МІНІСТЕРСТВО ОСВІТИ ТА НАУКИ УКРАЇНИ
ДЕРЖАВНЕ НЕКОМЕРЦІЙНЕ ПІДПРИЄМСТВО
«ДЕРЖАВНИЙ УНІВЕРСИТЕТ «КИЇВСЬКИЙ АВІАЦІЙНИЙ ІНСТИТУТ»
КАФЕДРА КОНСТРУКЦІЇ ЛІТАЛЬНИХ АПАРАТІВ

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«____» ____________ 2024 р.

КВАЛІФІКАЦІЙНА РОБОТА

ЗДОБУВАЧА ОСВІТНЬОГО СТУПЕНЯ «МАГІСТР»

ЗІ СПЕЦІАЛЬНОСТІ

«АВІАЦІЙНА ТА РАКЕТНО-КОСМІЧНА ТЕХНІКА»

Тема: «Метод врахування впливу місцевої втрати стійкості на несучу здатність стиснутих панелей обшивки»

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Київ 2024

MINISTRY OF EDUCATION AND SCIENCE OF UKRAINE
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DEPARTMENT OF AIRCRAFT DESIGN

PERMISSION TO DEFEND
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"___" _______________ 2024

QUALIFICATION PAPER

FOR A MASTER'S DEGREE

ON SPECIALITY

"AVIATION AND AEROSPACE TECHNOLOGIES"

Topic: " A method for the account of the impact of local loss of stability on bearing capacity of compressed panels "

Fulfilled by:	___________	**Myroslava KYRYK**
Supervisor: **Dr. of Sc., professor**	____________	**Mykhailo KARUSKEVYCH**
Labor protection advisor: **PhD, associate professor**	____________	**Kateryna KAZHAN**
Environmental protection adviser: **PhD, associate professor**	___________	**Lesya PAVLIUKH**
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Kyiv 2024

НАЦІОНАЛЬНИЙ АВІАЦІЙНИЙ УНІВЕРСИТЕТ

Аерокосмічний факультет
Кафедра конструкції літальних апаратів
Освітній ступінь «Магістр»
Спеціальність 134 «Авіаційна та ракетно-космічна техніка»
Освітньо-професійна програма «Обладнання повітряних суден»

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«_____» _____________ 2024 р.

ЗАВДАННЯ

на виконання кваліфікаційної роботи здобувача

КИРИК МИРОСЛАВИ ОЛЕГІВНИ

1. Тема роботи «Метод врахування впливу місцевої втрати стійкості на несучу здатність стиснутих панелей обшивки», затверджена наказом ректора від 10 травня року № 1480/од.

2. Термін виконання проекту: з 6 жовтня 2024р. по 15 листопада 2024 р.

3. Вихідні дані до проекту: вихідними даними для проекту є геометричні характеристики літака прототипу, а також внутрішні силові фактори.

4. Зміст пояснювальної записки: основна частина: Аналіз поточного стану досліджень втрати стійоксті, визначення основних методів врахування впливу місцевої втрати стійкості, а також огляд методів запобігання негативного впливу на несучу здатність панелі; Проектування панелей крила для дослідження оптимальності використання методів зниження впливу місцевої втрати стійкості. Охорона праці, Охорона навколишнього середовища.

5. Перелік обов’язкового графічного (ілюстративного) матеріалу: презентація Power Point, малюнки та схеми.

6. Календарний план-графік

№	Завдання	Термін виконання	Відмітка про виконання
1	Огляд літератури за проблематикою роботи. Аналіз різних видів втрати стійкості	26.08.2024 – 08.09.2024	
2	Визначення основних методів врахування місцевої втрати стійкості в загальній міцності панелі	09.09.2024 – 22.09.2024	
3	Проектування панелі крила літака для теоретичної верифікації методів зменшення впливу місцевої втрати стійкості	23.09.2024 – 06.10.2024	
4	Моделювання спроектованих панелей крила	07.10.2024 – 20.10.2024	
5	Написання розділів по охороні праці та навколишнього середовища	21.10.2024 – 03.11.2024	
6	Написання та оформлення пояснювальної записки	04.11.2024 – 17.11.2024	
7	Попередній захист кваліфікаційної роботи	18.11.2024 – 21.11.2024	
8	Подача роботи для перевірки на плагіат	22.11.2024 – 26.11.2024	
9	Виправлення зауважень. Підготовка супровідних документів та презентації доповіді	27.11.2024 – 02.12.2024	
10	Захист кваліфікаційної роботи	03.12.2024 – 15.12.2024	

7. Консультанти з окремих розділів:

Розділ	Консультант	Дата, підпис	
		Завдання видав	Завдання прийняв
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Охорона навколишнього середовища	к.т.н., професор Леся ПАВЛЮХ		

8. Дата видачі завдання: 26 серпня 2024 року

Керівник дипломної роботи ____________ Михайло КАРУСКЕВИЧ

Завдання прийняв до виконання ____________ Мирослава КИРИК

NATIONAL AVIATION UNIVERSITY

Aerospace Faculty
Department of Aircraft Design
Educational Degree "Master"
Specialty 134 "Aviation and Aerospace Technologies"
Educational Professional Program "Aircraft Equipment"

APPROVED BY
Head of the department,
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_____Sviatoslav YUTSKEVYCH
"___" _______________ 2024

TASK

for the qualification paper

Myroslava KYRYK

1. Topic: « A method for the account of the impact of local loss of stability on bearing capacity of compressed panels », approved by the Rector’s order № May 10 2024 year, № 1480/od

2. Period of work execution: from October 6 2024 y. to November 15 2024 y.

3. Initial data: the initial data for the project are the geometric characteristics of the prototype aircraft, as well as the internal load factors.

4. Content: the main part: Analysis of the current state of stability loss research, determination of the main methods of taking into account the impact of local loss of stability, as well as an overview of methods for preventing negative effects on the load-bearing capacity of the panel; Design of wing panels to investigate the optimality of using methods to reduce the impact of local loss of stability. Labor protection, Environmental protection.

5. Required material graphic (illustrative) material: Power Point presentation, drawings and diagrams.

6. Thesis schedule:

№	Task	Time limits	Done
1	Review of the literature on the issues of work. Analysis various types of buckling	26.08.2024 – 08.09.2024	
2	Determination of the main methods of taking into account the local loss of stability in the overall strength of the panel	09.09.2024 – 22.09.2024	
3	Design of an aircraft wing panel for theoretical verification of methods for reducing the effect of local loss of stability	23.09.2024 – 06.10.2024	
4	Modeling designed wing panels	07.10.2024 – 20.10.2024	
5	Execution of the parts, devoted to environmental and labor protection	21.10.2024 – 03.11.2024	
6	Writing and design explanatory note	04.11.2024 – 17.11.2024	
7	Preliminary defense of the thesis	18.11.2024 – 21.11.2024	
8	Submission of the work to plagiarism check	22.11.2024 – 26.11.2024	
9	Making corrections, preparation of documentation and presentation	27.11.2024 – 02.12.2024	
10	Defense of the qualification paper	03.12.2024 – 15.12.2024	

7. Special chapter advisers:

Chapter	Adviser	Date, signature	
		Task issued	Task received
Labor protection	PhD, associate professor Kateryna KAZHAN		
Environmental protection	PhD, associate professor Lesia PAVLIUKH		

8. Date of issue of the task: 26 August 2024

Supervisor: ____________ Myhailo KARUSKEVYCH

Student: ____________ Myroslava KYRYK

РЕФЕРАТ

Кваліфікаційна робота « Метод врахування впливу місцевої втрати стійкості на несучу здатність стиснутих панелей обшивки»

86 с., 19 рис., 4 табл., 26 джерел

Робота присвячена методам оптимізації несучої здатності панелей обшивки літака в умовах дії стискаючих напружень.

Основною метою роботи виступає розробка пропозицій стосовно зменшення негативного впливу місцевої втрати стійкості при стисканні панелей конструкцій літака, за допомогою аналітичних методів врахування місцевої втрати стійкості при оцінці статичної міцності стиснутої колони, а також методів зменшення негативного впливу місцевої втрати стійкості задля оптимізації проектування стиснутих панелей літака.

Проаналізовані найпоширеніші типи втрати стійкості авіаційній конструкції: загальна втрата стійкості стиснутої панелі, місцева втрата стійкості між стрингерами та нервюрами під дією комбінації зсувних та стискаючих напружень, міжкріпильна втрата стійкості, а також кріплінг, або пружно-пластична втрата стійкості коротких стрижнів є основною новизною цієї роботи. Обрано оптимальний метод розрахунку умов втрати місцевої стійкості.

Практична цінність роботи заключається в розгляді розповсюджених конструктивних сплавів: алюмінієвий сплав 7075-T6510, сталь 30 ХГСА та титановий сплав Ti-Al6-V4. Аналіз проведено для двох типів панелей. Визначена вагова ефективність використання основних підходів.

Авіаційні конструкції, стиснуті панелі, втрата стійкості, пластини, проектування, оптимізація статичної міцності

ABSTRACT

Qualification paper "A method for the account of the impact of local loss of stability on bearing capacity of compressed panels "

86 pages, 19 figures, 4 tables, 26 references

The work is devoted to methods of optimizing the bearing capacity of aircraft skin panels under compressive stresses.

The main purpose of the work is to develop proposals for reducing the negative impact of local loss of stability during compression of aircraft structural panels, using analytical methods for taking into account local loss of stability when assessing the static strength of a compressed column, as well as methods for reducing the negative impact of local loss of stability in order to optimize the design of compressed aircraft panels.

The most common types of loss of stability in an aircraft structure are analyzed: total loss of stability of a compressed panel, local loss of stability between stringers and ribs under the action of a combination of shear and compressive stresses, inter-fastener loss of stability, as well as crippling, or elastic-plastic loss of stability of short rods is the main novelty of this work. The optimal method for calculating the conditions for loss of local stability has been selected.

The practical value of the work lies in the consideration of common structural alloys: aluminum alloy 7075-T6510, steel 30 KhGSA and titanium alloy Ti-Al6-V4. The analysis was carried out for two types of panels. The weight efficiency of the main approaches was determined.

Aviation structures, compressed panels, buckling, plate, design, optimization of static strength

CONTENT

ABBREVIATIONS

EASA – European Union Aviation Safety Agency;

FAA – Federal Aviation Administration;

CFR – Civil Federal Aviation Regulations;

MC – Material characteristics;

MS – Margin of Safety

SAF - Substitutes For Aviation Fuel

HEFA - Hydroprocessed Esters and Fatty Acids.

CNC - computer numerical control

SC – shear center

INTRODUCTION

Even two centuries ago, science fiction writers wrote novels about what is now a reality thanks to airplanes. Moving from one continent to another in less than a day has become possible for almost every inhabitant of the planet. At the same time, aviation is still one of the industries that is developing very quickly. Annually, in the absence of global crisis conditions, passenger transportation grows by 5-10%, which exceeds the growth of most engineering and energy industries.

To make passenger transport more accessible, engineers had to face the problems of optimizing the frame and systems with the condition of losing weight, without degrading operational characteristics. The main design challenges faced by the engineers are the column and plate buckling of thin-walled panels and the fatigue of metal structures. Reducing the weight of the aircraft is not an easy task, because it is necessary not only to ensure a sufficient mass of parts, but also to ensure flight safety, which is a priority when designing any unit that will then be installed on the aircraft.

During operation, two types of buckling can occur in an aircraft: local and general. At the same time, the local buckling can affect the general one, reducing stiffness and causing premature bending of the column [1]. A local loss of stability at loads below the limit load can cause the premature appearance of fatigue cracks, as it causes additional loading by parasitic bending stresses. Also other types of buckling can lead to the safety problem during flight, since inter-rivet or plate buckling under loads below limit or even operational can lead to the distortion of the airfoil. Changing of the airfoil can increase drug of the wing and even can be reason of the aircraft stalling [2]. Plate buckling of the skin near to the air sensors is dangerous too. Since plate buckling of the skin can disturb the airflow and leads to the incorrect measurements of the air sensors that can negatively influence of the safety of the flight.

That is why the work will consider ways to reduce the impact of local buckling on the static strength of the compressed wing panel and on the safe operation of the aircraft.

In this work will be considered conventional method of the considering plate buckling in the total strength of the airplane. Also to analyze methods of the prevention detrimental impact on the ultimate capability of the plate buckling several panel of the aircraft will be designed.

PART 1. CONVENTIONAL BUCKLING METHODS OVERVIEW AND ANALYSIS

The topic of the buckling became relevant even before the appearance of the first aircraft with thin skins and slander rods. The buckling of the compressed column was important for the most structures of civil and industrial engineering, for shipbuilding and much more. That is why mathematicians and engineers from all over the world were looking for methods of analytical prediction of the critical strength of the loss of stability of any structure.

1.1. Euler equation

For the first time, the problem of column buckling was considered by the mathematician Leonard Euler. The scientist considered the general loss of stability of a straight column without initial defects, loaded with an axial compressive force. By the loss of stability, Euler meant the transition from a rectilinear state of equilibrium to a curvilinear elastic state of equilibrium. Now the buckling is called a sudden spontaneous change in the initial deformed state without a qualitative change in the nature of the load [3].

Euler's formula is the easiest and most common method of calculating the critical force for compressed columns.

$$F_{cb} = \frac{\pi^2 \cdot E}{\lambda} \tag{1.1.}$$

where F_{cb} – the critical stress of general buckling of the compressed column

π – the Pi constant which characterizes the shape of the rod's curvature - a sinusoid

E – Young's modulus of the column material.

λ – slenderness ratio, that characterizes the efficiency of the distribution of the material of the rod during compression The greater the flexibility of the rod, the less effectively it perceives compression and the sooner it loses stability [4].

The slenderness ratio of the rod is found according to the following formula:

$$\lambda = \frac{L}{\rho \cdot \sqrt{c}} \tag{1.2.}$$

where L is an length of the rod.

c is coefficient depends on the end fixity condition of the compressed bar, variation of the cross-section shape through the length of the bar and loading condition, see fig. 1.1.

