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Design and Analysis of Winglets on GOE767-il Aerofoil

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Abstract

Aerodynamic efficiency is defined as a ratio of co-efficient of lift to co-efficient of drag. Reduction of aerodynamic efficiency is a result of wing tip vortices which attributes to induced drag. These vortices are formed due to the difference in pressure between the top and bottom surfaces of the wing. Winglets can be used to improve overall aerodynamic efficiency of a wing. In this study, we will compare the effect of different configurations of winglets – Canted, Fenced, Raked and Spiroid on the aerodynamic efficiency of the wing. A GOE767-il aerofoil wing made of aluminium is modelled and retro-fitted with the above mentioned winglet configurations. CFD analysis for the wing and winglets will be done in three flight conditions – Take-off, Cruise and Landing, to calculate co-efficient of lift and drag. This computational analysis will be done on Ansys Fluent using Spalart – Allmaras turbulence model. The CFD results obtained will be compared based on the efficiency to determine the best winglet configuration for said aerofoil structure and wing parameters.

Keywords: Winglets, Induced Drag, Wingtip Vortices, co-efficient of lift, co-efficient of drag, Aerodynamic Efficiency

1. Introduction

For an aircraft one of the most important components is its wings, as it produces the lift required. However, this lift also creates 'lift induced drag' at the wing tips. To reduce this drag, wingtip devices also called winglets are used [1-4]. Winglets help do this by moving wingtip vortices (which are responsible for the ''lift induced drag') outwards.

1.1. Canted Winglet

Canted winglets are short, upward-sloping wedges. The cant angle cannot be decreased too much, as the flow separates more easily, affecting the properties of the wing at higher angles of attack (AoAs/α) [2][3].

1.2. Fenced Winglet

Fenced winglets are ones that extend both downward and upward from the tip of the wing and perpendicular to it. The smaller size results in a smaller bending moment at the fuselage.

1.3. Raked Winglet

Raked wingtip design is where the tip of the wing is given a further sweep angle than the rest of the wing. Raked wingtips increase the wingspan and thereby produce higher bending stresses.

1.4. Spiroid Winglet

Spiroid winglet technology was developed by former Boeing chief Dr. Louis Gratzer. It looks like a wingtip that has been bent through 360° to form a loop. This winglet will enhance the lift and reduce the drag [4][5]. Nikola N. Gavrilović, carries out CFD analysis of wing with and without winglets to compare the two results. It will be observed that wing without winglet produces larger vortices, which induces more drag, compared to wings with winglets [5]. A study by Hanlin Gongzhang Eric Axtelius on lift and drag of various winglet design showed spiroid and fenced winglets to be the least effective design [7]. Saravanan Rajendran conducted a theory based study and parameterized all associate parameters of the wing model. At optimal parameters, the payload of the aircraft could be increased [6]. Based on the survey, the expected ranking of the winglets in decreasing order of aerodynamic efficiency is [7] Raked, Canted, Spiroid and Fenced. This study aims to improve the aerodynamic efficiency of GOE 767-il aerofoil by introducing four winglet designs, namely – Canted, Raked, Spiroid, Fenced winglets. The team will carry out theoretical and CFD analysis of the wings and winglets in three flight conditions namely – Take-off, Cruise and Landing. During the analysis, different parameter such as density, altitude and viscosity will be considered. The wing and winglets will be designed on Solid Edge and then the winglets will be retro-fitted onto the wing. It will then be analysed on Ansys Fluent.

2. Governing Equations

2.1. Navier Stokes Equation

Continuity equation

$$\frac{\partial \rho}{\partial t} + \frac{\partial (\rho u)}{\partial x} + \frac{\partial (\rho v)}{\partial y} + \frac{\partial (\rho w)}{\partial z} = 0 \qquad (1)$$

X Momentum equation

$$\rho \frac{\partial (\rho u)}{\partial t} + \frac{\partial (\rho u^2)}{\partial x} + \frac{\partial (\rho uv)}{\partial y} + \frac{\partial (\rho uw)}{\partial z} =$$

$$\rho fx - \frac{\partial p}{\partial x} + 2\mu \left(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} + \frac{\partial^2 u}{\partial z^2} \right) + \mu \left(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial x \partial y} + \frac{\partial^2 u}{\partial x \partial z} \right) \qquad (2)$$

