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Research Paper

The effect of skin friction coefficient on the wing Cessna 172S

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Abstract
The main idea of this paper is to give a theoretical-deep investigation of the skin friction coefficient on the wing of Cessna 172S. The total drag of Cessna 172S is depending on the parasite drag and induced drag where the parasite drag or zero-lift drag depending mainly on the skin friction drag of Cessna 172S.the skin friction drag has been estimated according to the three regions: laminar, transition point, and turbulent, and according to the velocity and RE number that has been chosen the effect of skin friction drag has been calculated. the transition point of skin friction calculated depending on XFOIL program.
Keywords: *Xfoil, DATCOM method, Cessna 172S, lift curve parameters, Theory of wing section. Young boundary layer.*

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Nomenclature

AR = Aspect ratio
b = Wingspan
c = Chord length
c_r = Root chord
c_t = Tip chord
C_D = Drag coefficient
C_{Di} = Lift-induced drag coefficient
C_{Dmin} = Minimum drag coefficient
C_l = Two-dimensional lift coefficient
C_{LminD} = Lift coefficient at drag minimum
C_L = Three-dimensional lift coefficient
C_{Lmax} = Maximum 3D lift coefficient
C_{lmax} = Maximum 2D lift coefficient
$C_{l\alpha}$ = 2D lift curve slope
$C_{L\alpha}$ = 3D lift curve slope
$R_{L.S}$ = Lifting-surface correction factor
Re_c = Reynold number at mean chord
Re = Reynold number
S_{wet} = Wetted reference area
S_{ref} = Wing reference area
$\left(\frac{t}{c}\right)$ = Thickness ratio
V = Airspeed of aircraft
W = Maximum weight of aircraft
$\Lambda_{C/4}$ = Sweep angle of quarter chord
$\frac{x_{tr}}{c}$ = Transition point

β = Mach number parameter
δ = Induced-drag factor
λ = Taper ratio
L = Lift force
M = Mach number
Λ_{max} = Sweep angle of maximum thickness
C_{D_o} = The zero lift-drag coefficients
$\Lambda_{C/2}$ = Sweep angle of half chord
Λ_{LE} = Sweep angle of leading edge
$\Delta C_{L\,max}$ = Mach number correction
$\frac{x_0}{c}$ = Location where boundary layer starts

$\frac{x_{tr}}{c}$(Upper) = Transition point on upper wing

$\frac{x_{tr}}{c}$(Lower) = Transition point on lower wing

C_{flam} = Skin friction coefficient for fully laminar

C_{fturb} = Skin friction coefficient for fully turbulent

I. Introduction

The skin friction coefficient occurs because of the fluid of viscosity that flows over the surface of the wing. It's value depending on the viscosity of the fluid and the area of the wing or wetted area. The amount of viscosity depends mostly if the flow is laminar or turbulent. However, the Reynold number and the form of the pressure distribution determine if the flow above the wing is laminar or turbulent as well. When the surface of aircraft becomes rough, the analysis of skin friction coefficient becomes complex because of the process of transition. As can be shown in Figure 1.1, the skin friction of a turbulent boundary layer is greater than the laminar boundary layer for flow conditions. However, the laminar boundary layer expands from the leading edge of the wing to the upper point of the surface that indicates by $X_{tr\text{-}upper}$ and $X_{tr\text{-}lower}$ over the surface [1] [2].

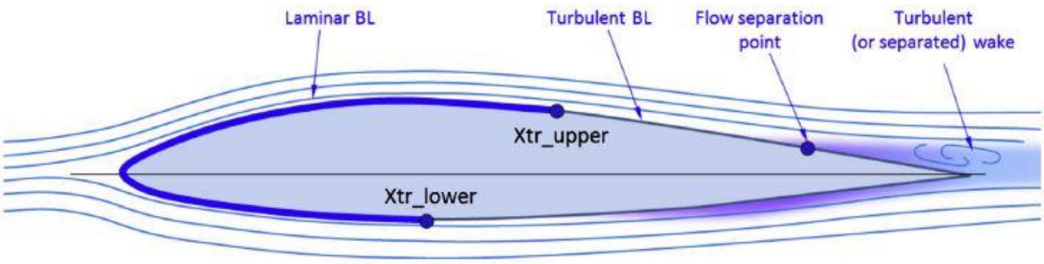

Figure1.1: Characteristics of flow over an airfoil [1].

