NEW GYROPLANE HUB CONNECTOR
WITH POSITIVE CONING ANGLE

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Abstract

The article presents advantages and disadvantages of two blade teetering rotors with constructional dihedral angle greater than 0º. Several structural design solutions of rotor hub connector are shown in this work. However, the main attention is focused on innovative hub connector design and manufactured by Trendak Aviation Company during the project "Research and development works on innovative construction of aircrafts of weight over 560 kilograms". Discusses structural advantages of the new rotor hub connector according to other construction. Also were raised issues related to the load of the gyroplane rotor during the flight, in particular the load of rotor blades root, during a gyroplane break manoeuvre, according to conning angle of rotor hub connector. The disadvantages of using the structural dihedral angle in teetering rotors are also presented, focusing on the rotor aeroelastic instability so-called waving, which from the literature analysed is concerned only with two blades teetering rotors. Performed a coarse analysis in SMOG program, prepared at the Institute of Aviation for the analysis of helicopter and gyroplanes rotors. The stability analysis of the rotor for a number of structural dihedral angle and blades setting pitch was performed. Basis of this analysis the stability boundary were determined for the analysed gyroplane rotor with connector hub with positive coning angle of 2.8º.

Keywords: blade dihedral angle, waving, rotor instability, teetering rotor

1. Introduction

Autogyros are equipped with main rotor, which is rotating because of autorotation phenomenon; it means autogyro rotor must have air flowing through the rotor disc to generate rotation. The primary function of the gyroplane rotor is generation of the lift force needed to keep the machine in the air. Whereas the thrust is generated by a pusher propeller or rarely, tractor propeller.

Most of gyroplanes produced by experienced aviation manufacturers as well as in individual amateur constructions have two-blade teetering main rotors with one centrally located beta hinge. Typically, in such constructions the hub arms are perpendicular to the axis of rotation. This solution works in small lightweight gyroplanes. However, the growing interest and faster development of such aircraft type goes hand in hand with the search for new solutions that will increase their total weight and performance and at the same time increase the safety of flights [16, 17].

This work presents the aspect of rotor hub blade connectors with constructional dihedral angle grader than 0º. Several constructional solutions of blade connectors with positive constructional dihedral angle are discussed including innovative connector, which was designed and

manufactured by Artur Trendak Aviation Company, during the project of the prototype six-seat gyroplane – T6. The advantages and disadvantages of such construction are also shown, referring to literature and basic analysis of teetering rotors loads and instability.

2. Rotor hub blades connectors

Most small gyroplanes have blade mounted horizontally in a straight line. Such a solution is described in the literature [7]. The advantages of such solution are inter alia: light weight, simple construction what affects low cost of manufacturing. Unfortunately, this solution also has its weaknesses; it causes significant stresses on the rotor components, what leads to increased vibration of the rotor and mechanical damage to the blades and hub connector.

