EXPERIMENTAL INVESTIGATION OF THE INFLUENCE OF DIFFERENT HELICOPTER RAMP GEOMETRIES ON THE WAKE STRUCTURE

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Abstract

In this work, the influence of two different rear fuselage upsweep geometries on the aerodynamic characteristics of a multipurpose medium lift helicopter fuselage is investigated. The fuselage geometry was very similar to Mil Mi-8 helicopter fuselage. The balance measurements, which were obtained at T-1K wind tunnel of KNRTU-KAI named after A.N. Tupolev, were supplemented with PIV measurements. Obtained results indicate that the flat ramp has higher drag coefficient values at negative angles of attack, compared to conventional rear fuselage upsweep geometry. The vortex core circulation of the vortices, obtained from PIV velocity fields showed the flow field behind the flat ramp of the fuselage had much higher vortex circulation values compared to conventional rear fuselage upsweep.

1. INTRODUCTION

Helicopter fuselage contributes significantly to overall drag of a helicopter. Hence, significant effort is directed to minimization of the fuselage drag [1].

The wake behind the ramp section is characterized by low static pressure in the backdoor area and it is primarily defined by the rear upsweep geometry of the fuselage. Vortices behind the ramp section of the fuselage can exhibit vertical forces at the tail boom, which can significantly alter the pitching moment of the helicopter. Other factors such as vortex wandering can exacerbate the problem, causing irregular random vibrations of the tail boom. Thus, being able to estimate the impact of the rear fuselage upsweep geometry on the flow is crucial and should be thought of during helicopter design. However, sometimes the design requirements dictate the implementation of fuselage geometries with expected non-optimal aerodynamic characteristics [2–4]. Such changes may include modifications of the rear fuselage upsweep geometries, which may lead to stronger vortex flow behind the fuselage and lead to the increase of the fuselage drag [5].

In this work, a typical multipurpose medium lift helicopter with two different rear fuselage upsweep geometries is investigated. In particular, a conventional rear fuselage upsweep is compared to a flat loading ramp in terms of integral load measurements and PIV measurements of the vortex flow behind the rear part of the fuselage.

Similar experiments were performed earlier in Russia [6] and in other countries [7].

2. EXPERIMENTAL SETUP

Experiments were carried out on an isolated fuselage model with replaceable rear fuselage upsweep geometries. The fuselage was manufactured from fiberglass. The first configuration of the fuselage is labelled as M1 model, and it had a conventional curved shape of the rear fuselage upsweep. The second configuration of the fuselage, labelled as M2 model, has a flat loading ramp with a constant width from the lower surface of the fuselage to the tail boom. The side views of M1 and M2 models are shown in Figure 1.

The measurements were performed in T-1K wind tunnel at KNRTU-KAI named after A.N. Tupolev. A

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Prandtl-type 6-KT balance with external decomposition of forces was used to measure three components of forces and three components of moments (see Figure 2). The model on this balance was installed on wire-based support system. The 6-KT balance was equipped with strain-gauge sensors. All measurements were performed at a free-stream velocity of $V_\infty = 28$ m/s, which corresponded to the Reynolds number $Re = 2.6 \cdot 10^6$. Reynolds number calculated based on the fuselage length.

2.1. Balance measurements and confidential intervals

The measurements were performed at a range of pitch and yaw angles. The range of the pitch angles was $-20° \leq \alpha \leq -16°$ with 2 degrees step and the range of yaw angles corresponded to $-15° \leq \beta \leq 6°$ with intervals of 3 degrees. The model is symmetrical relative to the vertical plane. Hence, balance measurements for yaw angles of $\beta = 3°$ and $\beta = 6°$ degrees were used for verification of the measurements.

Drag and lift coefficients were obtained as:

(1) $$C_D = \frac{2D}{\rho V_\infty^2 S}, \quad C_L = \frac{2L}{\rho V_\infty^2 S},$$

where D and L are drag and lift forces, respectively; S is the characteristic reference area of the fuselage at zero angle of attack ($\alpha = 0°$). The corrections due to the influence of the suspension system, the flow boundaries and the blocking effect were applied [8].

