STOCHASTIC NOISES AFFECTING DYNAMIC PERFORMANCES OF THE AUTOMATIC FLIGHT CONTROL SYSTEM

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Abstract: *External and internal disturbances affect dynamic performances of the automatic flight control systems and can lead to unwanted changes in accuracy of the closed loop control system. In worst case situation, i.e. in extreme meteorological circumstances they can lead to loose stability. The purpose of the authors is to summarize the basic features and equations of atmospheric disturbances. The paper deals with generating stochastic signals with pre-defined statistical parameters regarding different weather conditions. Main equations and transfer functions of the linear filters will be derived and given in the paper. Filter parameters will be chosen with consideration of the weather conditions given in military specifications of MIL–F–8785C, and MIL-STD-1797A. Generating of the stochastic signals with given statistical parameters, and the computer-aided simulation is supported by MATLAB® supplemented with necessary toolboxes.*

Keywords: *human pilot behavior, time delay, critical parameters.*

1. INTRODUCTION

The early mathematical models of the turbulent air were deterministic ones, and they made it possible to generate models such as step gust, '1-cos' gust etc. It is well-known that regarding altitude atmospheric turbulence models can be defined as low altitude ones, if height is less than 2000 ft, and medium/high altitude ones, if height is greater than 2000 ft. The paper will limit investigation to that of the low-altitude random atmospheric turbulences, and will show random time series representing components of the speed of the turbulent air; namely translational component of, u_g, lateral component of v_g, and finally, vertical component of w_g derived for several weather conditions. The proposed atmospheric turbulence models can be applied for design and analysis of the unmanned aerial vehicle (UAV) systems including unmanned aircraft, unmanned helicopter, or unmanned quadrotor systems flying at low altitudes and at low speed.

2. BRIEF HISTORY & LITTERATURE OVERVIEW

Basic equations, definitions, and characteristics of the random processes and random systems are given in [1]. Donald McLean in [2] propagates both deterministic and stochastic mathematical models of the atmospheric disturbances. A complex set mathematical models of the atmospheric disturbances including both deterministic and random ones are given in [2,3,4], and its implementation is shown in [2,5]. In [6] Szabolcsi and Mészáros focused attention and showed how to apply mathematical models of the low-altitude atmospheric turbulences for spreading air pollution. Pokorádi in [7] summarizes main characteristics of the stochastic signals, and applied Markov-chains for modeling aircraft ground maintenance and repair. He also used stochastic theory for solution of diagnostics problem in aircraft technical systems. Random time series are generated and filtered to that of the components of the speed of the atmospheric turbulence using computer packages MATLAB® [8], and Control System Toolbox [9].

3. MATHEMATICAL MODELS OF THE CONTINUOUS ATMOSPHERIC DISTURBANCES

This chapter mainly based upon [1,2,3,4,5,6,7], and strictly follows methodology given in [4,6]. The power spectral density (PSD) function of the turbulent air, the so-called von Kármán spectrum, which is better fit registrations of the turbulent air records, is given as follows [2,3,4]:

$$\Phi_{\text{Kármán}}(\Omega)=\frac{\sigma^2 L}{\pi}\frac{1+\frac{8}{3}(1{,}339L\Omega)^2}{\left(1+1{,}339L^2\Omega^2\right)^{11/6}} \quad (1)$$

where L [m] is the gust wavelength, $\Omega=\omega U_0^{-1}$ [rad/m] is spatial frequency, ω [rad/s] is the observed angular frequency, and finally, σ [m/s] is the r.m.s. gust velocity.

