NATURE AND SOME PECULIARITIES IN ATMOSPHERIC OPTICAL CHARACTERISTICS IMPORTANT FOR AIR TRAFFIC IN THE NORTH SIBERIAN REGIONS

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We consider here the problem of dazzling that may be experienced by an aircraft crew when landing under favorable meteorological conditions and cloudless sky, caused by certain optical properties of the atmosphere and sensitivity range of a human eye. The nowadays theories of slant visual range in the atmosphere are also briefly reviewed in the paper. We propose a specialized program to help avoiding the dazzling of aircraft crews when landing under the SMC. We recommend that atmospheric optical characteristics must to be taken into account to provide for higher flight safety.

Use of aviation is an important factor in industrial development of northern Siberian regions, including the regions with oil and gas fields. In doing the air transportation job in interests of national economy, the aircraft crews are often forced to perform landing on poorly equipped or even completely unequipped landing strips as well as to fly at extremely low heights. To do this, the crews certainly have a need for information on the visibility conditions at an angle to the Earth's surface or slant visibility.

The accuracy of air navigation tools is insufficient to provide successful instrumented landing, when an aircraft flies along a glide path after passing the inner mark of the guidance system. Normally pilots start to perform landing manually relying on visual observations, as psychologically a trained pilot is able to estimate height much more precisely than most perfect instruments, Ref. 1.

In this connection the problem may arise because sometimes, even under clear sky conditions and good horizontal visibility near the Earth's surface, the visibility along the glide path may become very poor, that makes landing difficult thus essentially decreasing the flight safety. It happened at some airports so that flights were stopped for 1.5–2.5 hours even under favorable meteorological conditions because of the dazzling menace for aircraft crews by the Sun, when it hung just above the runway while being very low above the horizon (see Fig. 1).

According to Ref. 1, the atmospheric haze has different brightness when observed along different directions under clear sky conditions and sunshine. Therefore, the reference objects and the landscape features are discernible at different distances when observed along different directions too. The brightness of the atmospheric haze under clear sky, if observed along different directions, varies depending on the Sun position. When estimating slant visibility of a runway and other objects, the sky near the horizon forms the background against which the aircraft crew observes those objects. At the same time the atmospheric haze brightness reaches the level that saturates the eye sensitivity when observed along the direction toward the horizon. The construction of aircraft cockpits does not provide the crew for being able to see objects situated immediately under the airplane during the flight. Each type of machine has its own maximum possible angle of observation along the flight line depending on the design of cabin glasses and other peculiarities of the aircraft construction.[2]

L.T. Matveev[3] pointed out that the sky brightness is determined by conditions of Sunlight scattering in the atmosphere. Table I shows the data on the brightness L for different real objects from Refs. 4 and 5.

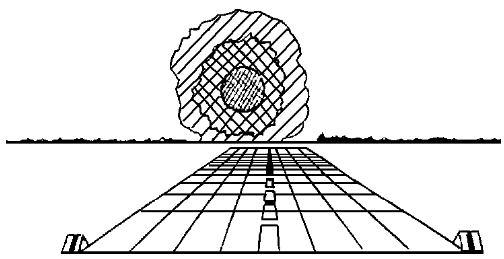

FIG. 1. Explanation of the dazzling effect by Sun when it hangs just above the runway while being very low above the horizon.

In such situations light reflected from the Earth's surface can significantly enhance the sky background

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brightness. The reflectivity of landscape is determined by its properties and by the environmental conditions, namely, by the height of the Sun and certain meteorological factors like cloudiness, cloud shapes and height, haze density, and its vertical distribution (Ref. 6).

TABLE I. The brightness of some typical real objects.

The object	L, cd/m^2
The Sun disk, observable through the atmosphere under standard conditions	$1.5{\cdot}10^9$
The day-time clear sky	$(0.5-2){\cdot}10^4$
Green landscape during day-time	$(1-30){\cdot}10^3$
The day-time overcast	10^2

From the angular size of the near-solar halo it is possible to state that within the solid angle of 20° about the direction toward the Sun, under clear sky, the sky brightness may occur to be close to that of the Sun disk. As the aircraft descents along the glide path that happened to be in the plane of the Sun vertical circle, the background brightness, perceived by a pilot, increases and may reach its maximum value at the very moment when the machine touches the runway.

