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Research Article

THE ANALYSIS OF THE EFFECTS OF SCREENING HELICOPTER ENGINE COMPARTMENTS FOR INFRARED EMISSION

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ABSTRACT
The paper presents the research on using infrared screens protecting an engine in an engine gondola in PZL W-3 helicopter to limit infrared emission to the surrounding. The methods of numerical modelling and computing simulation (hover and horizontal flight forward) were applied to the analysis. The results enabled formulating the guidelines to construct screens.

Keywords: helicopter, infrared screen, infrared emission, egine gondola.

INTRODUCTION

The previous experimental tests of infrared radiation emitted by a helicopter during flight [4, 5, 6] prove that intense radiation of diffusers and exhaust gases released from them, the radiation from the hubcaps of air inlets and the screens of engine compartments are accompanied by quite intensive as presented in the images taken with thermographic camera Therma CAM S45 during the flight of the PZL W-3 Sokół helicopter (Fig. 1).

In order to limit infrared emission it is necessary to decrease radiation intensity and change radiation wave frequency. This can be done as follows [7]:

- by intensifying cooling the engine compartment, which can result in excessively decreased of engine temperature and worse engine performance.
- by choosing materials of appropriate emission indicators for engine surface and internal gondola surfaces, which is not always possible, to avoid the risk of engine and supplementary system overheating.

Lowering the emission can also be achieved by screening shields of engine compartments, which is the most effective method here.

An internal or external gondola surface can be screened. The latter method facilitates cooling

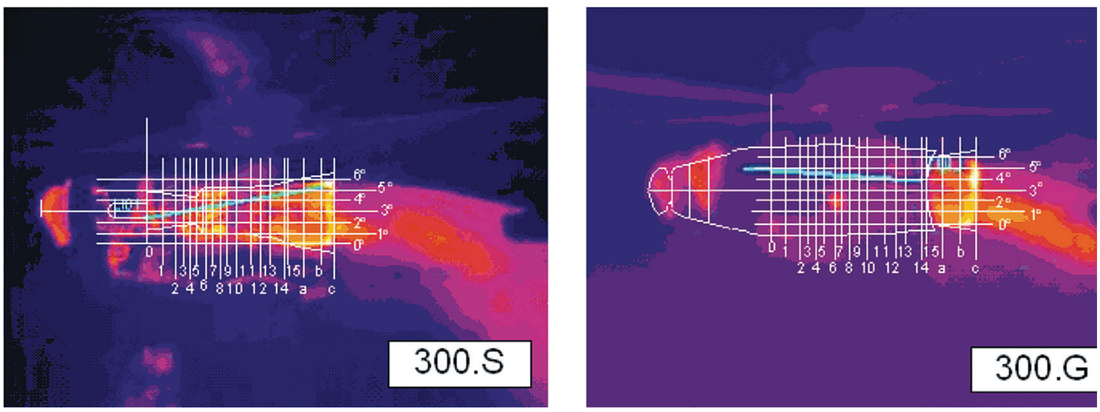

Fig. 1. Infrared emission by engine compartment screens to the surrounding during the flight of the PZL W-3 Sokół [4, 5, 6]

the screen and maintains the thermal conditions of the engine interior at the desired level (i.e. is avoided overheating the combustion chamber and engine turbine). Therefore, this paper discusses the external screening of engine compartment protection.

SCREENING INFRARED EMISSION FROM THE SURFACE OF A SOLID

An infrared screen in made of a substance that is impermeable for infrared radiation (zero transmission). It is not resistance for propagating radiation as such although it plays this role in radial systems [4]. Screen is to transform radiation energy that reaches it from the protected surface into energy radiated to the surrounding, as in the schematc in Fig. 2.

In the state of thermal and heat balance ($\dot{Q}_{1-E} = \dot{Q}_{E-O}$) the internal energy of a screen is defined at a certain level, which is manifested by the constant temperature of a screen.

Therefore, the role of screening as in [8, 9, 12] is to limit excessive infrared emission to the environment (decreasing the density of radial energy stream and decreasing the temperature). The functioning of a screen is demonstrated on the basis of a cylindrical-circular screen of unlimited length, without convective cooling. The schematic of screen geometry is in Fig. 3.

The screen is endlessly long without convectional cooling. In the system of transmitting solids 1-E-2, the non-concave surface of solid 1 is surrounded by the internal surface of screen E, and non-concave external surface of surrounded by solid 2. The surfaces of solids 1, E, 2 can differ in absorptiveness – *a* and – reflectiveness – *r*, at zero transmission – *p*, yet for each of them the following equations must be fulfilled:

- for total radiation:

$$a + r = 1 \qquad (1)$$

- for monochromatic radiation (spectral):

$$a_\lambda + r_\lambda = 1 \qquad (2)$$

The analyses of the technical screening of infrared emitting solids assume, in accordance with [8] and [9], that the solids are gray, and the reflectiveness of their surfaces is diffusion (dispersive). The reflectiveness of a concave screen surface may be of a mirror type (equality of angles of incidence and reflection) and then the equation is theoretically true:

$$r = r_\lambda = 1 \qquad (3)$$

The above mentioned features of solids' surfaces are significant for the description of mutual emissiveness of two products. The description of

