AVIATION TRANSPORT

UDC 629.735.05(045)
DOI:10.18372/1990-5548.71.16826

[1]M. P. Mukhina,
[2]A. I. Nikulin

DELAYED FUEL CONSUMPTION OPTIMIZATION SYSTEM

Aviation Computer-Integrated Complexes Department, Faculty of Air Navigation Electronics and Telecommunications, National Aviation University, Kyiv, Ukraine
E-mails: [1]maryna.mukhina@npp.nau.edu.ua, [2]5642598@stud.nau.edu.ua

Abstract—*In this work, we considered the problem of optimizing the crowd during aircraft delays before landing. Having examined the statistics, we can conclude that there was a constant increase in passenger traffic from 2013 to 2018. But also due to the constant growth of passenger traffic, the percentage of flights with delays is increasing. The problem is that that most of the flights accounted for a small percentage of the most "popular" airports (In Ukraine, 75 percent of all flights accounted for the airports of Boryspil and Zhuliany). Although since 2019 the number of air travel around the world has dropped sharply over time, the number of air travel will return to the previous number and even continue to grow. Also, a new problem has now arisen for air carriers - a significant increase in aviation fuel prices. According to the Mundi Index, since December 2021, there has been a constant increase in the price of fuel for aircraft. This is an additional incentive for airlines to optimize their routes in order to avoid unnecessary fuel costs. In this work, on the example of a flight for a Boeing 737 from Riga to Odessa, two parameters were considered, when changing which it is possible to minimize fuel costs during a delay. An algorithm was also developed to optimize crowd costs on flights with delays.*

Index Terms—Air delay; holding fuel; fuel consumption; flight level; flight speed.

I. INTRODUCTION

Until 2019, there was a steady growth in passenger traffic, which is a very pleasant development for airlines. But it also causes other problems. One of them is the congestion of airports, due to which there are problems with the delay of aircraft before landing. Delays can be caused by various factors. For example, bad weather, poor flight planning, lack of manpower, and more. And now they face a new problem. This is an increase in the price of jet fuel.

Even though organizations exist to ensure safe, fast and orderly air traffic. And also there are recommendation algorithms and protocols for optimizing all flight costs of a flight, an important component of which is fuel costs.

The problem with aircraft delays before landing is still relevant.

In this paper, we will consider two parameters - flight level and flight speed, at which fuel savings on delayed flights are possible.

II. PROBLEM STATEMENT

Airlines are trying to achieve both the effective use of their fleet and the resilience of the buffers to achieve something that would overcome along with sudden incidents. In order to resolve such issues, airlines use different methods, one of their buffering to compensate for delays, which leads to a compromise between the reliability of the decision and the cost of its implementation (Fig. 1).

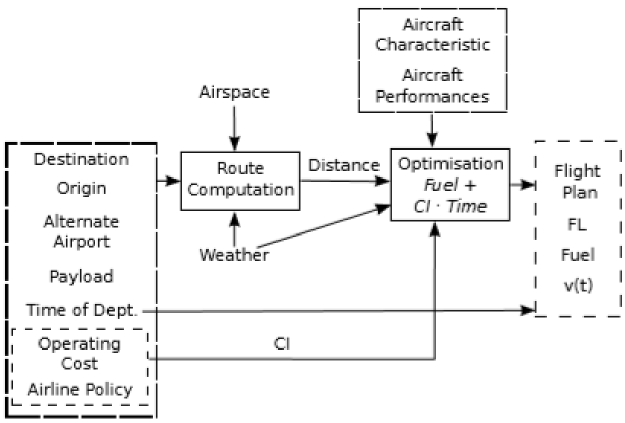

Fig. 1. Scheme of current flight optimization (J = Fuel + Cost Index · Time) implemented by aircraft operators

Main reasons for delays:

1) Differences in the capabilities of different air traffic control systems.

2) Insufficient advance notice of likely traffic demand.

3) Accumulation of traffic during certain periods of the year.