To estimate the accuracy of the balance measurements, eightfold measurements were performed. The 95% confidence intervals were obtained using the following relations:

(2) $$|\varepsilon| = \tau_{ab} \cdot S_n,$$

here, τ_{ab} is a Student`s coefficient for various number of measurements and confidential probabilities α_b. In this work, $\tau_{ab} = 2.37$ value corresponded to the eightfold experiments for $\alpha_b = 95\%$. S_n has been calculated as follows:

(3) $$S_n = \pm\sqrt{\frac{\sum(\delta C_i)^2}{n-1}},$$

here, C_i is a result of measurement number i, n is a number of measurements, δC_i is a residual error, equal to $\frac{\sum C_i}{n} - C_i$.

2.2. Particle Image Velocimetry

In this work, the flow-field was measured using Dantec PIV behind the rear fuselage upsweep region at the distance of $X = 945$ mm from the axis of rotation of the fuselage at different angles of attack, as shown in Figure 3. A three-dimensional model of the experimental setup is shown in Figure 4.

Dantec PIV-system was equipped with LITRON 425-10 dual-pulse laser which provides 425 mJ power 527 nm wavelength and maximum 10Hz pulse rate. Camera matrix had a resolution of 2048x2048 pix^2.

The PIV-camera was positioned behind the helicopter fuselage model to capture the tip vortices, trailing behind the rear part of the fuselage. The distance from the PIV camera to the laser sheet corresponded to 950 mm, as shown in Figure 3.

The obtained PIV images were analyzed using Adaptive PIV algorithm in Dynamic Studio 3.41 software using the interrogation size of 32x32 pix^2. For each measurement configuration ($-20 \leq \alpha \leq 16$), the statistical averaging based on 400 instantaneous velocity fields was performed.

The obtained velocity fields were then analysed using Q-criterion [9]. The vortex core boundaries were obtained using non-dimensional form of Q-criterion:

(4) $$\bar{Q} = \frac{l_c^2}{2\pi^2 V_\infty^2} \geq 0,$$

where l_c is the length of the rear fuselage upsweep. The selection of this l_c characteristic length value was chosen because the rear fuselage upsweep region is the portion of the fuselage where the formation of vortices occurs.

The circulation of the trailing vortices was obtained using Stokes' theorem [10] by integrating the velocity along the outer boundary of the vortex core:

(5) $$\Gamma_C = \oint \vec{V} \cdot d\vec{s},$$

where $\vec{V}$the velocity in the PIV measurement is plane, and $d\vec{s}$ is the oriented arc element along the outer boundary of the vortex core.

3. RESULTS

Figure 5 shows the comparison of the drag coefficient of the M1 model with a similar helicopter fuselage, which was tested in MAI [6]. This figure shows close results with the data acquired in similar wind tunnel for the similar model. As can be seen, a good agreement of the drag coefficient values is observed. The minor discrepancy at the negative range of pitch angles may occur due to minor geometry differences

The dependences of lift and drag coefficients from the angle of attack are shown in Figure 6. It can be seen that the drag coefficient of model M2 tends to rise significantly at negative angles of attack, compared to model M1. It can also be seen from Figure 6 that the modification of the rear fuselage upsweep shape of model M2 is associated with almost twice higher lift coefficients compared to model M1.

The dependence of the drag coefficient values from the yaw angles are shown in Figure 7. It can be seen that model M1 has slightly higher drag coefficient values at non-zero yaw angles. Furthermore, a rising values of the drag coefficient confidence intervals with the yaw angles indicates on the unsteady flow conditions.

The dependence of the vortex core circulation values for models M1 and M2 for different angles of attack is shown in Figure 8. As can be seen from Figure 8, generation of tip vortices behind the rear fuselage upsweep is almost twice higher for model M2 than the vortex core circulation for model M1. This may be the main factor explaining the difference of obtained integral coefficients.

