Upgrade on CAERI Automotive Full-Scale Aero-acoustic Wind Tunnel Intoduction

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Abstract: Automotive full-scale aero-acoustic wind tunnel is a crucial piece of equipment for the vehicle aerodynamics development. In this paper, CAERI wind tunnel upgrades, such as database and intelligent prediction, digital wind tunnel (DWT) and life time smart health management platform, are introduced. 1. Based on extensive data and industry expert experience, the CAERI wind tunnel platform has been developed, which is the leading one in China, with the largest amount of wind tunnel tests. It provides data viewing, comparison, and analysis. Neural network and artificial intelligence are used to deeply analyze the massive data, and the intelligent prediction model of the aerodynamic drag coefficient of a vehicle model is achieved with high accuracy and correlation. 2. Based on the geometric characteristics and flow parameters, the DWT highly reproduces the test environment of CAERI Aero-Acoustic Wind Tunnel, by which the accuracy of CFD simulation is significantly improved and contributes to the shorteness of the development phase durance for a vehicel model. 3. Based on the Internet of Things (IOT) technology, the smart wind tunnel system of the CAERI wind tunnel has been built with six management systems, which can effectively improve operating efficiency and reduce equipment maintenance duration and cost, enables CAERI wind tunnel to achieve operation management refinement, equipment information digitization, and health monitoring intellectualization.

Key words: aerodynamics； automotive wind tunnel; database; drag coefficient prediction; digital wind tunnel; internet of things; health management

1 Introduction

The Chinese government officially set strategic goals in 2020, aiming to achieve "carbon peak" by 2030 and "carbon neutrality" by 2060. These objectives are intended to enhance the global competitiveness of industries and the economy while continuously promoting adjustments in industrial and energy structures. Among these goals, energy efficiency and emission reduction in the automotive sector are crucial components of China's "dual carbon" strategy and vital measures for advancing national economic development and rejuvenation.

Aerodynamics play a significant role in achieving energy efficiency and emission reduction in automobiles, and the pursuit of low aerodynamic drag designs has become an industry trend. In the 20th CPC national congress report released in 2022, China introduced the strategic goal of "Digital China," elevating digital transformation to a national strategy from an economic perspective. Currently, most automotive performance development relies on physical equipment for testing and validation. Therefore, promoting the digital transformation of automotive development is a critical step in reducing development costs and improving development efficiency.

The development of digital economy has been defined as a crucial thematic during the 14th Five-Year Plan Period of China, and the car R&D and manufacture industry has been applying digital tools to increase the efficiency, especially for the new-energy car manufacturers. As a result of the fierce competition of the new-energy car industry, the development period of new model has been compressed to 2 years, and will still be compressing in the future, so the digital tools who can help to increase the quality and efficiency of the R&D phase of a vehicle model are favoured by the OEMs.

The CAERI Wind Tunnel Center has been in commercial operation for over 3 years since 2019. Based on the experience accumulated during the operational process and in response to the national "Dual Carbon" and the "Digital China" strategy, aimed to better support the high-quality development of the new energy vehicle industry, the CAERI Wind Tunnel Center has leveraged its proprietary wind tunnel hardware resources and accumulated experience in vehicle development to create a series of digital products. Chapter 2 introduces the wind tunnel database and the rapid prediction tool of the aerodynamic drag, the digital wind tunnel is introduced in chapter3, and chapter 4 introduces the smart wind tunnel system.

2 Database and Intelligent prediction model of the aerodynamic drag

To guide OEMs in formulating more reasonable and efficient vehicle aerodynamic and wind noise development targets and plans, leveraging the extensive full-scale wind tunnel test data from CAERI Wind Tunnel Center, we have established a wind tunnel database system. The main components of this system are as follows:

1. Summarizing wind tunnel test big data along dimensions such as vehicle classification, powertrain type, market launch date, price range, test status, and key macro-level design parameters of the vehicles.
2. Building a comprehensive wind tunnel database system based on the data compiled in step 1, which encompasses multiple dimensions for classification, reference, comparison, and evaluation.
3. Developing sound security strategies and measures to ensure data security during the construction, transmission, and utilization phases. Incorporating a real-time update mechanism into the database to maintain its timeliness.

2.1 Database

The database is divided into 3 components: the Intelligent Query of which can search and autosuggest target vehicle model and exam its aerodynamic and aero-acoustic performance parameters, the Pressure Measurement results of which can study the pressure distribution around the target vehicle model, and the Wind Noise Test results of which can compare and study the wind noise performance for different target vehicle models in aspect of SPL, AI, Loudness and Sharpness. The interface of the functions above is shown in figure 1.

