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ANALYSIS OF MODERN AIRFIELD LIGHTING SYSTEMS

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The reliability measures evaluating and assessment of the airfield lighting systems with standard and reduced number of lights in certain subsystems are considered in this article.

Problem presentation

The airfield lighting system (ALS) is the most important ground visual aid for the pilot during takeoff, visual approach, landing, running and taxing on the runway by day and night under complex meteorological conditions. Airfield lighting system consists of a number of subsystems each of them carries the certain information about aircraft position – altitude, distance and direction to the runway axis. The pilot on the decision height must see at least approach lights, and then he can make decision about landing.

The descent to the decision height is performed by using non-visual aids. The development of new systems of non-visual guidance based on satellite technology, such as the global positioning system, gives the potential for implementing all-weather operations at airports where the related infrastructure costs are currently judged to be prohibitive. While the new technologies may reduce the costs of the ground-based non-visual guidance, unfortunately the significant cost of approach and runway lighting remains. Whatever form of instrument approach guidance is used in the future, there will continue to be a need for visual references provided by lighting aids.

To upgrade a basic lighting system to the level required by International Civil Aviation Organization (ICAO) in document [1] for all-weather operations, according to the [2], about 1 million U. S. dollars should be allocated. It is clear that it is expensive even for large foreign airports and it is almost impossible to apply to Ukrainian airports. In these circumstances, it is logical to review and revalidate the lighting requirements to ensure that they adequately meet current and future needs for safe and regular aircraft operations at the maximum number of airports.

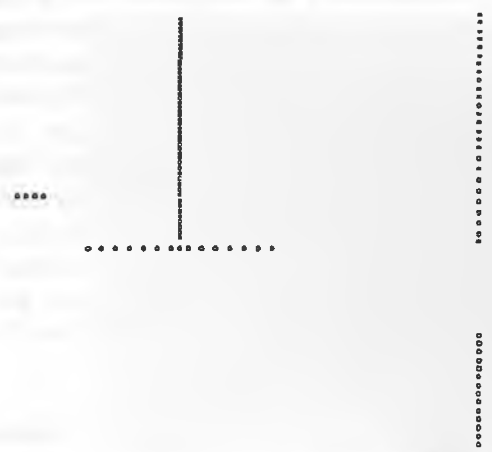
The analysis of last researches

The development of aerodrome lighting is of special interest for the All Weather Operations Team at the U.K. Defense Evaluation and Research Agency (DERA). Historically, DERA and its predecessors were deeply involved in the development of most of the visual aids specified by ICAO [1]. In an attempt to respond to the emerging need for a less costly system of approach and runway lighting, in 1989 DERA began its research of the operational and technical issues involved. At the outset, it was clear there was a need to ensure that any proposed changes to the specifications would not adversely affect both the safety and regularity of operations.

The goal of this article is to analyze the possibility of implementation the ALS with updated configuration in Ukrainian airports with the aim to provide their reliability.

Main subject

Over the last 30 years, ICAO has achieved international agreement on the level of approach and runway lighting required for the safe and regular operation of aircraft. The airfield lighting system shown in figure (*a*) fully supports all categories of landings and takeoffs in visibilities less than 1200 m runway visual range (RVR).



a *b*

The structure of II category ALS:
a – standard approach and runway lighting;
b – suggested shorten approach and runway lighting

However, not all the lighting is required in all conditions. The simplest lighting pattern is specified for Category I (RVR greater than 550 m) landing operations, with additional lighting being progressively required for Category II (RVR not less than 350 m) and Category III (RVR less than 350 m).

