THE PROBLEM OF CHOICE OF LIGHT PASSENGER SEAPLANE USED FOR SHORT-HAUL FLIGHTS

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Abstract

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 amphibian aircraft with the use of small and medium airports and natural water landings. 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 amphibian aircrafts. They can use less busy airports and adjusted and re-qualified landing grounds as well as natural landing fields on water. The potential places for take-off and landing operations are port pools located on the coast of the sea, lake or big rivers. Operators and entrepreneurs interested in starting new seaplane businesses report about missing modern airplanes. The aim of the paper is to conduct comparative analysis of the characteristics of selected types of light amphibian aircrafts (existed and modified presently used land-based planes), helped to identify best fitted seaplane to estimated range of operation.

Keywords: *air transport, seaplane transport, seaplanes*

1. Introduction

Europe is one of the Earth's most densely populated areas. There are approximately 1270 airports and 1300 airfields in Europe [6]. The total number includes 737 European airports that are equipped for IFR operations. In 2010, approximately 9.5 million IFR flights were performed in Europe and the forecast for 2017 assumes 21 per cent increase in the number of IFR flights, which is an equivalent to 11.5 million takeoffs, and the same number of landings, in European airports [4]. As much as 44 per cent of the total air traffic is concentrated on only 25 largest European airports [4]. That results in a very high air traffic density in the largest European airports and in their vicinity. What it involves, air traffic in the largest airports and their areas of operations approaches the capacity limits. Such high density of air traffic adversely influences the natural environment in the vicinity of airports by increasing cumulative noise level and the concentration of environmentally hazardous substances. 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, thus, the area of competition between the road, rail and air transport.

Europe is an exceptional area with unique properties favouring regional development of the air transport system of light amphibian aircraft with the use of small and medium airports and natural water landings. 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 amphibian aircraft using less busy airports and adjusted and re-qualified landing grounds as well as natural landing fields on water.

2. Possible Seaplane Base Locations in Europe

In Europe there are 1400 seaports qualified as eventual water aerodromes, i.e. there are enough technical conditions for realizing take-off and landing manoeuvres [6]. However, there are many other barriers preventing a utilization them as seaplane base. European seaports should be treated as potential for growing seaplane transport on territory of Europe.

Three alternative variants of amphibian aircraft use in the local passenger transport are:

1. the flight from the nearest land airport to the seaport (or the return flight),
2. the flight between two water landing fields (replacement of some ferry and hydrofoil connections in Europe),
3. the flight from the land airport to the seaport located in a far distance (transportation between the selected large European airports and local tourist resorts).

The distribution of distances between selected land airports and seaports (potential seaplane basis) for most populated countries of EU is presented in Fig. 1. It follows that the maximum distribution of distances is 600.3 km, and maximum distance is about 1270 km. The 50% of all connections have length smaller than 520 km. These values define wider sets of tasks realized by amphibian aircraft for variant 3 of the amphibian aircraft use. This result corresponds with variant 1 of the amphibian aircraft use, on the assumption that the flight is starting from one of the main European airport [6].

