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Optimization of the approach to Moscow Flight Information Region: Environmental and economic aspects of implementing the continuous descent procedure

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Abstract: With the growth of air traffic, the implementation of environmentally friendly and cost-effective technologies in civil aviation becomes increasingly important. One promising solution is the Continuous Descent Operations (CDO) mode, which ensures an optimal descent trajectory, reducing fuel consumption, CO_2 emissions, and noise near airports. This work develops an analytical model to evaluate the effectiveness of CDO implementation in the Moscow Flight Information Region, taking into account the optimization of air traffic control and airspace organization. The methodology includes mathematical modeling, expert evaluation, and simulation analysis. Algorithms are proposed for multifactor assessment of the impact of traffic density, air traffic control features, and weather conditions on CDO application. The results can be used to develop regulations and air traffic schemes in the Moscow area, contributing to fuel savings and environmental improvements in line with ICAO's 2016–2030 plan.

Key words: Continuous Descent Operations, efficiency assessment, air traffic control.

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Оптимизация захода на посадку в районе полетной информации Москвы: эколого-экономическая оценка внедрения процедуры непрерывного снижения

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Аннотация: В условиях роста воздушного движения важным становится внедрение экологичных и экономичных технологий в гражданской авиации. Одним из перспективных решений является режим непрерывного снижения (Continuous Descent Operations, CDO), обеспечивающий оптимальную траекторию снижения с уменьшением расхода топлива, выбросов CO_2 и шума вблизи аэропортов. В исследовании разработана аналитическая модель оценки эффективности внедрения CDO в Московском районе полетной информации, учитывающая оптимизацию диспетчерского управления и организацию воздушного пространства. Методология включает математическое моделирование, экспертный и имитационный анализ. Предложены алгоритмы мультифакторной оценки влияния плотности трафика, особенностей диспетчерского регулирования и метеоусловий на применение CDO. Результаты могут использоваться для формирования регламентов и схем воздушного движения в Московской зоне, способствуя снижению топливных затрат и экологическому улучшению в соответствии с планом ИКАО на 2016–2030 годы.

Ключевые слова: режим непрерывного снижения, оценка эффективности, обслуживание воздушного движения.

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Introduction

Given the dynamic development of civil aviation, the implementation of technological solutions aimed at reducing the environmental impact of air transport and enhancing the economic efficiency of flights is becoming a pressing task. One promising direction is the Continuous Descent Operations (CDO) procedure, which facilitates an optimized descent with minimal engine thrust, contributing to reduced fuel consumption and lower levels of aircraft noise.[1]

The relevance of this study is driven by the necessity to implement the provisions of the Global Air Navigation Plan (GANP) for 2016–2030, developed by the International Civil Aviation Organization (ICAO), within which the Continuous Descent Operations procedure plays a key role in the B1-RSEQ (Optimization of Arrival/Departure Sequencing and Merging) and B1-FRTO (Optimization of Flight Routes) modules.[2]

On the international stage, leading hub airports, such as Kansai International Airport (Japan) [1], as well as airports in the USA (Louisville and Los Angeles) [2, 3], have successfully implemented this technology, leading to significant reductions in operational costs and harmful emissions into the atmosphere. Implementing similar procedures in the Moscow airspace zone appears advisable and necessary from the perspective of improving the air traffic management (ATM) system and enhancing the efficiency of air navigation services.

A key advantage of implementing the continuous descent procedure is its low capital intensity, as modern civil aircraft are equipped with Flight Management Systems (FMS) capable of automatically calculating optimal descent parameters. The main changes involve adapting air traffic control procedures, updating the regulatory framework, and training personnel of air traffic services (ATS). International experience confirms that the implementation of continuous descent does not require large-scale infrastructure transformations, yet delivers significant environmental and economic benefits.[3]

The goal of this study is to develop a comprehensive analytical model to assess the effectiveness of implementing continuous descent procedures in the Moscow Flight Information Region (FIR). The development and implementation of such models represents a relevant scientific and applied task associated with optimizing approach trajectories, minimizing fuel costs, reducing carbon dioxide emissions, and lowering aircraft noise levels in areas surrounding airports.

To achieve the stated goal, the following tasks were defined in the course of the research:

- conducting a survey of an expert group to assess the effectiveness of applying the continuous descent procedure;
- application of mathematical modeling to analyze air traffic processes during the implementation of Continuous Descent Operations (CDO);
- development of an analytical model to assess the impact of continuous descent on fuel consumption and air traffic controller workload;
- creation of algorithms and software for simulating various scenarios of applying the continuous descent procedure in the Moscow airspace region.

The theoretical significance of this research lies in the development of a comprehensive methodological approach for assessing the effec-

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[1] Doc 9931-2010. (2010). Manual continuous descent operations (CDO). 1st ed. ICAO, 60 p.

