Laboratory Work № 7
THE INFLUENCE OF DESIGN PARAMETERS ON THE DURABILITY OF THE LONGITUDINAL JOINTS OF THE WEBS OF THE SPAR

<u>Purpose of the Work</u> – investigation of the influence of the design parameters of the longitudinal connection of the web of the spar with the cap on its durability and mass; selection of parameters of these joints, ensuring a given durability, and development their structures, allowing to consolidate and deepen the knowledge obtained in the process of studying the topic "Designing joints in the side members for a given durability".

<u>Content of the Work</u>

1. Acquaintance with typical design options, structural and technological features and the nature of fatigue failure of longitudinal joints of the spar web.

2. Acquaintance with the method of calculating the durability of the longitudinal joints of the web of the spar.

3. Study of the influence of design parameters on the durability and mass of longitudinal web joints.

4. The choice of the parameters of the joint wall for a given durability and the development of a sketch of the design of this joint.

Longitudinal joints of the wall with the cap of the spar is performed, as a rule, single-shear. However, the designs of the double-web spar of the Yak-25 aircraft and spars whose caps are made of two angle section profiles (Tu-134), are known. In this case, the joints of the wall with the cap are double shear. Fasteners are usually placed in two rows in a checkered manner. Commonly rivets, bolt-rivets, less often - bolts with a diameter of 4 ... 6 mm , arranged in increments in a row (3 ... 9)   and between rows (3 ... 7)   are used. The thickness of the spar cap rib greater than the web thickness in the connection zone of 1.7 - 2.6 times.

The longitudinal connections of the web parts are performed by single-shear, usually double-row, with a checkered arrangement of fasteners. Sketches of typical wall joints on aircraft side members are shown. on Fig. 7.1 - 7. 3.

The surface roughness of the workpiece corresponds to the class Rz 40. Holes for bolts or rivets corresponds H7 or H9 accuracy classes and discharge roughness Rz 1,25. All aluminum parts of the construction are anodized before assembly, and outside the area of the fuel tanks they are additionally covered with primer (for example , FL-086-244). When performing assembly operations, riveting is carried out on the press, and in hard-to-reach places - by hand. single or multi-impact instrument (in accordance with the manufacturer's instructions (for example, TI 36-21-86)). Bolts are set and nuts are tightened in accordance with OCT 1 00017-77. To ensure the tightness of the compounds, sealing compounds are used (for example, WITED-1 or U30-MES5) applied inside joint or on surface.
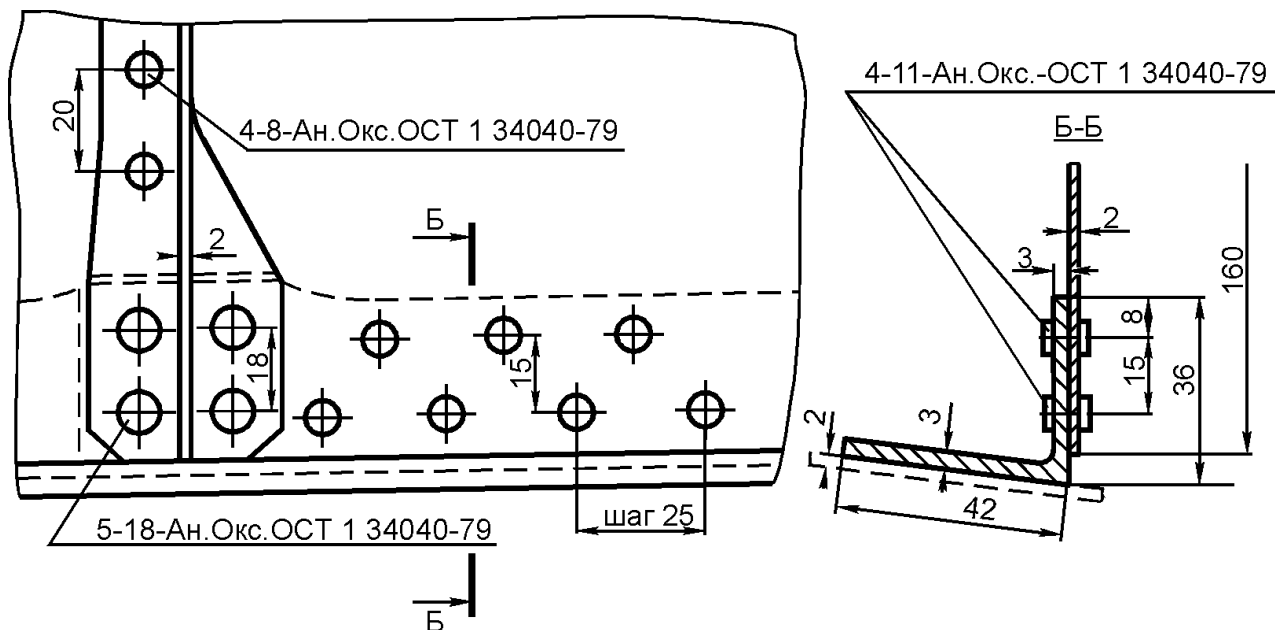
4-8-Ан.Окс.ОСТ 1 34040-79