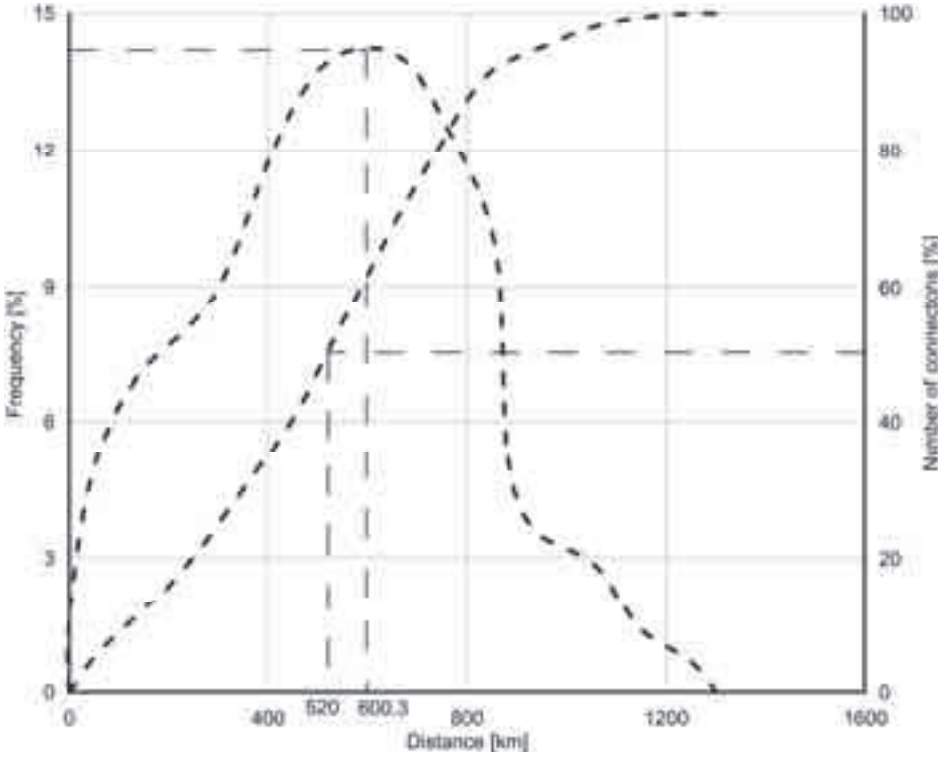

Fig. 1. Distribution of distances between airports and seaports in Europe [6]

2.1. Possible Seaplane Base Locations in Poland

The potential places for take-off and landing operations are port pools located on the coast of the sea, lake and big rivers. In Poland, there are 11 seaports, 6 river ports and 33 lakes qualified as eventual water aerodromes where amphibian aircraft can take-off and land. In Fig. 2 are presented example connections between land airports and seaports. Distribution of distances between airports and seaports is presented in Fig. 3. The largest concentration of the distances occurs at about 400 km. The minimum connection length is 188 km and the maximum is 680 km.

Fig. 2. Example connections between seaports and airports [6]

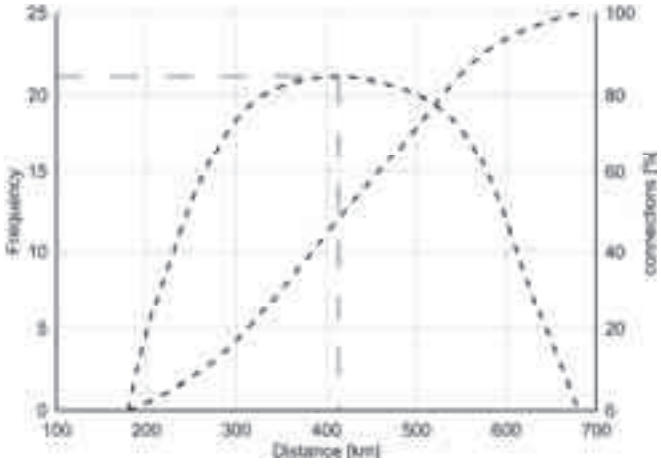

Fig. 3. Distribution of distances between airports and seaports in Poland [6]

3. Determining the structure of the aircraft fleet

The characteristic feature of the technical objects used in aviation 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 fulfil (e.g. an airline), and in different conditions of its functioning. For example, for passenger airplanes, the set of lines 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 plane use.

Every aircraft can perform a limited range of tasks. For transport aircrafts, 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 Ω_{12}, Ω_{123}, Ω_{23} (Fig. 4) to cover which two or more types of aircrafts 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.

