Summary: Europe is one of the densely populated continents on Earth. A characteristic feature of the European air transport service market is co-existence of several and large communication centres performing trans-continental links and dense net of local links between the majority of small cities and tourist resorts. Europe is an exceptional area with unique properties favouring regional development of the air transport system of light aircraft with the use of small and medium airports. Europe has a huge partly unused potential of airports and landing grounds which can be the basis for creating a competitive travel offer around Europe by light passenger aircrafts. They can use less busy airports and adjusted and re-qualified landing grounds as well as natural landing fields. Operators and entrepreneurs interested in starting new air transport businesses report about missing modern aircrafts. The present paper shows the algorithm of optimal selection of the designing parameters of the aircraft and optimal division of different tasks among the aircraft of a non-homogeneous system. In order to illustrate the issues, the computational example based on the optimal selection of several basic designing parameters of the aircraft performing an established set of tasks and based on the determining of the optimal areas of specialization for the elements of the analyzed aviation fleet.

Keywords: air transport, light aircraft, design optimisation

1. INTRODUCTION

Transportation is an activity aimed at moving from the point of origin to the point of destination. Among all the possibilities, air transportation represents only one branch. The criterion of division into branches strictly depends on the available facilities, the employed technology and the organization of the processes. For example air transportation has various basic facilities, including e.g. the aircraft, the airports, the ATC/AM, the regulatory bodies, or the industry. All these elements compose a system, often referred as transportation system.

Air transportation is considered to be the most efficient transportation mean and therefore has a dominating position at long distances. It is also significant at short or medium distances, but upon various factors influencing the passenger’s mode selection criteria, it competes with rail and car transport.
The European air traffic network contains about 170,000 links between airports [4]. Understanding the variety of airports in Europe, their distribution, their traffic patterns and their aircraft mix, is essential to understand the strengths of the air traffic network. Taking into account short distances between the European cities, transportation on the territory of Europe is performed mainly over short and medium distances, with the domination of the first ones. The European transport market is therefore, the area of competition between the road, rail and air transport.

A characteristic feature of the European air transport service market is co-existence of several but large communication centers performing trans-continental links and dense net of local links between the majority of small cities and tourist resorts. In Europe there are 43 main airports (large and medium hubs) and 450 country and regional airports (commercial service airports) [4]. European airports have 1336 hard take-off runways (concrete or asphalt) and 737 airports have necessary equipment to perform IFR flights [4, 5, 6]. In 2010, approximately 9.5 million IFR flights were performed in Europe and the forecast for 2017 assumes a 21 per cent increase in the number of IFR flights, which is an equivalent to 11.5 million take-offs, and the same number of landings, in the European airports [6]. As much as 44 per cent of the total air traffic is concentrated on only 25 largest European airports [5]. This results in a very high air traffic density in the largest European airports and in their vicinity. What it involves is that the air traffic in the largest airports and their areas of operations approaches the capacity limits.

The analysis of the European transport market helps come to the conclusion that Europe is an exceptional area with unique properties favoring regional development of the air transport system of light aircraft with the use of small and medium airports. Europe has a huge partly unused potential of airports and landing grounds which can be the basis for creating a competitive travel offer around Europe by light passenger aircraft using less busy airports and adjusted and re-qualified landing grounds as well as natural landing fields.

Operators and entrepreneurs interested in starting new air transport businesses report about missing modern aircrafts. At the turn of 80s and 90s of the 20th century many countries started study and project works aimed at designing liner perspective systems of the general aviation aircraft (GA - general aviation). The term "General Aviation" applies to a wide class of flying vehicles used to carry passengers (from 2 to 19 people), cargo, to patrol and protect forests, in medical service, mail service and so on.

The percentage of aircraft of this class reaches 90% of the whole civil aviation fleet. The majority of them are slow aircraft which use one or several reciprocating engines as a power unit. However, recently there has been a tendency to increase the flying speed to 500-600 km/h and the flying height to 6-8 km, which lead to an increase in the number of aircraft with turboprop engines.

Apart from that, when the take-off weight of the aircraft increases, the relative wing loading and the range also increase. Nowadays, this class aircraft have a smaller increasing tendency regarding the payload mass in comparison to air traffic aircrafts.

The accident risk of general aviation aircraft is still in the first place among other means of air traffic transportation. Such a high level of accident risk is influenced by the fact that the aircraft are operated by unprofessional pilots and insufficient number of calculating and experimental research on the design level.
Statistics show that in average half of the aviation accidents take place at approach to landing and at landing itself, however, 20% are connected with the take-off. That is why, one of the basic requirement put to the designed aircraft of this class is the increased safety in connection with the simplicity of operation. Using a relevant method of aerodynamic design of the general aviation aircraft and using modern methods of computational aerodynamics and experimental research of the models in aerodynamic tunnels, it is possible to reconcile high requirements concerning the safety with the desired level of profitability of this type of transport.