4. CONCLUSIONS

In this work, two different rear fuselage upsweep geometries were investigated. Obtained results indicate that the flat loading ramp geometry has significantly higher lift and drag coefficients at the negative angles of attack compared to conventional shape of the rear fuselage upsweep geometry . The measurements of the vortex core circulation values from PIV measurements indicate that the loading ramp configuration of the helicopter is also associated with higher circulation of the tip vortices, which trail behind the fuselage.

FUNDING

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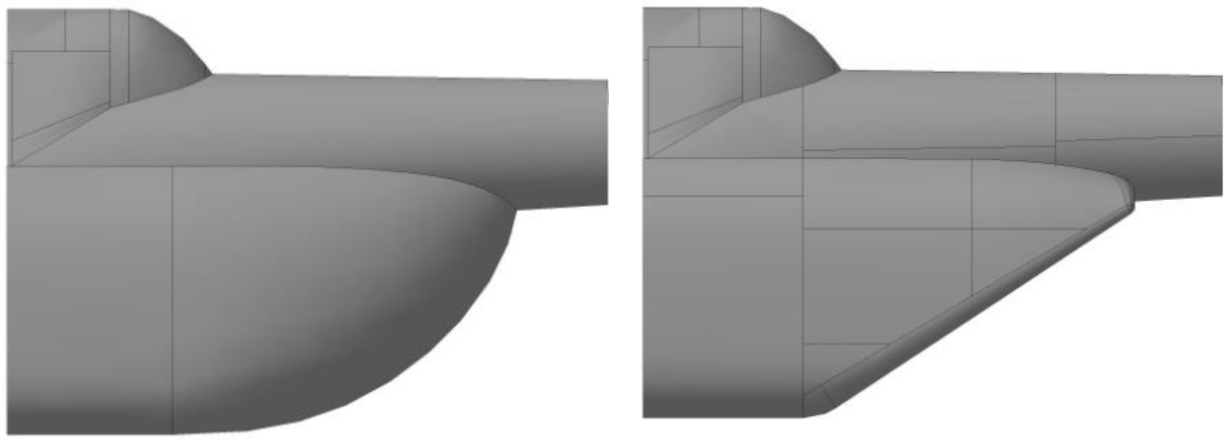

Figure 1. Side view investigated rear fuselage upsweep geometries: (left) M1 model; (right) M2 model.

