KOKKUVÕTE

Lõputöö käigus valmis vormelautole FEST22 toimiv aerodünaamika pakett mis vastab Formula Student Germany 2022. aasta reeglistikule.

Terve projekteerimise protsess kestis kokku viis kuud. Kuna kogu projekteerimise protsess on ajamahukas, siis ei käsitleta antud töös tootmist ning valmis lahenduse testimist. Projekteerimine algas võistlussarjas kehtivate reeglite uurimisega, peale seda analüüsiti eelneva aasta lahendust läbi ringrajal teostatavate testide. Testimise käigus leiti põhilised probleemkohad, millest kujunes kontseptsioon ehk suuremad eesmärgid järgnevaks hooajaks. Peale seda alustati projekteerimise ajamahukaima osa ehk voolavusanalüüside teostamisega, mille käigus lahendatakse püstitatud eesmärgid sammhaaval.

Lõputöö esimestes osades käsitleti nii võistlussarjas aerodünaamilistele elementidele kehtivaid reegleid, kui ka võistlusautode aerodünaamika teooriat. Leiti et auto põhjaalune aerodünaamika peab moodustama suure osa terve auto survejõust. Teooria osas pöörati olulist tähelepanu ka aerodünaamilisele balansile, saadi teada et seda kontrollitakse just esitiiva kui ka tagatiiva survejõu suurendamise/ kahandamisega.

Järgnevalt käsitleti voolavusanalüüsides kasutatud CAD mudeli ülesehitust, analüüsi piirtingimusi, füüsikalisi mudeleid ning elementideks jaotamist.

Lõputöö põhiosas uuriti eelneva aasta vormelauto FEST21 lahendust. Hooaja alguses leiti et voolavusanalüüsides varasemalt kasutatav balansiarvutus on olnud vigane ning auto tegelik aerodünaamiline balanss on 12,5% võrra liiga palju ees olnud. Veel teostati rajatestid, kus pandi auto aerodünaamilistele elementidele õhuvoolu eraldumise kontrollimiseks lõngajupid. Testide käigus leiti, et kurviolukorras tekkis difuusori lõpus õhuvoolu eraldumine. Seda ei saanud voolavusanalüüsiga kinnitada, kuna kurvisimulatsiooni ei oldud eelnevale lahendusel teostatud. Lisaks andsid sõitjad tagasisidet, et auto on kurvi tipus (ing. k. *apex*) ülejuhitav, ning auto pole stabiilne ehk balanss liigub liiga palju. Eelnevalt nimetatud probleemidest kujunes välja kolm põhilist eesmärki järgnevaks hooajaks: kurvianalüüsi teostamine, aerodünaamilise balansi kontrollimine ning difuusori survejõu osakaalu suurendamine. Lisaks lepiti meeskonnakaaslastega kokku et auto aerodünaamiline balanss ei tohiks kurvi ja sirge vahel liikuda rohkem kui 2% ning auto projekteeritakse 50/50 jaotuse peale kurviolukorras.

Eelneva lahenduse kurvianalüüs teostati meeskonnakaaslastelt saadud sisend-andmetele tuginedes ning leiti et difuusoril tekkinud eraldumise põhjuseks oli hoopis esitiivalt auto põhja alla liikuv ning esirehvi juures eraldumist põhjustav õhuvool. Lisaks oli balansi muutus võrreldes sirgeanalüüsiga 3,7%, mis oli 1,7% eesmärgist üle.

Otsustati et aerodünaamilise balansi liigatamiseks tahapoole muudetakse just esitiiva disaini, kuna kahe tiiva disainimine oli liiga ajamahukas töö ning tagatiiva puhul ei esinenud testimise käigus probleeme. Seega tähendas balansi liigutamine tahapoole seda, et esitiiva survejõud pidi vähenema. Kuna puudus teadmine kui palju peab esitiiva survejõudu vähendama, tehti selle jaoks vastavad arvutused. Leiti et tiiva survejõud võib väheneda 80 N võrra, mida pidi kompenseerima difuusori survejõu kasv, kuna taheti säilitada vähemalt samasugune auto survejõud mis oli eelmisel aastal. Esitiiva suurimad muudatused toimusid tiiva kolmanda profiili ning otsaplaadi juures. Tehtud muudatuste jaoks tehti ka kurvianalüüs, kus leiti et esirehvi juures tekkinud eraldumine oli märgatavalt paranenud ning ei põhjustanud enam difuusori eraldumist. Esitiiva survejõud vähenes kokku 65,8 N võrra, mis tuli kompenseerida difuusori survejõu suurendamisega.

Kuna eelneva difuusori lahenduse survejõu osakaal moodustas 24,5% terve auto omast ning auto survejõud pidi jääma vähemalt samaks eelmise aastaga, siis olid ka difuusoril tehtud muudatused põhjalikud. Kõigepealt leiti et survejõu suurendamiseks peab difuusoril suurendama paisumissuhet ehk difuusori väljalaske ning väikseima ristlõikepindala jagatist. FEST21 puhul on vastav näitaja 3,67. Paisumissuhte suurendamise jaoks otsustati suurendada difuusori välimiste kanalite tõusunurka 6,6° võrra ning tuua külgmised kanalid samale tasapinnale auto kerega. Lisaks muudeti difuusori peal olevate külgmiste tiibade ning otsaplaatide disaini ja asetust, et liigutada rohkem puhast õhku difuusori lõpu ning tagumise rehvi vahele. Muudatuste tulemusena kasvas difuusori survejõud 59,4% ning moodustab terve auto omast 36,9%.