The second one, the more favored PSD function is the Dryden PSD function, which can be programmed more easily then the von Kármán-model. If there is no structural analysis is performed the use of Dryden PSD function is permissible. The Dryden PSD function can be defined as given below [2,3,4,6]:

$$\Phi_{\text{Dryden}}(\Omega)=\frac{\sigma^2 L}{\pi}\frac{1+3L^2\Omega^2}{\left(1+L^2\Omega^2\right)^2} \quad (2)$$

Having goal to analyze hypothetical aircraft mathematical models with no interest in investigation of the structural behavior and supposing aircraft to be the rigid one, the simplest mathematical form of the PSD function defined by equation of (2) we will use in this article. Regarding basic references of [2,3,4,6] one can define PSD functions of the component speed of the turbulent air along body axis system of the aircraft, i.e.:

$$\Phi_{u_g}(\Omega)=\frac{2\sigma_u^2 L_u}{\pi}\frac{1}{1+(L_u\Omega)^2} \quad (3)$$

$$\Phi_{v_g}(\Omega)=\frac{\sigma_v^2 L_v}{\pi}\frac{(1+3(L_v\Omega)^2)}{\left[1+(L_v\Omega)^2\right]^2} \quad (4)$$

$$\Phi_{w_g}(\Omega)=\frac{\sigma_w^2 L_w}{\pi}\frac{(1+3(L_w\Omega)^2)}{\left[1+(L_w\Omega)^2\right]^2} \quad (5)$$

where $\sigma_i^2=\int_0^\infty \Phi_i(\Omega)\,d\,\Omega_i\Big|_{i=u,v,\text{ or } w}$. Since $\omega=U_o\Omega$ formulas of (3)–(5) may be rewritten as follows:

$$\Phi_{u_g}(\omega)=\frac{2\sigma_u^2 L_u}{U_o\pi}\frac{1}{\left\{1+(L_u/U_o)^2\omega^2\right\}} \quad (6)$$

$$\Phi_{v_g}(\omega)=\frac{\sigma_v^2 L_v}{U_o\pi}\frac{(1+3(L_v/U_o)^2\omega^2)}{\left\{(1+(L_v/U_o)^2\omega^2\right\}^2} \quad (7)$$

$$\Phi_{w_g}(\omega)=\frac{\sigma_w^2 L_w}{U_o\pi}\frac{(1+3(L_w/U_o)^2\omega^2)}{\left\{(1+(L_w/U_o)^2\omega^2\right\}^2} \quad (8)$$

For generating random signals with the required intensity, scale length, and PSD functions for given speed and height of the flight, a hypothetical wide-band noise generator with PSD function of $\Phi_N(\omega)$ must be used to provide signal with the linear filter, chosen such that it has an appropriate frequency response so that the output signal from the linear filter will have a PSD function of $\Phi_i(\omega)$ (see Figure 1) [2,4]:

$$\Phi_i(\omega)=\left|G_i(s)\right|^2_{s=j\omega}\Phi_N(\omega) = G_i(s)\,G_i(-s)\big|_{s=j\omega}\Phi_N(\omega) \quad (9)$$

If the white noise source is chosen so that its power spectrum is similar to that of called ‘white’ noise one can write that

$$\Phi_N(\omega)=1 \quad (10)$$

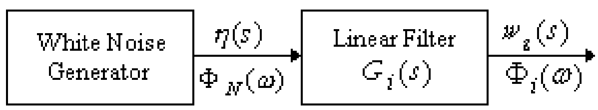

Fig. 1 Block Diagram for Generating Stochastic Signals

Substituting eq (10) into eq (9) result the following formula

$$\Phi_i(\omega)=\left|G_i(s)\right|^2_{s=j\omega}\Phi_N(\omega) = G_i(s)\,G_i(-s)\big|_{s=j\omega} \quad (11)$$