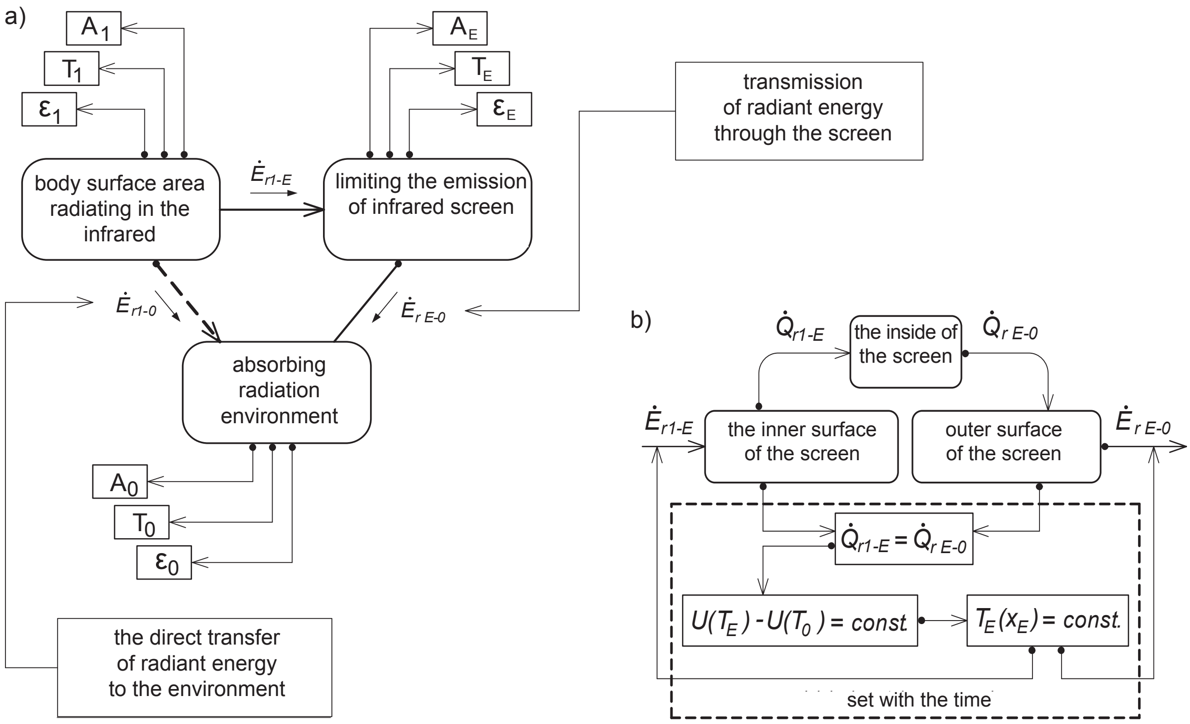

Fig. 2. Schematic of transforming the radiation energy in a screened system: a) a scheme of transforming energy, b) a scheme of balancing screen temperature

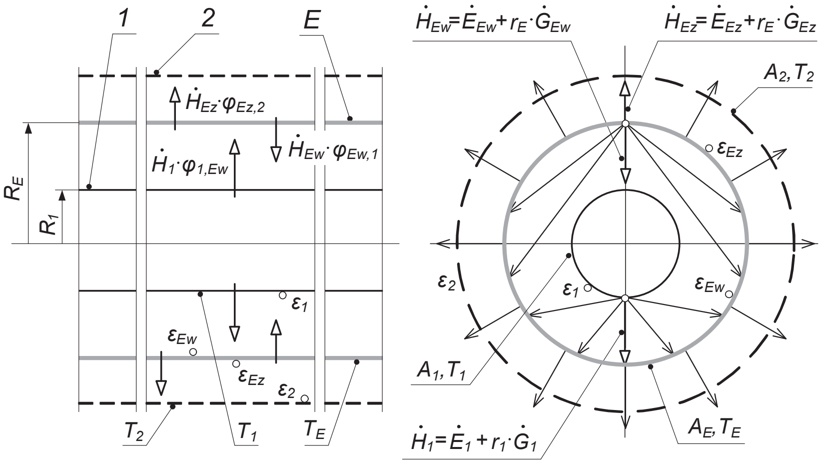

Fig. 3. Cylindrical-circular screen limiting infrared emission to the surrounding

a cylindrical-circular screen of unlimited length in the states of thermal and heat balance, without considering convection was presented with the method of lightness and radiating the surfaces of radiating solids [8]. These values refer to the energy exchange between two surfaces, one being non concave, closing a space filled with a diathermal factor (translucent for the infrared). The lightness and radiation of individual surfaces of the system (Fig. 3) is presented in Table 1.

The effective energy of radiation exchanged between the surfaces of system 1-E-2 is described by method following general equation, according the cited:

$$\dot{E}_{r_{k-l}} = \dot{Q}_{r_{k-l}} = \dot{H}_k \cdot \varphi_{k,l} - \dot{H}_i \cdot \varphi_{l,k} \qquad (4)$$

where: k, l – indexes attributed to particular surfaces 1, E, 2.

Measureless indicators φ in formula (1) are the relations to radiation, but to the isothermal surfaces, perfectly grey, radiating according to Lambert's law are, according to [8] equal to the relation of surface configuration.

The effective stream of radiant energy: emitted to screen $\dot{E}_{r1-E}$ aand to the environment given that $\dot{E}_{rE-O}$, and that external and internal inequality of screen emission ($\varepsilon_{Ew} \neq \varepsilon_{Ez}$) is described in the following equation:

$$\dot{E}_{r1-E} = \dot{Q}_{r1-E} = \frac{A_1 \cdot C}{\frac{1}{\varepsilon_1} + \frac{A_1}{A_E}\left(\frac{1}{\varepsilon_{Ew}} - 1\right)}\left(\Theta_1 - \Theta_E\right) \qquad (5)$$

$$\dot{E}_{rE-O} = \dot{Q}_{rE-O} = \frac{A_E \cdot C}{\frac{1}{\varepsilon_{Ez}} + \frac{A_E}{A_2}\left(\frac{1}{\varepsilon_2} - 1\right)}\left(\Theta_E - \Theta_2\right) \qquad (6)$$

where:

$$\Theta_1 = \left(\frac{T_1}{100}\right)^4, \quad \Theta_E = \left(\frac{T_E}{100}\right)^4, \quad \Theta_2 = \left(\frac{T_2}{100}\right)^4$$

C = 5,67 $\left[\frac{W}{m^2 \cdot K^4}\right]$ – radiation constant of a perfectly black solid.

