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MAGLEV ASSISTED TAKE-OFF

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Summary: 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. 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. There are several technologies that could be applied to reduce the harmful influence of the air transport on the environment. 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. If ground launched technologies are applied that accelerates and “launches” the aircraft in the air, than the power requirements could be substantially reduced even over the initial climb phase, as only such power would be needed that is required to manoeuvre and fly. One of the major concepts is using magnetic levitation (MAGLEV) technology to support aircraft take-off and landing. In 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 power is determined by the take-off phase in which substantial thrust is needed. Therefore, if the aircraft could take-off and start the initial climb phase with ground power, the installed power may be reduced, resulting in less weight, less drag and less overall fuel consumption that leads to emission reduction. In addition, less weight decreases the wake vortex that affects the airport capacity issues, whilst the production of aircraft having a smaller weight leads to savings on materials. These advantages, the lower fuel consumption and emissions, increase the sustainability of the transportation system.

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

1. INTRODUCTION

Europe is one of the densely populated continents on Earth. European Union occupies the area of 4,324,782 sq km and combined population of all 27 member states was forecast at 503,663,601 as of 1 January 2012 [7]. Its meridional extension is 4,200 km and its parallel extension is 5,600 km. The highest peak is 5,642 m above the sea level. These dimensions also characterize the field of functioning of the European transport market. There are approximately 1270 airports and 1300 airfields in Europe [3]. 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 take-offs, and the same number of landings, in the European airports [6]. As much as 44 per cent of the total air traffic is concentrated on only 25 largest European airports [5]. This results in a very high air traffic density in the largest European airports and in their vicinity. What it involves is that the air traffic in the largest airports and their areas of operations approaches the capacity limits. Such high density of the 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 surroundings 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 the air traffic density increase in the 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 take-off-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 take-offs and landings and reducing the duration of such procedures.

2. NEW CONCEPTS

The aircraft take-off is one of the most essential phases of the flight. The take-off of a large aircraft [4] consists of a run which ends by the rotation and four air stages: acceleration and climb in configuration to the take-off, retracting the landing gear, further climb and acceleration to the height of the configuration change, climb in the flight configuration until reaching the height of 457 m (1500, ft) above the take-off level, see Figure 1. The low efficiency of the take-off phase is caused by a relatively low liftoff speed in relation to the flight speed which is usually close to the maximal speed of the given aircraft. A large angle of attack at which the aircraft moves in the take-off phase and the extended devices increasing the carrying capacity (flaps, slots and so on) cause a high coefficient of the aerodynamic drag and relatively low lift/drag ratio. Additionally, the
extended landing gear increases the aerodynamic drag and the resistance connected with the friction force during the bowling of the aircraft at the runway. In the case of the conventional take-off there is no possibility to significantly increase the liftoff speed regarding the operation limitations of the landing gear, especially the durability of the tires, ability to dissipate the energy by the brakes, and landing gear strength and its retracting mechanism to the aerodynamic load. The small speed of the liftoff also follows from the limited abilities of the aircraft acceleration on the currently existing runways.

![Figure 1. Conventional take-off (Source: Own elaboration based on [8])](image)

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%.

New 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, spiraling 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 micro waves. 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.

2.1. TAKE-OFF WITH GROUND-BASED POWER

New technologies of the aircraft take-off and landing are mainly focused on: decreasing the fuel consumption and decreasing the surface of areas occupied by the airports. The first mentioned aim can be achieved by different methods: the aircraft take-off with using the catapult or the rail track, wireless microwave sending of energy used by the aircraft for the take-off and landing, using the phenomenon of the magnetic levitation (MAGLEV) in the phases of a take-off and landing etc.

The MAGLEV technology is one of the most effective methods of accelerating of the aircraft in the phase of the run operation. The use of this technology requires working out a ground based system, determining the range of modification of the aircraft design and working out the procedures of safe landing, including emergency landing. This technology is well known and has been used for many years in the design of trains which travel at very high speeds. It is considered to be safe and ecologically friendly. However, using it to accelerate and decelerate an aircraft requires additional theoretical and experimental research which should give an answer whether this system can be implemented, is safe and economically reasonable.