Also fuel first of all is one of the main items of expenditure forming the cost of a ticket. Its share in the ticket is from 26 to 40 percent. And from the statistics of passenger traffic, its constant growth until 2018 can be seen.

From the statistics of the Index Mundi portal, there has been an almost continuous increase in the price of jet fuel since September 2020 (Fig. 2).

Month	Price	Change
Nov 2021	2.19	-
Dec 2021	2.10	-4.47%
Jan 2022	2.45	16.75%
Feb 2022	2.68	9.65%
Mar 2022	3.50	30.31%
Apr 2022	3.91	11.99%

Fig. 2. Jet Fuel Daily Price from Index Mundi for six months

Some sources record an increase in airfare by 20% and predict an increase of up to 40%.

III. Review of Existing Methods

Ukraine is fully involved in the work of Eurocontrol as the manager of the European Air Navigation Network (Network Manager – NM), which performs the functions of air traffic management (ATFM) through the NMOC (Network Manager Operations Centre) [8].

Air Traffic Flow Management – A service established to ensure the safe, orderly and expeditious flow of air traffic by ensuring the maximum possible use of ATC capacity and respecting the amount of air traffic capacity declared by the relevant police authority [6].

The analysis of aircraft fuel consumption in flight is considered to be a significant problem. From the methodology widely used in the literature, devised as part of the EUROCONTROL Flight Database (BADA) plan of a European company under light traffic control, we have the formula [9].

$$f_{cr}(v) = c_1 v^3 + c_2 v^2 + \frac{c_3}{v} + \frac{c_4}{v^2}, \qquad (1)$$

where the coefficients $c_i > 0$, $i = 1, \ldots, 4$, are expressed in the form of coefficients of specific resistance of the aircraft and fuel consumption, as well as the mass of the aircraft, the density of air at the altitude and the acceleration of free fall.

Understanding the idea of fuel consumption, we can express a single fuel consumption in the cruising period. Assuming that the distance traveled in the cruising period is the same as d^{cr}, and the duration of the cruising stage is the same as d^{cr}/v, we can say the only fuel consumption is as follows:

$$F(v) = \frac{d^{cr}}{v} \cdot f_{cr}(v) = d^{cr}\left(c_1 v^2 + c_2 v + \frac{c_3}{v^2} + \frac{c_4}{v^3}\right). \quad (2)$$

The aircraft is more economical than fuel at maximum cruising speed (MRC). In other texts, the role of fuel consumption $F(v)$ is minimized in the MRC. Although, in terms of fuel consumption, it is ideal to fly at MRC speeds, time and planning considerations often set the highest speeds. Note that $F(v)$ is precisely convex and increases for velocities higher than its minimum MRC velocity. Suppose that in the initial schedule the estimated cruising speed is equal to v^0, which can be higher than the MRC speed due to labor costs and labor costs, and the cruising flight period is the same t^0.

Let v become an unstable cruising speed; in this case we get a change in the price of fuel in the route as well as

$$\Delta FC = p_{fuel}\left(F(v) - F(v^0)\right). \qquad (2)$$

where FC is the fuel cost; p_{fuel} is the cost of aviation gas ($ / kg).

In the figure, we explain the profitable auxiliary cost of fuel due to the increase in speed according to the MRC speed, as presented in Boeing (2007). In addition, one of the main conditions in flight planning is the installation of fuel load (Fig. 3). Reasoning according to the establishment

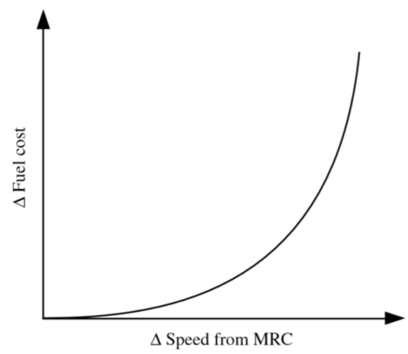

Fig. 3. Dependences of fuel price on cruising speed

Fuel loading contains the need for fuel to the destination, in particular stocks (which fluctuate due to the type of flight, for example, over water); destination weather and alternatives; suboptimal conditions for speed or height; as well as mechanical inconsistencies of the aircraft. In a similar way, there is an upper limit to cruising speed due to various physiological conditions, such as fuel tank, cabin exposure and noise limitation.

