Laboratory Work № 8

# INFLUENCE OF CUTOUTS ON WING PANELS DURABILITY

Purpose of the Work – investigation of the influence of the design parameters of the reinforced cutout on its durability and mass; choice of parameters gain region of the conditions specified durability and minimum weight, which will deepen and consolidate the knowledge acquired in the process of studying the theme "Designing cutout zones in the panels and webs on a given durability."

## Content of the Work

1. Familiarization with typical design solutions, structural and technological features and the nature of fatigue failure of panels in areas of reinforced cutouts.
2. Acquaintance with the methodology for calculating the durability of the cutout zones.
3. Study of the effect of structural reinforcement parameters on the durability and mass of the cutout zone
4. The choice of parameters for the reinforcement zone of cutout of the conditions for ensuring a given durability and the development of a sketch of the design of this zone.

The initial data for designing the reinforced cutout zone in the panel are its thickness in the regular area, the step of the reinforcing elements, the destructive and operational level of stresses in the panel, the value of the specified durability, and the geometric parameters of the cutout.

The stress concentration in the panel, caused by the cutout in it, in the calculations of durability can be taken into account by using the effective stress concentration factors, and the durability calculation itself was performed using the fatigue curve of a smooth sample (as shown in the laboratory work number 1).

However, the presence, as a rule, of a biaxial stress state and the relatively large dimensions of the cutout require the use of special calculation methods. The durability of structural elements with geometric concentrators that are in a complex stress state is characterized by the fact that the local stress-strain state (SSS) at the point from which fatigue failure begins can be considered uniaxial. The most appropriate method for calculating durability in this case is TsAGI GEKON [19], which allows to take into account the deformation properties of the material and their change in the process of cyclic loading. Durability calculated by the local deformation in the dangerous point on the basis of fatigue curves in coordinates $\varepsilon - N$.

Tangential stresses and strains acting on the free surface of the stress concentrator at the most loaded point is determined from the system of equations

$$\sigma_a \varepsilon_a = (k_f \sigma_{a.ном})^2 / E , \qquad (8.1)$$

$$\varepsilon_a = \sigma_a / E + (\sigma_a / k)^n , \qquad (8.2)$$

where $\sigma_a$, $\varepsilon_a$ – amplitudes of local stresses and strains; $\sigma_{a.ном}$ – amplitude of nominal stresses in the net section; $E$ – modulus of elasticity of the material; $k_f$ – effective stress concentration factor; $k$, $n$ – material constants.

The moment of crack occurrence is calculated based on a power approximation of the full fatigue diagram from

$$R = \delta / \varepsilon^m_{a.экв} , \qquad (8.3)$$

$$\varepsilon^m_{a.экв} = \varepsilon_a^{1-\chi} (\sigma_{max} / E)^\chi ; \qquad (8.4)$$

where $R$ – durability before the occurrence of fatigue cracks, expressed in half-cycles; $\varepsilon_{a.экв}$ – amplitude equivalent in durability of deformation of a symmetric cycle; $\sigma_{max}$ – the maximum stress of the real cycle; $\delta$, $m$, $\chi$ – material constants.

To perform calculations using the GECON method, it is necessary to know the coefficients. $k$ and $n$ cyclic curve of material deformation (8.2) and constants $\delta$, $m$ and $\chi$ a full fatigue pattern of a smooth specimen obtained under regular loading, and also to ensure that the nominal stresses in the "net" section did not exceed the proportionality limit.

The effective stress concentration factor can be found through theoretical dependence

$$k_\sigma = C_f \alpha_\sigma , \qquad (8.5)$$

where value of factor $C_f$ is 0,907 for the range of values durability $10^4$ … $10^6$ for semi-finished from alloys Д16Т and В95Т.

To calculate the durability of the reinforced cutout zone using the GECON method, it is necessary to solve the system of equations (8.1) and (8.2) respectively to the magnitude of the strain amplitude at the most loaded point on the cutout contour and find the number of cycles to failure from equation (8.3). Deformation amplitude is determined by the magnitude of the stresses at this point, taking into account the plastic behavior of the material.

