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FEATURES OF PROVISION OF SUSTAINABLE NAVIGATION AIDS FUNCTIONING UNDER HELIOGEOPHYSIC DISTURBANCES

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Abstract

Purpose: *The aim of this study is to research features of navigation provision of civil aviation aircraft using satellite navigation systems under heligeophysic disturbances.* ***Methods***: *The analysis of requirements for civil aviation aircraft navigation support in terms of implementing the concept of ICAO CNS / ATM using as the primary means of global navigation satellite systems and organization of space weather data provision for air traffic. The analysis of the main ways for modeling the values of total electron content of the Earth ionosphere. The analysis of problems of navigation support of civil aviation aircraft while using satellite navigation systems in terms of quiet and disturbed space weather. Development of a generalized complex model of satellite navigation systems functioning under the influence of external destabilizing factors.* ***Results***: *A generalized complex model of satellite navigation systems functioning under the influence of external destabilizing factors was developed. There were proposed the main mechanisms of functional stability of aircraft navigation aids operation in terms of heligeophysic disturbances distructive impact on them.* ***Discussion:*** *Exploring of the possibility of taking into account ionospheric parameters variations under space weather heligeophysic disturbances and clarifying the correction of satellite navigation system ionospheric errors based on the analysis of sygnal parameters of navigational sygnals that passed by the ionosphere in order to ensure the steady functioning of navigation aids under heligeophysic disturbances.*

Keywords: aeronautical system; aircraft positioning errors; air traffic services; destabilizing factors; civil aviation; concept CNS / ATM; functional stability; heliogeophysic disturbances; mathematical ionosphere's model; model of satellite navigation system functioning; navigation support; safety of flights; space weather

1. Introduction

Due to implementation in the system of air traffic management the concept ICAO (International Civil Aviation Organization) CNS/ATM (Communication, Navigation, Surveillance / Air Traffic Management) [1, 2] about creation of Global Navigation Satellite System there were significantly increased the quality requirements to civil aviation aircraft navigation support, leading to the need to improve the accuracy and reliability of their positioning using Global Navigation Satellite System (GNSS).

Numerous researches show that under any conditions the main contribution to the positioning error of civil aviation aircraft with technically good satellite navigation system is made by environment transformation of navigation systems signals distribution (ionosphere and troposphere) under heliogeophysical space weather disturbances.

Thus in the current conditions of particular importance for Ukraine becomes general scientific and applied problem of provision of sustainable navigation aids functioning under the influence of destabilizing factors of space weather. Applied research results in this area have dual use for both civilian and military aviation; have special importance to enhance defense and national security.

2. Analysis of latest research and publications

Principal points of functional stability theory were developed in the numerous works of O.A. Mashkov, O.V. Barabash, Y.V. Kravchenko, S.M. Nedilko, D.M. Obidin and others.

The authors have carried out the research of negative impacts of geophysical fields, leading to temporary failures of biological navigation mechanisms in space and time for their consideration to solve problems with new intellectual autonomous navigation systems creation on biological basis [3]. In addition, the authors [4, 5, 6] have developed the technological basis for provision of functional stability of automated air traffic management system, which is based on mathematical modeling process to identify areas of redundancy and optimal use of existing resources to counter the emergency situations. The studying of the process of navigational support functioning of civil aviation aircraft under the influence of destabilizing factors of space weather is one of links of above-mentioned research direction, but in the area of developing ways to improve the quality of navigation provision in terms of the need for high positioning precision of moving objects under the influence of dynamic variables geophysical fields, primarily to ensure the safety during the flight in aerodrome area and during categorical landing.

3. Purpose of the research

The aim of this study is to research features of navigation provision of civil aviation aircraft using satellite navigation systems under the influence of destabilizing factors of space weather and to identify new approaches to solve them.

4. Results

Despite the current serious scientific results of the functional stability theory the mathematical models of complex systems investigated in them cannot adequately describe the functioning of all existing systems. The system of functional stability provision should be considered for each system separately, be created at the design stage and be given to the features of construction and functioning in the conditions of different destabilizing impacts. This circumstance required to develop a comprehensive model of satellite navigation system functioning under the influence of a set of destabilizing factors.

