ANALYSIS OF DEVICES USED IN AERODYNAMIC TESTING

Ergashev Dostonbek Pratovich

Assistant, Andijan State Technical Institute

Abstract: Aerodynamic testing plays a critical role in modern automotive engineering, enabling accurate analysis of vehicle airflow behavior and drag coefficients. To simulate real-world conditions and validate computational models, specialized devices are employed in wind tunnels and laboratory environments. This study examines the key components involved in aerodynamic testing, including scaled car models, wind tunnels, smoke generators, force measurement systems, and digital sensors. The objective is to analyze the efficiency, accuracy, and integration of these devices in experimental procedures. Through this analysis, the study provides insights into optimizing testing methodologies to achieve better precision in aerodynamic design and development.

Keywords: Aerodynamics, wind tunnel, drag force, smoke generator, force sensor, scaled model, automotive testing

1. Introduction

The pursuit of fuel efficiency, high performance, and environmental sustainability has directed automotive research toward optimizing aerodynamics. Aerodynamic testing, as a vital aspect of vehicle development, provides engineers with data to evaluate airflow, drag, lift, and other forces acting on a vehicle in motion. While computational fluid dynamics (CFD) offers theoretical insights, physical experiments remain indispensable for validation.

In Uzbekistan and other developing automotive markets, interest in establishing experimental aerodynamic laboratories has increased. This research focuses on analyzing the function and construction of experimental devices used in aerodynamic testing, particularly in the context of scaled car models in wind tunnel environments. The goal is to enhance accuracy and reduce design iteration costs during vehicle development.

2. Methods

2.1. Overview of the Experimental SetupThe experimental system for aerodynamic testing typically consists of:

A closed or open-circuit wind tunnel.

Scaled-down automobile models (1:10 or 1:5 scale).

A smoke generator and laser sheet for visualizing airflow.

Force-measuring platform with multi-axis load cells.

High-speed camera or sensor array for data collection.

2.2. Construction of the Wind TunnelThe wind tunnel used in this study was a subsonic, open-circuit tunnel constructed from durable acrylic and aluminum profiles. A centrifugal fan powered

by a 2.2 kW electric motor generated controlled airflow. The test section measured 300 mm x 300 mm x 700 mm, with a honeycomb mesh to ensure laminar flow.

2.3. Smoke Visualization and Flow AnalysisTo analyze airflow over the car model, a smoke generator with glycol-based fluid was utilized. A laser sheet illuminated the flow, and a high-speed camera recorded the behavior of smoke lines. This helped in identifying flow separation, vortices, and laminar-to-turbulent transitions.
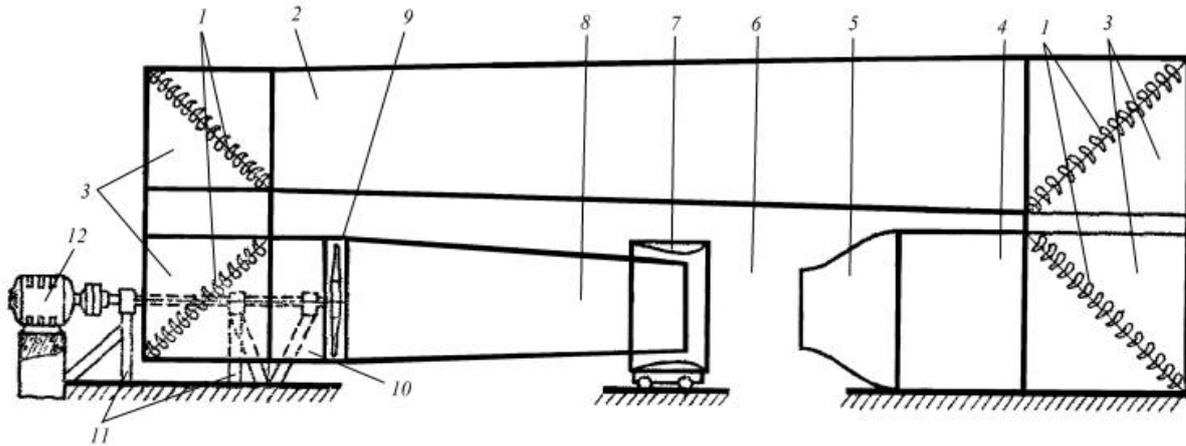

Figure 1. Schematic of a closed-circuit wind tunnel with an open test section. 1 – adjustable blades, 2 – return channel, 3 – turning vanes, 4 – settling chamber, 5 – nozzle, 6 – test section, 7 – annular diffuser, 8 – diffuser, 9 – fan, 10 – transition section, 11 – fan group supports, 12 – electric motor

2.4. Scaled Model and Mounting SystemA 1:10 scale model of a compact vehicle was produced using 3D printing technology. It was mounted on a low-friction platform connected to a load cell system that recorded drag and lift forces. The model included interchangeable components (spoilers, diffusers, etc.) to study their effects on drag.