[2] Doc 9750. (2016). Global Air Navigation Plan. 8th ed. ICAO, 54 p.

[3] International Civil Aviation Organization (ICAO). (2005). Rules of the Air. Annex 2 to the Convention on International Civil Aviation. 10th ed. ICAO, 104 p.

tiveness of implementing Continuous Descent Operations (CDO). This approach is based on the integration of expert analysis, simulation modeling on a high-fidelity flight simulator, and the development of specialized software for the parametric optimization of descent trajectories.

Thus, the research results will contribute to the scientifically-grounded implementation of CDO procedures in the Moscow airspace region. This is expected to enhance the efficiency of air navigation services, reduce airline fuel costs, and minimize the environmental and acoustic impact of air transport.

Research methodology

The methodological foundation of the research is a comprehensive approach combining theoretical justification, mathematical modeling, and expert-analytical procedures. The aim of the methodology is a comprehensive assessment of the applicability of Continuous Descent Operations (CDO) procedures under the high-density air traffic conditions of the Moscow FIR.

The primary research method is mathematical modeling, aimed at the quantitative assessment of the effectiveness of CDO procedure implementation, taking into account aerodynamic, navigational, and operational characteristics of aircraft, as well as the specifics of air traffic management in the Moscow aviation hub.

To ensure the reliability of the obtained results, an expert group was formed, including first-class air traffic controllers with over 10 years of experience. Within the empirical stage, expert surveys were conducted with the goal of identifying factors significantly influencing the composite index of CDO applicability, as well as determining key constraints related to the current airspace structure.

Simulation modeling was conducted in two stages:

1. The air traffic situation was modeled using a specialized simulator adapted for scenarios typical of the Moscow zone.
2. Numerical modeling of trajectory solutions was performed in the MATLAB environment using a multi-parameter optimization model that accounts for the aerodynamic characteristics of a Boeing 737-800 aircraft.

Initial parameters for the numerical modeling included:

- Cruise flight level: FL360;
- Aircraft mass: 71 tonnes;
- Air temperature at flight level: −43 °C;
- Wind conditions: calm;
- CDO profile: descent at a constant flight path angle of 3°;
- Fuel consumption calculation: based on a Thrust-Specific Fuel Consumption (TSFC) model dependent on engine operating mode;
- Trajectory data: obtained from FMS and simulator scenarios.

The system of differential equations of aircraft motion [4] during the descent phase has the following form

$$\frac{\mathrm{dh}}{\mathrm{dt}} = \mathrm{V} \cdot \sin\gamma; \tag{1}$$

$$\frac{\mathrm{dV}}{\mathrm{dt}} = \frac{T-D}{m} - g \cdot \sin\gamma; \tag{2}$$

$$\frac{\mathrm{dm}}{\mathrm{dt}} = -\mathrm{TSFC} \cdot \mathrm{T}, \tag{3}$$

where h – flight altitude;
V – horizontal velocity;
γ – flight path angle;
T – engine thrust (dependent on altitude and velocity);
D – aerodynamic drag;
m – current aircraft mass;
TSFC – thrust-specific fuel consumption (dependent on engine operating mode);
g – gravitational acceleration.

Aerodynamic drag was calculated using the formula [5]

$$D = \frac{1}{2} \cdot C_D \cdot \rho(h) \cdot V^2 \cdot S, \tag{4}$$

where C_D – drag coefficient (according to Boeing data);
ρ(h) – air density according to the ICAO standard atmosphere;
S – wing surface area.

The optimization criterion for the numerical experiment was formulated as a functional for minimizing fuel consumption [6]:

$$J = \int_{t_0}^{t_f} TSFC(t) \cdot T(t)dt. \qquad (5)$$

The integration of the equations was performed using the fourth-order Runge-Kutta method with a step of 0.1 seconds. To account for the influence of uncertainties, such as mass variations and weather conditions, the Monte Carlo method was used with a number of iterations N = 1000. The simulation assessed both fuel consumption and acoustic impact on areas adjacent to the flight path.

Additionally, a software module was developed in the JavaScript language, enabling the simulation of potential trajectory conflict scenarios within the current airspace structure of the Moscow FIR. This made it possible to evaluate the potential for integrating CDO from the perspectives of flight safety and possible air traffic conflicts arising during the simultaneous execution of descent procedures by multiple aircraft.

The simulation results were subjected to expert evaluation. The level of agreement among experts was assessed using Kendall's coefficient of concordance. The obtained value of $W = 0.7$ indicates a high degree of consensus among the respondents, confirming the reliability of the conclusions.

Thus, the proposed methodology has enabled a comprehensive assessment of the applicability of the Continuous Descent Operations procedure under the conditions of the real airspace structure and the high flight intensity characteristic of the Moscow FIR.

