SOME MEANS FOR INFORMATIONAL SUPPORT OF THE AIRLINER PILOT

A.M. Shevchenko

Trapeznikov Institute of Control Sciences, Russian Academy of Sciences (RAS)
65 Profsoyuznaya Str., Moscow, 117997, Russia
(Fax +7495 3349340, e-mail: anshev@ipu.ru)

Abstract

The human factor is responsible for the most flight accidence at takeoff and landing phases. For decreasing the psychological load and improving the situational awareness of the pilot the algorithmic and program means of informational support of the crew are offered in the given work. Methodological base of all our innovations is the energy approach to space motion of flying objects.

On the basis of this approach some information messages are generated on the flight deck. Among them there are: i) Index of the engine thrust control functionally similar to various symbolic markers for hand flight path control; ii) the warning panel for notification of atmospheric disturbances; iii) the indicator of a distance or time reserve for decision-making concerning the opportunity of takeoff maneuver and subsequent raising a sufficient height above an obstacle ahead; iv) estimation of the brake distance in situation of necessity of emergency braking.

Key words

Informational support, takeoff, landing, flight deck.

1 Introduction

Usual regular flight of a passenger aircraft comprises some phases with obligatory participation of the pilot. The role and responsibility of the pilot increase at critical phases and at off-optimum situation. Under the conditions of high-density air traffic the probability of the situations demanding urgent decision-making raises. During each flight the aircraft trajectory passes along the runway twice: once at the takeoff and then at the landing. At these critical flight phases various abnormal situations often arise. Such situations arise due to many reasons such as lowered thrust-to-weight ratio engine, engine failure, high mountains conditions, increased ambient temperature, extreme takeoff gross weight, runway inclination etc. Any abnormal situation increases the stress load, especially when the aircraft is within the runway edges. For decreasing the psychological load and improving the situational awareness of the pilot the means of informational support of the crew have become extremely necessary.

In the 80's the problem of flight control safety at takeoff and landing phases has become aggravated all over the world. It has been caused by the growing intensity of airline traffic and increasing number of flight incidents at given stages. The principal cause is the problem of the correct decision-making concerning the takeoff continuation or termination. In connection with this problem the intensive researches have started to be carried out in the leading foreign and domestic aviation organizations, such as NASA, Boeing, Aerospatiale, JSC Institute of Aircraft Equipment (NIIAO) (Russia), Flight Research Institute (Russia). The algorithms for early detection of critical situations at the takeoff and landing as well as appropriate information support of the crew have been developed. The most intensive researches were carried out by NASA together with Boeing from 1984 till 1994. The Take-Off Performance Monitoring System (TOPMS) has been developed [Middleton, Srivatsan, Person]. The TOPMS algorithm consists of preflight and flight parts [Pinder]. In the preflight part the nominal dependence of longitudinal plane acceleration on the main factors are defined. Among them are speed, weight, centering, environment parameters and a runway condition. The flight part of the TOPMS algorithm includes calculation of current aircraft position, the forecast of a distance of nose up speed achieving. Despite the positive estimation by test pilots, the estimation by aircraft operators was ambiguous. The French Aerospatiale has created similar Advisory Take-Off Monitoring System (ATOMS) [Bove, Andersen]. The information on current takeoff is displayed simultaneously at the navigating display and the flight director. However in comparison with TOPMS a number of symbols here is much less. If airspeed at running is much lower than its admissible minimum then the green symbolics on both indicators is replaced by the yellow one. The advisable messages are not indicated unlike the TOPMS ideology. The ATOMS is assigned for the new aircraft A380 developed in Airbus Industry consortium. The Maltese and Cranfield Universities (England) have developed Take-Off Performance Monitor (TOPM). The TOPM algorithm predicts the distance for decision making speed [Zammit-Mangion, Eshelby]. As a result of wide investigation in the JSC Institute of Aircraft Equipment (Russia) it was offered to include the information-measuring takeoff monitoring system in the structure of the onboard equipment [Nikiforov]. If the predicted distance exceeds the admissible one then the mentioned system forms a warning signal for the crew and a command signal of takeoff prohibition. The onboard decision-making support system developed in the Central Aerohydrodynamic Institute (TsAGI) (Russia) uses an alternative method of the takeoff process monitoring. This method is based on the rating of "effective takeoff weight" [Glubokaya]. There are some device patents concerning aircraft moving on the runway [Zavershinsky], [Constans]. In summary, it is necessary to notice that despite the numerous researches the safety problem at takeoff and landing phases remains unresolved till now. Unfortunately there are not any descriptions of algorithms of calculation of the current or predicted aircraft coordinates in the above-mentioned and other accessible publications. In the given paper the uniform methodological basis for generating the advisable and warning messages to the crew is offered. The methodological basis of all our innovations is the energy approach to space motion control of flying objects (FO) [Kurdjukov, Nachinkina, Shevtchenko], [Borisov, Nachinkina, Shevchenko, 1999] Moreover, some general estimations of current situation are received on the basis of the proprietary energy approach.