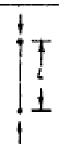
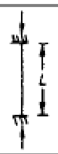
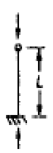
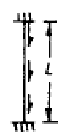
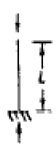
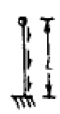
Column shape and end fixity		End fixity coefficient	Column shape and end fixity		End fixity coefficient
	Uniform column, axially loaded, pinned ends	$c = 1$ $\frac{1}{\sqrt{c}} = 1$		Uniform column, distributed axis load, one end fixed, one end free	$c = 0.794$ $\frac{1}{\sqrt{c}} = 1.12$
	Uniform column, axially loaded, fixed ends	$c = 4$ $\frac{1}{\sqrt{c}} = 0.5$		Uniform column, distributed axis load, pinned ends	$c = 1.87$ $\frac{1}{\sqrt{c}} = 0.732$
	Uniform column, axially loaded, one end fixed, one pinned end	$c = 2.05$ $\frac{1}{\sqrt{c}} = 0.7$		Uniform column, distributed axis load, fixed ends	$c = 7.5$ (Approx.) $\frac{1}{\sqrt{c}} = 0.365$
	Uniform column, axially loaded, one end fixed, one end free	$c = 0.25$ $\frac{1}{\sqrt{c}} = 2$		Uniform column, distributed axis load, one end fixed, one end pinned	$c = 6.08$ $\frac{1}{\sqrt{c}} = 0.406$

Fig. 1.1. The column end fixity factors, [5].

ρ is a radius of gyration, that can be found.

$$\rho = \sqrt{\frac{I}{A}} \tag{1.3}$$

where I is the minimum modulus of inertia of the cross-section about which axis column is going to buckle.

A is an area of the cross-section of the column.

The Euler equation has a few limitations that have to be considered before equation application. The main limitations of the Euler formula:

- Absence of the plate buckling. The Euler equation is commonly used for the classic column that has a stable cross-section. If there is plate bucking of the column cross-section, critical stresses of the column are very high and does not correspond to the real buckling stress. Using the Euler equation is very dangerous for thin-walled bars without local buckling prediction, because it will not provide conservative results.
- Critical stresses are lower than proportional limit. Euler question should not be used with column, critical stress of which is higher than proportional limit. Because after yielding of the material, modulus of elasticity is changed and critical stresses in reality will be lower than according to the analysis.
- Column is manufactured from one material. The build-up columns that are manufactured from different materials cannot be analyzed by the Euler equation. Because equation is derived from tha Novie's formula of the bending of the beam. The bending formula is derived for the single-material manufactured beam.

Regardless of all above, the buckling strength of the column, which does not correspond to the limitations mentioned above, correlates well with experimental data.

1.2. Engesser Euler

As already described above, Euler's formula can be used only for columns, in which critical stresses are lower than proportional limit. This limitation was not critical until the advent of more ductile steels or the widespread use of aluminum. However, as soon as ductile metals (total elongation at break > 5%) began to prevail as a structural material, this limitation greatly reduced the limits of use of the formula. If the obtained critical stresses exceeded the limit of proportionality, the obtained allowable compressive force significantly exceeded the real force at which the column lost its stability. That is why, in order to obtain results that coincided with reality, the engineers had to significantly reduce the effective stresses due to the narrowing of the cross-sectional area of the column, which greatly reduced the weight efficiency. That is why, to solve this problem, the German engineer Friedrich Engesser modified Euler's approach, using Young's modulus not within the limits of proportionality, but far beyond it. The Engesser-Euler formula is shown below.

$$F_{cb} = \frac{\pi^2 \cdot E_t}{\lambda}$$

where *Et* is tangential Young's modulus of the column material.

In order to find the value of the Young's modulus at a specific moment of time at a specific load, an iterative formula is used.

$$\eta = \sqrt{\frac{E_t}{E}} = \sqrt{\frac{1}{1 + \frac{0.002 \cdot E \cdot n}{F_{cy}} \cdot (\frac{F_{cr}}{F})^{n-1}}}$$

where η is a plasticity reduction factor that can be directly used in the Euler equation.

n is material shape parameter, that varies from the material to material and depends on the shape of the stress-strain curve.

F_{cy} is yield stress of the material under compression.

F_{cr} is critical stress

1.3. Local buckling formula

The formula of local loss of stability gained its relevance due to the spread of the mass trend to reduce the weight of the structure without changing the overall strength of the structure. The fact is that in order to design an effective section from the conditions of general loss of stability, it is necessary to ensure the maximum possible moment of inertia of the section, as shown in equation 3. However, to ensure the maximum moment of inertia, it is not necessary to increase the total area of the cross-section, on the contrary, it is necessary to spread the material as much as possible relative to the main of the central axes of the moment of inertia. And the material that will be closer to the main central axes of the cross-section should be minimized, because it is ineffective and almost does not perceive new stresses. Therefore, with the development of the need for mass efficiency, the cross-sections became increasingly thin-walled. However, the disadvantage of thin-walled structures is that at relatively small compressive or shear loads, the plates that make up the cross-section are warped, which significantly reduces the overall rigidity of the column [7].

Therefore, in order to effectively predict the overall strength of the column, the equation of the local buckling was obtained.

$$\sigma_l = k\frac{\pi^2 \cdot D}{b^2 \cdot t}$$

where σ_l is critical local buckling stresses

k is flat plate buckling factor that depends of the end fixity conditions and geometrical proportions of the plate, see fig. 1.2.

π is the Pi constant

b is the width of the plate

t is the thickness of the plate

D is the plate modulus, that can be found using the next formula

$$D = \frac{E \cdot t^3}{12(1-\nu^2)}$$

where υ is Poisson`s ratio

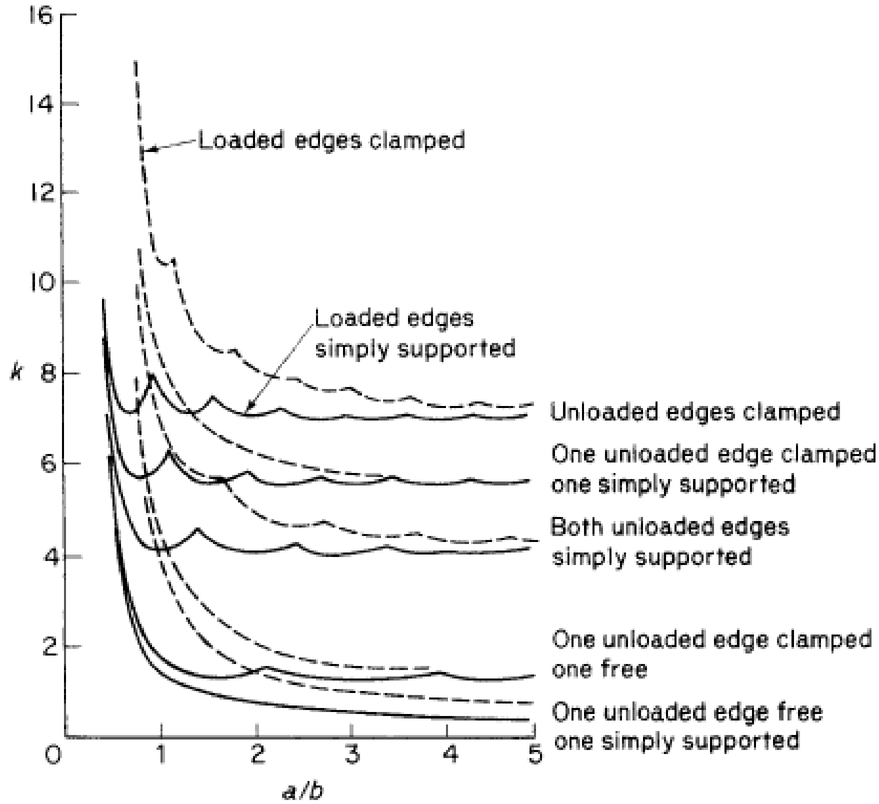


Fig. 1.2. The flat plate end fixity factors for the compressed plate, [8]

Since local buckling can occur not only in compressed plates, but also in plates that are subjected to shear and bending stresses, it is necessary to check for local loss of stability not only the compressed cross-section elements of stingers, trusses or other frame elements, but also it is necessary to ensure the absence of local loss of stability loss of stability in the skin before reaching specific loads. For example, for the fuselage skin, local loss of stability in the cells between stringers and spars is allowed at loads below the load limit, but in the wing, on the contrary, it is not allowed, because due to waves of local loss of stability, the aerodynamics of the wing will significantly deteriorate, and a stalling problem may even occur.

1.4. Inter-fastener buckling

However, the form of local loss of stability in the skin can also take the form of inter-fastener buckling. This type of failure is dangerous due to the fact that in the case of local failure of the panel, the skin will no longer be able to absorb the compressive stresses in full volume. Inter-rivet buckling is characterized for the skin with thin thickness. The formula for the inter-fastener loss of stability is shown below [9].

$$F_{if} = \frac{\pi^2 \cdot E}{\frac{p}{\left(\frac{\sqrt{c_{if}}}{0.29t}\right)^2}} \quad (1.4.)$$

where p_l is pitch of the fastener

c_{if} is fastener fixity condition factor, that depends on the fastener head type, see fig. 1.3.

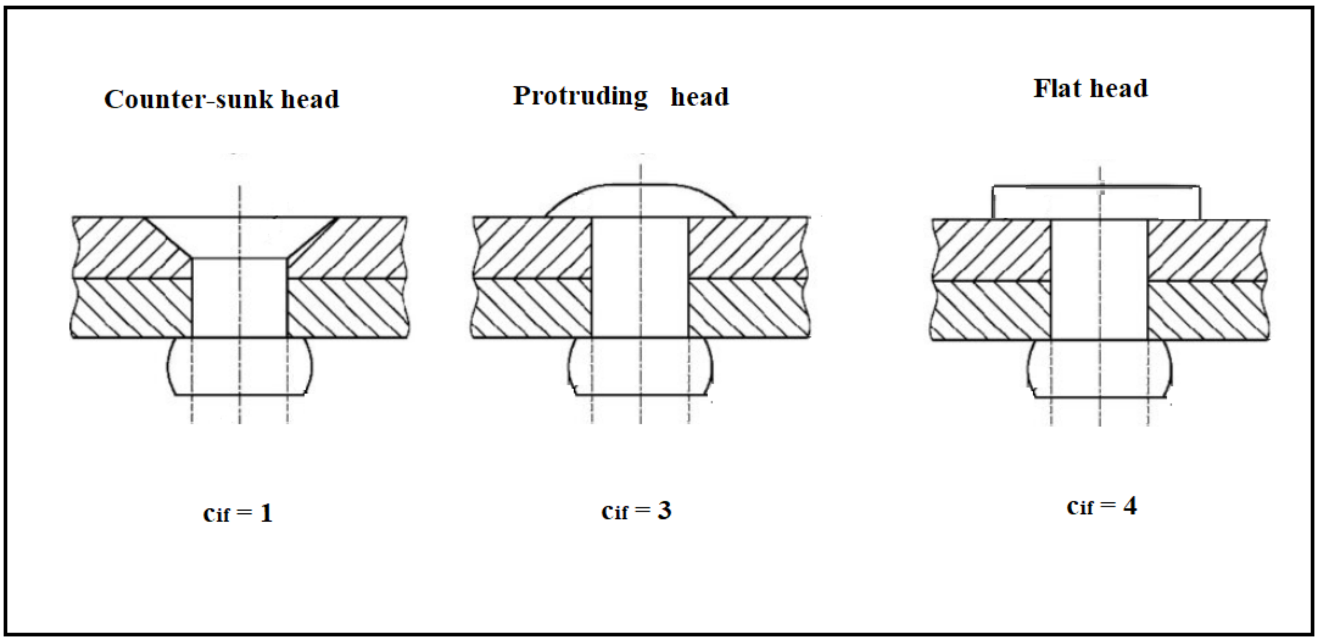


Fig. 1.3 The fastener fixity factor

Since the formula for the loss of stability between the fasteners is derived from Euler's formula, the plate between the fasteners is imagined as a column, where the fastener head is a type of fixity. From the picture above, the most optimal type of fastener for aerodynamics, namely countersunk, is the worst type of head for inter-fastener loss of stability.

Inter-fastener buckling can lead to the increasing of the pull-up loads of the fastener head and can cause the pull-through of the fastener. If inter-fastener occurs under operational load, cyclic pull through loading can lead to the reduction of the bolt bending fatigue capability.

1.5. Crippling strength

In very short rods, after the onset of a local loss of stability, a general loss of stability does not occur due to their advantageous length. However, after the appearance of the first waves of local loss of stability, that part of the cross-section that has lost stability is no longer able to take on the load, so stiffer elements, such as corners or intersections, take on more and more force. At the same time, as the load increases, more and more of the cross-section ceases to accept the compressive force, and at the moment of reaching the yield stress in the corners, the entire cross-section ceases to accept any load, elastic-plastic failure occurs, which is also called crippling, see Fig. 4 below.

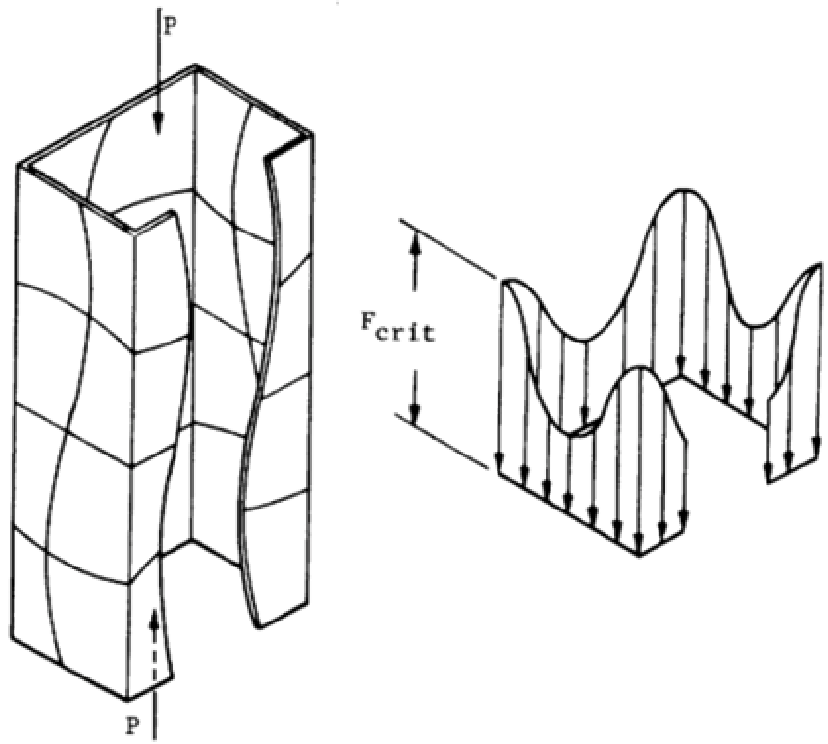


Fig. 1.4 Crippling

Currently, three main methods of determining the critical stresses of the crippling are widely used. They will be discussed below.