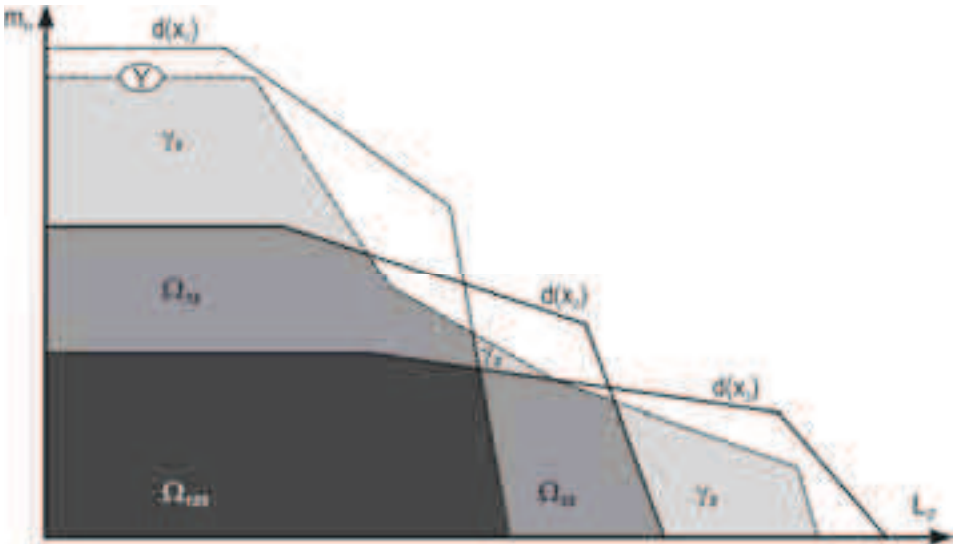

Fig. 4. Aircraft fleet transport potential (alternate fields) [1]

If the system elements (Fig. 4) can be treated as independent, then solving the complex task of optimizing is reduced to solving two simple tasks, which are solved separately. The first task is to find the optimal fields of specialization of the aircrafts, which are a consisting part of a system. The second task is to the find optimal parameters of the aircraft performing tasks assigned to it. The first task is solved with the method described below. The solution to the second task is beyond the scope of this research.

From the described aircraft fleet properties:

– existence of different conditions of functioning and task performing,
– using many quality coefficients to estimate the aircraft fleet,
– the complex aircraft fleet structure consisting of many different aircrafts (autonomous elements) between which a particular task performing is divided,

follows that the mathematical model of the aircraft fleet can be a multitask system [1].

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

$$\boldsymbol{x}_i \in \boldsymbol{X} \quad for \quad i = 1,\ldots,m\,, \tag{1}$$

and set $\boldsymbol{A}$ is defined as:

$$\boldsymbol{A} = \{\boldsymbol{x}_i\} \subset \boldsymbol{X} \quad where \quad i = 1,\ldots,m\,, \tag{2}$$

It is supposed that set $\boldsymbol{Y}$ will be set. The integral function $E(\boldsymbol{y})$ was determined in this set which takes values 1, 2,..., m – it is called the distribution function. The field of specialization $\boldsymbol{D}_i$, of the element $\boldsymbol{x}_i \in \boldsymbol{A}$ for i = 1,..., m, will be called a subset of the set $\boldsymbol{Y}$ in points of which the distribution function has values equal to i:

$$\boldsymbol{D}_i = \{\boldsymbol{y} \in \boldsymbol{Y} : E(\boldsymbol{y}) = i\} \quad for \quad i = 1,\ldots,m \ . \tag{3}$$

The fields of specialization must fulfil two criteria:

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

$$\boldsymbol{D}_i \cup \boldsymbol{D}_k = \varnothing;\ \forall\, i, k = 1,\ldots,m;\ i \neq k\,, \tag{4}$$

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

$$\bigcup_{i=1}^{m} \boldsymbol{D}_i = \boldsymbol{Y}\,, \tag{5}$$

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

$$F = F\left[\boldsymbol{A}, \boldsymbol{Y}, E(\boldsymbol{y})\right], \tag{6}$$

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

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

where:

$\mu(\boldsymbol{D}_i)$ – field of specialization measure $\boldsymbol{D}_i$.