2 The basics of the energy approach

We consider the flight of the FO in a perturbed atmosphere as the translational motion of a material point in the potential field of forces. We disregard rotation of the Earth and assume that its surface is flat and wind is stationary.

The distinctive property of this approach is that the dynamic equations are written in the coordinate system related with the moving mass of air. Therefore, the d'Alembert forces induced by translational acceleration have been added to the force equations.

Considering together dynamical equations of the vehicle translational motion, kinematic equations, and equations of total energy we obtained the energy balance equation:

Quantitative ratios between an energy sources and energy consumers are expressed in the form of

$$\Delta H_E = \Delta H_E^{eng} + \Delta H_E^{D} + \Delta H_E^{w} \quad . \qquad (1)$$

The equation is written in deviations of *specific energy*:

$$H_E\left(*\right) = E\left(*\right)/mg = h + V^2/2g.$$

Specific energy measure unit is the meters; therefore it is called also as energy height. Here ΔH_E is the increment of total energy height FO; ΔH_E^{eng}, ΔH_E^{D}, ΔH_E^{w} define specific engine work, the expenditure of energy for overcoming of harmful drag, and wind work, respectively.

Integral expressions for each term are received:

$$\begin{aligned}
\Delta H_E &= \int_{t_1}^{t_2} V\left(\theta + \frac{\dot{V}}{g}\right) dt, \\
\Delta H_E^{eng} &= \int_{t_1}^{t_2} V T_{nr} \cos(\alpha_W + \varphi_{eng}) dt, \\
\Delta H_E^{D} &= \int_{t_1}^{t_2} V D_{nr} dt, \\
\Delta H_E^{w} &= \int_{t_1}^{t_2} V f_w dt,
\end{aligned}$$

where θ, V, T_{nr} define the flight path angle, the airspeed, and the engine thrust normalized by aircraft weight; α and φ are the wing angle of attack and the angle of engine inclination; $f_w \simeq \dot{W}_x/g - W_y/V$ is the so-called "wind factor", where W_x and W_y are horizontal and vertical wind components. So the energy balance equation reflects interconnections of all energy sources and consumers in system "flying object — power plant — surroundings".

As a result of simultaneous solving of the energies balance equation together with the dynamic equations the speed and the height control algorithms were obtained. These algorithms (called as energy algorithms) provided the reaction to command signals and the suppression of external disturbances much better than conventional flight control systems [Pavlov, Shevchenko, Nachinkina] and [Borisov, Pavlov, Shevchenko, 2009]. The key feature of the energy approach is that the FO motion is characterized by the generalized measure, i.e. its full mechanical motion energy as well as its components: potential and kinetic.

3 Generation of the informational messages to the pilot

The energy approach has revealed its fruitful merits in other applications. From the energy point-of-view to aircraft motion the information messages could be generated. Some of them are described hereafter.

3.1 Formation of the command index for engine control

One of improbable but very terrible atmospheric phenomena is so-called “wind shear”. It is dangerous because the structure of air flows is never known. Moreover it is impossible for pilots to receive a practical piloting experience during a training course. For these reasons a number of the heavy accidents took place. It is noticed that erroneous actions of (the) pilots operating with the intuitive situation perception became preconditions to the aircrafts crashes. The prime pilot’s reaction was the aircraft holding on the reference trajectory. But atmospheric disturbances influence not only the height or the airspeed alone, but the full aircraft energy. The results of the foreign researches have shown, that pilot’s class rate directly depends on his possession of “the full energy feeling”.