In recent years, European airspace has become increasingly congested, and airlines may now find that the lack of bandwidth on the route is causing the fastest growing flight delays [7]. In 2010, this source of delay accounted for 19% of all flight delays in Europe, and between 2005 and 2010 it increased by an average of 17% per year (Fig. 4).

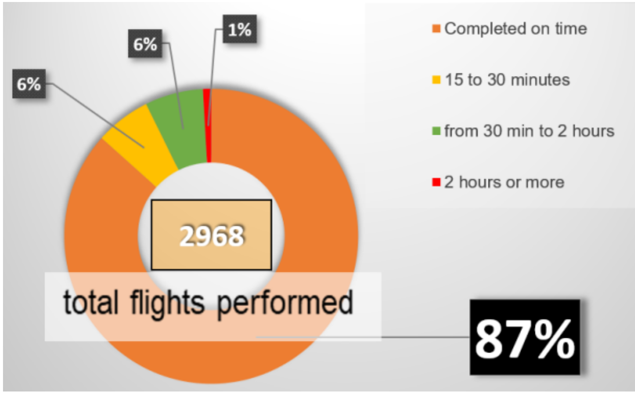

Fig. 4. Punctuality of foreign airlines in Ukraine in January 2020

Due to the increase in demand for air travel, the airspace is becoming loaded, which is why there are more and more problems with flight delays.

IV. PROBLEM SOLUTION

To solve this issue, we will use the data obtained during the simulation of a flight from Riga to Odessa for a Boeing 737 [5]. From the fuel consumption data obtained from the simulation, it can be seen that our aircraft needs 2260 kg of fuel for a 30-minute delay (Fig. 5).

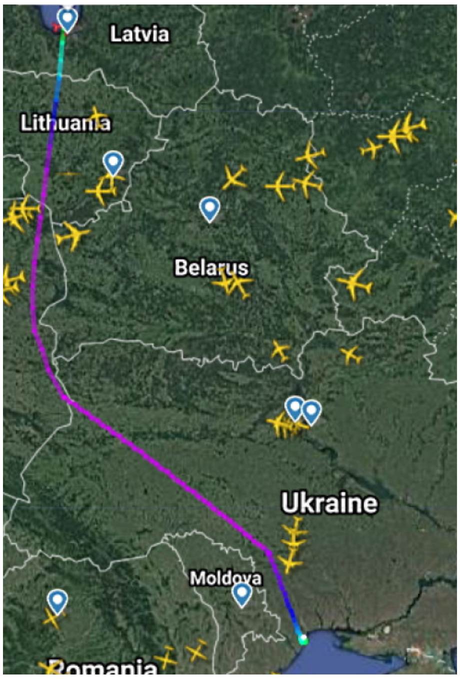

Fig. 5. Route from Riga to Odessa

Although there are times when the plane cannot land immediately upon arrival due to various factors, such as weather conditions or an incident on the runway. Of course, aircraft do not have to be in the holding area for those 30 minutes or more. But even if you have to wait 5 minutes until you can land, the plane will not be able to start landing immediately after this time. First, he will need to return to the landing point. That is, even with a minimum delay time, the aircraft will be forced to make a full circle before landing.

It is impossible to predict one hundred percent whether we will be able to land during flight planning or takeoff. But, having received a warning of bad weather or no runways prior to our scheduled arrival time, we were able to adjust our flight to stay out of the holding area.

For further consideration of crowd optimization, we will use the developed algorithm based on changing the flight speed or flight level (Fig. 6).

