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EVALUATION OF THE REQUIRED GROUND POWER OF A GROUND-BASED SYSTEM FOR SUPPORT OF THE AIRCRAFT SAFE TAKE-OFF AND LANDING

Andrzej Majka

Rzeszow University of Technology
Department of Aircrafts and Aircraft Engines
Powstancow Warszawy Street 12, 35-959 Rzeszow, Poland
tel.: +48 17 8651604, fax: +48 17 8543116
e-mail: andrzej.majka@prz.edu.pl

Abstract

Among the most important problems faced by the air transport today there can be mentioned some negative influences of aircraft and airports on the environment and the increasing costs of air transport. One of the possibilities to improve the situation is to work out innovative solutions aimed at decreasing of the aircraft pollution and improving the transport effectiveness. Among the most innovative ideas is the use of magnetic levitation to aid the take-off and landing of the transport aircraft. The use of the aiding system will bring a lot of benefits, however, regarding its innovative character and the problems connected with it, the idea can have been realized in a couple of years or even decades. The aim of this work was to carry out the analysis of the change to the required thrust of the transport aircraft in the take-off, landing and cruise using the system of magnetic levitation. Magnetic levitation or magnetic suspension is a method by which a body floats due to a special quality of magnets. The generated electromagnetic force is used to balance the weight of the object. The current work describes the ways of determining the weights of the main systems of the aircraft with classical construction solutions where the weight of the whole aircraft is estimated on the basis of the statistical methods. It allows determining the weights of all main systems of the aircraft and verifying the results using the known examples. Thanks to this approach, it could be possible to determine the modified aircraft weight more thoroughly, adding the changes in weights of the modified systems.

Keywords: *air transport, take-off and landing, magnetic levitation*

1. Introduction

Europe is one of the Earth's most densely populated areas. There are approximately 1270 airports and 1300 airfields in Europe. The total number includes 737 European airports that are equipped for IFR operations. In 2010, approximately 9.5 million IFR flights were performed in Europe and the forecast for 2017 assumes a 21 per cent increase in the number of IFR flights, which is an equivalent to 11.5 million takeoffs, and the same number of landings, in the European airports [3]. As much as 44 per cent of the total air traffic is concentrated on only 25 largest European airports. That results in a very high air traffic density in the largest European airports and in their vicinity. What it involves, air traffic in the largest airports and their areas of operations approaches the capacity limits. Such high density of air traffic adversely influences the natural environment in the vicinity of the airports due to the increasing cumulative noise level and the concentration of environmentally hazardous substances. These factors bring about a considerable decrease in the comfort of living for the inhabitants of the areas in the vicinity of large commercial airports. The increased air traffic density in the airports and their vicinity has also a significant impact on decreasing the flight safety level, lowering the safety margin to the absolute minimum, especially during approach and landing operations.

The activities carried out at present with the aim of reducing the harmful influence of the air transport on the environment include implementation of special anti-noise procedures and designing aircraft engines that are quieter and more environmentally friendly (lowered emissions level). The problem of air traffic density increase in hub airports is being solved by reducing the separation between aircraft to the required minimum and optimizing the queuing procedures concerning the aircraft involved in the airport area operations.

All these steps seem to be ad hoc rather than system solutions, addressing only the immediate needs. One of the remedies to the situation is implementation of innovative solutions, e.g. a takeoff-assisting system utilizing magnetic levitation (maglev). Such a system, owing to its reduced engine power requirement in the take-off phase, will help to reduce the adverse effect of the air traffic on the natural environment by reducing not only the emissivity during take-off and landing but also the noise level in the airport and in its vicinity. The maglev-assisted take-off will also have a positive influence on the transport efficiency by reducing the aircraft's weight (lighter landing gear and engines). The traffic capacity of airports and their areas of operations will also be improved owing to the possibility of performing multiple simultaneous takeoffs and landings and reducing the duration of such procedures.

The development of the maglev-assisted take-off and landing system is also connected with the necessity of solving some extremely complex problems, the most difficult of which seems to be performing the actual landing maneuver. The new solution cannot be developed, however, without analyzing the current state and the tendencies present in the air transport.

