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POSSIBILITIES OF IMPROVEMENT OF DIRECTIONAL CONTROL EFFECTIVENESS OF LIGHT GYROPLANE AT HIGH-ANGLE-OF-ATTACK FLIGHT CONDITIONS

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Summary

Several alternative modifications of original design solution of an inverted "V"-tail control surfaces of a light gyroplane are presented. The aim of the modification is improvement of high-angle-of attack directional controllability of the aircraft. The proposed modifications of the all-flying control surfaces include adjustable symmetric inclination of tail surfaces, split-surface version (stabilizer+rudder), split-surface version with additional, central element and more traditional, "H" configuration with one horizontal and two vertical surfaces. All the proposed modifications retain the second function of the tail surfaces – rear undercarriage. Adjusting the symmetric inclination of the tail surfaces allows for maintaining high values of the yaw control derivative up to the value of the fuselage angle of attack of 30°. Potentially unfavourable side-effect of this solution may be the change of pitching moment during such manoeuvre. For this reason this solution should be applied with the split control surface version (stabilizer+rudder) with additional mechanism adjusting the symmetric rudder deflection to the new elevator inclination in order to keep pitching moment constant. The other two options - additional third control surface in the symmetry plane with rudder and more classical "H" configuration of control surfaces are simpler in operation and safer, particularly the "H" configuration with retains high effectiveness of directional control at high fuselage angle of attack, up to 30°. The version with inverted "V" tailplanes and additional, central control surface has limited effectiveness at high angles of attack, due to geometrical and design constrains, limiting the size of the central control surface.

INTRODUCTION

In contrast to helicopters, gyroplanes do not have powered tail rotors and for yaw control have to rely on the effectiveness of tail control surfaces. In several situations, such as steep, power-off landing approach, the fuselage may reach angles of attack above 20° and in these conditions efficiency of the control surfaces has to be ensured. This could be difficult, due to low speed, interference of the fuselage or other factors, such as non-optimal arrangement of control surfaces. Such factors seriously degrade the effectiveness of an initial version of a dual-role, inverted-V-shaped empennage of a light gyroplane at high angle of attack. In the basic version the surfaces are all-flying, i.e. each one is a single-element surface rotated around its axis at 20% chord. It has been determined through numerical flow simulation, that at gyroplane angles of attack exceeding 10° a reverse action of the tail surfaces appears. This phenomenon consists in changing of sign of the yawing moment derivative with respect to deflection angle (yaw control derivative) [1],[2]. The originally designed tail is constrained by its assumed additional function as rear undercarriage, which limits the possibility of modification of the contour and dihedral angle of the control surfaces, so only minor changes are possible, or a complete redesign of the rear fuselage is necessary. Several approaches of solving this problem are presented in this paper.

1. ALTERNATIVE VARIANTS OF GYROPLANE TAIL

The second function of the tail surfaces leads to fixed values of its dihedral -30°, and sweep, 34° in the XZ plane (Figure 1). The airfoil applied for the surfaces was NACA 0012 – typical airfoil for such applications.

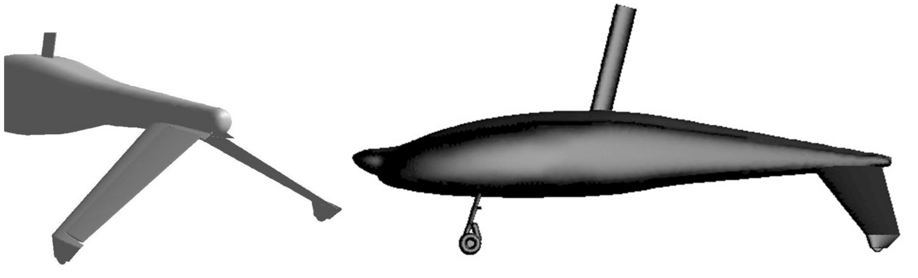

Figure 1. Geometry of the gyroplane fuselage and layout of the all-flying tail surfaces in perspective view

Since the contour of the two control surfaces and their dihedral and sweep angles have been fixed, the allowed modifications of the tail surfaces were as follows:

- introduction of an adjustable symmetrical inclination of the control surfaces (one inclination angle for cruise, another for steep landing approach),
- replacement of the all-flying surfaces by the classic stabilizer-rudder solution,
- addition of another control surface element in the symmetry plane,
- major redesign – application of a classic horizontal and vertical surfaces.