The linear filter transfer functions of $G_i(s)$

are given in [2] to be:

$$G_{u_g}(s) = \frac{\sqrt{K_u}}{s+\lambda_u}$$

$$G_{v_g}(s) = \sqrt{K_v}\,\frac{s+\beta_v}{(s+\lambda_v)^2}$$

$$G_{w_g}(s) = \sqrt{K_w}\,\frac{s+\beta_w}{(s+\lambda_w)^2} \qquad (12)$$

where:

$$K_u = \frac{2U_o\sigma_u^2}{L_u\pi},\; K_v = \frac{3U_o\sigma_v^2}{L_v\pi},$$

$$K_w = \frac{3U_o\sigma_w^2}{L_w\pi} \qquad (13)$$

$$\beta_v = \frac{U_o}{\sqrt{3}L_v},\; \beta_w = \frac{U_o}{\sqrt{3}L_w} \qquad (14)$$

$$\lambda_u = \frac{U_o}{L_u},\; \lambda_v = \frac{U_o}{L_v},\; \lambda_w = \frac{U_o}{L_w} \qquad (15)$$

It is easily can be derived that substitution equations (12)-(15) into equation (9) results in the PSD functions of the Dryden-models's PSD-functions of (6)-(8). If the air turbulence model is used for analysis of its effects on flight of the small UAV aircraft let the initial parameters be as they are given below:

$$H = 100\,\text{m} \cong 328{,}084\ \textit{feet}\ ^1$$

$$U_0 = 25\ \text{m/s} = 90\ \text{km/h} \qquad (16)$$

From equations (13)-(15) it is evident that for derivation of transfer functions of the linear filters defined by equation (12) it is necessary to know turbulence scale of L_i, and turbulence intensity of σ_i, measured along appropriate axis of the given coordinate system.

Let us consider NASA-parameters referred to [2,3] to be as follows:

- along longitudinal (OX) axis:

$$3{,}4\,\text{m/s} \le \sigma_u \le 0{,}85\,\text{m/s} \qquad (17)$$

- along lateral (OY) axis:

$$2{,}8\,\text{m/s} \le \sigma_v \le 0{,}7\,\text{m/s} \qquad (18)$$

- along vertical (OZ) axis:

$$1{,}8\,\text{m/s} \le \sigma_w \le 0{,}45\,\text{m/s} \qquad (19)$$

For extreme weather conditions (thunderstorm) McLean [2] suggests turbulence intensities as they given below:

$$\sigma_u = \sigma_v = \sigma_w = 7\,\text{m/s} \qquad (20)$$

Turbulence integral scale lengths L_i of the low altitude turbulence models for $10\ \textit{feet} \le h \le 1000\ \textit{feet}$ can be derived using following formulas [5,8,9]:

$$L_u = 2L_v = \frac{h}{(0{,}177 + 0{,}000823\cdot h)^{1,2}}$$

$$L_w = 0{,}5\,h \qquad (21)$$

Regarding McLean, for extreme weather conditions (thunderstorm) one can apply following integral scale lengths given in [2]:

$$L_u = L_v = L_w = 580\,\text{m} \qquad (22)$$

Constant speed components of the turbulent air are given in military standards of [4,7] as function of theirs exceedance. For the low altitude random turbulence models intensity of the turbulence, σ_w can be measured as:

$$\sigma_w = 0{,}1\,u_{20} \qquad (23)$$

where u_{20} is constant longitudinal component speed of the turbulent air measured at the altitude of $h = 20\,\text{feet}$. Using equations of (21)-(22) integral scale lengths of the air turbulence were found and they are summarized in Table 1.

Table 1 Integral scale lengths at altitude of $H = 100\,\text{m} \cong 328{,}084\,\text{feet}$

Scale length [m]	Nominal (Nom)	Extreme (Thunderstorm)
L_u	862,185497 feet ≅ 262,7941311 m	580
$L_v = 0{,}5\,L_u$	431,0927485 feet ≅	580
L_w	50	580

Using equations of (17)-(20) turbulence intensities were found and they are summarized in Table 2.

Table 2 Turbulence intensities

Turbulence intensities	NASA-Min (Min)	NASA-Max (Max)	Extreme (Thunderstorm)
σ_u, [m/s]	0,85	3,4	7
σ_v, [m/s]	0,7	2,7	7
σ_w, [m/s]	0,45	1,8	7

[1] *1 foot ≅ 0,3048 m — 1 m ≅ 3,28084 feet*

Constant longitudinal component speed of the turbulent air, called u_{20}, were found using military standard of [3], and using equations of (21)-(22).

