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[1]N. F. Tupitsin,
[2]H. O. Massalova

EXPERIMENTAL CHECKING OF GAS-DYNAMIC METHOD OF UAV LANDING

Aviation Computer-Integrated Complexes Department, National Aviation University, Kyiv, Ukraine
E-mails: [1]tupitsyn2@gmail.com, [2]Massalovaanna@gmail.com

Abstract—*In the paper construction of the experimental gas-dynamic stand for checking of the gas-dynamic method of unmanned aerial vehicle landing is developed. Characteristics of this stand were calculated and choose. Series of experiments for given model of unmanned aerial vehicle were conducted. Experiments reveal that at braking of unmanned aerial vehicle into artificial airstream on its motion act next main factors: 1) the angle of attack; 2) uniformity, velocity, and the artificial airstream motion direction. Moreover, obtained results allow more carefully ground requirements to equipment for implement new experiments.*

Index Terms—Experimental gas-dynamic system; artificial airstream; fan propeller; mechanical belt drive.

I. INTRODUCTION

In works [1] – [2], a description is given of the nonaerodrome gas-dynamic takeoff and landing (GTL) method of UAV and features of the implementation of this method are considered. In work [3], an exact and approximation analytical expression for calculation of the gas-dynamic jets parameters for gas-dynamic complex are obtained.

However, works about experimental checking of gas-dynamic method of the UAV takeoff and landing are absent.

II. PROBLEM STATEMENT

Theoretical research of GTL method is an important part of development real system of GTL.

Experiments allow hypotheses checking, which are accepted at theoretical research of GTL method. In addition, it is difficult to create the GTL system without experimental supporting evidence its operability.

The purpose of the work is to: 1) check the workability of GTL system; 2) to research of motion dynamic of the UAV at its braking under action from artificial airstream (AA); 3) to define main factors, which influence on the UAV braking distance.

III. PROBLEM SOLUTION

Block-diagram of the task solution algorithm is shown on Fig. 1.

Description of the task solution algorithm.

1) Prepare of technical specification.
2) Synthesis of gas-dynamic system of the UAV landing.
3) Choice of measurement equipment.
4) Choice of UAV.

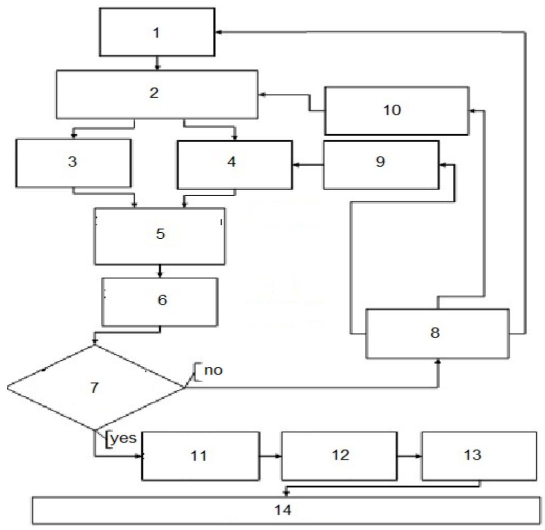

Fig. 1. Block-diagram of the task solution algorithm

5) Calculation of the executive units’ parameters.
6) Calculation of the artificial airstream velocity.
7) Condition checking about the artificial airstream velocity.

On this stage is executed a comparison the obtained result with required one. If the specified condition is not satisfied, then the technical specification correction is selected.

8) Correction of the technical specification.
9) Choice of the UAV new parameters.
10) Choice of the structure and/or parameters of gas-dynamic experimental stand.
11) If the specified condition is satisfied, then is executed the stage 11.
12) Matching of the system actuating elements.
13) On this stage developer calculates kinematics and dynamics of the UAV, which commit landing.

14) Installation and balancing of the system.
15) Experiments conduction.
16) Processing of results.

A. Development of the experimental gas-dynamic stand

Side view of the experimental gas-dynamic system (EGDS) is shown on Fig. 2, where *1* is a rear column of system; *2* is thin cable (wire rope); *3* rings of hook; *4* is the UAV; *5* is the central rear column of system; *6* is the artificial airstream; *7* is a propeller of an axial fan; *8* is a pulley; *9* is a secondary shaft; *10* is a main column of system; *11* is a belt; *12* is set of pulleys; *13* a primary shaft; *14* an engine.