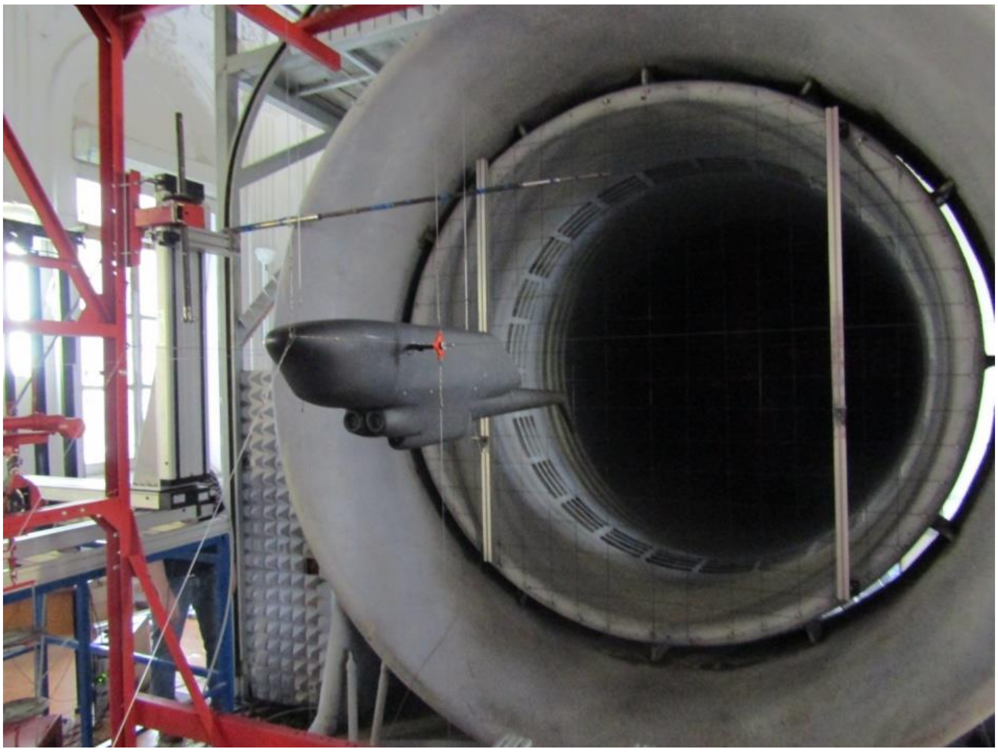
Figure 2. Experimental setup

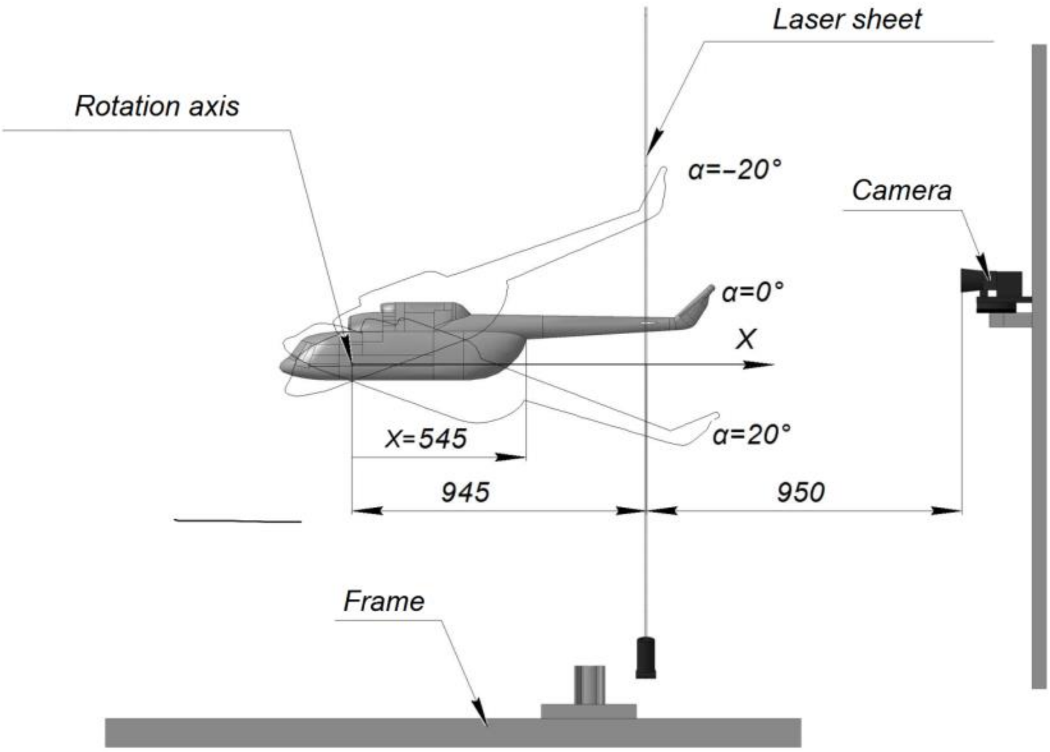

Figure 3. Side view of the PIV experimental setup

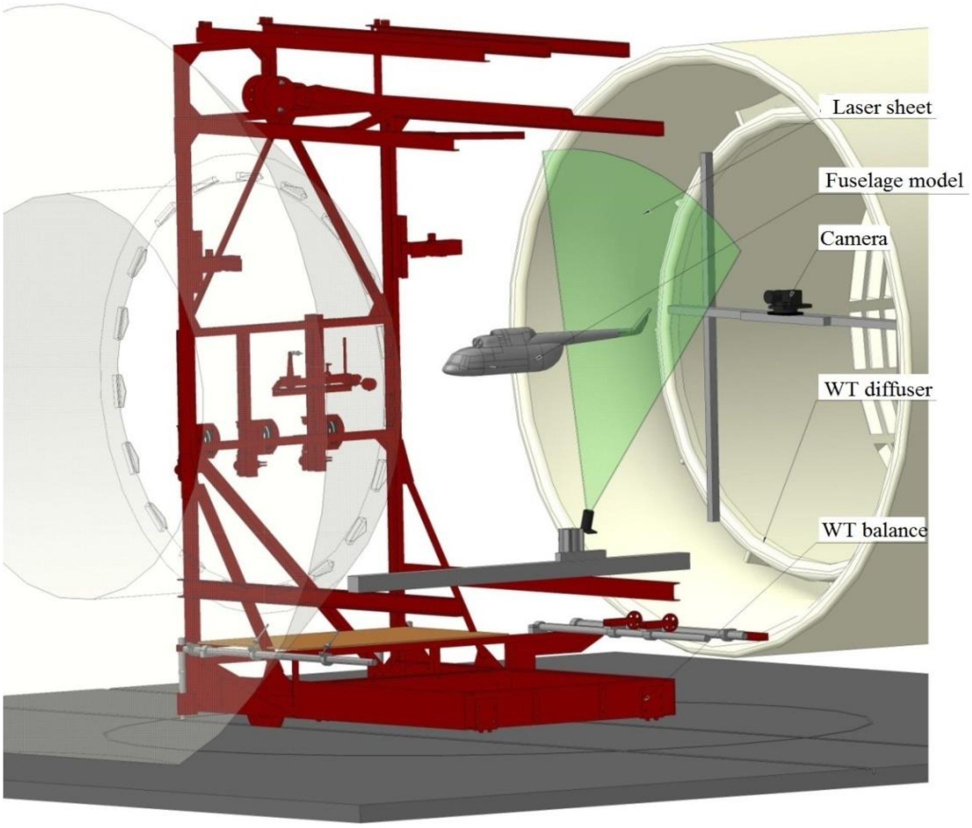