4. Task division

Input data for the algorithm:

- achievable task fields $\boldsymbol{D}(\boldsymbol{x}_i)$ of planes in fleet $\boldsymbol{A}$,
- resource vector $\boldsymbol{R} = \{\boldsymbol{R}_1, \boldsymbol{R}_2, ..., \boldsymbol{R}_{m+1}\}$ of the aircrafts of all types. Each component of vector $\boldsymbol{R}$ determines the number of hours, which can be logged by a single unit of a determined type in an analyzed time period,
- unit costs of performing the task $\boldsymbol{y}_j$, $j = 1,...,n$ for all types of the aircrafts, as presented in the matrix:

$$\left[C_{ij}\right] = \begin{bmatrix} C_{11} & C_{12} & \cdots & C_{1n} \\ C_{21} & C_{22} & \cdots & C_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ C_{m+1,1} & C_{m+1,2} & \cdots & C_{m+1,n} \end{bmatrix}. \tag{8}$$

The elements of the matrix $C_{ij} = C_{1ij} N_{ij}$ show effectiveness of performing of all j - type tasks by i - type planes (N_{ij} – number of flights of the aircrafts which is enough to perform a j task).

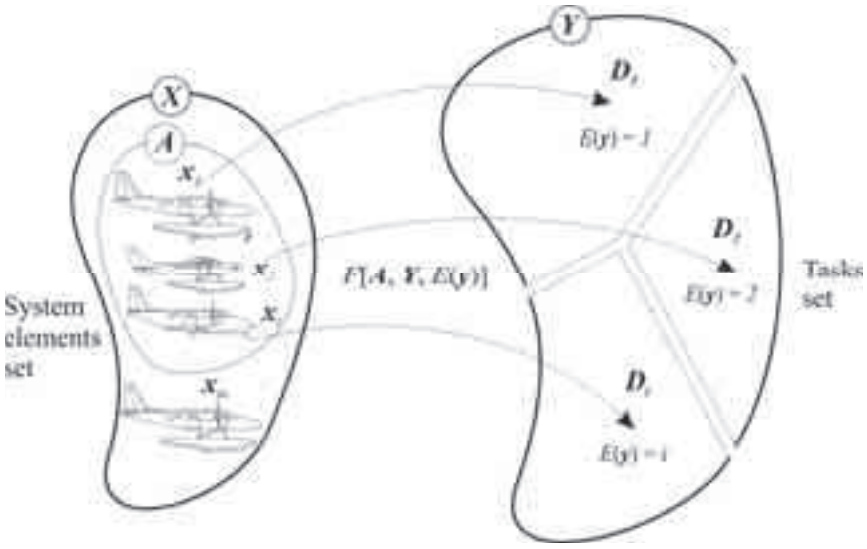

Fig. 5. Task division between planes within a fleet (system)

4.1. Algorithm of division

1. The matrix $[C_{ij}^{f}]$ of the ($m \times n$) size was input, its elements would be filled with performing cost values of all the tasks $\boldsymbol{Y}$.
2. In every column of the matrix $[C_{ij}^{f}]$ a minimal element is selected:

$$C_j^{min} = \min_i C_{ij} \ , \ j = 1,\ldots,n \ , \tag{9}$$

   a line with minimal elements (9) presents the minimal costs of performing all task types by the planes $i^*(j)$.
3. In line (9) the minimal element is selected:

$$C_j^{min} = \min_j C_j^{min} \ , \tag{10}$$

   and the number of task type j^* corresponding to it as well as the number of plane type $i(j^*)$. The found couple $(i(j^*), j^*)$ are an optimal solution in the first step.

4. Costs of flight $C_i^1{}_{(j^*)j^*}$ for this solution is written in a corresponding matrix cell $|C_{ij}^f|$.
5. The j^*- column of the matrix $|C_{ij}|$ is modified, decreasing $C_{i(j^*)j^*}$ by a "used" cost flight value $C_i^1{}_{(j^*)j^*}$

$$C^+_{i(\bar{j})\bar{j}} = C_{i(\bar{j})\bar{j}} - C^1_{i(\bar{j})\bar{j}} \ . \tag{11}$$

Further steps of the process are marked with index "+". The rest of the elements of the j^*-column are decreased by the value of one flight cost of the plane for corresponding plane types.

