



Flight Trajectory Modelling to Increase General Aviation Safety

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Abstract:

In connection with aircraft accident statistics of small aircraft, the paper deals with modelling applications for flight trajectories of these aeroplanes. The results of the modelling could be used for aircraft accident investigations or for increasing flight safety. The aircraft is considered as a mass point and its real weight, aerodynamic and power plant characteristics are respected for defining acting forces.

Keywords:

Aircraft, general aviation, aircraft accident, flight trajectory, modelling, mass point, aircraft characteristics

1. Introduction

Today, modelling is a widespread field used in all specializations of human activity. The advantage of modelling lies especially in time saving and relatively low-cost evaluation of relevant events, including situations, which cannot be realized in real conditions because of high risks involved.

High performance of today's advanced computers allows solving complex tasks which include a number of parameters. These conditions simulate real-life situations with high fidelity. New programmes developed for calculation tasks with high fidelity, however, require special software, which is expensive to acquire for the user and moreover it requires an experienced person whose training means additional cost of acquisition. Also other specializations are required for working with this type of device. Additionally, this device works on the basis of large amounts of important data. The data preparation often takes a long time and, in some cases, there is a problem with the acquisition of input information. Further enhancement of simulation

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fidelity is connected with unacceptably high costs and the benefits of improved accuracy of the final method are not proportional to the eventual cost.

The method of flight trajectory modelling mentioned in this paper provides a relatively simple approach with a minimal required amount of information on aircraft characteristics providing sufficient accuracy in these basic situations. The modelling method may be applied in the following basic fields of small aviation:

- Explanation of aircraft accident cause;
- Enlightenment from aircraft accident including safety recommendations;
- New pilots' training;
- Preparation for flights with more complex manoeuvres;
- Explanation of unexpected situations occurring during flight.

This paper contains a brief description of the operational safety situation of the Czech Republic civil aviation, selected approach to modelling, and also specified is the necessary information about the aircraft. For the purpose of presentation of the method, the study describes the most dangerous manoeuvre selected from aircraft accident statistics. At the end of this paper, the modelling method is evaluated in comparison with common simulators on the background of new trends in the training.

2. Safety in Civil Aviation

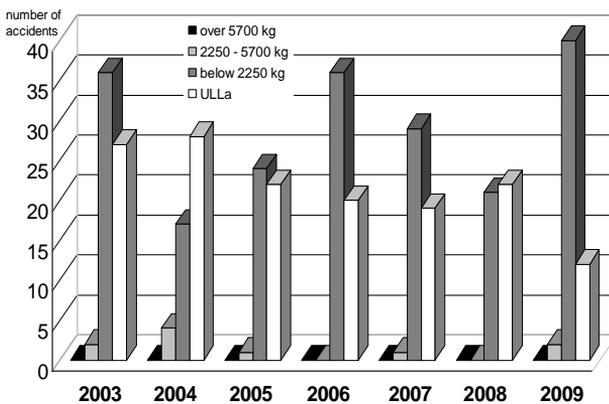


Fig. 1 Aircraft accident statistics

The safety in aviation can be assessed according to aircraft accident statistics. An aircraft accident is an event connected with aircraft operation when a person was injured, aircraft was damaged, aircraft was missing or aircraft was in an inaccessible place [1]. The quality of the pilot's training and skills as well as external flight conditions have an

essential effect on safety during the flight. Based on statistics, the human factor has the highest rate of aircraft accident [2]. Generally, high work stress increases the probability of a wrong decision. Currently, the use of simulators decreases the risk level via emergency procedure training.

According to statistic data (Fig. 1), there are high numbers of aircraft accidents in the lowest weight aircraft category below 2 250 kg. The small ultra light aircraft (ULLa) is a specific group of these aircrafts weighing 450 kg or less. Human factor is paramount in a major part of these aircraft accidents and the consequences are alarmingly fatal [3]. It is troubling to see that the causes are still the same [4]. These are especially aviation indiscipline, pilot's professional incompetence, overestimation of person's own skills or the aircraft performance. Additionally, there are insufficient pilot skills, weight limit overrun, wrong decision, landing mistake etc.