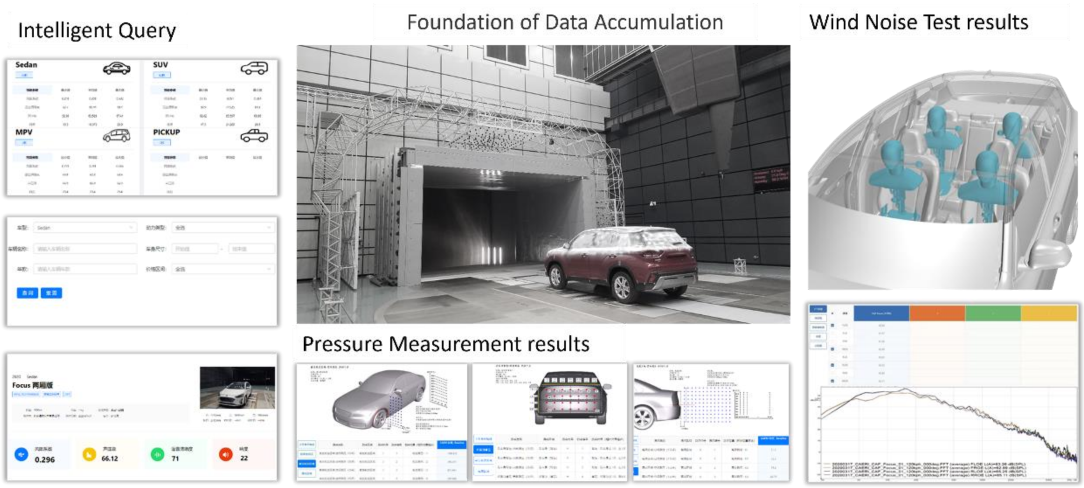


Figure 1: The interface of the database

2.2 Intelligent prediction model of the aerodynamic drag

By integrating aerodynamic performance test data and long-term accumulation of aerodynamic performance optimization design experience, we establish an intelligent predictive model for aerodynamic drag coefficients. This model enables us to set development goals at the project conceptual design stage, propose reasonable requirements for macro design, and provide quantitative support for rapidly assessing the impact of design changes on aerodynamic drag performance.

The ensemble machine learning algorithm Random Forest is used to train the intelligent predictive model, based on 24 macro design inputs and related wind tunnel test results for more than 80 production cars, the model can predict the aerodynamic drag coefficient for a certain vehicle model with prediction error less than 6%, compared to CAERI Wind Tunnel Center test results. The logic of the intelligent predictive model is shown in figure 2.