Constant speed of u_{20} are summarized in Table 3.

Table 3 Constant speed of u_{20}

Turbulent Air Characteristics	NASA-Min (Min)	NASA-Max (Max)	Extreme (Thunderstorm)
$\sigma_w = 0{,}1\,u_{20}$ [m/s]	0,45	1,8	7
u_{20} [m/s] - [km/h]	4,5 - 16,2	18 - 64,8	70 - 252

Linear transfer functions defined by equations (12) having parameters given by equations of (13)–(15), and satisfying conditions derived by equations (16)–(23), and considering weather conditions given by Table 1, and Table 2, can be determined, and they ca be found in the following tables given below [2,3]:

Table 4 Parameters of the linear filters providing longitudinal speed component of the air turbulence, $u_g(t)$

Filter Parameters		
Weather Conditions	$K_u = \frac{2\sigma_u^2 U_o}{L_u \pi}$ $\left[m^2/s^3\right]$	$\lambda_u = \frac{U_o}{L_u}$ $\left[s^{-1}\right]$
NASA-Min	0,043756496	0,095131547
NASA-Max	0,700103937	0,095131547
Extreme	1,344584864	0,043103448

Table 5 Parameters of the linear filters providing lateral speed component of the air turbulence, $v_g(t)$

Filter Parameters			
Weather Conditions	$K_v = \frac{3\sigma_v^2 U_o}{L_v \pi}$ $\left[m^2/s^3\right]$	$\beta_v = \frac{U_o}{\sqrt{3} L_v}$ $\left[s^{-1}\right]$	$\lambda_v = \frac{U_o}{L_v}$ $\left[s^{-1}\right]$
NASA-Min	0,089027057	0,109848449	0,190263095
NASA-Max	1,324504595	0,109848449	0,190263095
Extreme	8,902705783	0,024885787	0,043103448

Table 6 Parameters of the linear filters providing vertical speed component of the air turbulence, $w_g(t)$

Filter Parameters			
Weather Conditions	$K_w = \frac{3\sigma_w^2 U_o}{L_w \pi}$ $\left[m^2/s^3\right]$	$\beta_w = \frac{U_o}{\sqrt{3} L_w}$ $\left[s^{-1}\right]$	$\lambda_w = \frac{U_o}{L_w}$ $\left[s^{-1}\right]$
NASA-Min	0,096686627	0,288675134	0,5
NASA-Max	1,546986047	0,288675134	0,5
Extreme	2,016877296	0,024885787	0,043103448

Using parameters of Table 4, Table 5, Table 6, transfer functions of the linear filters defined by equation (12) can be derived as follows:

$$G_{u_g}^{Min}(s) = \frac{0{,}20918}{s + 0{,}09513} \tag{24-1}$$

$$G_{u_g}^{Max}(s) = \frac{0{,}83672}{s + 0{,}09513} \tag{24-2}$$

$$G_{u_g}^{Extr}(s) = \frac{1{,}15956}{s + 0{,}04310} \tag{24-3}$$

$$G_{v_g}^{Min}(s) = 0{,}29837 \frac{s + 0{,}10984}{s^2 + 0{,}38052\,s + 0{,}03620} \tag{25-1}$$

$$G_{v_g}^{Max}(s) = 1{,}1508 \frac{s + 0{,}10984}{s^2 + 0{,}38052\,s + 0{,}03620} \tag{25-2}$$

$$G_{v_g}^{Extr}(s) = 2{,}98374 \frac{s + 0{,}02488}{s^2 + 0{,}08620\,s + 0{,}00186} \tag{25-3}$$

$$G_{w_g}^{Min}(s) = 0{,}31094 \frac{s + 0{,}28867}{s^2 + s + 0{,}25} \tag{26-1}$$

$$G_{w_g}^{Max}(s) = 1{,}24377 \frac{s + 0{,}28867}{s^2 + s + 0{,}25} \tag{26-2}$$

$$G_{w_g}^{Extr}(s) = 1{,}42016 \frac{s + 0{,}02488}{s^2 + 0{,}08620\,s + 0{,}00185} \tag{26-3}$$