Using the condition of isothermicity and diffusiveness of all the surfaces, the state of thermal balance and the features of screen geometry (Fig. 3), are defined as:

Table 1. The description of lightness and radiation of specific elements of 1-E-2 system, according to Figure 3

Surface	Luminosity of surface	Radiation of surface
Solid 1 surface	$\dot{H}_1 = \dot{E}_1 + r_1 \cdot \dot{H}_{Ew} \cdot \varphi_{E,1}$	$\dot{G}_1 = \dot{H}_{Ew} \cdot \varphi_{E,1}$
Internal screen surface	$\dot{H}_{Ew} = \dot{E}_{Ew} + r_E \cdot \dot{H}_1 \cdot \varphi_{1,E}$	$\dot{G}_{Ew} = \dot{H}_1 \cdot \varphi_{1,E}$
External screen surface	$\dot{H}_{Ez} = \dot{E}_{Ez} + r_E \cdot \dot{H}_2 \cdot \varphi_{E,2}$	$\dot{G}_{Ez} = \dot{H}_2 \cdot \varphi_{E,2}$
Solid 2 surface	$\dot{H}_2 = \dot{E}_2 + r_2 \cdot \dot{H}_{Ez} \cdot \varphi_{2,Ez}$	$\dot{G}_2 = \dot{H}_{Ez} \cdot \varphi_{2,Ez}$

$$\Theta_E = \frac{\Theta_1\left[\frac{A_1}{A_E}\frac{1}{\varepsilon_{Ez}} + \frac{A_1}{A_2}\left(\frac{1}{\varepsilon_2}-1\right)\right] + \Theta_2\left[\frac{1}{\varepsilon_1} + \frac{A_1}{A_E}\left(\frac{1}{\varepsilon_{Ew}}-1\right)\right]}{\frac{1}{\varepsilon_1} + \frac{A_1}{A_E}\left(\frac{1}{\varepsilon_{Ew}} + \frac{1}{\varepsilon_{Ez}} - 1\right) + \frac{A_1}{A_2}\left(\frac{1}{\varepsilon_2}-1\right)}, \tag{7}$$

In this case, surface 2 represents the conditions that $\Theta_2 = \Theta_0$ and $\varepsilon_2 = \varepsilon_0 = 1$, the surface ratio is the configuration factors $\varphi_{E,1} = \frac{A_1}{A}$. The screen temperature in this case, is given by equation:

$$T_E = \left(\frac{T_1^4\left(\varphi_{E,1}\frac{1}{\varepsilon_{Ez}}\right) + T_0^4\left[\frac{1}{\varepsilon_1} + \varphi_{E,1}\left(\frac{1}{\varepsilon_{Ew}}-1\right)\right]}{\frac{1}{\varepsilon_1} + \varphi_{E,1}\left(\frac{1}{\varepsilon_{Ew}} + \frac{1}{\varepsilon_{Ez}} - 1\right)}\right)^{0,25}, \tag{8}$$

Equation (5) describes the temperature of screen knowing $\varepsilon_1, \varepsilon_E, \varphi_{E,1}$ and provided that the reflectiveness of the internal screen surface is diffusive.

If a surface is a mirror surface, [9], equation (5) changes and adopts a form:

$$T_E = \left(\frac{T_1^4\cdot\left(\varphi_{E,1}\frac{1}{\varepsilon_{Ez}}\right) + T_0^4\cdot\left(\frac{1}{\varepsilon_1} + \frac{1}{\varepsilon_{Ew}} - 1\right)}{\frac{1}{\varepsilon_1} + \frac{1}{\varepsilon_{Ew}} + \varphi_{E,1}\cdot\frac{1}{\varepsilon_{Ez}} - 1}\right)^{0,25}, \tag{9}$$

Limiting the stream of radial energy emitted to the surrounding through the screen depending on the internal surface quality, is described in the following way:

- for a diffusive surface:

$$K_{EK,D} = \frac{\dot{E}_{r1-E-O}}{\dot{E}_{r1-O}} = \frac{\dot{Q}_{1-E-O}}{\dot{Q}_{1-O}} = \frac{1}{1+\varphi_{E,1}\left(\frac{1}{\varepsilon_{Ew}} + \frac{1}{\varepsilon_{Ez}} - 1\right)\cdot\varepsilon_1} < 1 \tag{10}$$

- in case of mirror surface:

$$K_{EK,Z} = \frac{\dot{E}_{r1-E-O}}{\dot{E}_{r1-O}} = \frac{\dot{Q}_{1-E-O}}{\dot{Q}_{1-O}} = \frac{1}{1+\varepsilon_1\cdot\left(\frac{1}{\varepsilon_{Ew}} + \varphi_{E,1}\cdot\frac{1}{\varepsilon_{Ez}} - 1\right)} < 1 \tag{11}$$

Equation (6) implies that the decrease of energy emitted to the surrounding can be obtained by increasing configuration coefficient $\varphi_{E,1}$ and decreasing screen emission ε_E.

DESCRIPTION OF IN AIR-COOLED SCREEN

An air-cooled screen is described referring to a screen protecting a gondola of a helicopter drive motor (Fig. 4). Figure 5 presents a functional schematic of a module limiting infrared emission from a gondola surface of a helicopter drive to the environment with the use of a convection air-cooled cooling screen. The experimental research [4], [5], [6] enabled a description of a screen with two-sided convection cooling where:

- the field of temperature on the gondola surface is unevenly distributed along the gondola's length $T_G = T_G(x)$, whereas along the perimeter the changes are mathematically insignificant;
- the temperature in the immediate vicinity of the helicopter depends on flight altitude and the temperature at the ground $T_H = T_H(T_0, H)$;

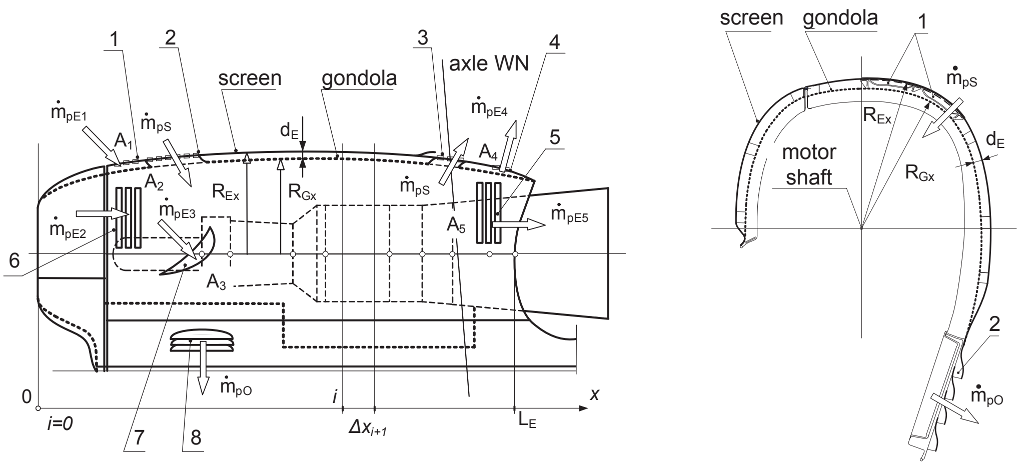

Fig. 4. Schematic of a screen limiting infrared emission through the gondola cover in the drive motor of the PZL W-3 Sokół. The scheme presents the location of the screen and air intakes and outlets cooling the screen interior. Own elaboration.

