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AIRCRAFT LANDING FLARE

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Abstract. *The method of aircraft flare onto airfield surface using ground speed and altitude exponential step change is considered. A Math modeling of this method has been performed.*

Keywords: aircraft; landing; way of flare.

1. Introduction

Landing is the most potentially dangerous phase of flight, stage of flare in particular, when the vertical speed is being significantly reduced.

Automation of this stage can improve flight safety.

Furthermore, implementation of unmanned aircraft depends on this process.

This problem is being much discussed recently and there are many suggestions about method of flare automation, but question about workable solution is still topical.

2. Analysis of recent research and publications

One of the first methods is method of automatic landing control using exponential flare trajectory [1].

It is assumed that the vertical speed of aircraft is proportional to its height at each moment.

It leads to the next expression of height:

$$H(t) = H_0 e^{-\frac{t}{T}},$$

where H_0 – the height of flare's beginning;

T – exponent constant.

One can find the unknown parameters under certain conditions.

Disadvantages of the method should include the ambiguity of simultaneous execution of requirements for height and speed.

Moreover, the main source of information is radar altimeter.

This method has been developed in paper [2].

It's author proposes a method of flare, where vertical speed is proportional to the current values of height and vertical acceleration.

The height changing is given as a sum of two exponents.

The most comprehensive solution to the problem of landing and alignment is considered in paper [3].

A method of nonlinear control using dynamic inversion for automatic landing of unmanned aircraft is given in this article.

The method has inner and outer loop structure.

External circuit converts guidance commands into the evolution of the object (aircraft motion) while the inner loop provides control on object motions (given by external loop).

There is also a separate loop for speed control, which regulates the engine thrust.

Consider this loop for solution of alignment (Fig. 1).

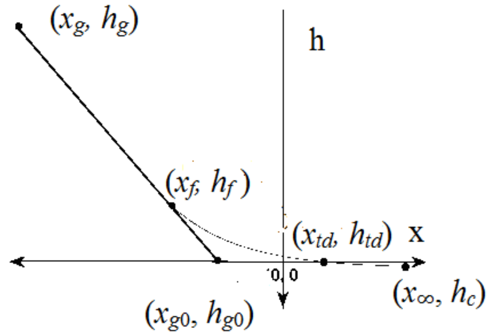


Fig. 1. Flare trajectory:
(x_g, h_g) – a point where glide path starts;
(x_f, h_f) – a point where flare starts;
(x_{td}, h_{td}) – a point which defines a place of touching down;
(0,0) – a point of the inertial reference system in the end of the runway;
(x_{g0}, h_{g0}) – a fictitious point on the ground on which glide path is projected;
(x_∞, h_c) – a final point of flare which is chosen in such way, that the exponent of flare trajectory intersects the ground at the touchdown point

When aircraft intrudes into zone of glide path's beginning, the desired trajectory angle must be calculated as following:

$$\gamma^* = \tan^{-1}\left(\frac{h_g - h_{g0}}{x_g - x_{g0}}\right).$$

Thus, the desired height for each flight on final approach can be written as a function of distance:

$$h^* = (x - x_{g0}) \tan\gamma^* .$$

Line path during flare is an exponential curve.

The desired height can be specified as a function of the direct distance:

$$h^* = h_c + (h_f - h_c) e^{-k_x(x - x_f)} .$$

In the last equation the unknowns are: flare height h_f, distance of flare's beginning x_f, final point below the ground level, where flare trajectory ends h_c, and the constant k_x.

To find the unknowns we have to solve following system of equations:

$$h_f = -(x_f - x_{g0}) \tan\gamma^* ,$$

$$(h_f - h_c) k_x = \tan\gamma^* ,$$

$$0 = h_c + (h_f - h_c) e^{-k_x(x_{td} - x_f)} ,$$

$$\dot{h}_t^* = -(h_f - h_c) k_x x_{td} e^{-\dot{k}_x(x_{td} - x_f)} .$$

As a result of solving this system of four equations, we obtain arbitrary values of x_f and h_f.

This leads to uncertainty of the moment of reaching the required speed of landing.

The goal of the article is upgrading and testing of a new method of aircraft flare with fixation of parameter h_f (height of flare beginning) and decreasing of the equation amount.

3. The main material

We consider the situation where the automatic control system has already led the aircraft to initial point of the glide path (x_g, h_g) with horizontal speed W.

We suppose that the wind speed is zero, and the automatic control system completely compensates the disturbances.

We will solve the task of reaching desired horizontal and vertical speed at touchdown point x_{td} in two stages.

On the first stage we decrease horizontal speed W up to desired value W_z from point x_g to point x_f while height is on level $h_f = h_z$.

When considered angle of trajectory is small, the horizontal speed is almost equal to speed on glide path.

We can find the exponent index α and the interval of speed change dT from the relation:

$$W_z = W e^{-\alpha dT} ,$$

$$h_z = (D_0 - \int_0^{dT} W e^{-\alpha t} dt) \sin\gamma ,$$

where D_0 – the distance between points (x_g, h_g) and (x_{g0}, h_{g0});

γ – glide path angle.

Solving the last system of equations, we can obtain:

$$\alpha = \frac{W\left(1 - e^{\ln\left(\frac{Wz}{W}\right)}\right)}{D_0 - \frac{h_z}{\sin\gamma}} ,$$

$$dT = \frac{-\ln\left(\frac{Wz}{W}\right)}{\alpha} .$$

On the second stage we can fix the horizontal speed and begin to change the height by the exponential law from the value $h_z - h_c$ to the value h_c in such a way, that the exponent line crosses the point x_{td} with the vertical speed of h_p.