The use of the system to aid take-off and landing of the aircraft should allow improvement the economic factor, safety and decrease the difficulty of these phases, especially noise and harmful substances emission into the environment. It can also contribute to development of very fast aircraft (e.g. hypersonic) which in the normal conditions were not able to spread their wings regarding the limitations of the contemporary wheel landing gear and the length of runways.

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. 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.
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.

Formulating the principles of the GABRIEL project, it was stated that an aircraft equipped with a device helping it to take-off (Figure 2.) 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).

Having analyzed different variants of the system the conception of the movable sledge was chosen which uses the Inductrack system [12, 13]. The conception supposes the use of a levitating vehicle in the form of a sledge on which a cart is placed; the aircraft stays still on the cart (Figure 2). The cart will move on the track of the Inductrack system constructed of two rails in the form of a laminate consisting of many sheets of copper. This system of levitation is currently the cheapest to construct, however it has not been commercially used so far.

The best effects of applying the system will be achieved for a specially designed aircraft. However, the versatility of the solution will allow using it for the existing constructions after performing some modifications. The linear synchronous motor will be responsible for accelerating and braking of the sledge. Its power would allow accelerating and braking of the heaviest aircraft keeping the safe acceleration.

3. AIRCRAFT CHARACTERISTICS ANALYSIS

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 manoeuvre 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. 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 [9].

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 [1, 2, 8, 10, 11, 14, 14, 15, 16]. The estimation in the first stage would be made using the combination of Raymer method [11] and Badjagin method [2] as the simplest and less exact. In the second stage the Torenbeek method [16] would be used to improve the precision of the mass estimation. The Roskam method [14] as the most exact would be used during the third stage.

The aerodynamic characteristics should be estimated for 3 different configurations, two low-speed: 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, 8, 10, 15, 16].

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4. RESULTS

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 traditionally.

Table 1 presents possible weight changes of modified group of an aircraft thanks to the application of the GABRIEL system.

<table>
<thead>
<tr>
<th>No.</th>
<th>Description</th>
<th>Weight changes, kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Wing group</td>
<td>-313,24</td>
</tr>
<tr>
<td>2.</td>
<td>Undercarriage group</td>
<td>-2 896,32</td>
</tr>
<tr>
<td>3.</td>
<td>Main landing gear doors with bear straps</td>
<td>-116,60</td>
</tr>
<tr>
<td>4.</td>
<td>Nose landing gear doors with bear straps</td>
<td>-23,40</td>
</tr>
<tr>
<td>5.</td>
<td>Ventral fairing</td>
<td>-382,80</td>
</tr>
<tr>
<td>6.</td>
<td>Power unit group (mounted)</td>
<td>-272,24</td>
</tr>
<tr>
<td>7.</td>
<td>Hydraulic, pneumatic and electrical</td>
<td>-86,85</td>
</tr>
<tr>
<td>8.</td>
<td>Three-point connection system (legs)</td>
<td>1 312,99</td>
</tr>
<tr>
<td>9.</td>
<td><strong>Total</strong></td>
<td><strong>-2 778,46</strong></td>
</tr>
</tbody>
</table>
Figure 3 shows the aerodynamic polar of the reference aircraft (continuous line) and modified / GABRIEL aircraft (dashed line) at different height of flight, from flight level 250 to flight level 400. Reference aircraft characteristics are determined for weight of 65 000 kg. For the same conditions modified aircraft has 2 778,46 kg smaller weight (see Table 1). The drag and lift coefficients of the GABRIEL aircraft are smaller than those for the reference aircraft, at the same Mach number.

Figure 3. Aerodynamic polar at cruise conditions

Figure 4 shows more clearly the difference between drag coefficients (proportional to required thrust) of the modified (dashed line) and reference (continuous line) aircraft at the
same Mach number and for different heights of flight. With increasing altitude, the difference gets more and more significant, especially at smaller Mach numbers. There is no significant effect of the cruise height of flight at cruise Mach numbers on the drag coefficient (required thrust).

Taking into account the artificial limitations of the thrust in the initial phase of the run up which follow from the limitations of the acceleration which can be safely endured by the onboard passengers (physiological limitations) it is possible to determine the relation of the roll-out speed in the function of the distance covered by the sledge (Figure 5). For the accepted assumption (the thrust of the linear motor and the weight of the accelerated system) the system is able to aid the take-off of the aircraft similar to the Airbus A-320 to the speed of 151 m/s. At higher speeds the relation between the power and the weight of the aircraft itself is higher than the relation between the power and the weight of the sledge-aircraft set.