6. Then the condition of presence of the period for all-type aircrafts:

$$\sum_{j=1}^{n_{ij}} T_j \le R_i \ , \tag{12}$$

where n_{ij} – number of flight of the i – type plane, T_j – time of onwards flights of the j – flight. If for a certain plain type the operating life R_i for all units is expired, the given type is excluded from the further analysis.

7. The condition of completing the task of the set $\boldsymbol{Y}$ is checked.

$$\sum_{j=1}^{n} N_j \le \sum_{i=1}^{m+1} \sum_{q=1}^{\mu} N_i^q \ , \tag{13}$$

where $N^q{}_i$ – the number of carried passengers by i – type of the plane in q - task, μ –number of complete tasks by i – type plane. If all the tasks are completed, the process of division is considered to be finished. Otherwise, it is necessary to return to point 2 of this algorithm.

5. Comparative analysis of the characteristics of modified land-based aircrafts

The aim of the current work is not to work out a design of a new seaplane which will fit the existing and possible to use in the future infrastructure. It was analysed the modifying possibilities of the presently used land-based planes which are classified as light planes (according to Certification specifications CS-23 [3]). In the analysed group of planes there are single-engined (MORRISON 6, Cessna 172R, Cessna 182T, Cessna 206H, Cessna 208 CARAVAN, GA-8 Airvan, EXPLORER 500T, T-101 GRACH) [6] as well as twin-engined (VulcanAir P68C, Britten-Norman BN-2B, Britten-Norman BN-2T, HAI Y-12, M-28) [6] constructions powered by piston or turbo-prop power units.

Regarding the possibilities of modification, it was assumed that single-engined planes could be modified to float planes of flying boat or amphibious floatplane type (Fig. 6). The same modifications are performed by some air companies in the world, e.g. American Wipaire Inc from South St. Paul. The data published by the company are used to verify the results obtained by computational methods.

In the case of twin-engined aircrafts, the research was limited to the high-wing monoplane type modified to the float version (flying boat or amphibian) or the plane with the boat fuselage, again in the flying boat or amphibian version (Fig. 7). High technical characteristics of the modified version were obtained by the methods of reckoning with the use of mathematical models specially designed for the analysis. The mathematical model includes sub-models: geometrical [5, 7], weight [7, 8], aerodynamic [5, 7, 9], power unit [9], performance [2, 5, 7, 9], usage and economical [10]. The results obtained due to the complex mathematical model were verified by the known examples of the existing aircrafts. The obtained results, then, should be treated as the characteristics of the new aircrafts with the geometry closed to the currently used land-based aircrafts.

Comparing technical and economical characteristics of the modified aircrafts, it was stated that the seaplanes, which do not have amphibian properties, float as well as boat fuselages, do not have much better performance and economical characteristics. They are also less universal. This was the reason why the further analysis was limited only to comparison of amphibious type version.