Let stop on the determination of the magnitude of local stresses at a dangerous point. One of the most accurate is the finite element method (FEM), which allows to take into account all the design features, the cutout geometry, the shape of the reinforcement, the presence of reinforcing and reinforcing elements. However, due to large time of calculation by FEM and impossible of its use for designing calculations in this work offers approximate expression for the calculation of the geometric concentration factors depending on the geometry of the cutout and gain parameters for the simplest cases: circular unsupported and supported by a cutout, elliptic reinforced cutout and rectangular with rounded corners reinforced cutout (Fig. 8.1 - 8.3). Approximating dependences are presented in table. 8.1.

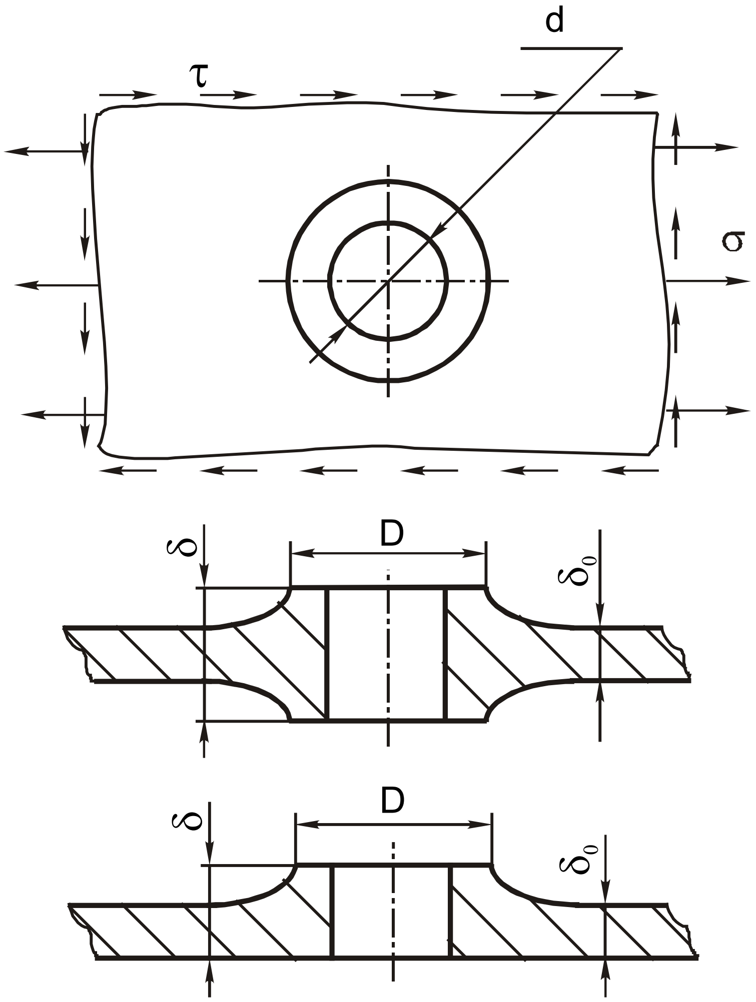



Fig. 8.1. Fragment of the panel with a round cutout

Thus, the local stresses at the most loaded point on the cutout contour are calculated from the nominal main stresses in the panel, determined in the “gross” section based on

$$\sigma_{лок} = k_\sigma (\sigma_1 + \frac{1}{3}\sigma_2). \tag{8.6}$$

The system of equations (8.1) and (8.2) can be transformed into one nonlinear equation relatively to $\sigma_a$ which solves by approximations method. As a first approximation using the equation for elastically deformed state as