- the radial coefficients of gondola and screen surfaces and air do not depend on temperature in the discussed range, thus they are described by average values;
- air as a mixture of two-atom gases is treated as transparent for infrared radiation (diathermic medium) [4].

Additionally, it was assumed that the screen is from the inside with air passing between the surfaces: gondola covers and screen interior; and from the outside with the rotor stream flowing around the gondola covered with the screen.

Air which flows inside the screen is generated by pressure distribution in the post-rotor stream in the areas of air intakes and outlets of the screen.

The description of the cooling screen was formulated, alike in point 2, by the method of surface luminosity and radiation, given that the internal and external screen emissions are not equal

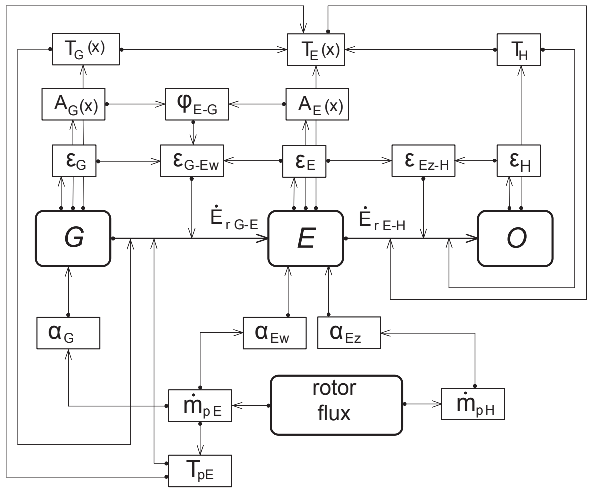

Fig. 5. Schematic of transforming radial energy in a system with convectional cooling from the side of gondola and from the outside, provided that $\varepsilon_H = 1$

($\varepsilon_{Ew} \neq \varepsilon_{Ez}$), and the surrounding emission ($\varepsilon_H = 1$). The coefficients of heat absorption are neither equal for the internal and external screen surfaces ($\alpha_{Ew} \neq \alpha_{Ez}$) (Fig. 6.)

The radial energy emitted as radiation to the screen assumed to be transmitted as radiation luminosity to the environment and as heat to the cooling air. The schematic of the model of the screen with two-sided convection cooling was presented.

Simultaneous equations describing the model of the screen: the equations of enthalpy of air inside the screen and the energy balance equation for the screen are as follows:

$$dT_P = \left(T_{Gx} - T_{Px}\right) \cdot \frac{\alpha_{Gx} \cdot O_{Gx}}{\dot{m}_{pE} \cdot c_p} dx + \left(T_{Ex} - T_{Px}\right) \cdot \frac{\alpha_{Ewx} \cdot O_{Ex}}{\dot{m}_{pE} \cdot c_p} dx \tag{12}$$

$$\left(\frac{T_{Ex}}{100}\right)^4 \cdot \left(1 + \frac{O_{Gx} \cdot \varepsilon_{GEw}}{O_{Ex} \cdot \varepsilon_{Ez}}\right) + T_{Ex} \cdot \left(\frac{\alpha_{Ewx} + \alpha_{Ezx}}{C_c \cdot \varepsilon_{Ez}}\right) - T_{px} \cdot \left(\frac{\alpha_{Ewx}}{C_c \cdot \varepsilon_{Ez}}\right) - \left(\frac{T_{Gx}}{100}\right)^4 \cdot \left(\frac{O_{Gx} \cdot \varepsilon_{GEw}}{O_{Ex} \cdot \varepsilon_{Ez}}\right) +$$

$$- \left(\frac{T_H}{100}\right)^4 - T_H \cdot \left(\frac{\alpha_{Ezx}}{C_c \cdot \varepsilon_{Ez}}\right) = 0 \tag{13}$$

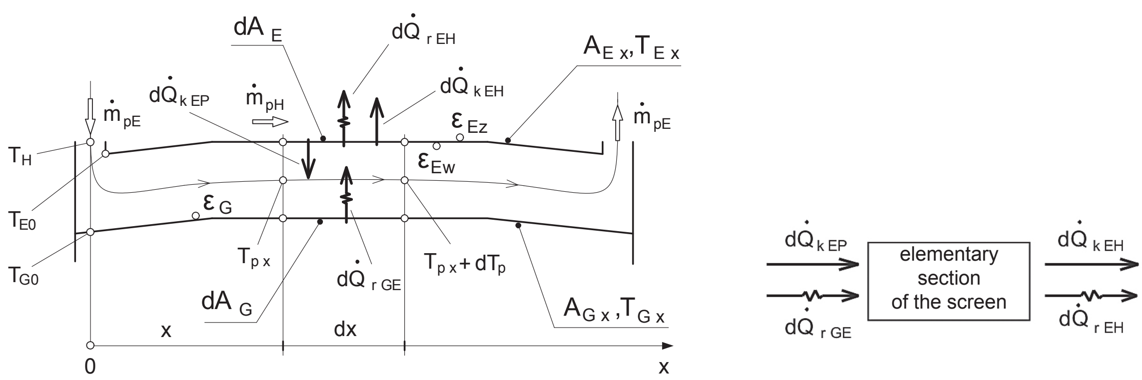

Fig. 6. Schematic of model of convection cooling module covering the motor drive gondola

with the boundary conditions:

$$\text{for } x = 0 \text{ is } T_{Gx} = T_{G0},\ T_{Ex} = T_{E0},\ T_{Px} = T_H \tag{14}$$

where: $\dot{m}_E$ – stream of the mass of air colling the screen interior,
C_c – constant of black body radiation,
ε_{GEw}, ε_{Ez} – emission coefficients: mutual emission of gondola and screen inside surface and external screen surface, respectively,
O_{Gx}, O_{Ex} – current perimeters of gondola and screen,
α_{Gx}, α_{Ewx}, α_{Ezx} – heat absorption coefficients: from the gondola surface, internal and external screen surface

