UDC 358.4 : 656.7

*Mykola Zhyvvytskyi*

# EVALUATION OF AIR NAVIGATION EFFECTIVENESS IN FREE FLIGHT CONDITIONS

## Introduction. Problem formulation

The analysis of the airway route air space (ARAS) operation and the influence of the destabilizing factors on it demonstrated that the task of free route air space construction (FRAS) is broad and multisided.

All measures for ensuring FRAS operation should be implemented taking into account minimum costs, the conditions of information impact on the air space organization system, the dramatic increase of air traffic amount, time reduction for information processing and decision making, and further mathematical model complication of calculation tasks for information processing.

The results of the ARAS existing system analysis confirm the limited airspace capacity and substantial economic loss the major causes of which are:

the lack of airways and flight levels;

complex entry-exit pattern in the airdrome areas (CTR);

flight restrictions at the minimum fuel consumption levels including flight operation at service ceiling altitudes;

the existence of airspace reserve for state (military) aircraft in the vicinity of civil airdromes that restricts fuel saving climb and descent performance.

One of the ways to solve the given problem is free route airspace organization.

The initial framework analysis has confirmed a need for an integration and optimization of its structure and a recent research and publications analysis. The existing methods of air traffic flow operational regulation while changing flight operation conditions under the current air traffic organization system were examined and grounded by such scientists as Babyeva S. I., Yemelyanov V. Ye., Nazarov P. V., Savelyev O. P., Guchkov V. K. and others. Such methods were examined and grounded for automated air traffic organization system and they allow ensuring flight safety despite economy and regularity limitations taking into account the associated route control centre workload standards. [1, 2].

The problems of air space use while realizing the free flight concept has been insufficiently examined.

## Aim formulation. Main part

The aim of the given work is the evaluation of air navigation efficiency in the free flight conditions.

Task formulating for FRAS synthesis. Given:

Initial ARAS structure graph $G_0$, consisting of N = 20 peaks (according to the number of Ukraine's main airports).

ARAS system airdrome location with designated false coordinates X, Y.

Air navigation probability between any two airdromes $v_i$ i $v_j$: p = 0,9.

To determine: air space optimum structure $G_\xi$ (V, E), $\xi$ = 1,2, ..., 5, that meets the requirements of the general task of FRAS system integration:

$$F_{FRAS} = f\,(P_{ij}) \to \max \tag{1}$$

Within limitations:

$$C_\xi = \sum_i \sum_j C_{ij}(l_{ij}, p_{ij}, h_{ij}) \le C_{ADD\xi} \tag{2}$$

$$\chi(G) \ge 2; \quad \lambda(G) \ge 2 \tag{3}$$

$$G_0(V,E) \subseteq G_\xi(V,E) \tag{4}$$

$$i, j = 1,2,\ldots,N. \tag{5}$$

Within given limitations:

$F_{FRAS}$ – generalised indicator of the quality functional, calculated according to the probable adjacency matrix considering weight coefficients $b_{ij}$:

$$F_{FRAS} = f\,(P_{ij}) = \sum_{i=1}^{N} \sum_{j}^{N} b_{ij} \cdot P_{ij} \tag{6}$$

where $P_{ij}$ – two-polar graph of air navigation probability with the rising peak $v_i$ sinking peak $v_j$, which is calculated by algorithmic method based on the Polisya updated evaluation [3, 4]. $\xi$ index allows the detection of a few structures for the given flight cost savings $C_{ADD}$.

Provided entering free route air space system between the airdromes:

$\xi = 1$: to define $G_1(V,E)$ for $C_{ADD1}$=$20 000;
$\xi = 2$: to define $G_2(V,E)$ for $C_{ADD2}$=$50 000;
$\xi = 3$: to define $G_3(V,E)$ for $C_{ADD3}$=$100 000;
$\xi = 4$: to define $G_4(V,E)$ for $C_{ADD4}$=$500 000;
$\xi = 5$: to define $G_5(V,E)$ for $C_{ADD5}$=$1 000 000.

Solving a few one criterion optimization problems with given $C_{ADDS}$ values has been taken to avoid graph solving two criteria problems that is difficult.