The basis to start working out the concept of the passenger transportation with the use of light passenger aircraft was the analysis of structure of the passenger car range in Europe and the analysis of the American transportation market.

Based on the analysis of the structure of the transportation market in Europe and the forecast percentage of the light passenger aircraft in performing passenger transportation the expected area of functioning of the passenger transportation system performed by light aircraft was determined.

It follows from the above analysis that it is possible to create a competitive offer of travelling around Europe using light aircrafts to people who have travelled by passenger aircrafts so far.

New aircraft can be design using an algorithm of optimal selection of the designing parameters of the aircraft and optimal division of different tasks among the aircraft of a non-homogeneous system.

2. AIRCRAFT AS A MULTITASK SYSTEM

The characteristic feature of the technical objects used in aviation (and not only) is their multipurpose and multitask character. This property concerns single aircrafts as well as their sets which constitute a certain aircraft fleet. It shows itself in different aims which this aircraft fleet is to fulfill (e.g. an airline) and in different conditions of its functioning. For example, for passenger aircrafts the set of lanes of different length, intensity and other characteristics is a set of tasks, and a variety of conditions of use is determined by technical, geographical, climate and other differences of the gateway airport. This defines the multipurpose (universal) character of the aircraft use. The mathematical model of the aircraft can be a multitask system [3].

Each multitask system consists of a certain finite number $m$ of elements which make set $A$ called a set of system elements. The set of all elements $x_i$, which can potentially enter the system structure, is determined by $X$, i.e.

$$x_i \in X \text{ for } i = 1, \ldots, m$$  \hspace{1cm} (1)

and set $A$ is defined as:

$$A = \{x_i\} \subset X \text{ where } i = 1, \ldots, m$$ \hspace{1cm} (2)
It is supposed that set $Y$ will be set. The integral function $E(y)$ was determined in this set which takes values $1, 2, \ldots, m$ – it is called the distribution function [3]. The field of specialization $D_i$ of the element $x_i \in A$ for $i = 1, \ldots, m$, will be called a subset of the set $Y$ in points of which the distribution function has values equal to $i$:

$$D_i = \{y \in Y : E(y) = i\} \text{ for } i = 1, \ldots, m \quad (3)$$

The fields of specialization must fulfill two criteria:

1. Fields of specialization for different elements cannot have common parts

$$D_i \bigcup D_k = \emptyset; \forall i, k = 1, \ldots, m; i \neq k \quad (4)$$

2. The sum of all Fields of specialization must be equal to external multitude $Y$

$$\bigcup_{i=1}^{m} D_i = Y \quad (5)$$

Three main elements of the presented model $<A, Y, E(y)>$ are called the multitask system. The vector of quality of the multitask non-vector system [3] can be defined as follows:

$$F = F[A, Y, E(y)] \quad (6)$$

Putting the mathematic multitask system into the notion of local quality function $f[x, y, \mu(D)]$ of the field of specialization $D_i$ of the aircraft $x_i \in A$, it is possible to express the coefficient of the multitask system quality (6) in terms of its values in particular fields of specialization $D_i$ of certain elements $x_i \in A$ [3]:

$$F[X, A, E(x)] = \sum_{i=1}^{m} \sum_{y_j \in D_i} f[x_i, y_j, \mu(D_i)] \quad Y = \bigcup_{i=1}^{m} D_i \quad (7)$$

where: $\mu(D_i)$ - field of specialization measure $D_i$ [3].

The desire to take into consideration when estimating the effectiveness of the multiplicity of the solutions and heterogeneity of their traits and performance properties leads to different criteria and as a result to heterogeneous estimation of the efficiency. It leads to the vector optimization task for which the methods of the solution seeking are known. The quality of solution $x \in X$ will be estimated by a certain set $n$ element of the scalar factor which is usually interpreted as a certain vector of objective function values $F$.

It is necessary to choose in the accepted set $X$ the best in some respects variant $\hat{x}$. It is known that the mathematical vector optimization model corresponds to this formulation

$$F(\hat{x}) = \text{opt}_{x \in X} \{F(x)\}, \quad F = \{f_1, \ldots, f_u\} \quad (8)$$
where: \( \text{opt} \) – is the operator of the optimization of the vector of objective function values which specifies the principle of the solution variants preference. For the purpose of a single-valued choice of the solution an additional principle is introduced to the analysis which specifies the compromise scheme between the factors \( f_1, ..., f_n \).