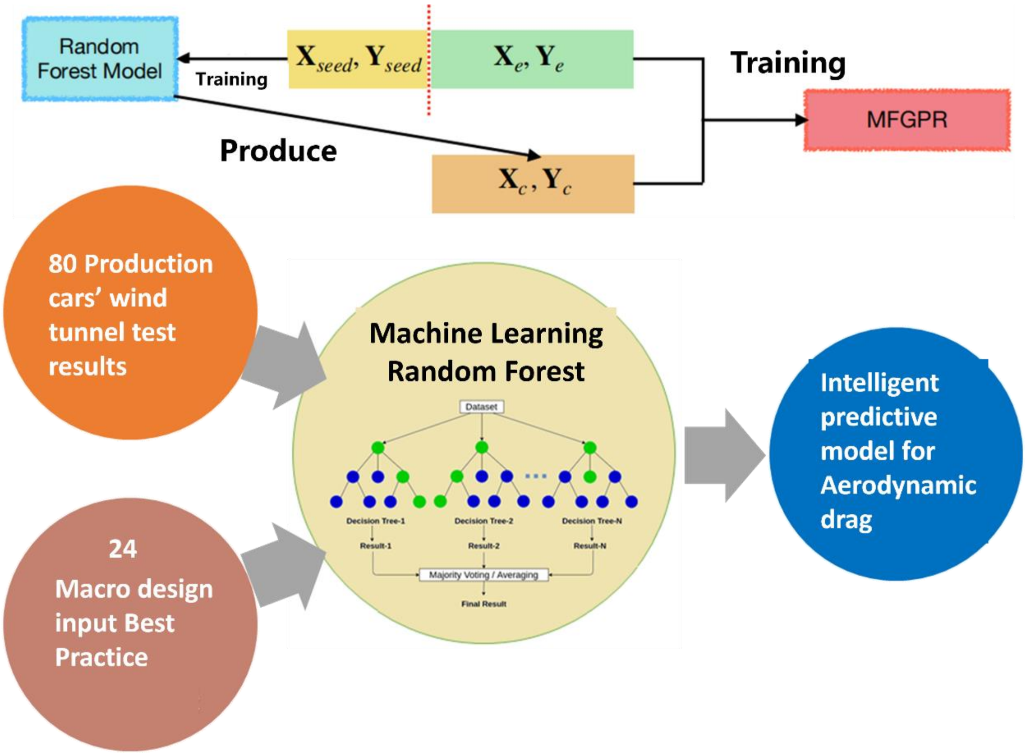


Figure 2: The logic of the Intelligent prediction model

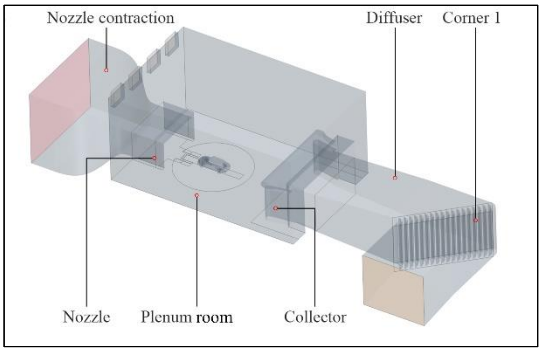
3 Digital wind tunnel

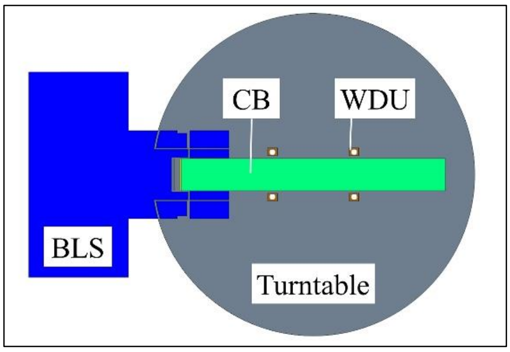
Based on the geometric dimensions and physical conditions of the physical wind tunnel, with the flow field calibration in the empty wind tunnel as the basis and the flow field calibration around the vehicle as the core, the aerodynamic and flow field coupling calibration of the standard vehicle model was carried out, taking into account the influence of the moving belt of the physical wind tunnel balance, and combined with the wheel aerodynamic optimization plan, a set of automotive aerodynamics simulation calibration and correction method was proposed, and a digital wind tunnel software tool was finally developed.

3.1 Boundaries of computational domain

A calculation domain with the same size as the CAERI full-scale wind tunnel was established and used for digital wind tunnel simulation. The DWT geometry includes nozzle contraction, nozzle, plenum room, collector, diffuser and the first corner behind the collector (see Figure 3a).

Moreover, in order to be consistent with the test scenario, pivotal boundary layer suction system and balance five-belt system with the same positions and operating parameters as the wind tunnel are considered (Figure 3b).





a b

Figure 3: The geometry of the digital wind tunnel (a); Boundary layer suction system and balance five-belt system of the digital wind tunnel (b)

3.2 Calibration results

Boundary layer thickness and longitudinal static pressure gradient are selected as the key indexes for empty wind tunnel flow field calibration. After fully considering the simulation of key wind tunnel wall systems and their operation parameters, such as the suction system, driving belt system and pressure balance system, the error of the boundary layer thickness between digital wind tunnel simulation results and the wind tunnel test results is less than 3%. For the longitudinal static pressure gradient, the maximum local error between the simulation results and the test results is less than 0.001dcp/dx. As shown in Figure 4a and Figure 4b.

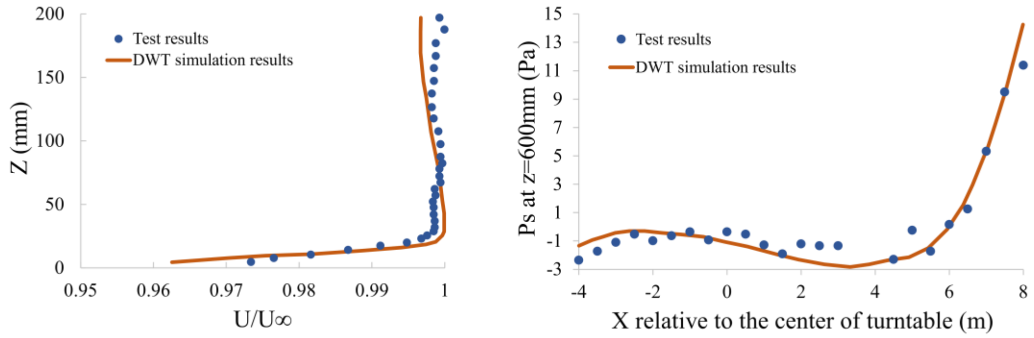


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Figure 4: Comparison of digital wind tunnel simulation results and test results: boundary layer thickness (a), longitudinal static pressure gradient (b)

Commissioning work with vehicle is carried out after the calculated metrics for the empty wind tunnel have been met. The vehicle used for the calculations is an expanded model of the DrivAer Model, as it possesses the ability to easily change rear back styling as well as multiple configuration states.