The mutual emission is described by the following equations:

- inside the screen

$$\varepsilon_{GEw} = \frac{\varepsilon_G \cdot \varepsilon_{Ew}}{\varepsilon_{Ew} + \left(\varepsilon_G - \varepsilon_{Ew} \cdot \varepsilon_G\right) \cdot \varphi_{GEw}} \tag{15}$$

- outside the screen

$$\varepsilon_{EzH} = \varepsilon_{Ez} \tag{16}$$

Equation (9) is a first order ordinary differential equation with a variable coefficient strongly non-linear, whereas equation (10) is an algebraic non-linear equation. Both of the equations are coupled with air temperature T_{Px} changing along the air path inside the screen. The solution of the equation is the function of temperature distribution in the screen T_{Ex}. The solution should be computed numerically because of those difficulties.

Thus, a discreet system of space variable *x*, yet, for a changeable grade Δx, the gives a method for experimental data processing from measuring the surface temperatures on gondola and motor drive surfaces:

$$x_{i+1} = x_i + \Delta x_{i+1},\ i = 0, 1, 2, 3,... \tag{17}$$

The discretisation of numerical solution is given in Figure 7.

The considered area of the gondola cover, screen, space between the gondola and the screen and external immediate surrounding were divided with the *i*-indexed planes into elementary parts of unequal thicknesses (uneven grades of surface discretisation). Therefore, i^{th} layer from the direction of flow ends with i^{th} cross section.

It was also assumed that the air flowing through i^{th} layer absorbs heat of average temperature T_{GGi} from the gondola wall and the heat of average temperature T_{EEi} from internal screen surface as specified in the following equations:

$$T_{GGi+1} = \frac{T_{Gi+1} + T_{Gi}}{2} \tag{18}$$

$$T_{EEi+1} = \frac{T_{Ei+1} + T_{Ei}}{2} \tag{19}$$

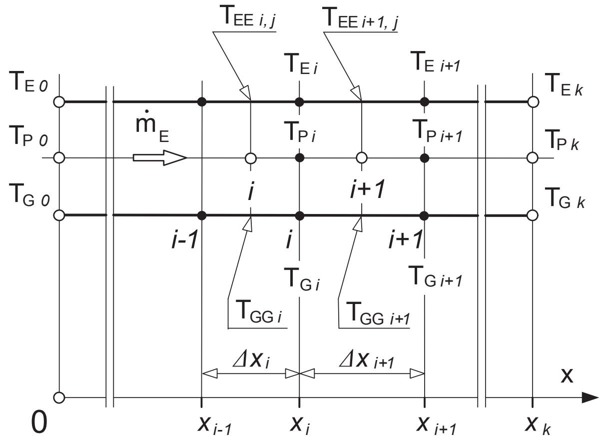

Fig. 7. Schematic of discretisation of the numerical solution

Equation (6) with the temperature derivative $\frac{dT_p}{dx}$ substituted with a difference quotient with "a grade forward" has the following form:

$$T_{Pi+1} = T_{Pi}\left[1-\left(S_G + S_E\right)_{i+1}\right] + T_{GGi+1}\cdot S_{Gi+1} + T_{EEi+1}\cdot S_{Ei+1}\ , \tag{20}$$

and equation (7) has the following numerical form:

$$\left(\frac{T_{EEi+1}}{100}\right)^4 \cdot E_{Ai+1} + T_{EEi+1}\cdot E_{Bi+1} - T_{Pi+1}\cdot E_{Di+1} - E_{Ci+1} = 0 \tag{21}$$

Individual equation coefficients (15) and (16) are described in the following way:

$$S_{Gi+1} = \frac{O_{Gi+1}\cdot \alpha_{Gi+1}}{\dot{m}_E \cdot c_p}\cdot \Delta x_{i+1}, \tag{22}$$

$$S_{Ei+1} = \frac{O_{Ei+1}\cdot \alpha_{Ewi+1}}{\dot{m}_E \cdot c_p}\cdot \Delta x_{i+1}, \tag{23}$$

$$E_{Ai+1} = 1 + \frac{O_{Gi+1}\cdot \varepsilon_{GE}}{O_{Ei+1}\cdot \varepsilon_{Ez}}\ , \tag{24}$$

$$E_{Bi+1} = \frac{\alpha_{EPi+1} + \alpha_{Ezi+1}}{\varepsilon_{Ez}\cdot C_C}\ , \tag{25}$$

$$E_{Di+1} = \frac{\alpha_{EPi+1}}{\varepsilon_{Ez}\cdot C_C}\ , \tag{26}$$

$$E_{Ci+1} = \frac{O_{Gi+1}\cdot \varepsilon_{GE}}{O_{Ei+1}\cdot \varepsilon_{Ez}}\left(\frac{T_{GGi+1}}{100}\right)^4 + \left(\frac{T_H}{100}\right)^4 + \frac{\alpha_{Ezi+1}}{\varepsilon_{Ez}\cdot C_C}\cdot T_H \tag{27}$$

The boundary conditions corresponding to the numerical solution i+0 are as follows:
for $i = 0$

$$\begin{aligned} T_{Pi} &= T_{P0} = T_H, \\ T_{Gi} &= T_{G0},\ T_{GG1} = T_{G0} \\ T_{Ei} &= T_{E0},\ T_{EE1} = T_{E0} \end{aligned} \tag{28}$$