The large increasing in the number of lighting units specified as operations move from the Category I to the Category II regime is particularly significant. A review of the research and development [illegible] rational number of lights can be [illegible]

[illegible] level. [illegible]

[illegible] phasized the usefulness of the lighting in [illegible] demanding than [illegible]

Although some [illegible]

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flying phase. The flight was performed under Category III "visibility conditions, with some landings and take-offs made in visibilities as low as 150-metres RVR. A total of 33 landings were achieved. Most approaches have been made using a flight director rather than auto-approach. This resulted in less precise and less stable approaches than would be normal in such visibility conditions. The difficulty of the piloting task was deliberately further increased by using abnormally high decision heights for many of the approaches. Since the visual cues provided by the lighting are crucial when the pilots are manually maneuvering the aircraft, the use of these approach techniques and decision heights explored the usefulness of the lighting in regimes more demanding than those normally used in airline operation.

Although some landings were made beyond the end of the touchdown zone (600 m), no adverse comments were made on the reduced length of the suggested lighting pattern. For the flare and roll-out, runway edges were adequately defined. This is a part of the overall pattern of lights for which no changes are proposed. All landings and take-offs were made with 30 m spaced runway centre-line lights. Steering cues from this lighting were adequate in all visibilities down to the lowest ones tested (150 m).

Overall, the flight trials validated the results previously obtained from simulation. This good correlation between flight and simulation suggested that the future research could be carried out adequately by suitable simulation experiments.

The research results raised several issues that could be beneficially addressed by a further experiment using a wide-body aircraft simulator, and subsequent trials were made using Boeing 747-400 flight simulator.

The Boeing-747 simulation focused on failure modes, in particular engine failure during take-off, and light failures that would result from circuit faults in the runway centre line. Simulated light failures increased the spacing from 30 to 60 m. In the most demanding experiment a take-off was attempted with 60 m spaced runway centre-line lights, an RVR of 100 m and a 10-knot crosswind. An unannounced engine failure was injected as the aircraft speed increased through 100 knots.

After completing the simulation exercise, pilot ratings of the proposed patterns were 100 % in support of his statement that the reduced patterns were "sufficient for the task." This significant result supported greatly the basic premise: the reduced lighting pattern is well matched to the operational requirement, whereas the current pattern provides excessive lighting.

Probably these researches were taken as a basis for ICAO recommendations delivered in the document [1] about possibility of using ALS Categories II and III with a reduced number of lights in *l*

– supplementary approach lighting subsystem 0-300 m from runway threshold;

– runway center line lights;

– runway touchdown zone lights.

But one restriction exists – updated ALS with a reduced number of lights can be used only under condition of maintenance the necessary lights reliability level. Recommendations about quantity and topological criterions of ALS subsystems failure are given in the same documents.

From the researches, made by British scientists, it is clear that updated ALS successfully meets safety and operational requirements. Let us evaluate and assess the reliability of the updated ALS and its ability to provide requiring flights safety level under complex meteorological conditions. There is the recommendation to normalize the probability of occurrence the "specific situation" during the flight - *KS* delivered in document [4]. Applying to ALS it could be shows

$$K_{ss} = Q_{als}(t) \cdot P_{cmc} \tag{1}$$

where $QA.J(t)$ - the ALS failure function during time period t; P_{cuc} - the probability of landing (take-off) under complex meteorological conditions.

To define the updated ALS ability for a normalized flight safety level it is necessary to evaluate and assess its reliability. For this purpose we use the method of ALS reliability evaluating, designed by author. The initial data for evaluating are presented in the table.

Airfield lighting system is considered as failed if at least one of its subsystems is in failure state.

As ALS failure criteria the criteria recommended by ICAO [1] was taken: quantitative *K* – maximum allowable quantity of failed lights, and topological *M* – the allowance of failure the couple of adjacent lights (table). The reliability of ALS is considered during the time between two maintenance – 12 h.

The reliability measures of main ALS subsystems elements - failure rate X are: illuminant (I) of aerodrome light - X_I = 6,36·10'4 1/h; optical system (OS) of aerodrome light - X_{os} = 2TCP 1/h; insulating transformer (IT) - LIT = 10" 1/h; constant current regulator (CCR) – L_{ccr} = 10-4 1/h.

According to the reliability evaluating method, firstly we evaluate the reliability function of each subsystem and then find the reliability and failure function of the whole ALS during time *t*.