Using linear transfer function models of equations (24)-(26) it is easy to generate random time series with given statistical parameters, which can be applied both for modeling, analysis and design purposes [9,10].

4. RESULTS OF THE COMPUTER SIMULATION

Using principle derived by Fig. 1., and using transfer functions of the linear filters defined for several weather conditions one can generate computer code for solution of this problem. In our preliminary study we have used MATLAB® 6.5 computer programs [8] supplemented with Control System Toolbox [9]. Regarding mathematical models of the random air outlined in Chapter 3 all components of the speeds of the turbulent air measured along axes of the aircraft body-axis system, and they will be presented in the next sections.

4.1. Random longitudinal speed component of the turbulent air.

The longitudinal speed component is very important from the point of view of the basic flight conditions, i.e. aircraft flight is limited with its minimum longitudinal speed of, say, u_{min}.

From Chapter 3 it is known that equilibrium speed of the hypothetical UAV aircraft is $u_o = 25\,m/s$. Result of the computer simulation can be seen in Fig. 2. From Fig. 2, it is easily can be determined that in time domain of (50÷100) seconds, in other words, in the root of the turbulent zone, the mean value of the longitudinal speed is approximately, $u_{mean} \cong 4{,}2\,m/s$, which is 16,8% of that of the equilibrium one. There is a question arising from analysis of the characteristics of the longitudinal speed component direction, i.e. it can be coinciding one to that of the mean direction of the flight, or it can oppose aircraft flight. In other words, longitudinal speed component of the turbulent air can be called for head-wind, or, tail wind.

Going that way, longitudinal speed of the aircraft flying through atmospheric turbulence can be derived as follows:

- for "head-wind":

$$u_{head} = u_o - u_{mean} = 25 - 4{,}2 = 20{,}8\,m/s \qquad (27)$$

- for "tail wind":

$$u_{tail} = u_o + u_{mean} = 25 + 4{,}2 = 29{,}2\,m/s \qquad (28)$$

From eq. (4.1) it is evident that decrease of the longitudinal speed can lead to minimum allowed longitudinal speed of the aircraft for the given aircraft. If aircraft flight parameters, i.e. its speed and height of the flight, go out of the flight envelope, aircraft can stall, and finally, as worst case, aircraft can crash.

4.2. Random lateral speed component of the turbulent air.

Using the same manner as it was shown in previous section, computer code for random lateral speed component of the turbulent air was generated, and results of the computer simulation can be seen in Fig. 3. From Fig. 3 it is easily can be seen that in the time domain of about (50÷100) seconds, the mean values of the lateral speed are:

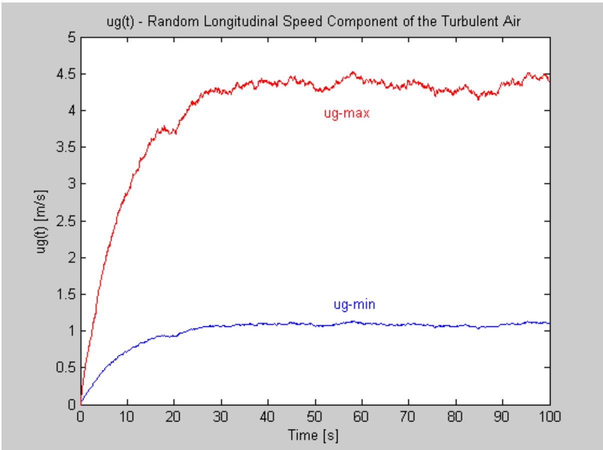

Fig. 2 Longitudinal Speed Component of the Stochastic Air

$$v_{max} \cong 1{,}7\,m/s\,,\ v_{min} \cong 0{,}5\,m/s \qquad (29)$$

If to suppose weather conditions having statistical parameters between weather conditions of NASA-Min, and NASA-Max, it can be supposed that mean value of the lateral speed is, approximately, of 1 m/s.