Similarly, y and z momentum equations can be framed.

$$C_L = \frac{2}{\rho V^2} \times \frac{W}{S} \qquad (3)$$

$$C_D = C_{DSF} + FF \times C_{DSF} + K \times {C_L}^2 \qquad (4)$$

$$C_{DSF} = \frac{0.455}{(\log(Re))^{2.58} (1+0.144M^2)^{0.65}} \qquad (5)$$

$$AE = \frac{C_L}{C_D} \qquad (6)$$

Table. 1. Symbols

Notation	Meaning
AE	Aerodynamic Efficiency
C_D	Drag Coefficient
C_{DFD}	Form Drag Coefficient
C_{DI}	Induced Drag Coefficient
C_{DSF}	Skin Friction Drag Coefficient
C_L	Coefficient of Lift
FF	Form Factor
K	Constant
L	Lift Force (N)
M	Mach Number
Re	Reynolds' Number
ρ	Density (kg/m^3)
S	Surface Area (m^2)
V	Velocity of incoming air (m/s)
W	Weight of wing
u	Velocity in x – direction (m/s)
v	Velocity in y – direction (m/s)
w	Velocity in z – direction (m/s)
t	Time period (s)
μ	Dynamic Viscosity (m^3/s)
p	Pressure (Pa)

3. Methodology

3.1. CAD Modeling

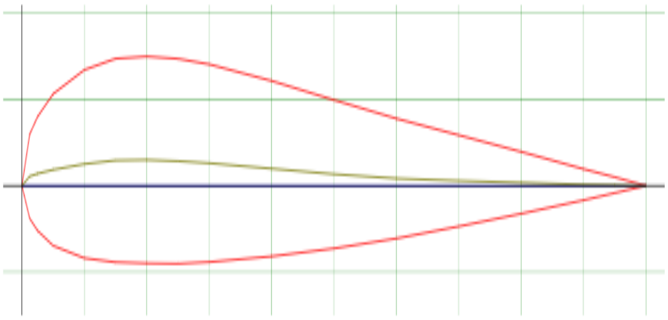

Fig. 1. Aerofoil Structure

The wing and winglets will be modelled using solid edge 2019 academic version. To create the aerofoil structure in Solid Edge, 'Curve by Table' function can be used. The co-ordinates of the aerofoil-GOE767-il are imported using this function and scaled. The curves are aligned and spaced to incorporate the wingspan and other parameters mentioned in 'Table. 2. Dimensions of Wing'. Lastly, 'Loft Protrusion' is done to obtain the final feature. Similarly, the winglets are modelled with appropriate dimensions.

Table. 2. Dimensions of Wing

Parameter	Value
Area	$214.45m^2$
Left Wing Length	21.27m
Mean Aerodynamic Chord Length	6.98m
Taper ratio	0.267
Aspect ratio	7.99
Chord Length	
-At root	8.57m
-At tip	2.29m
Trailing Edge Sweep Angle	
-1st sweep	84°
-2nd sweep	22.3°
Leading Edge Sweep Angle	31.5°
Dihedral Angle	6°
t/c ratio	11.5

3.2. CFD Analysis

Once modelling is completed, the analysis will be carried out on Ansys Fluent 2020 academic version. The turbulence model used in this analysis is Spalart-Alamas equation. But first, the geometries will first be imported into the Ansys workbench module. An artificial wind tunnel will be created around the wing(s). Next step is to create a discrete mesh and set appropriate boundary conditions based on the flight conditions as shown in 'Table.3.Input Parameters'. Lastly, the calculation will be completed and the results will be obtained and discussed in the coming chapters.

4. Results and Discussions

4.1. Theoretical & CFD Results

As shown in figure the various plots such as velocity magnitude and the pressure distribution were plotted. It was observed that the wing tip vortices which attribute to the induced drag and resulted in lower aerodynamic efficiency of the wing was improved upon retrofitting the winglets on to the wing. We can see a general trend where the wingtip vortices are reduced however from the values obtained. We can see that winglets help in increasing the efficiency in specific flight conditions.