2. Conventional take-off

The idea of the maglev-assisted take-off and landing system is to propose a radically new system enabling assisted takeoff and landing of transport aircraft. In particular, the study aims at exploring solutions that would allow the use of smaller engines during takeoff (and thus limiting noise and chemical emission in the vicinity of the airport) and a reduced aircraft weight since a standard landing gear would not be necessary any more. This reduction in weight would clearly offer benefits in terms of mission performance.

The new concept directly influences the take-off and landing phases of a mission. Therefore first will be presented simplified approach for the aircraft take-off analysis. Takeoff is a key phase of the mission and there are stringent CS-25 rules that define with a high level of detail several other specific speeds that should be considered during the analysis. However, during this early concept analysis, a simplified approach is used.

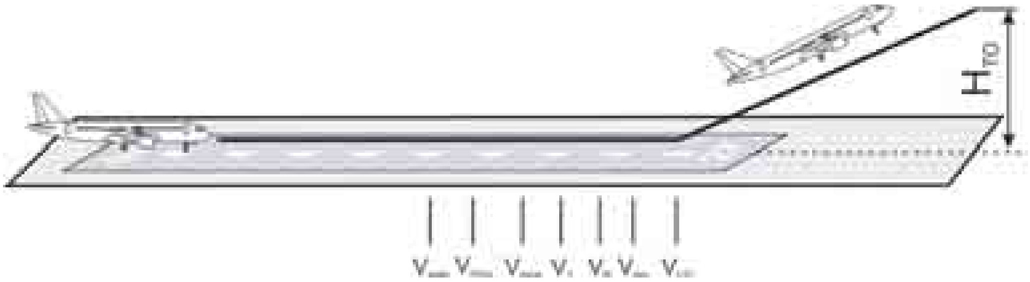

Fig. 1. Conventional take-off [4]. V_{STALL} *- stall speed or the minimum steady flight speed at which the aeroplane is controllable,* V_{MCG} *– minimum control speed, on or near ground,* V_{MCA} *– minimum control speed, take-off climb,* V_1 *– critical engine failure speed,* V_R *– rotation speed,* V_{MU} *– minimum unstick speed,* V_{LOF} *– liftoff speed*

A conventional takeoff operation starts with the aircraft at rest on the runway (Fig. 1). The take-off then consists of acceleration on the runway, a lift-off of the forward wheels, a rotation of the aircraft and an initial stage of airborne time with an initial climb gradient to clear an imaginary screen at a conventional height. Therefore, a complete take-off operation consists of a ground ran and an airborne phase. The angle of attack is constant during the ground run. The ground ran is the distance between brake release and lift-off of the forward wheels. The calculations below refer to the condition All Engines Operating (AEO), unless otherwise specified. The forces acting on an airplane during the ground roll portion of the takeoff are shown in Fig. 2.

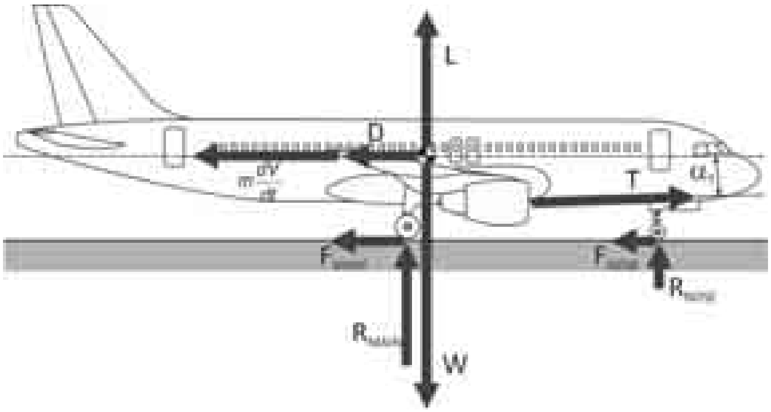

Fig. 2. Forces on an airplane during the ground roll [4, 5]

To calculate the ground run we write the dynamics equations on the centre of gravity of the aircraft in the horizontal and vertical direction, for a takeoff from a horizontal runway. The engine thrust is aligned with the vector velocity. The equations are, respectively

$$T - D - \mu\left(W - L\right) = m\frac{dV}{dt} \cdot \tag{1}$$

Where μ is the coefficient of rolling friction, and a dot above the *V* denotes differentiation with respect to time. μ values can range from approximately 0.02 to 0.1, depending on the surface. The lower value corresponds to a hard, dry surface; the higher value might correspond to moderately tall grass. Before rotation, the attitude of the airplane on the ground is constant and hence C_L and C_D are constant. After rotation, C_L and C_D increase, but still remain constant until lift off. Becoming airborne at the speed V_{LOF}, an airplane continues to accelerate to the speed V_2 over the obstacle height. An airplane that is accelerating both normal to and along its flight path is pictured in Fig. 3.