![Figure 5. Relation between roll out speed and distance covered](image)

The cruise performance of the aircraft mainly depends on its weight. A high lift-to-drag ratio of the transport aircraft will be reflected in the decrease of the relative thrust required to perform a horizontal flight at about 0.5% not giving a significant decrease of the consumed fuel. However, thanks to the smaller weight of the aircraft construction with the GABRIEL system, it will be possible either to take additional fuel or additional commercial cargo. It will cause an increase in the transport efficiency of the aircraft comparable to the decrease in its design weight. Another significant factor is the modified take-off (lack of taxiing, aided take-off by the GABRIEL system, different take-off profile) as well as landing procedure. Due to this, the aircraft on the take-off phase will definitely consume less fuel and will start the cruise at a higher initial weight. Thanks to this, the aircraft will have an increased range or higher load-carrying capacity depending on the needs.
Figure 6. Payload-range diagram with needed fuel weight for the reference aircraft and aircraft with GABRIEL system

Figure 6 shows the payload-range diagram with the required fuel weight for the reference and the GABRIEL aircraft. The dash line shows the fuel weight for the GABRIEL and the transportation capabilities identical to the reference aircraft. The fuel weight in the region of the maximum range is visibly lower than for the reference aircraft. The continuous line presents the maximum increase of the transport capabilities related to the GABRIEL aircraft and equivalent fuel weight change.

5. CONCLUSION

This analysis found that:
- A 4-5% of decrease in the take-off weight is feasible, if the take-off and landing processes are assisted with the GABRIEL concept, and thus the aircraft is not equipped with the traditional undercarriage.
- A 4-5% of drag reduction under cruise conditions are feasible, which would help to reduce fuel consumption. This is achieved through the smaller aircraft weight (a smaller induced drag), the modification of the wing-fuselage center section and the smaller dimensions of the engine nacelles.
- Potential fuel consumption cut in the take-off phase and during the initial climb depends on the lift-off speed of the aircraft. For the speed similar to that of a traditional aircraft, the reduction of the fuel consumption would not be more than 25%. For the supposed higher lift-off speed, the fuel consumption reduction would also increase, which would result in a higher range.
- The maximal potential range extension could be achieved with the maglev assisted TOL processes.
- A decrease in the airport area (the runway length) would be possible only at the lift-off speed similar to that of a traditional aircraft. If one wants to use the effect of the aided take-off to the full, it is necessary to build magnetic runways with the length similar, or even longer than the present length.
- The risk during the take-off aided by the GABRIEL system is not higher than the risk during the traditional take-off.

Acknowledgments

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References

START SAMOLOTU WSPOMAGANY SYSTEMEM MAGLEV

Streszczenie: Ruch lotniczy na największych lotniskach oraz w ich obszarze operacyjnym zbliża się do granicy przepustowości. Tak duże nasilenie ruchu lotniczego oddziaływuje w sposób bardzo niekorzystny na wokół lotniskowe środowisko naturalne poprzez kumulację emisji hałasu oraz substancji szkodliwych oraz wpływa znacznie na obniżenie poziomu bezpieczeństwa lotów. Obecnie podejmowane są działania doraźne, których celem jest zmniejszenie szkodliwego oddziaływania transportu lotniczego na otaczające środowisko. Jednym ze sposobów poprawy sytuacji jest zastosowanie nowatorskich rozwiązań, np. wspomagania startu z wykorzystaniem zjawiska lewitacji magnetycznej. System taki, dzięki mniejszemu wymaganemu poziomowi mocy silników w fazie startu, wpłynie na obniżenie niekorzystnego oddziaływania samolotów na środowisko naturalne poprzez redukcję emisyjności w fazie startu i lądowania oraz poziomu hałasu na lotnisku i w jego obszarze. Start wspomagany magnetycznie wpłynie również na zmniejszenie masy samolotu (lżejsze podwozie oraz silniki) co wpłynie korzystnie na poprawę efektywności transportowej. Celem pracy było przedstawienie koncepcji systemu wykorzystującego lewitację magnetyczną do wspomagania startu i lądowania samolotu transportowego oraz analiza korzyści wynikających z jego zastosowania.

Słowa kluczowe: transport lotniczy, lewitacja magnetyczna, start samolotu