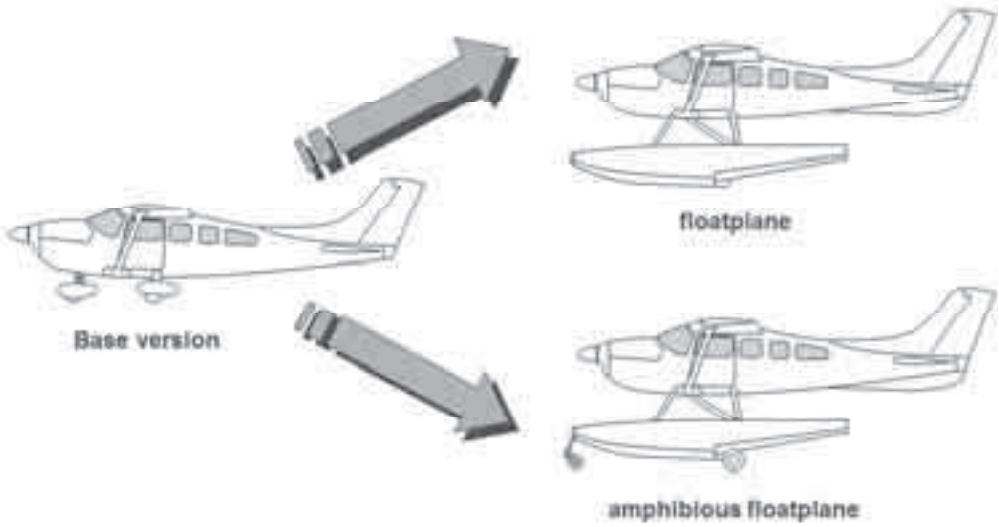

Fig. 6. Modification of single engined existing land-based aircraft

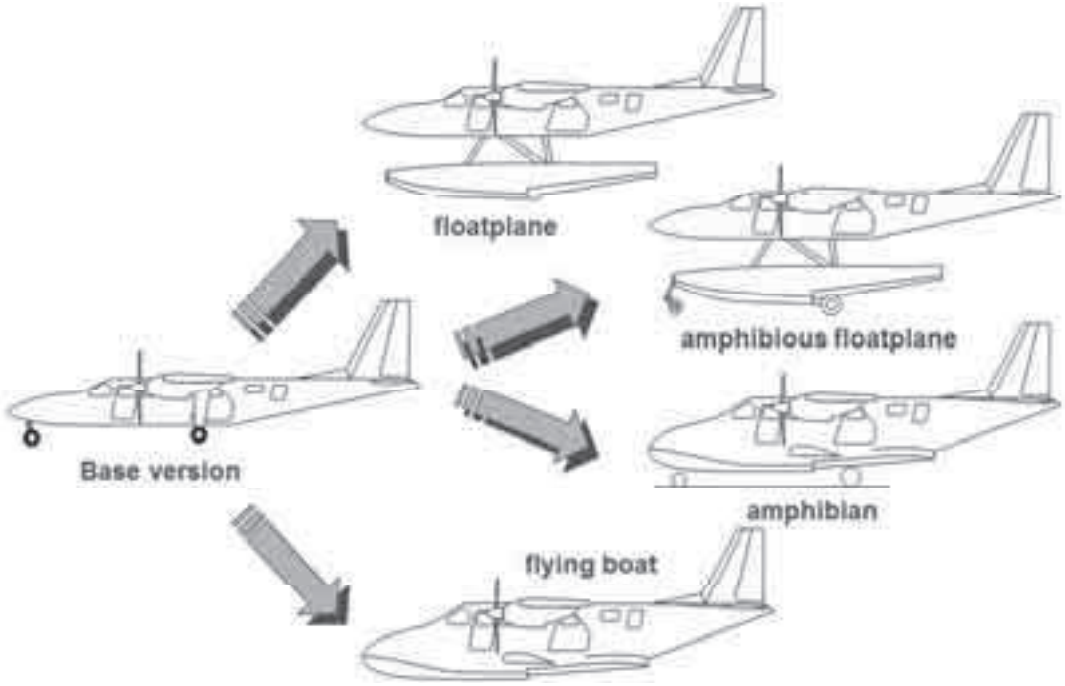

Fig. 7. Modification of twin-engined existing land-based aircraft

The comparative analysis of weight characteristics was done separately for single-engined and twin-engined aircrafts. It is necessary to distinguish two types: T-101 Grach and M-28. These are transport aircrafts adjusted to carry passengers. That is why their weight capacity in the passenger version is limited by the passenger board capacity but not by the maximum weight capacity. The T-101 Grach can carry 9 passengers with load maximum weight of 1400 kg, though M-28 can carry 19 passengers with weight capacity of 2546 kg. This is the main reason of their worse estimating ratio of transport and economical possibilities.

The second group includes such planes as Cessna 172R, GA-8 Airvan and HAI Y-12, which have a small reach with a maximum number of passengers. It is caused by the fact that the payload mass, which is the sum of fuel weight and the load, is not much bigger than the maximum load weight. Thus, when taking off with the maximum number of passengers these planes cannot take much fuel on board in order not to exceed the maximum take-off weight. It means that the maximum number of passengers was optimistically determined for these planes, though their weight capacity is relatively low.