Figure 4. 3D model of the PIV experimental setup

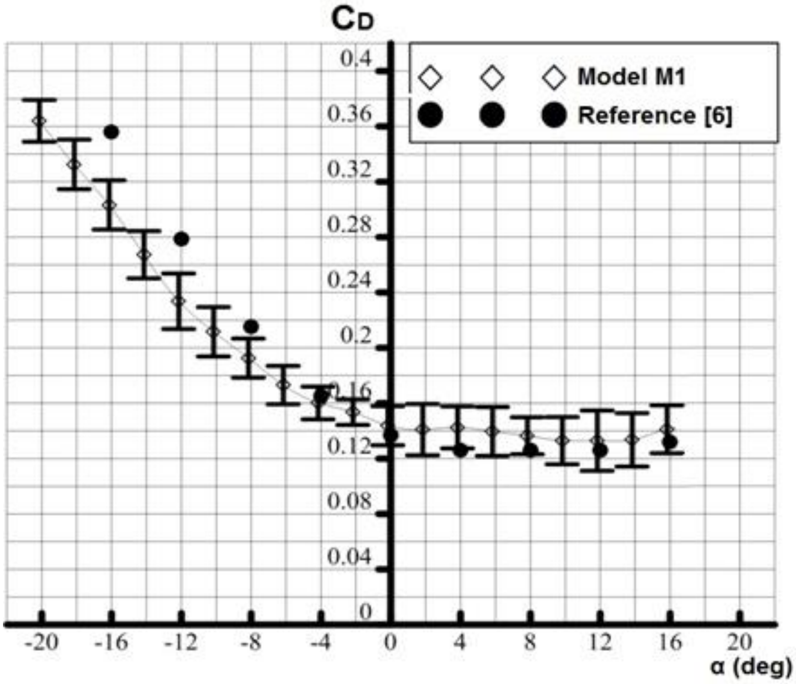

Figure 5. Comparisons of the obtained drag coefficient with Reference [6]

