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Investigation of the Influence of Passenger Aircraft's Thrust Reverser's Geometric Parameters to Aerodynamic Performance During Post-Landing Run

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A B S T R A C T

Nowadays, passenger aircraft continue becoming bigger, more powerful and they need more powerful engines such as Hight Bypass Ratio Turbofan Engines. For such aircrafts, break systems are sufficient but thrust reversers provide easier and safer landing, especially for wet or snow-covered landings. This paper presents the research and investigation of the influence of passenger aircrafts's thrust reverser's geometric parameters to aerodynamic performance during post-landing run using computational fluid dynamics (CFD). In the study, authors investigated the changes in the number of cascade vanes, cascade vane's exit angle, thickness with the main purposes are to minimize the flow separation and to enhance the aerodynamic performance of the thrust rever.

Keywords: Uhs: Aircraft's thrust reversers; Computational fluid dynamics; Cascade vane's exit angle.

I. Introduction

The thrust reverser is one of the methods used in modern aircraft to decelerate the aircraft after landing. When the brake system is ineffective, the thrust reverser provides excellent deceleration capability for aircraft with high landing speeds.

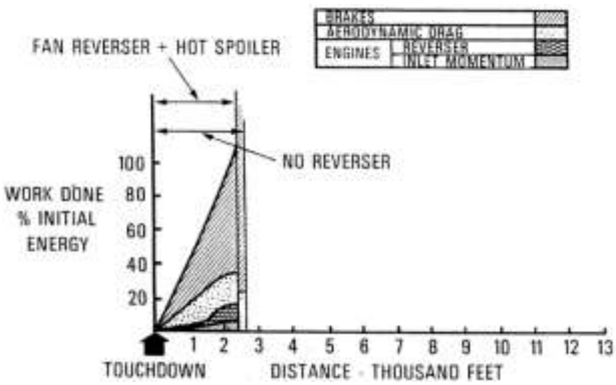


Figure 1. Landing distance of an aircraft on a dry runway

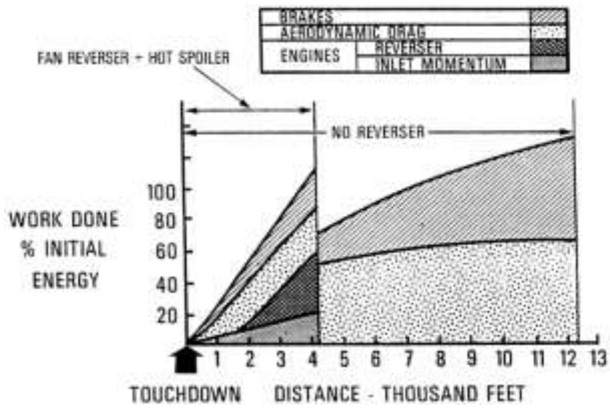


Figure 2. Landing distance of an aircraft on a wet runway

The thrust reverser can be considered as an auxiliary braking system that allows aircraft to land safely in adverse weather conditions, slippery or icy runways. According to airlines, the thrust reverser enhances aircraft safety, and most airlines consider it an essential device to provide the necessary safety during landing. Usually, in dry runway conditions, the effectiveness of the thrust reverser is insignificant compared to when it is not used (Figure 1). However, in wet or icy runway conditions, the thrust reverser can reduce the stopping distance by up to two-thirds (Figure 2) [1].

Nowadays, passenger aircraft mostly use turbofan engines with high bypass ratios due to their superior advantages. For this type of engine, the thrust reverser commonly used is the cold-stream thrust reverser in the bypass stream (Figure 3) [2].

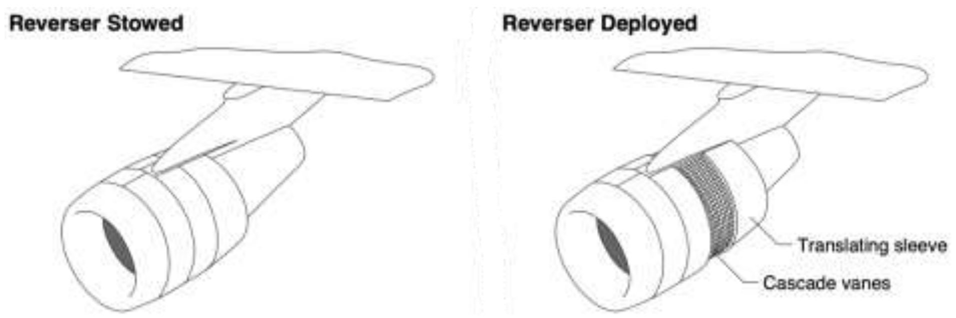


Figure 3. Sketch of the typical cold stream thrust reverser

In terms of structure, the cold-stream cascade thrust reverser consists of the translating sleeve, the blocker doors, and the cascade vanes. In the stowed mode, the blocker doors are positioned along the engine axis close to the nacelle, and the translating sleeve closes the air reversing path. In this position, the bypass stream of the engine is open, and the engine operates normally. When the reverser is deployed, the translating sleeve moves backward to open the cascade vanes' air path, and the thrust reverser's mechanical structure causes the blocker doors to move both translationally and rotationally to close the bypass stream of the engine. As a result, the airflow in the bypass stream of the engine passes through the cascade vanes and flows out (Figure 4).