$$\sigma_a^{(0)} = k_\sigma \sigma_{a.ном}. \tag{8.7}$$

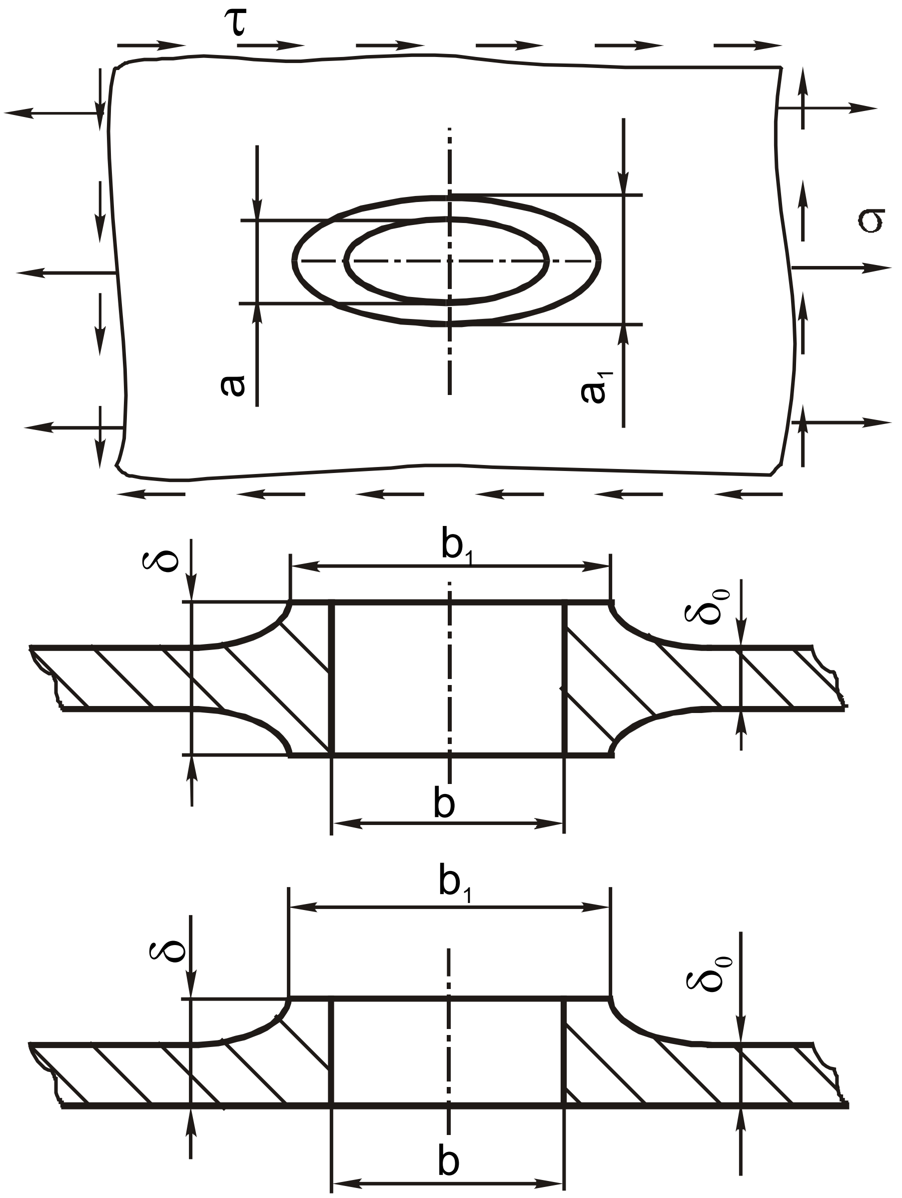



Fig. 8.2. Fragment of a panel with an elliptical cutout

If a $\sigma_a^{(0)} < \sigma_{\text{пц}}/2$ (where $\sigma_{\text{пц}}$ - the limit of proportionality of the material), then $\varepsilon_a$ calculated from equation (8.1). Otherwise $\varepsilon_a$ determined from equation (8.2), and according to it - $\sigma_a^{(2)}$ as a second approximation. The process is repeated until the moment of accuracy is reached. $\Delta = 10^{-4}$ . After convergence is reached, the strain amplitude is calculated from equation (8.1).