For the first time we have developed a generalized comprehensive model of the satellite navigation system operation which considers the formation of an optimal functional structure and determines the plurality of functions of provision and management of its functional stability, particularly under conditions of heliogeophysical perturbations influence. In this model there are descriptions: 1) the satellite navigation system resources; 2) the satellite navigation system morphology; 3) the set of information services from user navigation provision; 4) models of destabilizing impacts on the system; 5) models of the navigation signal medium; 6) technologies for determination of the positioning with compensation of ionospheric and other errors that arise under the influence of heliogeophysical perturbations and technological links of their implementation.

According to a concept CNS/ATM in the near future aircraft navigation support will be built on the basis of Global Navigation Satellite System [1, 2]. The requirements for civil aviation aircraft navigation support in terms of implementing the concept of ICAO CNS/ATM are primarily determined by the need of high-quality aircraft navigation provision and flight safety in conditions of increasing intensity of flights, and in the near future by the flights refusal on strictly regulated corridors and transition to flight at so-called the most profitable trajectories [1].

Base of navigation subsystem in the concept CNS/ATM are global acting Global Navigation Satellite System GPS and GLONASS; and European navigation satellite system Galileo which gradually puts in place.

According to ICAO recommendations we need to continue efforts to solve the problem of vulnerability of the Global Navigation Satellite System to space weather; to use optimally information about space weather to ensure high performances of global navigation satellite system [7].

In accordance with the decisions of the governing bodies of the International Civil Aviation Organization in 2016 air traffic support by space weather data should be included in regulations of the ICAO, which regulates traffic rules ConOps (Concept of Operations for the Provision of Space Weather Information in Support of International Air Navigation) [7]. As required ConOps since 2016 each ICAO member should establish national space weather services for airlines, which must provide to operators, air navigation services and flight crew reports about geomagnetic storms or storm sunlight occurring and are expected, which could affect communication, navigation, aviation electronic equipment and endanger human health.

The main types of consequences of space weather phenomena negative impact for the safety of aircraft operations are as follows: 1) the increase of the positioning errors during ionospheric disturbances due to appearing changes in electron density towards the spread of the signal from the transmitter to the receiver; 2) the loss of the signal due to the emergence of the scintillation during strong solar storms; 3) the appearance of radiosplashes at frequencies that coincide with the frequencies which are used by satellite navigation system during solar activity; 4) the significant radiation exposure at civil aviation aircraft flight altitudes; dielectric breakdown of aircraft technical devices; failure of aircraft electronic devices; errors in the flight instrument readouts; false geolocation as a result of solar proton events.

Ionospheric disturbances are the main destabilized factor of GNSS operation and the main cause of its failures [8]. The processes that occur in the ionosphere have complex non-linear character. In addition to signal transmitting space (state of the ionosphere and troposphere) navigation support precision is affected by another various factors such as quality of navigation signal, receiver design flaws and others [9]. However, their impact on the navigation support precision can be reduced to the required user level using different technical solutions, while influence of signal transmitting space because of its nature cannot be reduce by technical means.

The data processing system of navigational signals GPS contains Klobuchar's empiric ionosphere model [10]. This model takes into account not irregular, random variations (fluctuations) of ionospheric parameters influenced by changes in space weather. As a result, the Klobuchar's model gives the average error which reaches 50% [10, 11]. In recent years, it was developed an empirical Gemtec model of the ionosphere [12]. The authors of this model for representative volume data have obtained the value of the relative error are 19.6% [12]. Mathematical model IONEX (IONEX – IONosphere map Exchange) allows more precisely compensate the impact of the ionosphere. In the model IONEX the value of the relative error of time definitions is about 30% [13]. Currently there are several ionospheric models that are able to reproduce the electron density profile to navigation satellites orbit heights and they have global character. These models are IRI (IRI – International Reference Ionosphere) and NeQuick (NeQuick – Network Quick-run ionospheric electron density model) [14]. However, according to [13] IRI model is right to the heights of ~ 2000 km and model NeQuick is right to the heights of ~ 20,000 km, the accuracy of models is different and low [14].

The implementation of the elements of the concept ICAO CNS/ATM in the air traffic management system requires improving of the aircraft navigation support quality. With regard to satellite radio-navigation systems there is primarily the need to improve precision of positioning, integrity and reliability.