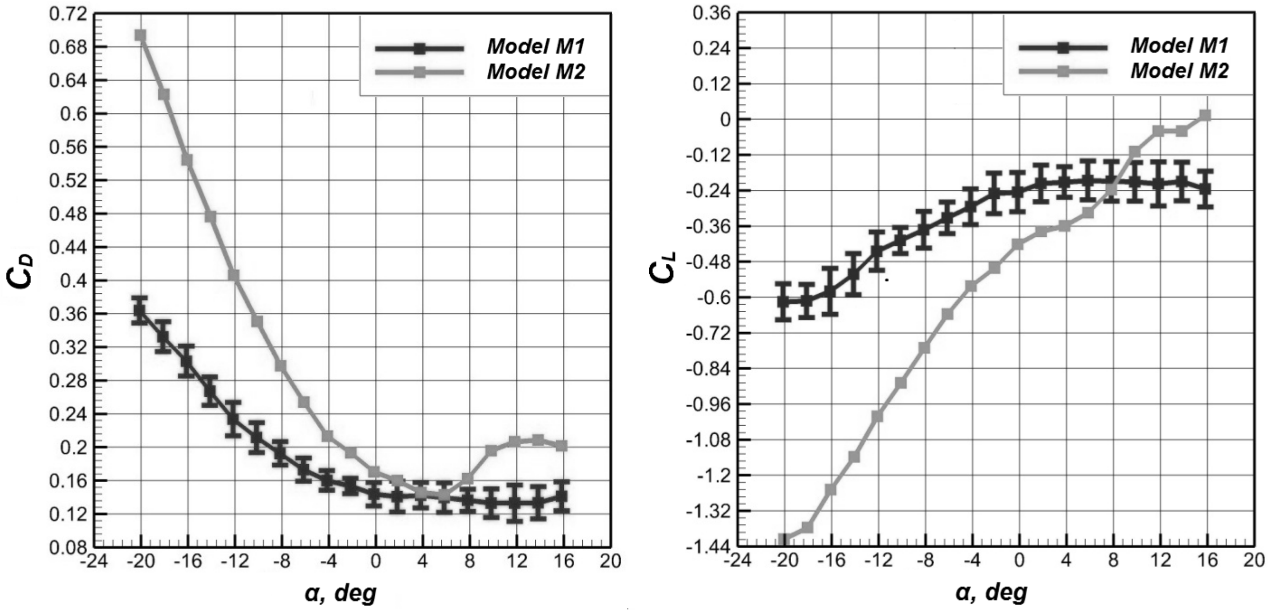

Figure 6. Dependence of the drag and lift coefficient values from the angle of attack for the fuselage with curved doors and with the flat ramp.

