FINAL REPORT

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BETWEEN

BROOKHAVEN SCIENCE ASSOCIATES

AND

GENERAL MOTORS LLC

Project Entitled: Drag and Noise Reduction for Road Vehicles

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TITLE:
Drag and Noise reduction for Road Vehicles

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OBJECTIVE:
The purpose of this research project is to evaluate, assess, and design new and innovative drag reduction techniques (passive and active) by applying up-to-date aerodynamics and acoustics, which will reduce power consumption of automobiles and negative impact on the environment.

PROJECT DESCRIPTION:
-Background

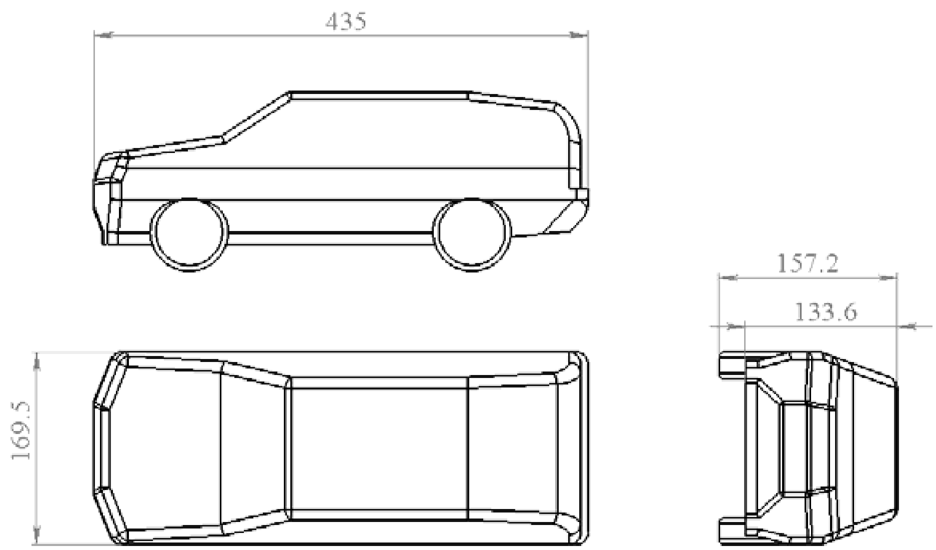
Many studies have been dedicated to reduce the aerodynamic drag on automobiles, which is a major factor in automobile power consumption. The principal attention has been paid to development of a well-streamlined design of the frontal section, and selection of a rear section to reduce separated air drag zones. However, the majority of research efforts were limited only to studies of aerodynamic drag with no account for singularities of the motion dynamics. Moreover, the automobile configuration was optimized only for a certain segment of velocities within the entire possible variable range.

The power consumption of the automobile, its motion stability and ecological safety are governed by a number of factors. Variation of airflow as functions of velocity, effect of side blow generated by the wind, and motion dynamics singularities governed by the automobile's dynamic scheme and status of the road surface are some of the important factors. All these factors affect the automobile power needs simultaneously, and in the aggregate determine its efficiency, ecological and dynamic characteristics.

This project will assess, develop and design the automobile configuration which will reduce the aerodynamic drag, and consequently reduce power consumption and negative effect on the environment, by simultaneously considering and analyzing singularities of the dynamic scheme for the entire possible range of vehicle velocity.

There are two distinct approaches; one is to streamline the body and another is to look for active and passive methods for decreasing drag on given body. The main emphasis in this project will be on the methods of decreasing drag and noise on a given body design. One approach is to study SUV Body as surrogate to automobile and perform analyses and tests on this body as the starting point. Figure 1 shows a model based on SUV Body. A literature search will be performed to find possible methods such as vortex generators at separation region, jets, suction, etc. to reduce flow separation, or to modify surface texture to achieve drag reduction. Similar approach will be taken for noise reduction, starting with SUV Body.

Figure 1. Example of SUV Body



As a research technique, the following systems on engineering analysis are selected: Ansys, Nastran, Flow Vision, in which methods of computational solution of differential equations in the domain of gas dynamics, acoustics and motion dynamics are formulated. The results and aerodynamic characteristics will be confirmed by tests in a wind tunnel.

The design studies will be performed by employees of Yuzhnoye SDO (State Enterprise "Yuzhnoye" Design Office, Dnepropetrovsk), an organization that has an extensive practical experience in optimization of aerodynamic and acoustic characteristics for various products which are subject to dynamic schematics in the aerospace sector. The approaches used for these objectives are consistent to those applied in the automobile industry. This project team includes a team of specialists who have a wide experience of the work in the Ansys, Nastran, Flow Vision software environments during solution of multiple tasks in the domain of aerodynamics, acoustics and dynamics. Yuzhnoye software and methodology will be used which were successfully utilized in previous work to systemize the big scope of experimental and design data.