Due to the coupling of the two equations (16) and (17), their solution for temperature T_E was completed with the subsequent approximations by Newton-Raphason method:

$$T_{EEi+1,j+1} = T_{EEi+1,j} - \frac{F\left(T_{EEi+1,j}\right)}{F'\left(T_{EEi+1,j}\right)}, \tag{29}$$

for:

$$F'\left(T_{EEi+1,j}\right)=\frac{d\ F}{d\ T_{EE}} \tag{30}$$

Function F and its derivative F' are described by the following equations:

$$F\left(T_{EEi+1,j}\right)=\left(\frac{T_{EEi+1}}{100}\right)^4\cdot E_{Ai+1}+T_{EEi+1}\cdot E_{Bi+1}-T_{Pi+1}\cdot E_{Di+1}-E_{Ci+1} \tag{31}$$

$$F'\left(T_{EEi+1,j}\right)=4\cdot\left(\frac{T_{EEi+1}}{100}\right)^3\cdot E_{Ai+1}+E_{Bi+1}-E_{Di+1}\cdot S_{Ei+1} \tag{32}$$

The initial value of $T_{EEi+1,0}$, due to the effect of cooling, the first approximation was assumed in a form of solution without convectional cooling, yet for a limited length of the screen. Then, for $j = 0$ the equation is:

$$T_{EEi+1,0}=\left(\frac{T_{Gi+1}^4\left(\varphi_{EG}\dfrac{1}{\varepsilon_{Ew}}\right)+T_H^4\left[\dfrac{1}{\varepsilon_G}+\dfrac{1}{\varepsilon_{Ez}}-1\right]}{\dfrac{1}{\varepsilon_G}+\varphi_{EwGi+1}\left(\dfrac{2}{\varepsilon_{Ew}}-1\right)}\right)^{0,25}, \tag{33}$$

Coefficients φ_{EwGi+1} corresponding to the radiation relations were expressed by the relations of configuration (according to previous reservations) as for cylindrical and circular surfaces of limited length.

Such an approach is justified for comparing the distances between the screen and gondola with the thickness of individual layers and for constant temperatures in i[th] layers of gondola surfaces and corresponding screen surfaces. In the first approximation coefficient φ_{EwGi+1} was described by the equation as for two concentric cylinder of limited length (labels as for Fig. 7). The equation has the following form:

$$\varphi_{Ew-Gi+1}=\frac{1}{ER_{i+1}}-\frac{1}{\pi\cdot ER_{i+1}}\left\{\arccos\frac{EB_{i+1}}{EA_{i+1}}-\frac{1}{2E\Lambda_{i+1}}\times\right.$$
$$\left.\times\left[\sqrt{\left(EA_{i+1}+2\right)^2-\left(2ER_{i+1}\right)^2}\arccos\frac{EB_{i+1}}{ER_{i+1}\cdot EA_{i+1}}+EB_{i+1}\arcsin\left(\frac{1}{ER_{i+1}}\right)-\frac{\pi\cdot EA_{i+1}}{2}\right]\right\} \tag{34}$$

where:

$$ER_{i+1}=\frac{R_{Ei+1}}{R_{Gi+1}},\ E\Lambda_{i+1}=\frac{\Delta x_{i+1}}{R_{Gi+1}},$$

$$EA_{i+1}=E\Lambda^2{}_{i+1}+ER^2{}_{i+1}-1,\ EB_{i+1}=E\Lambda^2{}_{i+1}-ER^2{}_{i+1}+1.$$

CONVECTIONAL SCREEN COOLING

A helicopter motor drive gondola screen is convection cooled from the inside and from the outside [7]. From the inside, the screen is cooled by the stream of air flowing into the space between the screen and gondola through intakes and flowing out through the outlets onto the side of screen due to the reaction of post-rotor stream (distribution of velocities and pressures in this stream). The external surface of the screen is also cooled by a post-rotor stream.

Table 2 presents the criteria equations that are used to described the coefficients of heat absorption from the internal screen surface to the stream of air cooling the space between the gondola and screen and from the external screen surface to the stream of air flowing down the screen in the post-rotor stream.

Table 2. Criteria equation to define the coefficient of heat absorption from the external screen surface to the stream of air flowing down the screen in the post-rotor stream

Form of equation	Condition	No
$Nu_{Ez} = 0{,}224 \cdot Re_Z^{0{,}612} \cdot (1 - 0{,}54 \cos^2 \beta)$, as in [9] $Nu_{Ez} = \frac{\alpha_{Ez}\, d_{Hz}}{\lambda_{pz}}$ Re_Z – Reynolds number for the post-rotor flow of gondola, β – angle of flow cutting.	$3 \cdot 10^3 \le Re \le 1{,}5 \cdot 10^4$	(34)

SIMULATION CALCULATIONS AND THEIR RESULTS

Simulation calculations concerning the infrared screen covering the gondola of motor drive PZL 10W in the PZL W-3 Sokół were made with author's own developed software INFRED-EKRAN_1_0.exe, Part 2 written in Fortan 95 language. The block scheme of the programme is depicted in Fig. 9.

In the numerical calculations, the results of calculations made in Part 1 of the programme were used (these results transfer automatically from Part 1 to Part 2 of the programme) and the experimental results concerning the distribution of temperatures in drive T_S and gondola surface T_G with thermographic camera Therma CAM S45.

The sample results and simulation calculations are depicted in the graphs. The heat absorption coefficients for the external gondola surface and for the internal screen surface were determined from equation (35) table 3, where as the heat absorption coefficients for the external gondola surface from equation (34). Emission coefficients for the external gondola surface, internal and external screen surface were assumed as in [11] and [13].

The results of experimental tests and temperature distribution are given in Figure 10.