To find out the merits and drawbacks of the proposed modifications numerical flow simulations were performed using the Fluent [3] – (U)RANS solver. The computations were concentrated on determining the values of the yawing moment coefficient derivative due to asymmetric deflection angle $\partial c_n/\partial \delta_r$. The range of gyroplane angles of attack was 0° ÷ 30°. The computations were performed on approximately 2mln-cell meshes using the Spalart-Almaras turbulence model. The y+ parameter, defining the height of the nearest to surface cell was equal approximately 30, which is optimal value for the accuracy of viscous flow simulations and total mesh size. The results of the numerical analysis for each geometry variant are presented in the following paragraphs.

2. RESULTS OF COMPUTATIONAL ANALYSES

2.1 Adjustable symmetric inclination

It was assumed, that the inclination change is performed by the rotation of the basic all-flying control surfaces around an axis in 20% chord (Figure 2). Four values of symmetric inclination angle were applied: 0° (basic version), -20°, -25° and -30°. These configurations were the reference configurations for the calculations of yawing moment derivatives The values of $\partial c_n/\partial \delta_r$ derivative were computed using the characteristics of the reference configuration and characteristics of configurations with control surfaces deflected by +5°(nose right – right surface) and -5° (left surface) from each of the reference configuration. The comparison of the $\partial c_n/\partial \delta_r$ derivative vs. angle of attack for the investigated configurations is shown in Figure 3.

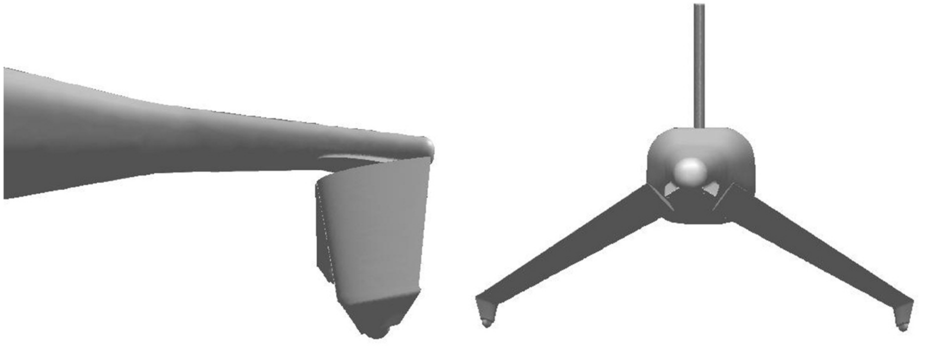

Figure 2. Basic version of all-flying (single-element) tail surfaces with inclination angle set at -20° - left view and rear view

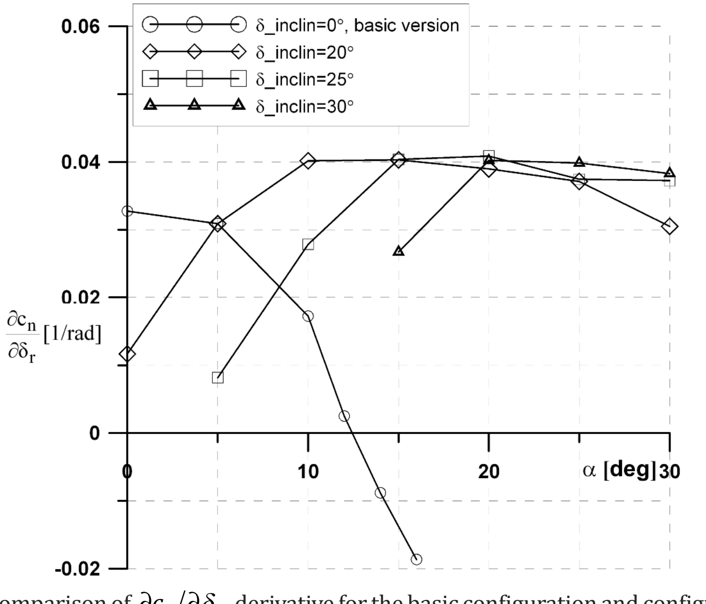

Figure 3. Comparison of $\partial c_n/\partial \delta_r$ derivative for the basic configuration and configurations with adjustable inclination of tail surfaces

For the basic version of the empennage there occurs a reverse action of the tail surfaces – change of sign of the yaw control derivative $\partial c_n/\partial \delta_r$. This is caused by the effect of extensive flow separation on the surface with increasing local angle of attack leading to rapid decrease of local lift force, and relatively lower decrease of local lift or even increase (if the angle of attack of undeflected surface is higher than profile α_{CLmax}) on the surface with lower angle of attack. This effect has been explained in detail in [1].

