The neural networks application for estimation of wheels braking actual parameters for an airplane on the runway covered with precipitations

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Abstract: The experience of neural network application for determination of airplane’s wheels drag actual coefficient on the runway covered with precipitations is introduced. DCSL (Dynamic Cell Structure) neural network from “Adaptive Neural Network Library” was selected as a tool of identification. The task is solved in Matlab Simulink environment. The program includes math model of aircraft motion along runway. Available aerodynamic and altitude-airspeed performances of engines are used. Runway surface gradients (slopes), which correspond to the experimental data, are taken into account. The data from airplane runs during flight tests in actual conditions are used to create a samples for neural networks training. The obtained by identification wheels drag parameters (braking, rolling resistance and contamination drag) and the convergence between the results received in test modeling and the experimental data are shown.

Keywords: Adaptive Neural Network, Math model of aircraft motion along runway, Identification, Runway surface gradients, Flight tests, Braking resistance, Rolling resistance.

1. Introduction

The experience in development and application of the procedure for the flight dynamics math model parameters estimation according to flight tests data [3, 4] has shown that the most complicated element of practical identification tasks is the adjustment of identification results obtained from different samples of initial data. The effort to solve this problem was made in the procedure [3] by identification of corrections for aerodynamic coefficients with “parallel” optimization of disagreement criteria in two (some) flight test data fragments obtained in similar conditions at similar speed and altitudes (for example: maneuvers with stick “to the left” and “to the right”, “forwards” and “backwards”). However, when solving the problem [4], main efforts were made to adjust the corrections determined by identification procedure on different data samples.

Artificial neural networks (ANN) include adaptive algorithms, which make it possible to simulate mathematical relations between input and output parameters of the object. Moreover, unlike the traditional identification methods, neural networks have a memory: it means that the results could be verified and accumulated during repeated “training” cycles (during the
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processing of new samples of initial data). Thus, neural networks allow getting the required relations for wide range of conditions at once and, as a result, to align random factors, which are unavoidable for experimental data.

This paper represents the experience of neural network application for solving the task of rolling resistance and wheels braking coefficients identification (during the aircraft takeoff run at the concrete runway). In recent years international aviation organizations used to pay much attention to the analysis of aircraft behavior during its motion on runway, in particular during take-off and landing on precipitation-covered runway. For instance, since 1996 NASA, FAA and Transport Canada have been performed JW/RFMP program (The Joint Winter Runway Friction Measurement Program). Present-day knowledge about aircraft behavior on the contaminated runway are generalized in the amendment to European certification requirements (NPA No. 14/2004)[6], developed by JAA, but the conclusion on the necessity of further investigation of this problem was made. Reports on flight accidents, related to aircraft overrun the runway indicate the necessity of such research.

At this stage we considered to estimate the efficiency of neural networks as the means of identification of the aircraft motion math model parameters. For this purpose was selected the simple enough but having practical importance task: evaluation of wheels compression and their rotational speed influence on the friction coefficient value (for dry concrete runway). This task is presented here in details.

Further developed more complex procedure based on ANN application, which is presented here in main results, is intended for identification of dependencies describing wheels resistance and braking performances on precipitation-covered runway (see [5]).

2. Longitudinal Forces During Takeoff Run

The given task is related to rolling friction for the entire aircraft wheel system, i.e. difference in conditions of separate wheels rolling is not taken into account. It is supposed that under these conditions the load on MLG wheels is distributed uniformly, and the load on NLG wheels is low, i.e. the error due to such simplification can not be large because of the inessential share of NLG wheels in the total resistance to rolling.

In the given task, projections of the forces to longitudinal axis (along runway) are presented as follows:

\[ F_x = P - G \cdot \sin(i) - X_{aero} - F_R \]  

\[ G \] – aircraft weight;  
\[ i \] – runway slope angle (uphill >0);  
\[ P \] – engines thrust;  
\[ X_{aero} = C_D \cdot q \cdot S \]  
\[ q \] – dynamic pressure, \( S \) – wing area;
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\[
F_R = \mu_R F_y, \\
F_y = G \cdot \cos(i) - Y_{aero}, \\
Y_{aero} = C_L \cdot q \cdot S.
\]

For dry, rigid horizontal surfaces, it is typically observed \(\mu_R = 0.005 - 0.03\) [1].

3. Problem Definition

Neural network is a tool of identification. Dependency of friction coefficient from the ground speed \(V_{travel}\) and the load on wheels \(F_y\) must be obtained during “training” process in the neural network (minimization of mismatch between empirical and calculated accelerations).

To solve this problem the simplified math model of aircraft motion along runway is developed. For identification purposes, math model is realized in the form of longitudinal accelerations computation in the process of reproduction of real aircraft runs conditions.

\[
\dot{w}_x = \frac{F_x}{m}, \quad \text{where} \quad F_x \text{ refer to formula (1),} \\
m \text{ is aircraft mass.}
\]

In the process of identification, mismatch between empirical \(w_{x_{emp}}\) and calculated accelerations is to be minimized. Minimization of accelerations mismatch is performed by modification of friction forces (rolling friction coefficient values). Other components of calculated acceleration are supposed to be valid. \(w_{x_{emp}}\) values are determined from \(V_{travel}\) experimental data. The task is solved in Matlab Simulink environment.