### 2.1. AIRCRAFT EFFICIENCY

The analysis of scientific literature [1, 2, 3, 9, 12, 13] helps distinguish some types of criteria of performance evaluation of planes with different range of their use and capability.

**Simple technical criteria** – technical criteria describe performing and bulk characteristics of the plane. The following values can act as criteria: maximum speed, maximum rate of climb, service ceiling, range, takeoff distance, landing distance, payload weight, and gross weight. These criteria are irrelative; they have nothing to do with the dimensions, weight or category of the plane. They determine only “isolated” facts.

**Complex technical criteria** [2, 3] – connect some Simple characteristics of the plane and give somehow more “meaningful” estimation of the quality, however limited, to a selected plane category with not so distant technical features. These criteria have a relative character. The range of velocity is often used as an indicator of quality.

**Economic criteria** – originally appeared for the needs of airlines (transport companies) [2, 3, 12, 13] using them to optimize the aircraft fleet, setting rational (and competitive) traffic tariff rates and so on. Despite the compilation and necessity to take into account a lot of components based on statistic data or given data these criteria are currently a basic form of estimation of the planes used commercially.

The most widened and most general economic criterion is the complete life cycle cost of a plane (LCC – Life Cycle Cost) [12] consisting of costs of development, research, production, acquisition, utilization and disposal of the majority of planes of a particular type. The LCC of a plane is a sum of four components:

\[
\text{LCC} = C_{RDTE} + C_{ACQ} + C_{OPS} + C_{DISP}
\]  

(9)

where:

- \( C_{RDTE} \) - costs of research, development, tests and evaluation,
- \( C_{ACQ} \) - costs of acquisition,
- \( C_{OPS} \) - operating costs,
- \( C_{DISP} \) - costs of disposal after use.

Thus the form of the criterion is especially useful when estimating functioning of aviation companies, types of military aviation, because it helps determine general costs of development and operation of the plane as well as annual expenditures on maintenance of the aircraft fleet.

A less general criterion is the DOC (Direct Operating Cost) expressing the cost of a time unit of operation of a given type of plane [12]. The DOC is a sum of costs directly connected with performing an aviation task. It consists of flight costs (fuel, personnel salaries, amortization, repairs, airport charges, navigation, etc.) which fall on each plane and calculation unit.
The economic criteria unlike simple technical criteria, which estimate separate plane characteristics, have “integral” properties, taking into account flight characteristics, construction of the fuselage, driving system, operation and market factors. Thus, it is a better, although not sufficient, measure of the general features of a plane.

3. AIRCRAFT FLEET SIZING

Every aircraft can perform a limited range of tasks. For transport planes the typical task is delivering a certain load (payload weight) over a given distance. To guarantee air transportation load aircraft fleets which consist of different types of airplanes are used, and their effective selection decides on the quality of the whole fleet. Cooperation of the planes within the fleet appears in the fact that capabilities of different planes as a rule are partially covered. Thus, alternative fields are created $\Omega_{12}, \Omega_{123}, \Omega_{23}$ (Figure 1) [3] to cover which two or more types of planes are used. A lack of uniqueness which appears in this case causes the necessity of distributing the tasks from the alternative fields between the “competing” aircraft and determining the fields of the most effective use for each of them. It is difficult to estimate the effectiveness of the complex aircraft fleet as a whole which performs the full range of tasks. However, it is possible to estimate a single task performed by one plane. In the majority of cases only with strong limitation of the requirements it is possible to estimate the goal achievement with the help of one quality criterion. In practice certain points of view must be determined with different quality criteria. In this approach, different variants of dividing the task sets between the planes included in the aircraft fleet are obtained, better regarding one indicator and worse regarding the others.

![Figure 1. Aircraft fleet transport potential (alternate fields)](image-url)
If the system elements (Figure 1) can be treated as independent, then solving the complex task of optimizing is reduced to solving two simple tasks which are solved separately [3]. The first task is to find the optimal fields of specialization of the planes (task division) which are a consisting part of a system. The second task is to find optimal parameters of the plane performing tasks assigned to it. In order to solve the first task, the algorithm was worked out; it uses specific properties of the aviation system and the defined coefficient of effectiveness. The solving procedure consists of alternate looping for Fields of specialization for the present aircraft fleet and looping for parameters of an optimal plane in its set of tasks.