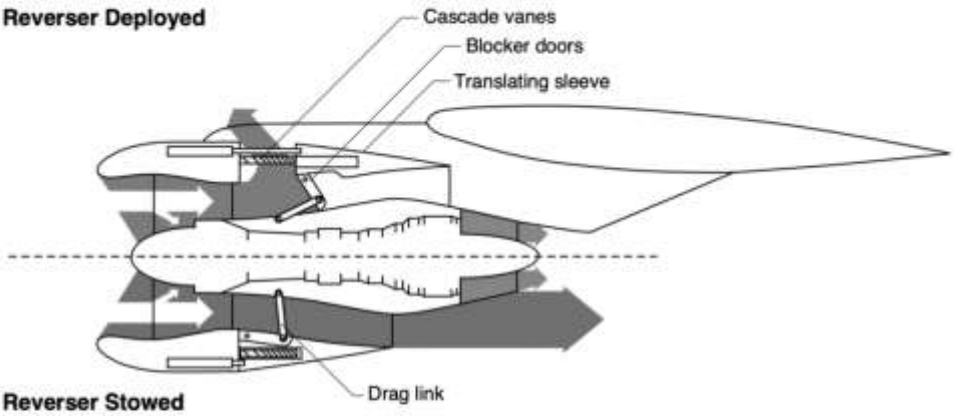
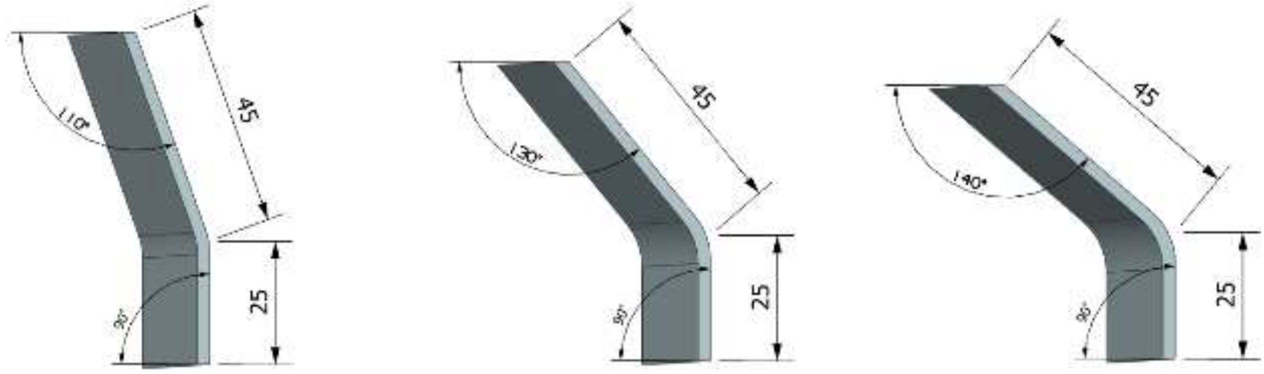


Figure 4. Cross-sectional view of a typical cold stream thrust reverser



a) Shape 1 *b) Shape 2* *c) Shape 3*

Figure 5. Different types of cascade vane profiles

The cascade vanes are an essential component of the thrust reverser. In the deployed mode, these vanes directly affect the flow rate and shape of the air passing through them, meaning they directly impact the ability to generate reversal thrust.

In this study, the authors investigated the impact of different numbers, shapes, and thicknesses of cascade vanes on the aerodynamic performance of a cold stream thrust reverser. Cascade vanes with different profile shapes (shown in Figure 5), numbers and thicknesses were examined [3]. For comparison, a case without cascade vanes was also considered. A total of 28 designs were investigated and are summarized in Table 1.

2. Mathematical model

2.1. Boundary conditions

In this study, the cascade vanes were investigated in the case of an aircraft running at deceleration after touchdown. Given that condition, the engine is idle, and the thrust reverser is deployed. The aircraft is moving at a velocity of 68.6 m/s (Mach number M = 0.2), and the ambient temperature and pressure are 288 K and 101325 Pa, respectively.