Kokkuvõttes suures auto survejõud 6,1%, takistusjõud vähenes 3,9% ning aerodünaamiline efektiivsus ehk surve- ja takistusjõu jagatis suurenes 9,6%. Aerodünaamilise balansi liikumine sirge- ja kurvianalüüside vahel on 0,7%. Aerodünaamiline balanss kurvi tipus on 49,8%. Seega suudeti kõik lõputöö alguses püstitatud eesmärgid täita ning autor on saavutatud tulemustega rahul.

Lõpetuseks soovitab autor jätkata tööd järgnevate vormelautode põhjaaluse aerodünaamika arendamist, kuna võistlussarja piirangud selle disaini väga ei mõjuta, ning lõputöö käigus saadud tulemuste põhjal on difuusor auto aerodünaamiliselt efektiivseim element. Lisaks on autori arvates mõistlik tagatiiba edasi arendada, kuna esitiiva survejõudu pidi balansi korrigeerimise jaoks vähendada.

SUMMARY

During the thesis, an aerodynamics package for the FEST22 racecar was completed, which compiles with the Formula Student Germany 2022 regulations.

The whole design process took a total of five months. As the whole design process is time consuming, this work does not cover production and testing of the finished solution. The design started with an examination of the rules in the competition series, after which the solution of the previous year was analyzed through tests performed on the circuit and flow sumulation. During the testing, the main problem areas were found, which became the concept or the main goals for the next season. After that, the most time-consuming part of the design, that is flow analysis, was started, during which the set goals are solved step by step.

The first parts of the thesis dealt with the rules applicable to aerodynamic elements in the competition series, as well as the theory of aerodynamics of competition cars. It was found that the underbody aerodynamics of a car must make up a large part of the downforce of a racing car. Regarding the theory, significant attention was also paid to the aerodynamic balance, it was found that it is controlled by increasing / decreasing the downforce of the front wing as well as the rear wing.

The structure of the CAD model used in the flow analyzes, the boundary conditions of the analysis, the physical models and the division into elements were discussed.

In the main part of the thesis, the solution of the previous year's formula car FEST21 was studied. At the beginning of the season, it was found that the balance calculation previously used in the flow analyzes has been flawed and the actual aerodynamic balance of the car has been too far ahead by 12.5%. Track tests were also carried out, in which wool tufts were placed on the car's aerodynamic elements to check the separation of the air flow. During the tests, it was found that in the corner situation, airflow was separating at the end of the diffuser. This could not be confirmed by flow analysis, as the corner simulation was not performed with the previous solution. In addition, the drivers gave feedback that the car is oversteering at the apex of the corner, and the car is not stable, that means the balance is moving too much. From the above-mentioned problems, three main goals emerged for the next season: performing a corner analysis, controlling the aerodynamic balance, and increasing the proportion of diffuser downforce. In addition, it was agreed with the teammates that the car's aerodynamic balance should not move more than 2% between corner and straight, and the car will be designed for a 50/50 balance condition.

The corner analysis of the previous solution was performed based on the input data obtained from the teammates, and it was found that the cause of the diffuser flow separation was the air flow moving downwards to the bottom of front wing and causing flow separation at the front tire. In addition, the change in the balance compared to the straight-line analysis was 3.7%, which was 1.7% above the target.

It was decided that the design of the front wing would be changed to shift the aerodynamic balance to the rear, as the design of the two wings was too time consuming and there were no problems with the rear wing during testing. Thus, moving the balance backwards meant that the downforce of the front wing had to decrease. As the lack of knowledge how much should the downforce needed to be reduced for the front wing, calculations were made accordingly. It was found that the downforce of the wing could be reduced by 80 N, which had to be compensated by the increase in the downforce of the diffuser, as it was desired to maintain at least the same downforce of the car as last year. The biggest changes in the front wing took place at the third profile of the wing and at the end plate. A corner analysis was also performed for the changes made, where it was found that the airflow separation at the front tire had significantly improved and no longer caused the separation in the diffuser. The downforce of the front wing decreased by a total of 65.8 N, which had to be compensated by increasing the downforce of the diffuser.

As the downforce of the previous diffuser solution was 24.5% of that of the whole car, the downforce of the whole car had to remain at least the same as last year, the changes made to the diffuser were also thorough. First, it was found that to increase the downforce, the expansion ratio of the diffuser must be increased, that means the outlet area of the diffuser divided by the smallest cross-sectional (choke point) area. For FEST21, the corresponding figure is 3.67. To increase the expansion ratio, it was decided to increase the rake angle of the outer channels of the diffuser by 6.6° and to bring the side channels flush with the car body. In addition, the design and placement of the side profiles and end plates on the top of the diffuser were changed to move more clean air between the end of the diffuser and the rear tire. As a result of the changes, the downforce of the diffuser increased by 59.4% and makes up 36.9% of that of the whole car.

In total, the downforce increased by 6.1%, the drag force decreased by 3.9% and the aerodynamic efficiency, that means the quotient of the downforce and drag force, increased by 9.6%. The movement of the aerodynamic balance between straight and corner analyzes is 0.7%. The aerodynamic balance at the corner apex is 49.8%. Thus, all the goals set at the beginning of the thesis were achieved and the author is satisfied with the achieved results.

Finally, the author recommends continuing the development of the underbody aerodynamics of the following formula cars, as the rules of the competition series does not significantly affect the design, and based on the results of the thesis, the diffuser is the most aerodynamically efficient element. In addition, the author believes that it is reasonable to further develop the rear wing, as the downforce of the front wing had to be reduced to adjust the aerodynamic balance.