Computational fluid dynamic analysis of race car wings engineering essay

This paper is to identify drag and lift coefficient of front and read wings of a race car with different angles of attack. Process simulation and analysis for both the model design was conducted with computer-aided drawing software and analyzed using software COSMOSFloworks to perform a turbulent simulation of the airflow on the front and rear wings of a race car with different angles of attack. Results are presented graphically, showing lift to drag ratio, lift (CL) and drag coefficients (CD) for the different cases. The aerofoils were tested at angles of attack ranging from 0°to 20°. The purpose of study is to find the suitable profile of aerofoil to generate the required lift force or drag force to the race car. The results were used in a simulation of a typical Formula SAE race car. It was shown that an angle of 16° below the horizontal seems to indicate stalling conditions except for the Formula One race car. Furthermore, the highest lift-to-drag ratio of front wing is found to be Formula Three race car with angles of attack of 0°meanwhile the highest lift-to-drag ratio of rear wing also found to be Formula One race car with angle of attack of 5°.

Keywords

CFD; Race Car; k-Îµ turbulent modeling; Aerofoil; COSMOS FloWorks 2008

Introduction

Overview

First racing cars were primarily designed to achieve high top speeds and the main goal was to minimize the air drag. But at high speeds, cars developed lift forces, which a¬€ected the stability. In order to improve their stability and handling, engineers mounted inverted wings pro¬ 🚺les to generating negative lift [13]. In open-wheel racing series such as Formula One, a front wing is inverted to produce downforce, that is, negative lift, leading to an enhancement of traction and cornering ability of cars [14]. The main function of the front wing is to generate downforce on the front-axis. In interaction with the bargeboards and the aerodynamic at the rear of the car, it is crucial for the performance of the car[8]. The front wing is operated in close proximity to a solid boundary, known as the ground effect regime, where different ¬, ow features are exhibited, compared with the free stream condition. Although wind tunnel testing remains a signi¬ cant tool for aerodynamic development, computational ¬, uid dynamics(CFD) plays an important role because of its ef¬ cient cost performance compared with wind tunnel testing , and the detailed ¬, ow information that is available[14]. Drag reduction is not commonly the main target of top race car aerodynamic optimisation but it is still an important factor for low power vehicles (F3, electric/solar cars)[4].

Objectives

The objectives of this project is to design three types of both wings for race car and to analyze aerodynamic characteristics of the wings on a race car by using software Computational Fluid Dynamics (CFD) software. Then, coefficient of drag and coefficient of lift for all the wings will be evaluated to figure out which profile of aerofoil is the best in term of lift-to-drag ratio. Lastly, the selected profile of aerofoil will be improved by carry out the new design of wing for race car.

Scope

In any investigation, there are always different approaches that can be taken. Numerical, analytical and experimental approaches all have their advantages and disadvantages. CFD initially appeared suited to this investigation owing to the large number of tests. The scope of this investigation is limited to a 2-D study shape to eliminate the vortex phenomena at the tip of aerofoil. In reality, the wings would be exposed to three dimensional (3-D) flows; however this would increase the number of variables to be explored greatly [7]. Race car typically use multi-element wings[2]. The multi-element design allows for much higher lift than is possible from a single element wing of similar dimensions. This investigation has been limited to the effects on a single element wing. A benefit of the single element is the simplicity of the design. The mechanism to actively control a single element wing would be a lot simpler than that for a multi-element, thus easier to implement in both FSAE and production vehicles. The angles of attack of wings this investigation is limited in the range of 0° to 20°.

Literature review

The Physical Model for Airfoil

A schematic configuration and a coordinate system of airfoils are shown in Fig. 2. 1a and Fig. 2. 1b.

Figure 2. 1a- Airfoil and its components

Figure 2. 1b- Airfoil nomenclature

From both figures above, the chord line is a line connecting leading a trailing edge. The chord length is the distance from the leading to the trailing edge, measured along the chord line. The camber is the maximum distance between mean camber line and chord line. The thickness is the distance between the upper and lower surfaces [13]. The flow around an airfoil is assumed to be turbulent and steady state with incompressible fluid [14]. The amount of lift L produced by the airfoil, can be expressed in term of lift coefficient CL

(1)

Where V denotes the free stream velocity, Ïf is fluid density and A is the airfoil area [13].