4-11-Ан.Окс.-ОСТ 1 34040-79

Б-Б

5-18-Ан.Окс.ОСТ 1 34040-79

шаг 25

Fig. 7.1. The design of the longitudinal joints of the wall with the rib of the cap of the wing of a modern passenger aircraft

A-A
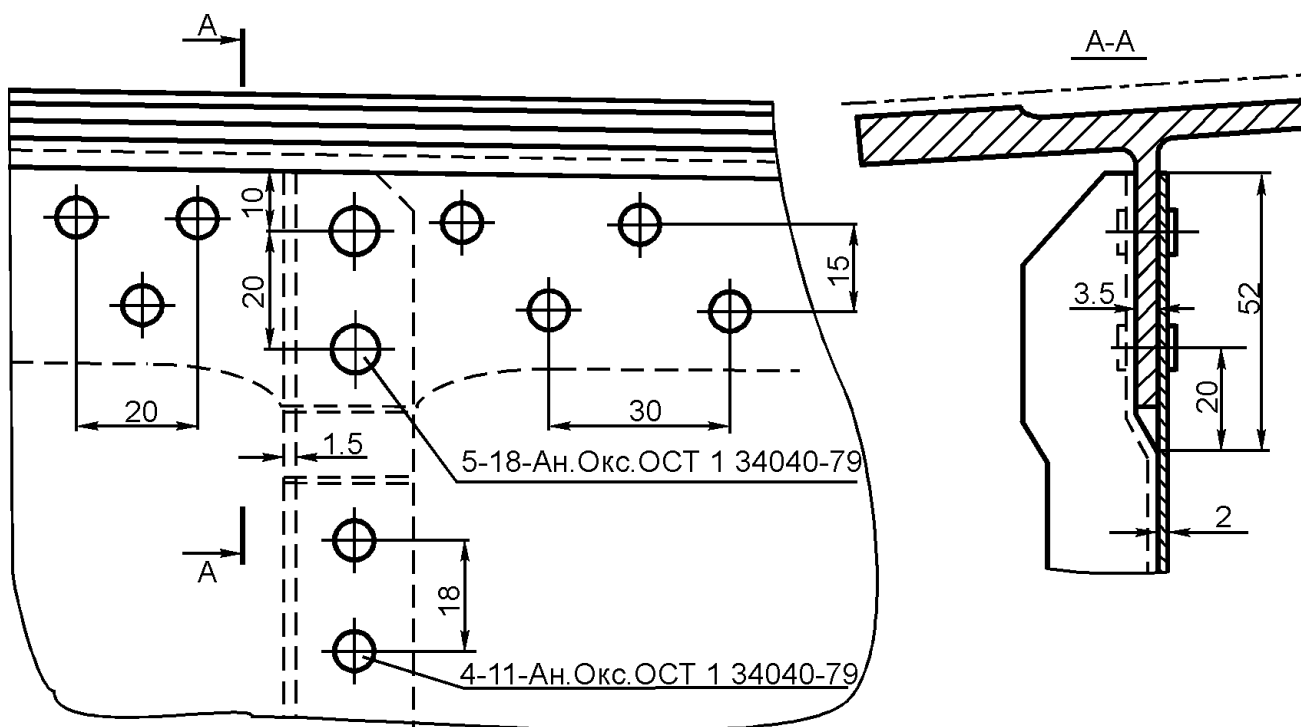
5-18-Ан.Окс.ОСТ 1 34040-79

4-11-Ан.Окс.ОСТ 1 34040-79

Fig. 7.2. The design of the longitudinal connection of the wall with the edge of the belt of the wing of a modern transport aircraft
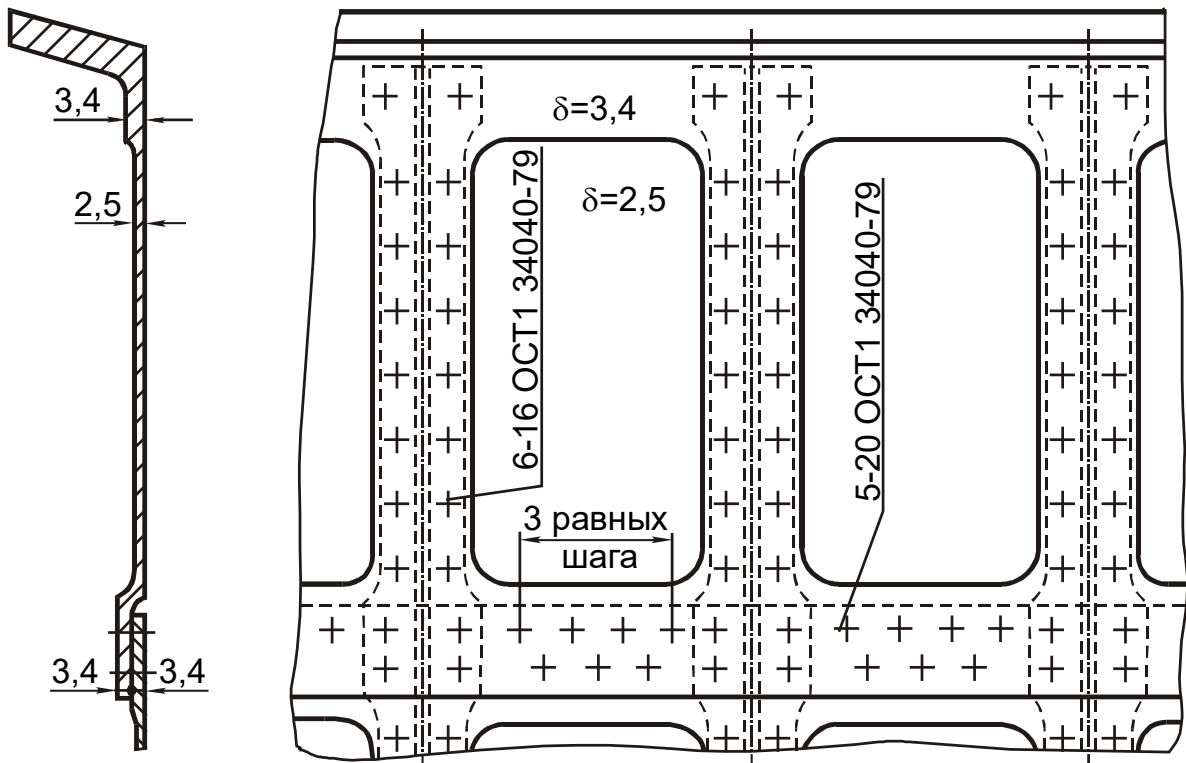
63

Fig. 7.3. Fragment of the wing design of a heavy transport aircraft with a longitudinal joint of the webs

In the longitudinal joints of the walls, fatigue cracks arise in the web from the holes of the fastening elements of the first row of the connection of the wall with the edge of the tensioned cap and propagate perpendicular to the action of the main tensile stresses in it, those. at an angle of 40 ... 60 ° to the longitudinal axis of the spar.