The cabin of the modern liner is equipped with set of flight and navigating devices. On the flight director display the symbolic information about spatial aircraft attitude is indicated both in automatic and in manual modes. There is a set of graphic indication patterns such as “pitch scale”, “way in the sky”, “telegraph pole” etc. And only quantitative information about airspeed is available. It is difficult to interpret such information as a measure of the aircraft energy state.

Being based on energy estimation of aircraft’s motion in the perturbed atmosphere, we had offered to submit the energy deviation index ΔH_E to the flight director (Fig.1) [Borisov, Pavlov, Shevchenko, 2010]. This index should be perceived as a command signal for engine thrust control as like as various forms of trajectory indexes are used by pilot for hand pitch control.

Presence of such “energy index” in the field-of-view will help to get “full energy feeling” to the pilot, will facilitate a hand control or serve as the indicator of the generalized error of the automatic control system.

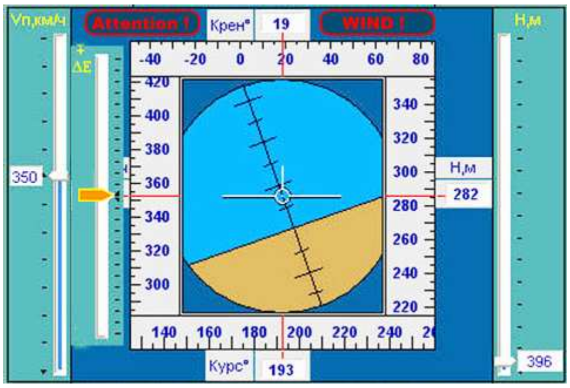

Figure 1. The flight director view with additional energy index and notification inscriptions about the disturbance hazard

3.2 Indication of external disturbances intensity

The energy balance equation let us to produce more means for the pilot informing about a current situation.

As it follows from (1), the third member describes atmospheric disturbances and is in the same measurement units as energy height. Therefore it seems quite reasonable to use wind components in the form of the wind factor f_W for an estimating the level of their influence on the aircraft’s energy state. Moreover, we have recommended using the wind factor value for indication of danger level to the pilot. Via computer modeling we have found the margin values of allowable wind factor for aircrafts of different classes at various flight phases. These values vary from 0.076 for light business-class aircraft to 0.34 for heavy passenger liner. Concerning cause-and-effect relations the wind factor usage is the utmost preferable because the wind is the original cause of subsequent deviations.

The direct measuring of the wind component is possible only by onboard weather-radar or with help of Doppler navigator or with satellite navigation system. At inaccessibility of exact measurements of the wind factor the other wind combinations can serve as danger criterion:

$$|W_x| + |W_y| \geq \varepsilon_1, \;\; \sqrt{(W_x^2 + W_y^2)} \geq \varepsilon_2, \text{ and so on.}$$

The aircraft’s energy state is subjected to disturbances of various nature such as a wind gust, engine thrust decay, extension of high-lift devices, external stores jettison, etc. The energy height uniformly reacts to any disturbances. For this reason the energy height can serve as the generalized measure of disturbed aircraft motion.

The most obvious criterion of disturbance hazard may be exceeding some limit by an error $\Delta H_E(t)$;

$$|\Delta H_E(t)| \geq \Delta(H_E)_{lim}.$$

This event points that the engine power capability is not sufficient for parrying a disturbances. Therefore for the crew notification about the disturbance hazard increasing by any reason it is offered to enter the alarm signal indication of the second level to notify the crew about the disturbance hazard increasing by any reason. This signal can be presented at the form of a flickering inscription, a sound signal, a voice announcement, etc.

3.3 The indicator of safe obstacle overflight

During a takeoff run an unforeseen contingency may arise. Among them there are engine failure, the raised ambient air temperature in high mountains at excessive loadings, runway damage and so on. In such situations it is extremely necessary to estimate the capability of the aircraft to carry out takeoff run within the runway edges and to gain sufficient height above an obstacle ahead.