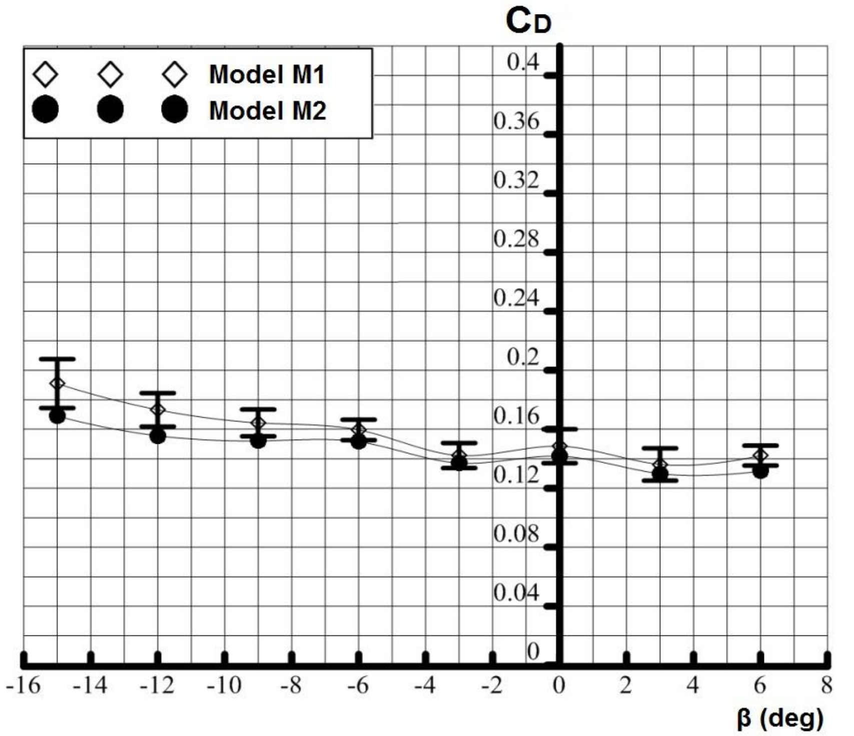

Figure 7. Dependence of the drag coefficient values from the yaw angle for the fuselage for M1 and M2 models.

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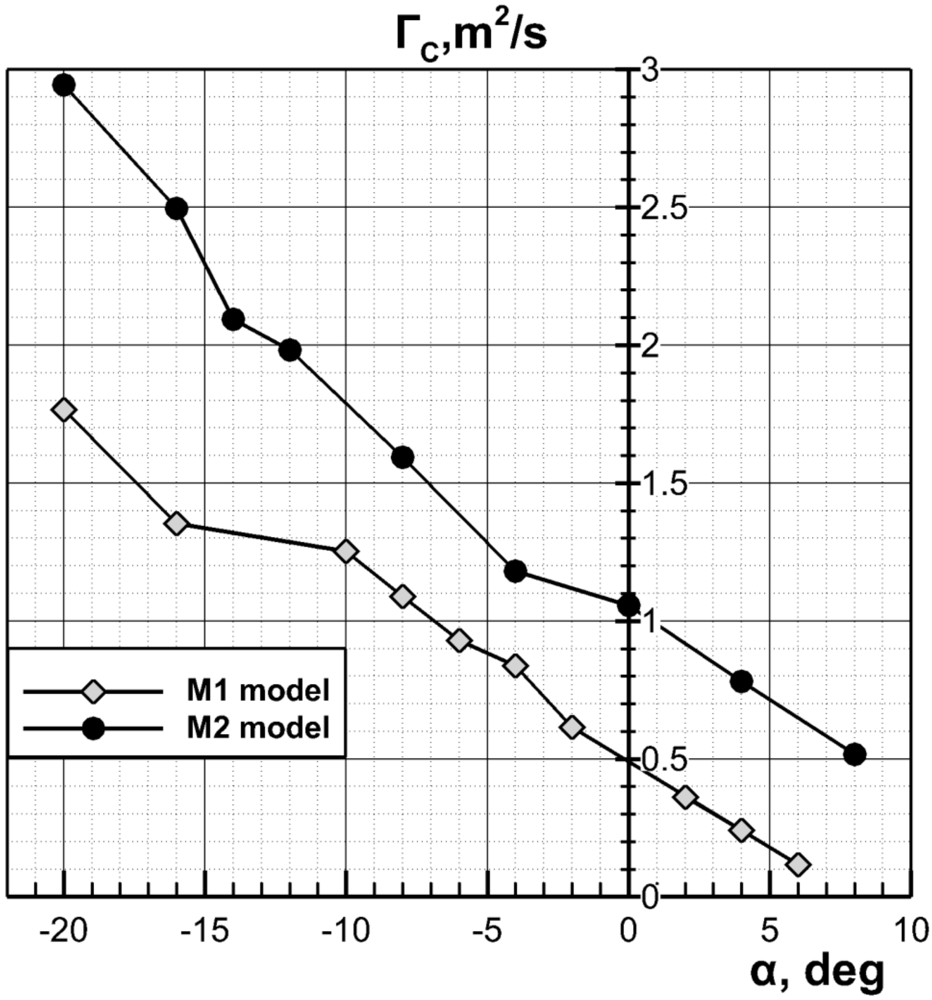

Figure 8.Dependence of the vortex core circulation for model M1 and model M2.

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