Data presented in Figure 3 show that adjusting the symmetric inclination for manoeuvres such as steep landing approach at high angle of attack allows to retain the necessary directional control during such manoeuvre. There are, however, two drawbacks of this solution if applied to the basic version of all-flying tailplanes. One of them is the necessity of measurement of the fuselage angle of attack in order to change the tailplanes' inclination angle in a proper moment, to avoid the danger of reverse action of the tailplanes, the other is the change of pitching moment caused by the change of the inclination of the tailplanes. This data is shown in Figure 4 for the airspeed of 50 km/h and angle of attack 10°. Change of symmetric inclination of the tailplanes from 0° to -10° involves change of pitching moment equal 390Nm. This may disturb the longitudinal balance of the gyroplane. For these two reasons the solution of adjustable inclination of the tailplanes is safer to adopt with tailplanes divided into stabilizer and rudder. It is possible to introduce a mechanism of simultaneous change of the stabilizer inclination and rudder deflection in order to keep pitching moment constant during this operation. The characteristics of a split-tailplanes version are shown in the following paragraph.

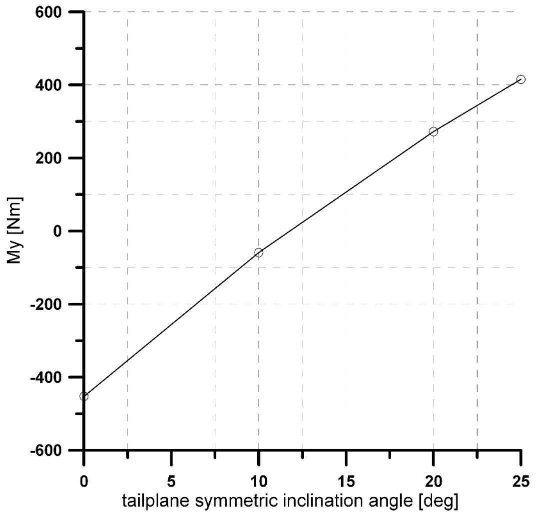

Figure 4. Change of pitching moment due to change of the inclination angle of the taiplanes at fuselage angle of attack of 10° and airspeed of 50 km/h

2.2 Split surfaces – stabilizer and rudder

In the Figure 5 the effectiveness of the basic all-flying version of tail surfaces was compared with the results for the split configuration with rudder chord ratio of 70%. The contour of the split surfaces was the same as the contour of the all-flying version. The rudder chord ratio was set based on the results of 2D computations which have shown that maximum value of the lift force for this chord ratio exceeds maximum lift of single-element airfoil, and on structural considerations which allowed for this high value of rudder chord ratio.

As it can be seen in Figure 5, the characteristics of the split control surfaces are safer than characteristics of the basic version, because there is no change of sign of the $\partial c_n / \partial \delta_r$ derivative at higher fuselage angles of attack, and hence, no reverse action.

The effectiveness of the rudder is, however, at fuselage angle of attack higher than 16° more than three times lower than at angles of attack below 6°. The reason for this is flow separation on upper parts of the tail surfaces which is caused by relatively low absolute value of the dihedral (-30°) which forces the tail surfaces to operate at high local angles of attack, above α_{CLmax}. The reasons of differences in high-angle-of –attack characteristics of these two version have been described more in detail in [1].