It means that during flight aircraft changes it lateral coordinate for about ≅4 m in one second.

If to take into consideration the free-flight of the aircraft, or even if in normal flight aircraft "pilot" does not corrects the lateral coordinate, in 50 seconds time period, being investigated above, aircraft maintains distance of 1250 m, changing its lateral coordinate for 200 m.

It is obvious, that there is a strong need to compensate lateral deviation measured from the flight direction.

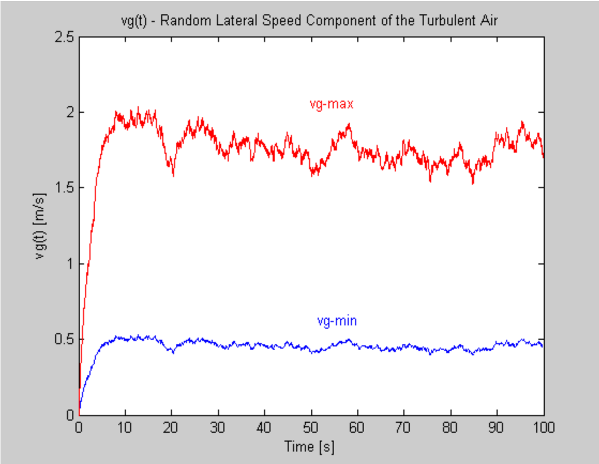

Fig. 3 Lateral Speed Component of the Stochastic Air

4.3. Random vertical speed component of the turbulent air. Random vertical speed of the turbulent air is very important from many aspects of the altitude control of the aircraft, from the point of view of the modeling of the aeroelastic structural motion of the fuselage, and wings. There are many other reasons highlighting importance of the knowledge of the stochastic vertical speed of the atmospheric turbulences. Results of the computer simulation including NASA-Min, and NASA-Max weather conditions can be seen in Fig. 4. From Fig. 4 it is easily can be seen that in the time domain of about (50÷100) seconds, the mean values of the vertical speed are as follows:

$$w_{max} \cong 0{,}7\ m/s,\ w_{min} \cong 0{,}2\ m/s \qquad (30)$$

If to take mean value of the vertical random speed of the wind to be of 0,5 m/s, during flight aircraft changes it altitude for 1,8 m per second. For the free-flight of the aircraft, or even if in normal flight aircraft “pilot” does not corrects the height of the flight, in 50 seconds time period, being investigated above, aircraft maintains distance of 1250 m, changing its height of the flight for 90 m, to that of the initial of $H_o \cong 100\,m$. It means that having no control on aircraft altitude, in turbulent air aircraft nearly duplicates its height of the flight. It is obvious, that height of the flight must be controlled, and altitude must be kept at its constant value.

If to take mean value of the vertical random speed of the wind to be of 0,5 m/s, during flight aircraft changes it altitude for 1,8 m per second. For the free-flight of the aircraft, or even if in normal flight aircraft “pilot” does not corrects the height of the flight, in 50 seconds time period, being investigated above, aircraft maintains distance of 1250 m, changing its height of the flight for 90 m, to that of the initial of $H_o \cong 100\,m$.