1.5.1. Needham's method

Needham's method is a semi-empirical method for determining the crippling stresses for thin-walled profiles. The method can be used only for sections made by molding and for certain forms of extrusion. The fact is that in order to determine the critical stresses, it is necessary to first divide the section into the corners of the profile, after which their geometry will be used in the formula shown below.

$$F_{cc} = \sqrt{F_{cy} \cdot E} \cdot \frac{C_e}{(\frac{b`}{t})^{0.75}} \tag{1.5.}$$

where F_{cc} is crippling stresses

b`/t is equivalent of the (a+b)/t

a and *b* are widths of the each corner flange

C_e is coefficient that depends on the degree of edge support along the edges of contiguous angle units [9], see Fig. 1.5.

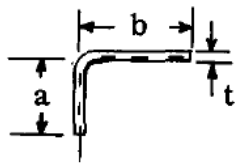
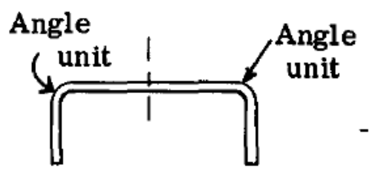
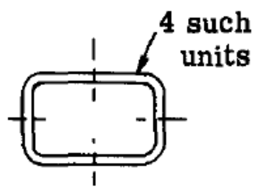
For angle with two edge free		**Ce =0.316**
For angle with one edge free		**Ce = 0.342**
For angle with no edge free		**Ce = 0.366**

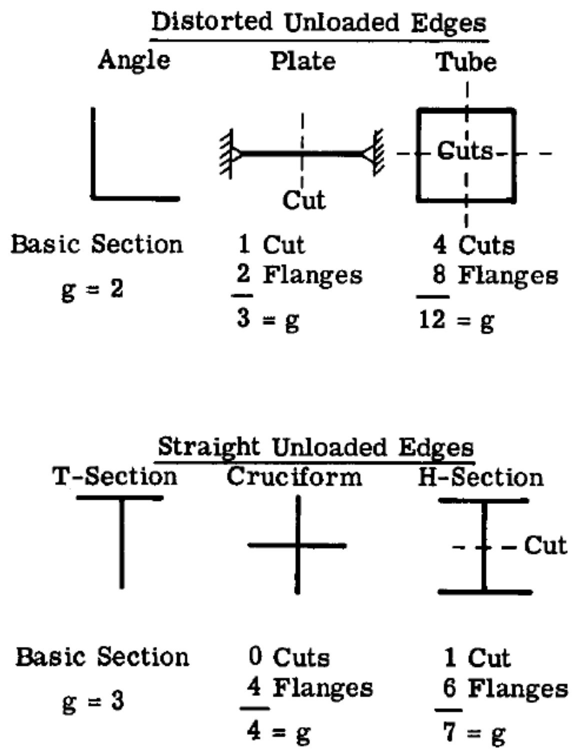
Fig.1.5 Crippling factors Ce for different fixity conditions

1.5.2. Gerard`s method

However, due to the inconvenience and limitations of using the Needham formula, the Gerard method was developad. It was also based on experiments and was semi-imperial, but when using it, it is not necessary to divide the section into corners. The method is to divide cross-section into simple shapes, for each shape the crippling stresses will then be found by formula below. This formula is usable for the stiffened panels, tubes and multi-corners section.

$$F_{cc} = F_{cy} \cdot 0.56 \cdot \left(\left(\frac{g \cdot t^2}{A} \right) \sqrt{\frac{E}{F_{cy}}} \right)^{0.65}$$

where g is number of flanges which compose the composite section, plus the number of cuts necessary to divide the section into a series of flanges.



Figю 1.6 The g factor, [9]

After that, all these stresses will be reduced to one weighted average value, which is obtained according to the formula below.

$$Fcc = \frac{\sum criplling\_loads\_of\_angels}{\sum area\_of\_angels} \qquad (1.6.)$$

1.5.3. Kumar approach

Indian scientists Prof. S.R.Satish Kumar and Prof. A.R.Santha Kumar in his work "Design of Steel Structures" [10] examines the effect of the propagation of the local loss of stability along the shelf of a steel corner, while observing how the increase in compressive force increasingly shows the increase in stresses in the stiffer areas. It is possible to obtain the distribution of stresses along the cross-section from the moment of the onset of local loss of stability and until the failure. Using the Formula 11 effective width of the flange of the cross-section can be found.

$$b_{ef}\, f = b \cdot (1 + 14 \cdot (\sqrt{\frac{F_c}{F_e}} - 0.35)^4)^{-0.2}$$

where *fc* is acting compression load

Despite the fact that the strength of the column at the onset of local and general loss of stability is easily predicted analytically, and the results of experiments show a good convergence of results when it comes to processes after the onset of local loss of stability, simple analytical methods are not enough. That is why formulas using coefficients obtained from experiments are used to predict the bearing capacity of a column after a local loss of stability. Despite the large number of conducted experiments, coefficients for similar formulas can be used only for materials that have been tested, since when using coefficients for low-proof materials, the obtained values will not be conservative and, on the contrary, will significantly overestimate the static strength of the column.

1.6. Effective plate width

However, creeping is a good model of failure only for short columns, which, due to their length, have too high fears of total loss of stability, which are destroyed even before it occurs. Most of the elements of the frame of the aircraft are not destroyed according to this model. Aircraft panels are characterized by a general loss of strength after local failure or adjacent section or skin members. First, the influence of the loss of stability of the skin cells on the overall loss of panel stability will be considered [11].

The concept of the effective width of the skin is a model that describes the behavior of the skin after the onset of local loss of stability. This method was first developad by Theodor von Karman. This method is widely used to reduce the weight of the structure, because despite its simplicity in calculations, it is well supported in the saddles. The method consists in the fact that after the occurrence of a local loss of stability, the compressive loads are gradually redistributed to stiffer elements, in the case of an airplane, these are either stingers or integrated frames. This allows to calculate a larger reserve of the bearing capacity of the panel, since the failure is blown out immediately after the occurrence of a local loss of stability, but only after the failure of the rigid element. It is worth noting that this model can be used not only for thin-walled aircraft skin panels, but also for any reinforced panel.

The formula for effective skin width is shown below.

$$w = 1.7 \cdot t \cdot \sqrt{\frac{E}{F}} \tag{1.7.}$$

where *Fc* is limit stress that corresponds to the maximum panel stress. It can be crippling, compression yield, column buckling or inter-fastener stress.

1.7. The Johnson Euler approach

The next method of taking into account the interaction of local and general loss of stability is the Johnson-Euler method. This method combines two approaches to determining the critical stresses of loss of stability, namely the Euler method, which was already described above, and the Johnson curve, which describes the behavior of the average length of columns, taking into account local loss of stability. The Johnson Euler formula is shown below.[9]

$$Fc = Fcc - \frac{Fcc^2 \cdot (\frac{L}{\rho \cdot \sqrt{c}})^2}{4 \cdot E \cdot \pi^2} \tag{1.8.}$$

This formula combines the main advantages and disadvantages of the two methods. It is simple to analyze and use by the engineer in the design of compressed columns and panels, but at the same time it contains a value of creeping, the value of which cannot be found without the use of empirical data, so the use of this formula is limited to only a certain number of materials.

Conclusions to the part 1

There are several methods of predicting critical stresses for compression members, including skins, stringers, and panels. The main methods were created to predict different forms of loss of stability such as general, local, inter-fastener bucklings and crippling, since the mechanics of body deformation with different losses of stability differ significantly. For qualitative use of the approaches described above, it is necessary not only to understand the mechanics of a solid body, but also to understand the basic approaches and assumptions that were used to derive the stability loss formulas. Despite the extensive number of formulas for determining the critical stresses of loss of stability, this topic is not exhaustive and requires additional research.

PART 2. THE METHODS OF THE REDUCTION OF NEGATIVE IMPACT OF THE LOCAL BUCKLING

A local buckling does not cause an instantaneous loss of the load-bearing capacity of the structure. Despite this, the spontaneous buckling of plates under loads below the load limit is a serious problem in aircraft operation and a real challenge for the aircraft design engineer. That is why prevention of local loss of stability is one of the key stages of aircraft design.

In this work the main types of prevention of the negative impact of local loss of stability on the overall static strength of a compressed panel will be considered with analyzing the weighty advantages of using certain methods of preventing the influence of local instability.

The main methods of preventing the impact of local buckling:

- Pad-up;
- Use of lips and bulbs;
- Use of closed profiles for stiffeners;
- Reduction of overall dimensions of the cell;
- Use of thinner skin , in case of local loss of resistance before reaching limit load.

2.1. Pad-up

Pad-up is a local thickening of a thin plate for high-quality fastening of stiffeners. The use of pad-up is a common practice of ensuring sufficient strength of the thin skin for inter-fastener loss of stability. The usage of local thickening can significantly increase the allowable stresses of inter-fastener loss of stability. Also, the pad-up is an important structural element that allows you to use countersunk bolts without the risk of a sharp-than-a-knife effect. Since the sharp knife-edge condition is not safe for the fatigue strength of the blade, because at the point of transition of the countersunk head into the shank, there is a complex stress state. This place will act as a stress concentrator and will be a likely place for crack initiation. If the galvanizing head is too deep in relation to the sheet itself, there is a danger of the bolt breaking out under significant shear stresses. Since the bending force will come perpendicular to the bolt head, there will be a significant vertical component of this force, which can not only pull the bolt out [12].

The presence of pad-up increases the fatigue characteristics of the connection, as it contributes to a more uniform distribution of the load on the bolted connection. The presence of pad-up allows more accurate distribution of the load on the connection, depending on the wishes of the engineer. Pad-up helps to reduce fretting, which occurs due to the wear of some elements relative to others, this occurs due to a slight fluctuation of the entire structure. This will reduce the probability of corrosion in the contact zone, which will contribute to the growth of fatigue characteristics.

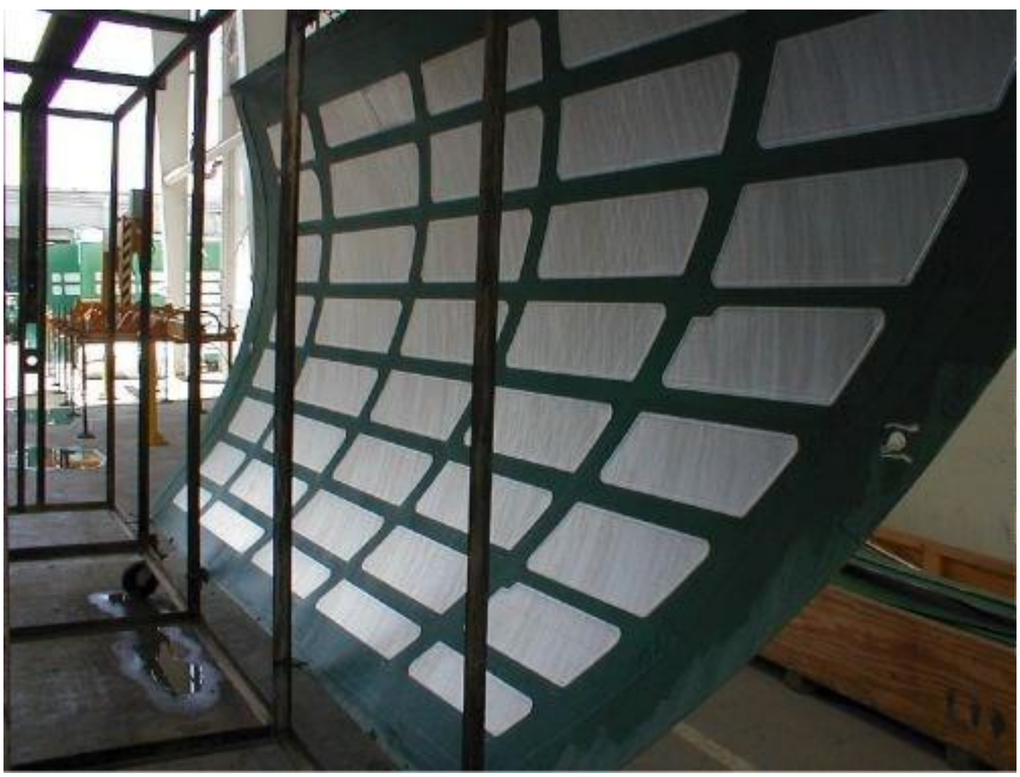


Fig. 2.1. Skin of the airplane with pad-ups

Pad-up can be manufactured using such technological processes as machining, chemical milling, stamping, casting and 3D printing. Machining will be performed using a milling machine, despite the high precision of the work performed and the high quality of the surface, the use of milling can significantly increase the cost of the final part, since high-quality milling is an expensive process that requires highly skilled personnel and expensive machines. During milling, the fibers of the material are cut, which helps to reduce the fatigue characteristics of the part, and also contributes to the faster appearance of corrosion.

Chemical milling is a more economically profitable type of technological processing of the part than classical milling. Also, one of the advantages of using chemical milling is its versatility, because thanks to the fact that the process does not depend on a specific machine, chemical milling can be used to make parts of more complex shapes. However, the disadvantages of using this type of processing include the limited depth of the technical process, the mandatory manual work with chemicals that can harm the human body, and the non ecological nature of the process, because it requires the disposal of used chemicals.

Stamping is a type of metal processing by pressure, in which the workpiece is deformed with the help of a stamp. This type of mechanical stamping is very common in mechanical engineering, because stamping ensures high productivity of the process, the accuracy of manufacturing the final part and the economic benefit of this process. However, it is worth considering that in order to perform high-quality stamping, it is necessary to provide high-precision stamps, which is very expensive. And due to the large number of unique parts, the use of stamping can be an unnecessarily expensive technical process. Also, not all airframe parts can be produced by stamping, as only a limited list of shapes can be produced using this process.

Casting is the process of manufacturing a part by pouring molten material into a mold. The advantages of this technical process are the ability to specify complex shapes for the final part, a wide selection of used parts, and the scalability of the process. Despite this, casting is not widely used as a final technical process for the manufacture of parts of the primary structure of the aircraft. Since in the production of parts by casting, there is a high chance of inclusions and unevenness of the internal structure of the material, which can lead to a significant decrease in the fatigue and corrosion characteristics of the parts.

