progressive airports in Asia is Tokyo Narita International Airport. To monitor the quality of the air, the six annual monitoring stations are around the airport. They constantly monitor the concentration of SO_2, NO_X, CO, photochemical oxidants, hydrocarbons, and PM.

In Europe, one of the busiest airports is Heathrow. In this connection, air quality control warrants special attention. There are 26 monitoring posts sites around the airport and in residential areas. They determine the concentration of pollutants from aircraft, handling equipment and passenger transport. They are in the city, near the road, in the suburbs and around the runway. The latter involves active and passive monitoring methods to determine pollution from aircraft, vehicle, commercial, space heating. The main traceable substances are NO_X, CO, CO_2, sulphur dioxide (SO_2), fine particles of various sizes, ozone and volatile organic compounds, hydrocarbons, etc. Despite the number of equipment, the contribution of specific emissions from aircraft engines remains unknown.

Heathrow airport implements measurements of ambient air quality at four sites according to monitoring program (BAA, 2008):

1. LHR (London Heathrow) site is located on the area of the old apron between the northern runway and the northern perimeter road to monitor air pollution arising from the airport area considering prevailing (south-west) wind direction.
2. Harlington site is established to measure air pollution concentrations in residential areas close to the airport.
3. Green Gate site is established to control of urban background.
4. Oaks Road site is in a residential area near the southwestern boundary of the airport to control urban background.

Fig.1 shows the estimated NO_X emissions that contribute to measurement at each monitoring site on and around the airport.

Over the last decade, the concentrations have fallen at most monitoring sites through the success of previous Air Quality Action Plans (BAA, 2008) and incorporating new initiatives and technological advances. The organisation of air pollution monitoring to detect and evaluate the aircraft engine emission contribution to total airport pollution should consider the influence of other emissions sources within the airport.

Zurich Airport has monitored the local air quality in the vicinity of the airport for many years. The monitoring sites have been selected following a monitoring concept that has been developed with the local authorities and last updated in 2005 (Fleuti, 2005; Zanetti et al., 2016). The monitoring stations are grouped according to their main potential contributor specified in the airport's ambient air quality monitoring concept (Fleuti, 2005; Celikel, 2005): monitoring stations most likely to be dominated by road traffic; monitoring stations most likely to be dominated by airport activities; monitoring stations most likely to dominate by other sources; background monitoring stations, Fig.7.

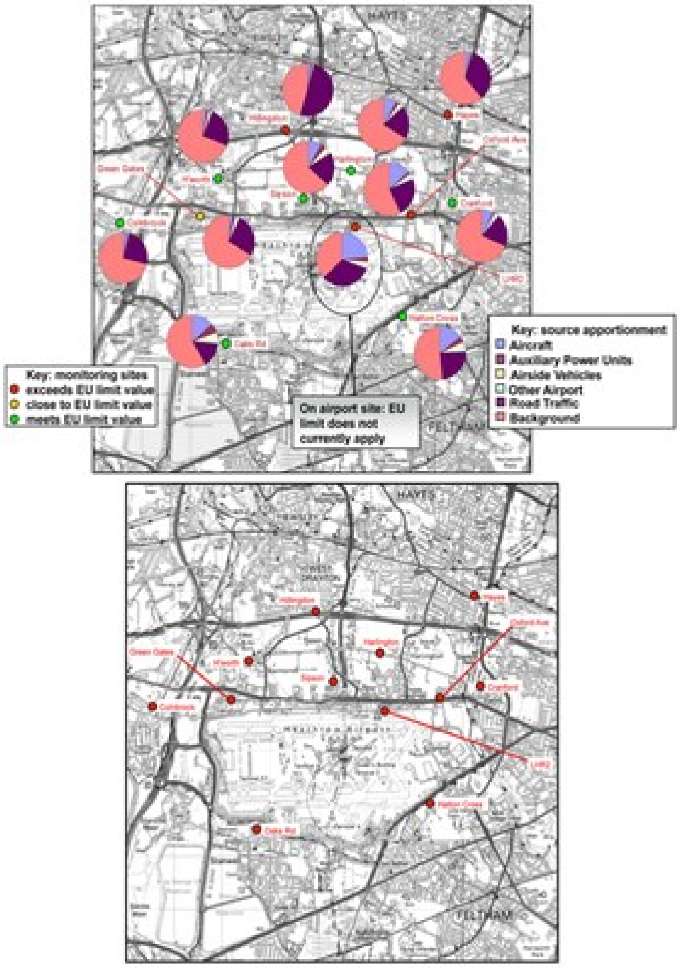


Fig. 6. Principal automatic air pollution monitoring sites near Heathrow Airport

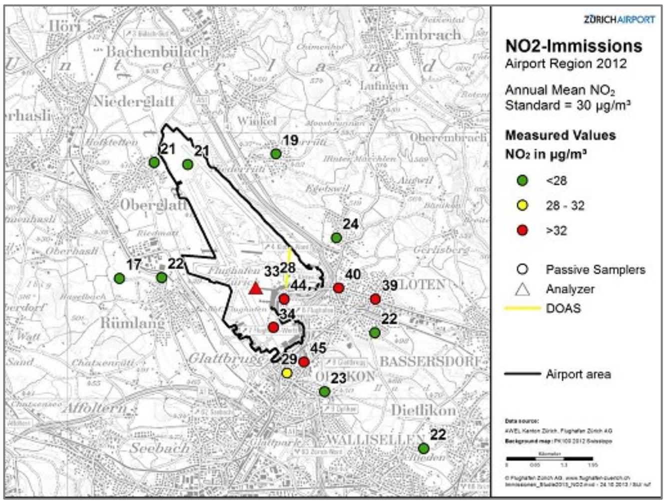


Fig.7. Measured NO_2 pollution concentration in 2012 (values are in µg NO_2/m^3)

Despite the increased attention given to aircraft emissions at the ground level and air pollution in the vicinity of airports, many research gaps remain concerning, including aircraft features as a particular source of air pollution by modelling and measurement methods.

The concentration field from aircraft operation at the airport is mainly determined by the exhaust jet distribution from aircraft engines. Hence, the maximum instantaneous concentrations observed in the exhaust gas jet's points are developed and spread. So, measurement campaigns of aircraft engine emissions must be proved by analytical models, which allow getting the understanding of contaminants transportation and dilution processes by exhaust jet from aircraft engine and meteorological conditions.

Such a combined approach of modelling and measurement methods ensures a relatively accurate and quite cost-efficient assessment of aircraft emission contribution to total air pollution in the vicinity of the airport.

2.2. Dispersion Modelling

Turning to airports, the essential document on air pollution control remains ICAO Document 9889 "Airport Air Quality Manual". It contains advice to assist the member states in implementing the instruments for air quality control. Typically, it provides a few main areas of an air quality assessment – the emission inventory and the dispersion modelling of pollution concentration.

Emissions modelling, a prerequisite to dispersion modelling, allows the change in emissions to be reviewed temporally and spatially. This requires the emissions data and explicit detail on when, where, and how the emissions occur, including airport spatial and temporal variation.

The common-used dispersion modelling methodologies are:

1. Gaussian formulation - It can be applied to plumes or individual puffs and provides needed flexibility for local air quality modelling. It has been adapted for point, line, and area sources.
2. Eddy diffusivity based on mass conservation formulation - This approach is used for widely or uniformly distributed pollutants where large individual plumes are not dominant. This occurs for such pollutants as carbon monoxide.
3. Lagrangian particle models - It relies on meteorological parameters that can be determined without dispersion experiments. The technique is routinely applied in air quality control.
4. Statistical models - Receptor modelling uses multivariate statistical methods to identify and quantify the apportionment of air pollutants to their sources.

The widely used models for the Airport air quality models are AEDT/EDMS, ADMS-Airport, ALAQS-AV, and LASPORT.

Aviation Environmental Design Tool (AEDT/EDMS) is a software system that dynamically models aircraft performance in space and time to produce fuel burn, emissions, and noise. The U.S. government currently uses the model to consider the interdependencies between aircraft-related fuel burn, noise, and emissions.

ADMS-Airport includes an allowance for all relevant emission sources at airports and utilises algorithms explicitly designed to model dispersion from aircraft engines.

Airport Local Air Quality Studies (ALAQS) - is based on delivering case study reports, guidance material, a database of default parameters for European Local Air Quality (LAQ), and the ALAQS-AV toolset.

LASPORT (LASAT - Lagrangian dispersion model for airports) – is based on experience with applying the LASAT at airports in Germany and Switzerland.

2.2.1. Complex Model PolEmiCa

A complex model PolEmiCa for assessing air pollution and emission inventory analysis, produced inside the airport, has been developed in the National Aviation University of Ukraine (Zaporozhets, 2017). It consists of the following basic components in a part of aircraft emissions:

1. Engine emission model – emission assessment for aircraft engines, including the influence of operational factors.
2. Jet transport model – transportation of the contaminants by jet from aircraft engine exhaust nozzle.
3. Dispersion model – dispersion of the contaminants in the atmosphere due to turbulent diffusion and wind transfer.

The jet transport model evaluates basic mechanisms of contaminants transportation and dilution by jet of exhausted gases from aircraft engine and provides basic parameters of the jet for further dispersion analysis, Fig.1.

The process of contaminant transport by exhaust gases jet is described by the semi-empirical theory of turbulent jets (Abramovich, 1987). The action of Archimedes forces causes buoyancy of a jet due to excess of temperature of jet gases above air temperature, fig.1. The Archimedes number (1) is used for the estimation of the plume rise height (2) (Zaporozhets, 2016):

$$Ar_0 = g \cdot D_0 \cdot (Q_T - 1)/U_0^2 \qquad (1)$$

$$\Delta h_A = 0.013 \cdot Ar_0 \cdot \overline{X_A^3} \cdot R_0 \qquad (2)$$

where parameter $Q_T = T_0/T_H$ for engines currently in operation changes within the limits of 1.15- 2; $\overline{X}_A$ is the longitudinal co-ordinate of jet axis concerning radius of the engine exhaust nozzle, $R_0 = D_0/2$.

Δh_A, X_A – height and longitudinal co-ordinate of jet axis rise due to buoyancy effect, m; h_{EN} – the height of engine installation, m; R_B – radius of jet expansion, m; X_1 – longitudinal co-ordinate of first contact point of jet with ground, m; X_2 – longitudinal co-ordinate of a point of jet lift-off from the ground due to buoyancy effect, m.

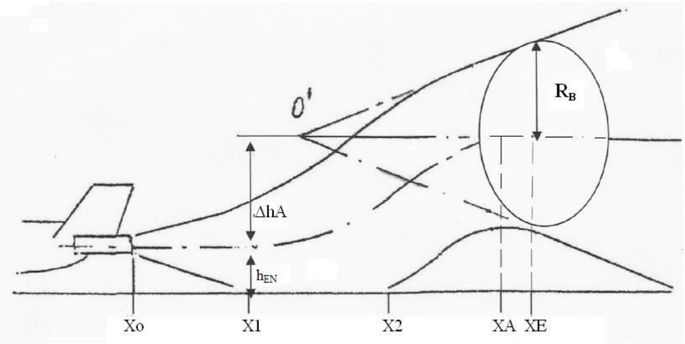


Fig. 8. Jet structure for jet transport model

The complex model PolEmiCa has been sufficiently improved in the subject of jet transport model by using computational fluid dynamics (CFD) package (FLUENT 6.3 Fluid Simulation Software) to investigate the physics and characteristics of ground vortices, which are generated between the ground surface and aircraft engine nozzle, to assess the ground surface impact on the jet structure, parameters and properties of jet development.

A fundamental equation of a complex model PolEmiCa for the definition of instantaneous concentration (dispersion model) from a moving source (from a single exhaust event) with preliminary transport on distance X_A and rise on altitude Δh_A and dilution σ_{0s} of contaminants by jet has a form (Zaporozhets, 2017; Zaporozhets, 2016):

$$c(x,y,z,t) = \frac{Q\exp\left[-\frac{(x-x')^2}{2\sigma_{x0}^2+4k_x t}-\frac{(y-y')^2}{2\sigma_{y0}^2+4k_y t}\right]}{\{8\pi^3[\sigma_{x0}^2+2K_x t][\sigma_{y0}^2+2K_y t]\}^{1/2}}\times$$
$$\times\left\{\frac{\exp\left[-\frac{(z-z'-H)^2}{2\sigma_{z0}^2+4k_z t}\right]+\exp\left[-\frac{(z+z'+H)^2}{2\sigma_{z0}^2+4k_z t}\right]}{[\sigma_{z0}^2+2k_z t]^{1/2}}\right\} \qquad (3)$$

Aircraft is considered as a moving emission source, thus current co-ordinates (x', y', z') of the emission source in movement during time t' are defined as:

$$x' = x_0 + u_{PL}t' + 0.5a_{PL}t'^2 + u_w(t+t'); \qquad (4)$$

$$y' = y_0 + v_{PL}t' + 0.5b_{PL}t'^2; \qquad (5)$$

$$z' = z_0 + w_{PL}t' + 0.5c_{PL}t'^2 \qquad (6)$$

where (x_0, y_0, z_0) – initial co-ordinates of the source; $(u_{PL},$

v_{PL}, w_{PL}) – velocity vector components of emission source; (a, b, c) – acceleration vector components of emission source; K_x, K_y, K_z. – coefficients of atmospheric turbulence.

The model calculates the co-ordinates (x_{wmax}; y_{wmax}) and period of maximum concentration formation (t_{wmax}) on the runway from the moment of aircraft engine run:

$$t_{w\max} = (x_{w\max} - x_{1w}) / u_{PL} \tag{7}$$

Also, the model predicts maximum concentration distribution due to dilution by jet and diffusion by atmospheric turbulence and its detection by monitoring station (Fig.9).

The maximum value of instantaneous concentration c_{max} at the detection point of the monitoring station will be derived now t_{max}, which is determined by the following formula:

$$t_{\max} = \frac{x_{wind}}{u_w} - \sqrt{x_{wind} \frac{dK_x}{u_w^3}} \tag{8}$$

where x_{wind} – the distance of the contaminants transport by the wind to monitoring station; u_w – wind velocity.

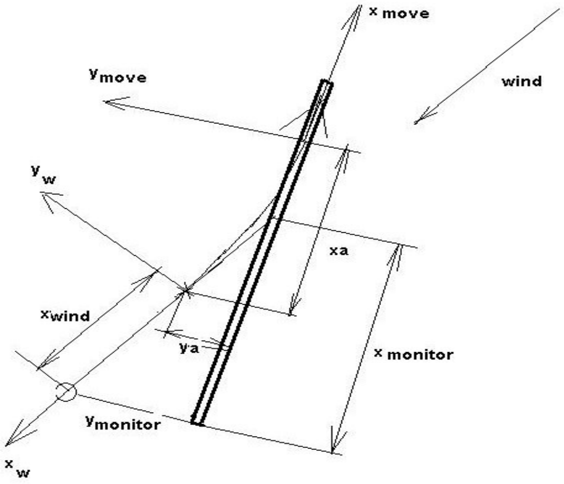


Fig.9. Modelling scheme of transport and dilution of air contaminants by exhaust gases jet from aircraft engine and atmospheric diffusion: (x_{move}; y_{move};) – initial co-ordinate system: axis X is directed toward an aircraft take-off; (x_{wind}; y_{wind};) – secondary co-ordinate system: axis X is directed toward a wind velocity vector u_w; ($x_{monitor}$; $y_{monitor}$) – co-ordinates of monitoring station B at initial co-ordinate system.

PolEmiCa calculates the emission inventory and concentration filed inside the airport area, considering the intensity of flights of airplanes, the loading factor of different taxiways and runways, and other operational circumstances.

Also, PolEmiCa provides the co-ordinated point at which maximum instantaneous concentrations will be fixed due to the development and spread of exhaust gas jet from aircraft engines. Thus, the models, for instance, PolEmiCa, provide grounding for scheme and height of sample systems installation, time-integration of measured values to detect aircraft engine emission and pollution with considering basic fluid mechanisms of the exhaust (buoyancy and Coanda effect) and ground impact on its structure and behaviour. Such a proposed approach of modelling and measurement methods were realised at Boryspol and Zulyany airports.

3. Results

3.1. Measurement of Aircraft Engine Emissions at Boryspol Airport

Based on measurement campaign analysis at main airports of the world (London-Heathrow, Frankfurt/Main, Vienna, Zurich, Munich, Budapest and Athens) and modelling results by complex model PolEmiCa, it was suggested the method and technical characteristics for a measurement system to detect the aircraft engine emissions:

- High time resolution of detected concentrations - 1 second: to measure the maximum concentration values in jets from each engine the aircraft and therefore to implement objective estimation of aircraft engine emissions contribution in total airport air pollution. Recommended equipment also provides measurements of averaged concentration for any period, which is an essential characteristic for air quality control according to the established sanitary-hygienic standards as - maximum permissible concentration MPC - with an averaging period of 20 minutes.
- The high detection limit (± 2ppbV): to guarantee the safe distance to the aircraft, identify peak concentrations of air contaminant in emissions from aircraft engine and their separation from other sources of airport air pollution (background pollution).
- The different heights to collect the gases samples considered the buoyancy effect of exhaust gases jet under different operational and meteorological conditions.