**Allowances.**

1. $G_\xi$ (V, E), $\xi$ structures = 1,2, ..., 5, shouldn't be multiple of 2.
2. The defined structures do not have any forbidden routes. It is possible to determine a route $e_{ij}$ ($v_i$, $v_j$), from any airdrome $v_i$ to any airdrome $v_j$ with the route length $l_{ij}$ and flight operation cost saving $C_{ij}$.

3. The route length $l_{ij}$ is calculated as:

$$l_{ij} = \frac{\sqrt{(X_j - X_i)^2 + (Y_j - Y_i)^2}}{K_L} \qquad (7)$$

where $K_L$ = \$1120 length/km,

$X_i$, $X_j$, $Y_i$, $Y_j$ – airdrome false coordinates.

4. A single route capacity is taken as $\rho_{ij} > h_{ij}$, where $h_{ij}$ – is the aircraft flow intensity between the airdromes $v_i$ and $v_j$.

5. The cost saving for any structure $G_\xi$ (V, E) is calculated by fuel consumption based on the navigational engineering calculation method for defined routes between airdromes and for specific aircraft types.

Experiment conditions.

The integration is performed with different $C_{ADD}$: \$20000, \$50000, \$100000, \$500000, \$1000000.

The capacity probability value ρ for solving integration problem was taken the same for every route: ρ = 0,9.

Integration task fulfilment was performed in Delphi 5.0 environment with the help of program product NET using PC Pentium-III-1700 made on the basis of the structural programming theory [8, 9]. The foundation for programming the integration task is the structure optimization algorithm.

The peculiarity of the integration task fulfilment is the application of the initial ARAS – $G_0$ (V, E) – all the FRAS $G_0$ routes are changed in the synthesized FRAS structures – $G_s$ (V, E).

The resulting ARAS and FRAS $G_s$ (V, E) for different $C_{ADD}$ values are given in fig. 1, 2.

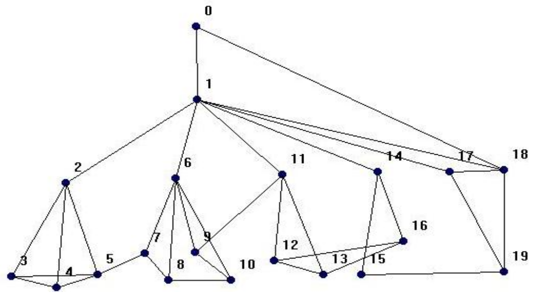

**Fig. 1. The ARAS $G_1$(V,E) synthesized structure when $C_{ADD}$=\$20000.**

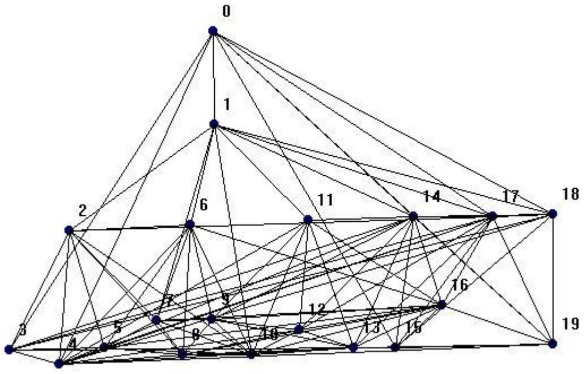

**Fig. 2. The FRAS $G_5$(V,E) synthesized structure when $C_{ADD}$=\$1000000.**

The corresponding adjacency matrix air navigation probability matrix $P_{ij}$ for optimized FRAS $G_i$ (V, E), structures have also been defined where i = 1, 2, ..., 5.

The analysis of the derived FRAS $G_\xi$(V,E), ξ = 1, 2, ..., 5 structures demonstrates that all of them are different from the initial $G_0$(V,E) structure by additional routes. Structural indicators of the FRAS optimized structures are given in Table 1.

The analysis of the structural indicator change dynamics allows to draw the following conclusions:

1) when the flight cost saving $C_{ADDS}$ rises the number of communication links M also increases and the excessiveness coefficient $K_e$ proportionally increases too.

