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WIND TUNNEL TESTS OF QUAD-ROTOR AUTOGYRO MODEL

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Abstract

The wind tunnel investigation of basic aerodynamic characteristics as well as flow visualization tests of the innovative quad-rotor autogyro model is presented. The wind tunnel measurements of aerodynamic characteristics were carried out using 6-component internal strain-gauge balance. In the area of the main rotor and quad-rotors, the flow visualization tests were performed by PIV (Particle Image Velocimetry) System. The work was carried out in cooperation with the Lublin University of Technology, which provided a model of gyroplane manufactured according to their own concept.

In the experimental study an influence of quad-rotors as well as pusher propeller on the autogyro model characteristics were determined by measurements aerodynamic forces and moments for a number of selected model configurations.

The wind tunnel experimental tests were performed in the Institute of Aviation low speed wind tunnel T-1, characterized by 1.5 m diameter test section. The investigations were carried out for undisturbed flow velocity $V\infty$ = *12.5 m/s, which corresponds to the Reynold's number,* $Re = 0.82 * 10^6$ *referred to 1 m, The angles of attack used in the experiment were implemented in two ranges* $-4^0 \leq \alpha \setminus \leq 2^0$ *and* $0^0 \leq \alpha \leq 13^0$*, with a sideslip angle* $\beta = 0$.

The tests showed that the flow induced by quad-rotors interfered with the flow induced by the main rotor changing the autogyro aerodynamic characteristics.

Keywords: *transport, autogyro, quad-rotor, aerodynamic characteristics*

1. Introduction

An autogyro is a type of rotorcraft that uses an unpowered main rotor in autorotation to develop lift, and an engine-powered propeller to provide thrust. The classic autogyro has to use the engine-powered propeller to force the autogyro forward movement during the take-off and cruise flight phases. The autogyro forward movement creates an airflow through the rotor disc and in this way generates its rotation. The rotation of the rotor blades induce the lift, which allows an autogyro to fly.

An autogyro was invented by the Spanish engineer Juan de la Cierva and had its first flight on 9 January 1923, at Cuatro Vientos Airfield in Madrid.[1]. It was the C-4 model equipped with four-blade rotor and with a front-mounted engine and propeller to pull this flying object through the air. Under license from Cierva in the 1920s and 1930s, the Pitcairn & Kellett companies made further innovations. An improved clutch and drive shaft system was introduced late in 1930 on the PCA-2 model. The aerodynamic characteristics of the full-scale PCA-2 autogyro rotor were tested in Langely Laboratory wind tunnel [2].

The next major advance in autogyros came in 1931 with the first flight of the Wilford's autogyro [3]. A it was single-seat open-cockpit autogiro (X794W) manufactured on the base of aircraft, where the wings were removed and replaced by a four-blade rotor. The new autogyro used a rigid rotor with cyclic pitch variation.

One of the significant problems associated with the use of the autogyro was creating such a solution that would allow its vertical take-off and landing. Although the autogyro mentioned earlier had a possibility of vertical landings at least in an emergency, they also needed some minimum run for take-off. To allow the vertical take-off of the autogyro, there was a need for creating lift by spinning its rotor at the minimum speed for autorotation. For the first time, such a solution was implemented on the C.30 autogyro model [4]. On October 28, 1934, after over a year of experimenting, the C.30 autogyro finally made a successful jump takes-off. In the next years many others autogyros were also designed for jump take-offs, using the same method as the C.30 [5]. Among them, was also I-28 gyroplane designed and manufactured in the Institute of Aviation (IoA) Warsaw, Poland [6, 7]. I-28B is a gyroplane with propeller in tractor configuration. Its engine is mounted in the middle part of the fuselage, which allows to power alternatively the propeller or the two-blade rotor. In a few others autogyros the main rotor was driven by tip jets or a rocket, which were put at the end of each rotor blade to spin the rotor in that way.