Based on the evaluation of critical states, which caused an aircraft accident, 62 typical aircraft accidents have been evaluated for the defined period [5]. Most of these critical states occurred during aircraft manoeuvring (35 %) or they were caused by a wrong procedure during landing (29 %). Landing is considered to be the most dangerous phase of the flight and it depends on the pilot's skills.

On the other hand, accidents caused by pilot errors during manoeuvring are the result of neglecting basic flight principles, physical laws, aircraft parameters or overestimation of the pilot's own skills.

Currently, there are 13 situations (21 %) where the aircraft exceeded its maximum take-off weight, 10 situations (16 %) where the aircraft flew below the minimum flight altitude, and additional 8 situations (13 %) when the pilot was flying under the influence of alcohol. Moreover, there are situations where all of the three mentioned conditions coincided in one flight.

The data analysis from Fig. 2 points to three main factors which cause more than 74 % of all aircraft accidents and they are: negligence in procedures, bad landing and wrong turning. It is typically wrong turning, which is the cause of most fatalities per one accident in the discussed cases.

Aircraft accident investigation is difficult for the low weight category according to Fig. 1, because this category has no flight data recorder. In this case, flight trajectory modelling offers its advantage as a method with low requirements on the source [5]. Monitoring of flight parameters in thrust diagram provides important information too.

3. Approach to Modelling

When modelling aircraft movement, the aircraft is considered as a mass point and its weight is concentrated in its centre of gravity. The solution is based on force equations only and moment equations are eliminated. The advantage of mass point model is seen in minimum requirements in terms of necessary aircraft characteristics, which is especially beneficial in the category of small sport aircraft. Unlike the real aircraft, which is controlled by control surfaces, the mass point model is controlled by "control parameters" as they are called. The aircraft movement is controlled so as to keep the modelled manoeuvre as close as possible to the real manoeuvre created by a pilot. Fixed weight of the aircraft can be used for short time manoeuvres.

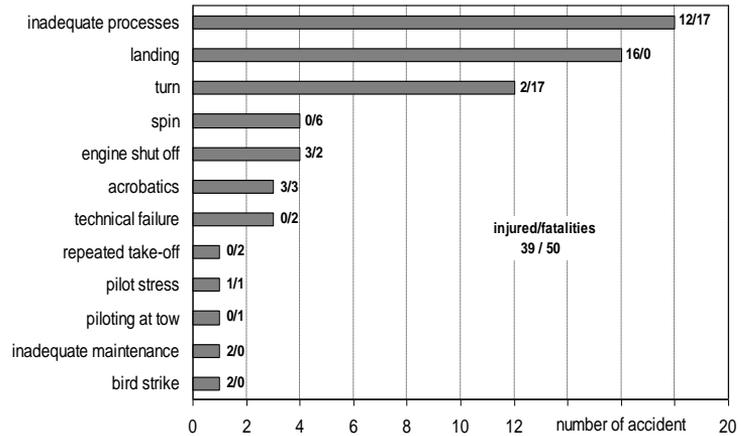


Fig. 2 Reasons and quantity of accidents with fatalities

The resultant force F acting on the aircraft is a sum of the aerodynamic force R , power plant thrust T , and the aircraft weight G (Fig. 3)

$$\vec{F} = \vec{R} + \vec{T} + \vec{G} \cdot \vec{V} \quad (1)$$

The resultant force F induces aircraft acceleration a , which can be defined from the Newton's law of motion

$$\vec{F} = m \frac{d\vec{V}}{dt},$$

$$\vec{a} = \frac{d\vec{V}}{dt}. \quad (2)$$

The aircraft movement is solved advantageously in a path coordinate system in International Standard Atmosphere (ISA) conditions [6]. The x -axis has the direction of flight velocity V in this coordinate system. The remaining axes are situated in vertical and horizontal planes. This coordinate system enables the projection of flight path simply into both planes