It should be underlined that the payload-range charts show the maximum commercial weight but not the weight that follows from a maximum number of passengers with their luggage, which the plane is able to carry.

Modification consists in adding the floats or reconstructing the fuselage into a boat type. The rest of the units stay without any great changes. It means that the plane take-off weight should not change considerably in order not to enlarge the payload to which the aircraft will be submitted. The capacity of the passenger board should be the same. The result of these changes is a relatively large decrease of the aircraft range for the maximum load weight which follows from the limited fuel weight that could be taken on board so that not to exceed the take-off weight.

6. Seaplane park structure

Using the algorithm described in subsection 4.1. the tasks were distributed between the aircrafts of the transport system based on direct operating cost (DOC [10]) criteria.

The calculations were conducted with the following simplifying assumptions:

– a single task realized by the aircraft during a continuous mission. It excludes inter-landings and the possibilities to perform several tasks in a multistage flight,
– the number of each type of the aircrafts is unlimited (unlimited resource for each type). Simplifying means that we have so many aircrafts as we need,
– there is no time limit to perform a particular transport task. It means that passenger flow is not taken into account in particular lines. This approach is dictated by a complete lack of information about this topic and it is in accordance with the previous assumption.

The result obtained regarding the abovementioned assumptions does not allow estimating the quantity demand for seaplanes in Europe, although it helps determine the preferable types depending on the area of use.

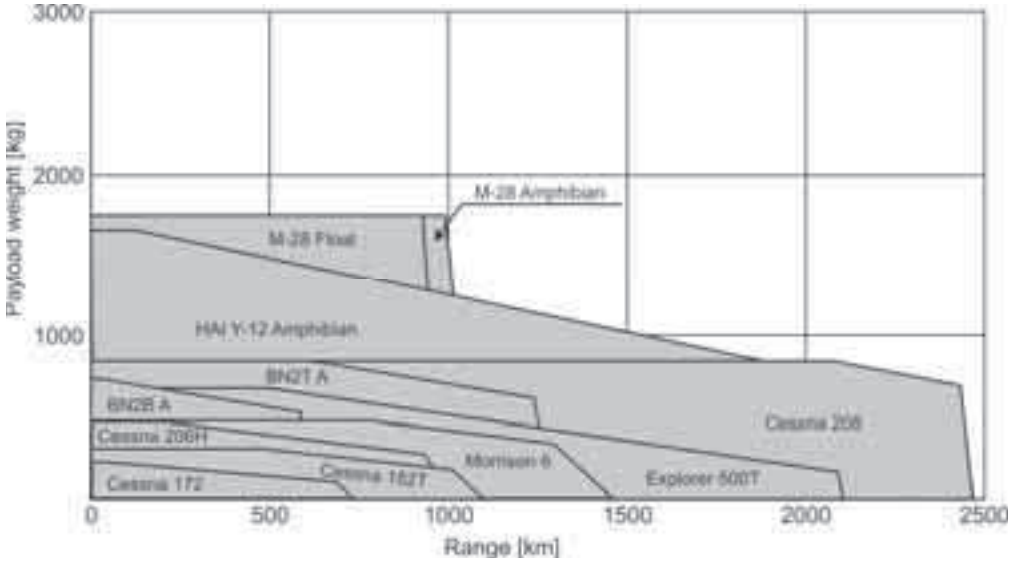

Fig. 8. Optimum specialization fields determined on the basis of Direct Operating Cost criterion, with limited passenger board capacity

Figure 8 shows the graphic solution of the task distribution for the direct operating cost (DOC) criterion, with taking into consideration passenger board capacity. It can be stated that for short distances and a small number of passengers light single-engined float or amphibious aircrafts should be used. For this task range, the dominant is the aircraft with Cessna 208 Caravan characteristics. The use of T-101 in passenger carriage is difficult to justify. This aircraft is not capable to use its transport capability due to the limited passenger board capacity. In unit carriages with more than 9 passengers, twin-engined amphibians should be used.