2.2. Turbulent model

During the simulation process, the authors selected a two-dimensional CFD model in a steady state with turbulent flow. In general, many turbulent models can be used for different specific cases of CFD problems. In this case, for simulating the aerodynamic characteristics of the thrust reverser at low speeds, the k - ε turbulent model was chosen to provide highly accurate results. The k - ε model employs mathematical functions in the vicinity of the boundary layer of the model, where k represents the turbulent kinetic energy and ε represents the dissipation rate per second [4].

Table 1. List of investigated designs

Design	**Number of cascade vanes n [3]**	**Profile shape**	**Thickness t (mm) [3]**
0	0	--	--
1	9	1	2.5
2	9	2	2.5
3	9	3	2.5
4	9	1	3
5	9	2	3
6	9	3	3
7	9	1	3.5
8	9	2	3.5
9	9	3	3.5
10	10	1	2.5
11	10	2	2.5
12	10	3	2.5
13	10	1	3
14	10	2	3
15	10	3	3
16	10	1	3.5
17	10	2	3.5
18	10	3	3.5
19	12	1	2.5
20	12	2	2.5
21	12	3	2.5
22	12	1	3
23	12	2	3
24	12	3	3
25	12	1	3.5
26	12	2	3.5
27	12	3	3.5

2.3. The formula for reverse velocity coefficient and mass flow rate coefficient

The aerodynamic performance of a thrust reverser is primarily evaluated through the reverse velocity coefficient and the mass flow coefficient, where:

The reverse velocity coefficient (C_{Vx}) is a coefficient for the magnitude of the velocity component moving in the opposite direction to the engine motion along the Ox axis (Figure 6). The reverse thrust coefficient is calculated as the ratio of the velocity component along the Ox axis to the total velocity:

$$C_{Vx} = \frac{-V_x}{V} = \frac{-V_x}{\sqrt{{V_x}^2+{V_y}^2}} \quad (1)$$

where V is the airflow velocity at the outlet of the cascade vanes, V_x and V_y are the velocity component along the Ox and Oy axes, respectively. The minus (-) sign indicates that V_x is opposite to the Ox axis of the coordinate system under consideration (Figure 7).

The flow coefficient is calculated as the ratio of the actual to the theoretical flow rate:

$$C_d = \frac{m_C}{A\sqrt{2\rho_C(P_C^*-P_C)}} \quad (2)$$

In the above equation, P_C^* represents the total pressure at the inlet of the cascade vanes, P_C is the static pressure at the outlet of the cascade vanes, A is the total cross-sectional area at the outlet of the gap between the cascade vanes, ρ_C is air density and m_C is the actual airflow rate through the cascade vanes.

3. CFD simulation with Star-CCM+

The simulation and evaluation of the influence of geometric parameters on the aerodynamic performance of a cold stream thrust reverser are carried out using the Star-CCM+ software. The geometric dimensions of the flow reversal device are referenced from the PS-90A engine [5].

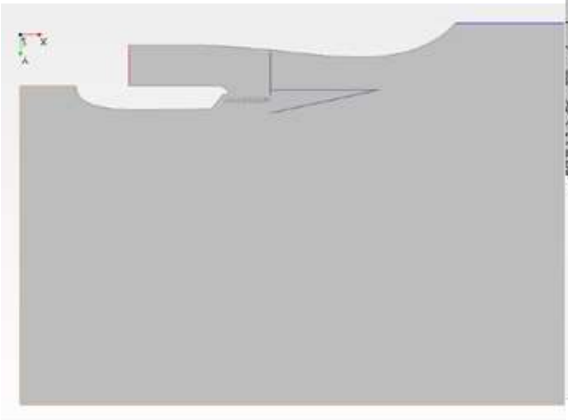


Figure 6. 2D model of thrust reverser

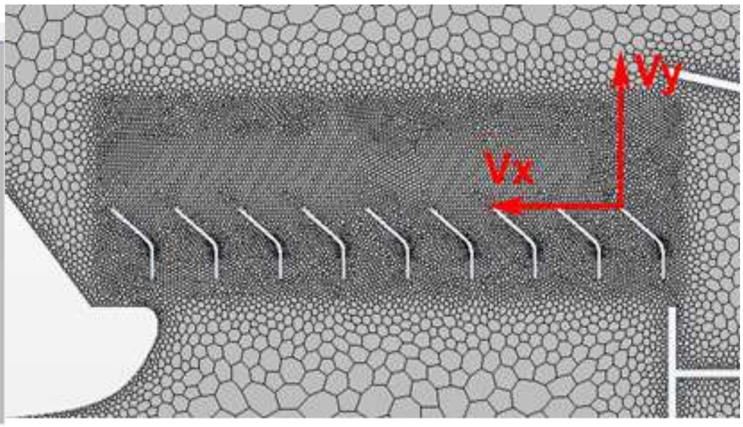


Figure 7. The mesh model of the thrust reverser

The mesh size of the model is divided into 8cm. To ensure accuracy, the edge of the thrust reverser and especially the edge of the cascade vanes are meshed with smaller sizes, ranging from 1 to 3mm (Figure 7).