Table.3.Input Parameters

		Take-off	Cruise	Landing
Geo.	AoA (deg)	10	3	6.5
Op. Cond.	Op Pres (Pa)	101325	19740.971	101325
Material Prop.	Density (kg/m^3)	1.225	0.32079	1.225
	Viscocity(kg/m-s)	1.46E-05	4.56E-05	1.46E-05
Boundary Cond.	Inlet velocity (m/s)	62.762	249.9	67.99
	Temp (K) (Inlet)	288.15	248.2854	288.15

4.1.1. Wing

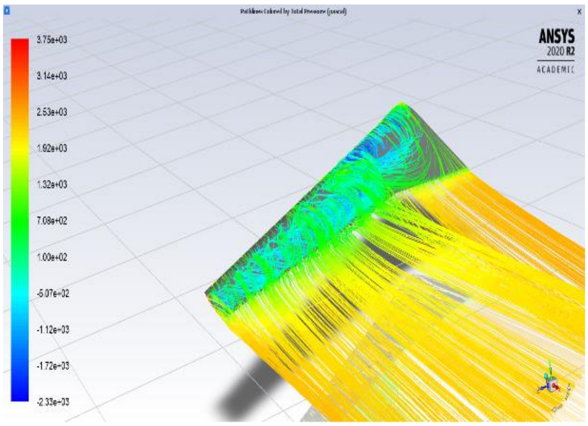

Fig. 1.1. Pressure Pathlines at Take-off

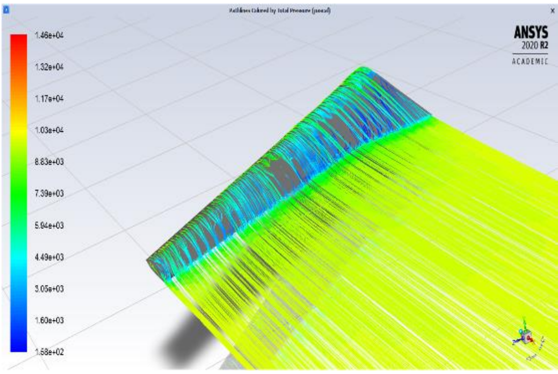

Fig. 2. Pressure Pathlines at Cruise

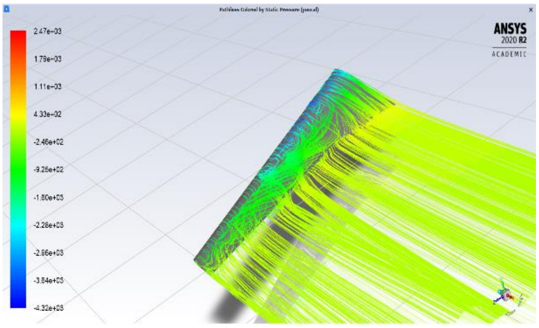

Fig. 3. Pressure Pathlines at Landing

Table.4.Table of values

Flight Condition	CFD Values		
	C_L	C_D	Efficiency
Take-Off	0.9302	0.1181	7.87638
Cruise	0.2704	0.0265	10.20377
Landing	0.7003	0.0559	12.52773