The considered technique and approximating dependences to determine the stress concentration factors presented in Table. 8.1, allow to calculate the durability of areas of reinforced cutout in the wing panels in cases of fatigue cracks on the edge of the notch.

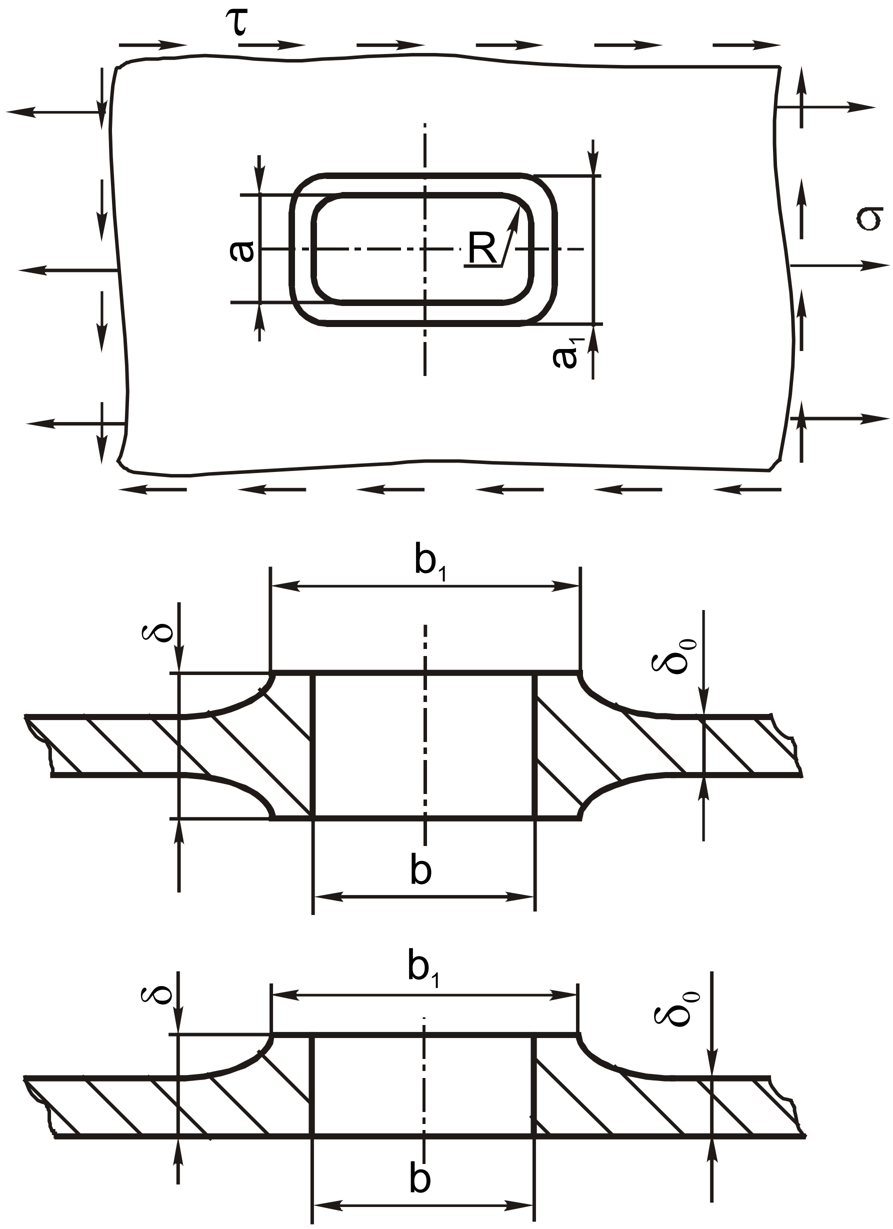
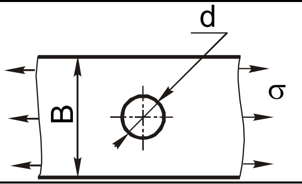
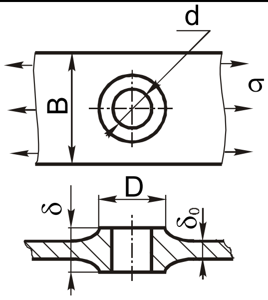
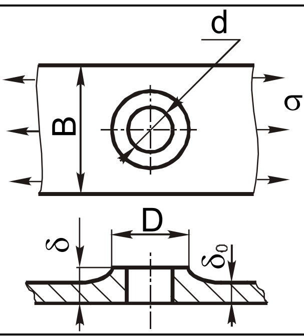
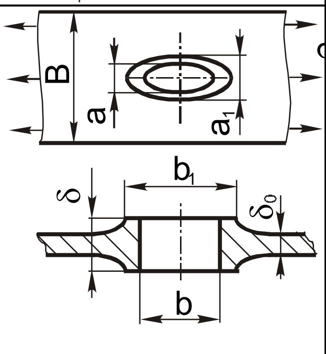
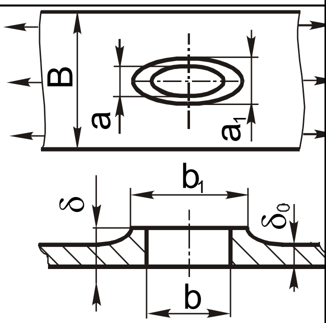