The combined approach of modelling and measurement methods was realised at International Boryspol Airport (IBA) within bilateral cooperation between Germany and Ukraine. Monitoring of air pollution produced by aircraft engine emissions at IBA was conducted by two stations (stationary station A and movable station B) under operation conditions: idle (aircraft is taxing) and maximum (aircraft is accelerating on the runway or takes-off). Scheme for disposition of the monitoring stations in the airport was developed with considering modelling results (model PolEmiCa) of transportation and dilution contaminants by jet (stationary station A) from aircraft engine and its transfer by wind and atmospheric turbulence (movable station B) for differential operational and meteorological conditions, fig.10. Station B (movable van) is oriented to dominant wind direction (south-east) and displayed at a distance of 120m from runway axis in west direction and opposite guide path near 36R end of the runway, fig.3. The position of the stations guaranteed that the most important sector of the aircraft exhaust for taxing, landing and take-off conditions was scanned by the measurement systems. Analysis results of measurement data at station "B" clearly demonstrated a correlation between the peak concentrations of NO_x and CO_2 are correlated with aircraft plumes correspondingly at take-off and taxing conditions, fig.11 (Zaporozhets, 2016).

As shown from Table 1 and Figure 12, the modelling results for each engine are in good agreement with the results of measurements by the AC32M system due to considering the jet- and plume-regime during an experimental investigation at Boryspol airport. Also, using CFD-code (Fluent 6.3) improves results by 30% (coefficient of correlation, r=0.76) by considering lateral wind and ground impact on jet parameters.

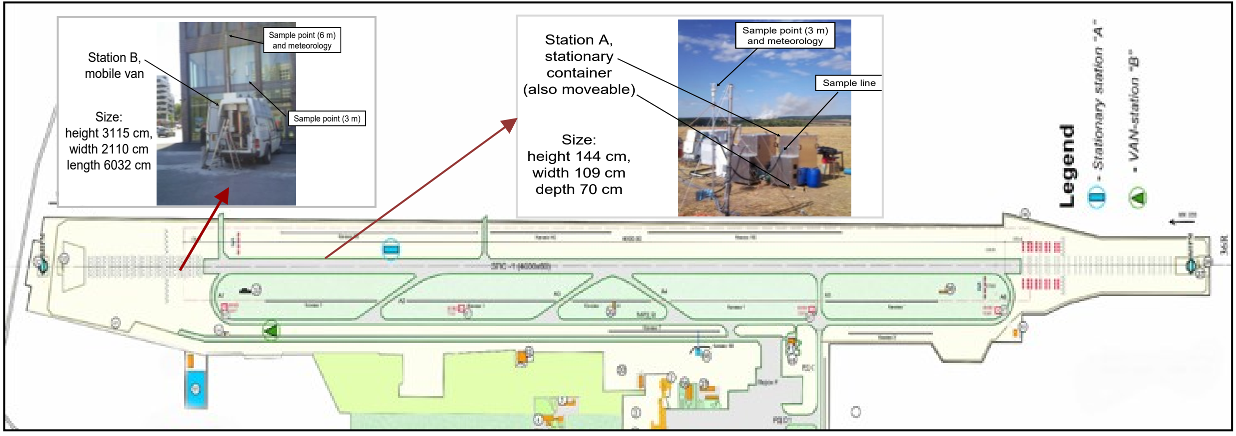


Fig.10. Location of stationary station A and movable station B at International Boryspol Airport

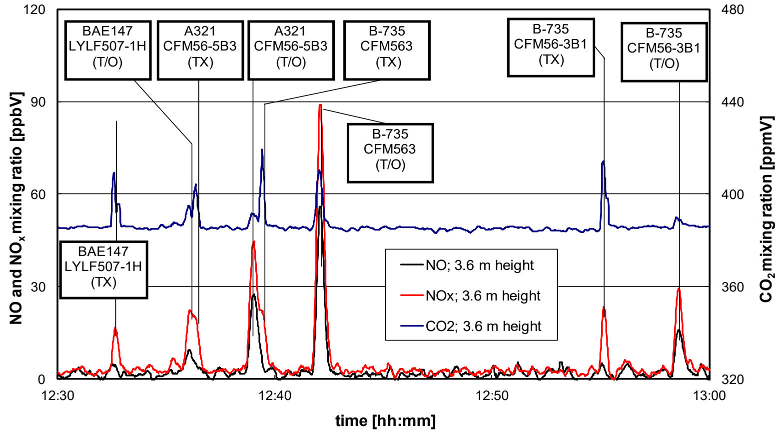


Fig.11. Background and plume concentration for NO, NO_x and CO_2 at mobile station B for different aircraft at take-off (T/O) and ground taxi (TX) conditions

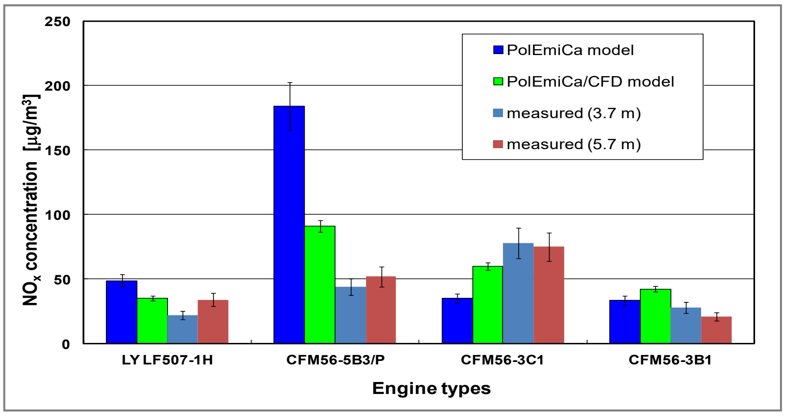


Figure 12. Comparison of the PolEmiCa and PolEmiCa/CFD model results with the measured NOx concentration at different height for selected aircraft engines under maximum operation mode

Therefore, the location of the monitoring station should consider the transport and dilution mechanisms of air contaminants by exhaust jet from aircraft engine and dispersion process by wind and atmospheric turbulence.

3.2. Measurement Of Aircraft Engine Emissions At Zuliany Airport

The residents around the airdrome can feel an acute problem of atmospheric air pollution. In this regard, in the summer of 2018, one more study was conducted at another airport - Kyiv International Airport (Zhuliany). This airport is an interesting object for studying atmospheric air pollution as it finds within the city and surrounding residential areas.

Air quality monitoring installed on the territory of the aerodrome. The location of the monitoring station determined according to the scenario of the aircraft moving (landing, running along the runway and take-off) and the dominant wind direction. The scheme for a disposition of the monitoring station was developed by considering the processes of transportation and dilution of air contaminants by exhaust gas jet from aircraft engine and its transfer by wind and atmospheric turbulence for differential operational and meteorological conditions Fig.13.

Instrumental air pollution studies within the aerodrome were performed in Zhuliany through the gas analysers Elan NO, Elan NO_2, Elan CO. The measured parameter is air pollutant concentration in the ambient air (mg/m3).

The method is electrochemical. It is pretty versatile and does not require the use of complicated equipment. Compactness, speed of operation and low cost are typical for these devices with an electrochemical sensor. The relative measurement error for the Elan gas analysers is 25%.

The gas analyser "Elan" is used to measure the instantaneous concentration of NO, NO_2, CO in the plume from the aircraft engine and ambient air (background level). Uncertainly -, time resolution – 0.5 s.

Fig.13- Scheme for the monitoring station disposition on the aerodrome.

Argued location of the monitoring station (fig.13) allows catching the instantaneous maximum concentration in the plume from the aircraft engine at the stages of taxing, clearing of take-off, acceleration on the runway and further take-off.

Analysis of measured instantaneous concentration (NO, NO_X, CO) demonstrates the following correlation (fig.15):

- Taxing of aircraft along the main taxiway causes the high concentration of NO, which can be explained short distance to aircraft (nearly 10 m) and most of NO_X is represented by NO in the exhaust.
- An extremely high concentration of CO characterises the stage of cleared for take-off before accelerating of aircraft.
- Accelerating of aircraft along the runway and Take-off leads to the detection of a high concentration of NO_X.

Table 1: Comparison measured (AC32M, ELAN) and calculated concentration (averaged for 3 seconds) of NOx produced by aircraft engine emissions at accelerating stage on the runway

Aircraft	Aircraft engine	ELAN		AC32M			PolEmiCa CFD (Fluent 6.3)		PolEmiCa	
		Peak 1	Peak 1	Back ground	3 м	6 м	1 engine	All engines	1 engine	All engines
		NO_X	NO_X	NO_X	NO_X	NO_X	NO_X	NO_X	NO_X	NO_X
BAE147	LY LF507-1H	38	35	1.70	22.07	33.90	35.10	70.46	48.90	202.30
A321	CFM56-5B3/P	39	39	0.72	44.00	54.20	90.85	182.90	184.20	371.20
B735	CFM-563C1	40	45	0.77	94.09	76.57	60.03	120.91	35.30	71.10
B735	CFM56-3B1	45	41	1.74	29,20	23.40	42.34	85.30	33.70	67.76

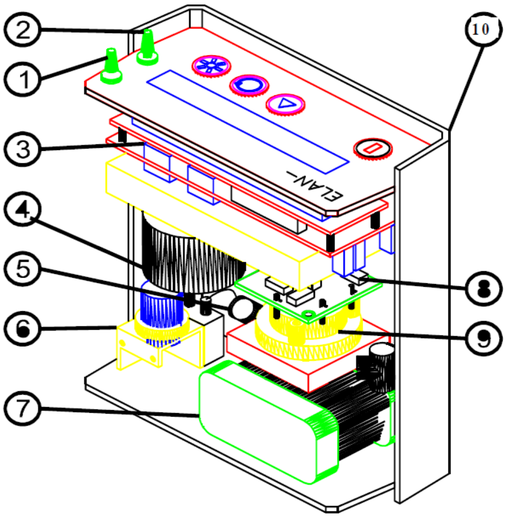


Fig. 14- The general form of the gas analyser includes 1. Fitting "Gas inlet". 2. The union "Gas outlet". 3. Processor module. 4. Filter. 5. Tee. 6. Pump. 7. Rechargeable battery. 8. Potentiostat. 9. Electrochemical cell. 10. Cover.

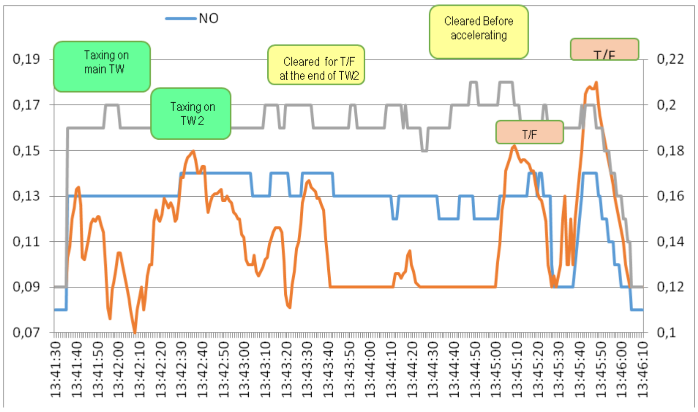


Fig.15. Background and plume concentration for NO, NO_x, CO_2 at monitoring station under taxing and take-off conditions of A320

The obtained results of the experiment within Kyiv International Airport (Zhuliany) confirm the necessity of organising continuous instrumental monitoring to define the field of pollutant concentrations as a result of emissions of aircraft engines within the airport.

4. Conclusions

Consequently, the monitoring of aircraft engine emissions should aim to detect the maximum instantaneous concentration of air contaminants in plume under real operational conditions to obtain objective information concerning aircraft engines emissions contribution to total air pollution within the airport area. The concentration field is mainly determined by the exhaust jet distribution from aircraft engines. Hence, the maximum instantaneous concentrations observed in the exhaust gas jet's points are developed and spread. Therefore, the location of the monitoring station should take into account the transport and dilution mechanisms of air contaminants by exhaust jet from aircraft engine and dispersion process by wind and atmospheric turbulence.

Based on measurement campaign analysis at main airports of the world (London-Heathrow, Frankfurt/Main, Vienna, Zurich, Munich, Budapest and Athens) and modelling results by complex model PolEmiCa it was suggested the method and technical characteristics for a measurement system to detect the aircraft engine emissions. The developed practical recommendations were realised at Ukrainian airports and used for validation of model PolEmiCa. To assess the concentration at the Ukrainian airports, there were applied the complex model PolEmiCa, and the short-term ambient air monitoring through gas analysers. Thus, the modelling results for each engine are in good agreement with the results of measurements by the AC32M system due to considering the jet- and plume-regime during an experimental investigation at Boryspol airport. Also, using CFD-code (Fluent 6.3) improves results by 30% (coefficient of correlation, r=0.76) by considering lateral wind and ground impact on jet parameters. Furthermore, the measured instantaneous concentration (NO, NOx, CO) analysis demonstrates a high correlation with the accelerating stage of aircraft along the runway and take-off at Zhulyany airport. The obtained results of the experimental investigations within Ukrainian airports confirm the necessity of organising continuous instrumental monitoring to define pollutant concentrations because of emissions of aircraft engines within the airport.

Abbreviations

ACARE	:	Advisory Council for Aeronautics Research in Europe
AEDT	:	Aviation Environmental Design Tool
ALAQS	:	Airport Local Air Quality Studies
CFD		Computational fluid dynamics
CO	:	Carbon Monoxide
CO_2	:	Carbon Dioxide
EASA	:	European Aviation Safety Agency
EDMS	:	Aviation Environmental Design Tool
FAA	:	Federal Aviation Authority
FLUENT	:	Fluid Simulation Software
GHG	:	Greenhouse gasses
ICAO	:	International Civil Aviation Organisation
LAQ	:	Local Air Quality
LASAT	:	Lagrangian Dispersion Method
LASPORT	:	LASAT for Aiportts
LHR	:	London Heathrow
LICOR	:	Non-dispersive infrared absorption method
LIDAR	:	Light Detection and Ranging
NO	:	Nitrogen Monoxide
NO_X	:	Nitrogen Oxides
PM	:	Particulate matter
PolEmiCa	:	Pollution and Emission Calculation)
SO_2	:	Sulphur Dioxide
TILDAS	:	Tuneable Diode Laser Differential Absorption Spectroscopy
UHC	:	Unburned hydrocarbons
VOC	:	Volatile organic compound

CRediT Author Statement

All authors: Writing-Original draft preparation, Writing-Reviewing and Editing, Software, Investigation, Data Curation, Supervision, Conceptualization, Validation, Project administration, Resources, Funding acquisition

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Research Article

Developing an Approach for Fault Detection and Diagnosis of Angular Velocity Sensors

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Abstract

Angular velocity sensor detection and diagnosis become increasingly essential for the improvement of reliability, safety, and efficiency of the control system on aircraft. The classical methods for fault detection and diagnosis are limit or trend checking of some measurable output variables. Due to they do not give a deeper insight and usually do not allow a fault diagnosis, model-based methods of fault detection and diagnosis were developed by using input and output signals and applying dynamic process models. These approaches are based on parameter estimation, parity equations, or state observers. This paper presents an improvement method to build algorithm fault diagnosis for angular velocity sensors on aircraft. Based on proposed method, results of paper can be used in designed intelligent systems that can automatically fault detection on aircraft.

Keywords

Block sensor
Fault diagnosis
Fault detection
Angular velocity sensor
Advanced control system

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1. Introduction

Recently, fault detection and diagnosis (FDD) have an essential role in obtaining fault tolerance of aircraft control systems (Xue et al., 2007; He et al., 2020). Many approaches have been proposed for sensor or actuator FDD (Chen et al. 2012; Isermann 2005; Lu et al. 2016). In aviation engineering, the FDD of sensors and actuators for fixed-wing aircraft widely studies can be found in references (Lu et al., 2015; Kim et al., 2008; Xue et al., 2007). Investigation of the FDD for unmanned aerial vehicles (UAV) can also be found in Baskaya et al. (2017), and Hajiyev et al. (2013).

In general, sensors provide information for the control system according to their characteristics to ensure that the control system works well. They need the angular velocity parameter in the three axes of the coordinate system. Angular rate sensors play an essential role in the control system. The sensors' accuracy affects the quality of control because it is a component in a loop that controls the angular position. These sensors' signals work as the reverse contact signals, which are essential signal components in building high-quality control systems. Its position in the flying equipment control system is shown in Fig.1.

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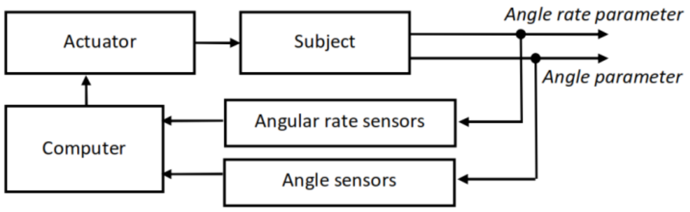

Fig. 1. Block diagram of flying equipment control

In Fig. 1, the aircraft is subject; the input parameter is angle deflection; the output parameters are the angular rate, angular position, including yaw, pitch, and roll angle. According to specific control laws, the computer functions to synthesize control signals to ensure the best quality for the control process of a specific flight mode.