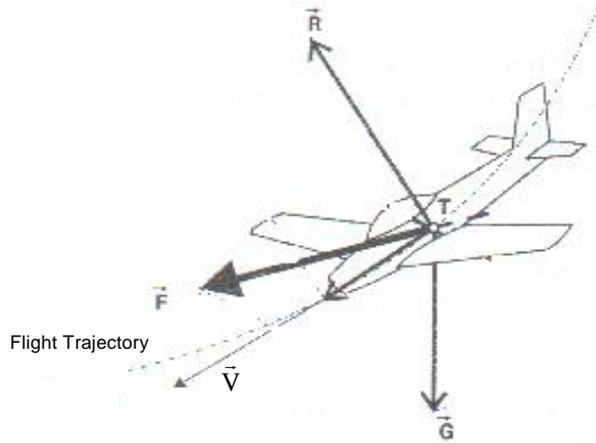


Fig. 3 Forces acting on aircraft

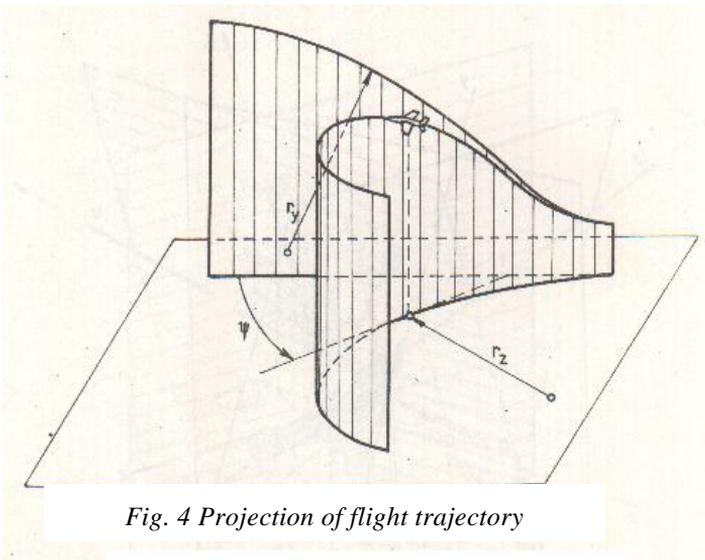


Fig. 4 Projection of flight trajectory

(Fig. 4). When defining the orientation of acting forces, the flight is assumed without sideslip and thrust acts in the flight speed direction.

By resolving the vector movement equation (2) into components of path coordinate system [6], a system of differential equations is obtained

$$\begin{aligned}
m \frac{dV}{dt} &= T - D - G \sin \gamma \\
mV \frac{d\gamma}{dt} &= L \cos \mu - G \cos \gamma, \\
-mV \cos \gamma \frac{d\chi}{dt} &= L \sin \mu
\end{aligned} \tag{3}$$

where γ is the climb angle, μ is the bank angle and χ is the azimuth angle. The first equation expresses the condition for the change of absolute value of the flight speed, the second equation expresses the condition for the change of flight direction in vertical plane and the third equation expresses the condition for the change of flight direction in horizontal plane.

The resultant force F acting on the aircraft creates aircraft acceleration, which depends on the aircraft weight. For the analysis of flight trajectories and aircraft manoeuvres evaluation, the load factor is a suitable parameter. Then, the motion equations (3) can be transformed into a general form. The load factor is defined as the ratio of resultant air force and aircraft weight [6]

$$\bar{n} = \frac{\bar{R} + \bar{T}}{G}. \tag{4}$$

The load factor can be separated into individual directions of the acting forces. It is the drag load factor n_D , lift load factor n_L , and lateral load factor n_Y , which is equal to zero in flights without sideslip angle. The load factor in component form is expressed as

$$n_D = \frac{T - D}{G}, \quad n_L = \frac{L}{G}, \quad n_Y = 0. \tag{5}$$

The motion equations (3) can be transformed into a general form by using components of the load factor (5) for flight path calculation

$$\begin{aligned}
\frac{1}{g} \frac{dV}{dt} &= n_D - \sin \gamma \\
\frac{V}{g} \frac{d\gamma}{dt} &= n_L \cos \mu - \cos \gamma. \\
-\frac{V \cos \gamma}{g} \frac{d\chi}{dt} &= n_L \sin \mu
\end{aligned} \tag{6}$$

It is necessary to complete the above-mentioned equations with kinematic conditions, which describe the geometric shape of flight trajectory in relation to the coordinate system fixedly connected to earth ($0; x, y, H$)

$$\begin{aligned}
\frac{dx}{dt} &= V \cos \gamma \cos \chi \\
\frac{dy}{dt} &= V \cos \gamma \sin \chi. \\
\frac{dH}{dt} &= V \sin \gamma
\end{aligned} \tag{7}$$

The motion equations (6) together with kinematic conditions (7) create the core of the mathematical model.