In the present paper, the innovative quad-rotor autogyro model was tested experimentally in the IoA low speed wind tunnel T-1. The model was equipped with a two-blade rotor, four side rotors situated in quadro arrangement and a pushing propeller. In assumption, four side rotors could be used to control the autogyro stability.

2. Experimental setup and instrumentation

2.1. Wind Tunnel

The experimental wind tunnel tests discussed in this paper were performed in the Low Speed Wind Tunnel T-1 in the Institute of Aviation (IoA). The T-1 wind tunnel is a closed-circuit continuous-flow wind tunnel with a 1.5 m diameter of the open test section, Fig. 1. The controlled range of freestream velocity is 15-40 m/s. The wind tunnel driving system consists of four-bladed fan powered by a 55 HP AC motor.

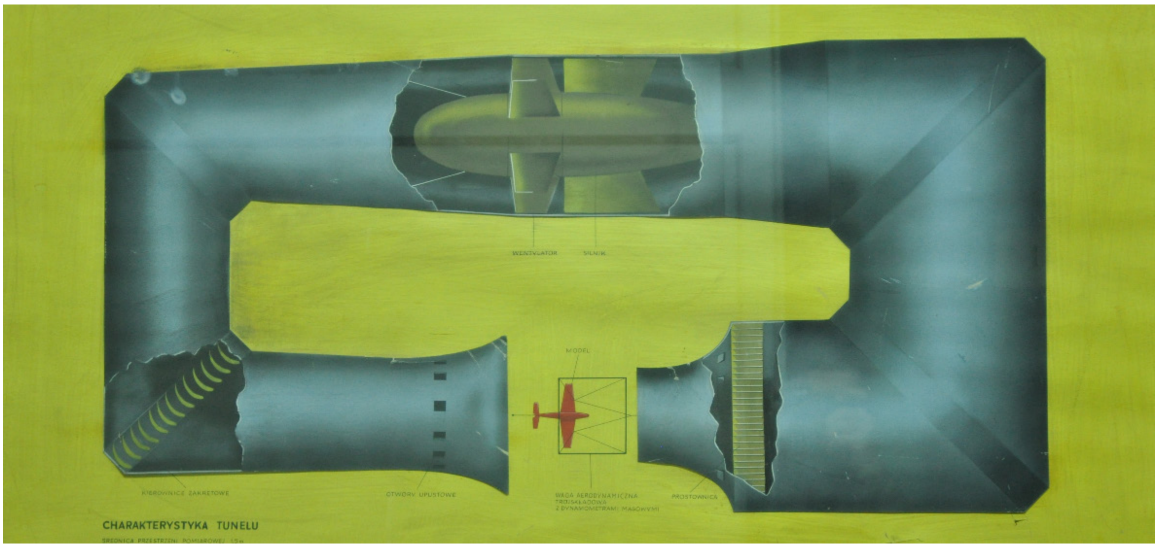

Fig. 1. Low Speed Wind Tunnel T-1

2.2. Tested model

The object of the study was a model of quad-rotor autogyro designed and manufactured by the Lublin University of Technology. It was a multi-rotor flying object which consisted of the fuselage, two-blade main rotor (diameter D = 1.1 m), four side rotors situated in quadro arrangement and pushing propeller. The model was entirely made of composite, except internal aerodynamic balance fixing. The model of the autogyro tested in T-1 IoA wind tunnel is presented in Fig. 2.

Fig. 2. The model of autogyro in T-1 IoA wind tunnel

2.3. Measuring technique

The tested model of autogyro was placed in the middle of the wind tunnel test section on the 6-component internal balance Rollab I-646-2. The aerodynamic balance was fixed to the wind tunnel model base by the vertical mast [3]. The wind tunnel model base allows to change the model's angles of attack in the range α = -15°-35° and the model's sideslip angles in the range β = ± 35°.