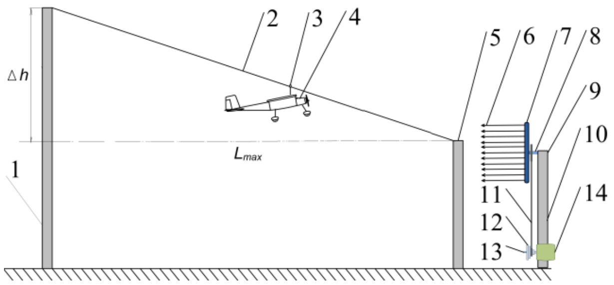

Fig. 2. Side view of the EGDS

Frontal view of the EGDS is shown on Fig. 3.

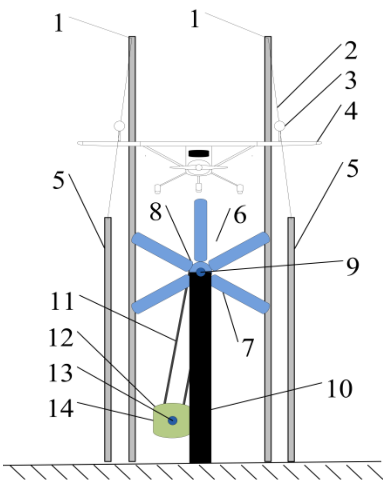

Fig. 3. Frontal view of the EGDS

Top view of the experimental gas-dynamic system is shown on Fig. 4.

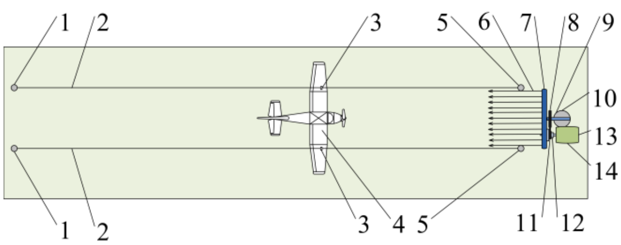

Fig. 4. Top view of the EGDS

B. Descriptiopn and calculation of the main elements of EGDS

Parameters of fan propeller are shown in Table I. The exterior view of the fan propeller is shown in Fig. 5.

TABLE I. PARAMETERS OF FAN PROPELLER

Diameter	0.66 m
Amount of blades	6
Length of blade	0.27 m
Average width of blade	0.085 m
Angle of blade inclination	30 deg

Parameters of stand engine are shown in Table II.

TABLE II. PARAMETERS OF STAND ENGINE

Type	Asynchronous
Amount of phases	3
Voltage	380 V
Frequency	50 Hz
Power	600 W
Rotary speed	1380 rpm

Fig. 5. The exterior view of the fan propeller

For experiments the UAV Cessna 182 M24 (Fig. 6) is used. This UAV has next characteristics:

- mass m = 0.48 kg;
- wingspan L_S = 0.948 m;
- wing area S = 0.128 m2;
- length of fuselage 0.668 m;
- cruising speed V_{CS} = 18 km/h.

Also this UAV has electric engine, which was not used on at experiments.

Fig. 6. The exterior view of UAV Cessna 182 M24

For registration of AA velocity was used two hot-wire anemometer AZ INSTRUMENT 8908. Peculiarity of this type device is that the displayed air speed is averaged for 2 seconds.

Proposed calculation of fan propeller parameters based on procedure [4]. Main calculated parameters are:

1) Helix lead H (Fig. 7)

$$H = 2\pi R\,\mathrm{tg}(\varphi), \tag{1}$$

where φ is the angle inclination of fan blade; R is the radius of fan.

2) Volume of air, which passable through the fan in a single revolution at ideal conditions:

$$Q_s = H\pi R^2. \tag{2}$$

3) Volume of air, which passable through the fan in n_c revolutions at ideal conditions:

$$Q = Q_s n_c, \tag{3}$$

where n_c is an amount of fan propeller revolution per second.