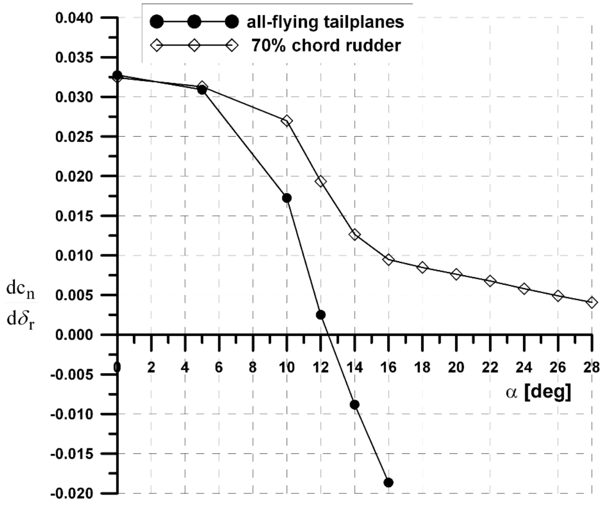

Figure 5. Comparison of the derivative of yawing moment coefficient with respect to rudder deflection for the all-flying tailplanes and the split (stabilizer + rudder) version

2.3 Additional vertical, central control surface

With the dihedral of the tail surfaces fixed due to reasons connected with the second function of the tail surfaces, it is possible to add another control surface in the rear fuselage, in the X-Z symmetry plane. This may be an idea worth considering, because in contrast to poor control characteristics at high angles of attack the basic configuration has some advantages at low angles of attack. The inverted "V" surfaces are located in the area of increased flow speed caused by the propeller effect. This improves directional control at low speed and during ground operations. Due to the danger of collision with rotor blades, any additional surface has to be located on the lower side of the fuselage. This, however, restricts its size because the space in this region is limited due to low distance from the rear fuselage to the ground. Taking into account these constraints, such additional control surface has been designed and is shown in Figure 6. The additional surface is designed as a classical vertical tail with rudder rotated around a vertical axis.

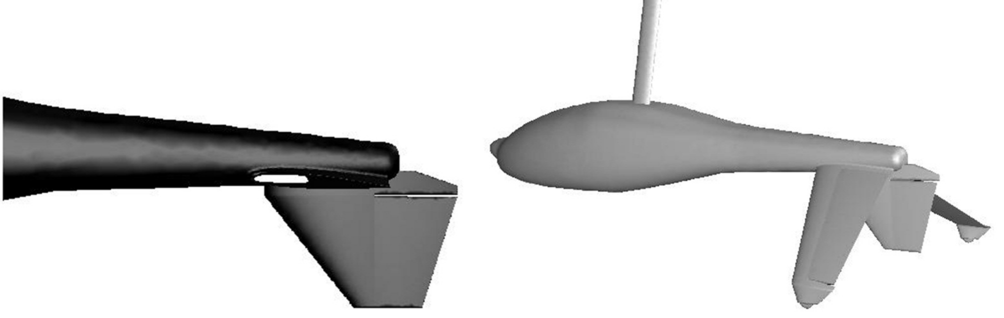

Figure 6 Side view of additional control surface (other two surfaces invisible) and a perspective view of the fuselage version with three control surfaces

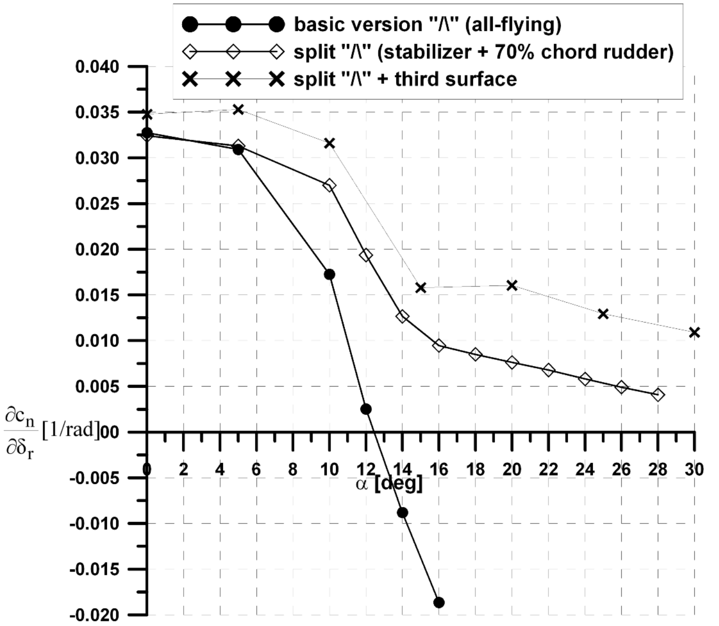

Figure 7 Comparison of the yaw control derivative for the three investigated empennage versions with inverted-V tail surfaces