4.1.2. Winglet – Canted

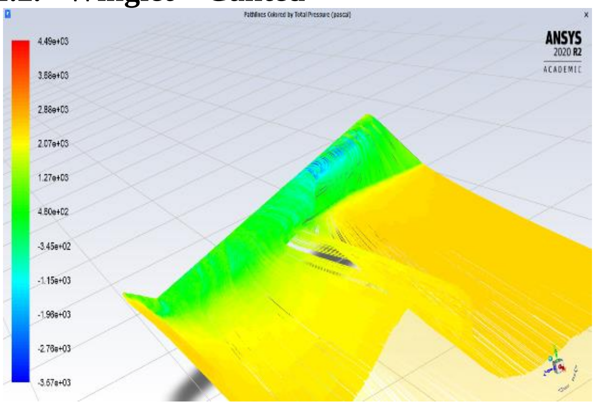

Fig. 4 Pressure Pathlines at Take-off

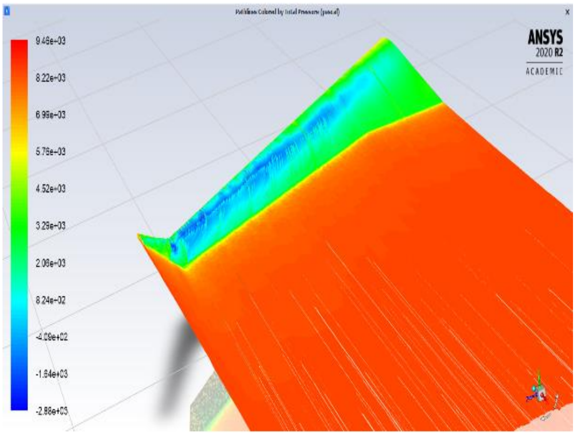

Fig. 5. Pressure Pathlines at Cruise

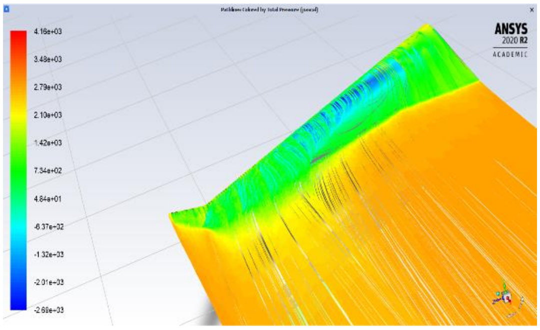

Fig. 6. Pressure Pathlines at Landing

Table.5.Table of values

Flight Condition	CFD Values		
	C_L	C_D	Efficiency
Take-Off	0.93915	0.10266	9.14816
Cruise	0.323	0.01781	18.13588
Landing	0.89139	0.063	14.14905

4.1.3. Winglet – Fenced

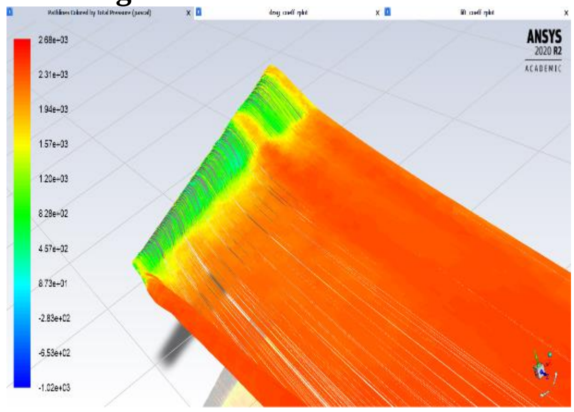

Fig.7. Pressure Pathlines at Take-off

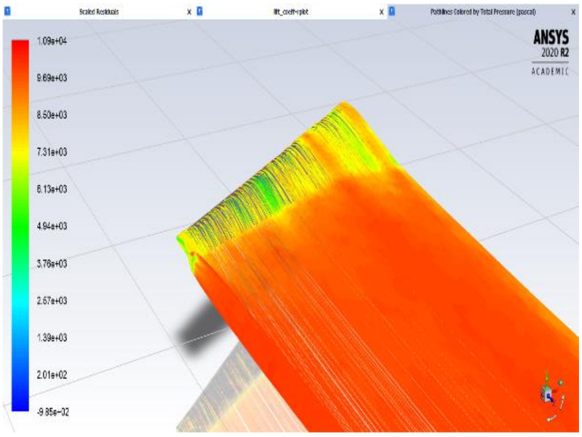

Fig. 8. Pressure Pathlines at Cruise

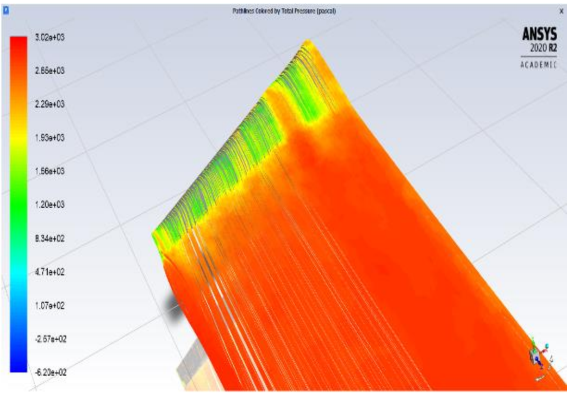

Fig. 9. Pressure Pathlines at Landing

Table.6. Table of Values

Flight Condition	CFD Values		
	C_L	C_D	Efficiency
Take-Off	0.75675	0.07810	9.68980
Cruise	0.29339	0.02835	10.34881
Landing	0.55275	0.04673	11.82959