4. Model Control

According to the motion equations, the number of physical parameters is greater than the number of equations. These surplus parameters correspond to the number of degrees of freedom and they can be used for the control of the mentioned mathematical model. The total number of parameters in the mathematical model is divided into two groups. The first group corresponds to the number of mathematical model equations representing the left side variables of these equations. They characterize the instantaneous state of the system. The system is defined by the aircraft centre of gravity position, flight speed value and its orientation in space when modelling.

The remaining “surplus” parameters are designated as control parameters and are used for mathematical model controlling. The knowledge of these parameters at any time allows explicit calculation of the differential equations system and thereby a complete history of the manoeuvre can be provided. For a general manoeuvre, there are four control parameters seen as the best solution to calculation of acting forces at a given flight moment. In the next step, the solution of the differential equations system of the remaining parameters on the left side is carried out. The suitable control parameters are following:

- Lift load factor n_L – it allows calculation of aircraft lift and induced component of drag.
- Engine speed n_P – it allows calculation of power plant thrust.
- Bank angle μ – it defines lift deflection from the vertical plane and radius of curvature of flight trajectory in the horizontal and vertical plane.
- Position of wing flaps or break flap δ – they affect the lift and drag of the aircraft.

The mode of control usually assumes a step change of the control parameters. The value of these control parameters ranges within permitted limits so as not to overrun the flight limitations. The control rules must be defined for a given individual modelled manoeuvre and, sometimes, heuristic. Individual control parameters are generally expressed as functional dependence between the required and instantaneous flight regimes. This manoeuvre section is terminated in time, when the process reaches the required regime with acceptable accuracy,

$$\mathbf{u} = [n_L, n_P, \mu, \delta]^T. \quad (8)$$

The aircraft movement can be analyzed based on the control parameters for the definition of flight trajectory as a dynamic determined system (Fig. 5). The control



Fig. 5 Control determined system

parameters \mathbf{u} are fed into the system input and the system state on output is defined by state coordinates \mathbf{X} . The instantaneous system state is defined by six-dimensional state vector, which includes the centre of gravity position, magnitude and direction

$$\mathbf{X} = [V, \gamma, \chi, x, y, H]^T. \quad (9)$$

of flight velocity (instantaneous weight is not included). In the components of path coordinate system, it has the form of

The dynamics of the system can be expressed by conditions for the time change of the system

$$\frac{d\mathbf{X}}{dt} = \mathbf{f}(\mathbf{X}; \mathbf{u}) \quad (10)$$

with the initial condition of $\mathbf{X}(t_0) = \mathbf{X}_0$.

The vector of system structure \mathbf{f} autonomously associates dynamic and kinematic conditions (6) and (7) which describe the flight trajectory in earth coordinate system with the absence of wind

$$\mathbf{f} = \begin{bmatrix} f_1 \\ f_2 \\ f_3 \\ f_4 \\ f_5 \\ f_6 \end{bmatrix} = \begin{bmatrix} g(n_D - \sin \gamma) \\ (g/V)(n_L \cos \mu - \cos \gamma) \\ -(gn_L/V)(\sin \mu / \cos \gamma) \\ V \cos \gamma \cos \chi \\ V \cos \gamma \sin \mu \\ V \sin \gamma \end{bmatrix}. \quad (11)$$

When solving an aircraft accident, initial conditions are defined from the supposed process at the beginning of the last flight phase and final conditions are usually based on wreckage analysis upon earth impact. The aim of modelling is a dynamic system transformation from the initial state (subscript 0) to the final state (subscript f)

$$\mathbf{X}_0 = \mathbf{X}(t_0) \quad \rightarrow \quad \mathbf{X}_f = \mathbf{X}(t_f)$$

The result of the solution is a flight trajectory displayed in phase space $\mathbf{X} = \mathbf{X}(t)$ and the entire history of the flight manoeuvre is expressed as a time process. A phase vector \mathbf{X} can be divided into a part corresponding to the course of flight parameters

$$x_1 = V(t), \quad x_2 = \gamma(t), \quad x_3 = \chi(t)$$

and a part displaying the flight trajectory

$$x_4 = x(t), \quad x_5 = y(t), \quad x_6 = H(t).$$

5. Source for Modelling

The advantage of an aircraft model represented by a mass point is seen especially in low requirements in terms of information about the aircraft. It is just in small sport aircraft, which moreover provide no flight records from the board flight recorder, where the aircraft characteristics are often missing. In such cases, necessary characteristics must be determined from semiempirical methods. For flight path modelling, the following aircraft characteristics must be available:

- Geometric characteristics including the wing area S and propeller diameter D_V .
- Mass characteristics including take-off weight m_0 (it is defined by the number of crew and passengers, luggage weight, fuel weight inside the tanks) and fuel consumption until the initial flight regime of the manoeuvre

$$m = m_0 - \int_0^t c_h dt,$$

where c_h is time fuel consumption and t is flight time.

- Aerodynamic characteristics of the aircraft are represented by a polar curve (it is the relation between the drag coefficient c_D and lift coefficient c_L) or, as the case may be, a lift curve (dependence of the lift coefficient c_L on the angle of attack α) too; the change of the characteristics when wing mechanism or aerodynamic breaks are extended. The aerodynamic characteristics allow calculation of the lift and drag

$$L = c_L q S, \quad D = c_D q S,$$

where q is dynamic pressure $q = \frac{1}{2} \rho V^2$ and ρ is air density from ISA.

- Power plant characteristics are engine characteristics $N = N(n, V, H)$ and aerodynamic propeller characteristics (it is the dependence between the power coefficient c_N and the thrust coefficient c_T of the propeller and the advance ratio λ for a given setting angle of the propeller φ). The power plant characteristics allow calculation of power N and propeller thrust T

$$N = c_N \rho n^3 D_V^5, \quad T = c_T \rho n^2 D_V^4, \quad \lambda = \frac{V}{n D_V}.$$

If these characteristics are not available, the values in question must be estimated. There are many methods for this, which are described in various literatures, for example [7-9].

The modelling takes place mainly under the conditions of International Standard Atmosphere [6] and occasionally calculation according to real atmospheric conditions is used [5]. During modelling including the wind effect, the mathematical model must be extended.

6. Flight Path Modelling

The mathematical model of flight path is expressed as a system of first order general differential equations with control parameters, which are changed in steps within defined limits. The calculation can be carried out on a computer using common software in an environment familiar to the user. Some programming language or even a spreadsheet application can be used for the calculation.

The modelling method is based on numeric integration of motion equations (11). The result is a complete history of the modelled manoeuvre i.e. the shape of the flight path and the process of individual flight parameters in dependence on the mode of system control. In numerical solution, the state in i -step of calculation is indicated by subscript “ i ”. During one step, the phase coordinates are changed by this value

$$\Delta \mathbf{X}_i = \mathbf{f}(\mathbf{X}_j; \mathbf{u}_j) \Delta t \quad (12.a)$$

The subscript “ j ” indicates a position inside the calculation step and it depends on the integration method used. In the next step ($i+1$), the phase vector value is defined by an associated change for the previous step

$$\mathbf{X}_{i+1} = \mathbf{X}_i + \Delta \mathbf{X}_i \quad (12.b)$$

The calculation of control parameters, atmospheric conditions and acting forces constitutes a part of each step.

Numeric calculation is affected by local error in each individual step of the calculation, which is cumulated in the next steps and it affects the final point of

trajectory. The local error depends on the length of a calculation step in all numeric methods. The purpose, especially in Excel applications, is to select a maximum length of the step while keeping the error within acceptable limits. The errors were monitored and evaluated for two kinds of manoeuvres [10]:

- Steady horizontal turn where a comparison between modelling and analytic solution was possible.
- Unsteady horizontal turn and looping in vertical plane where the results were monitored while shortening the calculation step.

The step in numeric integration does not always have to be time Δt . In some cases, it is better to modify the motion equations (3) and then the change of azimuth angle $\Delta\chi$, change of climb angle $\Delta\gamma$, or change of flight speed ΔV can be chosen as the steps. The Euler tangential method, Euler modified method for functional values in the middle of the calculation step and Runge-Kutta 4th order method were evaluated. The calculation step was changed alternatively: $\Delta t = 1; 0.5; 0.1; 0.05$ seconds, $\Delta\chi = 10^\circ; 5^\circ; 1^\circ; 0.5^\circ$, and $\Delta V = 5; 1; 0.5; 0.1$ km/h. The results were also affected by the curvature of flight path which is characterized by the lift load factor n_L .

