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Contribution to the modelling of characteristics of similar valves and model evaluation

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The methods for valve characteristics modelling have been defined along with the evaluation of the obtained model's level of agreement with the experimental results. In the evaluation of model suitability, based on the Fisher's criterion when a model inadequacy probability happens to be 95[%] (or 99[%]), the classical method theory of mathematical statistics demands that such models be rejected. The question is: to reject a model or to define a method for qualitative evaluation of models. This paper has the objective to give the right answer to this dilemma. In cases where the methods or mathematical statistics do not give a complete answer concerning model evaluation, the idea proposed in this study is that it is necessary to define methods of the analytical-qualitative assessment of the obtained model's level of agreement with the test results. This study gives the answer to the given dilemma.

Key words: **ventilation, valve, antishock valve, aerodynamics, resistance coefficient, modelling method.**

Goals and structure of the research

THIS paper is an extension of the previous papers [1 to 10].

It deals with methods of modelling of the resistance coefficient ξ_i of similar valves, and resistance air flow by way of the similar anti-shock valves with fins for regulation of overpressure of the objects and regulation of the air flow from the object as functions of the diameter D and air flow through the valves Q). Evaluation of the $\xi_i = KD_1^a Q_2^b$ model's accordance with the data base of experimental results is also given.

The goal of the research is to define the methods for modelling of aerodynamic characteristic valves (resistance coefficient of similar valves, as functions of the geometry and working characteristics (Q, D) of the valves) as well as qualitative evaluation of the $\xi_i = KD_1^a Q_2^b$ model's accordance with the data base of experimental results.

In other words, the goals of the research are to define:

1. Method for modelling the resistance coefficient ξ_i of similar valves.
2. Method for model adequacy estimation.
3. Experimental results presentation plain and experiment description of the resistance coefficient of the similar valves.
4. Method of qualitative estimation of harmonization between the obtained model and experimental results.

Models of resistance to air flow through the similar valves depending on the diameter name D and air flow Q of the valves are defined.

Purpose and operation of the valve

Within the spectrum of the ventilation conditions it is always imperative to maintain some overpressure inside the building with respect to the surrounding atmosphere.

The overpressuring is necessary to prevent nuclear, chemical or biological contamination of the building inner space.

Furthermore, it is also necessary to maintain overpressure between the rooms inside the building.

The task of the valves is to control the mass of the used air to be exhausted, so as to control the level of overpressure in that way as well, because the air flow through the valves is conditioned by the overpressure itself. In order to keep that overpressure within some desirable limits, the overpressure control valves are fitted to the used air exhausts.

Conception and design of the valves have to ensure their resistance and operation under the circumstances of high impulsive loads, viz. they must shut down under the action of the air-blast wave and open up when the action is ended in order to enable the used air to be exhausted.

Fig.1 gives a schematic view of the valve.

When the air-blast wave approaches a shelter, the directed wave acts by its pressure on the surface of the vanes through the vane fitted anti-shock valve channel, and causes immediate closing of the exhausting passage.

During the closing process of the valve, a small amount of the air-blast pressure impulse will pass through the valve.

The valve is closed until the outer atmosphere is overpressurized.

When the effect of the air-blast wave recedes, the airflow in the valve generates the force which acts on the valve vanes so they return to the opened position.

For realization of the specified functions of the valves, a series of technical requirements must be met.

It is of utmost importance that the valve closing time under the effect of the blast waves be as short as possible, and that the resistance to the air flow through the valves in the conditions of ventilation of the building is brought to

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minimum.

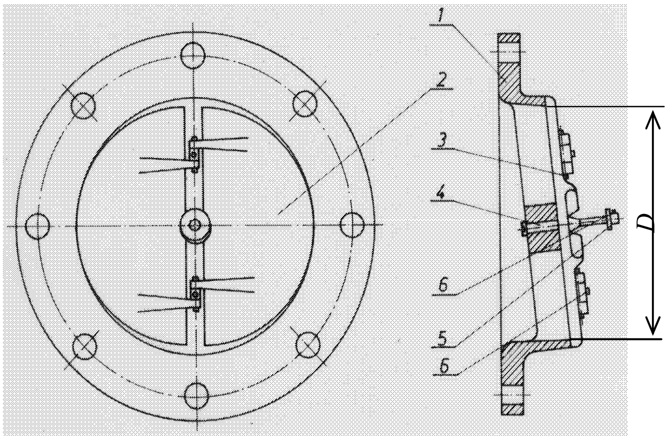

Figure 1. 1 - valve flesh, 2 - valve vanes, 3 - axle, 4 - central screw, 5 - delimiter, 6 -screw.