Table 3. Criteria equation to define the coefficient of heat absorption from the internal surface of the screen to the stream of air cooling the space between the gondola and the screen

Item.	Form of equation	Condition	No
1.	$Nu = 0{,}26 \cdot Re_p^{0{,}8} \cdot Gr_p^{-0{,}15}$, (for the air flow), as in [3, 14]	$10^3 \le Re \le 10^5$ $3 \cdot 10^3 \le Gr \le 10^6$	(35)
2.	a) internal surface of the screen $Nu_{Ew} = 0{,}023 \cdot Re_p^{0{,}8} \cdot Pr_p^{\frac{1}{3}} \cdot \left(\frac{\mu_p}{\mu_s}\right)^{0{,}14}$ b) external surface of the screen $Nu_{Gz} = 0{,}017 \cdot Re^{0{,}8} \cdot Pr^{\frac{1}{3}} \cdot \left(\frac{d_z}{d_w}\right)^{0{,}18}$	$Re > 10^4$; $0{,}7 < Pr < 16700$ $\frac{d_z}{d_w} = 1{,}2 \div 14$	(36)

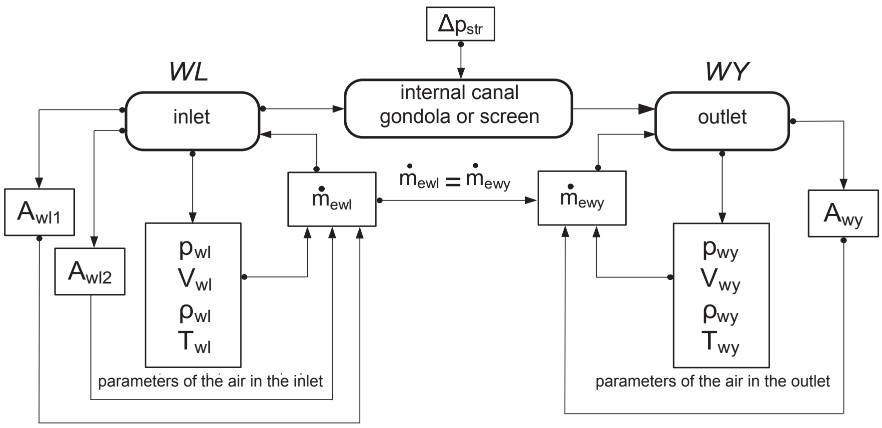

Fig. 8. Schematic of discretisation of the solved numerical task

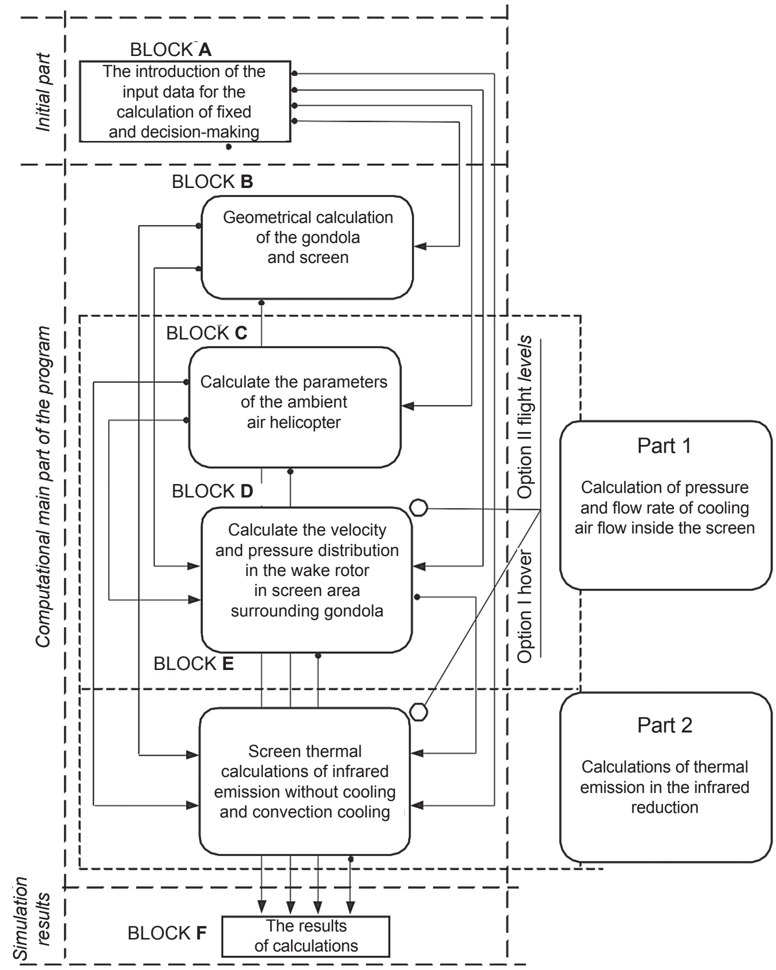

Fig. 9. Block schematic of calculation programme INFRED-EKRAN_1_0.exe, Part 2 written in Fortan 95 language