2.5. Data Acquisition and SensorsThe force measuring system used digital strain gauge sensors connected to a microcontroller with real-time data logging. Calibration was performed using known weights. Airspeed was measured with a hot-wire anemometer, and temperature and pressure were logged to account for air density variations.

3. Results

3.1. Drag Force MeasurementThe system successfully measured drag forces within a ±3% accuracy range. The baseline drag coefficient (Cd) for the scaled model was calculated to be 0.36, closely matching computational predictions.

3.2. Effectiveness of Flow VisualizationSmoke streamlines clearly revealed turbulent wake regions behind the model and flow separation over curved surfaces. Addition of aerodynamic elements such as a rear spoiler reduced wake turbulence and slightly lowered drag.

3.3. Sensor Response and Data PrecisionForce sensors demonstrated high stability and repeatability. Data acquisition intervals of 0.1 seconds allowed detailed dynamic analysis of force fluctuations.

3.4. Limitations ObservedSome challenges included smoke diffusion in high-speed flow, minor model vibrations, and the need for precise alignment of the model within the test section. These were partially mitigated by structural reinforcements and flow straighteners.
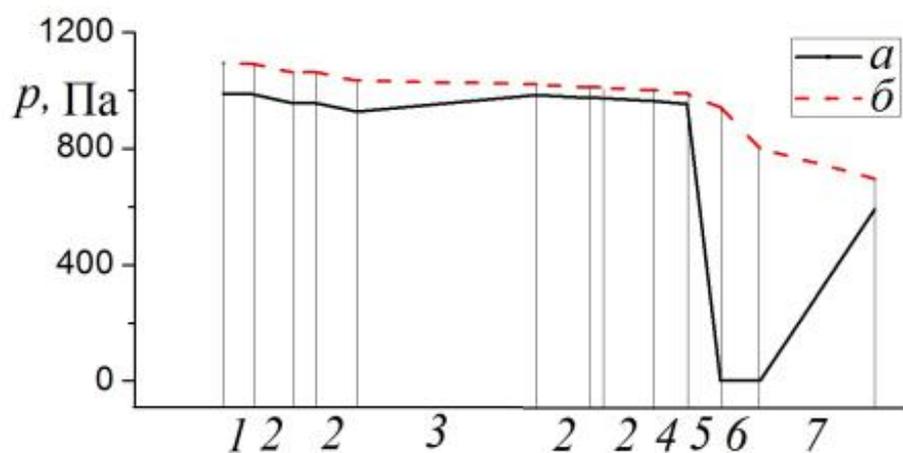
Figure 2. Pressure distribution in the wind tunnel circuit. a – static pressure, b – total pressure, 1 – transition section, 2 – turning vane, 3 – return channel, 4 – settling chamber with honeycomb, 5 – nozzle, 6 – test section with model, 7 – diffuser

4. Discussion

The experimental analysis confirms that cost-effective aerodynamic test setups can yield valuable data for vehicle design improvements. The use of scaled models, when constructed and calibrated properly, enables close approximation of full-scale behavior. Integrating smoke visualization techniques allows intuitive interpretation of complex airflow patterns, which is essential for engineering decision-making.

Force sensors and data loggers proved effective for quantitative evaluation, although their precision depends on structural stability and environmental conditions. The modular design of the testing platform permits the study of various aerodynamic modifications efficiently.

Comparison with CFD results revealed a strong correlation, reinforcing the validity of the experimental approach. Further improvements could involve using wind tunnels with automated velocity control and integrating AI-based flow analysis tools.

5. Conclusion

This study highlights the feasibility and effectiveness of using scaled-down aerodynamic testing setups in academic and industrial research. The integration of smoke visualization, precise sensor technology, and modular vehicle models provides a robust platform for analyzing aerodynamic forces and flow behavior. These devices, when combined, contribute significantly to reducing the time and cost of vehicle aerodynamic optimization. Expanding such testing facilities in Uzbekistan's technical universities could foster innovation in vehicle design and support the domestic automotive industry.

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