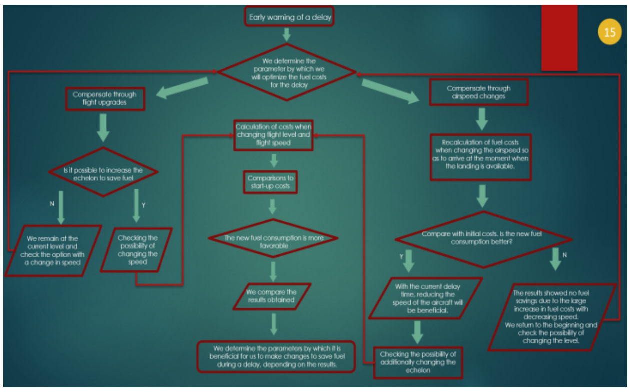

Fig. 6. Algorithm for optimizing fuel costs during delays

With known landing problems, the aircraft can climb to a higher flight level to reduce fuel consumption in a long and costly moment. Let's say there is a 5-minute landing delay. It turns out that in 5 minutes in the delay zone we would have burned 377 kg of fuel (Fig. 7).

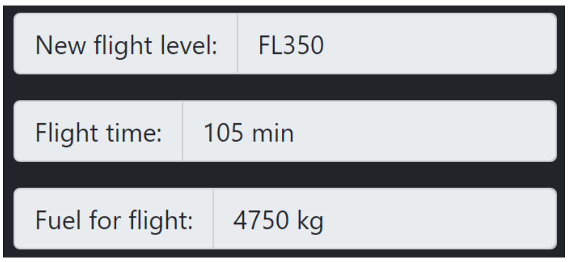

Fig. 7. Time and amount of fuel for FL350

From the B737 fuel and flight time chart, we first fly the FL350 with a headwind of 25 knots and a fuel consumption of 4750 kg (Fig. 8).

If we increase the flight level to FL370, the arrival time will not change, but the fuel costs will be lower, and some of the delay fuel will be saved. As a result, we save 120 kg of fuel (which is a saving of 32% of the initial costs).

The second parameter that we can influence is the speed of flight.

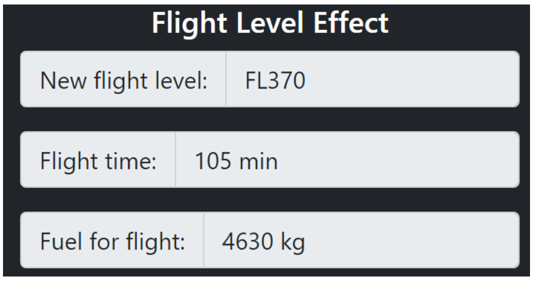

Fig. 8. Time and amount of fuel for FL370

With a small reduction in speed, we can completely avoid both delays and fuel costs for delay. Of course, due to the reduction of speed we will increase fuel consumption for the flight. Therefore, it is first necessary to make calculations for specific types of aircraft.

For the Boeing 737 with its fuel consumption hovering over the airport, we will be able to adjust the speed to avoid a delay of up to 15 minutes (Fig. 9).

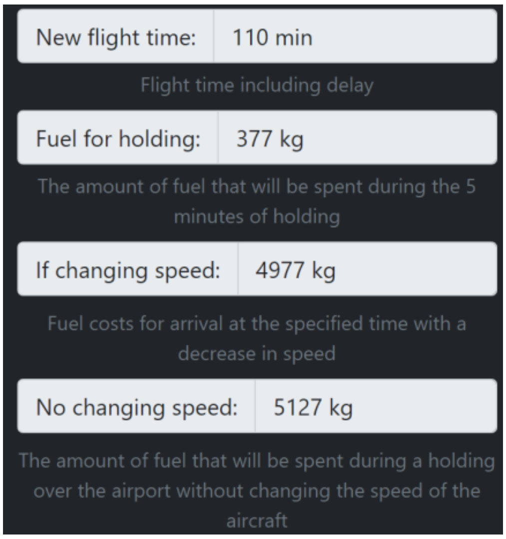

Fig. 9. New fuel starts when speed decreases due to a delay of 5 minutes

With a slight decrease in speed, we will increase fuel consumption from 4750 kg to 4977 kg (by 227 kg). And we will be able to completely avoid the cost of fuel for the delay. As a result, we will be able to save 150 kg (40%) of fuel on delay by increasing the flight speed.