- Technical Approach

As a research technique, the following systems are selected for engineering analysis: Ansys, Nastran, Flow Vision, in which methods of numerical solution of differential equations in the domain of gas dynamics, acoustics and motion dynamics are formulated.

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Complexity of construction and definition of characteristics of irregular-shape bodies is the main problem in application of these software products. For solution of differential equations in gas dynamics and acoustics, one applies either finite-element methods, or finite-difference methods. During the design and construction stages, it is necessary to separate the domains with varying degrees of gradients of characteristics. Since the accuracy of the methods of finite elements and methods of finite-differences is proportional to cell sizes of the design environment, zones with the bigger gradients call for introduction of a large number of design points. This is especially important during design of separated zones, which encompass flow in the automobile rear section that is the primary contributor to the aerodynamic drag. In this connection, the engineering analysis techniques provide the detailed structure of flow and load parameters acting on any element of an automobile.

Application of the aforementioned systems is complicated, and validity and authenticity of the results here are guaranteed only by qualification and experience of the specialists responsible for the analysis. Yuzhnoye SDO employs specialists who have a broad experience in application of these software products; however, it is common to conduct tests in wind tunnels for confirmation of the results obtained in the course of design efforts. To comply with the primary modeling criterion for an incompressible fluid (Reynolds number), one has to increase the flow velocity proportional to the model scale, and it calls for a wind tunnel with big dimensions of the working section, in which models fabricated in the scale of M~1:2 may be tested. Such a wind tunnel is available from the NAS, whose working section has the following dimensions: width – 4 meters, height – 2.5 meters, and length – 5.5 meters.

Tests will be performed in the wind tunnel to confirm the following characteristics and scopes;
• Definition of overall aerodynamic forces and moments acting on an automobile in the airflow during its motion.
• Studies of the flow structure around an automobile.
• Definition of forces and moments acting on the automobile surface elements, as well as affecting the installed superstructures.
• Investigation of new and innovative passive methods of drag and noise reduction
• Investigation of new and innovative active methods of noise and drag reduction

- Project Location and Facilities
The design studies will be performed by employees of Yuzhnoye SDO, an organization that has an extensive practical experience in optimization of aerodynamic and acoustic characteristics for various products which are subject to dynamic schematics in the aerospace sector. The approaches used for these objectives are consistent to those applied in the automobile industry. For solution of the assigned tasks, this project team includes a team of specialists who have a wide experience of the work in the Ansys, Nastran, Flow Vision software environments during solution of multiple tasks in the domain of aerodynamics, acoustics and dynamics. Yuzhnoye software and methodology will be used which were successfully utilized in previous work to systemize the big scope of experimental and design data. For the design and computational activities, Yuzhnoye SDO will utilize computing system of the calculation cluster Core2Quad class, as well as the aforementioned software.

Experimental test of the aerodynamic characteristics will be conducted in a big subsonic wind tunnel belonging to the NAS Laboratory of Experimental Aerodynamics. The dimensions of the wind tunnel's working section will allow testing of models with the dimensional array up to 2 meters. It assures modeling of automobiles with the scale M1:2. At these dimensions of the models, it can accommodate the entire range of possible motion velocities and Reynolds numbers based on the similarity criterion at subsonic speeds. Specialists of the NAS Laboratory of Experimental Aerodynamics have an extensive practical experience in performance of experimental studies at subsonic velocities in the interests of aviation industry.

- Milestones and Anticipated Results

The following tasks, milestones and results are planned,

• Optimize the automobile aerodynamic configuration using new and innovative methods based on SUV Body with the benchmark data.

• Install the automobile superstructures with variable geometry under the actual moving environment that will assure reduction of the aerodynamic drag for the entire range of vehicle speeds.

• Design prototype with reduced drag.

• Provide mathematical functions relating the automobile power consumption versus singularities of their dynamic configurations.

The results will take into consideration the real singularities of automobiles (their shape, dynamic scheme) on SUV Body. The proposals on optimization of the aerodynamic configuration will be discussed and agreed with GM to assure the feasibility of their implementation in production.

The main objective of the project is to derive a commercial benefit by reducing the automobile power consumption and improve their competitiveness.

Based on the results of the project, it is expected to obtain patents on optimized aerodynamic configurations, active and passive methods, and the automobile superstructures with variables subject to the motion speed geometry.

• Procedures for collaboration with other institutes

When the participating Russian institutes submit reports, GM and BNL PIs will review the reports and directs the project. GM and BNL PIs will have frequent e-mails and conference calls with Russian PIs and they will also visit the Russian institutes.

• Reports

The participating Russian institutes will provide a report for each task and a final report when the all tasks are completed. GM will review the reports and directs the project in conjunction with BNL.

ROLES AND RESPONSIBILITIES:

Most of the research and development will done by Ukrainian institute, Yuzhnoye SDO in collaboration with GM and BNL.