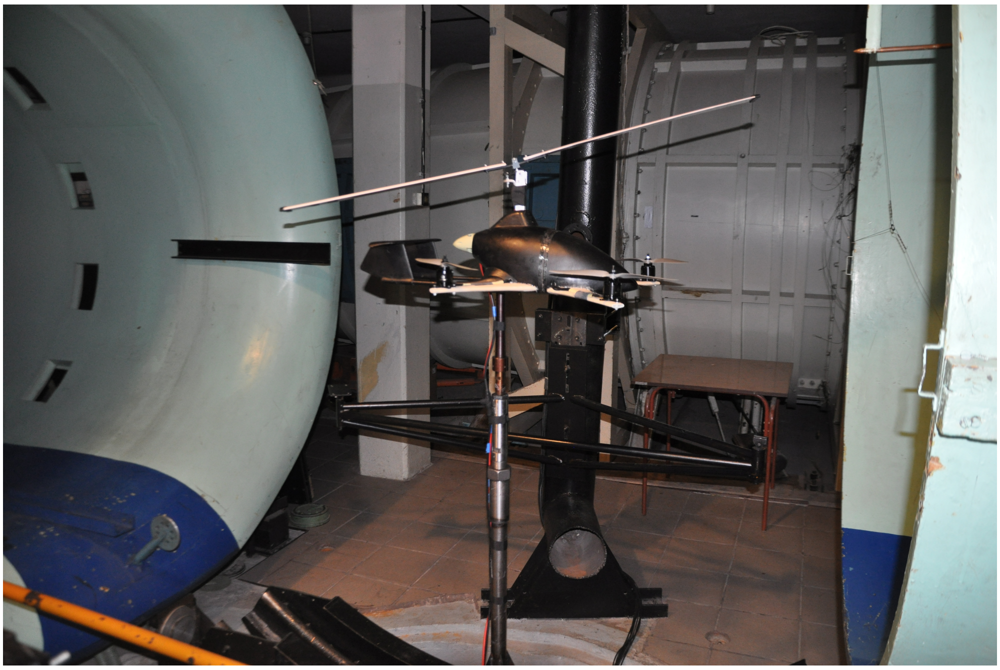

Fig. 3. The model of autogyro fixed to the wind tunnel model base

The multiple repeated tests showed that aerodynamic characteristics measured by internal balance Rollab I-646-2 are determined with the following accuracy: lift coefficient ± 0.01, drag coefficient ± 0.002 and pitching moment coefficient ± 0.001.

Model geometrical data taken into the coefficient calculations were as follows:

- Reference surface (rotor disc area), S = 0.95 m^2,
- Reference length (rotor radius), R = 0.1011 m,
- The centre of the coordinate system was situated on the balance axis at the distance l = 0.0831 m from its centre.

The used coordinate system is presented in Fig. 4.

To obtain the vector velocity field in the model surroundings the PIV method was used [8].