Besides that, the drag coefficient CD for vehicle body can define as: [6]

(2)

Where D is the drag and A is the airfoil area (A= b*c) [9], b and c are wingspan and chord length respectively [16].

Ground Effect

The Wings as downforce generating aerodynamic devices appeared in the 1960s. By 1970, the rear wing was placed at the rear of the car, behind and above the rear wheels, and the front wing in front of the front wheels in ground effect. This basic arrangement of the front and rear wings has remained the same since then [15]. The main di¬€erence between wing application in aviation and car racing is that cars are in contact with the ground. Therefore, wing experiences some additional e¬€ects due to ground proximity [13]. With the airfoil close to the ground, the velocity on the upper surface is slower than for the airfoil in free air. On the lower surface of the wing, the velocity is higher for the airfoil in ground effect than the one in free air using the principle of continuity to maintain the same ¬, ow under the wing downstream as the wing upstream [3].

Lift-to-Drag Ratio

(3)The lift-to-drag ratio is the amount of lift generated by a wing divided by the drag it creates by moving through the air.

Numerical Method for Flow Analysis

The numerical model was set up and run using the COSMOSFloworks Computational Fluid Dynamics (CFD) code. Due To the assumption of isothermal ¬, ows and no heat transfer, the energy equation was not introduced [3]. The front wing is basically attached to the sides of the body of the race car, while the back wing is attached using a strut to the body of the car. These would normally introduce some 3-D effects into the ¬, ow patterns developed around these wings . It is expected, though, that the results of the 2-D simulation will be uniformly affected by these construction details. However, the relative results and trends for the different simulations are expected to stay relatively the same[3]. Any end effects for either wings, such as vortex generation, are assumed to be relatively small due to the relatively small Reynolds number of the flow. The simulation here only concentrate on effect of the angle of attack on the front and rear wing. For conducting flow analysis in FloWorks we need to know the airspeed.

Reynolds number and airspeed are related by following equation:[16]

(4)

Where Ï is fluid density, V is horizontal component of airspeed , c is chord length and is fluid viscosity.

Methodology

This chapter explains the designs and simulations.

Conceptual Design of Formula Mazda Race Car

With the airfoil curve dimension given [3], the modified airfoil curve coordinates was obtained from the software JAVAFOIL. A 3D front wing model was designed in SolidWorks with 381. 85mm chord and 1400mm span is shown in Figure 3. 1a.

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Figure 3. 1a-Drawing of front wing (airfoil)

Figure 3. 1b-Drawing of rear wing (airfoil)

The Figure 3. 1b shows the drawing of rear wing designed by SolidWorks with the chord length is 452. 14mm and span of the wing is 1300mm.

Conceptual Design of Formula One Race Car

With the airfoil curve coordinates given [12]. A 3D front wing model was designed with some modification (The trailing edge given was not closed) in SolidWorks with 380. 19mm chord and 1400mm span is shown in Figure 3. 2a. The airfoil curve coordinates of rear wing is designed using JAVAFOIL with the information given [11]. The profile of rear wing is based on NACA 2104 which shown in Figure 3. 2b.

Figure 3. 2a- Drawing of front wing (airfoil)

Figure 3. 2b- Drawing of rear wing (airfoil)

Conceptual Design of Formula Three Race Car

With the airfoil curve coordinates given [12]. A 3D front wing model was designed in SolidWorks with 380. 04mm chord and 1400mm span is shown in Figure 3. 3a. The airfoil curve coordinates of rear wing is designed using JAVAFOIL with the information given [11]. The profile of rear wing is based on NACA 2312 which shown in Figure 3. 3b.