Based on the gained experience, further modelling took place using the Euler modified method with calculation steps of $\Delta t = 0.1$ second, or $\Delta\chi = 0.5^\circ$ and $\Delta V = \pm 0.1$ km/h. When modelling, the effect of altitude change, effect of reference altitude, effect of engine regime change, effect of initial flight speed, effect of aircraft weight, effect of angle of attack change, and effect of real critical angle of attack were monitored [11, 12].

7. Real Aircraft Accident Modelling

A pilot together with one passenger on board of EV-97 aircraft was performing horizontal turns at low altitude. According to witnesses, a series of horizontal turns was followed by a turn with greater bank angle in which process the aircraft went into a stall. The speed of the aircraft when flying over the terrain and starting to turn was estimated in the area of 140 to 160 km/h. The aircraft weight was determined to be 500 kg based on mass analysis.

The EV-97 is a low-wing single decker of self-supporting all-metal structure, side by side two-seater aircraft. The undercarriage consists of a fixed three-wheel landing-gear with steerable nose wheel. The power plant consists of Rotax 912 UL four-cylindrical four-stroke engine and V230C fixed pitch wooden two-blade propeller. The aircraft of this category has a maximum take-off weight limited to 450 kg and a limit of bank 60° in horizontal turn (lift load factor is 2). The maximum operational load factor is 4.

Before modelling the investigated manoeuvre, i.e. a horizontal turn, the situation and flight regimes can be analyzed in thrust diagram for turns (Fig. 6). The required thrust curves correspond to the real flight weight of 500 kg and they are changed according to the load factor (aircraft bank). The required thrust curve with load factor $n_L = 1$ corresponds to horizontal straight flight. Solid lines without marks differ by the value of lift load factor 0.5. The dotted line connects stall speeds at individual load factors. Available thrust T_v is indicated at full thrust (bold) and at reduced thrust T_{vr} , which corresponds to the flight speed of 160 km/h in level steady straight flight (thin) thus also being the flight speed at starting the turn.

During the turn, only the vertical component of the lift exceeds the weight force. When turning at the same speed as in straight flight, the aircraft must be flown at a

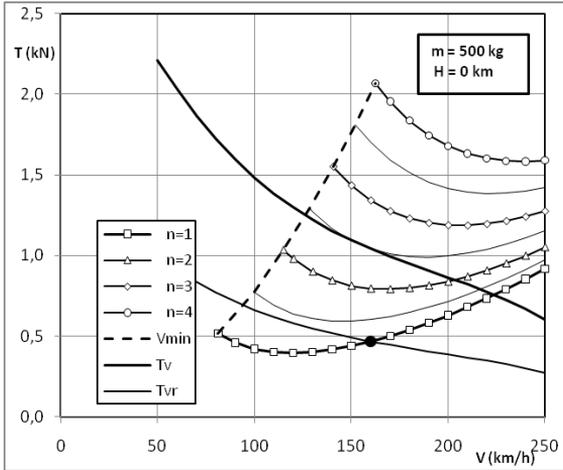


Fig. 6 Thrust diagram

greater angle of attack. This position ensures not only appropriate increased lift but the aircraft drag increases too. The curves of required thrust are shifted upwards and to the right in the thrust diagram and, at higher load factors, they run above the curve of available thrust. The aircraft has a lack of thrust and decelerates during turning. Increasing lift load factor simultaneously results in higher stall speed. The speed range between the initial speed and the stall speed is decreased and time of deceleration is reduced.

The analyses are based on the assumed initial speed of 160 km/h on turning start. The acquired data can be extended to higher or lower initial speeds. In case of a limit turn with the maximum operating load factor of 4, the initial speed is lower than the stall speed and the aircraft immediately goes into a stall during a roll. The situation is different in case that the load factor is 3 or lower up to the value corresponding to a point where the available thrust is in equilibrium with the required thrust and the turn will take place in a steady way at the initial speed or after certain deceleration. The break force is created causing aircraft deceleration during turning up to the stall speed. At reduced throttle, the lack of thrust is manifested at lower values of the load factor. Two boundary regimes of the engine are analyzed at the turn entry:

- Increasing engine throttle to maximum.
- Keeping engine throttle according to level straight flight.