Let’s consider a sketch takeoff trajectory (Fig.2).

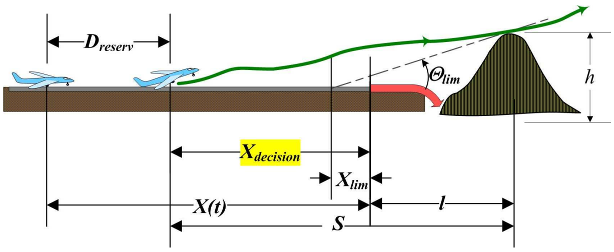

Figure 2. The layout of specific points along the takeoff trajectory

Here S is the distance within the energy could be accumulated which; Θ_{lim} is the maximum allowable flight path angle; $X_{decision}$ denotes the limit coordinate for decision-making.

At the moment of overcoming an obstacle the aircraft total energy is defined by its geometrical altitude h and minimal level flight airspeed V_{level}:

$$E_h = m\frac{V_{level}^2}{2} + mgh. \quad (2)$$

During any maneuver it is possible to predict the accumulated energy if the trajectory is known. It is calculated as the sum of current total energy and the work of all applied forces along the flight trajectory up to the obstacle. Neglecting the small flight path angle and the engine inclination angle we shall write down the equation:

$$E(t) = m\frac{V(t)^2}{2} + mgh(t) + S\sum_i F_i(t). \quad (3)$$

Among the applied forces $F_i(t)$ the most significant ones are the engine thrust, the aerodynamic drag, the undercarriage reaction, and the wind.

This equation may be interpreted as a method for prediction of the aircraft energy value sufficient for climbing above the obstacle. The required condition is expressed as follows:

$$E(t) \geq E_h.$$

Modeling of all forces $F_i(t)$ is a nontrivial problem. Instead of modeling we have offered using a certain measurable behavioral equivalent, namely a longitudinal acceleration:

$$\sum_i F_i = ma(t). \quad (4)$$

From (2) and (3) in consideration of (4) the limiting aircraft position, behind which takeoff is impossible, was found:

$$X_{decision} = \frac{g(h - h(t)) + 0.5(V_{level}^2 - V(t)^2) - l}{a(t)}.$$

Note that the resulting expression is invariant relative to the aircraft mass.

Apparently, the information concerning a distance (or time) left up to decision-making is extremely relevant for the pilot. This reserve may by calculated very simply: $D_{reserv} = X(t) - X_{decision}$.

The warning information may be presented to the pilot in form of the text annunciation, in graphic symbols or voice command.

3.4 The indicator of safe braking distance

After an unsuccessful touchdown or in situation of rejected takeoff a danger of overrunning beyond the runway edge may occur. Overrunning occurs by several reasons such as overshoot at landing, blocking up the runway by extraneous objects, runway damage, runway icing and so on. In such situations it is very important to estimate the possibility of emergency braking or executing an alternative maneuver e.g. go-around. The situations on the runway occurring during braking process are represented in figure 3.

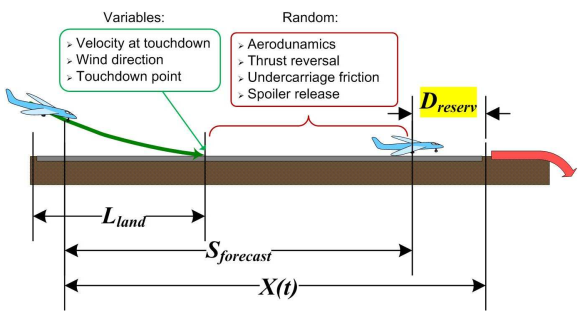

Figure 3. The various factors at landing and ground rolling

The point of decision-making concerning takeoff interruption or emergency braking is determined by distance from the runway edge sufficient to diminish kinetic energy (or ground speed) up to some small value ε close to zero.