The direct operating cost-to-distance ratio was also analysed. The calculations were performed for the average coefficient of the board fulfilment, which is 75 per cent for each aircraft. In the distance, range of about 250 km the cheapest costs has the aircraft GA-8 Airvan. For longer distances the cheapest unit costs has the plane Explorer 500 T. From 500 to 950 km the cheapest unit costs has the amphibian Cessna 208 Caravan. Thus, it can be stated that in the range of 500 km the cheapest unit transport costs have single-engine planes, which are able to carry from 7 to 9 passengers; however, for longer distances it is better to use twin-engine amphibious aircrafts. This conclusion is correct for passenger flows of bigger intensity.

Taking into account the above-mentioned solutions it can be stated that in Europe the use of single-engine aircrafts with passenger board capacity up to 9 people and twin-engine aircrafts with the capacity up to 19 passengers is the most reasonable.

7. Summary

It should be assumed that the development of local communication using amphibian aircraft would have the following aims:

- simplification of plane production and decrease in its costs. It is firstly connected with the search of new constructional conceptions (plane design regarding their further development by modification, model construction and so on),
- decrease in direct operating costs and increase in profitability of the user. It requires the use of computer software, which gives the possibility of complex plane design,
- increasing the lifespan and safety of the plane,
- improving flight and piloting characteristics influencing the increase in the safety level. It is connected with the development of supervision systems in connection with the above-mentioned works,
- improving the comfort. Apart from improving, the airborne systems (e.g. air-conditioning) or designing a cockpit with larger dimensions it is connected with working out aerodynamic systems assisted by active steering systems guaranteeing minimization of negative feelings of passengers during the flight in turbulent air.

To make the development of this kind of transport possible and to make it more competitive in comparison to other branches and fulfil its tasks, the following is required:

- adjustment of the flight training system to new needs,
- adjustment of the infrastructure and air traffic rules to the increased flight intensity and the use of air area. It is connected with building and equipping new small airports and water landing fields as well as creation of information service system.

The conducted comparative analysis of the characteristics of selected types of light amphibian aircrafts helped to identify some requirements and persistent advantages of the new amphibian seaplane.

- rather large dimensions (take-off weight) of the plane – approximately 2300 kg, which makes it possible to equip the plane with a modern set of flight and navigation equipment, transport 6-7 passengers with the necessary comfort level in its passenger version, transport cargo (including long cargo) up to 500-600 kg over a distance up to 1000-1200 km in its freighter version, and equip the plane with the appropriate equipment in its special application versions, having a payload mass reserve (fuel range),
- the conventional aircraft, high-wing, with two engines on a wing. The presence of two engines will considerably increase reliability and flight operating safety, provided the flight continues with one working engine at any flight stage. The high-wing configuration is more efficient aerodynamically than the low-wing due to positive interference between the wing and the fuselage, providing at the same time improvement of the roll stability of the aircraft. The high-positioned wing not touching the water at take-off and landing stages makes it possible to equip the wing with efficient take-off and landing devices. The engines and propellers are moved away from the runway or water surface without any additional weight costs, as they

are installed on the high-positioned wing. The high-positioned wing improves the view from the cockpit downwards and makes it possible to install various equipment for observation of the land or water surface alongside the fuselage.
- it is expected to use highly reliable certified and quite economical engines with certified variable pitch propellers on the aircraft. The use of certified engines is a very valuable advantage making it potentially possible to operate the aircraft without territorial limitations. Another important advantage of the selected engines is low-octane gasoline, which does not simply make the operation cheaper, but also makes it more reliable and independent on fuel supplies,
- the new amphibian plane declared performances should exceed those of all other amphibian aircraft analysed in this work, which was mentioned above in chapter 3 or appendixes. In the process of making the plane, the advantages of its design should to be realized, and first of all passed the weight limits and confirmed the declared take-off and landing characteristics. In this case, the new amphibian plane should have advantages over other planes considering not only declared, but also practically implemented performances.

Acknowledgments

This material is based upon work supported by the European Commission, under Contract No. 234052, „Future Seaplane Traffic - Transport Technologies for the Future" – FUSETRA.

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