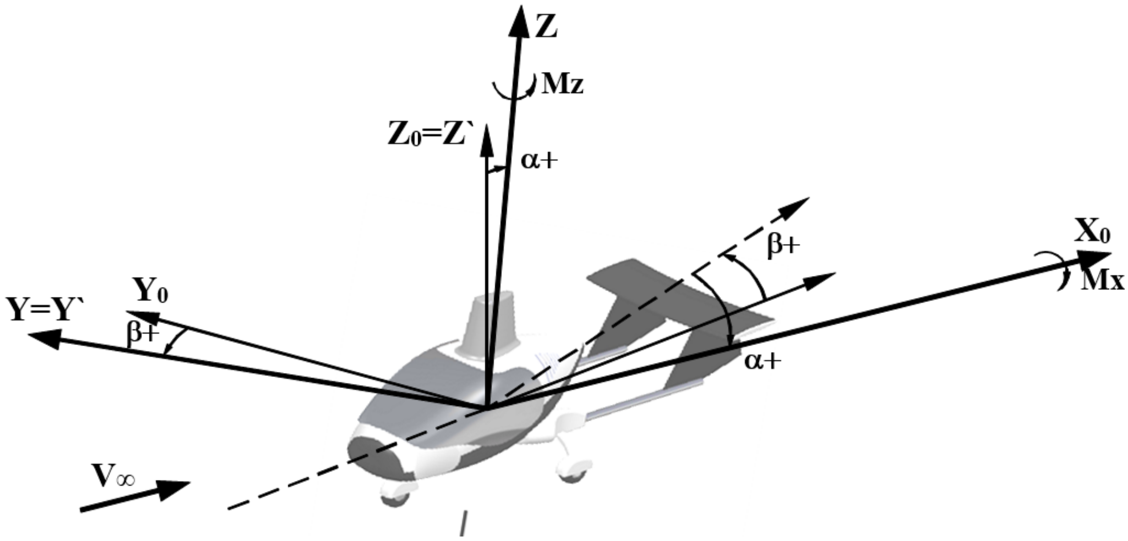

Fig. 4. The used coordinate system

3. Wind tunnel tests results

3.1. Tests program

Performed wind tunnel tests program is presented in Tab. 1.

Tab. 1. Wind tunnel tests program

No.	V_∞[m/s]	α[deg]	Collective pitch	Pushing propeller	Side rotors
1	12.5	$-4^0 – 8^0$	Θ = 5.4^0	removed	removed
2	0	$-4^0 – 2^0$	Θ = 5.4°	removed	50% of power
3	0	$-4^0 – 2^0$	Θ = 5.4°	removed	100% of power
4	12.5	$-4^0 – 2^0$	Θ = 5.4°	removed	50% of power
5	12.5	$-4^0 – 2^0$	Removed	removed	50% of power
6	12.5	$-4^0 – 2^0$	Removed	removed	100% of power
7	12.5	$0^0 – -13^0$	Θ = 13.5°	removed	50% of power
8	12.5	$0^0 – -13^0$	Θ = 13.5°	removed	100% of power
9	12.5	$0^0 – -13^0$	Θ = 13.5°	removed	0% - of power
10	0	$0^0 – -13^0$	Θ = 13.5°	removed	100% of power
11	12.5	$0^0 – -13^0$	Θ = 13.5°	removed	removed
12	12.5	$0^0 – -13^0$	Θ = 13.5°	100% of power	100% of power
13	12.5	$0^0 – -13.5^0$	Θ = 13.5°	100% of power	removed with arms
14	12.5	$0^0 – -13.5^0$	Θ = 13.5°	removed	removed with arms

3.2. Sample tests results

In Fig. 5 the influence of the side rotors, using 50% of their engine power, on the autogyro lift (L) (with the main rotor collective pitch $\Theta = 5.4^0$) versus the angle of attack for $V_\infty = 0$ m/s and 12.5 m/s is presented. Those results were compared with the autogyro lift generated by the gyroplane rotor at the collective pitch $\Theta = 5.4^0$ and stopped side rotors.