Figure 3. 3a- Drawing of front wing (airfoil)

Figure 3. 3b- Drawing of rear wing (airfoil)

Flow Analysis and Simulation in FloWorks

We considered using 2D flow analysis vs. 3D flow analysis over the surface of the wing model designed in SolidWorks[1]. In 3D flow analysis, the fluid dynamics computations are performed over the entire region of the solid, whereas, in 2D flow analysis the computations are performed in the cross sectional area of the solid. The various factors that came into our consideration for evaluating 2D flow analysis vs. 3D flow analysis were: time complexity and memory requirements for 3D computational analysis, practicalities involved in extrapolating 3D results from a series of 2D analysis, and the goal of developing a general method that could be used in subsequent research on other wing models [16]. The Reynolds number of 1. 4 million was used for front wing of race car which is based on the aerofoil chord length of 0. 38m, design speed of 58m/s, density of fluid is 1.

2041kg/m3 and the fluid viscosity is 1. 84e-5Pa. s. For the rear wing of race car, the Reynolds number of 1. 7 million was used which is based on the aerofoil chord length of 0. 45m.

StartSimulation Procedure

Import Coordinates

Extrude the Airfoil Profile

Define Input Data

Specify the Goals

Run Solver

Finish

A model of the airfoil was created in SolidWorks and the part was then exported to CosmosFloWorks. First, the coordinates for the airfoil of race car were imported into SolidWorks in the form of text file. Next, the airfoil profile was extruded. A trimetric view of the finished wing section in SolidWorks is shown in Figure 3. 5.

Figure 3. 5- The finished model of the wing section in SolidWorks

Using the CosmosFloWorks wizard, the SI unit system was first chosen followed by the choice of the external analysis type option. Next, air was chosen as the default fluid. The size of the computational domain in the stream wise direction was 0. 368 m in front of the leading edge and 0. 585 m after the trailing edge. In order to get a reasonable calculation time, a 2D plane steady flow calculation was selected. A free stream velocity of 58 m/s, a wall surface roughness of 0 micrometer and a turbulence intensity of 0. 5%

were chosen for the settings following the CosmosFloWorks wizard [5].

Lastly, two global goals and 1 surface goal need to be specified. X-component of Force is defined as aerodynamic drag force meanwhile the Y-component of the force represents the lift force. The surface goal used as criterion for stopping the flow analysis process by selecting the lower surface of airfoil and parameter is average total pressure.

Results & Discussions

The results of the computer simulations were only consider for free air without ground effect and compiled and plotted graphically. The lift coefficient and drag coefficient is plotted against the angles of attack. In the same manner, the lift-to-drag ratio was plotted against the angles of attack. These result maybe will revised later for improving the accuracy of the result.

Simulation 1 – Formula Mazda Race Car

Table 4. 1a- Simulation result for front wing

Angle Of Attack

(°)

Lift Force

(N)

Drag Force

(N)

CL

CD

L/D Ratio

0

807. 422

101. 695

0. 678

0. 085

7. 940

4

1108. 052

147. 735

0. 931

0. 124

7. 500

5

1268. 124

174. 324

1. 065

0. 146

7. 275

8

1405. 842

226. 975

1. 181

0. 191

6. 194

10

1627. 157

279. 311

1. 367

0. 235

5. 826

12

1709. 297

326. 045

1. 436

0. 274

5. 243

15

1806. 083

396. 969

1. 517

0. 333

4. 550

16

1942. 339

429. 391

1. 632

0. 361

4. 523

20

1719. 125

509. 954

1. 444

0. 428

3. 371

Table 4. 1b- Simulation result for rear wing

Angle Of Attack (°)	Lift Force (N)	Drag Force (N)	CL	CD	L/D Ratio
0	441. 399	69. 959	0. 408	0. 065	6. 309
4	685. 813	101. 324	0. 633		

0. 094

6. 769

5

760. 236

106. 275

0. 702

0. 098

7. 153

8

887. 205

151. 066

0. 819

0. 140

5. 873

10

1003. 711

183. 783

0. 927

0. 170

5. 461

12

1084. 839

218. 815

1. 002

0. 202

4. 958

15

1198. 604

270. 751

1. 107

0. 250

4. 427

16

1223. 307

278. 042

1. 130

0. 257

4. 400

20

1009. 002

375. 431

0. 932

0. 347

2. 688

Figure 4. 1a- Front wing variation of the CD and CL as a function of AOA.