4. RESULTS

In this example of computation the system consisting of four types of aircrafts with different dimensions and transport capacity was assumed. The task was to select a new aircraft with optimal parameters and determine new areas of specialization and the number of copies for each type.

<table>
<thead>
<tr>
<th>Description</th>
<th>Aircraft No 1</th>
<th>Aircraft No 2</th>
<th>Aircraft No 3</th>
<th>Aircraft No 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wing span, m</td>
<td>11.85</td>
<td>14.94</td>
<td>16.48</td>
<td>25.90</td>
</tr>
<tr>
<td>Wing area, m²</td>
<td>19.39</td>
<td>30.20</td>
<td>32.86</td>
<td>54.35</td>
</tr>
<tr>
<td>Length overall, m</td>
<td>8.22</td>
<td>10.86</td>
<td>12.89</td>
<td>20.82</td>
</tr>
<tr>
<td>Engine power, kW</td>
<td>2 x 180</td>
<td>2 x 220</td>
<td>2 x 540</td>
<td>2 x 1490</td>
</tr>
<tr>
<td>Take-off weight, kg</td>
<td>2050</td>
<td>2990</td>
<td>5800</td>
<td>15 500</td>
</tr>
<tr>
<td>number of passengers,</td>
<td>4</td>
<td>9</td>
<td>18</td>
<td>36</td>
</tr>
</tbody>
</table>

Table 1

Figure 2. The schedule of the transportation in the function of the route length
The new aircraft in the analyzed system is aircraft No. 3. Without limiting the generality of the solutions, the set of the parameters subjected to optimized selection was reduced to 4 values: wing span, wing area, engine power, number of passengers.

The following limitations were assumed: maximum take-off weight, stall speed at landing configuration, rate of climb, ceiling, range.

The calculations were made for a different number of tasks generated with the assumed schedule, typical for the European transportation. Each transportation task included caring an assumed number of passengers \( n_{pax} \) from the initial airport to the destination airport, in distance \( L_Z \). The example schedules of the transportations in the function of the route length for ten and twenty tasks are presented in Figure 2.

<table>
<thead>
<tr>
<th>Description</th>
<th>Original</th>
<th>Final</th>
<th>Change, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wing span, m</td>
<td>16.48</td>
<td>12.05</td>
<td>-31.10</td>
</tr>
<tr>
<td>Wing area, m(^2)</td>
<td>32.86</td>
<td>26.50</td>
<td>-13.30</td>
</tr>
<tr>
<td>Engine power, kW</td>
<td>2 x 540</td>
<td>2 x 554</td>
<td>2.60</td>
</tr>
<tr>
<td>Number of passengers, -</td>
<td>18</td>
<td>20</td>
<td>11.10</td>
</tr>
</tbody>
</table>

The presented results were obtained for 20 different tasks (Figure 2). Table 2 presents the change of chosen parameters after optimization. Figure 3 shows the influence of the optimization parameters of aircraft No 3 on the dependence of the cost of transportation of one passenger on the route length. The hatched area shows the improvement of costs of aircraft No 3 after optimal task division and optimization of the parameters. Figure 4 shows comparison of the shape of aircraft No 3 before and after optimization (shaded form).
5. CONCLUSION

This analysis found that:
- As a result of the carried out optimal task division, one type of aircraft (No 4) was eliminated from the system. This aircraft was eliminated from the system regarding small traffic density on the analyzed routes, which caused a low use of seats in each flight.
- Optimization of the parameters caused a 7.35% decrease in the total costs in relation to the solution of the optimal division and definitely allowed limitation of the use of aircraft No 1.
- Accepting a slight degradation of the global quality factor, it is also possible to eliminate aircraft No 1 from the system as it is not used frequently and there is only one unit of it.
- It follows from Figure 3 that optimization of the parameters did not change the areas of operation of the aircraft (regarding the number of the carried passengers). However, it improved the function of the local quality (the cost of transportation of one passenger over a given distance).
- The function of the local quality has a typical saw-tooth shape (Figure 3) which follows from the expansion of the area of the reached tasks $a(x_i)$ beyond the area of the transportation capacity of the aircraft in the continuous operation giving, as a result, the criterion of the compound operation.
- Even though that some parameters of only one aircraft (No 3) were subjected to optimal selection, the costs of transportation of one passenger in the function of distance decreased for all the aircrafts. It is explained by the overtaking of these tasks by the new aircraft which it could not perform before changing the parameters.

References


PROBLEM WYBORU CHARAKTERYSTYK LEKKIEGO SAMOLOTU TRANSPORTOWEGO


Słowa kluczowe: transport lotniczy, lekki samolot transportowy, projektowanie samolotu