4) The speed of airstream, which created by fan is calculated with help of formula:

$$V = Hn_c = Q_s/S, \tag{4}$$

where S is a fan airflow area.

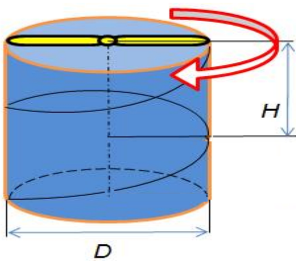

Fig. 7. Helix lead *H*

For experimental stand is chosen an electric motor with 1380 revolutions per minute. Adjust of the engine revolutions for the fan may with help of belt drive.

This belt drive allows decreasing engine speed and increasing torque on the secondary shaft. In addition, it allows descending the engine as low as possible from the cross section of the impeller of the fan to reduce the resistance of the incoming air flow into it.

For definition of the fan propeller rotary speed is necessary to calculate mechanical belt drive. Rotary speed of the belt drive second shaft between the engine and fan propeller is defined from proportion

$$\omega_1 / \omega_2 = D_{sh2} / D_{sh1}, \tag{5}$$

where ω_1 is rotary speed of the first shaft; ω_2 is rotary speed of the second shaft; D_{sh1} is diameter of the first shaft; D_{sh2} is diameter of the second shaft.

From (5) we can write

$$\omega_2 = (D_{sh1} \cdot \omega_1) / D_{sh2}. \tag{6}$$

At values ω_1 = 1380 rpm and D_{sh2} = 0.16 m calculated data for different types of shafts are shown in Table III.

For calculation of the experimental stand parameters is developed program on C++. Calculated characteristics of the experimental stand from (1) – (6) are shown in Table IV.

TABLE III. CALCULATED DATA FOR DIFFERENT TYPES OF SHAFTS

Shaft No	D_{sh1}, mm	ω_2, rpm
1	40	345
2	58	500.25
3	77	664.125
4	101	871.125
5	125	1078.125

The information panel of input and output data is shown on Fig. 8.

TABLE IV. CALCULATED DATA FOR DIFFERENT TYPES

Helix lead, *H*	m	0.35
Number of an engine revolutions, n_c	prs	11
	rpm	664
Air density, ρ	kg/m^2	1.24
Volume of air, *Qs*	m^3	0.119
Volume of air, *Q*	m^3	1.35
Speed of air stream, *V*	m/s	3.98
Power of an engine, *P*	hp	0.86
Fan airflow area, *S*	m^2	0.34

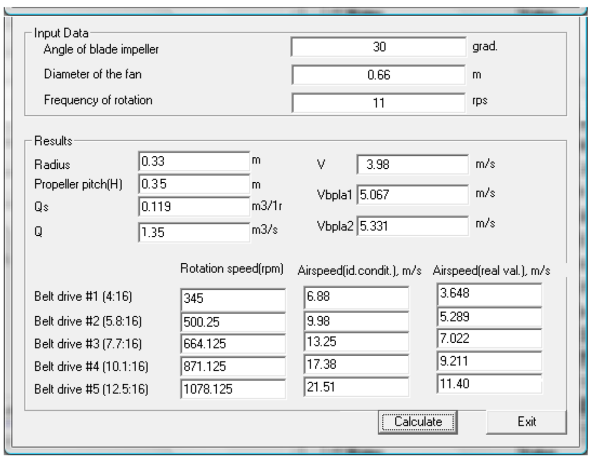

Fig. 8. The information panel of input and output data

In the information panel of program are represented next values:

- *Airspeed* (id.condit.) is airspeed of AA without account of the air viscosity;
– *Airspeed* (real val.) is airspeed of AA with account of the air viscosity;
– *Results* are results of calculations;
– V_{bpla1} is the UAV velocity near fan with account of friction rings of hook regarding wire yarn;
– V_{bpla2} is the UAV velocity near fan without account of the friction.