The benchmarking calculation vehicle model contains four kinds of back shapes and five kinds of key component states, and the flow field measurement results (surface and space pressure/velocity distributions) and force measurement results (aerodynamic drag, aerodynamic lift, etc.) are the key basis for evaluating the accuracy of numerical wind tunnel calculations.

The development studies of mesh delineation methods and dimensions, turbulence models and their parameter settings, and wheel rotation simulation methods were completed. The CFD simulation results obtained were in high agreement with the test results, both in terms of flow field measurements and force measurements. In particular, the average error for aerodynamic drag value, which is of highest concern in vehicle aerodynamic develop, is less than 1.5%. Some of the comparison results are showed in Figures 5 and 6.

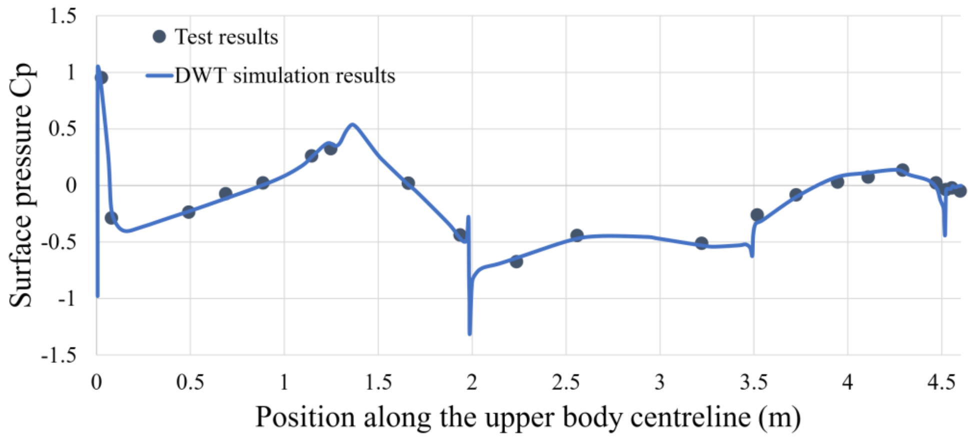

Figure 5: Comparison of surface pressure coefficients

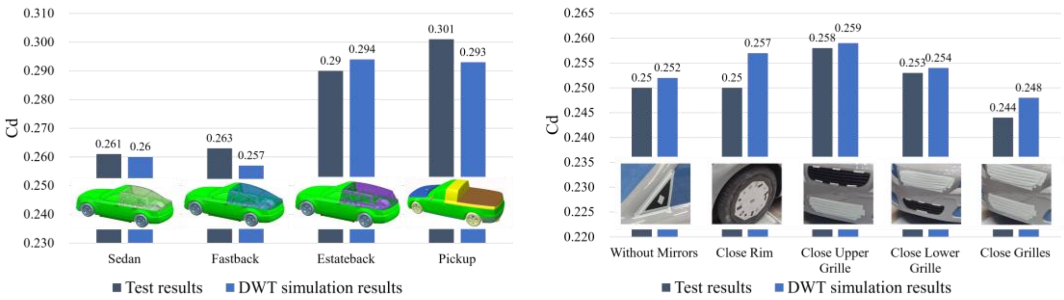

Figure 6: Comparison of aerodynamic drag coefficients for various working conditions

3.3 Digital platform deployment

The digital wind tunnel software is deployed on the digital platform of the Wind Tunnel Centre in CAERI, which has a high-speed data transfer rate and a huge amount of supercomputer resources. The digital wind tunnel software deployed based on the cloud platform is able to automate the execution of operations such as mesh generation, calculation parameter setting, simulating on cloud-high-performance-solver, post-processing, and analysis report compilation. The CFD simulation process has been standardised, which improves the accuracy of the simulation calculation and at the same time brings great convenience to the development of the aerodynamic performance of vehicles.

4 Smart wind tunnel system

It is an intelligent system based on the Internet of Things (IoT) that enables transparency of wind tunnel test process data, streamlines management, and brings intelligence to conduction of experiments.