Research results

1. Assessment of CDO applicability in the Moscow Flight Information Region (FIR)

The expert analysis method was applied to assess the applicability of the Continuous Descent Operations (CDO) procedure in the Moscow FIR. The goal of the expert analysis was to rank factors by the degree of their impact on the implementation of the CDO procedure to identify the most significant parameters influencing its application [7].

Based on an analysis of regulatory documents, features of air traffic organization, and the results of expert surveys, all factors affecting the possibility of implementing CDO were classified into three main groups:

1. Factors reducing the overall airspace capacity.

This group includes:

- adverse meteorological phenomena (low cloud cover, thunderstorm activity, strong winds at flight levels and in the surface layer);
- established temporary and permanent restriction zones, including those related to the activities of the ministry of defense;
- high density of inbound aircraft traffic;
- the need to apply separation and maneuvering procedures deviating from the optimal trajectory;
- close proximity of airports to each other;
- diversity of aircraft types in the airspace;
- possible misalignment between the CDO profile direction and established approach procedures.

2. Factors limiting the capacity of air traffic control units.

This category includes:

- complexity of the airspace structure (multiplicity of sectors and their configurations, presence of intersecting routes);
- regulatory-established sector capacity;
- high workload on controller positions during periods of intensive traffic;
- limited capabilities to grant priorities to different flight categories.

3. Organizational and technological factors.

This group includes:

- the need for prior coordination of CDO application with ATS units;
- absence of unified continuous descent procedures within the FIR;
- insufficient level of automation in air traffic management processes (lack of automatic CDO trajectory prediction);

Table 1

Data for calculation of integral index characterizing CDO applicability

Key factors for CDO feasibility	**Airspace structure**	**Traffic intensity**	**Meteorological conditions**	**Equipment**
Weighing coefficients	0.25	0.2	0.2	0.2
Factor scores	0.8	0.7	0.9	0.85

- limited compatibility of the continuous descent procedure with existing arrival sequencing algorithms.

To quantitatively assess and verify the expert opinions, a procedure for evaluating the competence of each expert was conducted. The competence assessment was carried out based on the following expression [8]:

$$K_{э_i} = \frac{K_{a_i} + K_{и_i}}{K_{a_{max}} + K_{и_{max}}}, \qquad (6)$$

where $K_{э_i}$ – coefficient reflecting the level of competence of the *i*-th expert;

$K_{и_i}$ – coefficient reflecting the level of informedness of the *i*-th expert;

K_{a_i} – coefficient reflecting the level of argumentation of the *i*-th expert;

$K_{a_{max}}$ and $K_{и_{max}}$ – maximum possible scores for coefficients K_{a_i} and $K_{и_i}$ typically equal to 1.

The aggregated competence value for the entire expert group was determined by the formula

$$Q = \frac{1}{z} \sum_{i=1}^{z} K_{э_i}. \qquad (7)$$

Based on the calculated competence level, a final sample was formed and used for the expert survey to determine the indicator of successful CDO application in the Moscow FIR.

To assess the degree of consensus among expert judgments, Kendall's coefficient of concordance was applied [9, 10], defined by the following relationship:

$$W = \frac{S}{S_{max}} = \frac{S}{\frac{1}{12} z^2 (m^3 - m) - z \sum_{j=1}^{z} T_j}, \qquad (8)$$

where S – the sum of squares of deviations of the total average ranks for each option from the overall average rank of all options;

S_{max} – the maximum possible sum of squares of deviations of the total average ranks for each option from the overall average rank of all options, considering the presence of tied ranks;

z – number of experts;

m – number of alternative options to be ranked by the experts;

T_j – correction factors accounting for tied ranks.

The calculated concordance coefficient was 0.7, which indicates a high degree of consensus in the expert assessments and allows for the conclusion that there is a significant probability of successfully implementing continuous descent operations in the airspace of the Moscow FIR. The assessment of CDO implementation feasibility was determined using the following expression [11]:

$$K = \sum_{i=1}^{n} \frac{W_i \cdot \phi}{W_i}, \qquad (9)$$

where W_i – weighting coefficients;

ϕ – factor scores.

Table 1 presents the data for calculating the integral indicator of CDO procedure applicability in the Moscow FIR, as determined by the expert group.

During the research, each expert was asked to assess the influence of a specific factor (e.g., "Airspace Structure," "Meteorological Conditions," etc.) on the possibility of applying CDO on a scale from 0 to 1, where

1 – maximum positive influence,
0 – no influence.

Individual expert assessments were averaged, taking into account weights dependent on their level of competence.

Based on the analysis of the expert survey, the integral indicator characterizing the possibility of successfully implementing the CDO procedure in the Moscow FIR amounted to 0.78. This indicates a high degree of feasibility for this technology under current operational conditions.