Consider the longitudinal connection of the wall with the rib of the cap or the longitudinal connection of the walls to each other (Fig. 7. 4), loaded by the flow of tangential forces and normal stresses.

The durability of the longitudinal joints of the walls in assemblied spars is found from the expression

$$\sigma^{*} = k_{CM}^{\tau}\sigma_{CM} + k_{\varPi}\sigma_{z},\qquad(7.1)$$

where σ_{CM} – the nominal bearing stress in the webs of the hole considered fastener; σ_{z} – nominal bending stresses in the web.

Stresses σ_{z} defined as the nominal stresses in the web in section along the axis of the fastener of the considered row from the action of the bending moment, and calculated according to the beam theory or the finite element method.
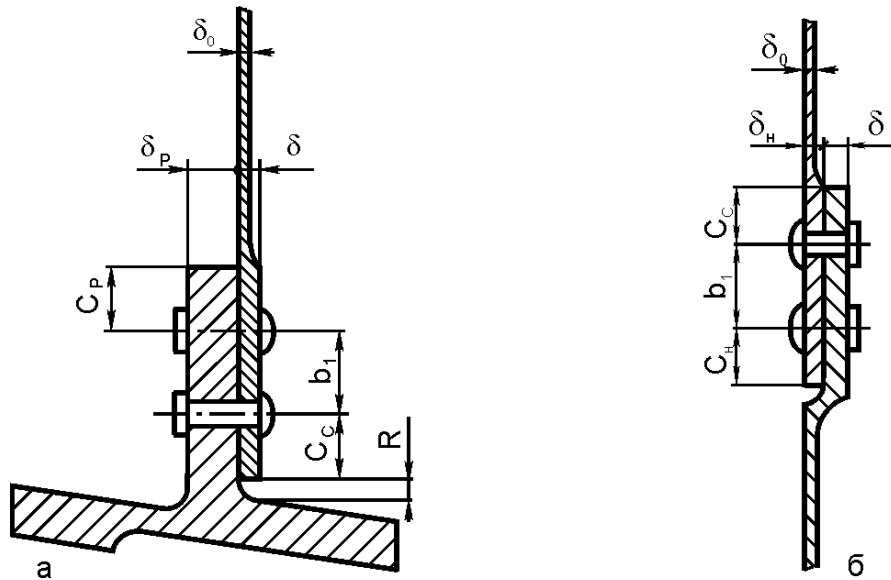
Рис.7.4. Longitudinal web joint:
a - connection of a web with an edge of a belt; b - the connection of the webs together

Coefficient $k_{\text{Л}}$ depends on used method of joint unloading in probable fatigue fracture zone, and it is determined according to the results of fatigue testing of design variants of the spar sections. The value of the coefficient a is in the range of 0.7 ... 1.0. In the absence of joint unloading $k_{\text{Л}}$ = 1.0.

Nominal bearing stresses are calculated by the formula

$$\sigma_{\text{см}} = \frac{P_{\text{к.э}}}{d\delta},$$
(7.2)

where d – diameter of the fastener; δ – web thickness in a zone fastener.