A conventional angular speed sensor uses a gyroscope as the critical element to measure angular speed. They come in many different forms in terms of construction and accuracy, such as using a sensitive element that is a 2-frame gyro or 3-frame gyro. The basic principle of an angular speed sensor is shown in the following figure.

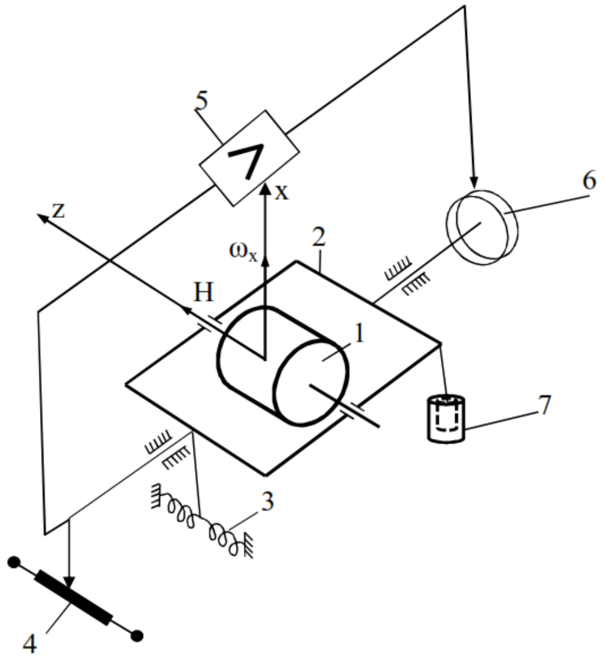

Fig. 2. Diagram of the principle of speed gyroscope

Where:

1. Gyro rotor.
2. Hanging frame.
3. Reactive springs.
4. Variable resistor.
5. Amplification.
6. Torque motor.
7. The damping mechanism.

When the gyro stand rotates around the Ox axis, the gyroscope performs two movements: a rotation around the rotor's axis and a rotation with the stand placing them around the measuring axis. Then there appears a gyro moment proportional to the angular speed vector of the gyro mount and the kinematic torque vector, causing the sling to tilt at an angle. Then the spring torque will produce a precession rate proportional to the angular speed to be measured. Typically, springs with linear characteristics are used, which means that the spring torque is proportional to the swing angle of the suspension frame relative to the angular speed measured by the inductance. In short, based on the precession properties of the gyroscope, the angular speed sensor measures the angular speed of the object. The layout of a single angular speed sensor is shown in the following figure.

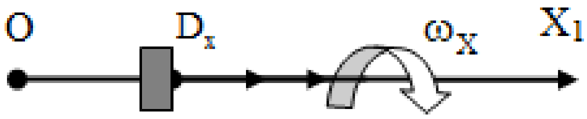

Fig. 3. Diagram of the principle of angular speed sensor on an axis

However, to ensure the safety of the flying object, angular speed sensors will be used with 1 to 4 sensors on each axis. On aircraft, the 3-axis scale of the standard coordinate system is 3-3-4.

The actuator is responsible for receiving control signals, handling and deflecting the steering blades so that under the action of aerodynamic forces and torque, the flying equipment's state changes. Angular velocity and angle sensors are responsible for sensing control parameters and providing information for the computer to synthesize control laws. Thus, the angular rate sensors are in the control system's loop, which plays an essential role in improving control quality. The angular rate sensors arranged on the flying equipment correspond to the axes of the coordinate system $OX_1Y_1Z_1$ in a 3-3-4 scale to ensure the redundancy of the sensors' information. However, with such a structure arrangement, the sensors can only provide angular rate information to the control system but cannot provide information about the operating quality of the sensors. According to the research results proposed in (Tuan et al. 2013), the author changed the layout of the angular speed sensors in the control system. There are nine angular rate sensors arranged in three axes of the coordinate system $OX_1Y_1Z_1$ (3 sensors per axis) used to measure the roll rate ω_x, yaw rate ω_y, pitch rate ω_z, respectively. The remaining sensor is used to determine the relationships between sensors. This sensor is arranged so that the sensitive axis coincides with the diagonal of the cube passing through the three axes, with 1 vertex being the origin O of the coordinate system $OX_1Y_1Z_1$ and a vertex on the OO' axis (the sensitive axis of sensor S_0) as shown in Fig. 2.

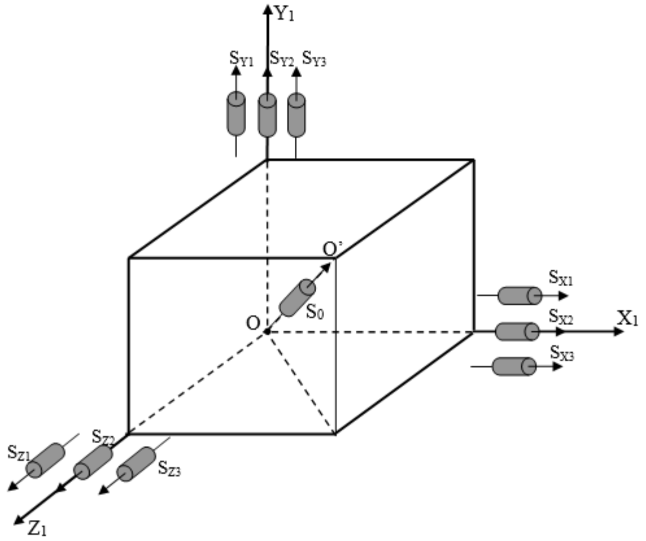

Fig. 4. Position of improved angular speed sensors on the three axes of the coordinate system

In general, we need to consider block sensors' error for diagnosing the fault of block sensors with its structure in fig 4.

The mathematical model of a sensor is given in the form:

$$U_D(t) = k_D\omega(t) \tag{1}$$

Where: $U_D(t)$ - Output voltage of the sensor;

k_D - The amplification coefficient of the sensor;

If the sensors are working well, the output voltage is proportional to the angular speed value along the respective axes. However, if this sensor has errors, this mathematical model is not correct. The primary cause of failures is generally due to various defects and failures of the system's elements. Based on the actual operation of the sensors, these failures can be non-positive (negative) drift, increase (decrease) amplification factor, short-circuit of sensors, breakage of sensors line. For each of these failures can be modelled in the form of a mathematical model as follows:

$$\tilde{U}_{D_X}(t) = k_{D_X}\omega_X(t) + \tilde{U}_{D_{X_0}}(t);\ \tilde{U}_{D_{X_0}}(t) < 0 \tag{2}$$

$$\tilde{U}_{D_X}(t) = k_{D_X}\omega_X(t) + \tilde{U}_{D_{X_0}}(t);\ \tilde{U}_{D_{X_0}}(t) > 0 \tag{3}$$

$$\tilde{U}_{D_X}(t) = \tilde{k}_{D_X}\omega_X(t);\ \tilde{k}_{D_X} = k_{D_X} + \Delta k_{D_X};\ \Delta k_{D_X} > 0 \tag{4}$$

$$\tilde{U}_{D_X}(t) = \tilde{k}_{D_X}\omega_X(t);\ \tilde{k}_{D_X} = k_{D_X} + \Delta k_{D_X};\ \Delta k_{D_X} > 0 \tag{5}$$

$$\tilde{U}_{D_X}(t) = \tilde{U}_{D_X}^{max}(t) = const \tag{6}$$

$$\tilde{U}_{D_X}(t) = \tilde{U}_{D_X}^{max}(t) = const \tag{7}$$

On the other hand, the arrangement on each axis of the three sensors aims to increase redundancy and ensure the system's safety in case of a problem. For sensors S_0 lying on diagonal OO' has the form of the mathematical model as follows:

$$\tilde{U}_0(t) = \frac{1}{\sqrt{3}}\left[k_{D_X}\omega_X(t) + k_{D_Y}\omega_Y(t) + k_{D_Z}\omega_Z(t)\right] \tag{8}$$

Where: $k_{D_X}\omega_X(t)$; $k_{D_Y}\omega_Y(t)$; $k_{D_Z}\omega_Z(t)$ - The output voltage of the sensors at the axes of the coordinate axis system.

From the mathematical and analytical models in the formulas from Eq. (1) to Eq. (8), we can observe that:

- There may be a malfunction on a sensor;
- There can be only one failure per sensors;
- Failures on each sensor are independent of each other;
- The output signal characteristics of the sensors are related to the failure modes that we have considered above;
- The output signal characteristic of the S0 sensor is related to angular speed sensors on the axes of the link coordinate system.

Therefore, we can rely on the sensors' output signal characteristics to serve as a basis for detecting the failure of these sensors.

2. Method

The failure detection of a diagnostic object is done according to the following principle diagram:

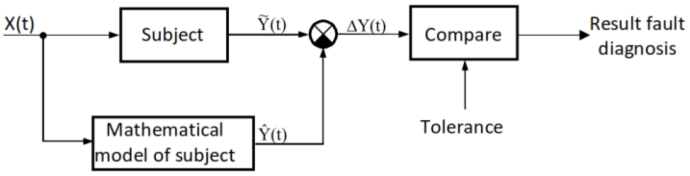

Fig.5. Principle of fault diagnosis

With the input value X(t) when passing the diagnostic object and its mathematical model, two different values are $\tilde{Y}(t)$ and $\hat{Y}(t)$. Let these two values through the subtractor, and we get the result $\Delta Y(t)$. Theoretically, the value $\Delta Y(t) = 0$, but, this value is always different from 0 and is always less than something we call this value tolerance. Comparisons $\Delta Y(t)$ and tolerance will give us the failure detection results.

Applying the above principle, we assume that the k coefficient of the sensors is the same, so we have the mathematical model of the sensor on the following axes:

For the axis OX (*Group* X)

$$\tilde{U}_{x1}(t) = k\omega_X(t);\ \tilde{U}_{x2}(t) = k\omega_X(t);\ \tilde{U}_{x3}(t) = k\omega_X(t) \tag{9}$$

For the axis OY (*Group* Y)

$$\tilde{U}_{y1}(t) = k\omega_Y(t);\ \tilde{U}_{y2}(t) = k\omega_Y(t);\ \tilde{U}_{y3}(t) = k\omega_Y(t) \tag{10}$$

For the axis OZ (*Group* Z)

$$\begin{aligned}&\tilde{U}_{z1}(t) = k\omega_Z(t);\ \tilde{U}_{z2}(t) = k\omega_Z(t);\\ &\tilde{U}_{z3}(t) = k\omega_Z(t)\end{aligned} \tag{11}$$

For the diagonal of the cube (OO')

$$\tilde{U}_0(t) = k\frac{1}{\sqrt{3}}[\omega_X(t) + \omega_Y(t) + \omega_Z(t)] \qquad (12)$$

Relationships:

$$\tilde{U}_m = \frac{1}{\sqrt{3}}(\tilde{U}_{Xi} + \tilde{U}_{Yj} + \tilde{U}_{Zk}) \qquad (13)$$

Where:

m=1:27; i, j, k =1:3;

$\tilde{U}_m$- the output voltage value of block sensors;

k_0 - the amplification coefficient of the sensors of the same type;

ω - the value of angular rate.

Thus, from the general relation expression (13), we have 27 specific relationships according to the indexes i, j, k;

To build the algorithm to diagnose the state and damage angular speed sensing block based on the expression (13). The expression (13) show that the expression is correct in the ideal case, but in reality, despite the normal operating conditions of all expressions, the expression (13) has the form:

$$\left|\tilde{U}_0 - \frac{1}{\sqrt{3}}(\tilde{U}_{Xi} + \tilde{U}_{Yj} + \tilde{U}_{Zk})\right| \qquad (14)$$

Where: δ - the largest deviation under normal operating conditions, $\delta > 0$.

When there is a failure error, the inequality (14) will not be true; that is $\left|\tilde{U}_0 - \frac{1}{\sqrt{3}}(\tilde{U}_{Xi} + \tilde{U}_{Yj} + \tilde{U}_{Zk})\right| > \delta$. Thus, the conditions to determine a failure in the block can be set as follows:

Consider $\Delta_n = \left|\tilde{U}_0 - \frac{1}{\sqrt{3}}(\tilde{U}_{Xi} + \tilde{U}_{Yj} + \tilde{U}_{Zk})\right|$, with n =1:27 is the ordinal number according to the combination options i, j, k.

If $\Delta_n > \delta$, (n=1:27) there is a failure in the sensors block.

If $\Delta_n \le \delta$, (with all n=1:27), there is no failure in the sensor block.

Based on the above analysis, the improved angular speed sensor failure diagnostic algorithm is set up as follows:

The above algorithm only allows detecting and diagnosing a faulty sensor. However, it has not determined which sensor's failure because this sensor block has ten single sensors. Therefore, to determine precisely which fault sensor in the sensor block, we have developed an algorithm to determine each sensor's failure.

In the general case, there are three different fault groups on three axes. Unfortunately, the algorithm was built in the previous section does not meet the fault detection requirements on each sensor. Therefore, we need to build a general algorithm that can fault detection on each axis's sensors.

The typical virtual output values of diagonal sensor S_0 are as follows:

$$\tilde{U}_{0m}(k) = \frac{1}{\sqrt{3}}(\tilde{U}_{Xi}(k) + \tilde{U}_{Yj}(k) + \tilde{U}_{Zk}(k)) \qquad (15)$$

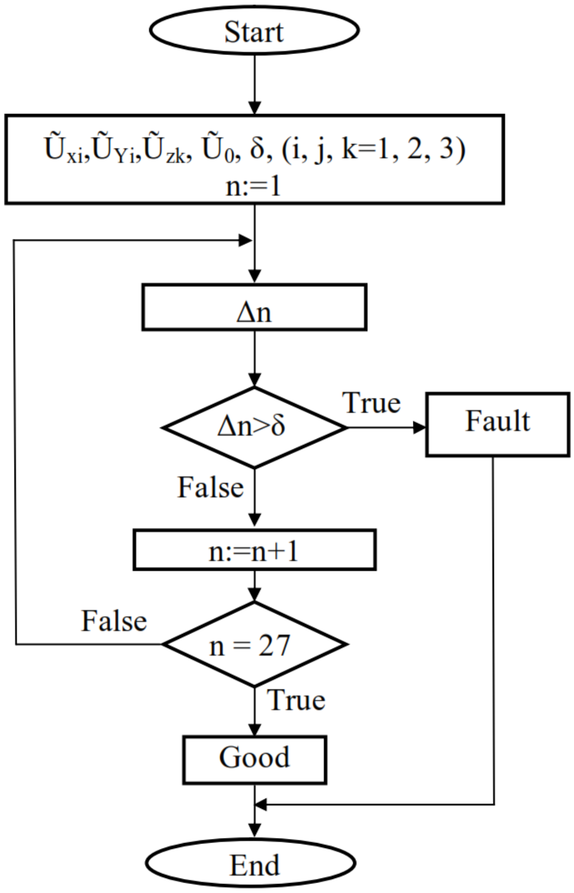

Fig. 6. Algorithm flowchart representing fault diagnostic algorithm improved angular rate sensors block.

Where: m- get values from 1 to 27;

i, j, k- get values from 1 to 3;

We will build a fault detection algorithm based on comparing the actual output value and the common virtual output value of the sensor S_0.

$$Z_m = S_m\{\Delta_{0m} = |\tilde{U}_0(k) - \tilde{U}_{0m}(k)| > \delta_0\} = \begin{cases} 0 - \quad \text{not fault in sensors} \\ 1 - \text{fault in sensor S(i,j,k)or } S_0 \end{cases} \qquad (16)$$

Based on equation (16), if there is 1 fault per sensor, then there are 9 values of $Z_m = 1$, and if there are 2 failures on 2 sensors, there are 18 values of $Z_m = 1$.

To facilitate the failure diagnosis in the general case, we set up a table of 27 values of Z_m corresponding to the values of i, j, k, taking the following values from 1 to 3, respectively:

From expression (16), we build a flow chart of fault diagnosis algorithm in the general case in fig 7.

Thus, with the general algorithm flowchart presented in Figure 7, we can diagnose the failure of angular speed sensors in 1 or 2 or all three groups.