2. Implementation of the CDO procedure in the Moscow FIR

The Continuous Descent Operation (CDO) procedure is a type of flight trajectory implemented during the aircraft descent phase, aimed at ensuring a smoother, more environmentally friendly, and efficient approach to the aerodrome. However, in real airspace conditions, multiple trajectory intersections and conflicts are possible due to existing arrival and departure routes. Given the priority task of ensuring flight safety, when designing new routes using CDO, it becomes necessary to develop and apply specialized tools capable of identifying potential conflicts between new and existing trajectories. Such tools should provide a comprehensive analysis of spatiotemporal flight parameters, model interaction scenarios, and generate feasible solutions for preventing or resolving identified conflict situations.

As part of the analysis of the airspace structure of the Aerodrome Control Center, potential trajectory intersections affecting safety were identified at the stage of designing CDO trajectories. Since trajectory creation is based on known waypoints using interpolation methods, a specialized program was developed in JavaScript for this work. Its logic is presented in Figure 1.

As the reference point for calculations, runway 06 of Vnukovo Airport was selected, its coordinates specified in latitude and longitude. To simplify mathematical computations, the coordinates were converted from degrees, minutes, and seconds format to decimal degrees.

The program utilizes the Haversine formula to calculate the distance between two points on the Earth's surface, allowing for the consideration of its curvature. The cross product is used to check the parallelism of two lines defined by pairs of points (p1, p2 and q1, q2), which is an important step in analyzing potential conflicts between trajectories. In the case of parallel lines, an additional collinearity check is performed to determine if the lines lie on the same straight line. If the lines are collinear, they either coincide or do not intersect.

If the lines are not parallel, the program calculates parameters t and u, which indicate their intersection point. Subsequently, the algorithm checks whether these intersection points lie within the line segments. If the intersection point is outside the segments, the program reports no conflict.

To enhance calculation accuracy, the algorithm analyzes the difference between the coordinates of intersection points using a threshold value (in this case, 10 units). If the difference between the coordinates is less than the specified threshold, the program returns the intersection point, accounting for computational inaccuracies. This approach allows for effective modeling and analysis of the interaction between various arrival routes, which is important for optimizing air traffic and preventing conflict situations in the aerodrome zone. Thus, the developed algorithm provides the capability to flexibly modify the arrival route with CDO while avoiding the occurrence of conflicting aircraft trajectory intersections.

In Figure 2, the URAGO 1C STAR will be used as an example of a CDO procedure for an eastern approach to Vnukovo. It consists of the following waypoints (data taken from the AIP):

URAGO (553300.00N, 0395953.00E);
GEKLA (553330.00N, 0395923.00E);
ENMUR (553310.00N, 0373419.00E);
WW239 (553531.10N, 0373010.50E);
AFISA (553817.80N, 0372814.00E);
WW451 (553659.54N, 0372221.97E).