II. Skin Friction Coefficient Prediction of Cessna 172S.

The skin friction coefficient for fully laminar flow and fully turbulent flow over the surface can be predicted according to Gudmundsson [1] by using Equation [1.1, 1.2].

$$C_{flam} = \frac{1.328}{\sqrt{Re}} \qquad 1.1$$

$$c_{fturb} = \frac{0.455}{(\log_{10}(Re))^{2.58}} \qquad 1.2$$

Roskam [3] and Raymer[4] have presented another method to estimate skin friction coefficient at fully turbulent flow by using Equation 1.3

$$C_f = \frac{0.455}{(\log_{10} Re)^{2.58}\,(1+0.144M^2)^{0.65}} \qquad 1.3$$

According to the DATCOM [2], the total skin friction coefficient for turbulent flow can be estimated as the function for Mach and Reynold number by using Figure 1.2

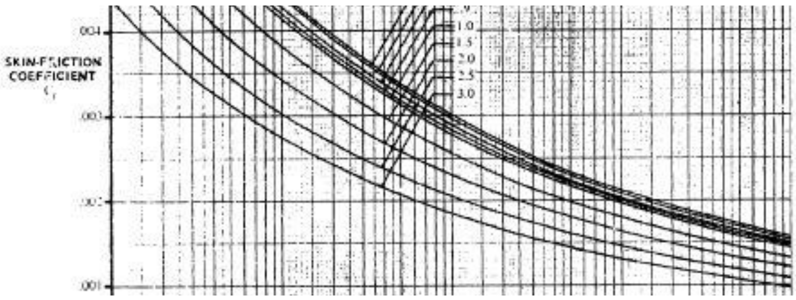

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Figure 1.2: Turbulent skin friction coefficient based on DATCOM[2].

2-1 Young's Method for Mixed Laminar-Turbulent.

According to the boundary layer theory by Young[5], the skin friction coefficient at mixed laminar-turbulent can be estimated by using Equation 2.1 that obtained from Gudmundsson [1].

$$C_f = \frac{0.074}{Re^{0.2}}\left(1-\left(\frac{X_{tr}-X_0}{C}\right)\right)^{0.8} \qquad 2.1$$

Where $\frac{X_{tr}}{C}$ is a transition point, which can be predicted from the database of the airfoil by using the Xfoil or javafoil[6], and $\frac{X_0}{C}$ is the location where the boundary layer starts and it can be estimated by using Equation 2.2.

$$\frac{X_0}{C} = 36.9 \times \left(\frac{X_{tr}}{C}\right)^{0.625}\left(\frac{1}{Re}\right)^{0.375} \qquad 2.2$$

The mixed boundary layer laminar-turbulent depending predominately on the transition point, where if the $\frac{X_{tr}}{C}$ is zero the results of the boundary layer is fully turbulent and when $\frac{X_{tr}}{C}$ is 100% the results of the boundary layer is a fully laminar.

Another method to estimate the total skin friction coefficient at the transition point from the laminar to turbulent is Prandtl-Schlichting formula [7] that obtained from Bertin by using Equation 2.3.

$$C_f = \frac{0.455}{(\log_{10}Re_c)^{2.58}} - \frac{1700}{Re_c} \qquad 2.3$$

Where Re_c is the mean Reynold number at mean aerodynamic chord.

III. Results And Discussion Of Skin Coefficient

The total drag of Cessna 172S has been predicted depending on the parasite drag and induced drag where the parasite drag or zero-lift drag depending mainly on the skin friction drag of Cessna 172S, the skin friction drag has been estimated according to the three regions: laminar, transition point, and turbulent. In addition, it is based on Gudmundsson [1] ,Roskam [3] ,Raymer[4] and DATCOM[2]. The skin friction coefficient for the turbulent region has calculated according to Equations [1.2, 1.3] and DATCOM[2]. As can be seen in Table 3.1 the magnitudes of skin friction seem closer to each other depending on the velocity of aircraft and Reynold number, and it becomes very close to the stall speed and max speed of Cessna 172S, and Figure 3.1 demonstrates the comparison between three methods of the turbulent region.

Table 3.1: The comparison of the turbulent region based on three methods.