Value of force $P_{\text{к.э}}$, perceived by the fastener of each row, for the case of the calculation of the longitudinal joint of the wall we find according to

$$P_{\text{к.э}} = \tau_0 \delta_0 b \eta \varphi,$$
(7.3)

where τ_0 – nominal stress in the web in the joint zone, calculated at the operating level of loads; δ_0 – web thickness in a regular zone without fastener holes; b – step of fasteners in a row;; η – loading degree on fasteners of the considered row, i.e. the part of the load, they carried; φ – factor of loading irregularity of fasteners along a rows of jont, depending on the degree of buckling of the wall (Fig. 7. 5) and in the range of 1.1 ... 1.3.
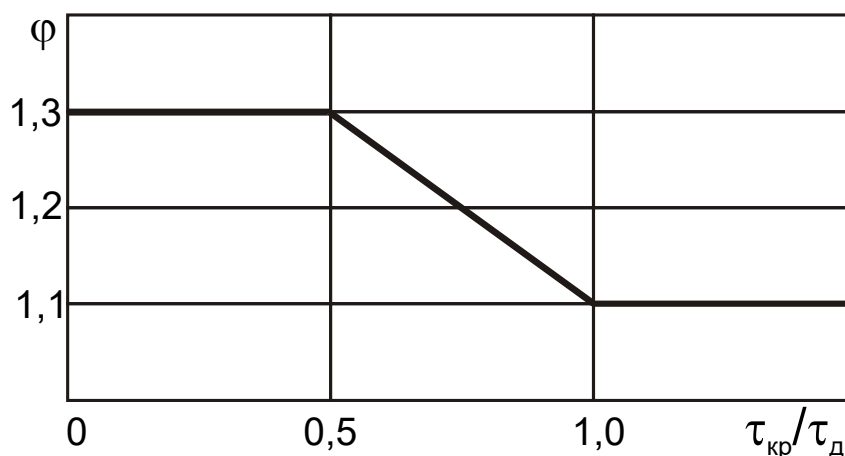
65

Fig. 7.5 . The change in the factor of loading irregularity of fasteners along a rows of joints depending on the degree of instability of the wall

Calculation of the distribution of forces between the rows of fasteners is performed by the method of forces [10]. The system of canonical equations of the force method includes $n-1$ unknown parameters (n - the number of rows of the connection) and in the general case is

$$\delta_{i,i-1}X_{i-1} + \delta_{i,i}X_i + \delta_{i,i+1}X_{i+1} = \Delta_{ip}, \tag{7.4}$$

where X_i – unknown forces in the cap in the area between the fasteners; $\delta_{i,j}$ – displacement of i force application points in j unitary state; Δ_i – displacement of the same points in loaded state.

To calculate the load distribution over the joint rows in the case of the application of the unitary force, the coefficients of the canonical equations are found by the formulas

$$\delta_{i,i} = \alpha_i + \beta_i + C_{i+1} + C_i; \qquad \delta_{i,i-1} = \delta_{i,i+1} = -C_i;$$

$$\Delta_{1p} = -(C_1 + \alpha_1), \qquad \Delta_{ip} = -\alpha_i \text{ for } \qquad i = 2,...,n-1,$$

where α_i – compliance of the web in the area between the rows of fasteners,

$$\alpha_i = \frac{b_1}{G_c \delta_в b};$$

β_i – compliance cap rib in the area between the rows of fasteners,

$$\beta_i = \frac{b_1}{G_p \delta_p b};$$

C_i – compliance of the mounting point,

$$C_i = \frac{5}{E_{к.э} d} + 0,8 \left[\frac{1}{E_c \delta} + \frac{1}{E_p \delta_p} \right];$$

b_1 – step between rows of fasteners;; $E_{к.э}$, E_c, E_p – the modulus of elasticity of the fastener, the web and the cap rib, respectively; G_c, G_p – shear modulus of the wall material and belt rib.

After forming and solving equations of the forces method degree of joint

roes find from dependencies

$$\eta_1 = 1 - X_1, \quad \eta_i = X_{i-1} - X_i \text{ for } i = 2,...,n-1.$$

To determine the coefficient of loading irregularity of fasteners along a rows of joints, it is necessary to calculate the critical stresses of buckling of the wall. The calculation is carried out according to the formula

$$\tau_{\kappa p} = k \frac{\pi^2 E_c}{12(1-v)^2}\left(\frac{\delta_0}{1}\right), \tag{7.5}$$

where 1 – step of web vertical stiffeners; k – coefficient taking into account the method of supporting the sides of the web cell: $k = 5,34+4\,(h/1)^2$ with hinged side support; $k = 8,98+3,3\,(h/1)^2$ with cantilever longitudinal and hinged support of the transverse sides; $k = 5,34+6,94\,(h/1)^2$ with hinged longitudinal and cantilever transverse sides; $k = 8,98+5,6\,(h/1)^2$ all sides cantilevered; h – web height.