Fig. 9. Power plant of the EGDS

C. Test preparation

More precise definition of the EGDS construction is shown on Fig. 11, where are introduced next designations:

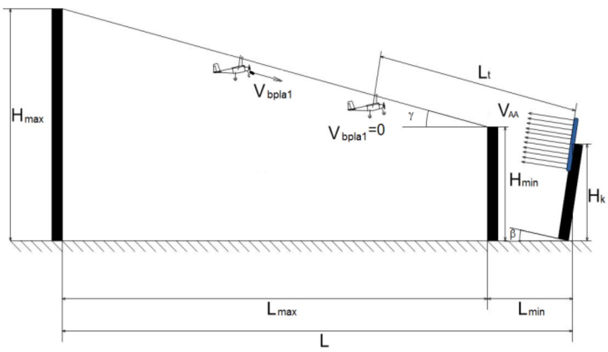

Fig. 11. More precise side view of the EGDS: $H_{\max}$ is a height of rear column; $H_{\min}$ is a height of central rear column; H_K is a distance between center of the fan propeller and plane of floor; $L_{\max}$ is a distance between columns; $L_{\min}$ is a distance between plane of central columns and center of the fan propeller; L_t is a distance between of the UAV nose part and center of the fan propeller at UAV stop with help of AA; β is an inclination angle of main column; γ is an inclination wire angle

Before conducting experiments next operations should be performed:

1) Adjustment of the inclination angle of main column, the inclination angle of wire rope, the angle attack of UAV.

The value V_{bpla2} is calculated with help of well known formula (see Fig. 2)

$$V_{bpla2}=\sqrt{2g\Delta h}.$$

After designing of the EGDS (Fig. 9), the AA speed measurements were made at 0.2 m from the plane of fan propeller (Fig. 10). In this case the AA speed is V = 11 m/s at number of an engine revolutions n_c = 664 rpm.

Fig. 10. The AA speed measurements

2) Hoist and fixing the UAV in initial position.
3) Start of power plant.
4) Start of UAV.
5) After UAV stop-ping, measurement of distance between the nose part of UAV and plane rotation of the fan propeller is executed.

The UAV motion towards of artificial airflow is shown on Fig. 12.

Fig. 12. The UAV motion in the AA

D. Experiments

Experiments are executed for next characteristics of EGDS: $H_{\max}$ = 2.55 m; L = 8.1 m; $L_{\max}$ = 7.6 m; $L_{\min}$= 0.5 m; V_{AA} = 7.6 m/s.

Position of UAV at its stopping into artificial airflow in test No.7 is shown on Fig. 13.

Measured parameters of the UAV motion into artificial airflow for eight experiments are shown in Table VI, where α is the UAV attack angle.

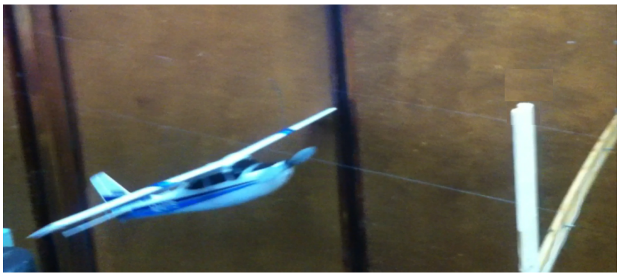

Fig. 13. Position of UAV at its stopping

TABLE VI. MEASURED PARAMETERS OF THE UAV MOTION INTO ARTIFICIAL AIRFLOW FOR EIGHT EXPERIMENTS

Test No	V_{bpla1}, m/s	H_{min}, m	H_k, m	γ, deg	α, deg	β, deg	L_t, m
1	5	1.24	0.9	10°	10°	0°	0.1
2	5	1.24	0.9	10°	15°	0°	0.2
3	5.33	1.1	1	11°	15°	4°	0.15
4	5.33	1.1	1	11°	30°	4°	0.45
5	5.33	1.1	1.05	11°	10°	5°	0.50
6	5.33	1.1	1.05	11°	15°	5°	0.70
7	5.33	1.1	1.05	11°	20°	5°	0.90
8	5.33	1.1	1.05	11°	30°	5°	1.05

IV. CONCLUSION

Experiments and observations were made on UAV dynamics of flight into artificial airflow. Experiments reveal that at braking of UAV into AA on its motion act three main factors: 1) the angle α;. 2) velocity and the AA motion direction; 3) the AA uniformity. Two first factors define a lenth of brake distance, and third factor – the oscillation process of UAV on brake distance. To improvement results of these experiments is necessary: a) for registration of AA parameters to apply device for measurement of the instantaneous velocity; b) to use UAV, which is covered by AA entirely.