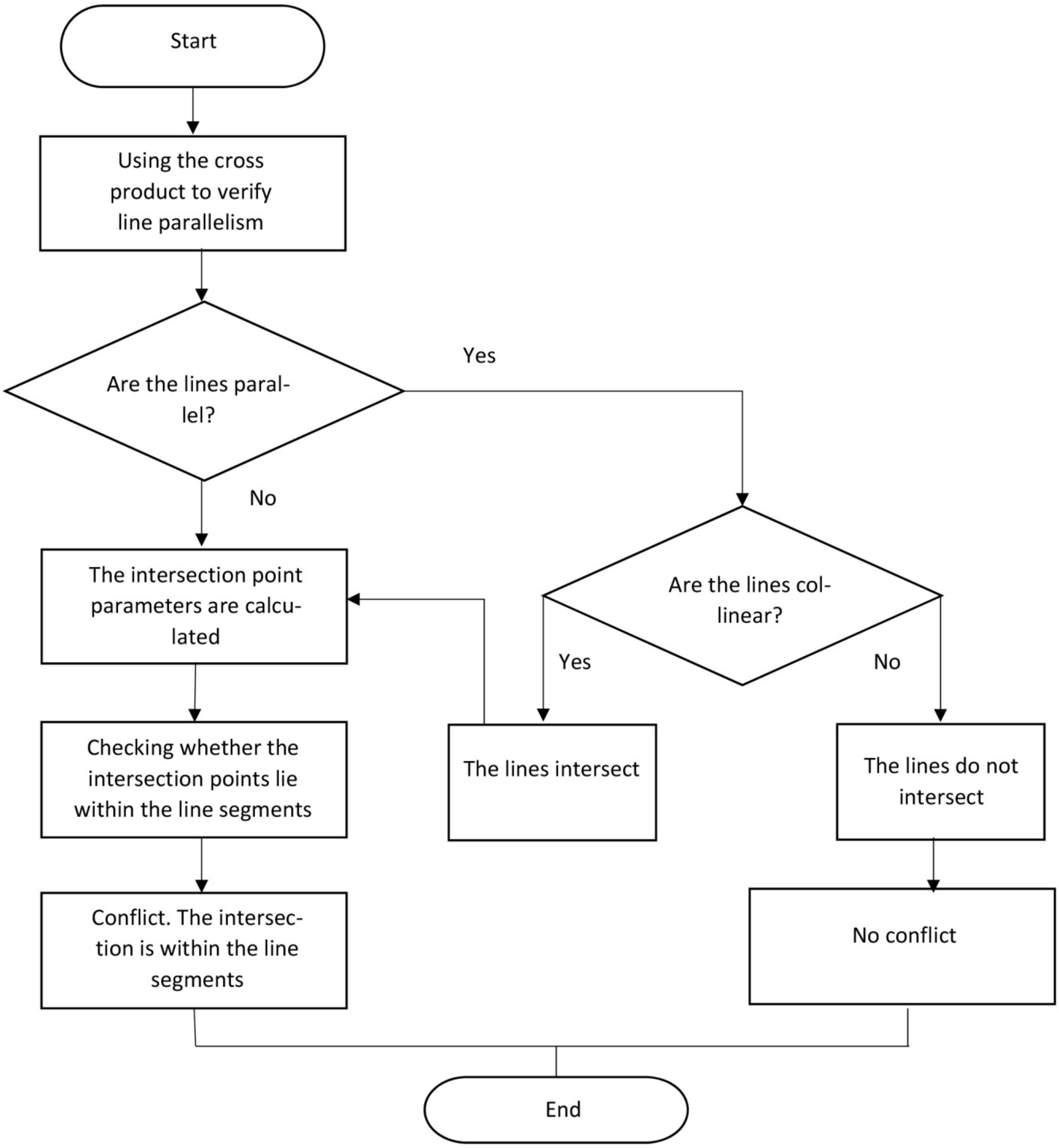

Fig. 1. Flowchart for determining the intersection point of aircraft routes

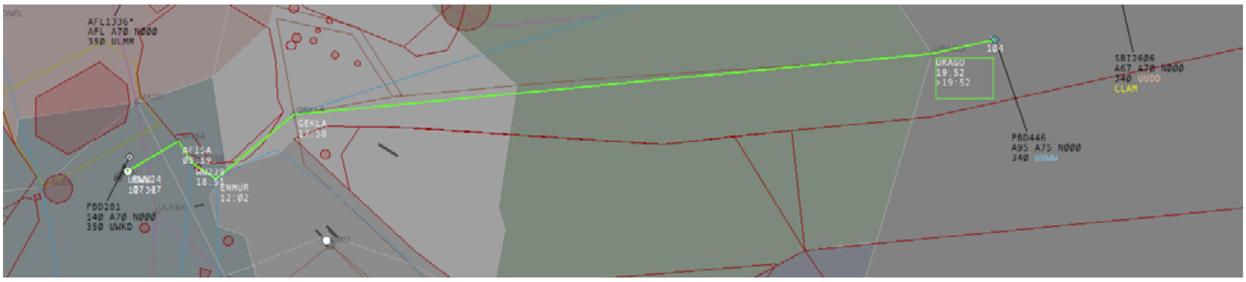

Fig. 2. STAR using CDO URAGO 1C

Fig. 3. STARs DIMGI 3A and DIMGI 3B

In this arrival procedure, the primary focus was placed on the Restricted Airspace UUR215 (Ramenskoye Aerodrome), which is active at altitudes from FL150 to FL980 [12]. However, it should be noted that this restriction is applied only during periods of active airspace use by Ramenskoye Aerodrome.

There are three scenarios for traversing the UUR215 restricted area when applying the continuous descent procedure via the URAGO 1C arrival:

1. If the flight schedule does not include the use of this part of the airspace, it becomes available for maneuvering. In this case, the URAGO 1C arrival will consist of waypoints URAGO-ENMUR-WW239-AFISA-WW451, and the flight trajectory will contain a minimal number of turn points.
2. If there are airspace restrictions, controllers at the Moscow ATM center can directly contact controllers at Ramenskoye Aerodrome to coordinate the transit of the restricted zone for individual aircraft, even with active airspace restrictions.
3. If the airspace in zone UUR215 is restricted, and transit of the zone by agreement is prohibited, the route using the CDO procedure will follow the full CDO arrival procedure and consist of waypoints URAGO-GEKLA-ENMUR-WW239-AFISA-WW451.

Thus, flexibility in route planning, considering airspace restrictions and the possibilities for coordination with aerodromes, allows for the effective use of CDO technologies while minimizing risks.