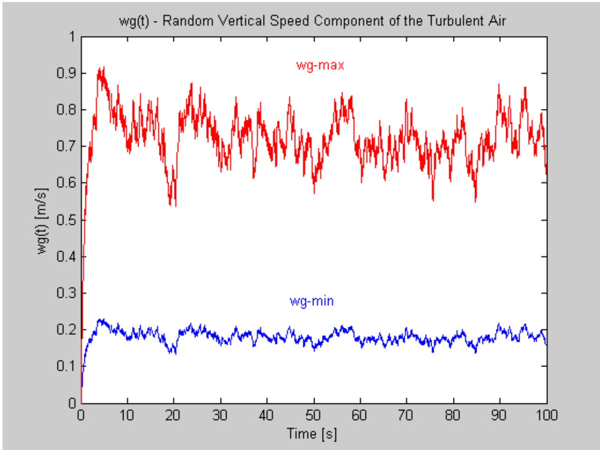

Fig. 4 Vertical Speed Component of the Stochastic Air

It means that having no control on aircraft altitude, in turbulent air aircraft nearly duplicates its height of the flight. It is obvious, that height of the flight must be controlled, and altitude must be kept at its constant value.

4.4. Results of the computer simulation on the atmospheric turbulences for the “NASA-Min” weather conditions. Using results of the previous computer simulation, for “NASA-Min” weather conditions all appropriate time series of the longitudinal, lateral, and vertical components of the random air were plot in common coordinate system, and they can be seen in Fig. 5.

From Fig. 5 it is evident that longitudinal speed component of the atmospheric turbulence has largest mean value. If the aircraft is the piloted one the vertical speed component $w_g(t)$ is important from point of view of the ride comfort.

For UAVs vertical speed is important for fatigue reduction purposes. Finally, lateral speed $v_g(t)$ can lead to worsening navigational performances, i.e. UAV can be lost during flight.

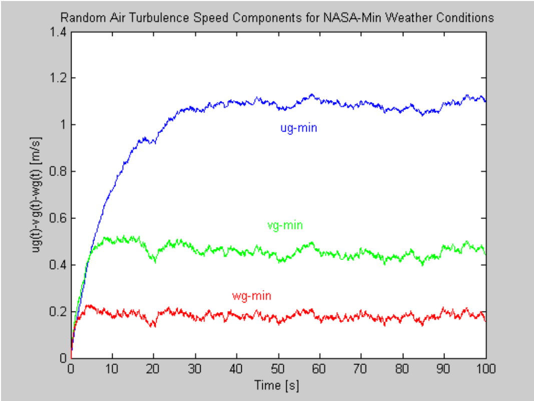

Fig. 5 Results of the Computer Simulation for "NASA-Min" Weather Conditions

4.5. Results of the computer simulation of the atmospheric turbulences for the "NASA-Max" weather conditions. Using results of the computer simulation made before, for "NASA-Max" weather conditions all appropriate time series of the longitudinal, lateral, and vertical components of the random air were plot in one, common coordinate system, and they can be seen in Fig. 6.

From Fig. 6 it is easily can be derived that longitudinal speed component, $u_g(t)$, of the atmospheric turbulence has largest mean value. It is evident that for head-wind weather conditions, there is exists a maximum value of the longitudinal random speed, $u_{g_{max}}(t)$, which is allowed to avoid stalling of the aircraft.

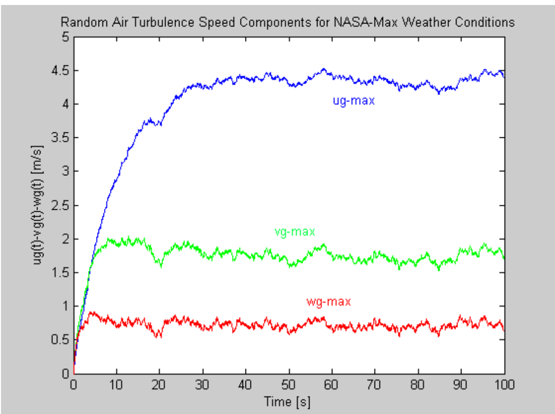

Fig. 6 Results of the Computer Simulation for "NASA-Max" Weather Conditions

4.6. Results of the computer simulation of the atmospheric turbulences for "Extreme-Thunderstorm" weather conditions. Result of these computer simulations are mainly hypothetical, however, it is necessary to know how extreme air masses are moving. These results are very important although from the point of view of the flight achieved beyond visual range for large distances, when there are big differences between weather conditions at arrival and departure airfields. Result of the computer simulation can be seen in Fig. 7.