The investigation was carried out with 28 designs, including one without cascade vanes and 27 with different profiles, thicknesses, and quantities of cascade vanes. The reverse velocity and mass flow rate coefficients were determined for each design as the basis for evaluation. The detailed results and observations are presented in the results section below.

4. Results

4.1. Velocity distribution through cascade vane with different profiles

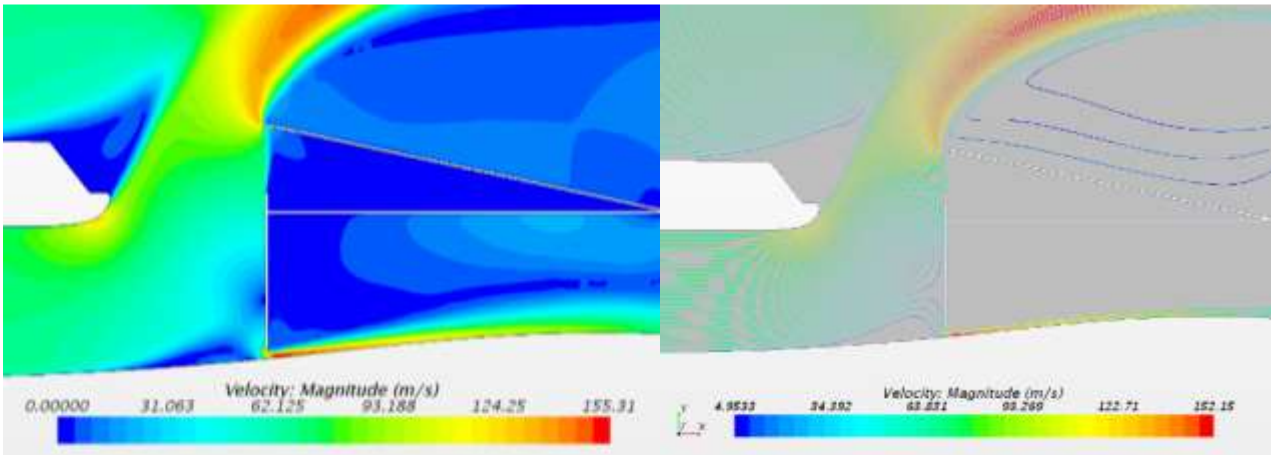
The velocity distribution and streamlines of airflow through thrust reversers of various designs are depicted in Figure 8. As shown in the figure, when there is no cascade vane, the airflow does not exhibit any reverse velocity component V_x, and hence no reverse thrust is generated. With the presence of cascade vanes, the airflow contributes to generating reverse thrust with different aerodynamic efficiencies. Furthermore, it can be observed that the gas flow passing through the cascade vanes of design 1 (with profile shape 1) is most severely separated, whereas the flow passing through the cascade vanes of design 3 (with profile shape 3) is least separated.

4.2. The impact of number, thickness and profile shape of cascade vanes on reverse velocity coefficient and mass flow rate coefficient

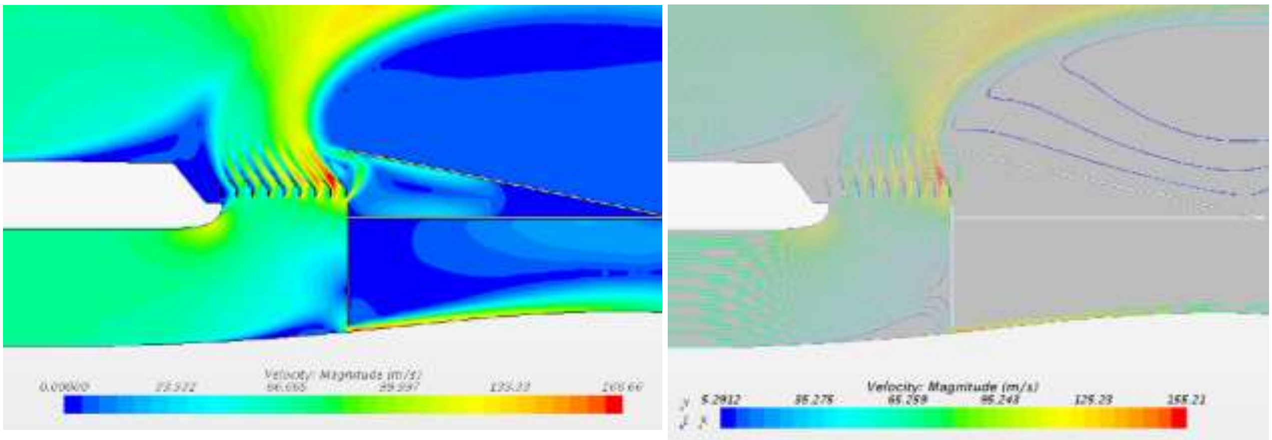
The aerodynamic efficiency of the thrust reverser for cold stream air, precisely the efficiency of cascade vanes, is evaluated using the reverse velocity and mass flow rate coefficients. The higher the values of these coefficients, the higher the aerodynamic efficiency of the thrust reversal device.