We also have the ability to change both the level and the flight speed at the same time.

For example, with a 5-minute delay for our aircraft, the calculations show that we need 4750 kg per flight and 376 kg per delay, a total of 5126 kg. By changing the echelon, we will reduce fuel consumption for the flight to 4630 kg and the remaining 376 for delay.

In addition, we reduce the flight speed and increase fuel consumption per flight to 4946 kg, but without delay. Initially, we needed 376 kg of fuel, after changes in the level and flight speed, we can save 180 kg of fuel (which is 47% of the initial cost).

V. CONCLUSION

The developed algorithm for optimizing fuel consumption for delays was demonstrated.

And according to this algorithm, we performed the optimization of fuel consumption for the Riga-Odessa flight. And we considered how much fuel can be saved by lowering the flight level or flight speed.

As a result, our B737 aircraft can optimize fuel consumption with a landing delay time of up to 15 minutes. Due to the high fuel consumption when flying in the holding area.

REFERENCES

[1] A-318 A-319 A-320 A-321 Flight Crew Operating Manual. Vol. 3. Flight Operations

[2] Airbus A318 A319 A320 A321 Flight Crew Operating Manual. Part 2 – Flight Preparation

[3] AIR TRANSPORT ACTION GROUP (ATAG). 2012 (Mar.). Aviation benefits beyond borders. Tech. rept. Air Transport Action Group, Oxford Economics, Geneva (Switzerland).

[4] Average weekly jet fuel price from October 2016 to March 2022 - https://www.statista.com/statistics/526660/aviation-fuel-cost-comparison-across-regions/

[5] Flight Planning and Performance Manual for Boing 737

[6] The European Air Traffic Flow Management

[7] Statistics of completed flights with delays - https://www.avianews.com/ukraine/2020/02/12/mau_91punctuality_jan2020/

[8] EUROCONTROL. 2008b. Network Operations Report Summer 2008. Eurocontrol

[9] EUROCONTROL EXPERIMENTAL CENTRE. 2011a (June). Coverage of 2010 European air traffic for the base of aircraftdata (BADA) - Revision 3.9.

[10] LEE, KEUMJIN, FERON, ERIC, & PRITCHETT, AMY. 2008 (Jan.). Describing Airspace Complexity:

Airspace Response to Disturbances. Ph.D. thesis, Georgia Institute of Technology. https://doi.org/10.2514/1.36308

[11] UNIVERSITY OF WESTMINSTER. 2011 (Mar.). European airline delay cost reference values. Tech. rept. Eurocontrol, Brussels.

Received December 18, 2021.

Mukhina Maryna. Doctor of Engineering Science. Professor.
Aviation Computer-Integrated Complexes Department, Faculty of Air Navigation Electronics and Telecommunications, National Aviation University, Kyiv, Ukraine.
Education: National Aviation University, Kyiv, Ukraine, (2002).
Research interests: correlation extreme navigation, non-linear estimation, Gaussian particle filtering.
Publications: more than 60 papers.
E-mail: m_mukhina@inbox.ru

Nikulin Artem. Student.
Aviation Computer-Integrated Complexes Department, Faculty of Air Navigation Electronics and Telecommunications, National Aviation University, Kyiv, Ukraine.
Education: National Aviation University, Kyiv, Ukraine, (2021).
Research area: Identification of Complex Systems.
E-mail: 5642598@stud.nau.edu.ua