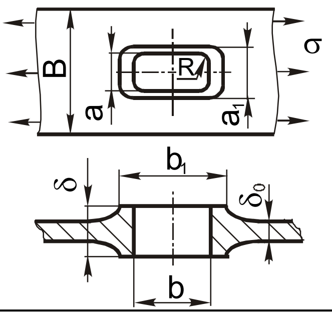
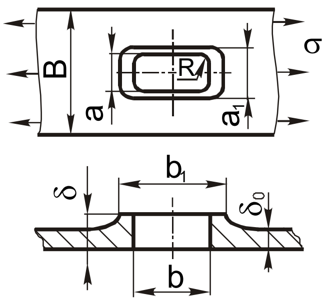

Fig. 8.3. Fragment of a panel with a rectangular cutout

Таблица 8.1

Аппроксимирующие зависимости по расчету геометрического коэффициента концентрации напряжений на контуре выреза

| № | Cutout shape | Formula for $\alpha_\sigma$ | Formula number |
|---|---|---|---|
| 1 |  | $\alpha_\sigma^{н} = 1 + 2(1 - d/B)^3$ | (8.8) |
| 2 |  | $\alpha_\sigma^{бр} = 3f + 0{,}2d/B$ для $d/B \le 0{,}6$; <br> $\alpha_\sigma^{бр} = 3f + C(d/2B - 0{,}3)^2 + 0{,}12$ для $d/B > 0{,}6$; <br> $f = 1 - (0{,}344 - 0{,}24d/D)(\delta/\delta_0 - 1)$; <br> $C = 51(d/D - 0{,}6)^2 + 9{,}8$ | (8.9) <br> (8.10) |
| 3 |  | $\alpha_{\sigma.нс}^{бр} = \alpha_{\sigma.сим}^{бр} \cdot f_1$; <br> $f_1 = \frac{\delta/\delta_0}{1{,}5}\left(\frac{1{,}72}{D/d}\right)^{0{,}7}$ | (8.11) |
| 4 |  | $\alpha_\sigma^{бр} = (1 + 2a/b) + 0{,}2d/B$ для $d/B \le 0{,}6$; <br> $\alpha_\sigma^{бр} = (1 + 2a/b)f + C(d/2B + 0{,}3)^2 + 0{,}12$ для $d/B > 0{,}6$; <br> $f = 1 - (0{,}344 - 0{,}24a/a_1)(\delta/\delta_0 - 1)$; <br> $C = 51(a/a_1 - 0{,}6)^2 + 9{,}8$ | (8.12) <br> (8.13) |
| 5 |  | $\alpha_{\sigma.нс}^{бр} = \alpha_{\sigma.сим}^{бр} \cdot f_1$; <br> $f_1 = \frac{\delta/\delta_0}{1{,}5}\left(\frac{1{,}72}{a_1/a}\right)^{0{,}7}$ | (8.14) |