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Tupitsin Nikolay. Candidate of Science. (Engineering). Associate Professor.
Aviation Computer-Integrated Complexes Department, National Aviation University, Kyiv, Ukraine.
Education: Moscow Phisics-thechnical Institute, Moscow, Russia (1975).
Research area: dynamic of flight, experimental methods of aerodynamic, aviation simulators.
Publications: 97.
E-mail: nift@mail.ru

Massalova Hanna. Master.
Aviation Computer-Integrated Complexes Department, National Aviation University, Kyiv, Ukraine.
Education: National Aviation University, Kyiv, Ukraine, (2017).
Research area: experimental methods of aerodynamic.
E-mail: serg_malahov@ukr.net

М. Ф. Тупіцин, Г. О. Массалова. Експериментальна перевірка газодинамічного методу посадки БПЛА

Розроблено конструкцію експериментального газодинамічного стенду для перевірки газодинамічного методу посадки безпілотного літального апарату. Розраховано і обрано характеристики стенду. Проведено серію експериментів для даної моделі безпілотного літального апарату. Експерименти показали, що під час гальмування безпілотного літального апарату в штучному повітряному потоці на його рух діють такі основні фактори: 1) кут атаки; 2) рівномірність, швидкість і напрямок руху штучного повітряного потоку. Крім того, отримані результати дозволяють більш ретельно обґрунтувати вимоги до обладнання для проведення нових експериментів.

Ключові слова: експериментальна газодинамічна система; штучний повітряний потік; пропелер вентилятора; механічний ремінний привід.

Тупіцин Микола Федорович. Кандидат технічних наук. Доцент.
Кафедра авіаційних комп'ютерно-інтегрованих комплексів, Національний авіаційний університет, Київ, Україна.
Освіта: Московський фізико-технічний інститут, Москва, Росія (1975).
Напрям наукових досліджень: динаміка польоту, експериментальні методи аеродинаміки.
Кількість публікацій: 97.
E-mail: nift@mail.ru

Массалова Ганна Олексіївна. Магістр.
Кафедра авіаційних комп'ютерно-інтегрованих комплексів, Національний авіаційний університет, Київ, Україна.
Освіта: Національний авіаційний університет, Київ, Україна, (2017).
Напрям наукових досліджень: динаміка руху літака.
E-mail: Massalovaanna@gmail.com

Н. Ф. Тупицин, А. А. Массалова. Экспериментальная проверка газодинамического метода посадки БПЛА

Разработана конструкция экспериментального газодинамического стенда для проверки газодинамического метода посадки беспилотного летательного аппарата. Характеристики этого стенда были рассчитаны и выбраны. Проведена серия экспериментов для данной модели беспилотного летательного аппарата. Эксперименты показывают, что при торможении беспилотного летательного аппарата в искусственном воздушном потоке на его движение действуют следующие основные факторы: 1) угол атаки; 2) равномерность, скорость и направление движения искусственного воздушного потока. Кроме того, полученные результаты позволяют более тщательно обосновать требования к оборудованию для проведения новых экспериментов.

Ключевые слова: экспериментальная газодинамическая система; искусственный поток воздуха; пропеллер вентилятора; механический ременный привод.

Тупицин Николай Федорович. Кандидат технических наук. Доцент.
Кафедра авиационных компьютерно-интегрированных комплексов, Национальный авиационный университет, Киев, Украина.
Образование: Московский физико-технический институт, Москва, Россия (1975).
Направление научной деятельности: динамика полета, экспериментальные методы аэродинамики.
Количество публикаций: 97.
E-mail: nift@mail.ru

Массалова Анна Алексеевна. Магистр.
Кафедра авиационных компьютерно-интегрированных комплексов, Национальный авиационный университет, Киев, Украина.
Образование: Национальный авиационный университет, Киев, Украина, (2017).
Направление научных исследований: динамика движения самолета.
E-mail: Massalovaanna@gmail.com