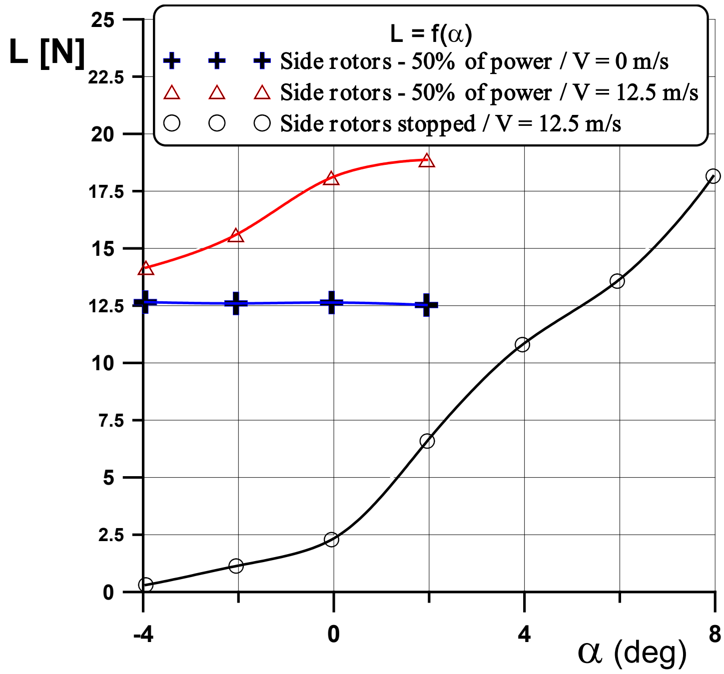

Fig. 5. Influence of the side rotors using 50% of their engine power on the autogyro lift

In Fig. 6 the effect of the side rotors (using 50% and 100% of their engine power) on the autogyro lift (with the main rotor collective pitch $\Theta = 13.5^0$) versus the angle of attack for undisturbed flow velocity $V\infty = 12.5$ m/s is shown.

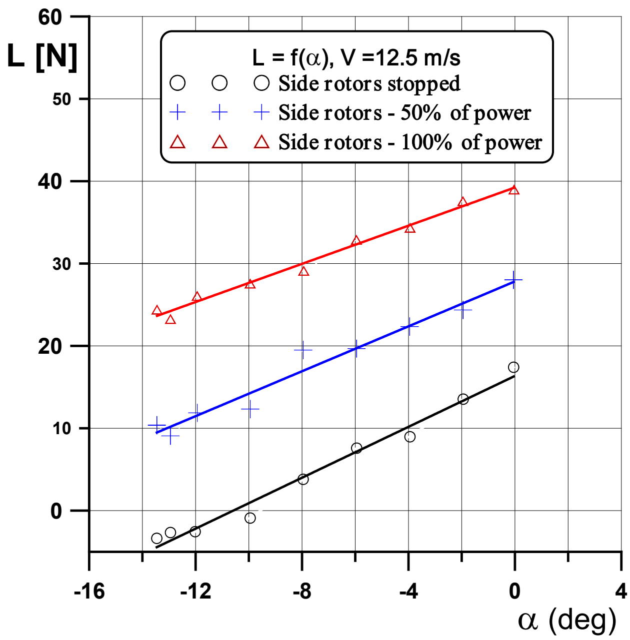

Fig. 6. Influence of the side rotors using 50% and 100% of their engine power on the autogyro lift

The influence of the side rotors and pushing propeller on the autogyro drag (D) (with the main rotor collective pitch $\Theta = 13.5^0$) versus the angle of attack for undisturbed flow velocity $V\infty = 12.5$ m/s is presented in Fig. 7. In Fig. 8, the influence of the same autogyro components on its pitching moment (My) versus autogyro lift is shown.