As known from ophthalmology, the luminance range, perceived by an eye, lies within the limits from $2{\cdot}10^{-5}$ up to $2{\cdot}10^4$ cd/m^2, while the dazzling brightness is equal to $2.24{\cdot}10^5$ cd/m^2. From Table I it follows, that the Sun disk brightness of $1.5{\cdot}10^9$ cd/m^2, when observed through the atmosphere, may produce the dazzling effect on a human eye. Besides, the day-time cloudless sky has the brightness value close to the dazzling brightness for the human eye.

V.A. Gavrilov has offered nomograms for determining the slant visual range in the beginning of a runway, that account for contrast between the object (the runway) and the environmental background, Refs. 1 and 6. The slant visual range is calculated, according to this approach by the formula

$$S_{\mathrm{lan}} = 0.62\, S_{\mathrm{m}} \log \frac{V + (B_{\mathrm{h}}/b_{\mathrm{rw}}) - 1}{B_{\mathrm{h}}/b_{\mathrm{rw}}}\,, \qquad (1)$$

where V is the factor of the object visibility, B_{h} is the maximum brightness of the atmospheric haze, b_{rw} is the runway brightness, and S_{m} is the meteorological visual range.

However, formula (1) is inapplicable when calculating visibility under clear sky conditions, when the Sun is low above the horizon while, at the same time, being seen along a direction close to that along the runway, because the value V is not determined under these conditions and the values B_{h} and b_{rw} are very close to the brightness that certainly dazzle a pilot.

B.M. Novikov, Ref. 7, proposed a method for calculation of slant visual range over a runway under cloudy conditions with low cloud fraction during daytime by using the “light-airB equation for slant paths. According to this technique, the visible brightness contrast K' calculated taking into account the haze brightness in the layer between the observer, being at some height above the runway (for example, on the glide path when approaching the runway), and the runway surface is determined by the following equation:

$$K' = \frac{K}{1 + (B/B_{\mathrm{tr}})\,[m/(m + m_{\mathrm{S}})]\,[(\mathrm{e}^{(m+m_{\mathrm{S}})\tau} - 1)}\,, \qquad (2)$$

where K' is the initial (true) contrast, B is the value depending on the illumination and the view of the scattering phase function, B_{tr} is the true (not distorted by haze) brightness of the object, m is the dimensionless mass along the sighting direction (ratio of the slant distance to the vertical one), m_{S} is the dimensionless mass along the direction towards the Sun, and τ is optical thickness of the atmospheric layer. However, it is too problematic to make such calculations operatively during the flight. At the same time it is not yet well understood how one should choose an atmospheric optical model that could provide for avoiding the use of real time observation data.

According to the definition of meteorological visual range by the international organizations (ICAO, WMO), it is recommend, in all cases, to accept as the minimum eye sensitivity threshold the value $e = 0.05$ (see Ref. 8). At the same time, it is noted in Ref. 9, that this e value is not true for all conditions of observations, because the actual value of the threshold eye sensitivity of an observer at the moment of visual observations is unknown.

In Ref. 10 it is recommended to determine the slant visual range S, when observing downward, by the following relation:

$$S = \frac{1}{\mu(S)} \left[\ln \left(\frac{K}{E} - 1 \right) + \ln \frac{L_{\mathrm{b}}}{L_{\mathrm{h}}(S)} \right], \qquad (3)$$

where $L_{\mathrm{h}}(S)$ is the brightness of the haze layer of the depth S, $\mu(S)$ is the attenuation coefficient, L_{b} is the background brightness, K is the brightness contrast, and e is the threshold contrast.

However, this formula can hardly be accepted too, from the viewpoint of the feasibility of operative measurements, because it uses model dependences that are difficult, if ever possible, to be checked in application to real atmospheric conditions.

Thus, it seems to be impossible to make use of the now existing techniques for calculating the slant visual range under favorable meteorological conditions and clear sky when estimating possible dazzling of the aircraft crew. At the same time to provide for a safe landing, when the Sun is close to the landing course, it is necessary to exclude the crew dazzling. For this purpose it is necessary to know the time interval (its beginning and end), when the crew may suffer from dazzling by the low Sun.

To calculate the time beginning and end of the phenomenon considered, it is necessary to determine the heights of the Sun above the horizon, at which the dazzling effect may occur. Since the main maxima of brightness caused by a strongly forward-peaked scattering phase function of aerosol, is observed always close to the Sun disk in the form of halo with the angular radius of 10–12°, there exists a source of increased sky brightness in the sector of 20–24° about the Sun. To exclude dazzling, it is necessary to arrange the flights so that this sector does not overlap the vision sector for pilots when landing (see Fig. 2).