Окончание табл. 8.1

| № | Cutout shape | Formula for $\alpha_\sigma$ | Formula number |
|---|---|---|---|
| 6 |  | $\alpha_\sigma^H = 2{,}15(R/a)^{-0{,}222}\cdot f\cdot f_1$<br>для $R/a \le 0{,}3;$<br>$\alpha_\sigma^H = (2{,}5+R/a)\cdot f\cdot f_1$<br>для $R/a > 0{,}3;$<br>$f = 1-(0{,}324-0{,}22a/a_1)(\delta/\delta_0-1);$<br>$f_1 = 0{,}636\,a/b+0{,}324$ | (8.15)<br><br>(8.16) |
| 7 |  | $\alpha_\sigma^H = 2{,}15(R/a)^{-0{,}222}\cdot f\cdot f_1\cdot f_2$<br>для $R/a \le 0{,}3;$<br>$\alpha_\sigma^H = (2{,}5+R/a)\cdot f\cdot f_1\cdot f_2$<br>для $R/a > 0{,}3;$<br>$f = 1-(0{,}324-0{,}22a/a_1)(\delta/\delta_0-1);$<br>$f_1 = 0{,}636a/b+0{,}324;$<br>$f_2 = \frac{\delta/\delta_0}{1{,}5}\left(\frac{1{,}72}{a_1/a}\right)^{0{,}7}$ | (8.17)<br><br>(8.18) |

Design calculation cutout zone performed according to the formula

$$(B-d)\delta_0+(\delta-\delta_0)(D-d)\ge B\delta_0, \tag{8.19}$$

where $B$ – the width of the panel in considering zone.

The reinforcement parameters calculated using formula (8.19) provide static panel strength in cross section along the cutout axis, however, they need to be tested according to the fatigue criterion. Durability of this zone determined by the above procedure, and comparing the calculated value of durability with specified. If the calculated value of durability exceeds the specified, then the process of designing the cutout zone can be considered complete. However, modern requirements for aircraft resource, as a rule, can not be satisfied in the calculations only for static strength. The reinforced cutout zone needs to be modified to meet the resource requirements.

Desighn parameters affecting the durability and weight of the cutout area is thickness of the panel in the area of reinforcement and width defined by values $\delta$, $D$, $a$ and $b$ (Fig. 8.1 - 8.3).

To calculate the influence of the design parameters of the reinforcement zone on its durability and weight will be assumed that the cutout shape may have a monolithic single or double loop reinforcement is limited equidistant of cutout curve. Reinforcement mass for each variant of the cutout shape:

- round reinforced cutout

$$m=\frac{\pi}{4}\rho(\delta-\delta_0)(D^2-d^2); \qquad (8.20)$$

- elliptical reinforced cutout

$$m=\frac{1}{2}\pi\rho(a_1b_1-ab)(\delta-\delta_0); \qquad (8.21)$$

- rectangular cutout with rounded corners

$$m=\left\{b_1a_1-ba-4\left(1-\frac{\pi}{4}\right)\left[\left(R+\frac{a_1-a}{2}\right)^2-R^2\right]\right\}\rho(\delta-\delta_0), \qquad (8.22)$$

where $m$ – the mass of material spent on reinforcement; $\rho$ – density of the panel material; $\delta_0$ – the thickness of the panel in the regular zone; $\delta$ –panel thickness in the reinforcement zone; $b$, $a$ – major and minor axis of the elliptical cutout (см. рис. 8.2) or the length and width of the rectangular cutout (Fig. 8.3); $D$ – the outer diameter of the reinforcement round cutout; $b_1$, $a_1$ – major and minor axes of the reinforcement of the elliptical cutout (Fig. 8.2) or length and width of the reinforcement of the rectangular cutout (Fig. 8.3); $R$ – corners fillet radius of a rectangular cutout.