Requirements for navigation support precision at every stage of the flight are different. To solve the problems of categorical landing using satellite radio-navigation systems it is necessary to improve the precision of setting out of spatial coordinates by reducing of satellite radio-navigation systems positioning errors. In this situation there is possible compensation of satellite radio-navigation systems navigational error in the aerodrome area using single-frequency navigation equipment of GPS users with provision of sustainable navigation aids functioning under external destabilized factors.

Functional stability of civil aviation aircraft navigational provision it is ability to perform functions and provide the basic parameters within the established norms under the influence of external and internal factors [4, 5, 6, etc.].

In a general way ehe complex model of satellite navigation system functioning under the influence of destabilized factors can be represented as:

$$G = \langle M, \gamma \rangle,$$

where, M is the model of satellite navigation system functioning; γ is the model of influence of external destabilized factors.

In turn, the model of the satellite navigation system functioning can be represented as:

$$M = \langle A, U, L, \beta \rangle,$$

where A is multitude of satellite navigation system resources which contains the infrastructure of hardware and software support which consists of the orbital grouping, complex of system management, user equipment, software and information support, means of communication for users (particularly for civil aviation aircraft);

U are the models of navigational signal transmitting space (such as ionosphere and troposphere);

L is the description of GNSS structure, organization of its operation, quantitative value requirements for navigation satellite system, indicators within the established norms (in particular, in compliance with the ICAO, the Radio-navigation plan of Ukraine, the concept CNS/ATM);

β is the description of technology of positioning determination (particularly for civil aviation aircraft) with compensation of ionospheric and other errors which appear under the influence of destabilized factors, hardware and software support methods for satellite navigation system ionospheric errors determination using resources of multitude *A* and *U*.

The general model of influence of external destabilized factors can be described as follows:

$$\gamma = \langle R, \alpha \rangle,$$

where *R* is the multitude of influence of external destabilized factors; α is the space-time structure of influence of external destabilized factors.

Multitude *R* is a set of factors which influence the satellite navigation system operation resulting in aircraft positioning errors, malfunction of systems and failures.

Space-time structure α of influence of external destabilized factors of multitude *R* on satellite navigation system operation characterizes the start of influences, their time duration for regular and non-regular space weather disturbances, the spatial distribution of their impact on navigational signal transmitting space, particularly the uneven distribution of ionospheric disturbances (latitudinal and longitudinal changes of influence) the uneven distribution of troposphere refraction, impact on receiver-transmitter radio equipment tracts, artificially created environment impact (created by the enemy), immediate enemy actions on the system elements. Can be represented as:

$$\alpha = \langle n, m, \tau \rangle,$$

where $n = <A, R, N>$ is the binary relation ($N \subseteq A$xR), which determines the distribution of destabilized factors influence of multitude *R* on multitude of satellite navigation system resources *A*;

$m = <U, R, M>$ is the binary relation ($M \subseteq U$xR), which determines the distribution of destabilized factors influence of multitude *R* on the models of navigational signal transmitting space;

τ is the parameter that determines the duration of influence of destabilized factors and the start moments of their impact.

The mutual influence of external destabilized factors on each other and on the stability of navigation components operation has a very complex nature.

Furthermore in order to solve the navigation task it is necessary the availability of the constellation of at least four visible satellites that enough to determine four parameters x, y, z, ΔT, where ΔT is receiver clock error relative to the satellite clock which are four unknowns in the system of four algebraic equations. Geometric essence of the solution means that two defined points are belonged to three spherical surfaces simultaneously with centers that coincide with satellites position and with radii that are represented as pseudoranges without clock errors.

Errors of satellite navigation system positioning of hardware nature that appear on transmitter-receiver radio equipment tracts (and during hardware signal processing) can be eliminated by improving equipment [2, 9]. Errors associated with the condition of the environment, especially of the ionosphere, aren't eliminated by technical means because of their natural character. This results from the fact that neutral and ionized components of the upper Earth atmosphere change the speed of radio wave propagation. Existing methods of ionospheric error compensation largely (to 95%) remove only regular part of total electron content (TEC) variations in the ionosphere [13].