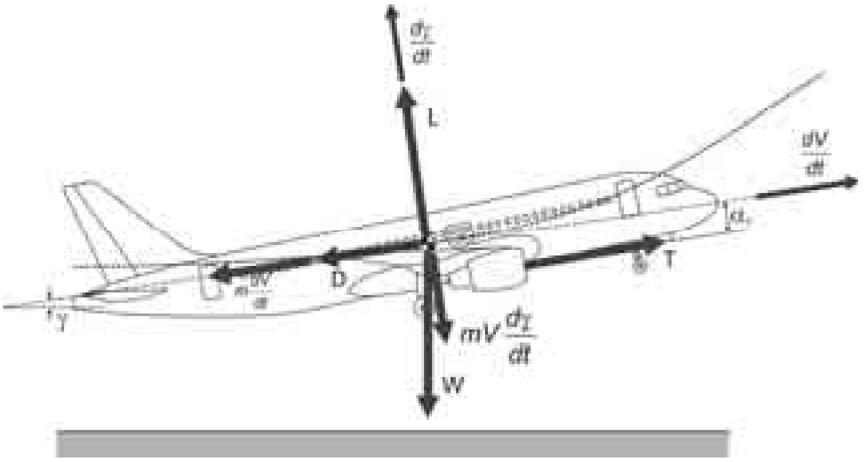

Fig. 3. The forces on an airplane in an accelerating climb [4, 5].

As shown (Fig. 3.), V (*dγ/dt*) is the acceleration normal to the flight path and *dV/dt* is the acceleration along the flight path. The equations of motion normal to and along the flight path can be written as:

$$T - D - W\sin\gamma = \frac{W}{g}\frac{dV}{dt}, \tag{2}$$

$$L - W\cos\gamma = \frac{W}{g}\frac{d\gamma}{dt}V\,. \tag{3}$$

The rate of climb, *dh*/*dt*, is found from:

$$\frac{dh}{dt} = V \sin\gamma \,. \tag{4}$$

Rate of climb is also denoted in the literature by *R*/*C*. Solving for sinγ from Equation (2), Equation (4). can be written as:

$$\frac{dh}{dt} = V\left(\frac{T-D}{W} - \frac{\frac{dV}{dt}}{g}\right). \tag{5}$$

This can also be expressed as:

$$\left(T-D\right)V = W\frac{dh}{dt} + \frac{d}{dt}\left(\frac{1}{2}\frac{W}{g}V^2\right), \tag{6}$$

where (*TV*) is the available power and (*DV*) is the required power. Thus (*T* - *D*)*V* is the excess power that, as Equation (6) shows, can be used either to climb or to accelerate. Actually, Equation (6) is an energy relationship that states that the excess power equals the sum of the time rates of change of the potential energy and the kinetic energy.

Let us now apply these relationships to the calculation of the horizontal distance required during the takeoff flare to attain a specified height. The actual flight path that is followed during the flare, or transition, segment of the takeoff depends on pilot technique. Referring to Equations (2) and (3), *V* and γ are the in dependent variables, while *g*, *W* and *T* are known, the latter as a function of *V*. *L* and *D* are functions of *V* and the airplane's angle of attack *α*. By controlling *α*, and hence C_L, the pilot can fly a desired trajectory (i.e., the pilot can accelerate or climb or do some of each). During the takeoff, however, in attempting to clear an obstacle, Regulations CS-25 limits the operating C_L to approximately $C_{Lmax}/1.21$ at V_{LOF} and to $C_{Lmax}/1.44$ at V_2.

Therefore, in calculating the flare distance, it will be assumed that C_L varies linearly with *V* between these limits and is constant for speeds above V_2. Thus, if V_2 is attained before the specified obstacle height is reached, the stall margin on C_L is maintained.

3. Take-off and landing with ground-based power

The stakeholders of the aeronautical industry and air transportation system agreed that the future air transport must ensure customer satisfaction, while being greener, safer, more secure and more time/cost effective. By reducing the fuel consumption and therefore the environmental load, the aircraft weight reduction might be the most effective method to make the future air transport more effective and environmental friendly. Considerable weight reduction needs radically new solutions.