4.1 Framework

Smart wind tunnel system is built using a microservice framework, which focuses on fully decoupling the business system, based on the independence of business functions. The original single business system is split into multiple small applications that can be independently developed, designed, operated, and maintained, and ultimately provide services to users. The specific technical architecture is shown in the figure below:

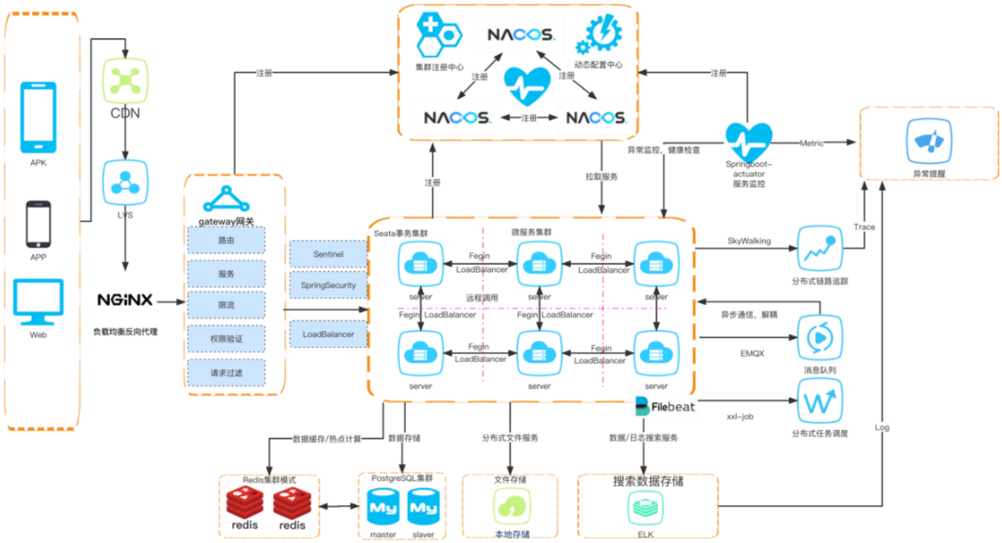

Figure 5: Technical Framework of Smart Wind Tunnel System

4.2 Components

The smart wind tunnel system consists of a management platform and six sub-applications and can be linked to the outside world through three interactive processes, while ensuring the security of the system.

Management platform is the central brain of the system and can receive and store equipment monitoring data and user test information. Using artificial intelligence to assist management, these data and information will be standardized and can be viewed and managed efficiently.

The application level including equipment health management, safety management, artificial intelligence assistance, test data analysis, customer experience management and energy management is the classification and value-added utilization of the data stored on the platform.

The smart wind tunnel system allows users to operate and interact through mobile terminals, web pages, and large-screen terminals to achieve full-time, anywhere monitoring and management of wind tunnel equipment and experiments.

4.3 Objectives

The smart wind tunnel system will be constructed and completed with the following objectives:

1. Based on the equipment internet, establish a set of intelligent wind tunnel system to achieve digital and intelligent test and lean management

2. Build a new system of safe, intelligent, and efficient digital management of wind tunnel test, using big data and artificial intelligence technology.

3. The real-time online monitoring rate of equipment working conditions reaches 80%, the real-time automatic warning rate of safety events reaches 85%, and the health prediction and maintenance rate of key components of core equipment reaches 50%.

4. For one year, reduce equipment downtime due to maintenance by about 100 hours, reduce equipment ineffective operation time due to ineffective testing by about 150 hours, and reduce test cancellation time due to unplanned downtime by 200 hours.

5 Conclusion

Wind tunnel database and intelligent prediction model, digital wind tunnel, smart wind tunnel system are products of the digital work of CAERI Wind Tunnel Center. These digital products greatly enhance the value of physical equipment and test data and are an important step towards intelligent operation of the CAERI Wind Tunnel Center.

Through the wind tunnel database and intelligent prediction models, it is possible to digitize experiments, label data, and realize intelligent aerodynamic drag prediction, achieving reasonable, accurate and efficient formulation of development goals in the concept development stage.

Committed to improving the correlation between CFD simulation results and wind tunnel test results, the digital wind tunnel was developed as a "virtual test" product for accurately representing test scenarios. The application of CAERI Digital wind tunnel can significantly improve the correlation between CFD simulation and CAERI wind tunnel test, compared with the traditional simulation using open rectangular solution domain.

The operation and maintenance of wind tunnel equipment currently seems to be a major and cumbersome task. Smart wind tunnel system can realize digital equipment operation, intelligent test management, and lean operation and maintenance, which can greatly improve the efficiency and economy of wind tunnel management.

6 Reference list

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