Figure 4. 1b- Rear wing variation of the CD and CL as a function of AOA

From the Table 4. 1a and Table 4. 1b, the simulation result shows that the airfoil is beginning to approach a “ stall condition” at 16° angle of attack as the critical angle of attack was achieved [16]. At a certain angle of attack there is no longer a smooth flow of air over the lower surface of a wing. At this point the lift produced by the wing is no longer sufficient to support the weight of the race car and so the race car is said to be in a stall condition. This angle is called the critical angle of attack. As we go on increasing the angle of attack beyond this critical point there is a sudden drop in lift force (the wing is stalled)as shown in Figure 4. 1a and Figure 4. 1b. So we can say that for a given airfoil the maximum lift is produced at the critical angle of attack.

Simulation 2 – Formula One Race Car

Table 4. 2a- Simulation result for front wing

Angle Of Attack (°)	Lift Force (N)	Drag Force (N)	CL	CD	L/D Ratio
0	255. 179	48. 621	0. 236	0. 045	5. 248

4

447. 884

53. 484

0. 414

0. 049

8. 374

5

500. 979

61. 587

0. 463

0. 057

8. 135

8

669. 044

83. 715

0. 618

0. 077

7. 992

10

742. 107

108. 065

0. 685

0. 100

6. 867

12

755. 574

122. 088

0. 698

0. 113

6. 189

15

981. 181

174. 258

0. 906

0. 161

5. 631

16

1016. 044

191. 147

0. 938

0. 177

5. 316

20

1172. 827

251. 666

1. 083

0. 232

4. 660Table 4. 2b- Simulation result for rear wing

Angle Of Attack

(°)

Lift Force

(N)

Drag Force

(N)

CL

CD

L/D Ratio

0

147. 106

18. 849

0. 125

0. 016

7. 805

4

425. 351

31. 452

0. 361

0. 027

13. 524

5

494. 393

31. 396

0. 419

0. 027

15. 747

8

694. 763

65. 524

0. 589

0. 056

10. 603

10

824. 518

95. 021

0. 699

0. 081

8. 677

12

880. 392

132. 412

0. 747

0. 112

6. 649

15

992. 648

203. 268

0. 842

0. 172

4. 883

16

979. 813

212. 350

0. 831

0. 180

4. 614

20

1033. 540

333. 587

0. 877

0. 283

3. 098Figure 4. 2a- Front wing variation of the CD and CL as a function of AOA.

Figure 4. 2b- Rear wing variation of the CD and CL as a function of AOA.

From the Table 4. 2a and Figure 4. 2b, the lift force still increasing when the angle of attack increased. This phenomenon indicates that the critical attack of angle of both wings of formula one race car is more than 20° angle of attack. The critical angle is dependent upon the profile of the wing,

its planform, its aspect ratio, and other factors, but is typically in the range of 8 to 20 degrees relative to the incoming wind for most subsonic airfoils. The graph for lift coefficient vs. angle of attack follows the same general shape for all airfoils, but the particular numbers will vary. The rear wing of

Formula One race car with 5° angle of attack is achieve the highest lift-to-drag ratio among all the race cars. From the Figure 4. 2a and Figure 4. 2b show the airfoil is not yet begin to reach the “ stall” condition where the angle of attack increases beyond a certain point such that the lift begins to decrease.