To determine the durability of joints from material D16T parameters in the formula (7.1) we find from the results of the fatigue tests conducted by the authors, and take:
- for connections made with rivets type OCT 1 34040-79,

$$\sigma^* = 589,1N^{-0,13}, \qquad k_{CM}^\tau = 0,23N^{0,064};$$

- for connections made with bolts of type OCT 1 31132-80, with a sliding fit (H9/h8)

$$\sigma^* = 1215N^{-0,197}, \qquad k_{CM}^\tau = 0,092N^{0,136};$$

- for connections made with bolts of type OCT 1 31138-80, when landing H7/p6

$$\sigma^* = 1160N^{-0,184}, \qquad k_{CM}^\tau = 0,089N^{0,132}.$$

Using the above dependencies, it is possible to calculate the durability of variants of longitudinal joints of the webs and evaluate the influence of design parameters. on the durability of these joints.

Design parameters that affect the durability of the longitudinal web joints are the step of fasteners, their diameter, web thickness in the joint area and into a regular zone, Step of vertical web stiffeners, height of web.

To calculate the effect of the design parameters of the joint on the durability and mass of the joint we limit its overall dimensions: along the length - distance between stiffeners, and width - a zone of interface of the connected parts. The mass of the joint is written as

$$m_c = m_{\text{Д}} - m_{\text{ОТ В}} + m_{\text{К.Э}}, \tag{7.6}$$

where $m_{\text{Д}}$ – the mass of the connected parts; $m_{\text{ОТ В}}$ – the mass of material

removed when making holes of fasteners; $m_{к.э}$ – mass of fasteners.

In accordance with the notation adopted in Fig. 7.4, we write the component mass in the following form:

$$m_{д} = \delta l \rho_{c}(4d + b_{1}) + \delta_{p} l \rho_{p}(4d + b_{1});$$

$$m_{от в} = \frac{nl\pi d^{2}}{4b}(\delta\rho_{c} + \delta\rho_{p});$$

$$m_{к.э} = \frac{nl\pi d^{2}}{4b}(\delta + \delta + 2,4d)\rho_{б},$$

where ρ_{c}, ρ_{p}, $\rho_{б}$ – density of the material of the web, cap rib and fastener , respectively.

Calculations of the durability of the longitudinal joints show that in order to achieve the required level of durability, it is necessary to change the connection parameters: the step of the fasteners, their diameter, the wall thickness in the joint zone. In addition, various design solutions can be applied to increase the durability of the joint. However, all ways to increase the durability of joints are connected with their masses. Therefore, it is advisable to select the connection parameters taking into account changes in the mass of the structure.