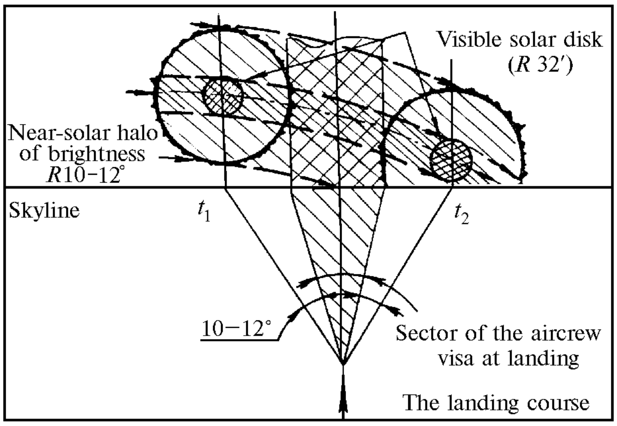

FIG. 2. The general case of the enhanced sky brightness, created by the low Sun and by the halo within the observation sector of an aircraft crew at landing.

It is known from astronomy, that the Sun during the year changes azimuths of sunset and sunrise from season to season. Since the time and the azimuth of sunset are closely related, the observation sector for the crew during landing can overlap completely or partially with the low Sun. As this takes place, the Sun has an angular height from 10–12° and down to 50′ above the horizon. Based on the Sun position on particular dates, it is possible to calculate the periods of the beginning and end of dazzling at any airport concerning any particular type of an aircraft.

We have created a specialized computer code to calculate the dangerous time intervals that can easily be adapted to conditions of any airport as well as to various types of aircrafts (see Fig. 3).

The time intervals are shown in the table of special form, in which the periods of the beginning and end of possible dazzling for concrete dates and specific landing courses are specified for different seasons (Table II).

We calculate the sunrise and sunset moments, and also the time of the beginning and end of navigation twilight during 10 days on the basis of the SUN-SET program offered by O. Montenbruck and T. Fleger.[11] The program is supplemented by the block for calculating the beginning and end moments of possible dazzling under favorable conditions and clear skies.

The initial data are the geographical latitude φ and longitude λ of an airport control mark with the accuracy of 1 min of arc, the difference of zonal and world time (dt) (in hours), and the direction of the runway, i.e., the courses of flight and landing ($A1$ and $A2$) with the accuracy of 1 min of arc. The program proposed has allowed one to calculate the time of the beginning and end of possible dazzling during the landing for each calendar date.