4. Identification Procedure

DCSL (Dynamic Cell Structure) neural network from “Adaptive Neural Network Library” [2] was selected as a tool of identification. The library [2] includes several versions of neural networks. During the performance of this work other variants were tested as well. The experience has shown that DCSL neural network is the best for our task, as it requires a small number of repeated “training” cycles to get high convergence in the separate sample of data. It is also very important that this neural network keeps high convergence when returning to the initial sample after training with the other samples. Main elements of identification algorithm are shown at Fig. 1.

5. Identification Results

The identification has been performed using four samples of aircraft take-off run in actual conditions. The samples, describing takeoff run process for different take-off weights, were selected.

Parameters of neural network do not give a visual presentation of the \(\mu_R (F_y, V_{travel})\) dependence received. To present the identification results visually, the neural network “probing” was performed. The results obtained
The obtained dependence is shown in Fig. 2.

It should be noted that not all of the “load-speed” combinations, which are given in Fig. 2, were available in the flight tests data. At low speeds (about zero), the aerodynamic unloading is not available, and the loads were not lower than 140 tons. At high speeds, the loads grew smaller (high loads were absent).
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6. Check Modeling
To analyze the validity of obtained rolling friction coefficient estimations, the check modeling task has been developed. In this task, the determination of friction coefficient is provided using three methods:
- by direct usage of neural network;
- by usage of $\mu_R (F_y, V_{travel})$ dependence obtained by neural network “probing”;
- by usage of constant value of $\mu_R = 0.02$.

The results of this paper demonstrate that influence on $\mu_R$ of wheels compression and wheels rotational speed really exists. Though, one must admit that for the computation of takeoff run characteristics in general conditions, this influence appeared to be inessential. Satisfactory convergence with experimental data is also observed using a constant (averaged over the obtained relation) value of coefficient.

The test consists in $L_{travel} (V_{air})$ comparison of dependences (obtained in the experiments and by computations). The test was performed for four data samples that were used for identification (neural network training). The test was also performed for three additional samples of data, which were not taken into account during neural network training.

Test results have shown the acceptable convergence of experimental and computational distances traveled during take-off run versus air speed reached. The satisfactory convergence is observed also for samples of initial data that were not used during neural network training.

![Fig. 3.](image)
The example of computations results in which the determination of $\mu_r$ value was done by different methods are compared and shown in Fig. 3. As it is evident from figures, the form of $\mu_r(F_y, V_{travel})$ dependence practically has no effect on the result during the computation of takeoff run length. In other words, to calculate the takeoff run length, the identification of rolling friction coefficient could be reduced to simple selection of constant value of $\mu_r$. It is possible to assume, that relation of friction coefficient $\mu_r$ to the load on wheels and their rotational speed must become more obvious in the math modeling of taxiing or run with the significant difference in loads on landing gear legs (if cross wind is strong).

7. Estimation of Actual Aircraft Braking Characteristics under Different Runway Conditions

Similar approach of ANN application has been used for identification of dependencies describing Be-200 amphibian aircraft wheels resistance and braking performances on precipitation-covered runway. This task needed to develop algorithm including more complex longitudinal forces formula than (1) and two ANN blocks were trained simultaneously (see [5]). In first ANN rolling resistance coefficient was estimated for complex: rolling itself and contamination drag (respectively to wheels load) in dependency $\mu_{rD}(\delta/r, V)$ from wheel inflation and aircraft ground speed. Braking coefficient (second ANN) was estimated as a dependency $\mu_{t/g}^{MAX}(V)$ from aircraft ground speed. In Fig.4 the final stage of identification process is shown: how neural networks changed the braking coefficient (left) and how it influenced the ground speed time histories. Fig.5 shows identification results: a) for dry and the compacted snow covered runway, b) for runway covered with slush. Dependencies are received by “probing” of neural networks (ANN) and smoothing (sm).

8. Future Solutions for ANN-based Identification Tasks

The accomplished research shows the possibility of neural networks application for the aircraft math model parameters identification. It is shown that ability to deal with dependencies instead of separate values and to align random factors in experimental data sets are provided using ANN-based approach. Advanced algorithms and estimation procedures will be required for aerodynamic characteristics identification. The algorithms, assumed in this paper, are based on the direct monitoring (minimization) of the calculated and empirical accelerations mismatch. Hypothetically, such approach can be used only for estimation of aerodynamic parameters, which characteristics become apparent in static or almost static flight conditions (during trimming, smooth approaching to the runway surface in order to estimate the ground effect, etc).
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Taking into account the measurements insufficiency and errors it is reasonable to use neural networks within the approach, given in papers [3, 4], to estimate the actual aerodynamic parameters in transient processes (stick displacements, etc). The features of the above-mentioned approach are the following:

- transient process is reproduced in the flight dynamics math model. At that, the control signals, recorded during experiment, are supplied;
- a priori known aerodynamic data (from wind-tunnel tests) are included initially into math model. The math model includes too the corrections to aerodynamic coefficients. The identification task is to optimize these corrections values;
- total mismatch (of transient process in all) of kinematical and dynamic parameters are the criteria for the selection of corrections.

It is obvious when applying approach, another conception of neural networks application will be required. As far as monitoring of integral (in all transient process) criterion of mismatching is supposed, one cycle of training for all transient process is possible, and during modeling of transient process, selection of corrections from the “frozen” neural network is to be used.

Practice of aerodynamic data identification [3, 4] has shown that the successful solving of this problem could not be fully settled by data
The neural networks application for estimation processing itself. The participation of the human-expert is necessary for the on-line data analysis and the processing procedure options tuning.

References