3D printing is one of the revolutionary types of aircraft frame parts manufacturing. The main advantages of this process are the possibility of creating complex geometric shapes of the final part. It is also possible to perform strong and efficient parts that could not be performed with the classical type of processing. It is also worth mentioning the reduction of the manufacturing time of the part, as the use of 3D printing makes it possible to reduce the list of necessary technological processes. Among the disadvantages of 3D printing, the main ones are the limitations of the dimensions of the final part, which is a significant problem for the production of large parts of the aircraft frame. Also, the cost of 3D printing can be high if high-quality materials are used. The reliability and durability of parts manufactured using. 3D printing still requires additional research, which leads engineers to the next drawback, such as the small number of studies related to 3D printing of metal parts [13].

2.2. Lips and bulbs

Lips and bulbs are structural elements of the cross-section of a stinger or other structural element, which are made to increase the strength of the cross-section under compression, namely to increase the allowable stresses of the local loss of stability of the cross-section elements. If the sizes of lip and bulbs are big enough, they can perform the function of hinge resistance, which significantly increases the strength of the local loss of stability of the element, which will then in turn increase the stress of clipping and the general buckling according to Johnson Euler. However, if the lip is performed incorrectly, it can significantly reduce the allowable stresses, because it will not act as a support for the cross-section element, but as a separate flange with a free edge. Bulb that is too large will only increase weight of the structure without high-quality support of the cross-section element. The main disadvantage of using lips and bulbes is the limitation of manufacturing the structural element, which will cause an increase in the cost of the final product [9].

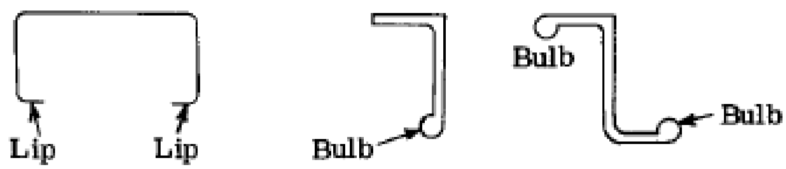


Fig. 2.2 The lip and the bulb of the cross-section

2.3. Usage of close profiles for the stiffeners

The use of closed profiles to improve the characteristics of the local loss of stability of the cross-section elements is the most advantageous option from the point of view of strength. After all, when the elements of the section are loaded, all the plates will work as plates supported on four sides. With a minimum number of elements, in such a section there will be the largest number of rigid elements that will increase the strength of the crippling of the stringer.

However, the use of such profiles is very limited due to difficulties in manufacturing and operation. After all, when connecting stringers of a closed profile with skin , there will be difficulties with riveting, so it will be necessary to use blind rivets, which are not recommended for use, because they have much lower strength characteristics than ordinary rivets, also with this type of installation it is much more difficult to control the quality of the technological of the process, as well as the increased cost of work, due to the fact that the process is more difficult to perform and will require more qualified personnel. Also, during operation, moisture can accumulate in such profiles, so it is necessary to make contact holes for drainage, which will have a very negative effect on fatigue characteristics, and the drilled hole is a large stress concentrator. In addition corrosion or a crack appears on the outer shelf of the section, it will be almost impossible to check with non-destructive testing, which will significantly lower the damage tolerance characteristics. the repair of such a section is more difficult than the classic version.

However, the closed profile is still used in modern aircraft construction, namely in the composite frame of the aircraft, where most of the above-mentioned disadvantages are not as significant as in the metal construction. Since the fracture mechanics of composite parts are different from metal counterparts, the main disadvantages such as stress concentrators in the open section are not critical, but the open hole is still a dangerous element for composite parts, because an open and unprotected edge with a special solution can cause degradation strength of the composite due to the ingress of moisture into the middle of the laminate. However, staying in a wet environment of a fully protected composite without scratches or bumps is completely safe and will not damage the durability of the part in any way [14].

Fig. 2.3. The panel of the composite airplane Boeing 787

In the Fig. 2.3. the panel of the fuselage of the composite airplane Boeing 787 is shown.

2.4. Reduction of overall dimensions of the cell

The next method of increasing the strength of the skin in case of loss of stability is to reduce the pitch of the stringer and ribs or frames. Since the overall length and width of the skin cell makes its contribution in a quadratic relationship. However, we should not forget about the need to ensure the weight efficiency of the structure, so it is not necessary to simply increase the number of stiffeners for the skin, because this can cause a significant increase in the mass of the structure. It is also worth understanding that with a very frequent arrangement of stiffeners, the number of rivets used increases, which also increases the final weight of the aircraft. A large number of holes causes a significant decrease in fatigue characteristics of parts, since the greater the number of concentrators in a part, the higher the probability of crack growth in this part. Therefore, during operation, all these details will be inspected more carefully, which will cause high time consumption and, accordingly, increase the losses of the airlines. Therefore, despite the increased compression strength of the skin in this way, the aircraft will be heavier and economically unprofitable in operation.

Conclusion to the part 2

There are various methods of preventing the deleterious effects of vengeful stability loss during aircraft design. The main methods are listed above. despite the significant contribution to increasing the load-bearing capacity of the panels, all methods also have a list of disadvantages that can cause an increase in the cost of aircraft production, an increase in the difficulty of operation, and can cause a decrease in fatigue strength. The engineer must be responsible for the choice of basic design methods in order to obtain an effective design and ensure flight safety.

PART 3. THE PRELIMINARY DESIGN OF THE COMPRESSED STIFFENED PANEL OF THE WING

Further, in this work will analyze the impact of the listed measures to reduce the impact of local instability on the ultimate load capacity of the panel in terms of economic efficiency of the construction. Aircraft panels will be designed from the conditions of strength and weight efficiency without and with methods of reducing the influence of local instability from the three most common aviation alloys of the aircraft: aluminum 7075-T6510, titanium Ti-6AL-4V and steel 30 HGSA.

7075-T6510 is one of the most common aluminum alloys used in aviation. The main ligating element of this alloy is zinc. The main advantages of using this alloy are a high tensile strength of 500-570 MPa. The density of aluminum is 2830 kg/m3.These properties determine the urgent use in the aircraft frame for parts that are designed primarily from the conditions of static strength. Alloy 7075-T6510 has an average resistance to corrosion, so before using this alloy in the frame, it must first be treated against corrosion, either by anodizing or plating. 7075-T6510 is a relatively ductile material, the maximum elongation at break is about 7-8%. Alloy 7075-T6510 is not very resistant to high temperatures. The maximum heating temperature without significant changes in properties is 150 C. at higher temperatures, the strength of aluminum may degrade. 7075-T6510 has poor weldability characteristics, because the magnesium content in the alloy is not high enough. Quality welding of 7075-T6510 requires special techniques, making this type of joint very expensive and unreliable [15].

Ti-6AL-4V is widely used in aviation. This titanium alloy is alloyed with aluminum and vanadium, which provides increased strength and improves mechanical properties and stability of the structure at high temperatures. The alloy has a high tensile strength of 900-1100 MPa. The density of titanium is 4430 kg/m3. Titanium has high heat resistance, can withstand 400-550 C without significant degradation of properties. One of the advantages of titanium is its high corrosion resistance, for example, if you place a plate made of titanium in a salt water solution, only 0.1 mm of the titanium thickness will corrode after 10 years of being in it. Titanium also has good weldability characteristics, but the process requires special conditions, such as protection from oxygen, as titanium tends to oxidize at high temperatures. Despite the advantages of titanium, it is very plastic, which makes mechanical processing of this material very difficult and, accordingly, very expensive.[15]

30 HGSA is a low-carbon structural steel that contains chromium and molybdenum, which increases its strength, wear resistance and resistance to high temperatures. It has a high tensile strength of more than 800-1000 MPa. This steel alloy is relatively lamellar, its elongation at break is 12-15%. The main advantages of this alloy are high wear resistance, which allows the use of this alloy in parts and assemblies that are constantly exposed to friction and other mechanical influences. 30 HGSA withstands high temperatures well, the steel does not lose its properties up to a temperature of 500 C. steel also has good corrosion resistance due to the presence of chromium in the composition, therefore, when operating in aggressive environments, the steel must be covered with an additional protective coating against corrosion. The material is characterized by good machinability both mechanically and thermally, however, due to the high hardness of steel, the tool must have the appropriate hardness and strength to avoid dulling or poor processing. Due to the significant density of the material of 7800 kg/m3, the weathering of the steel leads to a high weight of the structure [16].

Before designing the upper panel of the aircraft, it is necessary to determine the basic assumptions that will greatly simplify the calculations of the strength of the wing panel. At the same time, it is worth paying attention to the fact that the accepted assumptions do not significantly affect the accuracy of the calculations.

The main assumptions in the calculations:

- Symmetry of the upper and lower panels. Despite the fact that during the flight of the aircraft, the panels are in various stress states, but this does not affect the general requirements of static strength. Both the upper and lower panels are designed with no general loss of stability. However, the accepted assumption will allow to reduce the design time, since the main purpose of the calculation is to check the main methods of preventing the influence of local loss of stability.

- The main wing caisson prototype for which the compressed panel will be designed is the Airbus 220. Everything, including the basic geometric dimensions and loads, is based on the wing caisson of this aircraft. They will not be changed during the design process.
- In order to avoid the influence of the change in the geometric characteristics of the wing spars on the redistribution of internal stresses in the panels, the spar wall thickness is assumed to be static for a specific material. This was the basis of the shear strength conditions
- Since the shear strength in steel, aluminum and titanium is significantly different, to avoid redistribution of loads to the stiffer steel spar, in relation to its aluminum or titanium counterpart. It is assumed that the spar wall will be designed for a specific proportion of the shear force in relation to the entire internal load.
- The load-bearing capacity of the walls of the spar in the perception of normal stresses during bending is negligible
- In order to avoid redistribution of normal forces to spar shelves, the area of each spar shelf will be taken as half the area of one stringer.
- In the internal loads, the safety factor is already taken into account for the possibility of performing calculations according to the requirements for the ultimate load according to the CFR requirements.

Since the design of the wing panel is a long and iterative process, it is very important to divide the main work into stages to better control the quality of the design execution.

Stage I

The first step in designing an aircraft panel is to define the input data. Design inputs include bending and torsional moments as well as shear force.

The shear force in the wing is the result of the lifting force. The bending moment in an airplane wing is the result of the eccentricity of the lift force application. The torque in the wing appears due to the non-coincidence of the center of rigidity in the wing section with the equivalent transverse forces.

A table of input wing loads is shown below.

Table 3.1

Load Input			
Internal load	**Nomenclature**	**Value**	**Unit**
Shear force	V	372500	Lbs
Bending moment	M	2535000	Lbs · in
Torque	T	152630	Lbs · in

The inputs data of the wing box design includes main geometrical characteristics:

Height of the wing box H = 32.08 in

Width of the wing box W = 110 in

The spacing of the ribs S_r = 20 in

Pitch of the fasteners p = 2 in

The input data for the wing design also includes the characteristics of the materials from which the wing will be designed. A table of values is shown below.

Before using, the material properties in the design CFR requirements of the limit and ultimate load must be considered. Design ultimate stress is minimum value between the ultimate stresses of the material and product of the yield stress and safety factor (1.5)

Table 3.2.

Property	Nomenclature	Value			Unit
		Aluminum	Steel	Titanium	
Ultimate tensile stress	F_{tu}	82	154	134	ksi
Yield tensile stress	F_{ty}	74	118	126	ksi
Yield compressive stress	F_{cy}	74	119	133	ksi
Ultimate shear stress	F_{su}	41	72	87	ksi
Modulus of elasticity	E	10 700	31 000	16 000	ksi

Stage II

On the second stage of the design preliminary values of the preliminary geometrical values are considered. The minimum value of the panel are is found below. The minimum area of the panel is obtained from the overall static strength without consideration of the buckling. Minimum area of the panel is found with the next formula. The Yield compressive stress is taken as maximum stress as it is minimum value between maximum values of the compression and tension.

$$A_{pan} = \frac{P}{F_{cy}}$$

where P is maximum acting axial force that act on the panel

A_{pan} is minimum area of the panel

The maximum acting axial force in found by formula below. It is assumed that all bending moment is perceived by the stretching and compression of the upper and lower panel. Panels are considered as concentrated areas, since changing of the normal stresses over height of the skin stringer panel is not high and can be neglected. Free body diagram is shown below.

$$P = \frac{M}{H}$$

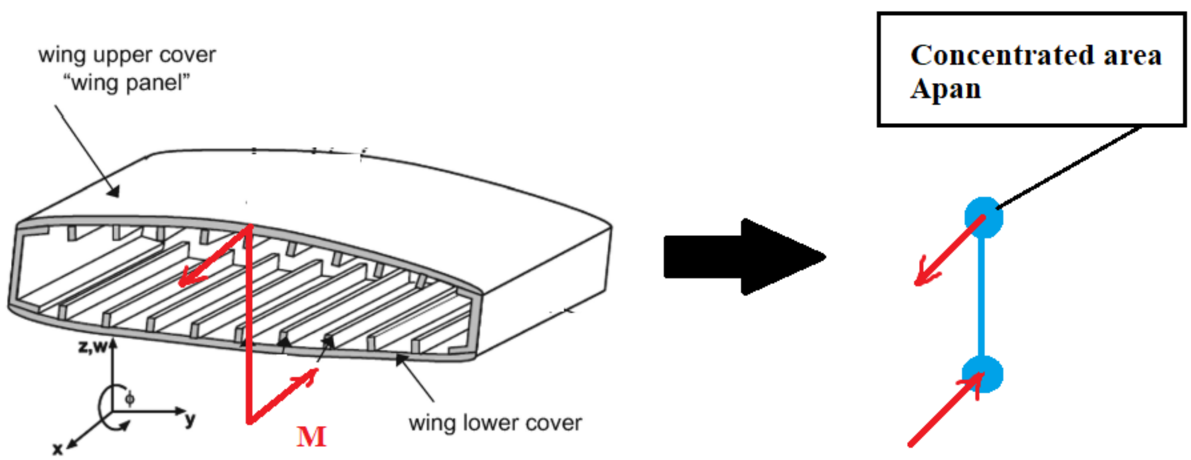


Fig. 3.1. The discretization of the wing structure.