Work of the project is in four stages. In the first stage it is planned to carry out analytical and experimental research of SUV Body models for definition drag and noise source. In the second stage, it is planned to carry out analytical and experimental research for develop of SUV Body models with passive methods of drag and noise reduction. In the third stage it is planned to carry out analytical and experimental research of SUV Body models for development of active method of drag and noise reduction. Finally in the fourth stage it is carried out analytical and experimental research of SUV Body models with combine active and passive methods of drag and noise reduction.

Here is breakdown of tasks for four stages.

#	Tasks
1	The first stage - "Analytical and experimental research of SUV Body models for definition drag and noise source"
1.1	Literature search for methods (passive and active) for drag and noise reduction. Select three methods (two passive and one active) for drag and three methods for noise reduction. Also search of analytical methods of flow prediction, drag estimate and noise estimate.
1.2	Selection of calculation methods for estimate of drag and noise and development of calculation model for SUV Body.
1.3	Build test SUV Body model based on SUV Body and instrumentation for testing in wind tunnel
1.4	Test the SUV Body model in the wind tunnel and identify flow structure and sources and locations of drag generation
1.5	Perform CFD analyses of the calculation model drag and compare prediction with the test data and identify the sources of drag and their locations
1.6	Perform calculation analyses of the calculation noise SUV Body model and identify the sources of noise and their locations
2	The second stage - "Analytical and experimental research for develop of SUV Body models with passive methods of drag and noise reduction."
2.1	Prepare calculation SUV Body model with the first passive method for drag reduction and perform CFD analyses to predict effect of drag reduction
2.2	Prepare calculation SUV Body model with the first passive method for noise reduction and perform calculation analyses to predict effect of noise reduction
2.3	Prepare test SUV Body model for first passive drag method reduction and test in wind tunnel
2.4	Prepare calculation SUV Body model with the second passive method for drag reduction and perform CFD analyses to predict effect of drag reduction
2.5	Prepare calculation SUV Body model with the second passive method for noise reduction and perform calculation analyses to predict effect of noise reduction
2.6	Prepare test SUV Body model for second passive drag method reduction and test in wind tunnel
2.7	Develop calculation SUV Body model of combined first passive drag method reduction and first drag passive method noise reduction
2.8	Perform calculation study of drag and noise of combined first passive drag method reduction and first passive method noise reduction and generate recommendations
2.9	Modify test SUV Body model for first passive method drag reduction with including

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	first method passive noise reduction and test in wind tunnel
2.10	Develop calculation model of combined second passive drag method reduction and second drag passive method noise reduction
2.11	Perform calculation study of drag and noise of SUV Body model with combined second passive drag method reduction and second passive method noise reduction and generate recommendations
2.12	Modify test SUV Body model for second passive method drag reduction with including second method passive noise reduction and test in wind tunnel
3	The third stage - "Analytical and experimental research of SUV Body models for development of active method of drag and noise reduction"
3.1	Prepare calculation SUV Body model with the active method for drag reduction and perform CFD analyses to predict effect of drag reduction
3.2	Prepare calculation SUV Body model with the active method for noise reduction and perform calculation analyses to predict effect of noise reduction
3.3	Prepare test SUV Body model for active method drag reduction and test in wind tunnel
3.4	Develop CFD SUV Body model of combined active method drag reduction and passive method noise reduction
4	The fourth stage" Analytical and experimental research of SUV Body models with combine active and passive methods of drag and noise reduction"
4.1	Modify CFD SUV Body models with combined active and passive methods of drag and noise reduction.
4.2	Modify test SUV Body models with combined active and passive methods of drag and noise reduction.
4.3	Perform calculation study of drag and noise reduction of models with combined passive and active methods and generate recommendations
4.4	Perform test study of drag and noise reduction of models with combined passive and active methods and generate recommendations
4.5	Generate total recommendations about drag and noise reduction passive and active methods.
4.6	Prepare final report with literature search, model description, wind tunnel description, code description, test and analytical results and recommendation

ACCOMPLISHMENTS:

Drag reduction study on GM SUV car model was undertaken by analytical apparoach and wind tunnel testing. A half size model was tested for drag and various active and passive options for drag reductions. Here are important conclusions.

Based on the performed calculations and experiments, the following ways to reduce aerodynamic drag can be recommended

Passive ways:
– rear screen (drag reducing ~ 6.5%, fuel efficiency increase ~ 4.1%, insignificant noise increase);

– four-tier tail cap and its parts (drag reduction ~ 14.7%, fuel efficiency increase ~ 9.2%, noise reduction of up to 3.21 db).

Active ways:
– evenly distributed blowing from rear zone to rarefaction zone behind vehicle, combined with air bleed above windscreen of vehicle (drag reducing ~ 8%, fuel efficiency increase ~ 4.1%, insignificant noise increase)