The ionosphere is the only cause of non-technical malfunctions in the work of satellite navigation system, which is also particularly evident demonstrated during heliogeophysical disturbances. It should be noted that in the two-frequency user equipment, the problem of ionospheric error compensation has been solved with sufficient accuracy. However, due to a number of economic and technical reasons, navigational support of civil aviation aircraft is based on the use, as standard equipment, of single-frequency receivers for which the problem of compensation of ionospheric errors under the influence of heliogeophysical disturbances remains very relevant.

It is expected that the creation of functionally stable satellite navigation system to the impacts of a plurality of destabilizing factors will enable to significantly expand the ranges of conditions for their effective application with constant significant changes in the parameters of the ionosphere; to provide complex optimization of the implementation of the assigned to systems functions; to substantially reduce the time and material costs of development and harnessing of individual hardware and software samples to ensure accurate positioning of aircraft.

5. Discussion

This study includes the analysis of the requirements for navigational support for civil aviation aircraft in the context of the implementation of ICAO CNS / ATM concept; which assumes the global satellite navigation systems as the basis of the navigation subsystem. Currently the requirements to the quality of aircraft navigation support have significantly increased, which leads to the need to improve the integrity, reliability, functional stability and accuracy of the satellite navigation systems positioning.

We have analyzed the problem of determination of the GPS satellite navigation system errors which has showed that the main source of system errors in determination the coordinates in the single-frequency mode is the signal propagation environment. Results show the main contribution to positioning errors is made by the ionosphere due to two factors: 1) low accuracy of the Klobuchar's empirical model of the ionosphere integrated into the data processing system of a single-frequency GPS receiver; 2) the presence in the ionosphere of irregular variations of ionospheric parameters, mainly due to the influence of heliogeophysical disturbances on it under the influence of space weather variation.

The developed in the study generalized comprehensive model of the satellite navigation system operation is the basis for creation of the system for provision of its functional stability. Our proposed mechanisms for provision of the functional stability of the satellite navigation system operation are the content of the organizational and technical level and a range of means, organizational measures and methodological points. They are aimed at active or passive counteraction to the threats to the system disruption or its individual elements under the influence of a variety of destabilizing factors.

This presents study points to the need for additional research of the methods of correction of satellite navigation system ionospheric errors based on the analysis of signal parameters of navigational signals that passed by the ionosphere in order to ensure the steady functioning of navigation aids under heliogeophysical disturbances.

We are planning to determine the impact on the navigational provision of civil aviation aircraft of disturbed by the wave activity ionosphere in terms of the middle latitudes through range research using group of single-frequency receivers for satellite navigation system signal and their combinations with multiple dimensions in terms of quiet and disturbed heliogeophysic environment on the basis of exiting model of the system "ionosphere-plasmasphere".

Upcoming studies include the following stages: 1) the holding of range research at the aerodrome of Flight Academy of National Aviation University to assess the impact of various factors of space weather on the value of civil aviation aircraft positioning errors in GPS satellite navigation system in terms of quiet and disturbed space weather; 2) the analysis of satellite navigation system error that are entered by transformed environment (ionosphere, troposphere) under disturbed space weather on navigational signal transmitting track; 3) theoretical justification of possibility to determine civil aviation aircraft positioning errors in technically serviceable satellite navigation system in terms of distribution of navigation signal on the level of geomagnetic and solar activity; 4) the development and experimental testing of the model that allows to determine satellite navigation system errors and influence of non-regular variations of space weather parameters on the civil aviation aircraft positioning precision.

The expected results are creation and testing of the model that allows to determine satellite navigation system errors under the influence of non-regular variations of space weather parameters on the civil aviation aircraft positioning precision that subsequently will allow:

- to predict failures in the satellite navigation system operation under the influence of non-regular variations of space weather causing the ionospheric errors of radio signal transmitting space under various space weather disturbances;
- to affect the accuracy and reliability of civil aviation aircraft navigation support by identifying errors in positioning under the influence of space weather variations causing the ionospheric transformations of radio signal transmitting;
- to provide the level of civil aviation flight safety by improving positioning precision using single-frequency receivers of satellite navigation system as onboard equipment.