2) the reduction of the graph diameter is not proportional to the costs and for the branched structure $G_\xi$(V,E) reaches the value of D=2. It means that the shortest route length between any graph peaks is not greater than 2;

Table 1

**Structural indexes of the optimized structures**

| Structure $G_\xi$ (V, E) | $C_{ADD}$ \$thousands. | Number of routes | Graph diameter D | Centralization coefficient | Excessiveness coefficient | Cost saving C \$. |
|---|---|---|---|---|---|---|
| $G_0$(V,E) | 0 | 19 | 4 | 0,906 | 0 | 1004 |
| $G_1$(V,E) | 20 | 27 | 4 | 0,806 | 0,421 | 19986 |
| $G_2$(V,E) | 50 | 34 | 4 | 0,770 | 0,789 | 49671 |
| $G_3$(V,E) | 100 | 45 | 4 | 0,511 | 1,368 | 99405 |
| $G_4$(V,E) | 500 | 100 | 3 | 0,308 | 4,263 | 499259 |
| $G_5$(V,E) | 100 | 158 | 2 | 0,304 | 7,316 | 999340 |

3) the centralization coefficient that characterizes loading irregularity of system elements also falls when $C_{ADD}$ rises and reaches acceptable values $K_c \leq 0,5$ when $C_{ADD} \geq \$100000$.

Fig. 3 and 4 demonstrate graphs of air navigation probability dependence $P_{ij}$ for the most important routes based on air space capacity ρ for different synthesized structures FRAS $G_\xi$ (V, E), ξ = 1,5.

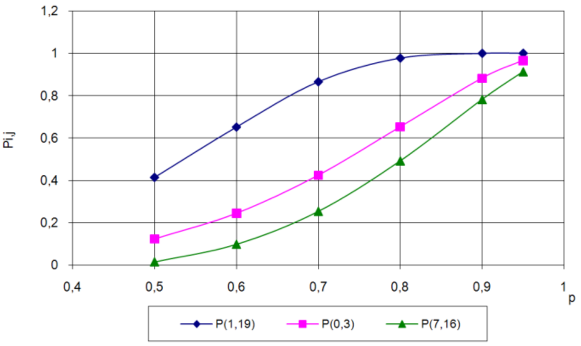

**Fig.3. Air navigation probability dependence $P_{1, 8}$, $P_{1, 15}$, $P_{1, 17}$ on ρ for optimized FRAS structure where $C_{ADD}$=\$20000.**

The following conclusions may be drawn from the given graphs:

1) for all structure when ρ→1 rises, the probability of two peak air navigation system also tends to 1: $P_{ij}$→1;

2) the graphs for structures, $G_3$, $G_4$, $G_5$, $P_{ij}$ have a pronounced saturation character that clearly

demonstrates a bigger effectiveness of the structural synthesis if compared to the parametric one. In order to reach the preselected level of air navigation probability $P_{ij}$ for specific directions it is necessary to plan additional routes instead of increasing the ρ value that is the probability of each route capacity;

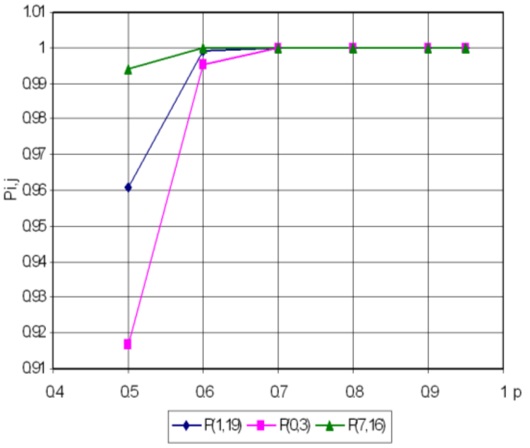

**Fig. 4. Air navigation probability dependence $P_{1,8}$, $P_{1,15}$, $P_{1,17}$ on ρ for optimized FRAS structure when $C_{ADD}$=$1000000.**

3) the greater free route number the bigger air navigation probability $P_{ij}$, and thus the bigger value of a generalized quality functional nominator $F_{FRAS}$.

Based on the received simulation results values of a generalized quality functional indicator $F_{FRAS}(P_{ij})$, were defined when $b_{ij} = 1$, i, $j = 1…20$. Table 2 demonstrates $F_{FRAS}(P_{ij})$ values for $G_5(V,E)$ synthesized structures depending on air navigation probability P.