There are several technologies that could be applied to reduce the weight of the aircraft. The use of the composite materials seems to be the most effective method. According to the new developments, the airframe weight can be reduced up to 25 %.

Novel ideas include, for example, the operation of the aircraft without the conventional undercarriage system and using the ground based power and supporting systems for the take-offs and landings. In this case, the size and the weight of engines can be reduced, the hydraulic and pneumatic systems could be modified or removed, which reduces weight even further, and decreases fuel consumption. These changes will have a great influence on the aircraft's aerodynamics, flight performance, as well as on the environmental impact in the airport areas.

The advanced take-off and landing technologies are developing for two different purposes: reducing fuel consumption of the aircraft and reducing the airport area. In the first case, three major concepts can be developed.

First, it changes the environmental condition of take-off and landing with the different physical principles. For example, the catapult systems, whirling take-off, spiralling rail take-off, spiral launched drones for freight and banked runways, or generating the air fluidic “runway”. These methods, on the one hand are based on the simple physical phenomena, but on the other hand their realization is questionable and their effectiveness seems to be too low.

Another concept is based on the use of ground power transferred to the aircraft by microwaves. This microwave transformation of energy is a potential candidate technology for the future application. However, this technology alone does not seem to be effective to assist the targeted take-off and landing.

Finally, the third interesting technology is magnetic levitation that is more effective and can be applied earlier. Magnetic levitation or magnetic suspension is a method by which a body floats due to a special quality of magnets. The generated electromagnetic force is used to balance the weight of the object.

3. Ground-based system using MAGLEV technology

The “Integrated Ground and on-Board system for Support of the Aircraft Safe Take-off and Landing” – GABRIEL, deals with radically new integration of the MAGLEV technology into the air transportation system that contains aircraft, airport, air traffic control, authority, logistic and operational support, maintenance, etc. [7]. Implementation of the MAGLEV technology has influences on all this system elements. It will influence the major changes in the aircraft structure, airports infrastructure and regulatory aspects.

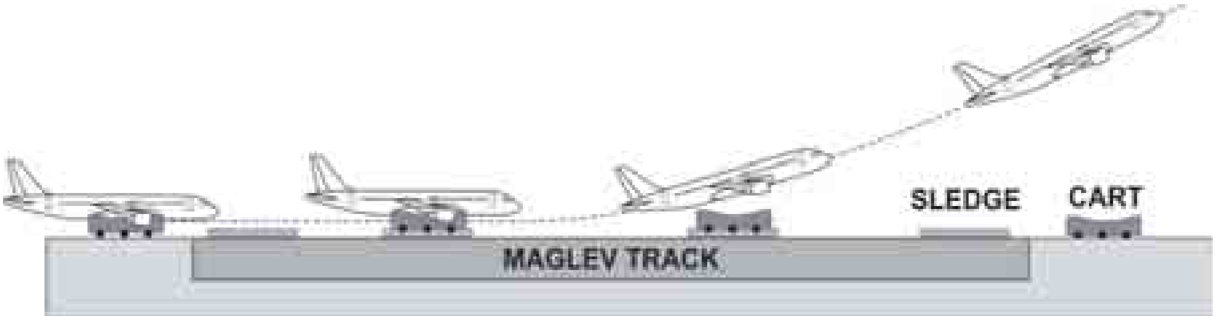

Fig. 4. GABRIEL concept - aircraft carried on the cart and connected to the sledge [7]

The Gabriel concept has the major effects on the aircraft, especially on the aircraft weight and energy balance. As the GABRIEL concept is under development, the analysis deals with developing an engineering methodology for evaluation of the changes in the aircraft weight and energy support.

Designing a new aircraft requires working out precise analytical models, which determine the following characteristics: geometrical, aerodynamic, engine system and utility characteristics (e.g. performance). One of the most difficult tasks is to estimate the aircraft weight and all its systems with enough precision as to the designing aims, as not all weights are justified from the point of view of the construction or the strength. The correct estimation of the weight characteristics has an influence on the other characteristics of the aircraft, especially its performance. This task becomes even more difficult in the situation when an aircraft with unconventional constructive solutions is being designed.