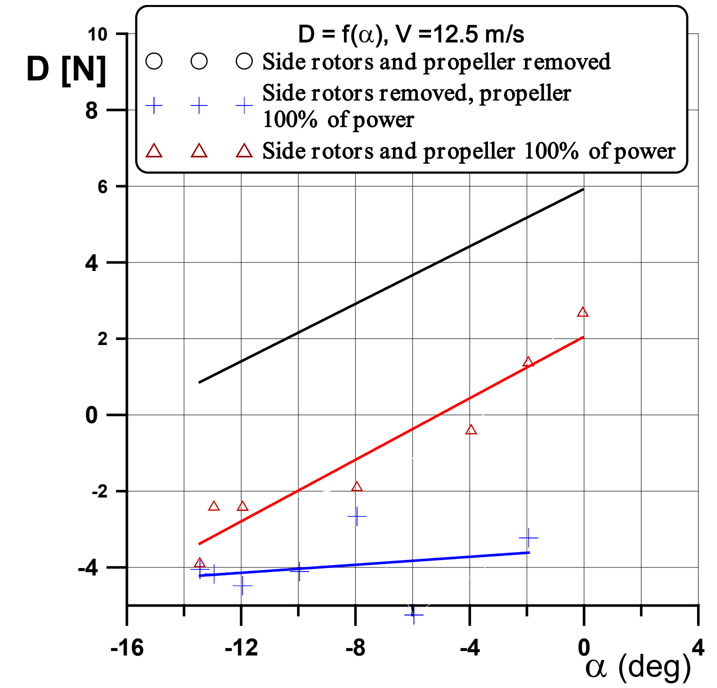

Fig. 7. Influence of the side rotors and propeller on the autogyro drag

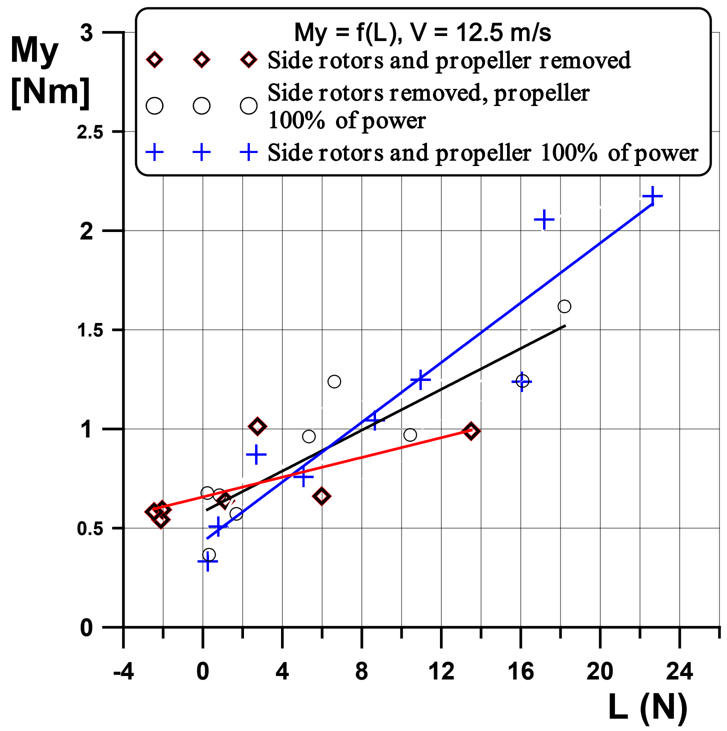

Fig. 8. Influence of the side rotors and propeller on the autogyro pitching moment

The performed research of the autogyro model in the IoA low speed wind tunnel T-1 included also flow visualization tests with the usage of PIV system. The sample visualization image depicting vector velocity field in the area behind the propeller and below the main rotor is shown.