Table 1. Table of symbols of fault cases

Z_m	U_X	U_Y	U_Z
1	1	1	1
2	1	1	2
3	1	1	3
4	1	2	1
5	1	2	2
6	1	2	3
7	1	3	1
8	1	3	2
9	1	3	3
10	2	1	1
11	2	1	2
12	2	1	3
13	2	2	1
14	2	2	2
15	2	2	3
16	2	3	1
17	2	3	2
18	2	3	3
19	3	1	1
20	3	1	2
21	3	1	3
22	3	2	1
23	3	2	2
24	3	2	3
25	3	3	1
26	3	3	2
27	3	3	3

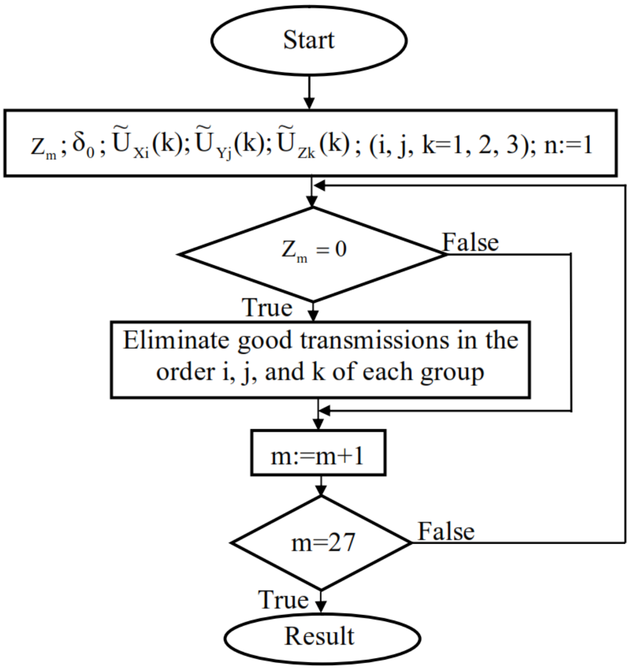

Fig. 7. Algorithm flowchart representing fault diagnostic algorithm improved angular rate sensor block in case of three group fault.

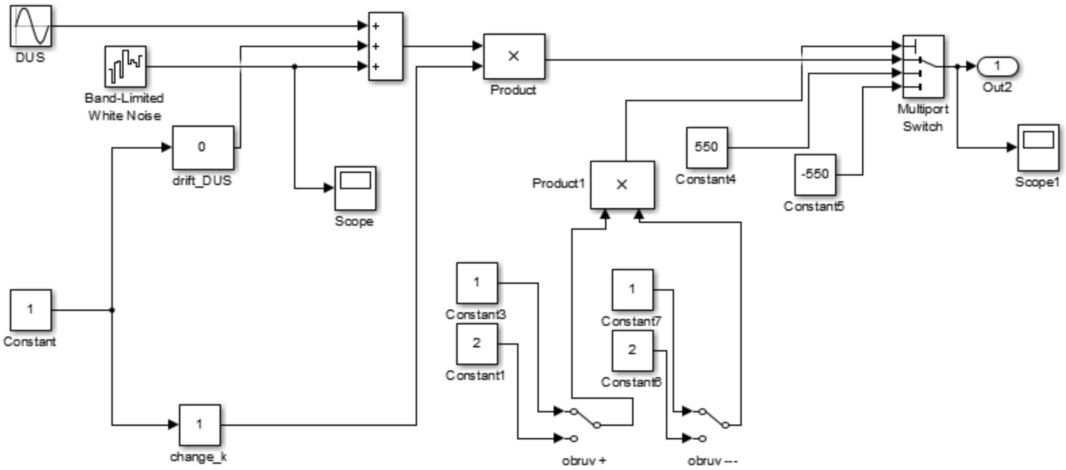

Fig. 8. Diagram simulation sensors block.

3. Results

The author uses the Matlab Simulink tool in Matlab software to simulate fault diagnosis algorithm in the general case.

The Simulink diagram simulates the operating principle of an angular speed sensor shown in Fig. 8.

The signal form of the sensor in the case of suitable working inductance is shown in the following Figs. 9-13.

With the characteristics of the output signal of the sensor simulated on Matlab Simulink, it is like the primary signal form of the actual angular speed sensor and like the mathematical model proposed by the author above.

A schematic diagram of the fault diagnosis algorithm in the case of 3 failure groups is shown in Fig. 14. The sensors block is calculated based on Eq. (2-8); the computational block is based on Eq. (16). Problem diagnosis block using State-Flow tool with 54 comparisons of fault diagnosis results shown at the output as a signal: 1- Fault sensor; 0-Good sensor.

A check on the algorithm's good operation shown in Fig. 5 is done by changing the sensors' parameters and seeing the sensors fail, and running the Matlab program to check the output parameters. Assumes sensors X_2; Y_3; Z_2 fault and runs the simulation. We have the results shown in Fig. 15.

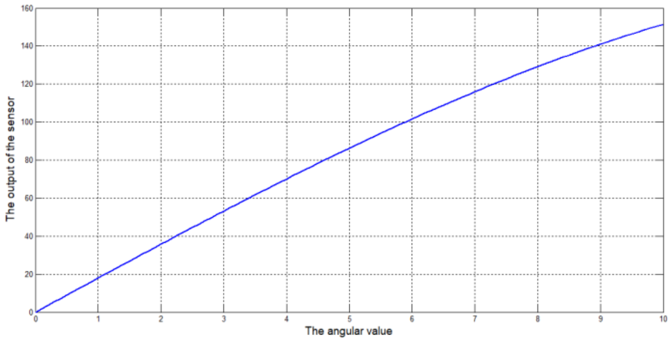

Fig. 9. Diagram showing the signal form of the good sensor.

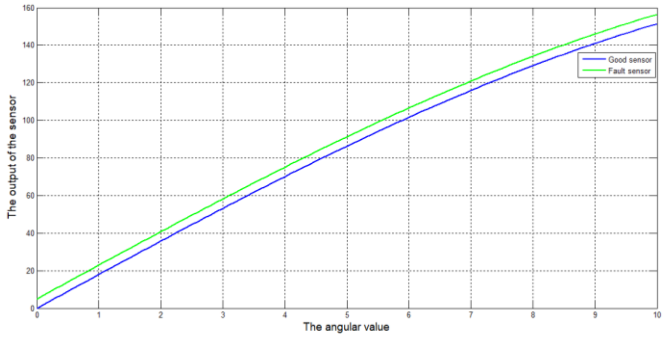

Fig. 10. The diagram comparing the signal form when the sensor has a signal drift problem.

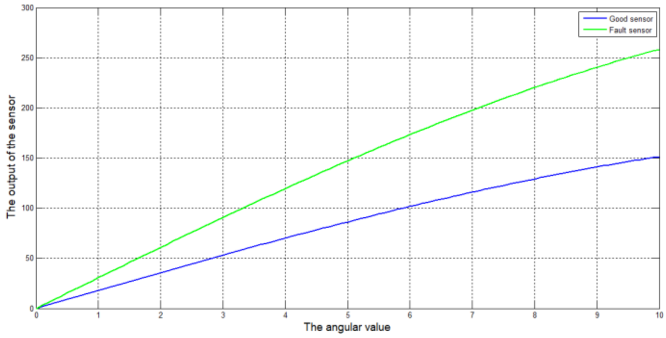

Fig. 11. The diagram compares the signal form when the sensor has a problem with the gain change.

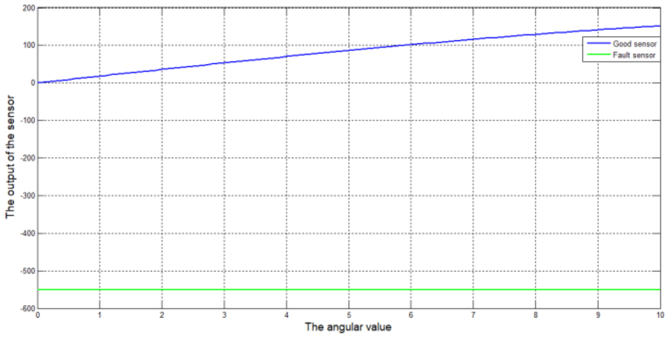

Fig. 12. The diagram compares the signal form when the sensor has a problem with the signal negative wire.

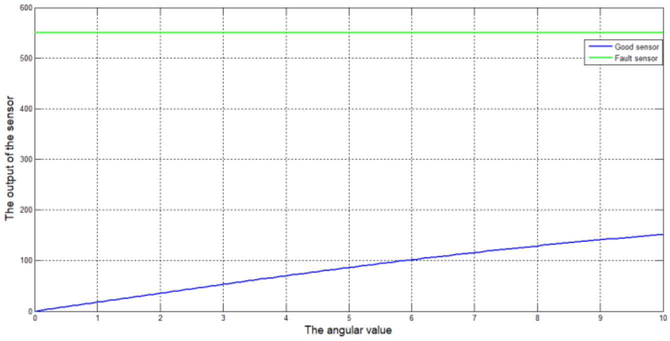

Fig. 13. The diagram compares the signal form the sensor has a problem with signal positive wire.

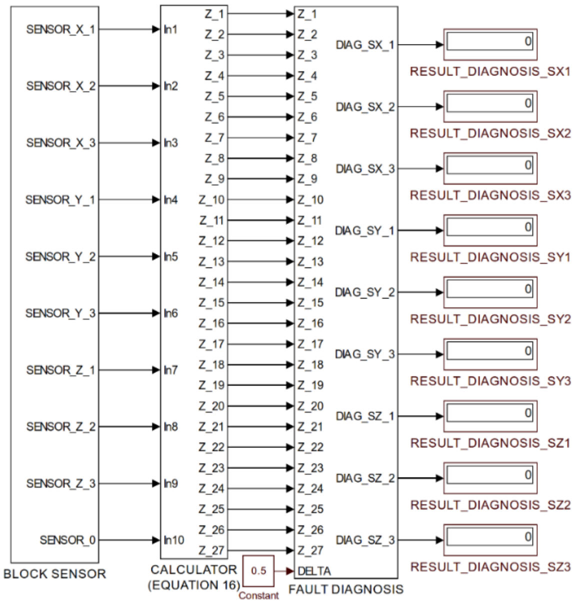

Fig. 14. Diagram simulation of fault diagnosis algorithm of improved sensors block.

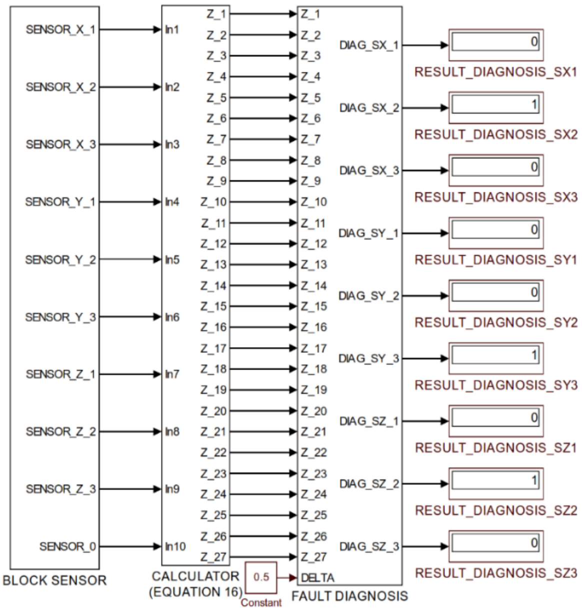

Fig. 15. Simulation results in case of fault sensors X_1, Y_3, Z_2

After that, we assume that the sensors X_2, Y_2, Y_3, and Z_2 fail, and we will have the results in Fig. 8.

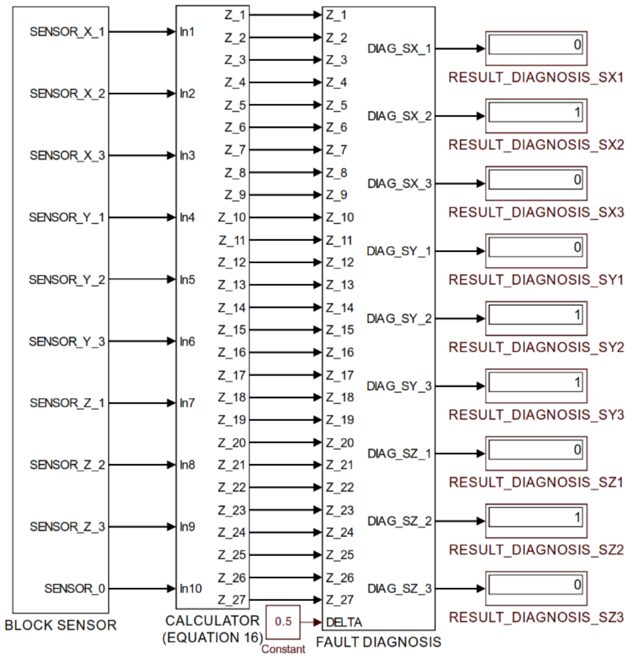

Fig. 16. Results in the case of fault sensors X_2, Y_2,Y_3, Z_2

4. Conclusions

In this paper, we developed a method for detecting and estimating the faults of angular velocity sensors in aircraft control systems, which can be used to expand block sensors' information. The simulation results show that the algorithm presented in Fig. 7 is entirely correct. Therefore, based on the results, we can expand the information of the angular velocity sensor. At this time, the output signal is an angular speed parameter and a failure signal of each sensor to warning the user.

Based on the sensors unit's information expansion method, it improves the control system's efficiency and ensures the safe operation of the aircraft based on multiple information sources. This method can be used for the same sensor in other systems in aircraft. However, this method stops the failure level. The subsequent studies will upgrade the algorithm to identify failure pattern and propose solutions to fix them.

Abbreviations

UAV : Unmanned Aerial Vehicle
FDD : Fault Detection and Diagnosis

CRediT Author Statement

Hong Son Tran: Conceptualization, Methodology, Software, Investigation, Validation, Writing-Original Draft. **Dinh Dung Nguyen:** Conceptualization, Methodology, Writing-Review & Editing, Visualization, Supervision. **Thi Thuy Tran:** Conceptualization, Methodology, Software, Investigation, Validation, Writing-Original Draft. **Quoc Dat Dang**: Conceptualization, Methodology, Software, Investigation, Resources, Writing-Original Draft. **Hong Tien Nguyen:** Conceptualization, Methodology, Software, Resources, Investigation, Writing-Original Draft.

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Research Article

A Study on Aerodynamic Behavior of Subsonic UAVs' Wing Sections with Flaps

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Abstract

This study, it is aimed to assess the aerodynamic and flight effects of the flap design on an airfoil. For this purpose, the NACA 4415 type wing profile, which can also be used in unmanned aerial vehicles (UAVs), is selected. The original design and the +5-degree flapped design which has constant other design features, are compared. Assessments are performed under constant Reynolds numbers and an angle of attack between 0-10 degrees with a 1-degree interval. Analyses are made using the open-source software XFLR5. For the flapped design is named NACA 4415-2, some basic aerodynamic performance parameters such as coefficient of drag (C_D), coefficient of lift (C_L), coefficient of pressure (C_p), maximum lift coefficient (C_{lmax}) and minimum stall velocity (V_{stall}) have been observed. According to results, when the flap with 5o is added to the airfoil, it has been observed that the C_L and Lift force of the original design of the airfoil increase significantly, C_D of the airfoil increase partially. The pressure coefficient tends to decrease significantly. Furthermore, it has been observed that while the minimum stall velocity has decreased, C_{lmax} values increased.

Keywords

Aerodynamic Performance
Wing Design
UAVs
NACA 4415
XFLR5

Time Scale of Article

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1. Introduction

Today, most of the budgets or investments made for UAVs are within the scope of military activities. These military activities are mainly in the form of control, surveillance, and intelligence activities. Apart from these, another area of use in the military field is the workgroups such as chemical, biological, nuclear, and radiological activities. Contrary to popular belief, UAVs are not used only in military applications. The UAV industry has developed rapidly, especially with the United States government allowing UAVs in civil aviation besides military fields. The use of UAVs is increasing. Especially in dangerous and risky applications and in areas where human use is inefficient and takes a long time, it is preferred because of the convenience it provides. It can also be preferred frequently in nuclear activities, which is detrimental for the human. Internet services and social media applications used in all areas of life also benefit from UAV technology. It is thought that UAVs in both civilian and military aviation will reach much wider dimensions in the future. It is foreseen to be used for air transportation, air battles, direct target scanning-recognition-destruction, destruction of enemy air defence targets, network node combat contact, electronic attack, defence, or attack against attack. Cost reduction is aimed at the production stage of UAVs. At this point, considering that UAVs also go through similar R&D processes; All component/system designs, calculations, analyzes, modelling, and simulations appear to be serious financial items for UAVs as well. Because the design-calculation-analysis-modelling simulation stages are the first and most important steps of UAV system production. These stages offer opportunities such as making repeatable tests and

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system verification. In this way, various studies are carried out to reduce costs. Free software studies have an essential place in these studies. Their quality and functionality vary, as they are generally carried out independently. Free software studies primarily focused on mechanical and aerodynamic parts. Because these two parameters are the areas where the designer has the highest capacity to act. There are many successful studies on this subject. With these studies and created software, costs are reduced, and efficient use of resources is provided (Gupta et al., 2013, Yigit et al., 2013; Vogeltanz, 2016; FAS, 2021a; FAS, 2021b; Quintana, 2008; Nonami et al. 2010).