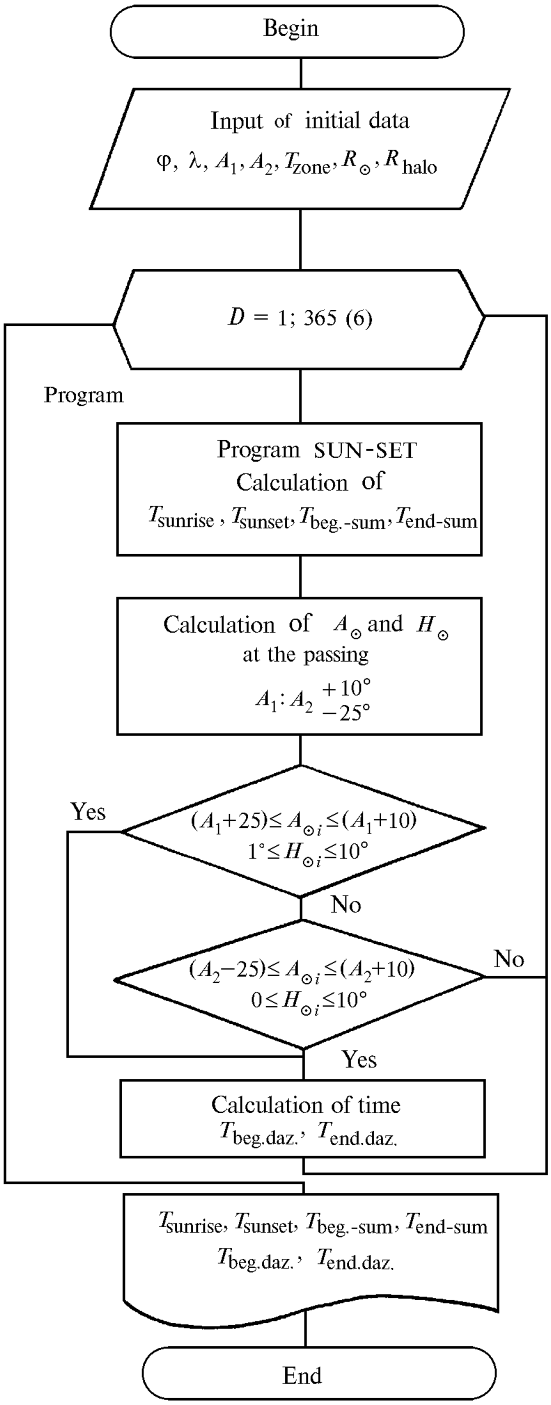

FIG. 3. The flowchart of the program for calculating of periods of possible dazzling of the aircraft crews.

TABLE II. The time of darkness onset, sunrise, sunset and the periods of dazzling by the Sun when landing under fair weather and clear sky for Siverskii airport (the coordinates of the airport breakpoint 59°21′N, 30°02′E, *zonal time* 02.00, *direction of the runway A1–A2).*

Date	Sunrise	Sunset	Darkness onset	Dawn	The dazzling phenomenon			
					Course *A*1		Course *A*2	
					Beginning	End	Beginning	End
				January				
01.01.98	09.56	16.11	17.05	09.02	No dazzling		15.14	16.10
01.02. 98	09.56	16.12	17.07	09.01	No dazzling		15.15	16.11
…	…	…	…	…	…	…	…	…
01.31. 98	09.13	17.15	18.01	08.26	No dazzling		15.22	17.14
				February				
02.01. 98	09.10	17.17	18.03	08.24	No dazzling		15.24	17.16
…	…	…	…	…	…	…	…	…
02.13.98	08.12	18.16	18.57	07.30	No dazzling		15.32	17.32
02.14.98	08.09	18.18	19.00	07.27	No dazzling		15.34	17.30
				March				
03.07.98	07.33	19.19	20.03	06.49	No dazzling		16.41	16.42
03.08.98	07.31	19.20	20.05	06.48	No dazzling		No dazzling	
				April				
04.26.98	06.08	21.46	22.30	05.26	06. 90	06.10	No dazzling	
				June				
06.22.98	04.13	23.45	00.59	03.02	04.14	06.07	No dazzling	
…	…	…	…	…	…	…	…	…
				August				
08.18.98	06.22	22.05	22.31	05.35	06.24	06.26	No dazzling	
				October				
10.01.98	07.05	18.33	19.14	06.24	No dazzling		No dazzling	
…	…	…	…	…	…	…	…	…
10.06.98	07.16	18.18	18.59	06.35	No dazzling		No dazzling	
10.07.98	07.19	18.15	18.56	06.38	No dazzling		16.45	16.46
10.29.98	07.58	17.33	17.59	07.40	No dazzling		15.41	17.27

The beginning and end of possible dazzling obtained are printed out in the form of a special table (see Table II).

The analysis of the data in the table shows, that for the particular airport considered the period of the maximum dazzling duration reaches 2 hours and it is on February 13 and on October 29 in the second half of the day. From August 18 to October 6 and from March 7 to April 25 the phenomenon is absent at all (i.e., for both landing courses).

In our opinion it is worth using the following scheme to provide for flight safety against dazzling of the aircraft crews when landing:

1. If favorable weather under clear skies is expected on certain date one must address to the special table to get information on the probability of dazzling conditions to occur.

2. In the case of a danger for the crew to be in situation when the enhanced background brightness can cause dazzling, it is necessary to eliminate landing in the dangerous direction.

Further actions of a weather forecaster on duty are depend on concrete situation. However, it is necessary to report to the chief flight supervisor about the expected dazzling and to take all precautions to prevent the dangerous situation.

The use of the algorithm proposed allows one to essentially improve the flight safety and, as a result, to increase the aviation efficiency. For instance, the account for the visibility quality would allow a more efficient and full use of the modern possibilities of monitoring remote oil and gas fields with the help of the objective control tools, as well as to optimize the planning, and to improve the safety of flights from airports and landing strips.

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