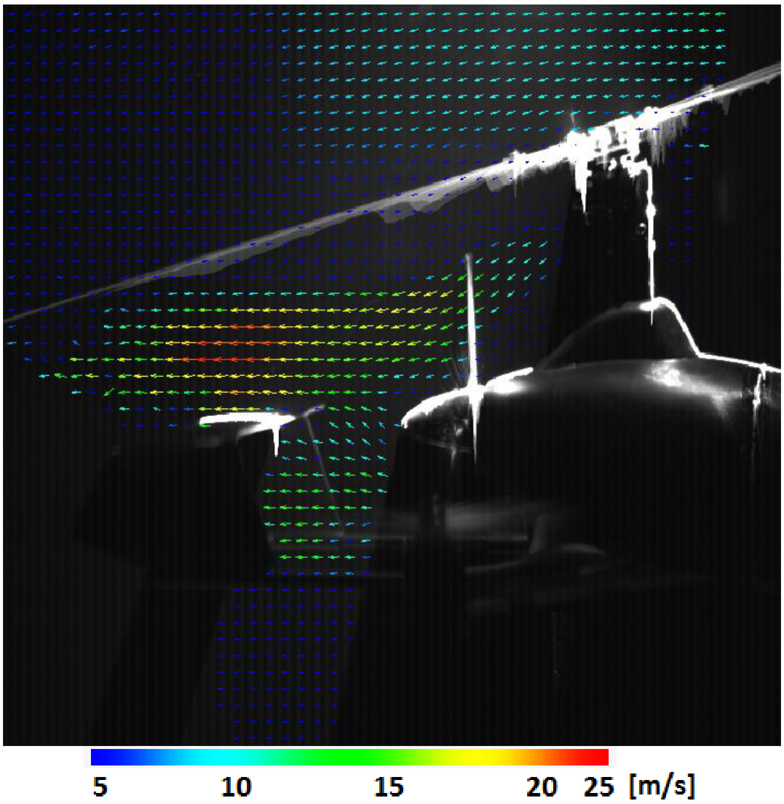

Fig. 9. PIV image depicting vector velocity field for side rotors and propeller working at 100% of theirs power and $\Theta = 12.5^0$, $V_\infty = 13.5$ m/s, $\alpha = 0^0$

3. Conclusions

The paper presents the results of experimental studies of the basic aerodynamic characteristics of the innovative quad-rotor autogyro model. The model was equipped with a two-blade rotor, four side rotors situated in quadro arrangement and a pushing propeller. The wind tunnel tests were performed in the Institute of Aviation low speed wind tunnel T-1, characterized by 1.5 m diameter test section. The investigations were carried out for undisturbed flow velocity $V\infty = 12.5$ m/s which corresponds to the Reynold's number, $Re = 0.82 * 10^6$.

The research has led to the following conclusions:

– in conditions, where there is no an airflow through the wind tunnel test section ($V\infty = 0$ m/s) the four side rotors give the total lift equal L = 12.5 N, using 50% of their engines power and lift L = 29 N, using 100% of their power,
– in comparison with the conditions where $V\infty = 0$ m/s, an air flow through the wind tunnel tests section (when the main rotor is removed) increases the autogyro lift induced by the four side rotors. As a result of an air blowing (with the velocity $V\infty = 12.5$ m/s) the operating side rotors, using 50% of their engines power, increases the autogyro lift of $\Delta L = 0.4$ N at $\alpha = -4^0$ and $\Delta L = 2.8$ N at $\alpha = 2^0$. In the case of the four side rotors operating, using 100% of their engines power, this increase is less and equal $\Delta L = 0.1$ N at $\alpha = -4^0$ and $\Delta L = 1$ N at $\alpha = 2^0$,
– the side rotors influence the main rotors by slowing down its rotation, reducing in this way its efficiency. For example, for the collective pitch $\Theta = 13.5^0$ and $\alpha = 0^0$ the operation of the side rotors, using 100% of their power, diminishes the main rotor rotations (n) from $n \approx 980$ rpm to $n \approx 700$ rpm,
– rotating main rotor at $\Theta = 5.4^0$ increases the autogyro lift force (depending on the model angle of attack) in the range from $\Delta L = 1.4$ N at $\alpha = -4^0$ to $\Delta L = 6$ N at $\alpha = 2^0$. This increase of the autogyro model lift is considerably less than the effect of the operation of the four side rotors,

- the increase of the collective pitch from $\Theta = 5.4^0$ to $\Theta = 13.5^0$ results in the lift increase of $\Delta L = 11.5 - 15$ N,
- the four side rotors (not operating) with their holding arms generate the autogyro drag of a value $\Delta D = 1.8$ N at $\alpha = -13^0$ to $\Delta D = 2.7$ N at $\alpha = 0^0$, which is about 50% of the total fuselage drag,
- pushing propeller using 100% of their power with the rotating main rotor at $\Theta = 13.5^0$ give the thrust $D = 5.8 - 7.1$ N,
- for all tested configurations the autogyro model was statically unstable.

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