The resultant maximum axial force:

$$P = 684\ 288\ lbs$$

Resultant areas for each material:

Aluminum A_{pan} =9.25 in^2

Steel A_{pan} = 5.7 in^2

Titanium A_{pan} = 5.3 in ^{2}

The minimum thickness of the web of the spar is found by the next formula.

$$t_w = \frac{V}{F_{su}}$$

Resultant minimum thickness of the spar for each material:

Aluminum t_{web} = 0.75 in

Steel t_{web} = 0.6 in

Titanium t_{web} = 0.61 in

Stage III

On the third stage the preliminary number of the stringer is estimated to find the redistribution of the internal load factors.

For the panel without using the method of the decreasing of the plate buckling impact number of the stringer is N= 7.

For the improved panel is N = 16 to decrease with of the skin sell.

Shear flow in the skin of the panel can occurs because of the acting several loads, such as shear force and torque. For the determination of the shear flow from the shear force formula below is used, [17]:

$$q_V = \frac{V_z \cdot S_y(s)}{I_y}$$

where *Sy(s)* is first moment of area for each cut section;

Iy is moment of inertia about horizontal axis of the wing box.

The moment of inertia is found by the formula below. During calculation own moment of inertia of the each panel is neglected since additional moment of inertia of the panel has most significant impact.

$$I = A \cdot \frac{H^2}{2} + \frac{H^2 \cdot t_w}{6}$$

For the determination of the shear flow from the torque formula below is used [19]:

$$q_T = \frac{T}{2A`}$$

where *A`* is enclosed area of the win box. *A`* is simplified to be *H* and *W* product.

For the determination of the distribution shear flow on the wing box, stringer and half bay of the skin at each side of the stringer are considered as concentrated area.

The total distribution of the shear flow is shown below. Since distribution of the shear flow is typical and during the future design only scale of the diagram values will be changed, no additional diagram is required.

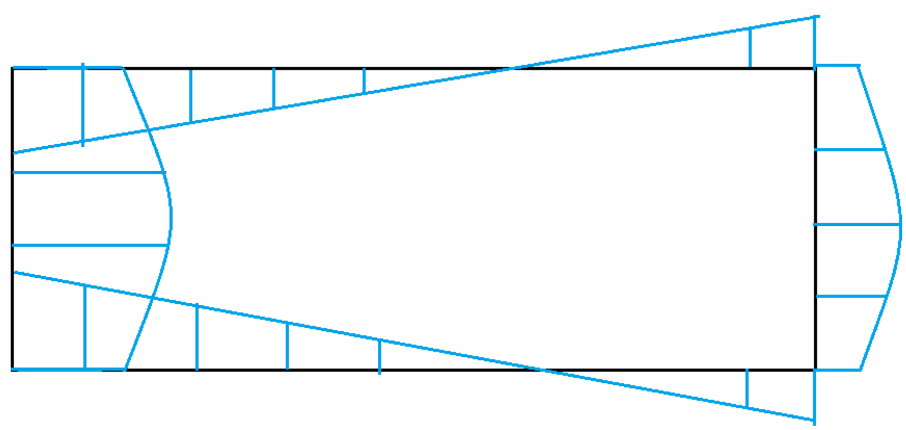


Fig. 3.2. The shear flow distribution scheme

Stage IV

The determination of the allowable stresses of the panel. Only compression load case is considered during design.

The panel is being designed with consideration of the next critical modes:

- Column buckling;
- Crippling;
- Inter-rivet buckling;
- Plate buckling of the skin under combination of the axial and shear stresses.

The formulas of the determination of the critical stresses were shown below. The providing of the strength requirements will be checked using Margin of Safety (MS). Formula of the MS for the crippling, column and inter-rivet buckling is shown below [9].

$$MS = \frac{F}{f} - 1 \qquad (2.1)$$

where *F* is allowable stress

f is acting stress

For the determination of the combined buckling MS next formula is used, [9].

$$MS = \frac{2}{\frac{f_a}{F_a} + \sqrt{(\frac{f_a}{F_a})^2 + 4 \cdot (\frac{f_s}{F_s})^2}} - 1 \qquad (2.2.)$$

where fa is axial acting stresses;

Fa is axial allowable stresses;

fs is shear acting stresses;

Fs is shear allowable stress.

Stage V

On the fifth stage preliminary sizing of the stringer and skin is provided. As stringer shape is Z section is chosen due to simplicity of the manufacturing, attachment to the skin and good visibility during inspections.

Stage VI

During this stage will be provided all strength checks of the panel. Since minimum area of the panel is not enough, all stages are repeated as many times as necessary to provide sufficient values of the MS.

Also during .designing were estimated that thickness of the web of the spar is not enough and must be increase.

When all design iterations were done, final results of the panel have been obtained. Due to all stingers of the each panel has same configuration, there is no necessity to show all panel, only stinger and half of the skin bays are shown.

Stage VII

Stage seven is is aimed at checking the already designed panels of the wing. Since the cutouts are typical, they will be made only for the panel made of aluminum alloy 7075-T6510.

The skin stringer element of the panel is shown below, see fig. 3.3.

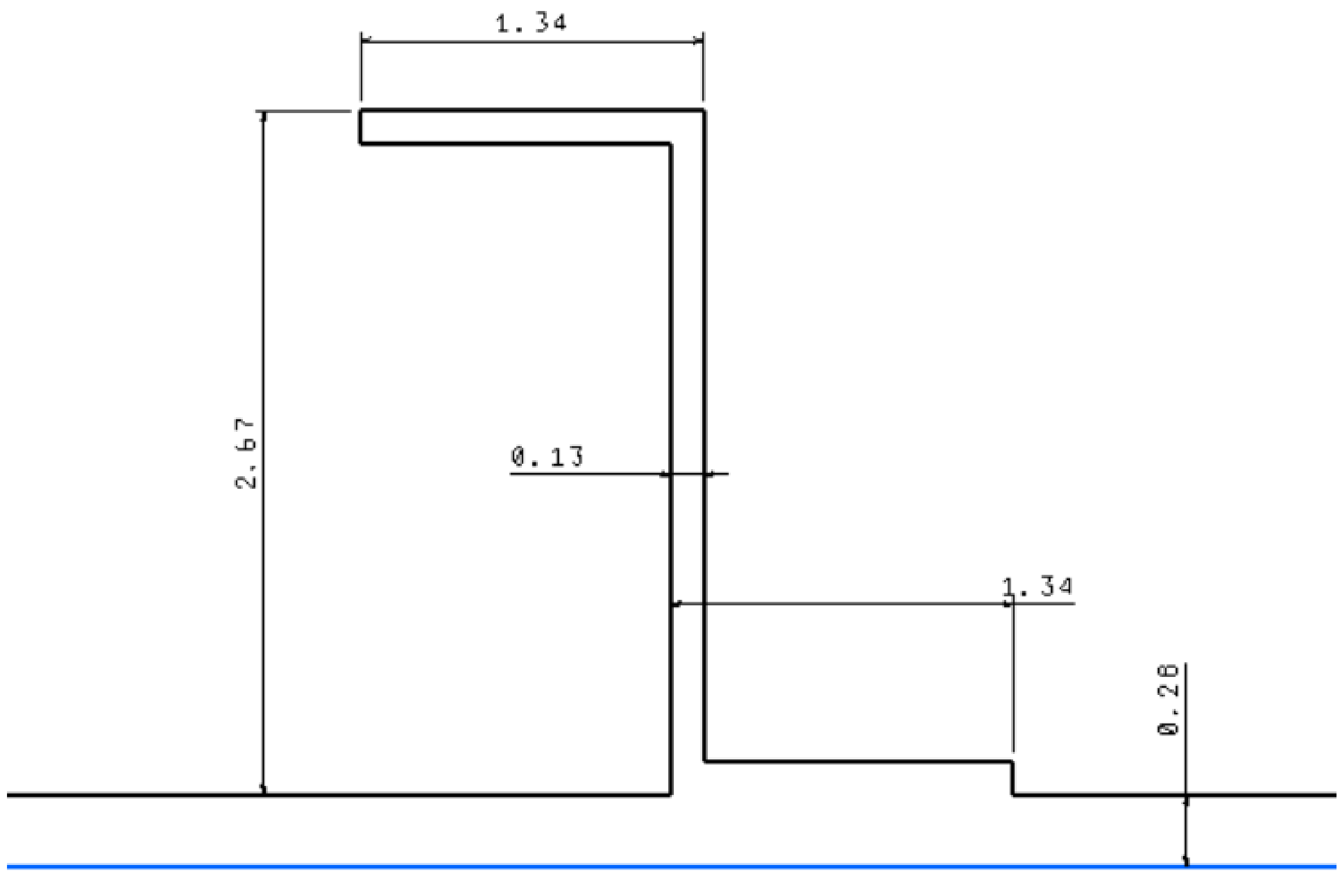


Fig. 3.3. The dimensions of the designed stringer

The check of the skin stringer panel that has been designed is shown below.

The panel without the application of methods of reducing the impact of the local instability.

The nomenclature is shown below.

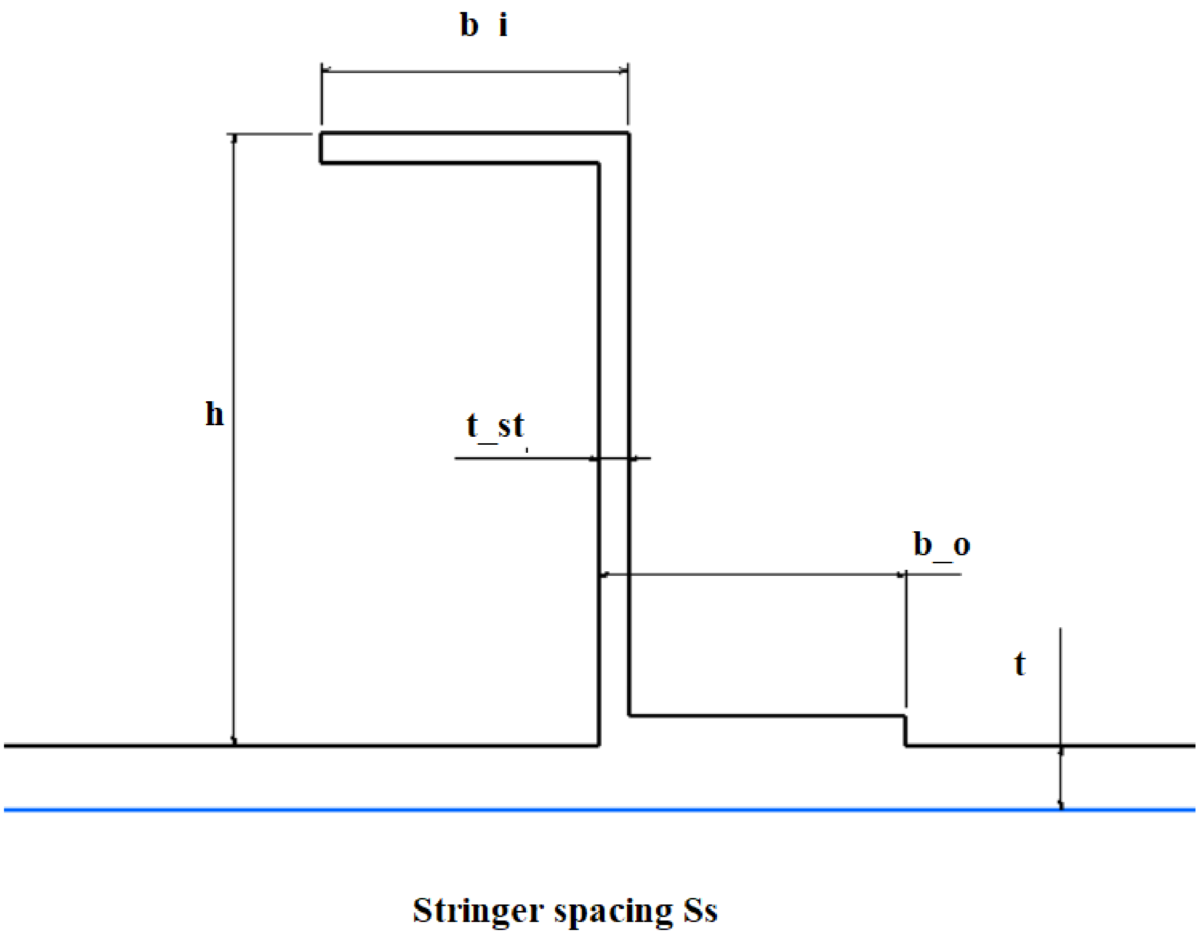


Fig. 3.4. The nomenclature of the designed stringer

Crippling stresses

Critical crippling stresses are found using the Needham method. The cross-section of the stringer is cut on the two the same angles.

The crippling stress of the particular angle is found with eq. 1.5.:

$$F_{cc} = \sqrt{F_{cy} \cdot E} \cdot \frac{C_e}{(\frac{b`}{t})^{0.75}} = \sqrt{74 \cdot 10.5 \cdot 10^3} \cdot \frac{0.342}{(\frac{1.34+1.33}{0.13})^{0.75}} = 31.5 \text{ksi}$$

The Euler column buckling stress

Before estimating the critical stresses of the column buckling, it is necessary to find effective width of the skin. The effective skin width with eq. 1.7.:

$$w = 1.7 \cdot t \cdot \sqrt{\frac{E}{F}} = 1.7 \cdot 0.28 \cdot \sqrt{\frac{10.5 \cdot 10^3}{31.5}} = 8.77 \text{ in}$$

Value of the effective skin width is taken into account during the moment of inertia calculation.

Moment of inertia:

$$I = \sum Ai \cdot y_i^2 + \sum \frac{h_i^3 \cdot b}{12} = 2.5 \; in^4$$

Area of the cross-section:

$$A = \sum b_i \cdot t_i = 4.11 \; in^2$$

Radius of gyration, see eq. 1.3.:

$$\rho = \sqrt{\frac{I}{A}} = \sqrt{\frac{2.5}{4.11}} = 0.78 \; in$$

The critical column buckling stresses by the Euler equation (eq. 1.1. ad 1.2):

$$F_{cb} = \frac{\pi^2 \cdot E}{(\frac{L}{\rho \cdot \sqrt{c}})^2} = \frac{\pi^2 \cdot 10.5 \cdot 10^3}{(\frac{20}{0.78 \cdot 1})^2} = 161 \; ksi$$

In the analysis length of the column is considered as the rib spacing. Attachment is simply-supported for conservatism (c = 1).

Since critical buckling stress by Euler equation is higher than yield limit and crippling stresses, Johnson Euler approach must be applied.