Formulating the principles of the GABRIEL project, it was stated that an aircraft equipped with a device helping it to take-off (Fig. 4.) and land using the phenomenon of magnetic levitation would be to some extend a modification of the already-existing construction in which some systems would not be modified (wings, fins, deck facilities etc.) and some parts would be modified for the needs of the MAGLEV system (for example, the lower part of the fuselage, power unit and so on).

4. Aircraft characteristics estimation

The aircraft weight has a direct effect on the noise and pollution impact in the airport areas, as well as on the cost efficiency. An aircraft of a smaller weight needs less lift, and has less drag. If ground launched technologies are applied, that accelerate and "launch" the aircraft in the air, than the thrust requirements could be substantially reduced even over the initial climb phase, as only such thrust would be needed that is required to maneuver and fly. In the case of using the magnetic levitation technology, the airframe weight can be considerably reduced, since the undercarriage system could be lighter or even be ignored. The required engine thrust is determined by the take-off phase in which a substantial thrust is needed. Once airborne, a far less thrust is needed to keep the aircraft in the air and to maneuver. Therefore, if the aircraft could take-off and start the initial climb phase with the ground power, the installed thrust may be reduced, resulting in less weight, less drag and less overall fuel consumption that leads to emission reduction.

The current work describes the ways of determining the weights of the main systems of the aircraft with classical construction solutions where the weight of the whole aircraft is estimated on the basis of the statistical methods. It allows determining the weights of all main systems of the aircraft and verifying the results using the known examples. Thanks to this approach, it could be possible to determine the modified aircraft weight more thoroughly, adding the changes in weights of the modified systems.

Understanding of the weight characteristics is essential for the energy balance of all phases of the flight. On its basis it is possible to determine the thrust demand in the take-off and the thrust demand for the braking operation of the aircraft during its landing. Determination of the thrust demand would be carried out using simulating methods whose application requires the knowledge of the other technical characteristics of the aircraft and the take-off and landing profile. Based on the results of the energy balance it would be possible to make a choice of technical characteristics of the systems helping the takeoff, especially the participation of the engine system and the MAGLEV system, which ensures maximization of the chosen estimation indicator.

The first estimation of the radical changes in the structure and operation of the aircraft may be based on modification of the simplified and well-known weight and required thrust calculations that are described by many authors. This paper is mostly based on the methods described by [2, 6, 8, 10]. All these methods are based on the weight balance carried out for a stated relative division of the aircraft into parts and subparts. All these methods use the formulas developed on the basis of the dimensional analysis the constants of which are determined using statistic methods. Each method is in fact a nonlinear equation, which is solved regarding the maximal take-off weight. The most frequently used method is the iterative method. It requires determination of the first approximation of the solution meeting certain criteria, which ensures obtaining the consecutive order convergent to the exact solution. It is suggested to divide the estimation of the take-off weight of the aircraft into three stages. The estimation in the first stage would be made using the combination of Raymer method [6] and Badjagin method [2] as the simplest and less exact. In the second stage the Torenbeek method [10] would be used to improve the precision of the mass estimation. The Roskam method [8] as the most exact would be used during the third stage.

The weight breakdown will concentrate on the prediction of the weight of the aircraft main parts and systems that might be modified as a result of the GABRIEL concept implementation.

The thrust required will be analyzed from the aircraft point of view. For this purpose, the aircraft flight performance must be determined first. It needs evaluation of the aerodynamic characteristics, which are necessary to estimate the aircraft performance. The aerodynamic characteristics should be estimated for 3 different configurations, two low-speeds: the take-off and landing, and third, the en route configuration. The two low-speed configurations should take into account the ground effect. The estimation in the first stage would be made using the classical methods presented in [1, 2, 5, 9]. In the second stage the suggested methods give a lot of precision of the aerodynamic characteristics and are based on the use of the advanced CFD techniques.

The aircraft performance was estimated taking into account the limits which follow from the requirements concerning the current procedures of the take-off (Fig. 1.) as well as the approach and landing of the aircraft in accordance with the flight operational procedures [1, 5, 4]. Then the methods of defining the aircraft performance in different phases of the flight using the classical equations of motion were used.