From the aerodynamic perspective, wings are crucial for any aerial vehicle and other design components. Wings are the building blocks of a suitable aircraft, and airfoils are the core component required to craft a well-designed wing. Due to their smaller size and velocity, UAVs (Unmanned Air Vehicles) need wings other than typical aircraft. The design of the wings for such aircraft must be carried out with data from previous airfoil studies. An airfoil is a cross-sectional form of an object that produces an aerodynamic force as it is moved through fluid-like air. Airfoils are used as wings for lifting or propeller blades for thrust output on aircraft. Both these forces are produced perpendicular to the airflow. The unit of this force is called lift, which is perpendicular to motion direction. The element is called the drag parallel to the movement direction. Airfoils are based on the main camber and the chord of two different forms. The symmetrical airfoil without a camber produces a lift on either side and also while flying inverted. To prevent the aircraft to swing too far to the right or the connection without any manual input, the airfoils present in stabilizers and rudders must be of a symmetrical design. The other type of airfoil is an asymmetric airfoil with a medium chord camber. These types of airfoils generate uneven lift and are much safer for conventional aircraft than symmetrical airfoils. They are used to produce more lift than symmetrical wings in the wing section of the aircraft. When aircraft are inverted, asymmetric airfoils do not produce lifts. Therefore, for acrobatic aircraft, only symmetrical airfoils are used. These considerations affect the selection of the aircraft type to be used. Preliminary calculations and estimates that are vital for selecting an airfoil have to take place before the design and analysis process is started (Phillips, 2004; Khan, 2019; Joseph, 2020; Akdeniz, 2020).

The earliest significant work started in the late 1800s on the development of airfoil parts. H.F. Phillips patented a sequence of airfoil types in 1884. They were tested in one of the earliest wind tunnels in which "artificial currents of air were produced from induction by a steam jet in a wooden trunk or conduit." A large proportion of airfoils have been developed and tested by the National Aeronautics Advisory Committee (NACA). The UIUC Airfoil Coordinates database now offers the modern airfoil database. The designers still have not specified the perfect airfoil. The fact that the flow conditions and the design objectives vary from one application to the next explains the modern airfoils. The subsonic flight designs of airfoil vary from those of supersonic flight. Subsonic flight airfoils have a characteristic shape with a rounded leading edge, followed by a sharp trailing edge, often with a symmetric curvature of upper and lower surfaces (UIUC Aerofoil Coordinates Database, 2020; Joseph, 2020; Alam et al., 2021; Phillips, 2004; Khan, 2019; Akdeniz, 2020).

Even though studies on the aerodynamics of airfoils have been conducted for a long time, driven by the needs of applications, the knowledge obtained thus far is limited due to recent developments such as small wind turbines, rooftop wind turbines, UAV, MAV, and NAV. Because the vehicles mentioned above and systems operate at low Reynolds numbers in the order of 104-106, the effect of turbulence intensity on airfoil aerodynamic performance is significant. At low Reynolds numbers, the presence of turbulence can effectively delay the flow separation caused by the transition and cause significant aerodynamic performance changes. To better understand the ability of turbulence to influence the aerodynamic characteristics of an airfoil, a detailed experimental study is required (Arunvinthan et al., 2019).

Some researchers have investigated the performance behaviour of airfoils as experiment-based or software-based. Some of them are given as follows (Srinivasan et al., 1995). studied an airfoil oscillating for the assessment of turbulence models in unstable flows. It uses various turbulence models to operate on NACA0015 airfoil. Experimental findings have shown a good consistency with the lift, drag and moment coefficient spalart Allmaras turbulence model (Chervonenko et al., 1993) studied the effect of AOA on the non-stationary aerodynamic characteristics (Chuprun, 1993).

Investigated the deviation and validation of aerodynamics characteristics of NACA 0015 airfoil at different value of attack angle at different air velocities by determining the forces at every two degrees from 00 to 180 for experimental and numerical method (Rubel et al., 2016). While the authors used the low-speed wind tunnel in the experimental stage of the study, they used the ANSYS software in the numerical stage. At the end of the study, the authors claimed that both lift and drag coefficients rise as the attack angle is raised. The coefficient of drag gradually is dropped as the Reynolds number rises. However, the rise of Reynolds number coefficient of lift rises slightly and once at a certain point reduces (Rubel et al., 2016). Have examined the aerodynamic performance of a VAWT with Gurney flaps (Yan et al., 2020). The studies showed that the rotor's performance improves in the low tip-speed regime but degrades at higher rotational speeds. The Gurney flap heights used in these studies were limited to two values (Yan et al., 2020).

The primary purpose of this study is to investigate the aerodynamic behaviour of the new design (with a 5-

NACA 4415 type airfoil flap is added. Analyzes were performed under constant Reynolds numbers and an angle of attack between 0-10 degrees with a 1-degree interval.

2. Methods

2.1. Theoretical Background

Fluid viscosity is the most significant fluid element for low-speed airfoils. The viscosity produces lifting force indirectly, produces direct drag force and induces fluid separation. The Reynolds number expresses this influence. The ratio of inertial forces to viscous forces (internal friction) in any fluid is called the Reynolds number. The Reynolds number and its dependent parameters are shown as in Equation (1) (HF, 1979; Chen et al., 2017):

$$\mathrm{Re} = \frac{\rho V_0 l}{\mu} \tag{1}$$

In Equation (1), V_0 is the average velocity of the flow, L is the characteristic length of the flow, μ is the dynamic viscosity, and ρ is the fluid density (Chen et al., 2017).

Airfoil architecture is an important element in aerodynamics. Various flight regimes show varying outputs. There are fundamental differences between symmetric and asymmetric airfoil like at zero-degree angle of attack; asymmetric airfoils can produce lift, whereas a frequently inverted flight suits symmetric airfoil as in the case of an aerobatic aircraft. Therefore, without boundary layer separation, we can use various angles. Subsonic airfoils have a round leading edge that is naturally insensitive to the angle of attack (Amano et al., 2009; Kanimozhi, 2018). The cross-section geometry of an example airfoil is shown in Fig. 1.

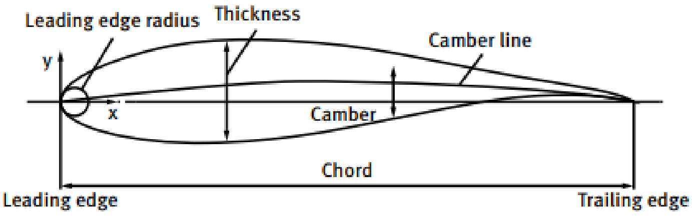

Fig. 1. The geometric parameters for an airfoil (Chen et al. 2017)

The leading edge is defined as the point on the front of the airfoil with maximum curvature. At the back of the airfoil, the trailing edge is known as a minimum point of curvature. The straight line joining the leading edge and trailing edge of the airfoil section is the chord line. The chamber line is the point locus between the top and the bottom of the airfoil. A different angle between free stream speed and chord lines is determined by taking the angle of attack. It is called the ratio ratio ratio of the span of an airfoil to the chord length of an airfoil (Kanimozhi, 2018). Mach Number is another important parameter in airfoil architecture. Equation (2) represents the relation of the Mach number to local velocity and speed of sound (Chen et al., 2017; Drela, 1982; Yi et al., 2005; Qian, 2005).

$$Ma = \frac{V}{V_C} \tag{2}$$

The reacting force is generated by the wind interacting with the upper and lower airfoil. Two surface forces are obtainable; one is the normal force, that is to say, pressure; the other is the tangential force, that is, friction. Typically, the lift is the force component perpendicular to motion direction. Drag is called the component parallel to the movement direction. The pressure coefficient is defined as (Chen et al., 2017):

$$C_p = \frac{p - p_0}{\frac{1}{2}\rho V_0^2} \tag{3}$$

In Equation (3), p_0 is the pressure in the free flow, p is the pressure to be obtained. When the flow hits the airfoil surface, there is a stagnation point at the leading edge. The stagnation point is defined as the point at which the fluid's local velocity is zero, and the pressure is at its maximum, i.e., the pressure coefficient Cp = +1.0. Starting from the stagnation point, the flow over the stagnation line travels a short distance before bypassing the leading edge and proceeding along the upper surface to the trailing edge. At the leading edge, the flow will reach a high local velocity. The larger the AOA (Angle of Attack), the further back the stagnation point is and the higher the local velocity at the leading edge. The lowest pressure that corresponds to the peak speed could be highly negative. Meanwhile, the higher the AOA, the lower the pressure point is for the same airfoil (Chen et al., 2017).

Characteristics of a lifting airfoil usually mean the lifting coefficient curve vs AOA. The lift coefficient Cl is defined as (Chen et al., 2017):

$$C_l = \frac{L}{\frac{1}{2}\rho V_0^2 c} \tag{4}$$

In Equation (4), L is the lift, ρ is the density of the flow, V0 is wind speed, and c is the length of the airfoil chord (Chen et al., 2017).

The Airfoil drag characteristics usually mean the curve of drag coefficient Cd variation vs AOA, but can also refer to the curve of drag coefficient vs lift coefficient (Chen et al., 2017).

$$C_d = \frac{D}{\frac{1}{2}\rho V_0^2 c} \tag{5}$$

A plane force system is a theoretical mechanics synthesis of a force and torque at a given point. Pressure distribution on the surface of an airfoil can also be a synthesis of a force and a torque at a specific point. This torque is referred to as the pitching moment. In aerodynamic studies, this point is referred to as the acting point of force because the aerodynamic airfoil centre is incremental at the point of the lift, i.e., the torque at this point does not change with AOA. The pitching moment coefficient, like the lift and drag coefficients, is defined as follows (Chen et al., 2017):

$$C_m = \frac{M}{\frac{1}{2}\rho V_0^2 c^2} \tag{6}$$

Pitching moment characteristics of an airfoil are typically defined as the curve of pitching moment coefficient Cm vs AOA. This curve varies linearly in the attached flow area, while the pitching moment coefficient remains constant around the aerodynamic centre (Chen et al., 2017).

2.2. Airfoil Selection and Operating Parameters

NACA 4415 type of airfoil was chosen for the analysis. The airfoil geometry is taken from Aerofoil Coordinates Database (UIUC, 2010). On the other hand, XFLR5 software was used for the software-based analysis. The software is open to public use and does not require any license (XFLR5, 2020; Yilmaz, 2018; Akdeniz, 2020). The analysis was performed depending on the following conditions.

Operating Conditions:

- Evaluations were performed via XFLR5 open code software.
- Discussed elements are the original design, NACA 4415, and flapped design, which added a 5-degree flap.
- Non-changeable Reynolds number which is 100,000.
- Angles of attack range is 0o to 10o degrees and 1-degree intervals.
- Analyses were made at subsonic velocity value and considering 0.25 Mach number.
- Monitored parameters are aerodynamic coefficients of airfoil Cd, CL, and Cm for the original design and flapped design.

Beyond all of this, since the minimum stall velocity is an important parameter for the UAV characteristics, this parameter is also considered and compared for both cases. The minimum stall velocity is calculated according to Equation (7) (Selim, 2018; Akdeniz, 2020):

$$V_{stall} = \sqrt{\left(\frac{2Wg}{\rho S Cl_{\max}}\right)} \tag{7}$$

In Eq. (7), W is the total weight of the UAV to take-off, S is the wing surface area, and $C_{l\max}$ is the maximum lift coefficient. Thus, $C_{l\max}$ value indicates the maximum C_L value that the wing profile can reach (Selim, 2018; Raymer, 2018; Akdeniz, 2020).

3. Results

The aerodynamic behaviour of the NACA 4415 type airfoil between 0 - and 10 - degrees angle of attack and a fixed 100,000 Reynolds number was obtained through the XFLR5 software. The results obtained first original design and then flapped design were combined. Once the conditions are determined, the lift and drag coefficients changes for the original design and flapped design in which both cases depending on the angle of attacks are given in Figure 2.

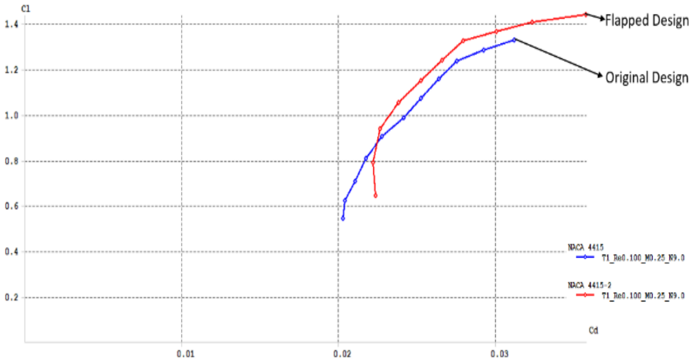

Fig. 2. C_L-C_D variations due to angle of attack values

In Figure 2, the red line shows the design with a 5-degree flap added to the airfoil, while the blue line shows the original design. Figure 2 indicates that when the flap with 5-degree is added to the airfoil, it has been observed that the Lift coefficient (C_L) and Lift force of the wing increase significantly. In addition, the maximum coefficient of lift value was obtained when the angle of attack is 10 - degrees. The changes of the pressure coefficient for both cases depending on the angle of attack are given in Figure 3.

In Figure 3, the pressure coefficient of the Airfoil design with an added 5° flap tends to decrease significantly compared to the original design. The changes of the C_L/C_D for both cases depending on the angle of attack are given in Figure 4.

Figure 4 denotes that when the flap with 5° is added to the airfoil, it has been observed that the drag coefficient (C_d) of the wing increase partially.

According to Equation (7), V_{stall} results for both cases are obtained to be following:

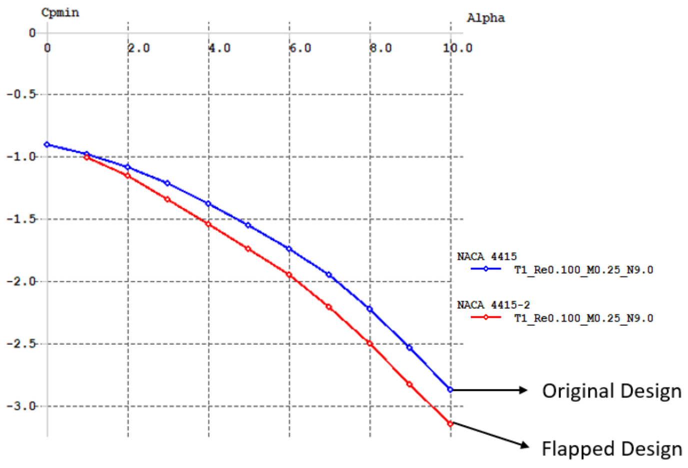

Fig.3. C_{pmin} variations due to angle of attack values

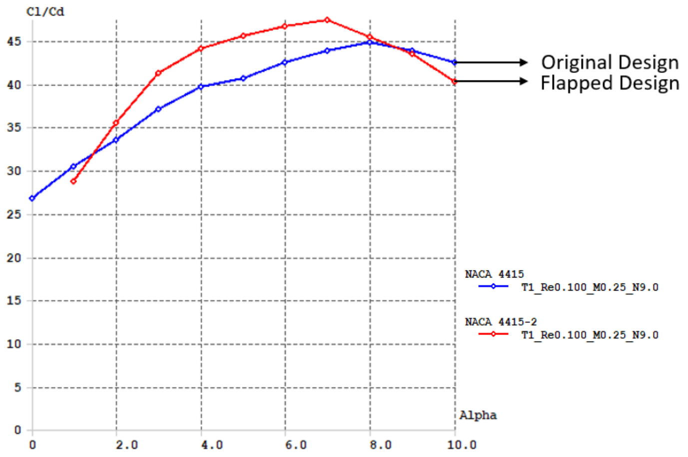

Fig. 4. C_L/C_D variations due to angle of attack values

When the flap is added to the original design, the minimum stall velocity has decreased because wing weight and wing area increased. Additionally, C_{Lmax} value increased. The maximum C_{Lmax} value was obtained when the angle of attack was 10°.

4. Conclusions

This paper aims to analyze the aerodynamic behaviour of a NACA 4415 type airfoil at a fixed Reynolds number with a value of 100,000, angle of attack values between 0-10°, and when a 5° flap is added to the airfoil design. Although the flapped design is named NACA 4415-2, some basic aerodynamic performance parameters have been observed using XFLR5 software. When the flap with 5o is added to the airfoil, it has been observed that the C_L and Lift force of the original design of the airfoil increase significantly, C_D of the airfoil increase partially. The pressure coefficient tends to decrease significantly. Furthermore, while the minimum stall velocity has decreased, C_{Lmax} values increased.

Nomenclature

UAV : Unmanned Aerial Vehicle
C_L : Lift Coefficient
C_D : Drag Coefficient
C_M : Center of Gravity
F_L : Lift Force
AOA : Angle of Attack
ρ : Density of Air
V : Inlet Velocity of Air
V_{stall} : Minimum Stall Velocity
A : Area of the Airfoil
F_D : Drag Force
R_e : Reynolds Number
μ : Dynamic Viscosity of the Fluid
c : Chord Length

Acknowledment

The author of this paper states that the presented work is an extended version of conference proceeding entitled “Performance Analysis Of A Wing Used In Unmanned Systems " which presented in ISEAS 2020.