Figure 3 presents the traditional STARs in Vnukovo: DIMGI 3A and DIMGI 3B.

Navigation routes within the new airspace structure were designed following the principle of conflict-free routing [13]. The navigation waypoint DIMGI is intended for directing aircraft landing at Sheremetyevo and Vnukovo, while aircraft landing at Domodedo pass through the URAGO waypoint. The key difference between the traditional arrival procedures and the continuous descent arrival procedure is the shift of the Top of Descent (ToD) point from DIMGI to URAGO for aircraft bound for Vnukovo Airport. Shifting the ToD point from DIMGI to URAGO will alleviate controller workload by redistributing aircraft flows. According to official data from the Federal Air Transport Agency, as of the end of 2024, Sheremetyevo Airport (Moscow) is the busiest airport in Russia, having served approximately 43.7 million passengers. By redirecting a portion of the traffic bound for Vnukovo through the URAGO point, a more balanced and safer flow of aircraft can be achieved.

As a result of moving the Top of Descent point to above URAGO, potential conflicts may arise between the trajectories of aircraft arriving on CDO procedures and those departing from Vnukovo and Sheremetyevo. Using the developed software to model the modified airspace structure within the Aerodrome Control Center

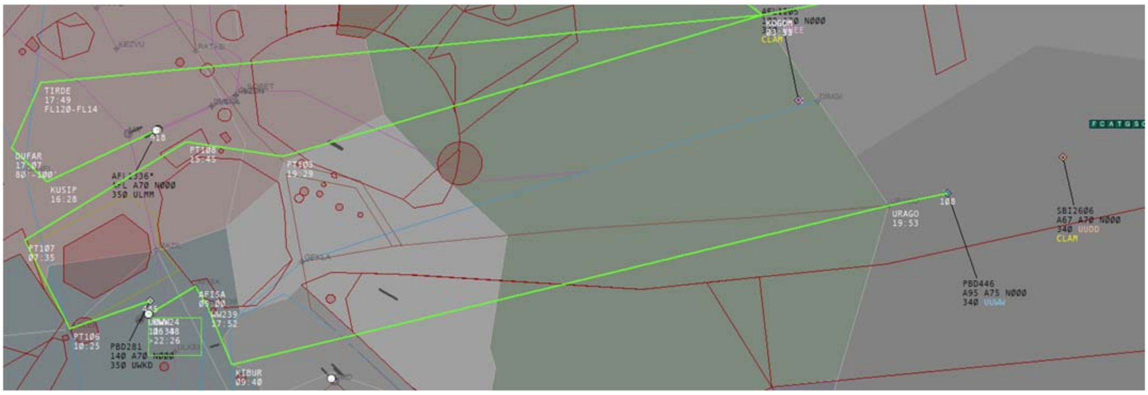

Fig. 4. Change in departure routes from Vnukovo and Sheremetyevo

zone, intersections of aircraft trajectories were identified. Accordingly, it is necessary to reorganize a portion of the departures from Vnukovo. Aircraft should depart westward to avoid conflict with inbound traffic, circumvent the prohibited areas UUP52 and UUP53, and then execute a right turn toward the planned flight route to the KOGOM waypoint. To ensure the reorganized departures from Vnukovo do not conflict with departures from Sheremetyevo, aircraft from the latter must perform a similar maneuver: initially westward, parallel to the Vnukovo departure route, followed by a right turn towards waypoints DUFAR – TIRDE – KOGOM. Altitude constraints are already in place above KOGOM for aircraft departing from different aerodromes, thus eliminating the possibility of conflicting trajectory intersections in that area. The reorganized departure routes are schematically presented in Figure 4.

The development and implementation of the Continuous Descent Operations (CDO) procedure in the Moscow FIR airspace are aimed not only at optimizing air traffic flows and enhancing safety but also at achieving tangible operational and environmental benefits. The positive effect of applying CDO is particularly noticeable in the vicinity of Vnukovo Airport, where the reduction of engine thrust during descent and the shortening of level flight segments contribute to decreased fuel consumption and reduced noise levels near the airport. Let us examine in more detail the key advantages that the implementation of this procedure provides under the conditions of high-density air traffic in the Moscow Flight Information Region.

3. Advantages of implementing the Continuous Descent Procedure in the Moscow FIR

Continuous Descent Operations are widely adopted due to a number of significant advantages. Their implementation not only enhances flight efficiency but also reduces the negative environmental impact of aviation. The primary benefits of CDO include:

1. **Fuel efficiency** – reduced fuel consumption during the descent phase compared to the conventional stepping down descent.
2. **Reduction of harmful emissions** – decreased amount of CO_2, NOx, and other pollutant emissions into the atmosphere.
3. **Noise abatement** – diminished acoustic impact due to a smoother and more predictable descent profile.