The Johnson Euler buckling stress

The critical stresses of the column buckling by Johnson Euler approach (eq. 1.8):

$$Fc = Fcc - \frac{Fcc^2 \cdot (\frac{L}{\rho \cdot \sqrt{c}})^2}{4 \cdot E \cdot \pi^2} = 31.5 - \frac{31.5^2 \cdot (\frac{20}{0.78 \cdot \sqrt{1}})^2}{4 \cdot 10.5 \cdot 10^3 \cdot \pi^2} = 29.9\,\text{ksi}$$

Inter-fastener buckling stresses

The critical stresses of the inter-fastener buckling, see eq. 1.4.:

$$F_{if} = \frac{\pi^2 \cdot E}{\left(\frac{\frac{p}{\sqrt{c_{if}}}}{0.29t}\right)^2} = \frac{\pi^2 \cdot 10.5 \cdot 10^3}{\left(\frac{\frac{2}{\sqrt{1}}}{0.29 \cdot 0.28}\right)^2} = 174\,\text{ksi}$$

It is assumed than fastener types are counter sink (c=1).

Since critical inter-fastener buckling stress is higher than yield limit, no plate distortion between fasteners occurs.

Plate buckling of the skin under axial load

Local buckling stress under compression:

$$F_{lc} = k_c \cdot E \cdot (\frac{t}{b})^2 = 3.6 \cdot 10.5 \cdot 10^3 \cdot (\frac{0.28}{12.2})^2 = 20.3\,\text{ksi}$$

The end fixity conditions are considered as simply-supported from the four sides.

The width of the plate (b) is the stringer spacing. The length of the plate (a) is the rib spacing.

b/a = 12.2 in / 20 in =1.64

k = 3.6

Plate buckling of the skin under shear load

Local buckling stress under shear:

$$F_{lc} = k_s \cdot E \cdot (\frac{t}{b})^2 = 7 \cdot 10.5 \cdot 10^3 \cdot (\frac{0.28}{12.2})^2 = 39.5 \text{ ksi}$$

b/a = 12.2 in / 20 in =1.64

k = 7

Determination of the acting axial stresses of the panel:

Acting stresses in the panel:

$$f_a = \frac{P}{8 \cdot A} = 18.5 \text{ ksi}$$

Determination of the acting shear stresses in the panel.

During iteration process, maximum value of the shear flow q was defined.

$$f_s = \frac{q_V + q_T}{t} = 9.7 \text{ ksi}$$

MSs determination by eq. 2.1 and 2.2:

Column buckling:

$$MS = \frac{F_{cb}}{f_a} - 1 = \frac{30}{18.5} - 1 = 0.62$$

Crippling:

$$MS = \frac{F_{cc}}{f_a} - 1 = \frac{31.5}{18.5} - 1 = 0.7$$

Inter-fastener buckling:

$$MS = \frac{F_{if}}{f_a} - 1 = \frac{74}{18.5} - 1 = 3$$

Plate buckling under combination of the axial and shear stresses:

$$MS = \frac{2}{\frac{f_a}{F_a} + \sqrt{(\frac{f_a}{F_a})^2 + 4 \cdot (\frac{f_s}{F_s})^2}} - 1 = \frac{2}{\frac{18.5}{20.3} + \sqrt{(\frac{18.5}{20.3})^2 + 4 \cdot (\frac{9.7}{39.5})^2}} - 1 = 0.03$$

Since analysis of the modified wing panel is similar to the unmodified for shortening of the analysis it is not shown. Only the dimensions, allowable and acting stresses are shown below.

Area of the single stringer and skin panel:

$$A = 1.25 \text{ in}^2$$

Moment of inertia of the single panel:

$$I = 3.71 \text{ in}^4$$

Stringer spacing:

$$S_s = 6.46 \text{ in}$$

Critical buckling stress:

$$F_{cb} = 30\ 292 \text{ psi}$$

Critical crippling stress:

$$F_{cc} = 30\ 683 \text{ psi}$$

Inter-fastener buckling:

$$F_{if} = 74\ 000 \text{ psi}$$

Critical plate buckling stress under compressive load:

$$F_{lc} = 43\ 534 \text{ psi}$$

Critical plate buckling stress under shear load:

$$Fl_s = 67\ 720 \text{ psi}$$

Acting axial stress:

$$f_a = 24\ 666 \text{ psi}$$

Acting shear stress:

$$f_s = 40\ 824 \text{ psi}$$

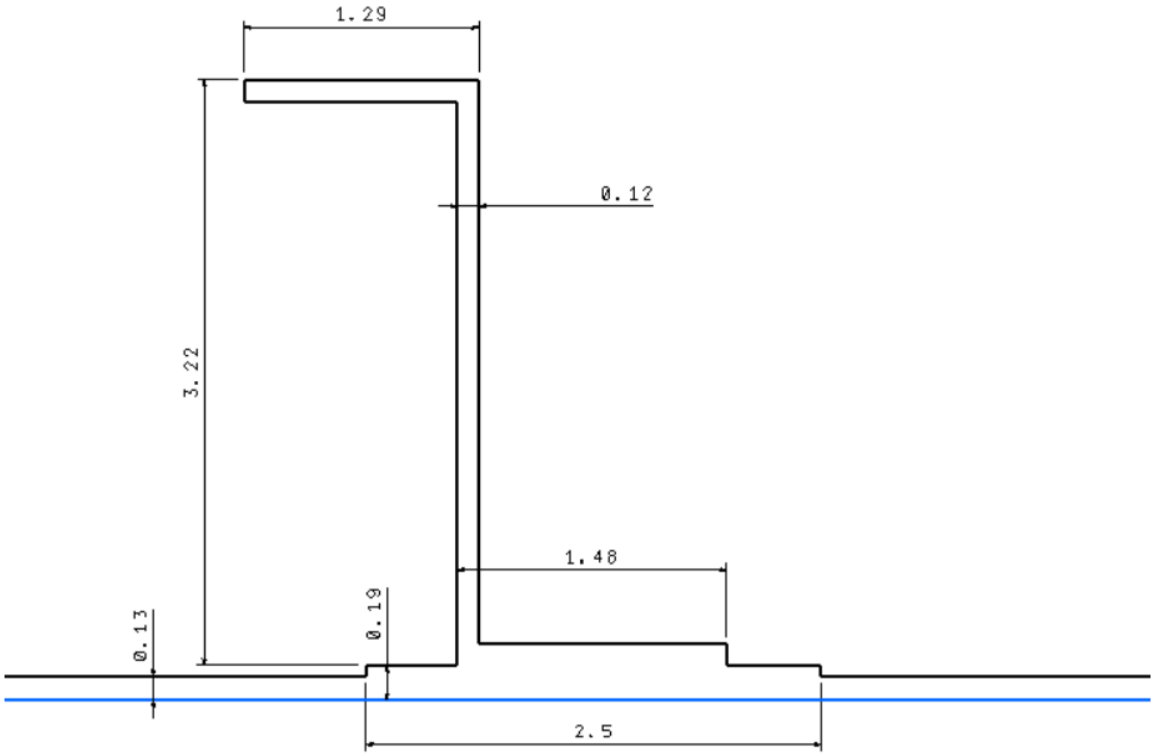
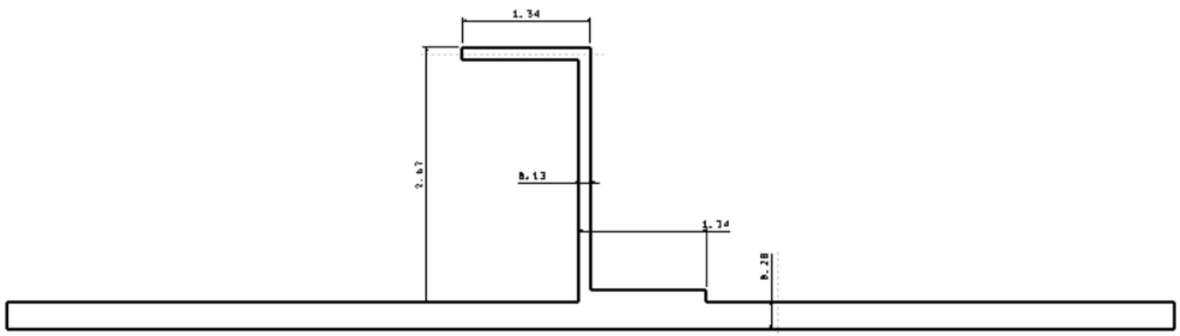


Fig. 3.5. The cross-section of the designed panel

In the fig. 3.6.. the difference between cross-sections that are design according to the different approaches.

Design without methods consideration



Design with methods consideration

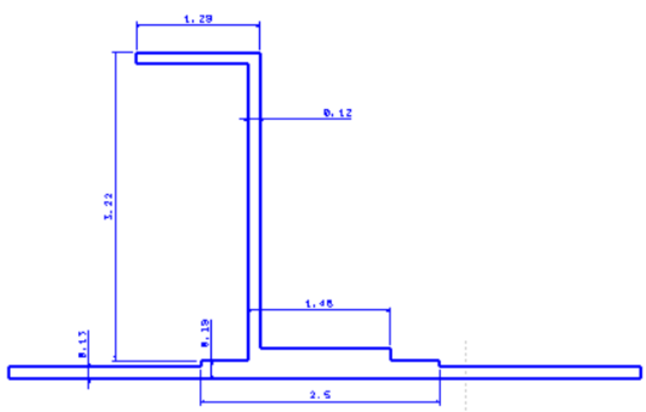


Fig. 3.6. The comparison of the designed aluminum panel

The comparison of the minimum MS of the structure, that are manufactured from the different materials are shown below in the table 3.3. The minimum MS corresponds to the skin buckling under combine loading.

Table 3.3.

Material	Initial design	Improved design
Aluminum	0.03	0.05
Steel	0.045	0.06
Titanium	0.02	0.01

The weight comparison is shown below in the Table 3.4.

Table 3.4.

Material	Initial design	Improved design
Aluminum	67.01 lb	56.6 lb
Steel	97 lb	81.3 lb
Titanium	82 lb	68.6 lb

The most efficient design is aluminum panel with all proposed design features.

Conclusion to the part 3

In this part, preliminary designs of the compressed build-up panels were prepared. During analysis considering of the influence of the local buckling on the overall static strength was provided. The highest impact on the local instability was noticed when the thickness and width of the skin were changed. The most dangerous failure mode was the plate buckling, because of the lower thickness of the skin it was hard to control weight increase with reduction of the acting stresses.

Design of the panel is complex process that expect high diligence to the detail. Improper design of the structure con not only lead to the not economical efficient structure, but also for the non conservative results that can affect on the safety of flight.

According to the results of the design, improvement of the local buckling strength leads not only to the increase of the reliability of the structure, but also can facilitate to the weight reduction of the structure.

The most efficient material as structural metal is aluminum alloy. It can be explained through high strength-weight capacity. Also it is important to notice that regardless fact, that material stiffness influence on the all modes of the buckling, improving compression strength, material with the highest modulus of elasticity relatively to other considered metals is not most efficient in buckling resistance. The point is that geometrical characteristics of the cross-section influence on the compression strength nonlinear, that it is why eve with higher material stiffness, overall weight of the structure can be higher.

PART 4. ENVIRONMENTAL PROTECTION

Having picked up a tool for the first time, a person began to influence the environment, even if the influence was insignificant, but it happened. Then, with the advent of the industrial revolution and the development of technology, the influx became more and more large-scale. With accelerated industrialization, environmental problems only became more acute: active deforestation, emissions of carbon dioxide into the atmosphere, excessive use of natural resources, emissions of gases not related to carbon dioxide. All this caused an increase in the average temperature, a change in the climate, which in turn entailed a change in rainfall, melting of glaciers, an increase in the frequency of storms and hurricanes, a halving of the temperature of the world ocean, a halving of the sea level, an impact on ecosystems and human health. That is why society began to worry more and more about the environmental friendliness of certain technological processes and industries. Despite concerns about environmental issues, the solution to the problem is very slow, because it is necessary not only to change the view on the use of natural resources, but also to change the approaches to conducting business, to the creation of new products, to influence the leadership of the states, in order to change more than one legislation, because the environmental issue should be raised at the state level in every country of the world. [18] Companies, in turn, are beginning to actively implement environmental initiatives in the processes of production and operation of their goods. The aviation industry is no exception.

It is already impossible to imagine the modern world without aviation. Airplanes not only get us to any point on the globe quickly, but also play an important role in the global economy, ensuring the rapid movement of goods between countries. The popularity of air travel is constantly growing. During periods of stable economic development, the number of passengers increases by 5-10% annually. Such growth rates are ahead of the development of many other branches of industry, for example, mechanical engineering or energy.

The growth of air transportation, unfortunately, has a negative side. Each flight is accompanied by emissions of harmful substances into the atmosphere, which negatively affects the ecology of the planet. And the more airplanes in the sky, the greater their contribution to global environmental pollution. That is why the aviation industry is facing a challenge today - how to meet the growing demand for air transportation and at the same time minimize its negative impact on the planet. This requires the development and implementation of new, environmentally friendly technologies, as well as a conscious approach to flight planning and execution [19].

Aviation technology creates pollution long before its creation. Even with the extraction of the most common aviation material, the environment suffers. First, the process of extracting bauxite, the ore from which aluminum is obtained, leads to the destruction of forests and soil erosion. Open pits leave huge scars on the landscape, disrupting natural ecosystems. Second, aluminum production requires large amounts of energy, often produced by burning fossil fuels. This leads to emissions of greenhouse gases that contribute to climate change. In addition, the electrolysis process used to produce aluminum generates significant amounts of waste, including red mud, which contains toxic substances. Improper storage of red mud can lead to contamination of groundwater and reservoirs. Aluminum mining can also have a negative impact on people's health, especially those who live near mines and factories. Dust generated during bauxite mining and processing can contain harmful substances that irritate the respiratory tract and cause other health problems [20].

The next factor of environmental damage is noise pollution of the environment. The main source of noise pollution is the aircraft engine. At the same time, it is worth noting that the technology and innovation of the power plant does not reduce noise pollution in any way. For example, the only supersonic passenger airliners Concorde and Tu 144 were real engineering challenges in terms of airframe and power plant, but the environmental friendliness of the engine wants to expect better. Not only did it cause a lot of noise pollution, but it also burned a lot of fuel to maintain the aircraft's required speed and power, while releasing huge amounts of burnt gases into the air. The main consequences of noise pollution are disruption of the normal life activity of animals, deterioration of hunting, noise interferes with communication between animals. Noise also has a rather harmful effect on people, namely, it worsens the overall psychological state of a person, causes cardiovascular diseases, causes an increase in blood pressure, contributes to a decrease in a person's concentration, and impairs hearing. Also, constant stay in a noisy environment increases the general level of stress, which can have a very negative impact on a person's life.