The most important result is that atmospheric turbulence has largest value in the mean of lateral component of the turbulent air.

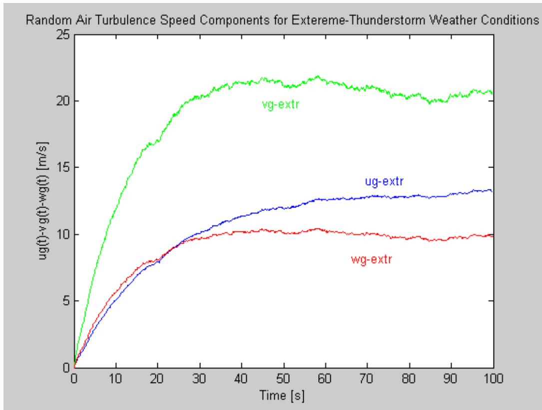

Fig. 7 Results of the Computer Simulation for "Extreme" Weather Conditions

The other important statement coming form this analysis, that if to consider maximum value of the longitudinal head-wind to be of $u_{g\_head}(t) = 5\,m/s$, this maximum value is reached at about 5 seconds of the computer-aided simulation

It means that to avoid stalling of the aircraft it is necessary to compensate decrease of the longitudinal speed of the aircraft increasing throttle, or it is necessary to maintain maneuver to keep given flight parameters in the defined flight envelope of the given type of the aircraft.

5. MODELING OF SENSOR NOISES IN AUTOMATIC FLIGHT CONTROL SYSTEMS

Most of the modern automatic flight control systems are driven by electric energy, i.e. outputs of the flight control systems are electrical signals proportional to state variables of the spatial motion of the aircraft. Additive noises of the output signals can be regarded as random ones. It is well-known that statistical parameters of these stochastic signals are purely described, and they can be derived from analysis of the registered time histories of the random flight parameters.

The second method is the study of the computer simulation of the random time series. This particular case supposes random flight parameters to have Gaussian distribution. These signals are to be filtered from those of the output signals of the white noise generator, and in most cases are filtered using linear filters to have zero mean value. In general, typical drift of the attitude gyroscope is $0{,}1^0/\mathrm{h}$. The accuracy of the rate gyro is $0{,}1^0/\sec$, and $0{,}1^0$ for attitude gyros. Static error of the accelerometers is typically $3{,}5\cdot 10^{-3}\mathrm{m}/\mathrm{s}^2$. Barometric altimeters have r.m.s. errors of 16 m [2].

6. SUMMARY & CLOSING REMARKS

This paper deals with mathematical modeling of the atmospheric turbulences. Main references are cited to highlight importance of this scientific article. Mathematical modeling of the atmospheric turbulences are important from many aspects of the flight: these models are used for derivation of the flight envelope of the aircraft, for derivation of the limitations of the flight parameters and derivation of the meteorological minimums defined for given type of the aircraft, and finally, these models are widely applied for preliminary design of the automatic flight control systems.

In this article it was discussed that statistical parameters of the atmospheric turbulence depend not only on flight parameters but on weather conditions, too. Limiting our investigations to that of the analysis of the low-altitude turbulent air models we have considered several weather conditions, namely '*NASA-Min*', '*NASA-Max*', and finally, '*Extreme-thunderstorm*' weather conditions were analyzed.

For given initial flight parameters and weather conditions author had created a new embedded MATLAB® m-file to produce time series applicable to visualize random speed components of the turbulent air, namely longitudinal, lateral, and finally, vertical speed components of the turbulent air were investigated.

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