In the case of no cascade vanes (design 0), the values of the mass flow rate and reverse velocity coefficients are 0.817 and -0.304, respectively. The reverse velocity coefficient is less than 0 indicates that design 0 cannot generate reverse thrust (due to the absence of a reverse velocity component in the airflow).

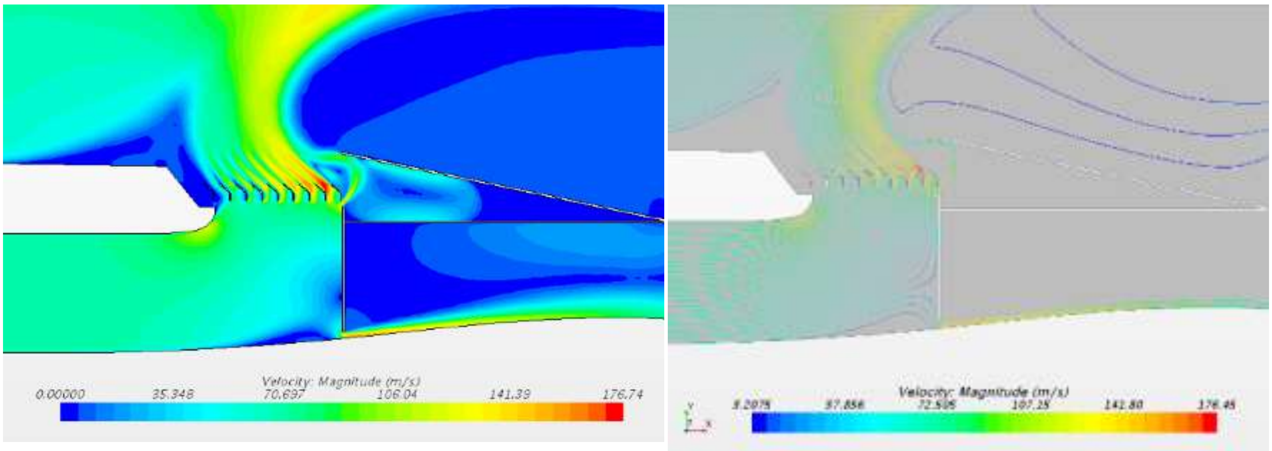
For the remaining cases where the thrust reversal device has cascade vanes, the investigated results are presented in Figures 9-11.