4.1.4. Winglet – Raked

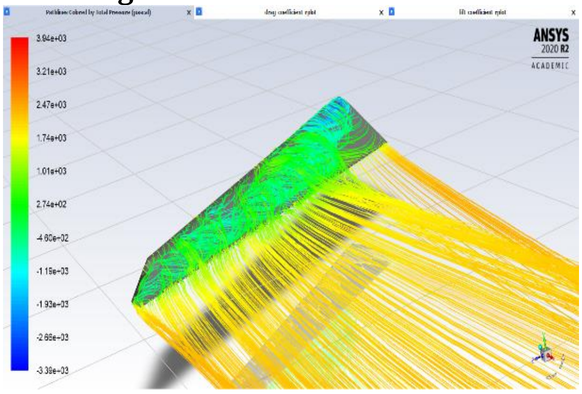

Fig. 10. Pressure Pathlines at Take-off

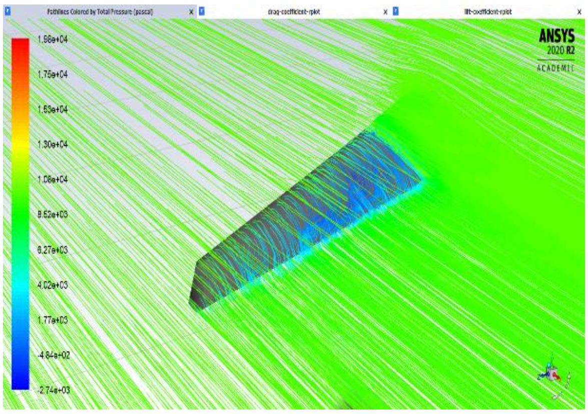

Fig. 11. Pressure Pathlines at Cruise

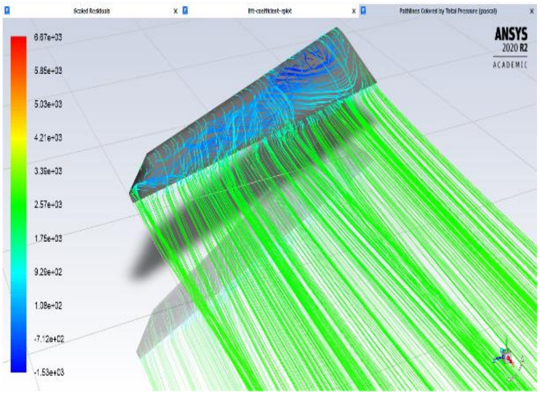

Fig. 12. Pressure Pathlines at Landing

Table.7.Table of Values

Flight Condition	CFD Values		
	C_L	C_D	Efficiency
Take-Off	0.51865	0.09004	5.76022
Cruise	0.18632	0.01678	11.10369
Landing	0.39855	0.04305	9.25784