After touchdown the total aircraft energy varies in accordance with the law:

$$E(t)_{forecast} = m\frac{{V_{land}}^2}{2} + mgh(t) + S\sum_i F_i.$$

Taking into account the same assumptions as above we get the formula for prediction of full stop distance:

$$S_{forecast} = \frac{gh(t) - 0.5(\varepsilon^2 - V(t)^2)}{a(t)}.$$

Note that distance forecasting is based on the current measurement of acceleration which in turn reflects the resultant reaction of all applied forces including such an unpredictable force as undercarriage friction. Comparing the brake distance estimation with current aircraft position relative to the runway edge the warning inscription about the reserve of time (in seconds) or distance (in meters) may be generated in the pilot field-of-view.

$$D_{reserv} = X(t) - S_{forecast}$$

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5 Conclusion

Abnormal situations during the takeoff and the landing of passenger aircraft result in stressful pilot loadings. In situation a lack of time and information about flight condition the erroneous actions of the pilot are probable. Therefore the development of the audio-visual prompts for decision-making is extremely urgent. Such prompts reduce the psychological load and improve the situational awareness of the pilot. In our previous works the energy approach to space motion control was developed. In the given work this approach has been used for calculating some integrated/generalized estimations of the current situation. In particular, it has been offered to form the command index for engine thrust control at presence of wind. For the purpose of estimating the degree of wind danger it was offered to calculate the energy characteristic of wind and to form the notification signal on the flight director display. The aircraft motion at the takeoff and the landing has been also considered from the energy point of view. The necessary conditions for continuation of takeoff and subsequent climbout on sufficient height above any obstacles along flight path have been found. In situations of emergency braking the estimations of a safe brake distance have been received.

All our researches have conceptual character and will be continued on iron bird or flight modeling stand.

References

Borisov V.G., Nachinkina G.N., Shevchenko A.M. (1999). *Energy approach to flight control. Automation and Remote Control.* Vol.60,6, pp.805-813.

Borisov V.G., Pavlov B.V., Shevchenko A.M. (2009). Some Methods of High Handling Qualities Providing in Whole Flight Envelope. *2nd IFAC International Conference on Intelligent Control Systems and Signal Processing (ICONS'09).Istanbul, Turkey,* CD ROM, ID 190, pp.1-6.

Borisov V.G., Pavlov B.V., Shevchenko A.M. (2010). Means of information support of the pilot. *7nd scientific and technical conference "Mechatronics, Automation, Control" (MAC-2010), St.Petersburg, Russia,* pp. 74-77.

Bove T., Andersen H.B. (2002). The effect of an advisory system on pilots' go/no-go decision during takeoff. *Reliability Engineering and System Safety.* Vol. 75, 2, pp. 179-191.

Constans F. (2007). Method and device to facilitate aircraft landing. *FR0605157.*

Glubokaya M.G. (2008). The onboard system for the decision-making support during the passenger aircraft takeoff. *Technology of Air Fleet.* Vol.82. 1,pp. 21-30.

Kurdjukov A.P., Natchinkina G.N., Shevtchenko A.M. (1998). Energy Approach to Flight Control. *AIAA Guidance Navigation and Control Conf., AIAA, Paper 98-4211.* Boston, MA.

Middleton D., Srivatsan R., Person L. Jr. (1994). Flight Test of Takeoff Performance Monitoring System Indicates Successful Use in Research Vehicle. *Flight Safety Foundation Digest.* Vol. 13 10.

Nikiforov S. (2002). The onboard takeoff monitoring system - effective means of the transport aircraft safety increase *Technology of Air Fleet.* Vol.76. 3.

Pavlov B.V., Shevchenko A.M., Nachinkina G.N. (2003). Energy Approach and its Usage for Flight Control System Design. *Actual Problems of Aviation and Aerospace.* Vol.8, 2(16), pp. 24-43.

Pinder S.D. (2002). Aircraft Take-Off Performance Monitoring in Far-Northern Regions: An Application of the Global Positioning System. *Ph.D. thesis. University of Saskatchewan.*

Zammit-Mangion D., Eshelby M. (2002). An Operational Evaluation Of A Take-Off Performance Monitoring Algorithm. *ICAS2002 Congress. http://lu.fme.vutbr.cz/icas2002/paper7105.pdf*

Zavershinsky V.V. (2008). The device for prevention the aircraft overrunning beyond the runway. *RU2373115.*