a) Design 0

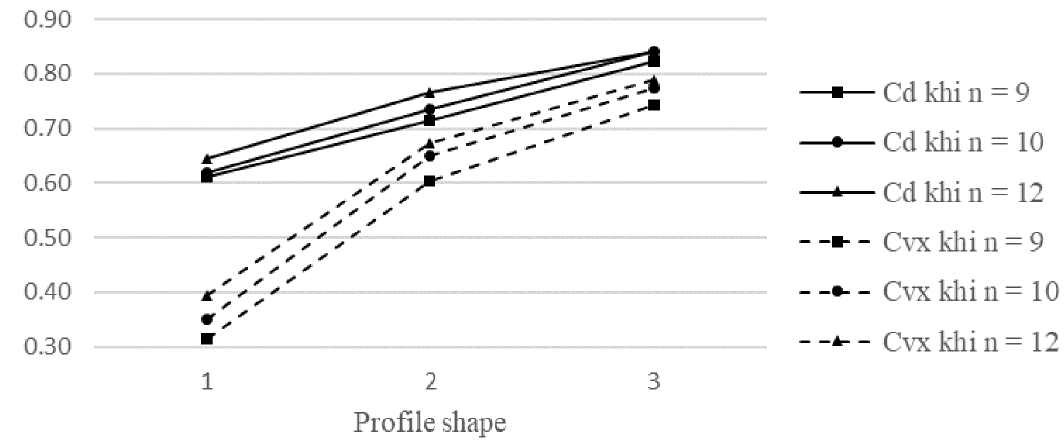


b) Design 1

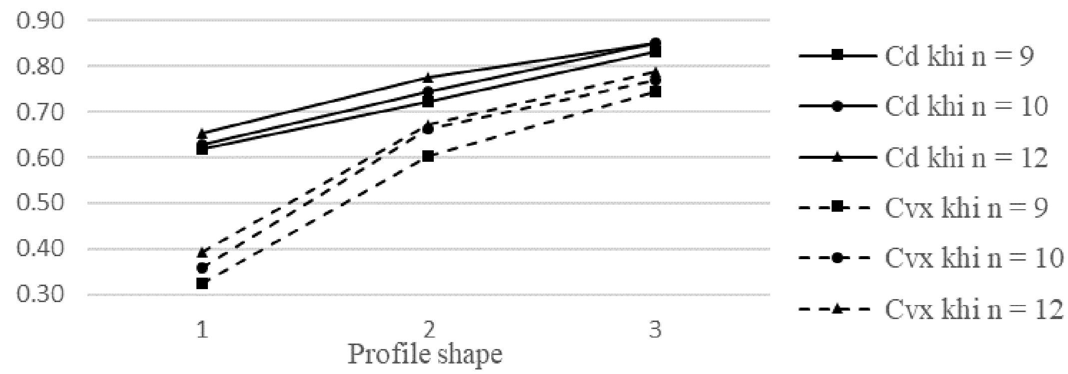


c) Design 3

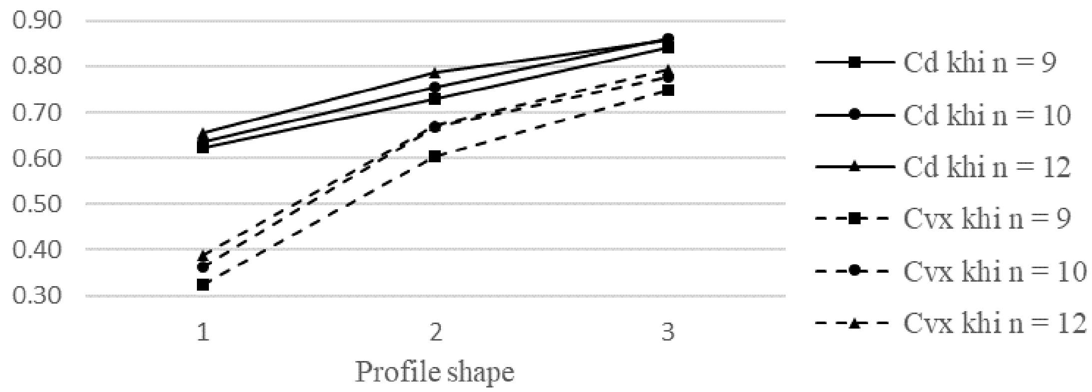
Figure 8. Velocity distribution and streamlines of gas flow through thrust reverser of some designs.