Table 2

**Generalized quality functional nominator $F_{FRAS.}(P_{ij})$**

| Structure $G_\xi(V,E)$ | $C_{ADD}$ $ thousands. | p=0,5 | p=0,7 | p=0,9 | p=0,95 |
|---|---|---|---|---|---|
| $G_0(V,E)$ | 0 | 65,9 | 145,5 | 282,6 | 312,9 |
| $G_1(V,E)$ | 20 | 66,5 | 200,1 | 340,6 | 364,8 |
| $G_2(V,E)$ | 50 | 121,1 | 286,7 | 376,2 | 379,5 |
| $G_3(V,E)$ | 100 | 171,9 | 343,9 | 379,8 | 380,0 |
| $G_4(V,E)$ | 500 | 320,0 | 379,8 | 380,0 | 380,0 |
| $G_5(V,E)$ | 1000 | 370,4 | 380,00 | 380,0 | 380,0 |

## Conclusions

1. A method of FRAS structure synthesis was applied as a result of the performed research. The maximum quality functional was taken as an optimization criterion.

2. Ukraine's FRAS system structure optimization based on the predetermined cost saving $C_{ADD}$=$20000 leads to the increase of the generalized quality functional nominator – $FRAS(P_{ij})$ by 34% (from 205,5 to 275,7) when compared with the initial structure.

3. The results obtained underline the selected research direction prospectively and its usefulness for designing and improving other types of complex systems as such systems are synthesized together with the introduction of the optimum structural excessiveness by redistribution of the system parameters between the elements adapted for specific conditions.

## *Bibliography*

**1. Бабаєва С. І.** Методи аналізу потоків повітряного руху. / СІ. Бабаєва // Науковий вісник МГТУ ГА, серія «Інформатика. Прикладна математика», № 77. – М.: МГТУ ГА, 2004. **2. Таха Х.** Введення в дослідження операцій. / Х. Таха. / – М.: Мир. 1985. **3. Артюшин Л. М.** Большие технические системы: проектирование и управление / Л. М. Артюшин, Ю. К. Зиатдинов, И. А. Попов, А. В. Харченко. Под ред. И. А. Попова./ – Харьков, Факт, 1997. – 400 с. **4. Басакер Р.** Конечные графы и сети / Р. Басакер, Т. Саати / М.: Наука, 1994. – 368 с. **5. Емельянов В. Е.** Трирівнева модель функціонування типової інформаційної системи і її використовування при виборі принципів побудови систем захисту інформації / В. Е. Емельянов, П. В. Назаров // Науковий вісник МГТУ ГА, серія «Інформатика. Прикладна математика», № 92. – М.: МГТУ ГА, 2005. **6. Савельев О. П.** Алгоритм відшукання найкоротшого маршруту польоту на заданій мережі повітряних трас / Управління повітряним рухом, вип. 2. / О. П. Савельев, В. К. Гучков / – М.: Повітряний транспорт, 1983. **7. Бабаєва С. І.** Модель використовування повітряного простору на основі інформаційних образів польотної інформації. / У збірці статі «Математичні методи і інформаційні технології в економіці, соціології і освіті»./ – Пенза: Пріволжськїй Будинок знань, 2005. **8. Васильев В. В.** Моделирование задач оптимизации и дифференциальных игр / В. В. Васильев, В. Л. Баранов. Отв. ред. Г. Е. Пухов / – К. Наукова думка, 1989. – 296 с. **9. Баранов Г. Л.** Структурное моделирование сложных динамических систем / Г. Л. Баранов, А. В. Макаров / – К.: Наукова думка, 1986. – 272 с.

---

На основе методики синтеза структуры воздушного пространства в статье проведена оценка эффективности воздушной навигации в условиях режима свободного полета. На основе полученных результатов моделирования были определены значения обобщенного показателя функционала качества функционирования воздушного пространства свободных маршрутов и его зависимость от оптимизации структуры воздушного пространства.

*Ключевые слова*: воздушное пространство свободных маршрутов, воздушная навигация, оценка эффективности.

На основі методики синтезу структури повітряного простору в статті проведена оцінка ефективності повітряної навігації в умовах режиму вільного польоту. На основі отриманих результатів моделювання були визначені значення узагальненого показника функціонала якості функціонування повітряного простору вільних маршрутів і його залежність від оптимізації структури повітряного простору.

*Ключові слова*: повітряний простір вільних маршрутів, повітряна навігація, оцінка ефективності.