AVIACIJOS TECHNOLOGIJOS
AVIATION TEHCNOLOGIES

ISSN 2029-9974 online
2014 2(1): - doi: 1038/at.2014.10

EVALUATION OF AIR NAVIGATION EFFECTIVENESS IN FREE FLIGHT CONDITIONS

Mykola G. Zhyvitskyi
Kirovograd Flight Academy of National Aviation University, Ukraine
E-mail: kinoranok@i.ua

Abstract. The analysis of the initial structure of Ukraine's airspace confirmed a need for integration and optimization of this structure through gradual introduction of a free flight concept. On the basis of airspace structure integration techniques the article evaluates air navigation effectiveness in free flight conditions. Based on the received simulation results, the generalized quality indicator values of airspace operational free route quality functional and its dependence on airspace structure optimization were determined.

Keywords: free route air space, air navigation, effectiveness evaluation.

1. Introduction

The analysis of 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 wide-ranging 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, time reduction for information processing and decision making, and further complication of mathematical model of calculation tasks for information processing.

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

- the lack of airways and flight levels;
- complex entry-exit pattern in the airdrome areas (CTR);
- flight restrictions at 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 airspace structure, which is also evident from the analysis of recent research publications. The existing methods of operational regulation of air traffic flow with changing flight operation conditions within the current air traffic organization system were examined and grounded by such scientists as S. I. Babyeva, V. Ye. Yemelyanov, P. V. Nazarov, O. P. Savelyev, V. K. Guchkov and others (Бабаєва 2005; Емельянов, Назаров 2005; Савельев, Гучков 1983). The methods were examined and grounded for an automated air traffic organization system, and they allow ensuring flight safety despite of economical factors and regularity limitations, by taking into account the associated route control centre workload standards (Бабаєва 2004; Таха 1985).

However, the issues of air space use while realizing the free flight concept have not been examined sufficiently.

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

2. Research Methods

Task formulation for FRAS synthesis, given the following parameters:

– 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: $p = 0{,}9$;

In order 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:

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

Within limitations:

$$C_\xi = \sum_i \sum_j C_{ij}\left(l_{ij}, \rho_{ij}, h_{ij}\right) \le C_{ADD\,\xi} \qquad (2)$$

$$\chi(G) \ge 2; \quad \lambda(G) \ge 2 \qquad (3)$$

$$G_0(V,E) \subseteq G_\xi(V,E) \qquad (4)$$

$$i, j = 1,2,\dots,N. \qquad (5)$$

Within given limitations, F_{FRAS} stands for the generalised indicator of the quality functional, calculated according to the probable adjacency matrix considering weight coefficients b_{ij}:

$$F_{FRAS} = f(P_{ij}) = \sum_{i=1}^{N} \sum_{j=1}^{N} b_{ij} \cdot P_{ij}, \qquad (7)$$

where P_{ij} indicates a two-polar graph of air navigation probability with rising peak v_i and sinking peak v_j, which is calculated by an algorithmic method based on the Polisya updated evaluation (Артюшин *и др*. 1997; Басакер, Саати 1994). ξ index allows the detection of a few structures for the given flight cost savings C_{ADD}.

Entering free route air space system between the airdromes for the following indexes is provided:

ξ = 1: to define $G_1(V,E)$ for C_{ADD1}=$20 000;
ξ = 2: to define $G_2(V,E)$ for C_{ADD2}=$50 000;
ξ = 3: to define $G_3(V,E)$ for C_{ADD3}=$100 000;
ξ = 4: to define $G_4(V,E)$ for C_{ADD4}=$500 000;
ξ = 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 chosen in order to avoid difficult graph solving two criteria problems.

3. Allowances

1. G_ξ (V, E), ξ structures = 1,2, ..., 5, should not be a 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 route length l_{ij} and flight operation cost saving C_{ij}.