a) When thickness t = 2,5mm

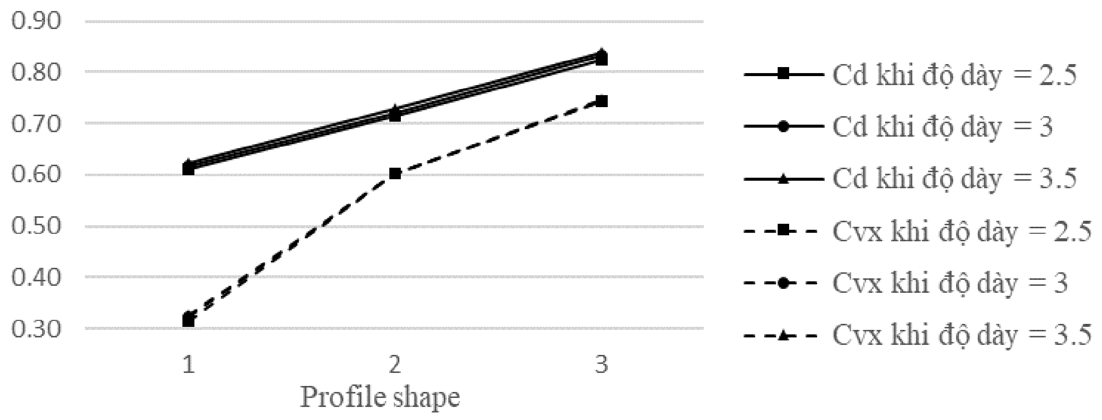


b) When thickness t = 3mm

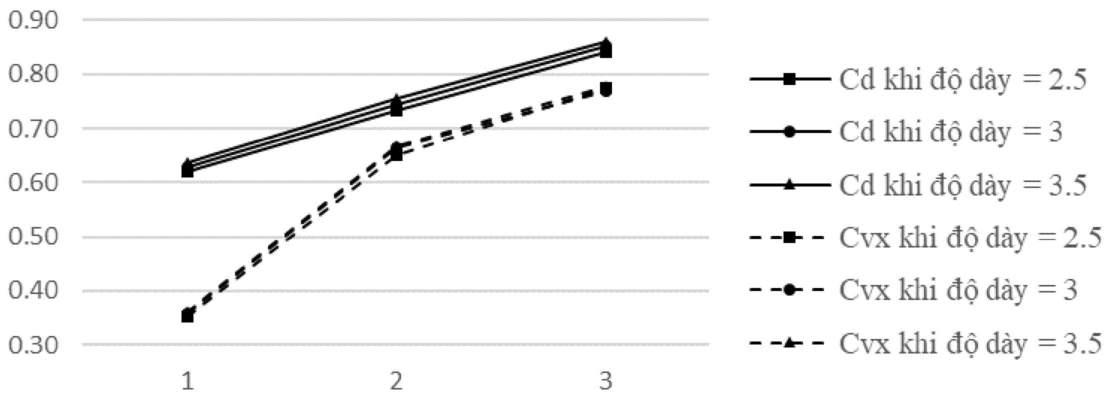


c) When thickness t = 3,5mm

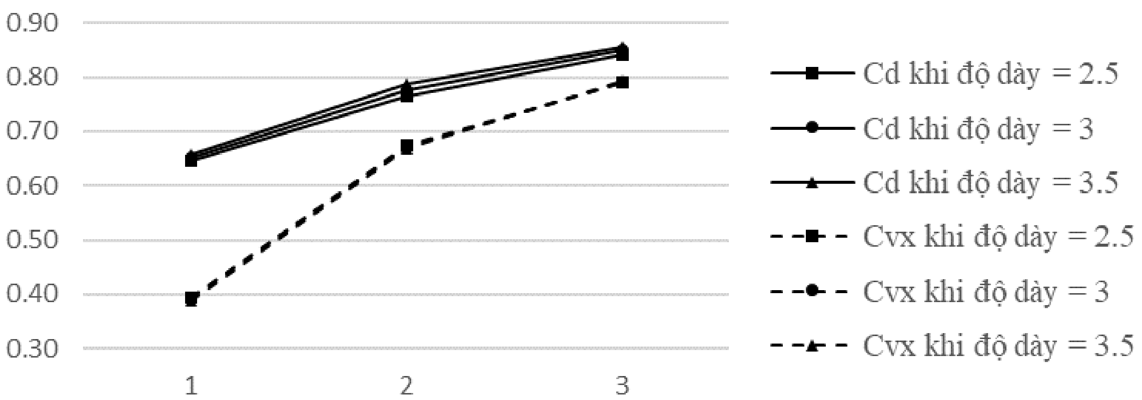
Figure 9. The variations of the reverse velocity and mass flow rate coefficients as functions of cascade vane design when the thickness is constant