4.1.5. Winglet – Spiroid

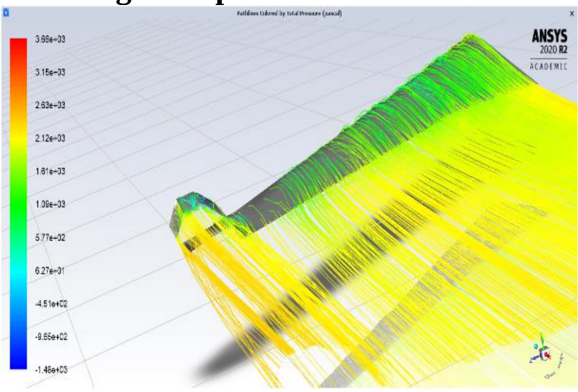

Fig. 13. Pressure Pathlines at Take-off

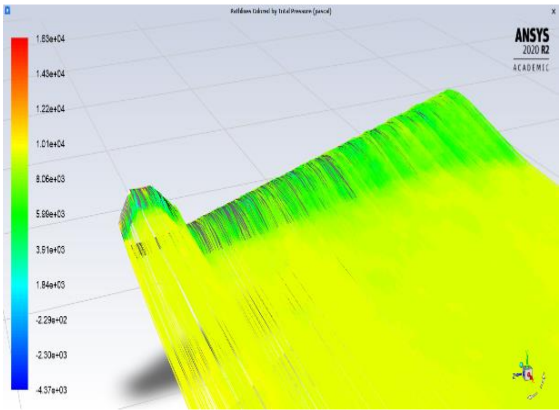

Fig. 14. Pressure Pathlines at Cruise

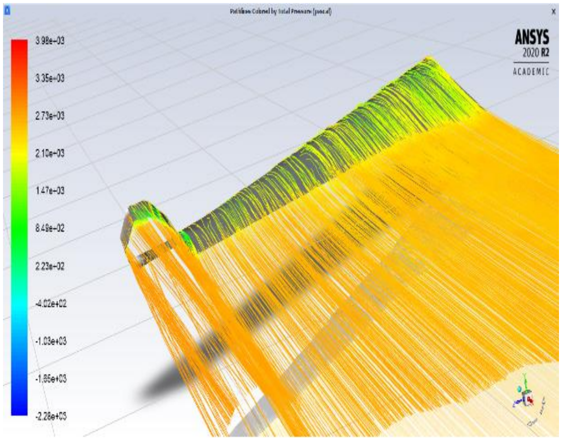

Fig. 15. Pressure Pathlines at Landing

Table. 8.Table of Values

Flight Condition	CFD Values		
	C_L	C_D	Efficiency
Take-Off	0.77436	0.07346	10.54186
Cruise	0.31950	0.03430	9.31487
Landing	0.52356	0.04389	11.92828

4.2. Comparison of Winglets

One can see that Spiroid offers the least efficiency when it comes to the cruise phase of the flight to a point where the efficiency is lower than that of the wing without winglets by 9%. Canted winglet shows the maximum efficiency when it comes to the cruise phase of the flight whereas the gains obtained from fenced and raked winglets are 1% and 9% respectively. Speaking of the take-off phase Spiroid shows the maximum gain in efficiency of 34% and canted showing a 13% rise in efficiency in the landing phase of the flight as shown in the table below.

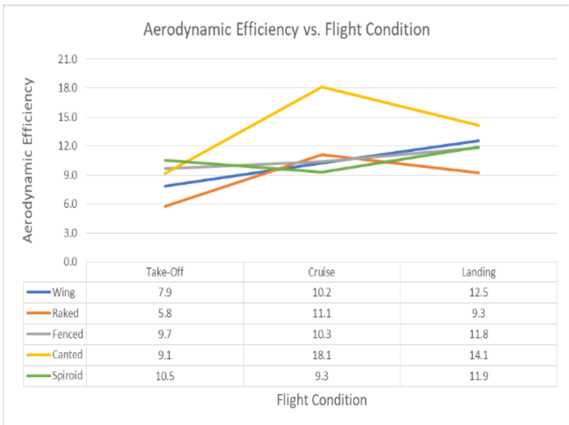

Chart.1. Aerodynamic Efficiency vs. Flight Condition

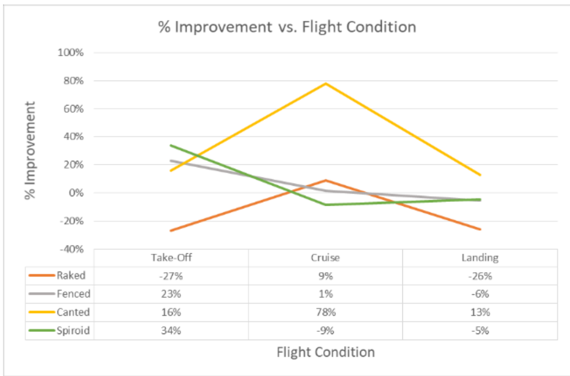

Chart. 2. Improvement vs. Flight Condition

Conclusion

- Canted winglet was found to show most improvement in cruise condition. Therefore, Canted winglet is best configuration of all the other configurations analyzed.
- After Canted winglet, Raked and Fenced winglet configurations gave desirable results.
- Spiroid winglet was found to give negative improvement in cruise condition and is therefore not a viable configuration for wing parameters used in this project.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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