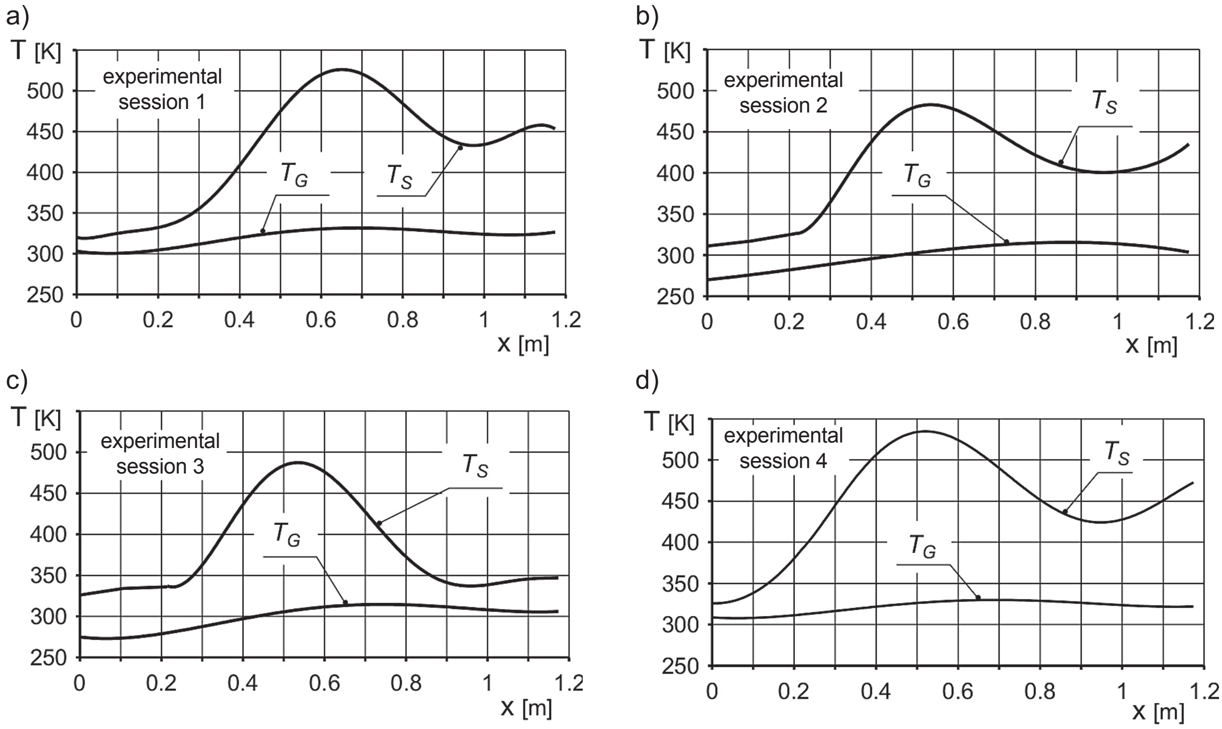

Fig. 10. Distribution of temperatures in drive T_S and gondola surface T_G along the path determined in four experimental sessions

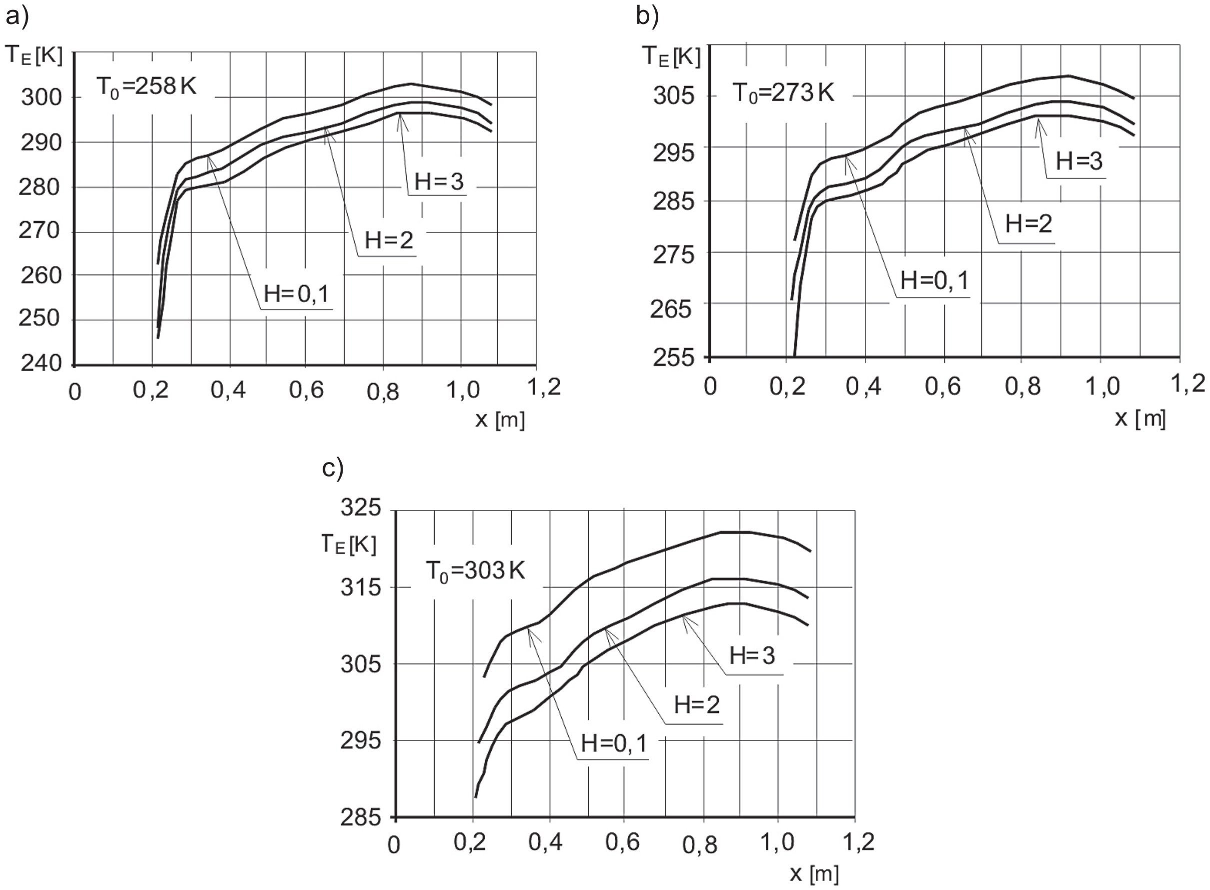

Fig. 11. Distribution of temperatures on the screen surface along the path of the gondola protecting the drive in helicopter PZL W-3 Sokół at different flight altitudes, for different initial temperatures at the ground level: a) $T_0 = 258K$, b) $T_0 = 273K$, c) $T_0 = 303K$

Figure 11 presents the results of numerical solutions of screen temperatures at different altitudes and for initial temperatures at the ground level T0.

CONCLUSIONS

The results of modelling and simulations allow for the following conclusions:

1. The simulation calculations concerning the functioning of infrared screens protecting a helicopter drive gondola confirm that the screens in helicopter PZL W-3 Sokół are necessary. The same applies to other types of helicopters with similar engine compartments.
2. The internal screen surface should manifest reflectiveness similar to the reflective body, which increases the efficiency of screening.
3. The internal cooling of the screen by the post-rotor air stream in the proximal surrounding of a gondola increases the efficiency of infrared screening. At the same time, cooling the space between gondola and the screen decreases the danger of overheating the gondola and helicopter turbine drive.

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