The values of exponent k_x and h_c can be found by solving the system of equations:

$$h_c + (h_z - h_c) e^{-k_x(x_{td} - x_f)} ;$$

$$h_p = (h_z - h_c) k_x x_p e^{-k_x(x_{td} - x_f)} ,$$

where h_p – vertical speed.

The math modeling is carried out to test the method.

The complex includes programs for calculating changing parameters of speed and height and also program for repositioning the aircraft in time.

We assume that automatic control system is perfect, and there is no wind.

Initial modeling data is:

$D_0 = 3{,}008 \cdot 10^4$ m;

$W = 200$ km/h;

$W_z = 40$ m/s;

$h_p = 0{,}2$ m/s;

$x_{td} = 100$ m;

$\gamma = 0{,}05$ rad.

Modeling results are shown in Table.

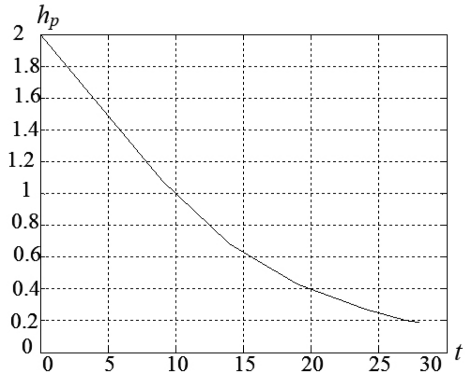
Zero point of the x-coordinate is chosen in such a way that distance until touchdown point x_{td} is 100 m.

Modeling result

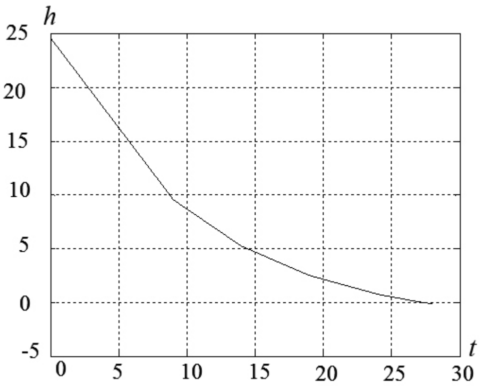
t, s	641	650	655	660	665	668	669
h, m	24,56	9,5	5,2	2,48	0,76	0,055	-0,14
h_p, m/s	2	1,08	0,68	0,43	0,27	0,2	0,19
W, m/s	40	40	40	40	40	40	40
x, m	-991	-631	-431	-231	-31	89	129

Note: h – height; x – distances along the axis running along the runway.

Using data from Table we have built the dependence graphs of height (Fig. 2, *a*) and vertical speed (Fig. 2, *b*) on time.



a



b

Fig. 2. Dependence of height (*a*) and vertical speed (*b*) on time

As we can see from this data, we have reached the desired values of horizontal and vertical speed in the touchdown point.

The value of vertical speed is 0,2 m/s, the value of horizontal speed is 40 m/s.

The interval from point of glide path beginning to point of flare beginning is covered during 641 s.

Note that if aircraft entered the glide path with touchdown horizontal speed, it would cover this interval during 759 s.

The landing accuracy is 0.23 m, it is much better than accuracy of modeling with 4 equation system solving.

4. Conclusions

The performed modeling has shown that the upgraded flare method provides reaching the desired values of vertical and horizontal speed in the touchdown point.

In contrast of method with solving 4 non-linear equations, the proposed method sets the initial flare height.

This allows us to decrease the number of equations.

Besides, the reduction of horizontal speed up to the touchdown value in the beginning of flare stage is carried.

This method provides more precise landing than other methods, which were proposed earlier.

Relations for parameters of height and speed control are given.

The results would be useful for developers of automatic landing systems.

References

[1] *Agajanov, P.A.; Vorobyov, V.G.; Kuznetsov, A.A.* Automation of air navigation and air traffic control. Moscow, Transport. 1980. 357 p. (in Russian).

[2] *Burnashev, V.V.* Algorithms of UAV navigation and control system during automatic landing. Materials of VIII International Conference. Kyiv, Kyiv Polytechnic Institute. 2011.

[3] *Singh, S.; Padhi, R.* Automatic Path Planning and Control Design for Autonomous Landing of UAVs using Dynamic Inversion. American Control Conference Hyatt Regency Riverfront, St.Lous, Mo, USA. June 10-12. 2009.

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Е.А. Ковалевський[1], В.В. Конін[2], Т.І. Олевінська[3]. Вирівнювання під час посадки літальних апаратів

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Розглянуто спосіб вирівнювання літальних апаратів під час посадки на необладнаний майданчик із поступовою зміною шляхової швидкості та висоти. Виконано математичне моделювання.

Ключові слова: літальний апарат; посадка; спосіб вирівнювання.

Э.А. Ковалевский[1], В.В. Конин[2], Т.И. Олевинская[3]. Выравнивание при посадке летательных аппаратов
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Рассмотрен способ выравнивания летательных аппаратов при посадке на необорудованную площадку с постепенным изменением путевой скорости и высоты. Выполнено математическое моделирование.

Ключевые слова: летательный апарат; посадка; способ выравнивания.

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