However, the engine is a source of environmental problems not only from the side of noise pollution, but also from the side of excessive burning of fuel, which causes the emission of carbon dioxide into the atmosphere, as well as other gases associated with combustion. The peculiarity of air transport emissions is their height. Modern liners cruise at an altitude of 8-13 km, where the substances they emit have a prolonged effect on atmospheric processes. Since carbon dioxide, nitrogen oxides and unburned carbohydrates are released into the atmosphere during engine operation.

Carbon dioxide (CO_2): The main greenhouse gas that contributes to global warming. Aviation is responsible for approximately 2-3% of global anthropogenic CO_2 emissions. Nitrogen oxides (NO_x) affect the formation of tropospheric ozone and the destruction of stratospheric ozone. NO_x is also a precursor to acid rain. A significant amount of water vapor is released during flight, and although water vapor is a natural component of the atmosphere, its emissions from high-altitude aircraft can contribute to the formation of contrails and cirrus clouds, which affect the Earth's radiation balance. Unburned hydrocarbons are one of the most dangerous emissions, because they include methane, ethane, propane, acetylene, benzene and others. Some of them are toxic and carcinogenic. Solid particles also enter the atmosphere with exhaust gases. Soot, which is the result of active burning of fuel, absorbs solar radiation and contributes to the heating of the atmosphere. In addition, it can serve as condensation nuclei for the formation of clouds. Also, sulfate particles enter the atmosphere, which affect the formation of clouds and acid rain. The consequences of such cases are very significant: pollution of the upper layers of the atmosphere, climate change: emissions of CO_2, NO_x, water vapor and soot contribute to global warming, Depletion of the ozone layer, NOx and other substances can destroy the stratospheric ozone that protects us from ultraviolet radiation, Cloud formation, emissions of water vapor, soot and sulfate particles contribute to the formation of clouds, which affect climate and weather conditions. Changing the chemical composition of the atmosphere: Emissions of various substances can change the chemical composition of the atmosphere and affect atmospheric processes. One of the new methods of preventing atmospheric pollution during fuel combustion is the development of ecological substitutes for aviation fuel. Environmentally friendly aviation fuel (SAF) is currently being developed. Already in April 2023, the European Parliament and the Council introduced new rules proposed by ReFuelEU Aviation. According to which, by 2025, 2% of aviation fuel will be replaced by biological fuel, and by 2050, the percentage of ecological fuel will be more than 70%. Among the main rules adopted for the "greening" of aviation fuel is the need to replace 2% of the aircraft's fuel with an ecological analogue, it is also required that the operators do not exceed the required amount of fuel when refueling the aircraft, which will not cause the need to drain the fuel for landing, provided that the weight of the aircraft , which is required at landing is exceeded. After all, environmental damage is caused not only by spent fuel, but also by spilled fuel during landing, which litters the adjacent soils and lakes, and also causes the penetration of harmful fuel components into groundwater, which directly harms the health of people and animals living on adjacent territories [19].

New green fuel or SAF is obtained from renewable sources, namely organic waste, biomass and direct capture of carbon dioxide. The production of SAF is actively expanding, in the ten years from 2007 to 2018, the production of fuel increased more than 7 times, which is shown in the picture below, see fig. 4.1.

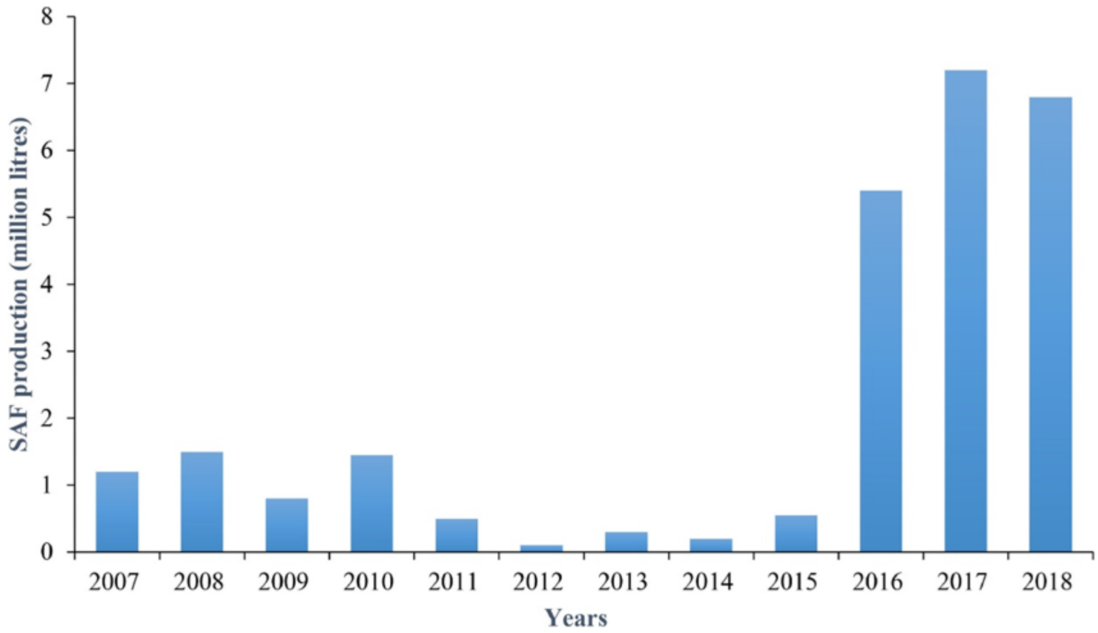
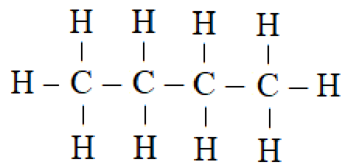
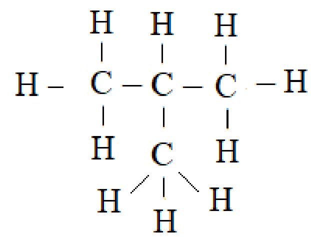


Fig. 4.1. The production of SAF

At the same time, the new ecological fuel has similar physical and chemical characteristics compared to traditional aviation fuel. Although its composition has undergone changes since its appearance. In the early stages of development, SAF consisted mainly of normal and isomeric alkanes. However, due to advances in production technology, modern SAF also includes aromatics and cycloalkanes. Normal and isomeric alkanes have the same molecular formula C_nH_{n+2} , but differ in the structure of the carbon chain, which leads to differences in their physical and chemical properties. The figure below shows the chemical structure of normal and isomeric alkanes using the alkane C_4H_6 as an example, see fig. 4.2.



Butane



Isobutane

Fig. 4.2. The chemical structure of the butane and Isobutan

Normal alkanes have higher boiling and melting points compared to isomeric alkanes for the same amount of carbon. Also, normal and isomeric alkanes are less prone to detonation at high temperatures, which has a positive effect on flight safety, because unused fuel is very often in the zone of elevated temperatures next to the engine, despite the fact that the engine is usually carried on the pylon by a meter - one and a half from the wing, precisely to reduce the temperature effect on the fuel, although this has a very negative effect on the stressed state of the aircraft structure.

Cycloalkanes are saturated carbohydrates in which carbon atoms are connected in a ring. Their chemical formula has the following form, and the chemical structure is shown in the figure below, see the fig. 4.3.

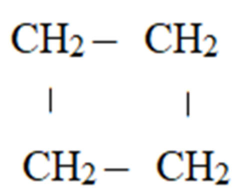


Fig. 4.3. The chemical structure of the cyclobutane

Cycloalkanes have the following chemical properties: they are low-reactive, that is, they are inert and do not react much, which is a good characteristic for aviation fuel, because the fuel will not lose its properties during long-term storage, and no interaction reaction will occur when stored in an airplane fuel tank between aircraft parts and fuel, which reduces the risk of corrosion and wear of aircraft parts. However, despite this, the fuel still creates a harmful environment for the aluminum frame parts. However, if you use ecological fuel in parts made of composite materials, the inertness of the fuel is a good advantage. Also, cycloalkanes have good combustion characteristics, which makes them a suitable raw material for fuel. The main advantages of cycloalkanes are high energy density, that is, with the same number of atoms, during an exothermic reaction, cycloalkanes will release a high amount of heat. If we compare cycloalkanes and normal alkanes, then the former have a higher specific heat during combustion. Also, cycloalkanes have better low-temperature properties, such as freezing point, and are comparable to normal alkanes. Despite all this, despite the advantages of cycloalkanes as the main raw material for the production of fuel, they also have a number of disadvantages. One of them is the complexity of the synthesis, which causes an increase in the cost of the final fuel, which, accordingly, affects the final cost of the flight. Also, due to the difficulty of synthesis, cycloalkanes have limited availability, which will slow down their widespread use in the aviation industry, and also make it impossible to quickly scale up the production of ecological fuel.

Aromatic substances are also one of the components of fuel. Although they have a lower energy density compared to the main component of raw materials, they play an important role in sealing fuel systems. Despite this, during combustion, aromatic substances can cause the emission of solid particles into the atmosphere. That is why it was decided to reduce the share of aromatic substances in subsequent versions of SAF.

The new SAF ecological fuel has a number of advantages. The main advantage is a significant reduction in greenhouse gas emissions, depending on the type of raw material and fuel production, SAF can reduce greenhouse gas emissions by 20% - 80%, compared to aviation fuel. This is achieved thanks to the use of renewable carbon sources and a closed production cycle, because aviation fuel has a harmful effect on the environment even at the production stage. After all, methane, carbon dioxide and other greenhouse gases that contribute to global warming are released into the atmosphere at the stage of oil production. Also, energy-intensive processes of refining and mixing components take place during the production of fuel, which causes the emission of carbon dioxide.

However, despite the undeniable advantages, the widespread adoption of SAF faces certain difficulties, such as the high cost, the production of SAF is currently more expensive than the production of traditional aviation fuel. This is due to the use of new technologies and limited availability of raw materials.

The storage, transportation and refueling of SAF may require the upgrading of existing airport infrastructure that is adapted to handle conventional aviation fuel.

One of the new ecological fuels is HEFA (Hydroprocessed Esters and Fatty Acids). Currently, it is one of the most common types of aviation fuel, it is produced from vegetable oils or animal fats, which is converted with the help of hydrogen into green aviation fuel. It was primarily used as an ecological component of classic aviation fuel, that is, it replaced 50% of the solution [21]. Now this substance can be used as a solid fuel, without the need for admixture of petroleum products. Now this fuel is actively introduced in the aviation industry, the Boeing company uses analog fuel with a very similar chemical composition in 787 Dreamliners [22].

The main advantages of such fuel are the availability and ease of obtaining raw materials, because the fuel can be made from various oils, such as soybean, rapeseed, palm, as well as already spent cooking oil or animal fats. What makes the production of fuel even more environmentally friendly, because it includes secondary processing, and secondary processing also helps to reduce the cost of the final product. Also, compared to SAF, HEFA does not require modernization or change of airport infrastructure, because it is adjacent to already used fuel systems and engines.

However, HEFA also has a number of disadvantages, such as limited scaling potential, because although raw materials are more accessible, they are still in limited quantities. There is also high competition for raw materials with food industries. It should also not be forgotten that the need to increase the raw materials for the production of fuel causes the need to increase the soil suitable for growing crops, which can cause deforestation.

FT-SPK (Fischer-Tropsch Synthetic Paraffinic Kerosene) is a type of synthetic aviation fuel that is considered one of the most promising types of sustainable aviation fuel due to its properties. This type of fuel is produced using the Fischer-Tropsch process. This process involves feeding carbon-rich raw materials such as natural gas, coal, or biomass. The raw material is fed into a reactor, where a reaction takes place under the influence of catalysts, the result of which can be gases, such as methane and ethane, or liquid substances (gasoline, diesel fuel, aviation fuel) and paraffin. After that, the obtained hydrocarbons are separated into fractions using distillation [23].

The advantages of this type of fuel are the high quality of the final product, with a low content of sulfur and aromatic compounds, which during combustion will not worsen air quality so much. Compatibility with the existing infrastructure of airports, because the fuel can be used not only as a basic product, but also as a solvent for traditional aviation fuel. Since biomass is the raw material for fuel, the fuel can be made from already spent substances, and also act as a method of processing.

However, among the advantages of fuel there are also a number of disadvantages, such as the high cost of the final product due to the high manufacturability of the process. Which makes it impossible to quickly implement in airlines. The complexity of the synthesis process causes high energy consumption of production, which can affect the overall ecological balance. Expensive scaling of the production process, since for the active introduction of fuel, it is necessary to build new plants for biomass gasification and fuel synthesis.

Conclusion to the part 4

Despite the challenges faced by the use of environmentally friendly fuel, the process of improving the environmental friendliness of air travel has already begun and will accelerate with the growth of technology. That is why the need to reduce carbon dioxide emissions is very urgent and requires decisive action.

PART 5. LABOR PROTECTION

This part will describe the basic methods of working with chemicals and cutting tools, and will also describe methods of improving human safety when working with these tools. The main machining tools such as turning, drilling and milling machines will be listed.

Turning:

Turning is one of the most common process in material machining. Without turning a lot of the industries couldn`t develop properly. Since many key details are manufactured by this type of process. Turning is used for the manufacturing, mechanical engineering, and other production sectors.

Turning is a process of the creating details using the special turning machine, that is shown in the fig. 5.1. Process involve cutting of the material to create appropriate form of the detail. Turning can be used for the big numbers of the material such as metals, wood and plastic.

Turning machines come in various forms, including manual and computer numerical control (CNC) models, which allow for higher precision and automation in the manufacturing process. Modern CNC turnings can achieve remarkable accuracy, often down to thousandths of a millimeter, making them essential for producing complex, precision parts [24].

Turning also involves strict quality control, with finished parts being checked using precision measuring tools to ensure they meet the required specifications and standards.

Advances in technology have made turning processes more efficient and cost-effective, resulting in lower production costs and higher product quality. As a result, skilled turners are in high demand, as they play a vital role in the production of components across many industrial fields.