Table. 8.2 shows the options for individual tasks for calculating the durability of the cutout zone, as well as the design of a reinforced cutout zone for a given durability

We calculate durability in zone at the edge of the reinforced cutout for circular, elliptic and rectangular shapes in different embodiments cutout amplification.

According to the results of calculations, it is necessary to construct graphs showing the effect of the form on the durability of the zone of the reinforced notch, to analyze them and make conclusions.

Cutout reinforcement parameters in the wing panel is selected as follows. For the given geometry of the cutout and the stressed state in the wing panel, from the condition of providing static strength over the section passing along the axis of the cutout (8.7), we calculate the reinforcement parameters in the first approximation. The next step is to calculate the durability at the edge of the reinforced cutout. If the reinforcement parameters determined from the static strength conditions provide the specified durability, the design process can be considered complete. Otherwise, the cutout must be strengthened by changing the reinforcement parameters in accordance with their effect on durability and mass, checking that the conditions for ensuring the specified durability are met. Note that the change in the external size of the reinforcement of the cutout is more favorable by the criterion of durability - weight, than the change in the thickness of the panel in the area of the reinforcement. The process is repeated until a given durability is ensured, and from the alternatives, you should choose one that, in addition to meeting the requirements of static strength and given durability, has a minimum mass.

Table 8.2

Individual tasks for laboratory work

| № | Diameter of round hole $d$, ellipts axis - $a$ or the width of the rectangular cutout a, mm | Panel Width $B$, мм | Panel thickness in regular zone $\delta_0$, mm | Panel thickness in reinforcement zone $\delta$, mm | Rectangular cutout corners fillet radius $R$, mm | $\sigma_{max\,0}$, MPa | $\tau_{max\,0}$, MPa |
|---|---|---|---|---|---|---|---|
| 1 | 20 | 120 | 2 | 4 | 2 | 90 | 60 |
| 2 | 30 | 180 | 3 | 6 | 2 | 100 | 50 |
| 3 | 40 | 240 | 3 | 6 | 3 | 110 | 40 |
| 4 | 50 | 300 | 4 | 8 | 4 | 120 | 30 |
| 5 | 60 | 360 | 4 | 7 | 10 | 130 | 20 |
| 6 | 70 | 420 | 4 | 8 | 12 | 140 | 10 |
| 7 | 80 | 480 | 4 | 8 | 14 | 130 | 10 |
| 8 | 90 | 540 | 4 | 8 | 16 | 120 | 20 |
| 9 | 100 | 600 | 4 | 8 | 18 | 110 | 30 |
| 10 | 100 | 600 | 5 | 8 | 20 | 100 | 40 |
| 11 | 100 | 600 | 6 | 10 | 20 | 105 | 35 |
| 12 | 100 | 600 | 8 | 14 | 20 | 110 | 30 |
| 13 | 90 | 540 | 2 | 4 | 16 | 115 | 25 |
| 14 | 80 | 480 | 2 | 4 | 14 | 120 | 20 |
| 15 | 70 | 420 | 2 | 4 | 12 | 125 | 15 |
| 16 | 60 | 360 | 3 | 5 | 12 | 130 | 10 |
| 17 | 70 | 420 | 3 | 5 | 12 | 135 | 15 |
| 18 | 80 | 480 | 3 | 6 | 12 | 140 | 10 |
| 19 | 90 | 540 | 4 | 7 | 12 | 145 | 15 |
| 20 | 100 | 600 | 4 | 8 | 12 | 150 | 10 |