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Review Article

Overview of Studies on the Cognitive Workload of the Air Traffic Controller

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Abstract

Air Traffic Control Officer (ATCO) will be the branch that will have the most impact on the air transport system. The duty of ATCOs is to prevent the collision of airplanes in the air provided by the controllers on the ground and overcome the possible confusion. Being exposed to a very high cognitive workload of ATCOs, one of the high-risk occupational groups, is important in terms of flight safety. However, it has been observed that studies on the differences in cognitive workload that may occur between experienced and inexperienced ATCO under different task difficulties are quite insufficient in the literature. This study presents research studies on cognitive workload measurement methods and ATCO's cognitive workload. In this study, the importance of determining the cognitive workload and its measurement methods is explained. In addition, literature studies related to the cognitive workload of ATCOs, particularly by using eye tracker, are presented.

Keywords

Cognitive Workload
Air Traffic Controller
Eye Monitoring Device

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1. Human Factors

Ergonomics (or human factors) is an applied discipline that draws on basic research in (behavioural) science and engineering and fieldwork and experience in industrial practice and many other domains. The goal of Ergonomics is to match how people work, their environment, their tools and equipment, and the products they use to human qualities and limits (Moray, 2005).

Bailey (1982) describes a similar tendency to equate poor system performance with poor human performance. However, detailed analyses of accidents and near-accidents reveal that human error is rarely the sole cause of poor system performance. Bailey cites three examples, including Three Mile Island nuclear incident and aircraft accidents, to illustrate this point. In order to understand why accidents, errors, or any unexpected system behaviours occur, one must look beyond human behaviour to the rest of the system. Important factors which need to be investigated are:

1. Design of system components, particularly human-machine interfaces.
2. State of the system leading up to the incident (e.g., stable/unstable, quiet/busy, on a course/off course, etc.)
3. Operator's cognitive and physical workload
4. Work organisation (e.g., shift system and during shift, supervision, design of workgroups)
5. External factors (e.g., weather)

It is now universally acknowledged that human error is cited as the primary cause of about 70% of aircraft accidents (Edwards, 1995). The term "human factors" has grown increasingly popular as the commercial aviation industry has realised that human error, rather than mechanical failure, underlies most aviation accidents and incidents. Human factors involve gathering

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information about human abilities, limitations, and other characteristics and applying it to tools, machines, systems, tasks, jobs, and environments to produce safe, comfortable, and effective human use. Human factors are dedicated to better understanding how humans can safely and efficiently integrate with the technology in aviation. Despite rapid gains in technology, humans are ultimately responsible for ensuring the success and safety of the aviation industry. Therefore, they must continue to be knowledgeable, flexible, dedicated, and efficient while exercising good judgment. Because technology continues to evolve faster than the ability to predict how humans will interact with it, the industry can no longer depend on experience and intuition to guide decisions related to human performance. Instead, a sound scientific basis is necessary for assessing human performance implications in design, training, and procedures, just as developing a new wing requires sound aerodynamic engineering. In addition, human factors specialists participate in analysing operational safety and developing methods and tools to help operators better manage human error (Graeber, 2021).

Aviation as a system is safe. Safety is made by people doing the work every day. Safety is made at the intersection of man (a human being), machine (an aircraft, a helicopter or an airplane) and procedures. Nevertheless, safety is also made at the confluence of boundaries:

- The boundary of economic failure
- The boundary of functionally acceptable performance
- The boundary of unacceptable workload.

Human Factors has come to be concerned with diverse elements in the aviation system. These include human behaviour and performance; decision-making and other cognitive processes; the design of controls and displays; flight deck and cabin layout; communication and software aspects of computers; maps, charts and documentation; and the refinement of staff selection and training. Each of these aspects demands skilled and effective human performance (CAA-CAP 720, 2002).

Aviation management is becoming more and more critical with the increasing passenger capacity and the number of flights. With the automated world, aviation management also reduces the human factor. With systems such as ADS-B (Automatic Dependent Surveillance-Broadcast) and Mode-S that provide faster and more reliable data transfer to the ATCO, human-caused errors in aviation management are tried to be prevented.

In the second section of this study step, the cognitive workload is briefly explained to better understand the importance of determining the cognitive workload as the main subject of this study is cognitive workload and ATCO. In the third section, cognitive workload measurement methods are presented. Then literature studies related to the cognitive workload of ATCOs. The final section provides a conclusion based on the research explained in other sections, and future research are explored.

2. Cognitive Workload

In the world countries which developing as industrially since the middle of the 20th century has increasing tendency work which has consisted of cognitive work rather than physical work.

Many of us are familiar with this kind of work, such as driving a car and using a computer. In addition, many of the work named high risk are characterised by more cognitive demands than physical demands. The work of pilots, train drives, medical personnel and process control operators can be given examples of such jobs (Megaw, 2005).

There is no universally accepted definition of cognitive (or mental) workload, and it is often considered by analogy to the physical workload. However, it can be said that cognitive workload refers to all cognitive activities such as estimation, decision making, communication, identification and search, and is defined as the relationship between the cognitive resources required to perform a task and the ability of individuals to use these resources. The cognitive workload is a subjective concept that cannot be measured directly or considered an absolute value. However, given that the human mind can process the information at a limited rate, then the cognitive workload is the percentage of the capacity used at any time point (Galy et al., 2018).

Gopher and Donchin (1986) stated that cognitive workload was a feature of direct response, rules, control systems that mediate between stimuli and information processing. The researchers emphasised that cognitive workload was characteristic of the human-workload cycle. The effects of workload on human performance were studied only concerning the model of the human processing process.

The workload is often defined in terms of getting the job done or job requirements factors. However, since these factors are related to complex situations, it would be pointless to think of the workload in only one direction. Therefore, these factors are briefly as follows.

Task Demands: Task demands can be defined as the workload resulting from the analysis of the jobs requested from the operator. However, individual differences must be considered. For example, a novice and an experienced person will experience different workload levels while performing the same job.

Effort: It is the value of effort on the job. (e.g. cognitive processing resources distribute consciously) When exposed to high job demands, one should not choose to increase the level of effort within this situation.

Performance: Most studies on workload deal with the levels of performance that is achieved. However, performance measures cannot be alone considered as a sufficient measure of workload. (Farmer et al., 2003)

It is simply the amount of cognitive effort that one puts into a task, and requires actions such as concentration, reminder, decision making, and attention, and is essentially related to the individual's cognitive abilities and how the information is received and processed, and at the end leads to decision making and action, In other words, Cognitive Workload is a level of cognitive need or an analytical effort required by an individual to fulfil the physical, spatial, and environmental demands of a specific task (Safari et al., 2013).

Cognitive fatigue is characterised by subjective feelings of "tiredness" and "lack of energy". This psychobiological state has been extensively researched on professions where cognitive demand is very high, such as drivers and air pilots and its contribution to the development of work-related musculoskeletal disorders (Goode, 2003).

Determining the workload in cognitive work has increasing importance. The reason for this situation can be listed as follows:

1. When the operator has to work around the limits of his/her capacity, the probability of errors occurring is very high.
2. Load reactions occur when the operator has to work for a long time under high workload conditions.
3. When the factors that constitute a high workload can be identified, job structuring and working environment can be developed.
4. When the expected workload is known, new jobs or job assignments can be made more quickly.
5. Workload determination is also essential in wage policy, personnel selection and personnel training (Fığlalı, 1998).

According to Sanders and McCormick (1993), a useful measure of cognitive workload should meet the following criteria:

1. *Sensitivity*: The measurement must distinguish intuitively arising business situations that require different levels of workload.
2. *Selectivity*: The measurement should not be affected by factors that are not usually considered part of the cognitive workload, such as physical load or emotional stress.
3. *Interference*: The measurement should not interfere with the performance of the primary task whose workload has been previously assessed.
4. *Reliability*: The measurement must be reliable; the results must be reproducible over time.
5. *Acceptability*: The measurement technique must be accepted by the person being measured.

2.1. Reasons for Measuring Cognitive Workload

The most important reason for measuring cognitive workload is measured cost of jobs to estimated performance of system and operator. Although this is an intermediate measure and is also used to compare system designs, procedures, or person assignment requests where increasing business demands lead to unacceptable performance, workload metrics assess the system's attractiveness if performance measures fail to distinguish between options. This approach is implicitly believed that as the work gets harder, performance often decreases, the response of time and errors increase, control variability increases, per unit time, is completed too little work, job performance strategies change. There is the less residual capacity to deal with other issues.

Although it is generally accepted that there is a difference between workload and performance, it is not well understood. Within a situation, part of the system designer's goal is to optimise system performance and workload (Cain, 2007).

3. Cognitive Workload Measurement Methods

There is no direct method for measuring cognitive workload. Instead, some measurements have been developed. Common types of indirect cognitive Workload measurement techniques include the following components:

- Physiological Measurements (EEG, Eye Tracker)
- Performance Measurements (Primary Task Measurement, Secondary Task Measurement
- Subjective Measurements (SWAT, NASA-TLX)

Neither of these techniques is a mere measure of cognitive workload. The influence of other factors distorts each one. Combining two or more techniques is recommended as the most effective approach (O'Donnell and Eggemeier., 1986; Yazgan and Erol, 2013).

3.1. Physiological Measurements

One approach to evaluating cognitive workload is used to the physiological signals received from the operator. Changes in cognitive activities (including cognitive workload) are associated with changes in the body function in some measures. This measurement's rationale is that the information processing process involving the central nervous system, or its indicators, is measurable (Sander and McCormick, 1993). The most commonly used measurements are; heart rate, blink rate, breathing rate, and brainwave activity (Wilson and Eggmeier, 2006; Yazgan and Erol, 2013).

3.1.1. Eye Tracker

Visual information is essential in one operation of many systems. Operator blinking speed is reduced in high workload situations with a significant visual component. Blinking is usually measured electrophysiologically or using small cameras. Blinks are determined, and their speed, length of closure and amplitude are measured. There are many situations where blinking speed does not decrease in some of the visual demands of a job. Blinking is sensitive and diagnostic (Wilson and Eggmeier, 2006; Yazgan and Erol, 2013; Palma Fraga et al., 2018; Palma Fraga et al., 2020).

With the eye tracker, the pupil radius of the participants, the number of blinking, the mean blink time, the number of eye fixation, the eye fixation time, the average number of fixations, the frequency and number of eye saccades, and finally, the average eye saccade time can be measured. Blink duration and saccadic distance are expected to decrease inversely with the air traffic density in the eye-tracking device. The pupil diameter is expected to change in direct proportion. However, in the planned experiment, the areas of interest (AOI, Area of Interest) will be created. It is planned to reveal the browsing time and eye heat map on the AOI of the participants and reveal whether there is a difference between experienced and inexperienced. In this study, air traffic controllers, one of the critical elements in Air traffic Control and Management, are divided into two groups as experienced and inexperienced. It aims to measure cognitive workloads with Eye-Tracking Device. However, it is planned to conduct a statistical analysis of whether the possible cognitive fatigue levels of the air traffic controller, which plays at least as many roles as the pilot for flight safety, correlate with work experience under different task difficulties.

Every stage of cognitive fatigue such as blink rate, fixation number and fixation time can be monitored gradually with the Eye tracker, which can be considered as newer than other methods. In addition, the Eye-Tracker, which is easier to analyse than other physiological measurements, is a lightweight device.

In addition to eye-tracking technology, other approaches are available based on neuro-ergonomics, the science that investigates the relationship between human behaviour and the brain (Parasuraman and Rizzo, 2007; Parasuraman, 2003) to understand the underlying mechanisms of the brain. These techniques generally consist of quantifying changes in the human brain electromagnetic or hemodynamic activity. They are both sensitive to changes in human mental workload (Parasuraman, 2011) while exposed to complex tasks. On the other hand, hemodynamic activity can be measured through a functional near-infrared (fNIR) spectroscopy device to quantify changes in blood oxygenation during neural activity (Izzetoglu et al., 2004; Izzetoglu et al., 2005; Bunce et al., 2006; Izzetoglu et al., 2019; Palma Fraga, 2020).

Electroencephalography (EEG) has long been a cost-effective method for assessing cognitive workload. Cognitive workload increase is consistently correlated with an increase in the frontal theta (4-8 Hz) and beta (13-30 Hz) band power and parietal alpha (8-12 Hz) band power. However, despite the high temporal resolution, EEG suffers from difficulties with localisation of the sources and an associated low spatial resolution (Aghajani et al., 2006; Parasuman and Wilson, 2008; Ayaz et al., 2012; Palma Fraga et al., 2020).

Furthermore, physiological analyses including electrocardiography (EKG), electromyography (EMG), respiratory measurements, electrodermal activity (EDA) (Caldwell et al., 1994; Wientjes, 1992) and skin temperature measurements are also included in the studies conducted on the determination of mental workloads. In addition, oculometric analysis, including the acoustic properties of human speech, eye gaze and pupil analysis, and facial analysis are also evaluated in studies (Wilson and Eggemeier, 1991; Ćosić et al., 2019a; Ćosić et al., 2019b; Kesedžić et al., 2020). In this context, one of the most researched psychophysiological measures is related to changing cardiac activity (e.g. heart rate variability) during mental workload (Speyer et al., 1988; Aricò et al., 2017).

3.2. Performance Measurements

Performance metrics indicate operator workload from some method of the operator's capabilities to perform a system function or a job (Wilson ve Eggemeier, 2006; Yazgan and Erol,2013).

Performance measures can be classified into two main types:

- Primary task measurements
- Secondary task measurements

Primary task measures are capable of discriminating the resource competition between individual differences. For example, speed instability, distance headway instability, a lateral position from road centreline, lane excursion, time spent out of lane can be widely used to represent the primary driver performances.

Secondary task measures are more diagnostic than primary task measures and subjective measures. The correct response, time response of additional secondary task is a well-known example of secondary task performance measures in driving research. For example, the sensitivity of secondary reaction time in general aviation training has been investigated regarding the differences in the difficulties within and between the two flight scenarios. Flight scenarios are designed to show different workload levels and are based on data from previous studies (Eggmeier and Wilson, 1991).

3.3. Subjective Measurements

Subjective measures are becoming an increasingly important tool in system evaluations and have been used extensively to assess operator workload. The reasons for the frequent use of subjective procedures include their practical advantages (ease of implementation, non-intrusiveness) and current data, which support their capability to provide sensitive measures of operator load. In addition, as human-machine systems have become more complex and automated, evaluations based on the operator's performance have become prohibitively tricky, and the need to assess subjective cognitive workload has become critical (Rubio et al., 2004).

3.2.1. NASA-TLX

Hart and Staveland developed the NASA-TLX Scale in 1988 to quantify the physical and cognitive cost or workload associated with performing a given task. Since its initial creation, the scale has seen widespread use in public and private industries to evaluate the benefits and possible interference caused by a set variable, such as a new form of technology. The NASA-TLX Scale has demonstrated very low interrater variability due to its category weighting system, which accounts for an individual's self-reported strengths and weaknesses (Hart et al., 2006)

The NASA-TLX provides the entire subjective workload value based on a weighted average evaluation over six subscales or dimensions. The six scales evaluated are:

1. Cognitive demands.
2. Physical demands.
3. Temporal, time demands.
4. Own performance.
5. Effort.
6. Frustration.

Each of the six scales is used to show the basis for the characteristics of the subjective workload. In the final part of the job, people make evaluations on each of the six scales. These evaluations are then weighted to the total workload related to the performance of the job based on personally generated data, including each dimension's contribution. The weighted evaluations are then combined to form the entire index of subjective workload (Eggemeier et al., 1991). NASA TLX is applicable to the in-flight simulator, real flight jobs, air defence, remotely controlled vehicles and different business environments such as signal sensing (Damos, 1991).

3.2.2. SWAT

The Subjective Workload Assessment Technique (SWAT) (Reid & Nygren, 1988) is a subjective rating technique that uses three levels: (1) low, (2) medium, and (3) high, for each of three dimensions of time load, cognitive effort load, and psychological stress load to assess workload.

Subjective techniques have the advantage of being reasonably easy to manage and explain and do not require extensive training or equipment to be implemented. However, although subjective workload measurements are frequently used in aviation applications, they tend to be situation-specific and fail to consider changes in the operator's emotional state, natural ability, experience, learning ability, and adaptation. Moreover, subjective measurements, when used alone, are insufficient to explain the brain mechanisms related to work performance, and more importantly, from a system design point of view, they cannot be used for continuous real-time monitoring of the workload (Öztürk, 2006).

4. Literature Studies Related to Cognitive Workload of ATCO's

Strang et al. (2014) searched that heart rate examined correlates of cognitive workload in a Large-Scale Air-Combat Simulation Training Exercise; measurements based on physiological data are expected in calculating cognitive workload in aviation.

Collet et al. (2003) studied that subjective aspects of cognitive workload in air traffic control cognitive fatigue was calculated with subjective methods. Contrary to this study, it was planned to use Eye Tracker because physiological data were considered more reliable methods.