Literature [10] presents a solution of the system allowing lifting rotor blade to reduce the loads occurring on the gyroplane main rotor. However, this construction is much more complicated, introduces moving joints, which increases the weight and the cost of the hub connector. Another solution [1], proposes to apply rubber pads for cushioning the rotor blades and also allowing for a small changes in blade pitch angle. The literature [2], provides a solution of hub connector in which constructional dihedral angle is about 5.7°. This solution requires the blades matched to such a connection. In case of lightweight metal blades, they require additional technological process which quality has a significant influence on the behaviour of the whole rotor. Besides mechanical machining of the rotor blade, it is also necessary to introduce additional strengthening elements. Such construction causes deviations from nominal value of the blade angle of attack moreover the exact representation of blade constructional dihedral angle depends on the quality of the flat surfaces of the blade adhering to the connector.
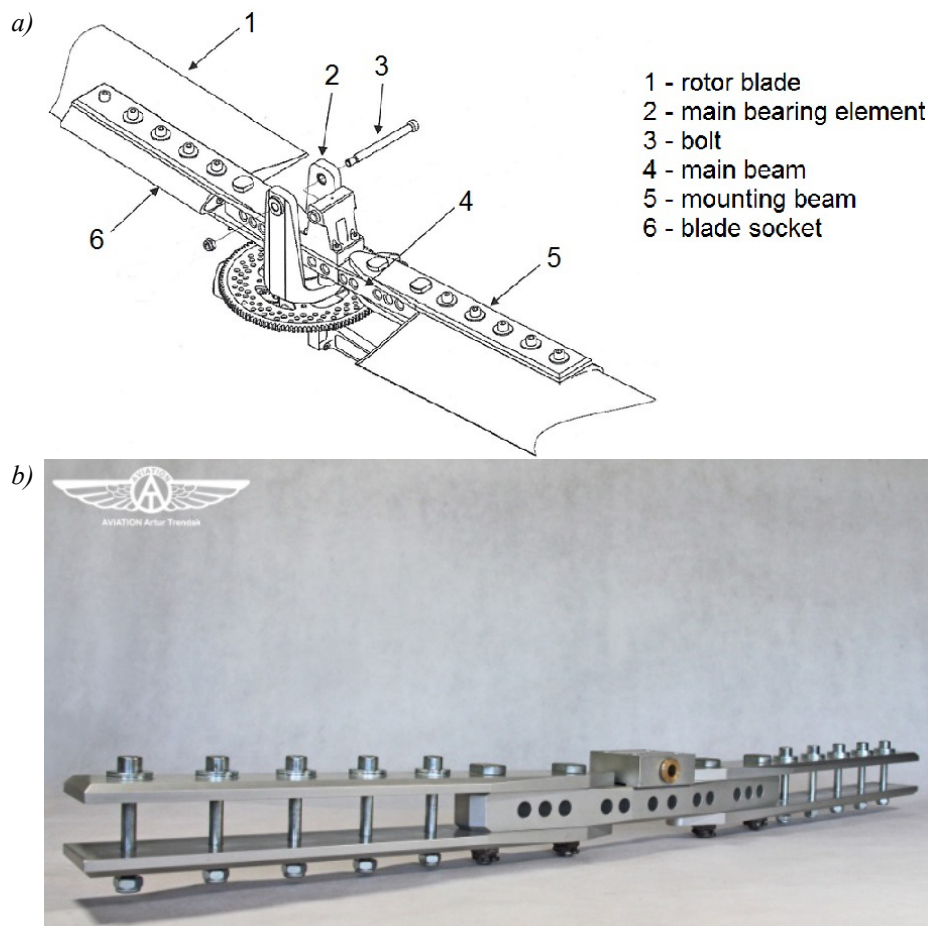

1 - rotor blade
2 - main bearing element
3 - bolt
4 - main beam
5 - mounting beam
6 - blade socket

Fig. 1. Innovative hub connector construction: a) construction shame of connector, b) connector visualization

Innovative gyroplanes hub connector with constructional dihedral angle was designed and manufactured by Artur Trendak Aviation Company shown on Fig. 1 [18]. The hub connector includes a main beam provided with a middle part, and side arms. In each of the side arms are placed at least two mounting holes. The hub connector is characterized in that the side arms of the main beam connector are formed integrally with the central part and are deflected upwards so that each of them forms the same angle from range of 2 to 3 degrees with the horizontal axis. Another characteristic feature of this hub connector is that it contains at least four fastening beam fixed horizontally to the side arms of the main beam, whereby the beams are provided with mounting holes adapted to mount the connector in the rotor hub by means of a horizontal bolt.