The value of drag load factor describes the rate of deceleration (5). Drag load factor curves corresponding to the lift load factor when the aircraft deceleration occurs, are presented in Fig. 7. Deceleration time and turn angle were investigated when modelling unsteady turns with constant bank angle μ (lift load factor n_L), which correspond to engine throttle in the initial speed range of 140 to 160 km/h up to the stall speed. For a manoeuvre thus defined, the control parameters are constants:

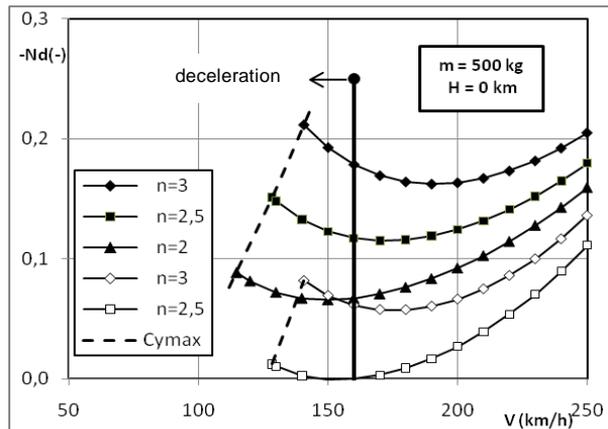


Fig. 7 Drag load factor

$$u_1 = n_L = \text{const.}, \quad n_L \in \langle n_3; 3 \rangle,$$

$$u_2 = n_P = \text{const.}, \quad n_P \in \langle n_r; 1 \rangle,$$

$$u_3 = \arccos\left(\frac{1}{n_L}\right),$$

$$u_4 = \delta = 0.$$

Obtained characteristics for chosen values of lift load factors are presented in Tab. 1. The full thrust value is indicated for load factor $n_L = 3$ only, because the speed of around 150 km/h with the value of load factor $n_L = 2.5$ results in equilibrium between the thrust and drag and then the turn takes place in a steady form. At reduced throttle, the turns are modelled in the range of lift load factors of 2 to 3. The subscript 1 indicates parameters at the turn start; subscript 2 indicates parameters at the moment when the aircraft achieves the stall speed. Instantaneous turn radius and instantaneous angular speed in turn are defined based on these formulas [6]

$$r = \frac{V^2}{g\sqrt{n_L^2 - 1}}, \quad \omega = \frac{g\sqrt{n_L^2 - 1}}{V}.$$

Tab. 1 Flight parameters for initial speed of 160 km/h

Flight Parameters			Full Thrust	Lower Thrust		
			$n_L = 3$	$n_L = 2$	$n_L = 2.5$	$n_L = 3$
Initial Speed	V_1	[km/h]	160			
Bank Angle	μ	[deg]	70.5	60.0	66.4	70.5
Stall Speed	V_2	[km/h]	140.6	114.8	128.4	140.6
Turn Radius	r_1	[m]	71.2	116.3	87.9	71.2
	r_2	[m]	55.0	59.9	56.6	55.0
Angular Speed	ω_1	[deg/s]	35.8	21.9	29.0	35.8
	ω_2	[deg/s]	40.7	30.5	36.1	40.7
Drag Load Factor	n_D	[1]	0,070	0,073	0,134	0,194
Turn Time	t	[s]	7.9	18.1	6.9	3.9
Turn Angle	χ	[deg]	300	462	222	151

If the turn was started at a lower speed of 150 or 140 km/h, then the turning time and angle are smaller. Flight parameters are presented in Tab. 2. Turn transition at the speed of 140 km/h with load factor 3 leads to immediate stalling irrespective of the engine throttle.

The described analyses are affected by flight weight too. The flight weight effect is shown in Fig. 8. Solid lines correspond to real flight weight, and the dashed lines correspond to the maximum permitted weight for this aircraft category. There is an obvious flight weight overrun in the figure. This causes aircraft deceleration even at smaller bank angles, which is difficult to perceive during flight. The difference increases with growing weight.