3. The route length l_{ij} is calculated according to:

$$l_{ij} = \frac{\sqrt{\left(X_j - X_i\right)^2 + \left(Y_j - Y_i\right)^2}}{K_L} \tag{6}$$

where K_L = $1120 length/km and X_i, X_j, Y_i, Y_j indicate airdrome false coordinates.

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

5. The cost saving for any structure G_ξ *(V, E)* is calculated according to fuel consumption based on the navigational engineering calculation method for defined routes between airdromes and for specific aircraft types.

3.1. Experiment conditions

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

The same capacity probability value $\rho = 0,9$ for solving integration problem for every route was chosen.

Completion of integration task was performed in Delphi 5.0 environment with the help of program product NET, using PC Pentium-III-1700, designed on the basis of structural programming theory (Васильев *и др*. 1989; Баранов, Макаров 1986). The foundation for programming the integration task is the structure optimization algorithm.

The peculiarity of the integration task completion is the application of the initial ARAS (G_0 *(V, E)*) by interchanging all the FRAS G_0 routes with the synthesized FRAS structures, G_s *(V, E)*.

The resulting ARAS and FRAS G_s *(V, E)* for different C_{ADD} values are presented in figures 1and 2.

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

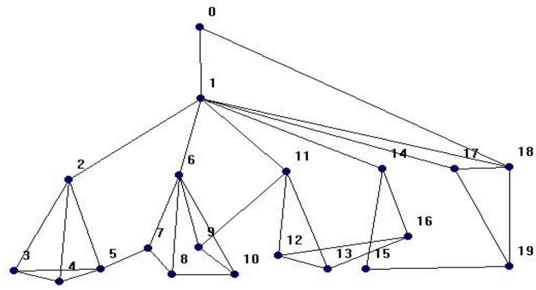

Fig. 1. The ARAS $G_1(V,E)$ synthesized structure with C_{ADD}=$20000

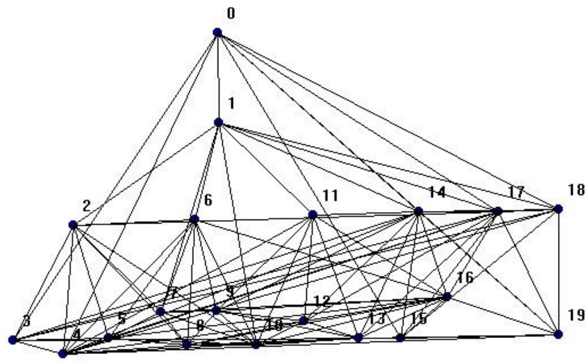

Fig. 2. The FRAS $G_5(V,E)$ synthesized structure with C_{ADD}=$1000000

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 presented in table 1.

Table 1. Structural indexes of the optimized structures

Structure G_ξ (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

The analysis of the structural indicator change dynamics permits 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 increases in proportion as well;

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 denotes that the shortest route length between any graph peaks is does not exceed 2;

3) The centralization coefficient that characterizes loading irregularity of system elements also decreases

when C_{ADD} increases and reaches acceptable values $K_c \leq 0,5$ when $C_{ADD} \geq \$100000$.

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

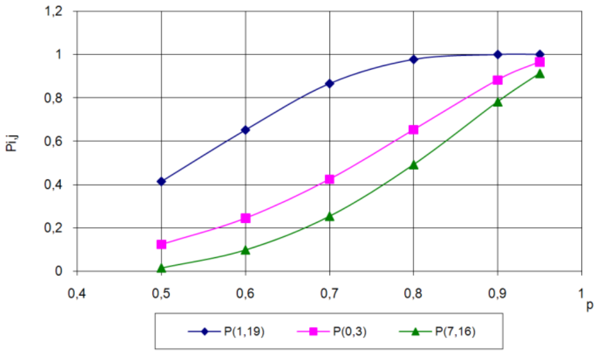

Fig. 3. Air navigation probability dependence $P_{1,8}$, $P_{1,15}$, $P_{1,17}$ on ρ for an optimized FRAS structure, where C_{ADD}=\$20000