6. Conclusions

To solve the problem of provision of sustainable navigation aids functioning under disturbed space weather it is necessary primarily study the possibility of determination of the impact on the navigational provision of civil aviation aircraft of disturbed by the wave activity ionosphere in terms of the middle latitudes through range research using group of single-frequency receivers for satellite navigation system signal and their combinations with multiple dimensions in terms of various conditions of heliogeophysic environment. The determined patterns will allow to upgrade the existing physical-mathematical and hardware and software methods for determination of ionospheric errors of GPS satellite navigation systems using signal single-frequency receivers; to develop and experimentally test the methods for correct determination of GPS GNSS ionospheric errors through the determination of the most optimal location for single-frequency receivers on board aircraft under disturbed heliogeophysic environment that will be used in further research.

References

[1] Kryzhansky G.A. (2003) Kontseptsiya i sistemyi CNS/ATM v grazhdanskoy aviatsii [The concept and systems of CNS / ATM in civil aviation]. Moscow: IKTs Akademkniga, 415 p.

[2] International Civil Aviation Organization (1998), Doc. 9719. 1998. Report on the world wide CNS / ATM Systems Implementation Conference, Rio de Janerio 11-15 May 1998: ICAO Publications, 58 p.

[3] Kalashnik A.A. and Nedelko V.N. (2014) Primenenie sinerheticheskoho podkhoda – osnovnoi put k sozdaniu novykh intellektualnykh avtonomnykh navshatsyonnykh system na byotekhnolohycheskyi osnove [The application of the synergetic approach is the main way to create new intelligent autonomous navigation systems on a biotechnological basis]. *Control, Navigation and Communication Systems*, no. 3(31), pp.8-17. (in Russian)

[4] Obidin D.M. (2014) Matematychna formalizatsiia funktsionalnoi stiikosti protsesiv upravlinnia litalnymy aparatamy [Mathematical formalization of functional stability control processes aircraft]. *Weapons Systems and Military equipment*, no. 1 (37), pp.179-182. (in Ukrainian)

[5] Barabash O.V. and Bernaz N.M. (2015) Matematychna model zabezpechennia funktsionalnoi stiikosti mobilnykh system [Mathematical model of providing of functional stability of mobile systems]. *Information Processing Systems*, no. 12(137), pp.97-100. (in Ukrainian)

[6] Kalashnyk G.A., Obidin D.M., Kalashnyk M.A. (2016) Zabezpechennia stiikoho funktsionuvannia zasobiv navihatsii litalnykh aparativ pid vplyvom zovnishnikh destabilizuiuchykh faktoriv [Provision of stable of aircraft navigation aids under the influence of destabilizing factors]. *Information Processing Systems*, no. 3 (140), pp.52-56. (in Ukrainian)

[7] International Civil Aviation Organization (2012), Concept of Operations (ConOps) for the Provision of Space Weather Information in Support of International Air Navigation, December 2012/ IAVWOPSG/7-WP/19

[8] http:// www.gps.faa.gov (Accessed 1 March 2018).

[9] Soloviev Yu.A. (2003) Sputnikovaya navigatsiya i eyo prilozheniya [Satellite navigation and its applications]. Moscow: Eco-Trends, 2003. 376 p. (in Russian)

[10] Klobuchar J.A. (1996) Ionospheric effects on GPS, Global Positioning System: Theory and Applications, Published by the American Institute of Aeronautics and Astronomies Inc., Washington DC, pp. 513-514.

[11] Ahmed El-Rabbany (2002) Introduction to GPS, Artech house, Inc., 176 p.

[12] Gorbachev O. A., Ivanov V.B., Nechaev E.E. (2012) Otsenka effektivnosti modeli korrektsii ionosfernoy po-greshnosti Gemtec dlya sistem GPS/GLONASS [Estimating the Effectiveness of Gemtec Ionospheric Correction Model for GPS / GLONASS Systems]. *Scientific Herald of MGTU GA*, no.180, pp.78-83. (in Russian)

[13] Sazhin V.I., Vdovin E.M., Torshina A.E. (2014) Modelirovanie polnogo elektronnogo soderzhaniya ionosferyi [Simulation of the Full Electronic Content of ionospheres [Simulation of the Full Electronic Content of ionospheres], *Izvestiya Irkutsk State University*, Volume.9, pp. 94-102. (in Russian)

[14] Radicella S.M. (2009) The NeQuick model genesis, uses and evolution, Annals of Geophysics, Vol. 52, pp. 417-422.