When the literature was examined, it was seen that Eye Tracker in Aviation is less. Therefore, unlike other studies, it will be analysed the cognitive fatigue of ATCO by using the Eye Tracker device in our future work. In this study, literature studies about the measurement methods of cognitive workload, particularly by using eye tracker in the aviation sector, is examined.

Ahlstrom and Friedman-Berg (2006) calculated the cognitive workload that occurs when the meteorology radar is added to the working environment. 6 experienced air traffic controllers participated in this study. Eye tracker and subjective measurement methods were used in the calculation of cognitive workload. It was concluded that by increasing the number of aircraft, blink time and the distance of saccades decreased, and the pupil diameter increased. These results conclude that there is a positive relationship between subjective measurements and eye movements. In this study, the relationship between eye movements and cognitive fatigue was investigated, but no difference was revealed between experienced and inexperienced air traffic controllers.

Another study was carried out by Marchitto, Benedetto, Baccino, and Canas (2015). Inexperienced 26 students who do not wear glasses were included in the study voluntarily. Subjective, physiological (with eye tracker) and performance measurements were made in the study investigating the proportionality of the subjective methods of cognitive workload during the management of the airspace of the air traffic controller with the eye movements. Since the participants were inexperienced, the summary of the study and the distinction to be used in the study (1000 feet separation, 5 miles side separation) were explained, and the training was given beforehand. As a result of the study, a positive proportion was measured between total fixation number and fixation time and cognitive workload. In addition, there was a positive correlation between performance measures and subjective measurements. However, when the differences between this study and the planned study were examined, no distinction was made between experienced and inexperienced air traffic controllers. The difference in cognitive workload that could occur in any task change was not measured.

Di Stasi et al. (2010) evaluated the cognitive workload of inexperienced air traffic controllers in different task difficulties. In the study, cognitive workload calculation methods, eye tracking device for physiological measurements, MWT (Mental Workload Test) for subjective measurements and secondary task performance measurement methods were used. In the secondary business, method measurements were measured the number of wrong answers and non-responses. As a result, a positive correlation was found between task difficulties and subjective measurement results in this study. Contrary to expectations, although the number of wrong answers was expected to increase with the difficulty level, a decrease was observed. On the contrary, the number of non-responses increased. In this study, no distinction was made between experienced and inexperienced air traffic controllers.

Averty et al. (2004) examined cognitive fatigue in a real work environment. In this study, the subjective work method of 25 experienced and licensed air Traffic Controllers, who were assigned to approach control at the French Saint Exupery airport, was measured. In this study, the term TLI (Traffic Load Index) was found by adding the number of aircraft in the area of responsibility and time load. The study was planned in a way that each controller would perform 1-hour duty in a real environment. In this study, only subjective measurement methods were used as measurement methods and no distinction was made between experienced and inexperienced air traffic controllers.

Bruder et al. (2013) analysed the cognitive workload of experienced and inexperienced air traffic controllers to monitor the system during automated airspace control. Air traffic controllers and pilots participated in this study. Twenty-one of the participants is experienced and active in their duties. Eighteen participants are controllers, and three are pilots. Participants were asked to identify errors. AOI (Area of Interest) heat maps were created by measuring each participant with an eye tracker. As a result of the measurement, there was no significant difference between experienced and inexperienced participants. This situation related to that task of monitoring is mentally relatively simple. In this study, only physiological measurement was used as the measurement method. Airspace control and management did not exercise; only the task of finding errors was performed.

5. Conclusion

The aviation industry is an increasingly critical industry where the consequences of any human error can lead to the loss of many people's lives. For this reason, personnel working in every field in the aviation sector are essential, and the minor mistake that can be made can lead to negative results. The air traffic controller works with the most difficult critical decisions, with the effort and knowledge to make as soon as possible. For this reason, the cognitive workload of the air traffic controller is vital due to the criticality of its work. Within precise results cannot be obtained in measuring cognitive workload, different measurement methods are used.

Many methods can be used to measure cognitive fatigue. While some methods use physiological values, cognitive fatigue is calculated with the questions asked to the user in some methods. In this context, trying to calculate the cognitive fatigue of the ATCO with Eye Tracker, which can be considered new, will constitute the essence of our work. In a future study, we aim to use Eye Tracker, a physiological evaluation for evaluating the cognitive workload of ATCO. First, however, we will work on the simulation, considering flight safety. The number of subjects will be evaluated according to age, gender, and experience. A separate evaluation will be made for each group by planning an experiment using an eye-tracking device. Also, ANOVA statistics will be used in the variance analysis of the obtained data. With the completion of this experiment planned on mental workload, it is envisaged that it will shed light on schools that provide air traffic control training and airports and contribute to the relevant organisations to see the necessary measures to reduce cognitive-induced ATCO errors and to revise their processes. Furthermore, it is thought that this planned experiment will also be of great importance in terms of guiding the aviation literature.

Abbreviations

ADS-B	:	Automatic Dependent Surveillance-Broadcast
ANOVA	:	Analysis of variance
AOI	:	Area of Interest
ATCO	:	Air Traffic Control Officer
EDA	:	electrodermal activity
EEG	:	Electroencephalography
EKG	:	electrocardiography
EMG	:	electromyography
fNIR	:	Functional near-infrared
MWT	:	Mental Workload Test
NASA-TLX	:	National Aeronautics and Space Administration - Task Load Index
SWAT	:	Subjective Workload Assessment Technique
TLI	:	Traffic Load Index

CRediT Author Statement

Ebru Yazgan: Conceptualisation, Writing- Original draft preparation, Visualisation, Investigation, Supervision, Writing - Review & Editing, Project administration **Erdi Sert:** Visualization, Investigation **Deniz Şimşek**: Writing - Review & Editing.

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Research Article

Problems of Providing Travel Services to Inclusive Aviation Tourists: World and Ukrainian experience

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Abstract

The article examines the features of the development of the modern world tourism market and the problems of providing tourism services to inclusive aviation tourists. The world experience of air transportation of inclusive tourists in different countries is analysed. Analytical material is offered, reflecting the problems of airlines work in transporting tourists from inclusive groups. The prospects of the infrastructure of Ukrainian airports are assessed; problems associated with air services for people with different categories of inclusion, especially people with disabilities, are identified. The emphasis is on developing tourism in Ukraine as a segment of the Ukrainian economy within the framework of studying the issue of development and implementation of inclusive tourism in Ukraine. In this regard, the legal regulation of relations between representatives of air transportation and an inclusive tourist, who requires special conditions of movement, which is usually associated with physical health (people with heavyweight, older adults, pregnant women) or disability, are relevant. The research identified the problems and suggested solutions that relate to tourist services in developing a consistent, logical and compromise approach to providing comfortable services for air travel for people with disabilities and passengers of other inclusive categories.

Keywords

Inclusive air tourists,
Travel services,
Air travel,
People with disabilities

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1. Introduction

Tourism, in recent decades, was a powerful economic component that has been actively developing in the world, gaining constant momentum, introducing the best innovative technologies and accumulating significant financial flows, which for some countries were the primary source of income.

According to the World Tourism Organization (UNWTO Tourism Highlights, 2018), tourism has become the leading sector of the economy, accounting for 10% of world GDP and 7% of world exports (Bielousova, 2017).

For Ukraine, the tourism sector is one of the essential segments of the economic complex, supporting the economic development of the country and enabling Ukraine's competitive access to European and international tourism markets. (Bielousova, 2019)

Despite the significant recession in the global economy associated with the COVID-19 pandemic, tourism remains a multifunctional sphere of providing various services, including tourist air flights. People with

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inclusion require special attention to themselves (from the English inclusion - inclusion): persons with disabilities of various nosology, old people with physical and psychological health characteristics, people with “war syndrome”, large families, pregnant women and other members of society (Bielousova and Skorostetska, 2020).

For such categories of inclusive tourists, a certain accessible environment of existence is formed. Therefore, we propose to call an inclusive environment and the main task of creating comprehensive accessibility, comprehensive adaptation, and barrier-free.

The popularity of inclusive tourism is dynamically developing and increasing due to the continuous growth of the relative and absolute number of people of few mobile groups, people with various nosologies and types of disabilities worldwide and in Ukraine.

Integrating people with inclusion (people with disabilities) into Ukrainian society, their social activity and professional self-realisation remain practically unclaimed. And so far, there is only talk about inclusively accessible modes of transport.

In this context, a logical and consistent action seems to us to be a regular scientifically grounded monitoring of both the global and the national system of tourist services associated with the provision of a wide range of tourist services for all categories of people with inclusion, including transport services using the example of air transportation. Considering the popularity of air transport in the world, it must be stated that many companies create favourable conditions for passengers with inclusive travel, which means they are included in the program of creating an inclusive environment.

Therefore, the purpose of this article is to analyse the level of development of inclusive tourism, as a modern segment of the tourism industry in Ukraine (Bielousova, 2019), in the process of providing travel services for air transportation of people with inclusion, especially people with disabilities, taking into account the world experience of travel by air.

2. Literature Review

Scientists from different countries are engaged in inclusive accessibility and comfortable life, proposing their own algorithm for introducing inclusive tourism to create a comfortable environment for those who have disabilities or need social assistance.

Since 2006, the inclusion problems have been considered both by foreign experts in various fields and fields of science and by scientists from Ukraine and neighbouring countries. Various foreign scientific schools offer many research papers (Konanova, 2019; Le Man, 2011; Mezhevaya et al., 2015; Naumenko et al., 2015) highlighting the problems of theoretical substantiation and practical application of methods, techniques, developments that are associated with inclusive tourism, where tourism acts as an accessible, barrier-free environment that helps people with disabilities adapt (Bielousova, 2019).

Many authors associate tourism with sports (the institution of social tourism includes sports tourism), social protection (the institution of social protection includes rehabilitation tourism) and education (the educational institution includes children) as social institutions directly related to tourism (youth tourism) (Bielousova, 2020), separately considering rehabilitation or medical assistance (Bielousova, 2017).

The article also highlighted the issues of comfortable passenger transportation under the environmental conditions for the operation of air transport (State Aviation Administration of Ukraine, 2018) and focused on scientific and practical research of scientists of the National Aviation University in Kyiv (Yun and Marintseva, 2014; Zaporozhets and Synylo 2012; Zaporozhets, 2014; Boyko and Prusov, 2018).

At the formation and scientific substantiation stage, fundamental research on the development and implementation of inclusive tourism in Ukraine will be based on a comprehensible application methodology and a mechanism for the practical application of modern methods of socialisation of people with inclusion through tourism services. (Bielousova, 2019)

3 Research Methodology

The inquiry of the integration process and the practical solution of the problems of integration into society of persons with inclusion, and first of all people with disabilities, the development of its principles, mechanisms, key directions and the justification of practical recommendations, is an essential and urgent task of any society. (Bielousova, 2019)

Therefore, it seems logical to us to analyse the methodological research in air transportation, including tourism.

The methodological basis for the study of air transportation as a tourist product is made up of general scientific, analytical, and predictive methods and methodological techniques that provide a conceptual vision of the problem of air transportation of tourist flows, taking into account the specifics and transport policy of the country, the specifics and rules for the movement of tourists, as well as compliance with international standards for the transportation of air tourists.

System analysis allows us to consider any situation as a kind of object for study with a wide range of internal and external cause-and-effect relationships (Bielousova, 2019) which in this article are presented in the form of statistical data of quantitative and qualitative indicators of internal and external air transportation of passengers, with an emphasis on tourist transportation by air.

For the cost-effective transport of tourists, it is important to assess the optimal costs for both regular passengers and inclusive tourists. Therefore, the economic models of air transportation of tourists, taking into account the existing factors of market capacity, make it possible to determine the most rational strategies for using air transport, taking into account government funding for those companies that expand the range of services for categories of people with inclusion.

One of the popular methods of modern society is the information accessibility method. Considering a wide range of information sources, the task of a tourist or aviation enterprise is to make high-quality and reliable self-advertising about the services offered.

4. Analysis & Discussion

Tourism for people with disabilities, including international, is an urgent problem since, according to a study by the World Health Organization (2019), 785 million people aged 15 years and older live with disabilities (UNWTO Tourism Highlights, 2018), more than 1 billion people with disabilities, equivalent to 15% of the world's population. Moreover, this number is expected to grow in the coming years (Bielousova, 2017).

Demographic data also indicate that the number of older people and people with disabilities who want to travel by air will increase significantly in the future (UNWTO Tourism Highlights, 2018).

In the countries of the world, organising international tourism and the availability of travel for people with disabilities has already developed.

Based on this, we consider tourism in Ukraine a paradigm for sustainable development of the country, where tourism works for the stable development of regions, and not vice versa. In addition, through the prism of tourism activities, it is possible to stabilise the economic situation in the country, given the huge regional tourism potential, which includes transport infrastructure, in particular air travel. (Bielousova, 2019)

The existing international framework for inclusive tourism development include the UN Convention on the Rights of Persons with Disabilities, the 2030 Agenda for Sustainable Development, which provides targeted action in providing a variety of social services by businesses, including in the transport sector. In addition, the UN Framework Convention recognises that accessibility, freedom of movement and personal mobility are fundamental rights of persons with disabilities and that respect for these rights requires the participation of a wide range of different stakeholders. (Bielousova, 2017)

These and other documents apply to air transportation, being the regulators of consumer relations.

Despite the existence of such international legal norms and guidelines, the aviation industry is suffering the effects of a steady increase in the number of national/regional policies for people with inclusion. Again, the category of people with disabilities stands out. Unfortunately, these strategies can often be either inconsistent or in direct conflict with each other, leading to complications in the operation of airlines and confusion for passengers with disabilities.

To support the creation of consistent rules for ensuring accessibility and the provision of high-quality services, national air carriers develop principles and methods of tourism services, following national legislation and within the national policy of a particular country concerning people with inclusion, people with disabilities.

The rules of modern transportation require each person with a disability to coordinate their transportation with the airline and have a personal escort, which does not guarantee service by the airline - the carrier of people with disabilities. If earlier the airline could refuse transportation to a disabled person, citing the lack of "special conditions of transportation", today every self-respecting air carrier offers a certain range of services for the transportation of people of inclusive categories.

For tourists in wheelchairs, airports are equipped with travelators, special elevators, hygiene rooms (WC), accessible passages through the airport, special transport is offered for transporting tourists to the airport. Such tourists usually check-in for the flight first of all in the main queue or a separate area. One or more seats are retracted (folded) in the tail section of the aircraft. A disabled passenger gets on and off the plane last.

For people who do not see, an adaptable special floor covering is offered, which makes it possible to coordinate the movement of a person. When escorting a blind person on board an aircraft, special lifts are often used.

The studies carried out on the issue of safe air transportation of inclusive passengers made it possible to both confirm and refute the influence of the listed factors. Therefore, the question arises of creating a unified model of tourist services for inclusive air passengers. Furthermore, if we talk about people with disabilities, then the comfort of movement and the level of accessibility is a priority for them.

The problem of providing tourism services to inclusive aviators can be viewed from several aspects. Firstly, the process of providing air services for passengers with different inclusions and disabilities has clear rules spelt out in international and state regulatory documents, which are discussed, supplemented and revised over time.

To understand this issue, a clear understanding is needed for who can be referred to as inclusive tourists and why there are several problems associated with providing various kinds of social and tourist services for this category of people.

In comparison with the already well-known international typification of people with inclusion (older adults, overweight people, pregnant women, people with disabilities, etc.), in Ukraine, the author's typing is proposed (Bielousova, 2020), the editing of which is dictated by the socio-economic development in the country, the level of social security of Ukrainians, as well as modern historical events.

We include the following low-mobility groups of the population as an inclusive society: social group (Chernobyl victims, pensioners, pregnant women, large families and others); a group of people with disabilities (various groups of disabilities and nosologies) people with a "war syndrome" (Afghans, ATO military zones, migrants, persons with psychological trauma, war children, war veterans and others) (Fig. 1).

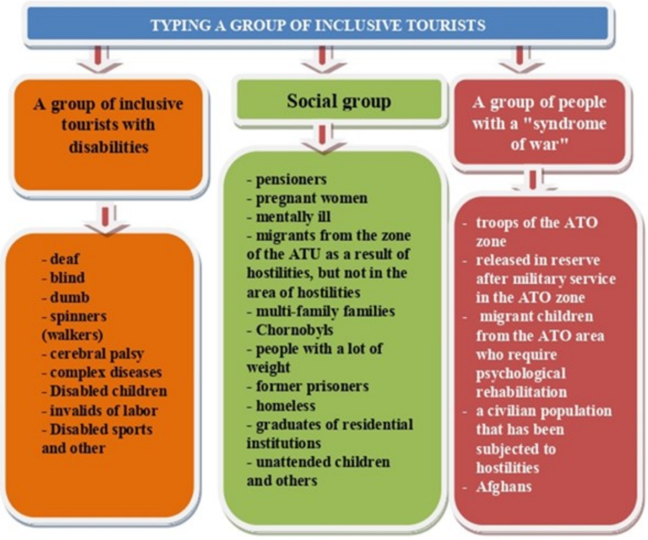

Fig. 1. The scheme of typing groups of inclusive tourists in Ukraine (Bielousova, 2020)

The most vulnerable in terms of socialisation and creation of a barrier-free comfortable environment are people with disabilities. Back in 2006, the United Nations (UN) adopted the Convention on the Rights of Persons with Disabilities (CRPD), making states responsible for supporting and protecting the rights of people with disabilities. (Bielousova,2018)

And the International Civil Aviation Organization (ICAO) has established International Standards and Recommended Practices (SARPs) in Appendix 9 to the Chicago Convention concerning the facilitation of formalities for persons with disabilities in air transport (Bielousova, 2017; Le, 2011)

The principles (main provisions) of this Convention are as follows:

- Respect for a person's inherent dignity, his independence, including the freedom to make his own choice, and independence.
- Non-discrimination (equal treatment of all).
- Full and effective involvement and inclusion in society.
- Respect for the characteristics of persons with disabilities and their acceptance as a component of human diversity and part of humanity.
- Equality of opportunity.
- Accessibility (free access to vehicles, places and information and the impossibility of denying access due to disability) (Boyko, 2018).