Each of these advantages is important both from the perspective of aircraft operations and from the standpoint of the sustainable development of the aviation industry. A more detailed explanation of each follows below.

To assess the effectiveness of the Continuous Descent Operations procedure in the Moscow FIR, let's introduce the concept of fuel consumption. In the Flight Management System (FMS), fuel consumption during aircraft descent is calculated based on several parameters, including

Table 2

Aircraft parameters during descent under URAGO 1C (with CDO) and DIMGI 3B arrivals

STAR	DIMGI 3B	URAGO 1C (with CDO)
ToD fuel remaining	6440 kg	6260 kg
Post-descent fuel remaining	5400 kg	6000 kg
Wind	calm	calm
OAT at FL300	−43 degrees Centigrade	−43 degrees Centigrade
Aircraft mass	71 tons	71 tons
Aircraft type	B737	B737
Fuel consumption	1040 kg	260 kg

aerodynamic drag, engine operating mode, aircraft mass, descent profile, and meteorological conditions.

The main formulae used to calculate fuel consumption are [14]

$$^{\cdot}m_{fuel} = TSFC \cdot T, \qquad (10)$$

where m_{fuel} – instantaneous fuel flow rate;
$TSFC$ – thrust-specific fuel consumption;
T – engine thrust.

During descent, engines operate at a reduced power setting, so T decreases significantly, which lowers fuel consumption [15].

$$T \approx D,$$
$$D = \frac{1}{2} C_D \rho V^2 S, \qquad (11)$$

where D – aerodynamic drag;
C_D – drag coefficient;
P – air density;
V – flight speed;
S – wing surface area.

To estimate fuel consumption during descent, accounting for speed and altitude data, the FMS uses the following relationship:

$$m_{duel,desc} = \frac{TSFC \cdot C_D \rho V^2 S (h_{init} - h_{final})}{2V_{vert}}. \qquad (12)$$

After reorganizing a part of the airspace structure and developing the URAGO 1C arrival utilizing continuous descent, modeling was conducted on a “full flight” simulator. The fuel efficiency of the procedure using CDO and the conventional procedure was calculated using expression (12) and is presented in Table 2.

Thus, the reduction in fuel consumption during the continuous descent amounted to 780 kg, which is approximately 75% compared to the conventional descent, resulting in an average savings of about 25% of the total fuel consumption for the entire route. Figure 5 shows the relationship between fuel consumption and engine operating mode, as well as flight altitude.

The obtained difference in fuel consumption between conventional descent and descent with CDO allows for calculating the financial benefit of implementing continuous descent. In the Russian market, the price of Jet A-1 aviation fuel varies depending on the region, purchase volume, and supply terms. For example, the wholesale price for Jet A-1 aviation fuel is approximately 56,000–62,000 rubles per ton (or about 56–62 rubles per kilogram) according to data from major suppliers such as Gazpromneft-Aero. However, exact prices may depend on contract terms and the supply region. Thus, the financial benefit from changing one arrival procedure to continuous descent amounts to about 46,020 rubles per single flight.

In addition to significant fuel savings, the implementation of the continuous descent procedure allows for a substantial reduction in acoustic impact on the surrounding area, which is particularly relevant for the Moscow area of responsibility. The reduction in engine thrust and the elimination of level flight segments lead to a decrease in the overall noise level during the ap-

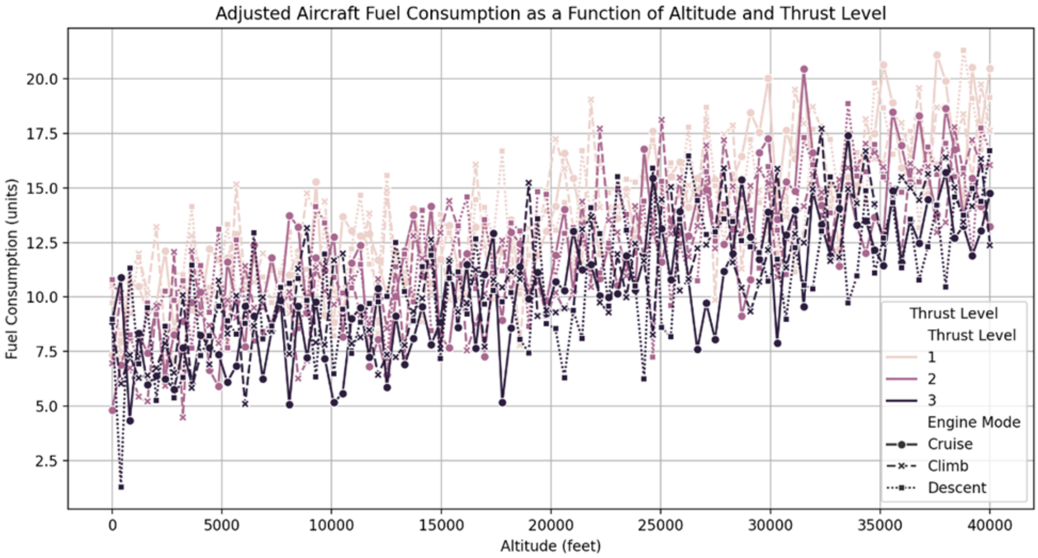

Fig. 5. Graph of dependence of aircraft fuel consumption on engine operation mode and flight altitude