М.А. Калашник-Рибалко

Особливості забезпечення сталого функціонування засобів навігації під впливом геліогеофізичних збурень

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Мета: Метою цієї статті є дослідження особливостей забезпечення сталого функціонування засобів навігації повітряних суден цивільної авіації, які використовують системи супутникової навігації в умовах впливу геліогеофізичних збурень. **Методи досліджень:** Аналіз вимог до навігаційного забезпечення повітряних суден цивільної авіації в умовах реалізації концепції ICAO CNS / ATM з використанням в якості основного засобу навігації глобальних систем супутникової навігації та організації забезпечення авіаперевезень даними про космічну погоду. Аналіз основних способів моделювання значень повного електронного вмісту іоносфери Землі. Аналіз проблем навігаційного забезпечення повітряних суден цивільної авіації при використанні супутникових систем навігації в умовах спокійної і збуреної космічної погоди. Створення узагальненої комплексної моделі функціонування супутникових систем навігації під впливом зовнішніх дестабілізуючих факторів. **Результати:** Розроблена загальна комплексна модель функціонування супутникових систем навігації під впливом зовнішніх дестабілізуючих факторів. Запропоновано основні механізми функціональної стійкості роботи засобів навігації літальних апаратів в умовах деструктивного впливу на них геліогеофізичних збурень. **Обговорення**: Вивчення можливості врахування варіацій параметрів іоносфери під дією геліогеофізичних збурень космічної погоди і уточнення коригування іоносферних похибок систем супутникової навігації, виходячи з аналізу самих параметрів сигналів навігаційних сигналів, що пройшли іоносферу з метою забезпечення сталого функціонування засобів навігації під впливом геліогеофізичних збурень.

Ключові слова: аеронавігаційне забезпечення; аеронавігаційна система; безпека польотів; геліогеофізичні збурення; дестабілізуючі фактори; концепція CNS /ATM; космічна погода; математична модель іоносфери; модель функціонування супутникової системи навігації; помилки позиціонування повітряного судна; функціональна стійкість; цивільна авіація.

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Особенности обеспечения устойчивого функционирования средств навигации под влиянием гелиогеофизических возмущений

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Цель: Целью данной статьи является исследование особенностей обеспечения устойчивого функционирования средств навигации воздушных судов гражданской авиации, использующих системы спутниковой навигации в условиях воздействия гелиогеофизических возмущений. **Методы исследований:** Анализ требований к навигационному обеспечению воздушных судов гражданской авиации в условиях реализации концепции ICAO CNS / ATM с использованием в качестве основного средства навигации глобальных систем спутниковой навигации и организации обеспечения авиаперевозок данным о космической погоде. Анализ основных способов моделирования значений полного электронного содержания ионосферы Земли. Анализ проблем навигационного обеспечения воздушных судов гражданской авиации при использовании спутниковых систем навигации в условиях спокойной и возмущенной космической погоды. Создание общей комплексной модели функционирования спутниковых систем навигации под влиянием внешних дестабилизирующих факторов**. Результаты:** Разработана обобщенная комплексная модель функционирования спутниковых систем навигации под влиянием внешних дестабилизирующих факторов. Предложены основные механизмы обеспечения устойчивого функционирования средств навигации летательных аппаратов в условиях деструктивного воздействия на них гелиогеофизических возмущений. **Обсуждение:** Изучение возможности учета вариаций параметров ионосферы под действием гелиогеофизических возмущений космической погоды и уточнения корректировки ионосферных погрешностей систем спутниковой навигации, исходя из анализа самых параметров сигналов навигационных сигналов, прошедших ионосферу с целью обеспечения устойчивого функционирования средств навигации под влиянием гелиогеофизических возмущений.

Ключевые слова: аэронавигационная система; аэронавигационное обеспечение; безопасность полетов; гелиогеофизические возмущения; гражданская авиация; дестабилизирующие факторы; концепция CNS /ATM; космическая погода; математическая модель ионосферы; модель функционирования спутниковой системы навигации; ошибки позиционирования воздушного судна; функциональная устойчивость

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