The goal of the energy balance is the investigation of changes in required thrust. This paper, at this stage of the concept development, deals with the thrust required for reaching the required flight performance only. The energy methods are used for the transport aircraft performance characteristic analysis, which will be helpful for making the energy balance of each of the chosen phases of the flight. The example results are presented for heavy transport aircraft whose technical characteristics are known with enough precision (such as the weight characteristics, aerodynamic and power unit characteristics).

The analysis of required power

In the work the change in the weight, required thrust and transport efficiency coefficients was carried out. It was supposed that the aircraft using the aiding system in the take-off and landing phase is the modification of the Airbus A-320. The presented results for the modified version were compared to the calculating characteristics of the aircraft, which takes off and lands conventionally.

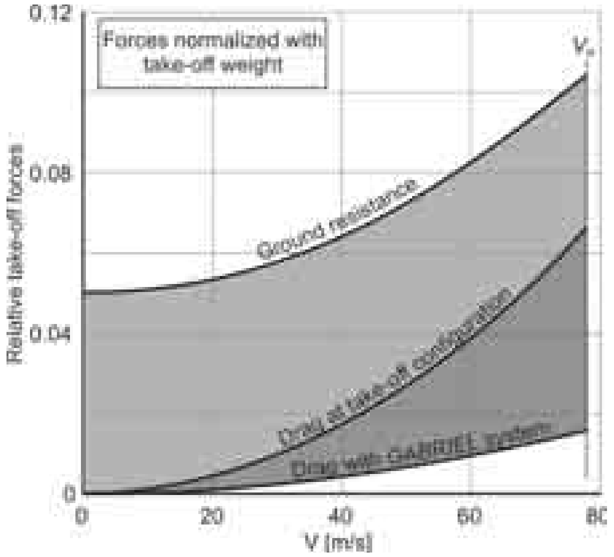

Fig. 5. Relative take-off forces for conventional aircraft and aircraft with GABRIEL system (shaded area shows difference)

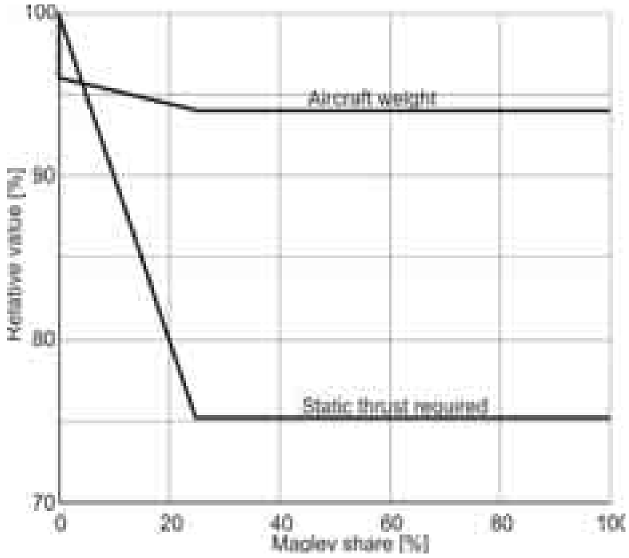

Fig. 6. Relative maximum take-off weight and static thrust

Figure 5 presents the change of relative forces normalized with maximum take-off weight affected on the aircraft during take-off for conventional aircraft and aircraft with GABRIEL system. With use of GABRIEL system aerodynamic drag will decrease due to another configuration (no flaps) and less lift coefficient. Ground resistance drops away. Fig. 6 presents the change in the relative thrust required and relative aircraft weight depending on maglev force share with influence of the conditions of the flight.

Summary

Nowadays there are a lot of works being carried out whose aim is to find the way of improving the air transport efficiency and reduce its negative influence on the environment. Among different ideas, a group of solutions can be separated which stands out of the common schemes and can be an alternative way of development in the future. This group includes the following ideas: the ground aiding system of the aircraft take-off and landing using the phenomenon of magnetic levitation. This is an advanced innovative idea, it is not schematic (out of the box). Implementation of this idea requires a solution to a number of important and complex technical problems. However, the benefits, which can be gained due to implementation of this system, are worth the investment necessary to improve the system.

The presented work focuses on the analysis of the change in the required thrust and the factors of the transport efficiency of the aircraft in the take-off and landing phase using the system of magnetic levitation. On the basis of the obtained results it can be noticed that the introduction of this system can be justified not only regarding ecological matters (decreased emission of harmful substances and noise pollution) but also regarding economic factors.

Acknowledgments

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