25.48128	2605901.71	0.00379	0.00375883	0.00376077
30	3068019.01	0.0037	0.00365302	0.00365563
35	3579355.51	0.00362	0.0035566	0.00356007
40	4090692.01	0.00352	0.00347564	0.00348006
45	4602028.51	0.00345	0.00340607	0.00341155
50	5113365.01	0.00339	0.00334519	0.00335184
55	5624701.51	0.00336	0.00329116	0.00329907
60	6136038.01	0.00331	0.00324262	0.00325189
64.374	6583355.18	0.00324	0.00320387	0.00321442
69.374	7094691.68	0.00314	0.00316315	0.00317524
74.374	7606028.18	0.00309	0.00312565	0.00313939

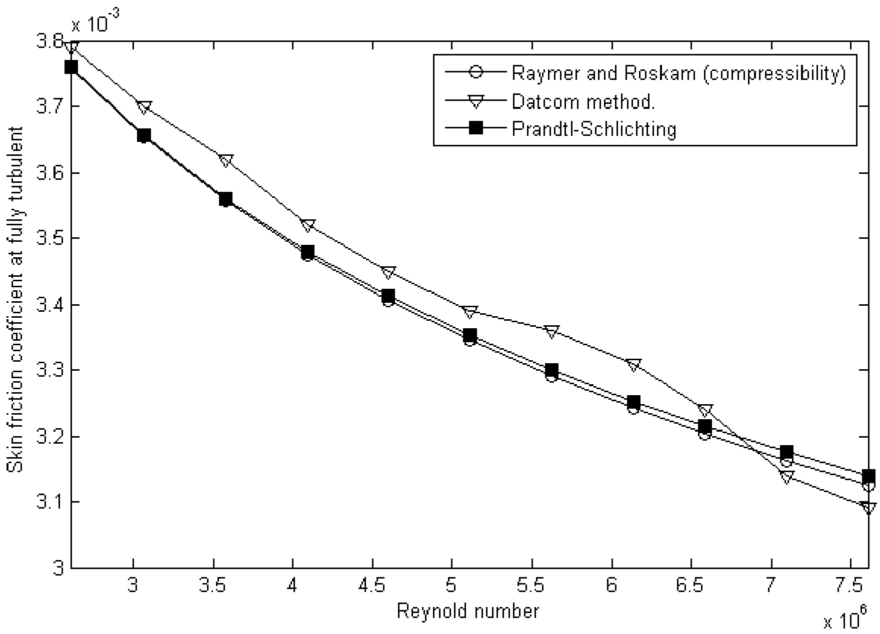


Figure 3.1: The effect of RE on the fully turbulent region based on three methods.

The mixed laminar-turbulent region has evaluated according to the Young's[5] boundary layer theory by using Equation 2.1, which is depending on transition point and the location of boundary layer when it starts, where the value of transition point has obtained from Xfoil-data[8] that shown in Table 3.2, and it has done with the lower surface and upper surface according to the mean aerodynamic chord of Cessna 172S. Also, the location of the boundary layer of the surface was evaluated according to Equation 2.2 for upper and lower surface as well depending on Reynold number.

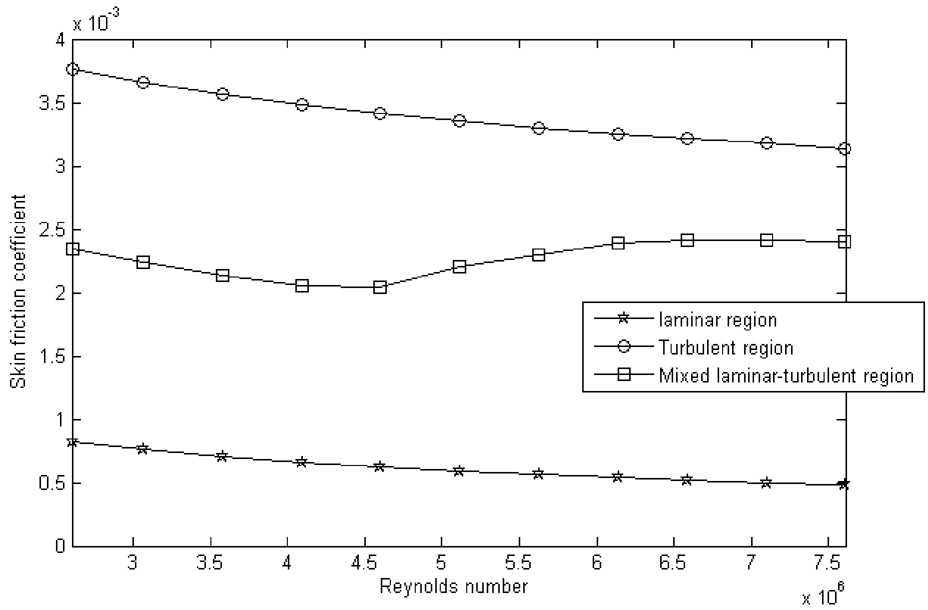
Table 3.2: The mixed laminar-turbulent region based on Young's method for different RE number.