Data presented in Figure 7 show that the additional tail surface improves the directional control at high fuselage angles of attack. The value of $\partial c_n/\partial \delta_r$ derivative at α_{fus}=20° is, however, two times, and at α_{fus}=30° three times lower than at α_{fus}=0°. At the same time, the contribution of the third surface to the yaw control derivative at low α_{fus} is relatively small due probably to the effect of the wake of front part of the fuselage. At higher fuselage angles of attack, above 20°, the central control surface becomes the most effective one. It may be concluded that given the restraints due to the geometry of fuselage and the teetering rotor, the possibilities of significantly improving yaw control effectiveness at high angles of attack by the addition of another surface to the basic version are limited.

2.4. "H-tail" configuration

More significant improvement of directional control at high angles of attack is possible by major redesign of the empennage. Such idea is presented in Figure 8. It consists of the replacement of the two slanted tail surfaces by a more classical configuration, composed of one horizontal and two vertical surfaces. The vertical surfaces are placed in larger part below the horizontal tail, so the second function of the tail surfaces – the rear undercarriage is retained in the design. The span of the horizontal surface is the same as the span of the basic configuration, and so is the distance between the wheels of the rear undercarriage. The surface area of the vertical elements is equal to the surface area of the projections of the slanted "/\" tail surfaces on the X-Z plane. Rudder chord ratio of the vertical elements is 50%.

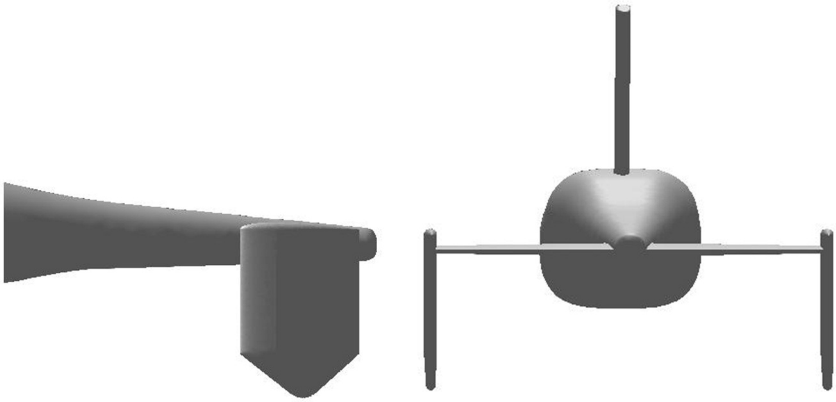

Figure 8. The layout of the proposed "H" configuration of control surfaces

The comparison of the yaw control derivative for the version with fixed "/\" tail surfaces and the "H" version is presented in Figure 9. The "H" configuration in comparison with the other versions has very good directional control characteristics at high fuselage angles of attack, the yaw control derivative decreases only by approximately 10% at α_{fus}=30°. The disadvantages of this version in comparison with the basic one may consist in decreased directional control effectiveness at low speed and on the ground, due to the placement of the vertical elements out of the propeller wake. There is also some increase of drag and mass, because of greater surface area and additional structural connections between elements. However, low fuselage drag in rotorcraft is not as important as in conventional aircraft because of lower flight speeds and another source of drag – rotating blades. The mass increase may also be not much higher in comparison with the other presented modification versions.