Table 3

Comparison of Sound Exposure Levels (SEL) under Different Descent Scenarios

Scenario	SEL, dB(A) per 6 km	Difference
traditional DIMGI 3B arrival	81.4	
CDO URAGO 1C descent	77.6	−3.8

proach. To assess the acoustic effects of implementing the continuous descent procedure in the Moscow Flight Information Region, a model for calculating the sound exposure level on the ground was used, employing the INM v7.0 (Integrated Noise Model) software package. This software product is a recognized global standard for acoustic modeling in civil aviation and is officially recommended by ICAO for assessing the impact of aviation noise.

The input data for the calculation included:

- trajectory profiles: obtained from numerical modeling in MATLAB and using a Full Flight Simulator (for DIMGI 3B and CDO URAGO 1C profiles);
- aircraft type: Boeing 737-800 with CFM56-7B engines;
- aircraft mass on approach: 67–71 tons (variable mass from Monte Carlo simulation was considered);
- meteorological conditions: ICAO standard atmosphere, surface wind speed < 5 knots;
- engine operating modes: According to FMS and CDO profiles, accounting for reduced thrust during descent.

The acoustic indicator selected was SEL (Sound Exposure Level), dB(A) – the total sound exposure level, which considers both the loudness and duration of the noise (recommended by ICAO as the primary integrated indicator for analyzing ground-level noise from aircraft overflights).

The control point was:

- distance: 6 km from the runway threshold of Vnukovo Airport (along the runway centerline);
- measurement point height: at ground surface level (1.5 m above ground level).

In INM v7.0, for each scenario (conventional descent DIMGI 3B and CDO URAGO 1C), the trajectories and acoustic impact were calculated using the “Single Event SEL” methodology. This allows for assessing the effect of a single aircraft overflight at the given point (tab. 3).

Thus, the reduction in aircraft noise exposure on the ground when transitioning to CDO amounted to 3.8 dB(A) in terms of the SEL indicator at the control point.

Furthermore, continuous descent profiles demonstrate a more uniform and gradual reduction in acoustic impact across the entire approach segment. This is achieved by decreasing the number of segments where engines operate at higher power settings (intermediate level-off segments in conventional descent), increasing the flight altitude over populated areas, and reducing the duration of the sound event (shorter level flight phases).

Conclusion

Within the framework of this research, a comprehensive assessment of the applicability of the Continuous Descent Operations (CDO) procedure in the airspace of the Moscow FIR was provided, along with an analysis of the specifics of its integration into the existing route structure and air traffic control (ATC) provision.

The analysis of regulatory documents, features of air traffic organization, and expert surveys allowed for the identification of key factors influencing the implementation of CDO in this high-density airspace. These factors were classified into three main groups: those affecting airspace capacity, those affecting ATC unit workload, and organizational-technological factors. To ensure a well-founded ranking of these factors, an expert assessment methodology was implemented, accounting for the participants' competence, and the consistency of judgments was confirmed by a high value of Kendall's coefficient of concordance (W = 0.7).

As a result of the quantitative analysis, an integral indicator of CDO feasibility in the Moscow FIR was obtained, equal to 0.78. This indicates a high degree of readiness of the region for implementing the continuous descent procedure under current operational conditions, provided certain technological and organizational adaptations are made.

To enhance the efficiency of designing CDO trajectories, a software implementation of an algorithm in JavaScript was developed as part of this work. This algorithm allows for the prompt identification of potential trajectory intersection points, considering spatiotemporal flight parameters. This solution aims to minimize the probability of conflicts and to form safe and optimal arrival trajectories.

Special attention was paid to designing the URAGO 1C procedure utilizing CDO for approaches to Vnukovo Airport from the eastern direction. Various scenarios for navigating around the UUR215 restricted zone were considered, confirming the possibility of flexible CDO application, taking into account the dynamics of airspace use and coordination with other ATS units.

Therefore, this research demonstrates not only the theoretical validity of applying CDO in the conditions of complex and dense air traffic in the Moscow FIR but also proposes concrete solutions for integrating this technology into the existing air traffic management system. The obtained results can be used for further development of recommendations for CDO implementation in Russia, as well as for improving the regulatory and methodological framework that ensures safe and efficient airspace operations.

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