The specification of ALS Category II – high intensity lights

ALS subsystem	Configuration		Number of cable lines	Failure criteria	
	Standard	Shorten		K, %	M
Approach lights: 0–450 m	30	30	2	5	–
450–900 m	30	30	2	15	–
Supplementary (0–300 m)	18	8	3	5	–
Crossbar lights	10	10	2	5	+
Runway threshold and runway end lights	32	32	2	5/25	–
Runway center line lights	200	100	2	5	+
Runway edge lights	100	100	2	5	+
Runway touch-down zone lights	100	50	3	10	–

ALS subsystem (ALSS) consists of aerodrome lights power supply subsystem (ALPSS) and aerodrome lights subsystem (ALSs).

The reliability function of ALSs $P_{\mathrm{ALSs}}(t)$ is defined according to the failure criteria using the following formulas

$$P_{\mathrm{ALSs}}(t)=\sum_{i=0}^{K}C_{N_{\mathrm{AL}}}^{i}P_{\mathrm{AL}}^{N_{\mathrm{AL}}-i}(t)Q_{\mathrm{AL}}^{i}(t), \qquad (2)$$

if the couple of adjacent failed lights is allowed, and

$$P_{\mathrm{ALSs}}(t)=\sum_{i=0}^{K}C_{N_{AL}-i+1}^{i}P_{\mathrm{AL}}^{N_{\mathrm{AL}}-i}(t)Q_{\mathrm{AL}}^{i}(t), \qquad (3)$$

if the couple of adjacent failed lights is forbidden.

In formulas (2) and (3) $P_{\mathrm{AL}}(t)$, $Q_{\mathrm{AL}}(t)$ – are reliability and failure functions of aerodrome light respectively; N_{AL} – the subsystem's number of lights.

The reliability function of the aerodrome light is

$$P_{\mathrm{AL}}(t)=e^{-t(\lambda_{l}+\lambda_{os}+\lambda_{IT})}$$

For the linear lights the reliability function is defined by the formula of Newton binomial (2).

The reliability and failure functions $P_{\mathrm{ALS}}(t)$ and $Q_{\mathrm{ALS}}(t)$ for the whole ALS are defined as

$$P_{ALS}(t)=\prod_{i=1}^{N}P_{ALSS}(t)_{i}; \qquad (4)$$

$$Q_{\mathrm{ALS}}(t)=1-P_{\mathrm{ALS}}(t).$$

The reliability function for standard ALS Category II type high intensity lights – $P_{\mathrm{ALS}}(t)$ could be found according to the (4) and equals $P_{\mathrm{ALS}}(t)$ = = 0,98856, failure functions $Q_{\mathrm{ALS}}(t)$ = 0,01144. For update ALS – $P_{\mathrm{ALS}}(t)$ = 0,98425, $Q_{\mathrm{ALS}}(t)$ = 0,01575.

According to the (1) with P_{CMC} = 0,01 (1% of all landings is performed in complex meteorological conditions) for standard ALS $K_{\mathrm{SS}}=1{,}14\cdot10^{-4}$, and for updated ALS $K_{\mathrm{SS}}=1{,}15\cdot10^{-4}$.

Conclusions

The scientific researches have shown that ALS with updated configuration in certain subsystems can meet all operational and safety requirements. The reducing of a number of lights almost does not influence ALS reliability level, in comparison with standard ALS. That is why the update ALS is able to be used at Ukraine civil aviation aerodromes provided with the automatic lights monitoring systems.

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Аналіз сучасних світлосигнальних систем аеродромів

Розглянуто визначення і оцінку показників надійності сучасних світлосигнальних систем аеродромів зі стандартною та зменшеною кількістю вогнів у певних підсистемах.

С.С. Девяткина

Анализ современных светосигнальных систем аэродромов

Рассмотрены определение и оценка показателей надежности современных светосигнальных систем аэродромов со стандартным и уменьшенным количеством огней в определенных подсистемах.