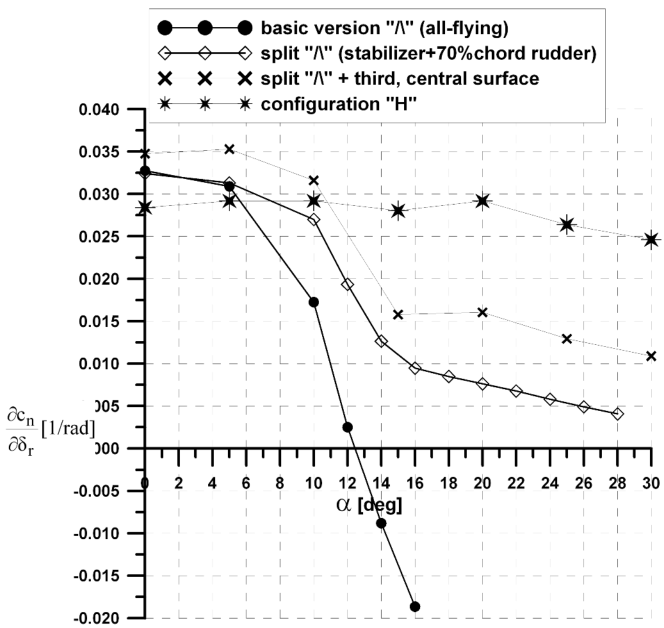

Figure 9. Comparison of the yaw control derivative for the "H" configuration and the three versions with inverted-V tail surfaces

CONCLUSIONS

The presented modifications of the basic version of the empennage of the light gyroplane were meant to improve unfavourable directional control characteristics of the initial version – sharp decrease and change of sign of the yaw control derivative at high fuselage angles of attack. The most efficient solutions are the introduction of the adjustable symmetrical inclination and redesign replacing the slanted surfaces with classical solution composed of horizontal and vertical surfaces. The first solution seems to be rather complicated due to the change of longitudinal balance during the operation of inclination change. In order to minimise this problem, and to avoid the danger of inverse action at high angles of attack, this solution should be applied with the split tailplane version. For this version an additional mechanism of adjusting the rudder deflection to the inclination angle could be designed, such that would keep the fuselage pitching moment constant. The last solution of replacing the inverted "V" configuration with more classical "H" one seems to be the simplest and most effective, because it ensures high effectiveness of the directional control surfaces over the widest range of angle of attack. The mass increase due to larger surface area and additional structural connections of the "H" configuration may be not higher than for the adjustable inclination of the "V" shaped elevators, if similar safety level should be achieved (high directional control effectiveness, no change of longitudinal balance). The solution with additional control surface is not as effective as the "H" configuration and may require similar mass increase.

ACKNOWLEDGEMENTS

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MOŻLIWOŚCI POPRAWY SKUTECZNOŚCI KONTROLI KIERUNKU ŚWIATŁA WIATRAKOWCA NA DUŻYCH KĄTACH NATARCIA

Streszczenie

W pracy przedstawiono kilka alternatywnych modyfikacji wersji wyjściowej usterzenia lekkiego wiatrakowca, płytowego w układzie odwróconego "V". Celem modyfikacji jest poprawa sterowności kierunkowej wiatrakowca na dużych kątach natarcia. Proponowane modyfikacje usterzenia płytowego obejmują przestawialne symetryczne zaklinowanie powierzchni sterowych, wprowadzenie podziału na statecznik i ster, dodanie do wersji usterzenia dzielonego trzeciego, centralnego elementu a także bardziej tradycyjnego układu "H" z jednym, dzielonym usterzeniem poziomym i dwoma dzielonymi powierzchniami pionowymi. Wszystkie proponowane modyfikacje zachowują drugą funkcję usterzenia – funkcję tylnego podwozia.

Zmiana symetrycznego zaklinowania powierzchni sterowych pozwala na zachowanie wysokich wartości pochodnej momentu odchylającego względem kąta wychylenia steru do wartości kąta natarcia kadłuba równego 30°. Potencjalnym efektem szkodliwym tego rozwiązania może być zmiana momentu pochylającego w czasie operacji zmiany zaklinowania steru. Z tego powodu takie rozwiązanie powinno być zastosowane z usterzeniem dzielonym na statecznik i ster razem z dodatkowym mechanizmem dopasowującym symetryczne wychylenie steru do nowego kąta zaklinowania statecznika w celu utrzymywania stałego momentu pochylającego. Pozostałe dwa warianty - dodatkowa trzecia powierzchnia sterowa w płaszczyźnie symetrii i klasyczne usterzenie w układzie "H" są prostsze w działaniu i bezpieczniejsze, szczególnie układ "H" który utrzymuje wysoką sterowność kierunkową na dużych kątach natarcia kadłuba, do 30°. Wersja z dwoma powierzchniami w układzie odwróconego "V" i dodatkową, centralną powierzchnią sterową ma ograniczoną skuteczność na dużych kątach natarcia z powodu ograniczeń geometrycznych i konstrukcyjnych, limitujących rozmiar dodatkowej, centralnej powierzchni.