3. Teetering rotor loads and instability

Referring to the section above two approaches are used in the design of biplanes teetering rotors. First is a simple construction with hub arms are perpendicular to the axis of rotor rotation, as shown on Fig. 2a, second more complex with positive cone angle β_0 shown on Fig. 2b.
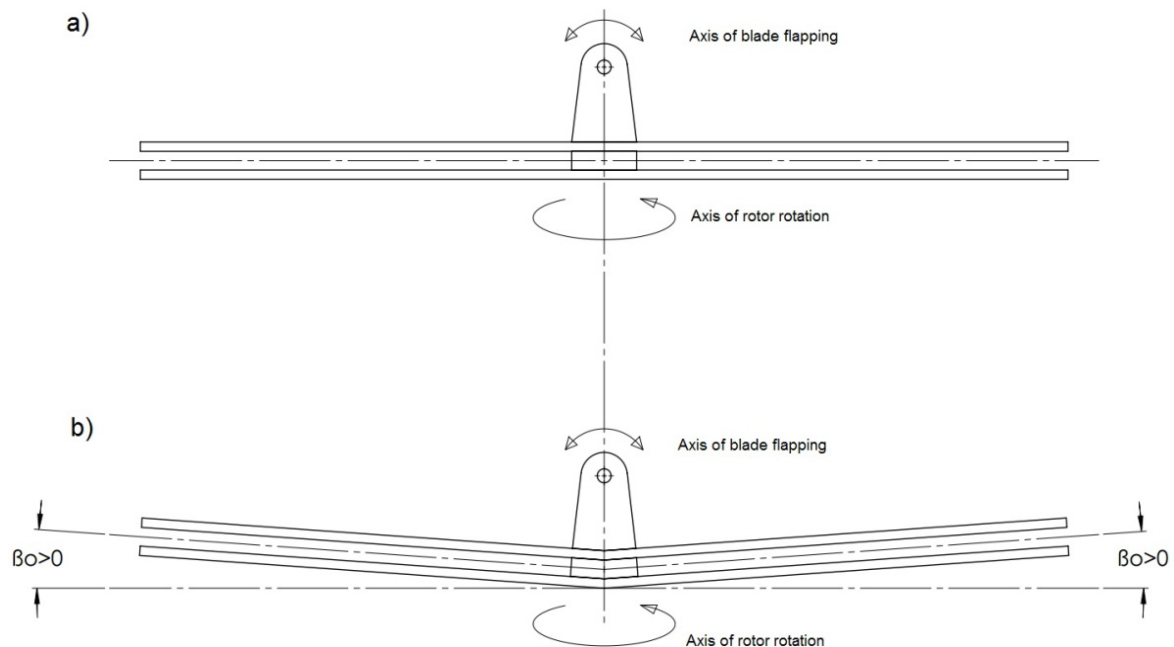

Fig. 2. The construction scheme of teetering gyroplane rotor: a) rotor without coning angle $\beta_0 = 0$; b) rotor with coning angle $\beta_0 > 0$

It is known, however, that the use of a construction dihedral angle greater than $0°$, positively affects the reduction of the blade bending moment in thrust plane, particularly in the zone of the blade root. Appliance of a structural dihedral angle can also have a negative effect on the dynamics of the gyroplane main rotor. It is clear that too high dihedral angle have destabilizing effect on the rotating blades. This does not mean that each teetering rotor with positive structural coning angle is fraught with the risk of blade motion instability, other blades structural factors are also affected such as: torsional stiffness and collective pitch of the blade [4, 6].