2.6	**0.0091**	**1**	**0.0100**	**0.1890**	**0.0010**	**0.0008**	**0.0023**
3.0	**0.0159**	**1**	**0.0133**	**0.1783**	**0.0009**	**0.0007**	**0.0022**
3.5	**0.0403**	**1**	**0.0226**	**0.1687**	**0.0008**	**0.0007**	**0.0021**
4.2	**0.1309**	**0.9971**	**0.0451**	**0.1606**	**0.0008**	**0.0032**	**0.0020**
4.6	**0.2645**	**0.8742**	**0.0672**	**0.1418**	**0.0011**	**0.0028**	**0.0020**
5.1	**0.3464**	**0.6646**	**0.0766**	**0.1151**	**0.0017**	**0.0026**	**0.0021**
5.6	**0.3951**	**0.5079**	**0.0803**	**0.0940**	**0.0021**	**0.0024**	**0.0022**
6.1	**0.4183**	**0.3743**	**0.0807**	**0.0753**	**0.0024**	**0.0023**	**0.0023**
6.5	**0.4348**	**0.3054**	**0.0806**	**0.0646**	**0.0025**	**0.0022**	**0.0024**
7.0	**0.4474**	**0.2566**	**0.0799**	**0.0564**	**0.0026**	**0.0021**	**0.0024**
7.6	**0.456**	**0.2222**	**0.0789**	**0.0503**	**0.0026**	**0.0021**	**0.0024**

The fully laminar region has calculated according to Equation 2.3 in chapter four depending on the mean aerodynamic chord. As can be shown in Figure (3.2, 3.3) and the Table 3.3 the comparison of three methods depending fundamentally on the RE number and transition point of the surface.

Table 3.3: Comparing Skin Friction Analysis Methods.

2.6		**0.0023**	**0.0037**	**160%**	**0.00082**	**35.7%**
3.0		**0.0022**	**0.0036**	**163.6%**	**0.00075**	**34%**
3.5		**0.0021**	**0.0035**	**166.6%**	**0.00070**	**33.33%**
4.2		**0.0020**	**0.0034**	**170%**	**0.00065**	**32.5%**
4.6		**0.0020**	**0.0034**	**170%**	**0.00061**	**30.5%**
5.1		**0.0021**	**0.00335184**	**159.5%**	**0.00058728**	**27.6%**



3.2: Comparing Skin Friction Analysis of three Methods based on RE.

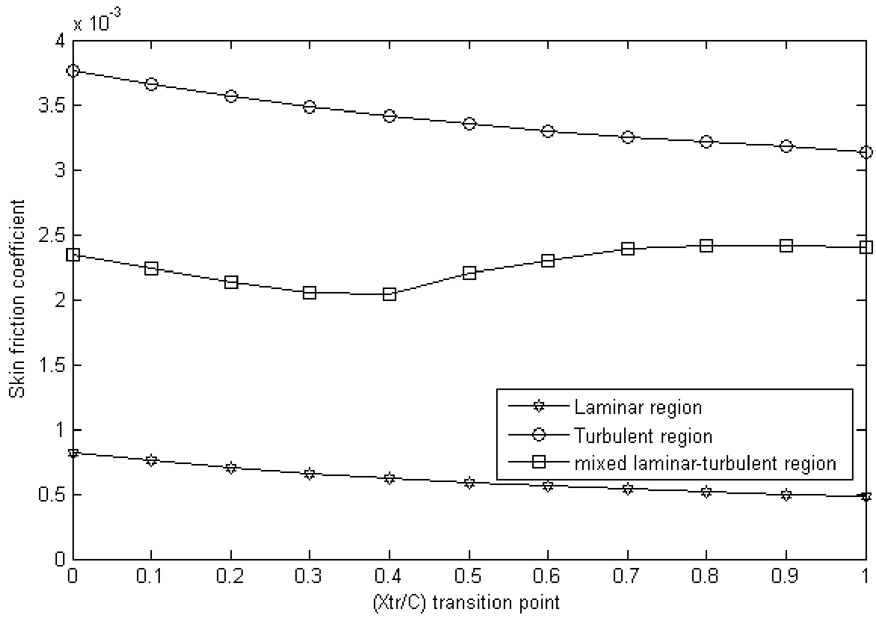


Figure 3.3 Comparing Skin Friction Analysis of three Methods based on Xtr/C.

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