М. П. Мухіна, А. І. Нікулін. Система оптимізації витрат палива
У цій роботі розглянуто завдання оптимізації скупчення людей при затримках літаків перед посадкою. Вивчивши статистику, можна дійти невтішного висновку, що з 2013 по 2018 рік спостерігалося постійне зростання пасажиропотоку. Але також за рахунок постійного зростання пасажиропотоку збільшується відсоток рейсів із затримками. Проблема в тому, що більша частина рейсів припадає на невеликий відсоток найпопулярніших аеропортів (в Україні 75 відсотків усіх рейсів припадає на аеропорти Бориспіль та Жуляни). Хоча з 2019 року кількість авіаперевезень по всьому світу з часом різко скоротилася, кількість авіаперельотів повернеться до колишньої цифри і продовжуватиме зростати. Також зараз у авіаперевізників виникла нова проблема – значне зростання цін на авіапаливо. За даними Mundi Index, з грудня 2021 спостерігається постійне зростання цін на паливо для літаків. Це додатковий стимул для авіакомпаній оптимізувати свої маршрути, щоб уникнути непотрібних витрат на пальне. У цій роботі на прикладі перельоту Боїнга 737 з Риги до Одеси було розглянуто два параметри, за зміни яких можна мінімізувати витрати палива при затримці. Також було розроблено алгоритм оптимізації витрат на натовп на рейсах із затримками.
Ключові слова: затримка повітря; запас палива; витрата палива; ешелон польоту; швидкість польоту.

Мухіна Марина Петрівна. Доктор технічних наук. Професор.
Кафедра комп’ютерно-інтегрованих комплексів, Національний авіаційний університет, Київ, Україна.
Освіта: Національний авіаційний університет, Київ, Україна, (2002).
Напрям наукової діяльності: кореляційно-екстремальна навігація, нелінійне оцінювання, гаусовський багатоточковий фільтр.
Кількість публікацій: більше 60 наукових робіт.
E-mail: m_mukhina@inbox.ru

Нікулін Артем Іванович. Студент.
Кафедра авіаційних комп’ютерно-інтегрованих комплексів, Факультет аеронавігації електроніки і телекомунікацій, Національний авіаційний університет, Київ, Україна.
Освіта: Національний авіаційний університет, Київ, Україна, (2021).
Напрям наукової діяльності: ідентифікація складних систем.
E-mail: 5642598@stud.nau.edu.ua

М. П. Мухина, А. И. Никулин. Система оптимизации расхода топлива
В данной работе рассмотрена задача оптимизации скопления людей при задержках самолетов перед посадкой. Изучив статистику, можно сделать вывод, что с 2013 по 2018 год наблюдался постоянный рост пассажиропотока. Но также за счет постоянного роста пассажиропотока увеличивается процент рейсов с задержками. Проблема в том, что большая часть рейсов приходится на небольшой процент самых «популярных» аэропортов (в Украине 75 процентов всех рейсов приходится на аэропорты Борисполь и Жуляны). Хотя с 2019 года количество авиаперевозок по всему миру со временем резко сократилось,

количество авиаперелетов вернется к прежней цифре и даже продолжит расти. Также сейчас у авиаперевозчиков возникла новая проблема – значительный рост цен на авиатопливо. По данным Mundi Index, с декабря 2021 года наблюдается постоянный рост цен на топливо для самолетов. Это дополнительный стимул для авиакомпаний оптимизировать свои маршруты, чтобы избежать ненужных расходов на топливо. В данной работе на примере перелета Боинга 737 из Риги в Одессу были рассмотрены два параметра, при изменении которых можно минимизировать затраты топлива при задержке. Также был разработан алгоритм оптимизации расходов на толпу на рейсах с задержками.

Ключевые слова: задержка в воздухе; запас топлива; расход топлива; эшелон полета; скорость полета.

Мухина Марина Петровна. Доктор технических наук. Профессор.

Кафедра компьютерно-интегрированных комплексов, Национальный авиационный университет, Киев, Украина.

Образование: Национальный авиационный университет, Киев, Украина, (2002).

Направление научной деятельности: корреляционно-экстремальная навигация, нелинейное оценивание, гауссовский многоточечный фильтр.

Количество публикаций: более 60 научных работ.

E-mail: m_mukhina@inbox.ru

Никулин Артем Иванович. Студент.

Кафедра авиационных компьютерно-интегрированных комплексов, Факультет аэронавигации электроники и телекоммуникаций, Национальный авиационный университет, Киев, Украина.

Образование: Национальный авиационный университет, Киев, Украина, (2021).

Направление научной деятельности: идентификация сложных систем

E-mail: 5642598@stud.nau.edu.ua