3.1. Loads

After analysing the available literature [6, 8, 9, 11, 13] and based on the analysis of the innovative designed gyrohead connector with positive cone angle, illustrates the benefits of using that solution. Figure 3 shows the graph of the bending moment of the blade along its distribution at the angle of cone $\beta_0 = 0°$ and the angle of cone $\beta_0 = 3°$.
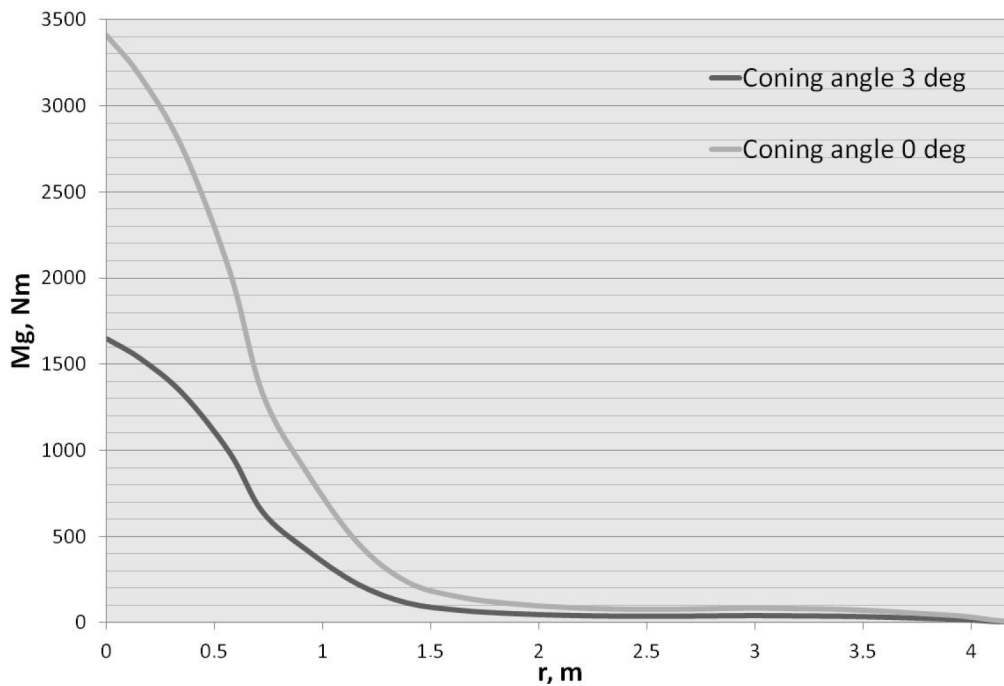
Fig. 3. Graph illustrating the bending moment in the thrust plane as a function of the blade span without positive coning angle ($\beta_0 = 0$) and with coning angle ($\beta_0 = 3°$) [6, 13]

The illustrated bending moment values shown on the graph (Fig. 3) are calculated for the gyroplane in the break manoeuvre where it is possible to achieve an overload factor of level about $n_z = 2$. As it clearly, for β_0 angle of 3°, blade root bending moment M_g it is about 50% less.

During the research of innovative hub connector, it was noted that for two- sits autogiros' with a starting mass of about 600 kg, the rotor span to approximately 8.8 m with aluminum blades, the optimum constructional dihedral angle is the range of 2 to 3 degrees and particularly preferred is the coning angle 2.8 degree [18].

3.2. Rotor blade instability

Autogyros rotors operating in autorotation at high speed, particularly when it is lightly loaded, can become unstable in flapping. In general, flight instability of autogyros can be either due to aerodynamically unstable airframes, or due to unstable main rotors.

It is widely known that rotating rotors during flight are exposed to various kinds of aeroelastic instability caused by mass and aerodynamic forces changing during the rotation of the blades [5, 12, 14, 15].

In case of teetering main rotors the most interesting rotor instability is blade waving. According to the literature [4], it only appears in rotors in which blades are rigidly connected together at their root ends with a built in non-zero coning angle, and suspended on a central flapping or teetering hinge.

On the chart (Fig. 4) shown the distribution of instability limits depending on the structural blade coning angle, the general collective pitch function, and the blade centre of gravity along the chord in percent.