Economically developed countries in Europe (France, Germany, Great Britain, Austria, Sweden, Norway and others) and the world (USA, Japan, China, Turkey, Singapore and others) are considering the possibility of developing a new strategic policy related to ensuring accessibility in the aviation industry (Airbus, 2019).

In the air travel industry, the erection of inclusive accessibility barriers has a historical rationale:

1. Concern for the safety of the disabled person himself, incl. in emergency situations.
2. Concern for the safety of other passengers, whom a person with a disability can potentially interfere with during evacuation.
3. The need to provide additional types of services to people with disabilities, as well as other inclusive categories (people with heavy weight, pregnant women, elderly people, etc.) from airlines and the airport (Le Man, 2011).

In the last decade, the level of service in air transport has improved: it has become more comfortable, innovative and technologically advanced. As a result, the world's leading airports position themselves as universal organisations to provide air services. Air carriers compete in the passenger air transportation market to cover all categories of passengers, including those with inclusion.

For the sixth year in a row (2011-2019), Singapore Changi International Airport was recognised as the best airport. The TOP-5 also includes South Korean Incheon, Tokyo Haneda, airports in Hong Kong and Doha (Qatar) (AON, 2020; Boyko, 2018).

Among European airports, the top ten were German Munich (sixth), British London Heathrow (8th), Swiss Zurich (9th) and German Frankfurt (10th) (Boyko, 2018).

If we take the traffic statistics of the ten busiest airports in the world for 2016 and 2019, we can see a steady increase in passenger traffic, and proportionally in different countries of the world, Fig. 2 (Boyko, 2018).

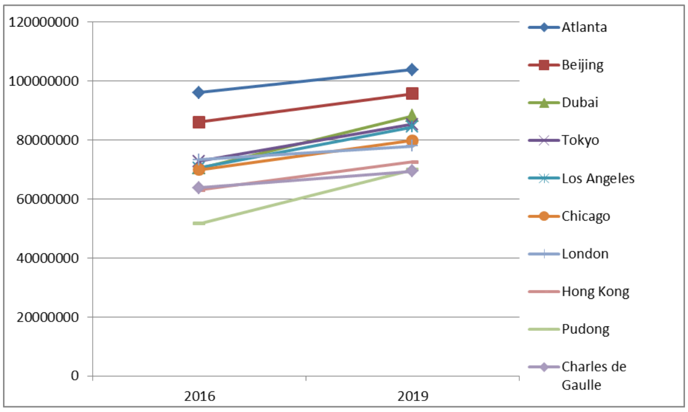

Fig. 2. Passenger traffic of ten most secured airports in the world for 2016 and 2019 (Boyko, 2018)

The main flows of air transport passengers include inclusive tourists, who make up 0.7% of the total number of air carriers in the world (AON, 2020).

According to statistics, in 2016, the ranking of the 100 busiest airports in the world was headed by Lisbon (Portugal) airport, with passenger traffic of 18 142 000 people, in the fiftieth line of the rating was Domodedovo airport (Moscow, Russia) with passenger traffic of 33 108 000 people, and the tenth - by Hong Kong airport (China) 63,122,000 people, and the first place was occupied by the airport in the city of Atlanta (USA) with passenger traffic of 96,179,000 people (Boyko, 2018).

In 2019, the fiftieth place was taken by Sheremetyevo airport (Moscow, Russia) with passenger traffic of 40,092,806 people, 10th place was taken by Charles de Gaulle airport (France) with passenger traffic of 69,471,000 people, and the first place was occupied by the airport of Atlanta (USA) with a record 103,902,992 passengers. If we compare with the passenger traffic and the workload of the airport of Ukraine "Boryspil", the figures will be ten times lower (Boyko, 2018).

According to the State Aviation Service, in April 2021, there are 20 airports, 11 civil aviation airfields, 2 heliports and 42 landing sites in Ukraine (SSU, 2017; Boyko, 2018).

The largest international airports in Ukraine are Boryspil (Kyiv), Kyiv (Zhulyany), Odessa, Lviv, Kharkov, Dnieper and Zaporizhzhia (Boyko, 2018).

It should be noted that 98% of total passenger traffic and freight traffic are concentrated in these seven leading airports. In comparison, the fate of the country's main airport «Boryspil» in the total volume of passenger traffic decreased from 67% in 2016 to 64% in 2019. On the other hand, it immediately increased the share of the airports «Kyiv (Zhulyany)», «Lviv» and «Kharkov» (Boyko, 2018) slightly.

According to the State Aviation Administration of Ukraine, the ratio of the leading airports in the total volume of passenger traffic is shown in Figure 3 (SSU, 2017; Boyko, 2018).

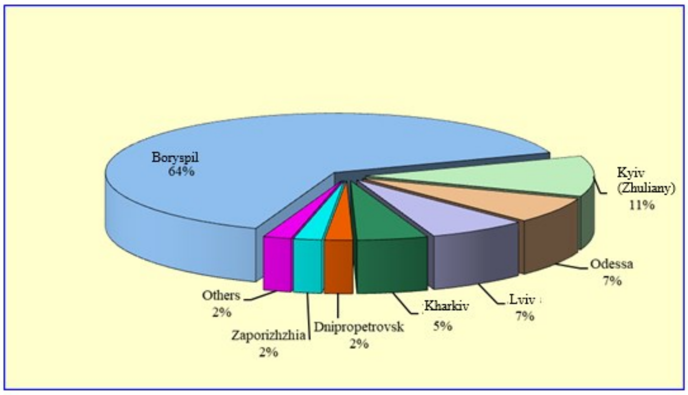

Fig. 3. Pitoma of the carriage of provincial airports in the foreign services of passengers for 2021

In recent years, there has been a tendency to increase passenger traffic at Ukrainian airports, and airport complexes are becoming major financial regulators and infrastructural elements of territorial development. Figure 4 shows the dynamics of passenger traffic at regional airports in Ukraine from 2009 to 2019 (Boyko, 2018). The pandemic has made adjustments to the volume of passenger traffic - therefore, the period 2020-2021 is not considered in this study.

In recent years, there has been a tendency to increase passenger traffic at Ukrainian airports, and airport complexes are becoming major financial regulators and infrastructural elements of territorial development (Boyko, 2018).

The annual result of the central air gates of Ukraine is in the region of the 50th place among European airports. Boryspil`s neighbours are the airports of such cities as Stuttgart (Germany), Porto (Portugal), Venice (Italy) and Lyon (France). London`s Heathrow traditionally remains the European leader, with about 78,000,000 people using its services. In total, the first place in the world has long been occupied by the Hartsfield-Jackson Atlanta International Airport in Atlanta (USA); in 2019, 104 million passengers passed through it (Boyko, 2018).

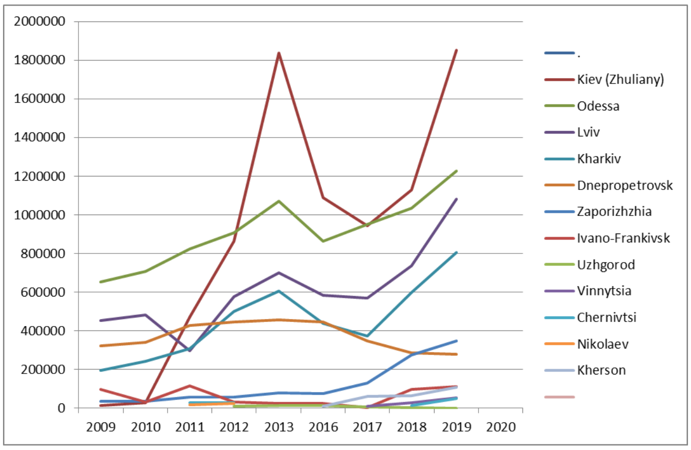

Fig. 4. Passenger traffic of Ukrainian airports for 2009-2019 (since March 2020, the information is approximate, so the authors did not refer to it)

The trend in the quantitative indicators of airports should not affect the quality and variety of travel services. On the contrary, national airports can increase the volume of passenger traffic. In order to bring regional airports to international standards, Ukraine adopted the State Target Program for the Development of Airports until 2023 (Ministry of Infrastructure of Ukraine, 2020) and the Aviation Transport Strategy of Ukraine until 2030 (State Aviation Administration of Ukraine, 2018). The programs are aimed at meeting the needs of the state in ensuring the stable development of the aviation industry, bringing aviation transport in line with international standards, ensuring that Ukraine acquires the status of a transit state, taking into account its unique geographical location, increasing the efficiency of state property management, introducing modern information technologies (UNWTO Tourism Highlights, 2018).

Of course, a logical question arises about the social support of airlines regarding the financing of air travel for passengers with disabilities or those belonging to the categories of inclusive tourists (Fig. 1), which we propose in the form of the second financial aspect, or rather state subsidies, which allows in different percentages to compensate for the costs of special servicing inclusive passengers both at the airport and onboard.

Due to differences in the economic conditions for performing various types of air transportation, deregulation practices should reflect the problems of both civil aviation in general and the problems of low-intensive passenger traffic on airlines serving remote, sparsely populated areas.

This approach required the legislative consolidation of the Public Service Obligation (PSO) system - a system of airlines' obligations to carry out state-subsidised «necessary» (socially significant) air transportation, ensuring the implementation of «equal» rights and opportunities for citizens of any country. Such a document in the EU is the act of the Council of Europe No. 2408/92 of 23.07.1992 «On access for air carriers of the European Community to domestic air routes» (Le, 2011).

In order to motivate a commercial carrier to transport people with disabilities and inclusive passengers by air, it is necessary to propose a range of measures to stimulate it to carry out air transportation, referred to the social network of airlines EAS (Essential Air Service). This is the segment of "essential" air travel, operating under special rules under the PSO`s system of obligations. According to similar but not uniform rules, these shipments are supported by the state or regional authorities of different countries, based on local circumstances.

Interesting in this regard is the practice of the United States, Australia and Canada, as states that have significant PSO funding and the size of the EAS network, to a large extent functioning in northern, remote regions with an underdeveloped network of land transport communications.

For example, in Australia, up to 75% of local air travel is carried out using government support (subsidies equal to 45% of the value of the commercially reasonable fare). The same subsidising approach is typical for a number of socially important airlines in Alaska, USA, where the size of federal government subsidies is about $ 140 million per year. The practice of Canada, for example, is interesting in that one of the main directions in the state and regional policy for the development of local air transportation is the support of small airports (Zapesotsky, 2012).

Elsewhere in the world, the PSO system has a limited nature, mainly aimed at maintaining separate airlines to the island parts of the state. In the UK, the EAS network includes 16 airlines serving routes within Scotland. Portugal subsidises routes from the mainland to the Azores and Madeira, Spain supports routes to the Canary Islands. Norway - routes connecting the center with the remote regions of the west and north of the country (Nechiporuk, 2019).

Having proposed a simple analysis of international experience in the procedure for subsidising air transportation, two main conclusions can be drawn:

1. Subsidising air travel is closely related to solving the state's social problems to ensure transport accessibility of the population for travel. Subsidies are implemented on an integrated basis - primarily through two main funding channels - air carriers operating flights on socially significant routes and airports.
2. Mechanisms of budget subsidies, as a rule, work effectively only when priorities of national interests are formulated at the state level, a balance of interests covering the spheres of interaction between air carriers, airports and passengers (tourists) is maintained.

A study of the situation on the market of regional and local air traffic in Ukraine showed the following critical factors:

1. Regional airlines have insufficient funding.
2. The aircraft fleet is morally and physically obsolete.
3. The regional network of airports has been significantly reduced.
4. The ageing of flight and technical personnel of regional airlines is going on, a shortage of new generation pilots will be felt.
5. Low salaries in regional airlines cannot keep young professionals and stop staff drain.
6. The chain of incentives for regional and local flights in airport tariffs and charges, payment for meteorological support, and the cost of jet fuel is practically non-existent. The main principle of improving the system of measures of state support for regional air transportation in the current state of the Ukrainian air transport market, in our

opinion, is to maintain a single strategy of action, the application of uniform standards to all subjects and participants in the technological chain of the transportation process, which can be presented in the form of a block diagram (Fig. 5).

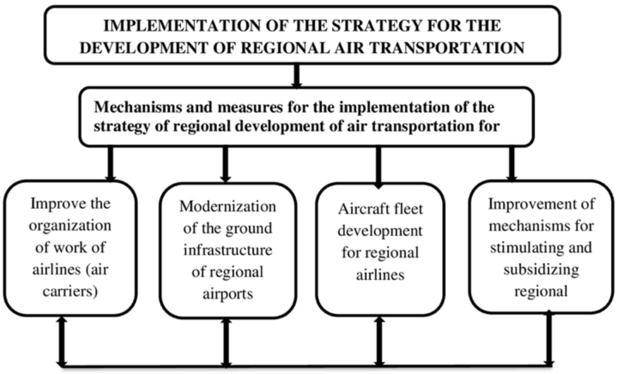

Fig. 5. Block diagram of the implementation of the strategy for the development of regional air transportation in Ukraine

Airlines must assist passengers with disabilities to provide passengers with disabilities with clear guidance regarding their requirements for the carriage of mobile devices and medical equipment in a manner that considers the interests of passengers, relevant safety regulations and real operational capabilities. At the same time, the national legislation of the carrier countries should be balanced in its application and should not impose excessive or unattainable tasks on airlines.

An important aspect of air transport operation is the coordination of stakeholders of their transport rules. Furthermore, it approaches its implementation to ensure a consistent, integrated service for passengers with disabilities, regardless of their location and national borders.

Consequently, it will be relevant to develop a coherent, logical and compromise approach based on mutually agreed principles within the study issue, which will bring significant benefits to inclusive passengers, including passengers with disabilities and the aviation industry itself. Such approaches include:

a) increasing the availability of air travel worldwide for inclusive people in general and people with disabilities in particular.
b) Harmonisation of national policies of different countries, which will be able to provide diversified information support to inclusive tourists in domestic and international travel.
c) They are avoiding situations of operational complexity and additional costs for airlines.
d) The aviation industry's contribution to the achievement of the UN Sustainable Development Goals so that no individual or country is left behind.

5. Conclusions and Recommendations

Based on the international experience, the following conclusions can be drawn:

1. Subsidising air travel in the northern and remote territories ensures equal civil rights of the population to move regardless of residence (social task). (Skryleva, 2018)
2. Budget subsidies for airports with low flight intensity, but socially significant, is effective when the state clearly defines the priorities of public needs and the interests of air carriers, airports and users.
3. In Ukraine, at the moment, there are various measures of state support for regional aviation. Subsidies are distributed in the following areas:(Skryleva,2018)
    - Support of domestic manufacturers of regional aircraft (including an important factor - guarantees of after-sales service),
    - Subsidising of airlines' expenses when paying lease payments for regional aircraft,
    - Financing of small regional airports and landing sites in remote and inaccessible territories, united in enterprises of different forms of ownership, subsidising and co-financing of socially significant flight routes.
4. An important trend in supporting regional transportation is the participation of the Administrations of the constituent entities of Ukraine in sharing the financial burden with air carriers serving the territories of these entities.
5. To carry out, within the framework of the regulatory framework for subsidising, the division of regional transport into social and commercial, differing in terms and mechanisms of subsidising:
    - Socially significant transportation is carried out in hard-to-reach territories that do not have year-round ground communication in order to ensure transport accessibility of the population with a low effective demand;
    - Commercial (competitive) air transportation is developing in a year-round competition with land transport to attract an active part of the population, ready to pay extra for the speed of transport communication, temporary state support for «rolling» routes.
6. Adopt the developed regulatory documents that regulate the comfortable conditions of air travel for people with disabilities and passengers of other inclusive categories. For people with disabilities, such living conditions must be created that will allow them to lead an active social life with a minimum of their own efforts and costs aimed at compensating for their physical disabilities, as well as in the absence of unreasonable administrative and economic barriers generated by their disability or delusions of society.

Studying, discussing and developing promising solutions regarding urgent problems in the tourist transport infrastructure will help to smoothly reorganise the basic plans, strategies, prospects for providing comfortable transport services for the transportation of inclusive air passengers.

CRediT author statement

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