The typical turning machine is shown in the Figure 6.1. the typical turning machine consists of:

- Headstock assembly;
- Spindle;
- Workpiece holder;
- Tool post;
- Cutting tool;
- Compound;
- Cross slide;
- Tailstock assembly;
- Bed;
- Lead screw;
- Carriage;
- Cross slide hand wheel;
- Carriage hand wheel.

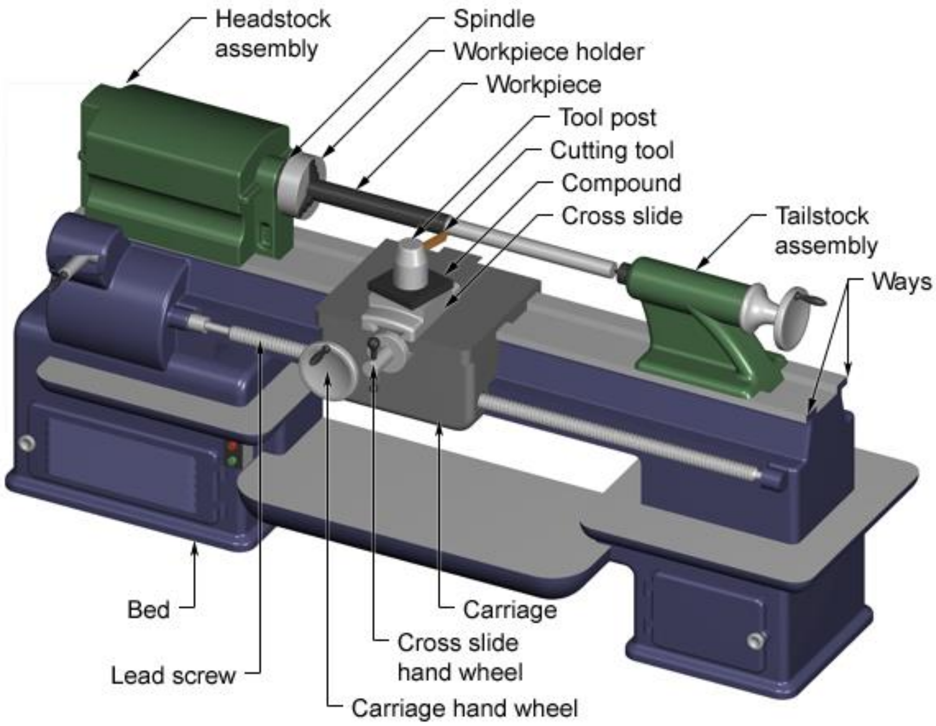


Fig. 5.1. The typical construction of the turning machine

Working with turning machines is a precise and efficient process, but it also involves certain safety risks for operators. A turning machine is a powerful rotating tool, and improper interaction with it can lead to various injuries if proper safety measures are not followed.

Potential Hazards When Working with Turning Machines

1. **Cuts and Hand or Finger Injuries.** The main risk when working with a turning machine is the possibility of cuts or injuries to the hands and fingers due to contact with rotating parts of the machine, such as the cutting tool or the workpiece being processed. The high rotational speed and sharpness of the tools create a significant risk to the operator.

2. **Injuries from Ejected Material**. During metalworking, especially at high rotational speeds, small pieces of material can break off and fly off the workpiece, potentially causing injury to the operator.

3. **Injuries from Rotating Parts of the Machine**. Rotating parts of the turning, such as the spindle, chuck, and other moving mechanisms, can cause serious injuries if the operator interacts with them improperly or fails to follow safety protocols when loading or changing workpieces.

4. **Electrical Hazards**. The turning machine is powered by electricity, which poses a risk of electrical shock, especially when the electrical systems are not handled properly or if there are issues with the wiring.

5. **Burns and Thermal Injuries**. During machining, high temperatures may be generated from friction, particularly when working with hard metals. This can lead to burns or thermal injuries to the operator.

Drilling machine

Drilling machine is one of the essential types of equipment used in the metalworking industry for performing drilling operations. It is designed to create holes in materials using a drill bit that rotates at high speed. Since drilling is a critical operation in many fields of production, such as mechanical engineering, automotive manufacturing, aerospace, and others, drilling machines have a wide range of applications.

The typical drilling machine is shown in the fig. 6.2.

Fig. 5.2. The typical drilling machine

The typical drilling machine that is shown in the photo above consists of:

- Step cone pulley;

- Drill feed handle;
- Belt;
- Motor;
- Spindle head;
- Spindle;
- Table;
- Base and column.

Classification of Drilling Machines

There are several types of drilling machines that differ in design, capabilities, and functionality:

- **Bench Drilling Machines** — Compact models typically used for small parts. They have a limited workspace and are not suitable for processing larger workpieces but are ideal for precise operations.
- **Vertical Drilling Machines** — In these machines, the drill bit is positioned vertically. This allows convenient processing of various workpieces and is often used for mass production.
- **Horizontal Drilling Machines** — In these machines, the drill bit is positioned horizontally, allowing them to process larger workpieces and handle more complex operations.
- **Drilling and Milling Machines** — Multifunctional machines that combine drilling and milling operations. These machines are used for complex processes where multiple operations are required on the same workpiece [25].

Operating Principle of a Drilling Machine

The core mechanism that drives the operation of a drilling machine is an electric motor, which turns the spindle that holds the drill bit. The table movement system allows the precise positioning of the workpiece beneath the drill bit, and vertical or horizontal movements ensure accurate positioning and material processing.

During operation, the drill bit rotates at high speeds, enabling it to move into the workpiece. Depending on the material and characteristics of the workpiece, the rotation speed, feed rate, and drilling depth can be adjusted.

Structural Features

Modern drilling machines come with various design features that enable them to be used for different types of work:

- **Spindle** — The rotating part that holds and drives the drill bit.
- **Table** — The working surface on which the workpiece is fixed. Tables may have different clamping systems, including magnetic, mechanical, or vacuum systems.
- **Feed** — The system that controls the speed of the drill bit or the movement of the table. It may be manual or automatic.
- **Control Systems** — Modern drilling machines are often equipped with Computer Numerical Control (CNC), which allows for automation of the machining process and high precision.

Applications of Drilling Machines

Drilling machines are used in many industries for machining various materials. Their primary applications include:

- **Mechanical Engineering**: For creating holes of various diameters and depths in machine components, mechanisms, and tools.
- **Automotive Manufacturing**: For drilling holes in car bodies, as well as manufacturing engines and other critical parts.

- **Aerospace Industry**: For making high-precision parts for aircraft and spacecraft, where drilling accuracy is critical.
- **Electronics and Instrumentation**: For processing small components such as printed circuit boards (PCBs) and other electronic devices.
- **Construction and Metallurgy**: For drilling holes in metal for the assembly of structures and other related applications.

Maintenance of Drilling Machines

To ensure the long-lasting and safe operation of a drilling machine, regular maintenance is essential. Key maintenance activities include:

- **Cleaning from Chips and Dust**: Contaminants can reduce the machine's efficiency and damage components.
- **Lubrication and Greasing**: For proper functioning of the mechanisms, it is necessary to lubricate the bearings, gear teeth, and other moving parts.
- **Precision Adjustment**: It is important to regularly check the machine's precision and adjust settings when necessary.

Milling machine

A milling machine is a versatile piece of equipment used for processing various materials such as metals, plastics, wood, and others by cutting away material with a rotating milling cutter. This process allows for the creation of parts with high precision and the production of complex geometric shapes. The typical milling machine is shown below, see fig. 5.2, [26].

Fig. 5.2. Typical milling machine

The typical milling machine consist of:

- Motor;
- Head and column;
- Springe;
- Ram;
- Table;
- Table power feed;
- Vertical positing screw;

- Table traverse crank handle;
- Vertical knee traverse crank.

The main element of a milling machine is the milling cutter — a rotating tool with multiple cutting edges. During the milling process, the workpiece is securely fixed on the machine table, and the milling cutter rotates at high speed, removing material from the surface of the workpiece. Depending on the type of operation and the shape of the cutter, various tasks can be performed, such as milling flat surfaces, creating grooves, drilling holes, and machining complex contours.

Milling machines can be classified into several types:

- **Vertical Milling Machines**: The milling cutter rotates vertically, which is ideal for machining flat surfaces and performing tasks with precise dimensions.
- **Horizontal Milling Machines**: The milling cutter is positioned horizontally, making it effective for processing larger workpieces and performing more complex operations.
- **CNC Milling Machines**: These machines are equipped with computer numerical control (CNC), enabling automated control of the milling process, which enhances Milling machines are used across various industries, including mechanical engineering, aerospace, electronics, and metallurgy. They are employed to manufacture complex components such as housings, shafts, grooves, gears, and other parts that require high precision.

Milling provides high precision and the ability to machine complex shapes and geometric figures. This makes milling machines indispensable in both mass production and custom manufacturing, where accuracy and versatility are key requirements.

The main disadvantages of the milling machine are high initial cost, complex operation and maintence, limited material thickness, noise and vibrations.

Injury Prevention Methods

- **Use of Protective Equipment**. Operators should always wear appropriate protective gear: safety goggles to protect the eyes from flying particles, gloves to protect the hands, and protective clothing to prevent loose fabric from getting caught in rotating parts. Helmets or shields may also be necessary to protect against sparks when working with metals.

- **Training and Instruction**. Workers should receive proper training in safety techniques, familiarize themselves with turning machine operation manuals, and regularly undergo safety briefings to stay informed about new risks and preventive methods.
- **Regular Machine Maintenance and Inspections**. Regular maintenance checks are essential for ensuring the safe operation of turning machines. It is necessary to inspect the rotating components, lubrication systems, and mechanical connections for wear or damage. Any defects should be addressed before the machine is put into operation.
- **Proper Securing of Workpieces and Tools**. All workpieces and tools must be securely fastened before starting machining. This prevents accidental ejection of the workpiece during the operation. Special chucks are used to ensure precise clamping of the material.
- **Handling Rotating Parts Properly**. Operators should avoid getting too close to rotating parts and should never be distracted while operating the machine. All operations involving tool changes or adjustments should only be performed after the machine has come to a complete stop.
- **Use of Dust and Chip Removal Systems**. An efficient system for removing chips and dust is essential, as their accumulation can lead to dangerous situations such as fires or mechanical damage to the machine.
- **Workplace Organization**. The workplace should be well-lit, clean, and organized to minimize risks associated with dropped tools or materials and to reduce the likelihood of operator error.
- **Monitoring Electrical and Mechanical Systems.** Regular maintenance and inspection of electrical connections and control systems are critical for preventing malfunctions that could lead to injury.

Conclusions to the part 5

Turning, drilling and milling machines are an integral part of aircraft production. they allow parts to be made faster and more accurately, which positively affects the overall strength and durability of the aircraft. However, like any instrument, machines must be maintained with special care. If the tool is used carelessly, it will not only not bring the proper benefit, but also may cause serious injuries to the engineer working at the machine. Therefore, you should carefully follow the operating instructions when using the tools and do not neglect safety techniques.

GENERAL CONCLUSION

There are several methods for predicting critical stresses for compression members such as skins, stringers, and panels. The main of these methods were developed to determine different forms of loss of stability, such as general, local, inter-fastener swelling, as well as fractures, since the mechanics of body deformation in each of these types of loss of stability are significantly different. Stability loss is one of the most critical problems in structural mechanics, particularly in the design of compression elements. Therefore, it is important not only to have a clear idea of the mechanics of deformations, but also to understand the foundations on which the corresponding formulas and assumptions underlying the methods of estimating critical stresses are built.

These methods are widely used to analyze and evaluate the strength of structures under various load conditions, and although there are a significant number of formulas for determining the critical stresses of the loss of stability, the question of studying this phenomenon remains relevant. Different types of loss of stability depend not only on the geometric characteristics of the structure, but also on the material, operating conditions, as well as on the type and form of loads. Therefore, this topic requires constant research and refinement, since modern models and approaches are not always able to cover all possible scenarios.

Various methods are used to prevent the negative consequences of loss of stability in aircraft design. They include special structural elements such as stiffeners, load-distributing stringers, and panels with optimized geometry capable of withstanding high compression without significant deformation. Despite the significant contribution of these methods to increasing the load-bearing capacity of structures, they all have their limitations and disadvantages. For example, to ensure the necessary stiffness and strength of the structure, it may be necessary to use additional materials or technologies, which, in turn, may lead to an increase in the cost of production and the complexity of operation. In addition, such design solutions can affect the fatigue of the material, reducing the fatigue strength and, as a result, shortening the service life of the structural elements.

Choosing the right design method is extremely important, as mistakes at this stage can lead not only to uneconomical or ineffective solutions, but also to dangerous situations during operation. The structure must be calculated so as not only to withstand the designed loads, but also to have a safety margin that ensures safety under variable or extreme operating conditions. This applies both to the design of individual structural elements and to the analysis of their interaction within the framework of the entire system.

In the studies carried out for this project, preliminary designs of compression precast panels were prepared. The effect of local swelling on the overall static strength of the panels was taken into account. As the analysis showed, the change in the thickness and width of the cladding significantly affects the local stability. In particular, with a decrease in the thickness of the cladding, the panel became more prone to local swelling, which, in turn, leads to a decrease in its overall strength. This is especially important for the design of panels subjected to high compressive loads. Slab swelling, which is one of the most critical failure modes, occurs when the skin thickness is insufficient to support the load without significant deformation. Such deformation not only deteriorates the mechanical characteristics of the panel, but can also lead to serious structural damage, which reduces the safety of the structure.

The panel design process is complex and requires a lot of effort to optimize each element of the structure. Errors at the stage of calculations or selection of materials can lead not only to the deterioration of economic indicators, but also to a violation of safety, which is critical in aviation engineering. Therefore, it is important to take into account all possible variants of loads, bends, as well as the interaction between various structural elements.

The design results showed that increasing the strength of the panels against local swelling not only increases their reliability, but can also contribute to reducing the total weight of the structure. Thanks to the improved resistance to local swelling, the structure can be manufactured with less material usage, which in turn reduces the overall weight and thus improves the efficiency of the aircraft as a whole. Optimizing the strength of the panels allows you to maintain the necessary characteristics, while reducing excess mass, which is an important aspect for improving the efficiency of aircraft.

As a material for structures, aluminum alloy is the most effective, as it combines high strength and low weight. This material is used for its excellent strength-to-weight ratio, which is an important factor in aircraft design, where every gram counts. However, it is worth noting that although materials with a higher modulus of elasticity, such as titanium or steel alloys, may be stiffer, they are not always the most effective in resisting swelling.

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