Calculations of instability of teetering rotor were performed using the SMOG program. The analysis was performed for main rotor of 600-kilogram gyroplane, with aluminum blades with NACA 9H12 airfoil, and a chord of 220 mm. Analysis was made for different angles of the cone and at different blade pitch setting. The chart in Fig. 5 shows that the analysed gyroplane rotor with positive coning angle 2.8 deg operates at safe design parameters below the boundary of instability.
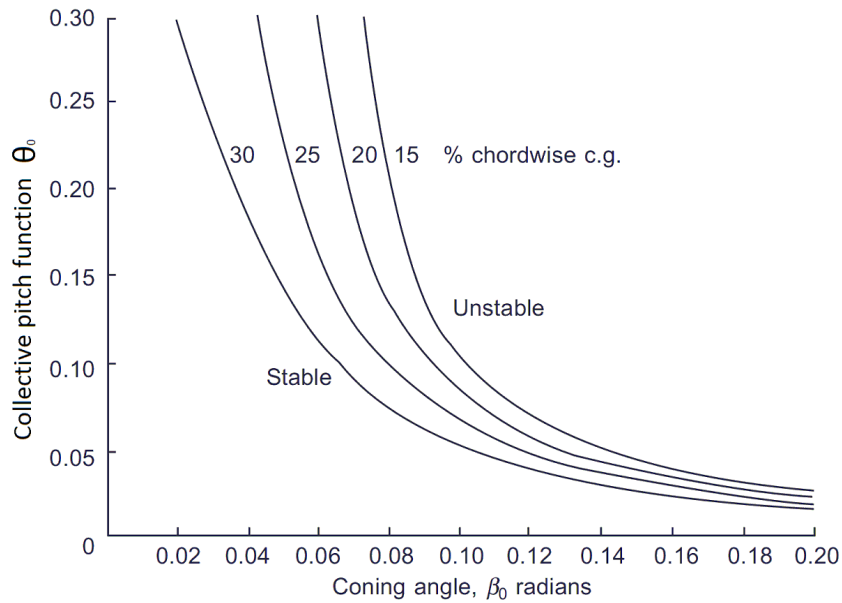
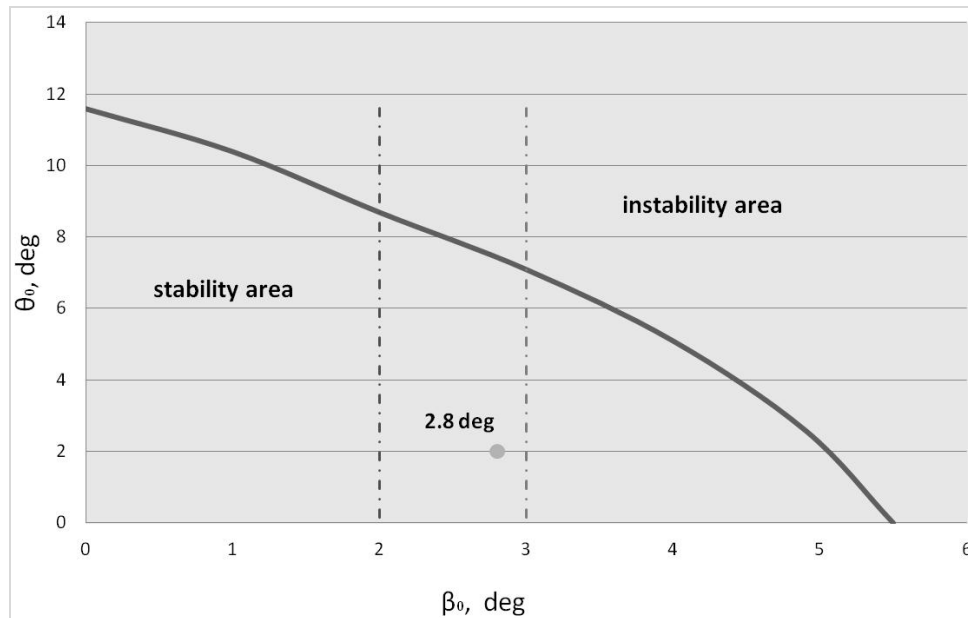*Fig. 4. Stability boundaries of blade weaving motion for two blades teetering rotors [4]*

Fig. 5. Stability boundaries analysis of rotor with hub connector with positive cone angle

4. Conclusion

The article discuses advantages and disadvantages of two blade rotors with positive coning angles in reference to newly developed rotor hub connector.