The nature of propagation of fatigue cracks in the joints of the wall and cap of the spar is shown in fig. 7.6.
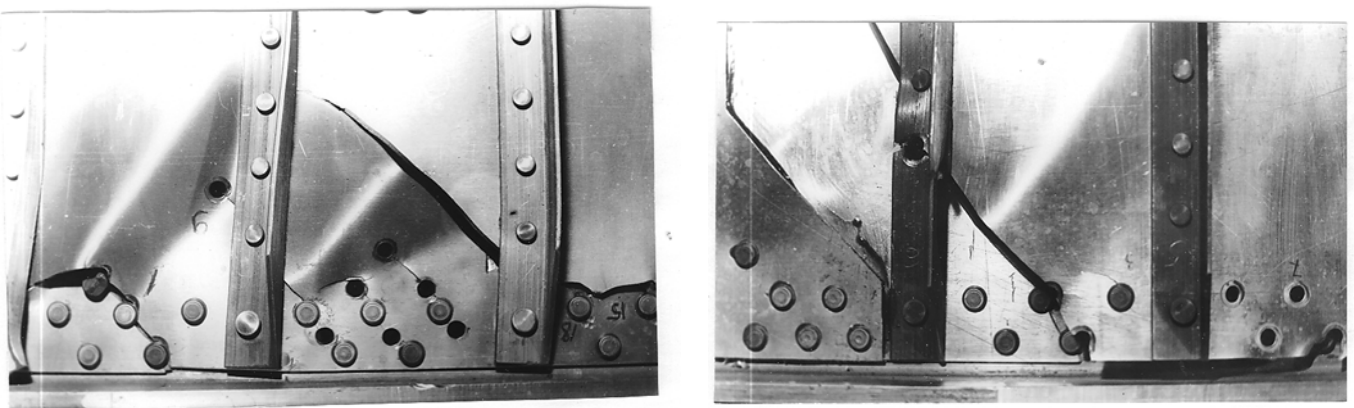

Fig. 7.6. The nature of the spread of fatigue cracks in the joints of the wall and cap of the spar

The algorithm for selecting the parameters of the longitudinal joints of the web and spar cap:

1. Select joint parameters from the first conditions of static strength and durability to calculate this embodiment. If the estimated durability exceeds the specified, then the design process for a given durability can be considered complete.

2. If the calculated durability is less than the specified one, it is necessary

to change the parameters of the joint design that affect the durability, calculate the durability of the modified variants of the joint and their mass.

3. The joint parameters should be considered rational, providing the given static strength and fatigue life, as well as leading to the smallest increase in the mass of the structure.

In laboratory work, initial data for calculating the durability of design variants for longitudinal joints of the spar web and cap are: stress state in the wall, represented by stresses σ_z and τ_{xy} in the zone of the first row of the joint; wall height in the calculated section; type of fasteners; web stiffener step l = 100 mm ; cap rib thickness = 5 mm ; aluminum alloy density ρ = 0,0027 kg / mm^3 ; steel ρ = 0,0078 kg / mm^3 ; step between fastener rows b_1 = 3. Variants of individual task are presented in Table. 7.1.

Table 7.1

Индивидуальные задания для выполнения лабораторной работы

№	Type of fastener and fit	σ_z, MPa	τ_{xy}, MPa	h_j, MPa
1	Rivet OCT1 34040-79	100	50	300
2	Rivet OCT1 34040-79	100	60	320
3	Rivet OCT1 34040-79	100	70	340
4	Rivet OCT1 34040-79	100	80	360
5	Rivet OCT1 34040-79	90	50	380
6	Rivet OCT1 34040-79	90	60	400
7	Rivet OCT1 34040-79	90	70	420
8	Rivet OCT1 34040-79	90	80	440
9	Bolt OCT1 31132-80 (H9/h8)	100	50	300
10	Bolt OCT1 31132-80 (H9/h8)	100	60	320
11	Bolt OCT1 31132-80 (H9/h8)	100	70	340
12	Bolt OCT1 31132-80 (H9/h8)	100	80	360
13	Bolt OCT1 31132-80 (H9/h8)	90	50	380
14	Bolt OCT1 31132-80 (H9/h8)	90	60	400
15	Bolt OCT1 31132-80 (H9/h8)	90	70	420
16	Bolt OCT1 31132-80 (H9/h8)	90	80	440
17	Bolt OCT1 31138-80 (H7/p6)	100	50	300
18	Bolt OCT1 31138-80 (H7/p6)	100	60	320
19	Bolt OCT1 31138-80 (H7/p6)	100	70	340
20	Bolt OCT1 31138-80 (H7/p6)	100	80	360
21	Bolt OCT1 31138-80 (H7/p6)	90	50	380
22	Bolt OCT1 31138-80 (H7/p6)	90	60	400
23	Bolt OCT1 31138-80 (H7/p6)	90	70	420
24	Bolt OCT1 31138-80 (H7/p6)	90	80	440