a) When number of cascade vanes n = 9

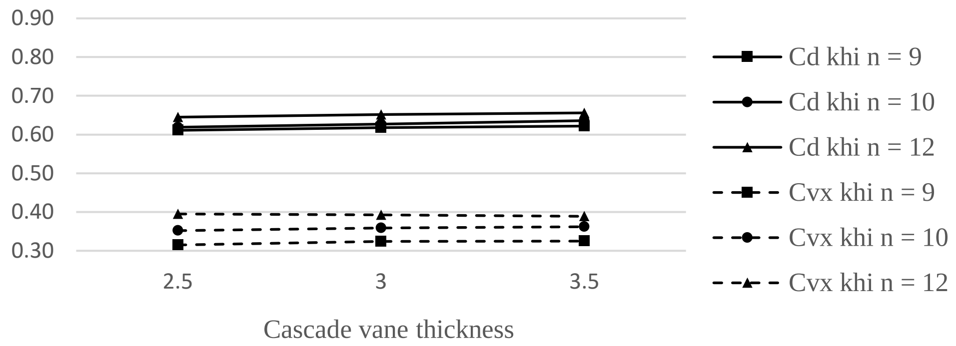


b) When number of cascade vanes n = 10

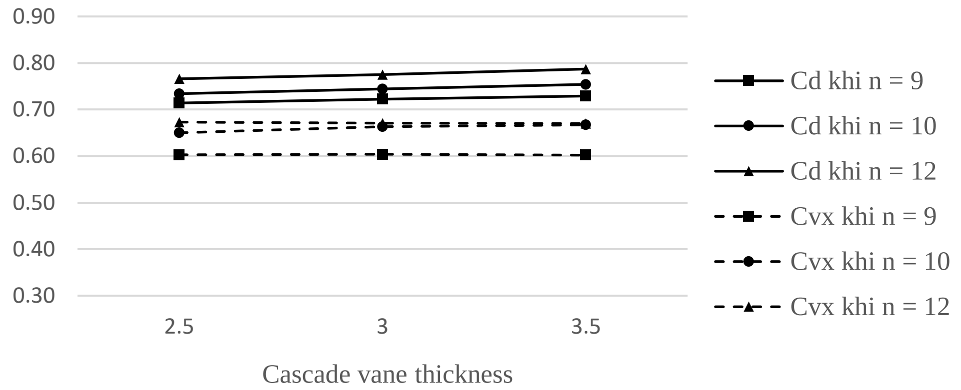


c) When number of cascade vanes n = 12

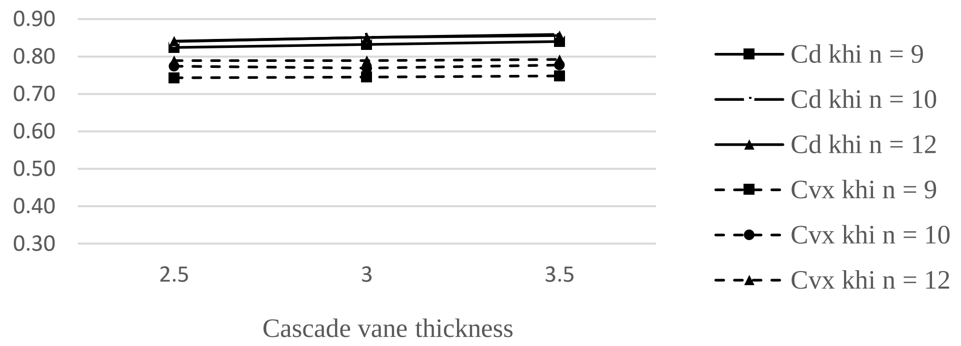
Figure 10. The variations of the reverse velocity and mass flow rate coefficients as functions of cascade vane design when the number of cascade vane is constant



a) Profile shape 1



b) Profile shape 2



c) Profile shape 3

Figure 11. The variations of the reverse velocity and mass flow rate coefficients as functions of cascade vane thickness when the profile shape is constant

From the study results, we can draw some observations as follows:

- When there are no cascade vanes, the thrust reverser cannot generate reverse thrust.

- For designs with the same thickness and number of cascade vanes, the design with profile shape 3 has the highest aerodynamic efficiency, followed by design with profile shapes 2 and 1. For example, for the design with ten cascade vanes and a thickness of 3mm:

$$\frac{C_{D_{profile\ 2}}}{C_{D_{profile\ 1}}} = 1{,}168;\ \frac{C_{D_{profile\ 3}}}{C_{D_{profile\ 1}}} = 1{,}346;\ \frac{C_{Vx_{profile\ 2}}}{C_{Vx_{profile\ 1}}} = 1{,}864;\ \frac{C_{Vx_{profile\ 3}}}{C_{Vx_{profile\ 1}}} = 2{,}3;$$

- The thickness of the cascade vanes has little effect on the aerodynamic performance. Their aerodynamic efficiencies are almost identical for designs with the same number and shape of cascade vanes. For example, for the design with ten cascades and profile shape 2:

$$\frac{C_{D_{3mm}}}{C_{D_{2,5mm}}} = 1{,}014;\ \frac{C_{D_{3,5mm}}}{C_{D_{2,5mm}}} = 1{,}027;\ \frac{C_{Vx_{3mm}}}{C_{Vx_{2,5mm}}} = 1{,}02;\ \frac{C_{Vx_{3,5mm}}}{C_{Vx_{2,5mm}}} = 1{,}026;$$

- For designs with the same thickness and shape of cascade vanes, those with more cascade vanes have higher aerodynamic efficiency, although the effect of this factor is relatively small. For example, for the design with cascade vanes of profile shape 2 and thickness of 3mm:

$$\frac{C_{D_{n=10}}}{C_{D_{n=9}}} = 1{,}03;\ \frac{C_{D_{n=12}}}{C_{D_{n=9}}} = 1{,}073;\ \frac{C_{Vx_{n=10}}}{C_{Vx_{n=9}}} = 1{,}098;\ \frac{C_{Vx_{n=12}}}{C_{Vx_{n=9}}} = 1{,}111$$

- Regarding the design with the profile form 3, when the number of vanes is increased to 12 and the thickness is increased to 3.5mm, the flow coefficient decreases. This can be explained as the large curvature of the profile shape 3 causes a significant change in flow direction. Moreover, when the number of vanes increases along with a large thickness, the increasing flow-vane interactions lead to a decrease in flow.

CONCLUSION

This paper presented the process of investigating the influence of geometric parameters of cascade vanes on the aerodynamic performance of a cold stream thrust reverser using CFD method with Star-CCM+ software. From the study results, useful parameters can be drawn as a basis for calculating and designing cascade vanes for thrust reversers on different types of passenger aircraft.

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