Construction of a new hub connector is not as complicated as the others solution described in this article. The connector can be used to assemble different types of blades, both made of light metal (e.g. aluminum alloy) as well as new composite blades constructions, with different kinds of mounting holes.

The bend of the hub connector allowed mounting blades at a slight constructional dihedral angle that helps avoids tensions in the rotor hub connector, reduces the blades bending moment in the thrust plane and reduces the vibration of the entire structure during the gyroplane flight. For small gyroplanes the optimum constructional dihedral angle is in range of 2 to 3 degrees, preferred is 2.8 degree angle.

An area of instability was determined depending on the value of blade pitch setting θ_0 and the construction dihedral angle β_0. The analysed teetering rotor with dihedral angle 2.8 is in the stable working area and the margin of stability is big enough, allowing for increase blade pitch setting angle and coning angle by several degrees.

Acknowledgements

References

[1] Aubry, J. A., *Rotary-wing aircraft rotor having a compact articulated hub*, US Patent 4361415, 1982.

[2] Barltrop, A., *Rotor for an autogiro*, US Patent 4092084, 1978.

[3] Bielawa, R. L., *Rotary Wing Structural Dynamics and Aeroelasticity*, AIAA, Washington DC, 1992.

[4] Bramwell, A. R. S., Done, G., Balmford, D., *Bramwell's Helicopter Dynamics*, Butterworth-Heinemann, 2001.

[5] Cheol-Yong, Y., et al., *Dynamic characteristics of helicopter bearingless main rotor*, Journal of the Korean Society Aeronautical and Space Sciences, Vol. 44, No. 5, pp. 439-446, 2016.

[6] Cieślak, S., *Instability of the gyroplane teetering rotor in axial flow*, Transactions of the Institute of Aviation, No. 2 (235), pp. 28-37, Warsaw 2014.

[7] Cresap, W. L., Drees, J. M., *Rotor System*, US Patent 3193019, 1965.

[8] Delega, M., Krzymień, W., *Weryfikacja rozwiązań prerotacji wirnika wiatrakowca*, Transactions of the Institute of Aviation, No. 3 (236), pp. 35-40, Warsaw 2014.

[9] Niemi Jr., E. E., Raghu Gowda, B. V., *Gyroplane rotor aerodynamics revisited – blade flapping and RPM variation in zero-g flight*, 49th AIAA Aerospace Sciences Meeting including the New Horizons Forum and Aerospace Exposition, Orlando, Florida 2011.

[10] Ferris, D. L., Rybicki, R. C., *Two-position helicopter main rotor*, US Patent 397249, 1976.

[11] Krzymień, W., *Vibration properties of the gyrocopter*, Transactions of the Institute of Aviation, No. 219, pp. 234-239, Warsaw 2011,

[12] Leishman, J. G., *Principles of Helicopter aerodynamics*, Cambridge University Press, London 2008.

[13] *Obciążenia łopat i głowicy wirnika nośnego wiatrakowca I-28 wariant b*, internal report, Institute of Aviatiom, 2013.

[14] Rezgui, D., Lowenberg, M. H., Bunniss, P. C., *Experimental and numerical analysis of the stability of an autogyro teetering rotor*, Department of Aerospace Engineering, University of Bristol, Bristol 2008.

[15] Stalewski, W., Zalewski, W., *Computational simulation of operation of gyroplane main rotor in initial phase of vertical take-off*, Transactions of the Institute of Aviation, No. 219, pp. 289-295, Warsaw 2011.

[16] Szczepanik, T., *Analysis of the state of the gyroplane world market*, Transactions of the Institute of Aviation, No. 3 (244), pp. 227-238, Warsaw 2016.

[17] Szczepanik, T., Łusiak, T., *The maintenance of gyroplanes as aircraft*, Transactions of the Institute of Aviation, No. 4 (241), pp. 87-95, Warsaw 2015.

[18] Trendak A., *Łącznik wirnika wiatrakowca*, RP Patent PL409109, 2014.