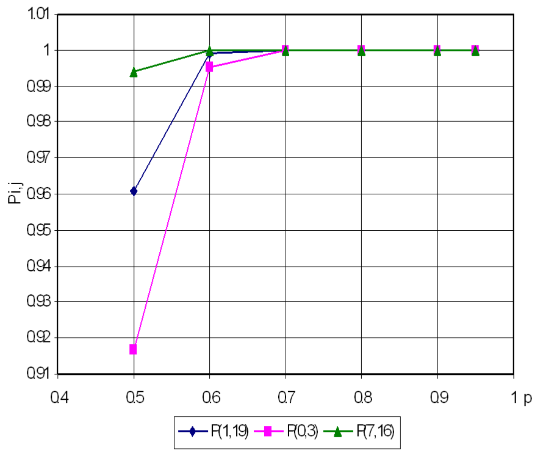

Fig. 4. Air navigation probability dependence $P_{1,8}$, $P_{1,15}$, $P_{1,17}$ on ρ for optimized FRAS structure with C_{ADD}=\$1000000

From the given graphs the following conclusions may be drawn:

1) for all structures when $\rho \rightarrow 1$ rises, the probability of two peak air navigation system also tends towards 1: $P_{ij} \rightarrow 1$;

2) the graphs for structures G_3, G_4, G_5, P_{ij} have a pronounced saturation character that clearly demonstrates an increased effectiveness of the structural synthesis in comparison 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;

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

Based on the received simulation result, values of a generalized quality functional indicator $F_{FRAS}(P_{ij})$ were defined: where $b_{ij} = 1$, $i, j = 1 \ldots 20$. Table 2 presents $F_{FRAS}(P_{ij})$ 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

4. 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 results in 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 a prospective selected research direction and its usefulness for designing and improving other types of complex systems since such systems are synthesized together with the introduction of the optimum structural excessiveness by redistributing the system parameters between the elements adapted for specific conditions

References

Артюшин, Л. М.: Зиатдинов, Ю. К.; Попов, И. А., *и др.* 1997. *Большие технические системы: проектирование и управление.* Под ред. Попова, И. А. Харьков: Факт, 400 с.

Бабаєва, С. І. 2004. Методи аналізу потоків повітряного руху, *Науковий вісник МГТУ ГА, серія «Інформатика. Прикладна математика* (77). М.: МГТУ ГА.

Бабаєва, С. І. 2005. *Модель використовування повітряного простору на основі інформаційних образів польотної інформації,* у збірці *Математичні методи і інформаційні технології в економіці, соціології і освіті.* Пенза: Пріволжськїй Будинок знань.

Баранов, Г. Л.; Макаров, А. В. 1986. *Структурное моделирование сложных динамических систем.* К.: Наукова думка, *272 с.*

Басакер, Р.; Саати, Т. 1994. *Конечные графы и сети М.: Наука, 368 с.*

Васильев, В. В.; Баранов, В. Л. 1989. *Моделирование задач оптимизации и дифференциальных игр.* Отв. ред. Пухов, Г. Е. К.: Наукова думка, 296 с.

Емельянов, В. Е.; Назаров, П. В. 2005. Трирівнева модель функціонування типової інформаційної системи і її використовування при виборі принципів побудови систем захисту інформації, *Науковий вісник МГТУ ГА, Серія «Інформатика. Прикладна математика»* (92). М.: МГТУ ГА.

Савельев, О. П.; Гучков, В. К. 1983. Алгоритм відшукання найкоротшого маршруту польоту на заданій мережі повітряних трас, *Управління повітряним рухом. Вип. 2.* М.: Повітряний транспорт.

Таха, Х. 1985. *Введення в дослідження операцій.* М.: Мир.