Simulation 3 – Formula Three Race Car

Table 4. 3a- Simulation result for front wing

Angle Of Attack

(°)

Lift Force

(N)

Drag Force

(N)

CL

CD

L/D Ratio

0

377. 748

43. 199

0. 351

0. 040

8. 744

4

548. 895

78. 886

0. 509

0. 073

6. 958

5

596. 547

90. 630

0. 554

0. 084

6. 582

8

713. 457

128. 911

0. 662

0. 120

5. 534

10

793. 868

148. 813

0. 737

0. 138

5. 335

12

860. 532

183. 200

0. 799

0. 170

4. 697

15

972. 378

237. 509

0. 902

0. 220

4. 094

16

968. 535

259. 049

0. 900

0. 240

3. 739

20

686. 048

328. 960

0. 637

0. 305

2. 086 Table 4. 3b- Simulation result for rear wing

Angle Of Attack

(°)

Lift Force

(N)

Drag Force

(N)

CL

CD

L/D Ratio

0

164. 329

21. 574

0. 139

0. 018

7. 617

4

431. 943

39. 280

0. 366

0. 033

10. 996

5

506. 952

44. 851

0. 430

0. 038

11. 303

8

719. 325

76. 319

0. 610

0. 065

9. 425

10

864. 084

97. 833

0. 733

0. 083

8. 832

12

979. 200

135. 459

0. 831

0. 115

7. 229

15

1043. 234

186. 148

0. 885

0. 158

5. 604

16

1139. 602

215. 209

0. 967

0. 183

5. 295

20

872. 240

315. 443

0. 740

0. 268

2. 765

Figure 4. 3a- Front wing variation of the CD and CL as a function of AOA

Figure 4. 3b- Rear wing variation of the CD and CL as a function of AOA.

From the Table 4. 3a and Table 4. 3b, the simulation result shows that the airfoil is beginning to approach a “ stall condition” at 16° angle of attack as the critical angle of attack was achieved. The process of ¬, ow detaching from the surface often happens instantaneously when the angle of attack is increased, making the loss of lift rather sudden and dangerous-this is called stall [10]. The plot of lift coefficient vs. angle of attack is significant to us because it gives the critical angle of attack (the angle of attack at which lift coefficient is maximum) for the particular airfoil as shown in Figure 4. 3a and Figure 4. 3b. For each aerofoil, the highly cambered side which features accelerated flow (and associated suction force) is called the ‘ suction side’ of the aerofoil. This corresponds to the bottom side of the inverted aerofoil. The other, less cambered side features slower flow and, usually, a positive pressure force. This side is called the ‘ pressure side’ and is the top side of the inverted aerofoil. the airfoil. This low velocity region extends downstream of the trailing edge into the wake of the airfoil. In addition, there is a marked decrease in CL by about 23%-32%, which may indicate that between 16° and 20° angle of attack there is a potential for a “ stall” condition with the airfoil.

Comparison of Simulation Result

Figure 4. 4a- Lift-to-Drag Ratio for all race cars (front wing)

Figure 4. 4b- Lift-to-Drag Ratio for all race cars (rear wing)

The Figure 4. 4a and Figure 4. 4b show the variation of the lift-to-drag ratio for various angles of attack of the wings. The highest lift-to-drag ratio for front wing occurs at 0â-¦ (Formula Three) meanwhile the highest lift-to-drag ratio for rear wing occurs at 5â-¦ (Formula One).

Conclusion & Recommendation

After simulation of all the three airfoils, we could conclude that the front wing of Formula Three race car and the rear wing of Formula One race car, which was giving a lift-to-drag ratio of 8. 744 and 15. 747 respectively, will be the better choice which could be used for the airfoil for the race car. For both airfoils, the hydrodynamic performance of the foils is signi¬ ficantly affected by the angle of attack. If the profiles tested are judged according to the performance, the wing profile of Formula One race car is found to be the optimum in term of lift-to-drag ratio.

Recommendation

The lift-to-drag ratio can be improved by utilizes the aspect ratio and the cross sectional area of wing. As we know, the wing span and the chord length will influence the aspect ratio of the wing. Future work is suggested to perform a new design improvement by changing the aspect ratio of the wing for the selected wings of race car. Thus, the lift-to-drag ratio of the new design of the race car wings should be higher than the current design.