Tab. 2 Flight parameters for initial speeds of 150 km/h and 140 km/h

Flight Parameters			Full Thrust		Lower Thrust	
			$n_L = 3$	$n_L = 2$	$n_L = 2.5$	$n_L = 3$
Initial Speed	V_I	[km/h]	150			
Turn Time	t	[s]	3.5	13,8	4,6	2,5
Turn Angle	χ	[deg]	138	365	152	99
Initial Speed	V_I	[km/h]	140			
Turn Time	t	[s]	0	9.5	2.3	0
Turn Angle	χ	[deg]	0	262	81	0

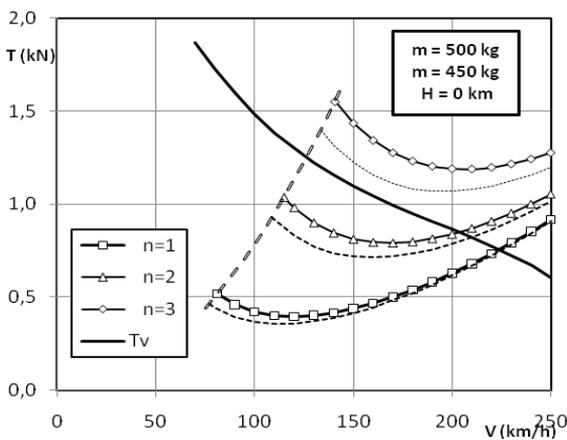


Fig. 8 Effect of aircraft weight on the thrust diagram

Modelling in connection with previous analyses enables formulation of hypotheses about the progress of the aircraft accident. The probable cause of the accident was the attempt to make a turn with a smaller radius when a lack of thrust was present, which also affected the engine regime. The aircraft decelerated down to the stall speed in a short time in the course of turning. The airflow on the wing was separated which occurred at a seemingly high flight speed and the aircraft went into an

asymmetric stall. Given the low altitude, the aircraft could not resume flight. The initial lack of thrust could have been small and the pilot could have perceived a slight deceleration as steady flight and did not pay attention to the airspeed indicator. However, deceleration grows more intense when the speed is approaching stall speed.

8. Conclusion

The effort to increase aviation safety leads to extended use of simulators on which pilots are trained and practise procedures for the solution of emergency situations. However, there are still aircraft categories where the development and use of fidelity simulators is inefficient and a change of the situation is not very likely. Simultaneously, the possibility of an enhanced training method is searched for in the world not only for the flying crews [1] and new training approaches are designed at the same time. The purpose of these methods is to increase the percentage of new information retained in the memory (Fig. 9).

While traditional training, the so called passive learning, declares the retention of about 50 % of new information in the best case, the so called active learning declares the retention of new information of about 80 % or more.



Fig. 9 Comparison between traditional and active training

Enhancing simulator fidelity results in higher costs of development up to a certain limit of effectiveness [5]. Moreover, using a simulator does not provide knowledge indicating why a situation occurred, what the characteristics of other aircraft with different parameters and weights are. In view of this fact, using a simulator is classified as traditional learning when the pilot can only improve his skills on a certain aircraft type (routinely on a more powerful aircraft) including solution of emergency situations.

On the other hand, when the pilot is able to enter various flight conditions and various aircraft characteristics, flight path modelling provides the user with knowledge about different behaviour of various aircraft categories or different aircraft configurations, e.g. aircraft with lower power or aircraft with higher weight. The use of flight path modelling provides a survey of physical laws for general aircraft based on its characteristics and the user thereby acquires vast theoretical knowledge. This kind of knowledge gaining can be counted among active learning forms. On the background of current difficult economic situation, minimal costs of modelling methods and the needed software are

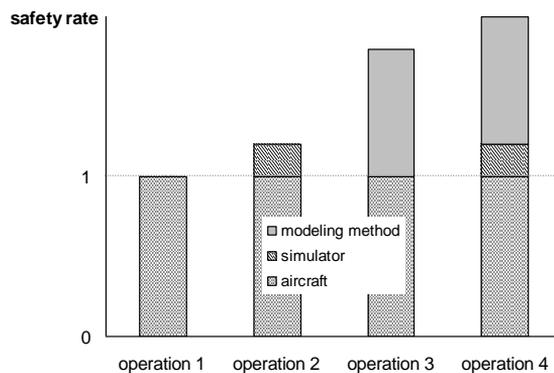


Fig. 10 Safety rate at various operations

appreciated. Moreover, this method offers a higher rate of safety (Fig. 10) in comparison with the use of common simulators.

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