Resistance coefficient of the similar valves modelling method

In general, the resistance coefficient of similar valves ξ_i is in function of two parameters, which can be expressed in the following way [2, 4-18]:

$$\xi_i = KD^a Q^b \quad (1)$$

Models for the similar valves resistance coefficient depending on (D,Q) can be obtained by regression analysis, using the least square method as well as experimental data for T_{z_i}. Once the logarithms of the equations are found (1), substitutions introduced, the test error ε taken into account, the linear regression equations will be obtained:

$$Y_i = a_0 + a_1 X_1 + a_2 X_2 + \varepsilon \quad (2)$$

Constants (a_0, a_1, a_2) are determined by processing the experimental data, using the least square method [10-27]. The method comprises minimizing the test results dispersion from the regression polynomial:

$$\left|\varepsilon\left(Y_i - a_0 - a_1 X_{1i} - a_2 X_{2i}\right)\right|_{\min} = \left(\varepsilon^2\right)_{\min} \quad (3)$$

The minimal dispersions can be obtained by the polynomials (3) derivation with respect to the parameters needed and by equalizing derivatives to zero. As a result, the linear regression equations system will be represented in the matrix form:

$$\begin{bmatrix} N & \Sigma X_{1i} & \Sigma X_{2i} \\ \Sigma X_{1i} & \Sigma X_{1i}^2 & \Sigma X_{2i} X_{1i} \\ \Sigma X_{2i} & \Sigma X_{1i} X_{2i} & \Sigma X_{2i}^2 \end{bmatrix} \begin{bmatrix} a_0 \\ a_1 \\ a_2 \end{bmatrix} = \begin{bmatrix} B(0) \\ B(1) \\ B(2) \end{bmatrix} \equiv \begin{bmatrix} \Sigma Y_i \\ \Sigma X_{1i} Y_i \\ \Sigma X_{2i} Y_i \end{bmatrix} \quad (4)$$

After processing experimental data, according to Table 1 and obtaining the equation system solutions, analytical expression for the pneumatics valves shutting time will have the following form:

$$\xi_i = K_1 D_1^{e1} Q_2^{e2} \quad (5)$$

The adequacy check of the analytical expression for the similar pneumatics valves' resistance coefficient has to be done.

Method for checking the resistance coefficient valves model adequacy

The adequacy check of resistance coefficient of the similar valves model cold be done using the numerical values of the multiple correlation coefficients $R_{i\cdot 12}$, and partial correlation characteristics coefficient $r_{i1\cdot 2}$ and $r_{i2\cdot 1}$ functional relationship (5), which have to be analytically defined.

Therefore, the following subscripts were introduced into expressions (1): diameter D_m received subscript "1", and the air flow Q subscript "2":

$$\xi_i = KD_1^a Q_2^b \quad (6)$$

Multiple correlation coefficients $R_{i\cdot 12}$ for relation $\xi_i = KD_1^a Q_2^b$

Multiple correlation coefficient $R_{i\cdot 12}$ defines the level of agreement between the similar valves resistance coefficient between model (5) and experimental results.
Multiple correlation coefficient $R_{i\cdot 12}$ is defined by the following expression:

$$R_{i\cdot 12} = \sqrt{1 - \left[\left(1 - r_{i1}^2\right)\left(1 - r_{i2\cdot 1}^2\right)\right]} \quad (7)$$

The partial correlation coefficients from expression (7) have to be analytically defined.

Partial correlation coefficient $r_{i2\cdot 1}$

The partial correlation coefficient $r_{i2\cdot 1}$ of the functional relationships (1) and (6), defines the level of agreement between the dependent variable ξ_i and independent parameter Q when the other independent parameter D is constant. The partial correlation coefficient $r_{i2\cdot 1}$ of the functional relationship (6) defines the probability of transmitting-reduction of model (6) into plain $\xi_i Q$ models when the other independent parameter D is constant. The partial correlation coefficient $r_{i2\cdot 1}$ can be defined by the expression [18]:

$$r_{i2\cdot 1} = \frac{r_{i2} - r_{i1} \cdot r_{21}}{\sqrt{\left(1 - r_{i1}^2\right)\left(1 - r_{21}^2\right)}} \quad (8)$$

Partial correlation coefficients r_{i1}, r_{i2} and r_{12}

The partial correlation coefficients r_{i1} and r_{i2} define the correlation between the dependent variable ξ_i and independent parameter D and Q, respectively. The partial correlation coefficients r_{i1} and r_{i2} can be defined by expressions [18, 19]:

$$r_{i1} = \frac{\sum Y_i X_{1i}}{\sqrt{\left(\sum X_{1i}^2\right)\left(\sum Y_i^2\right)}} = \frac{B(1)}{\sqrt{X(1,1) C(0)}} \quad (9)$$

$$r_{i2} = \frac{\sum Y_i X_{2i}}{\sqrt{\left(\sum X_{2i}^2\right)\left(\sum Y_i^2\right)}} = \frac{B(2)}{\sqrt{X(2,2)C(0)}} \qquad (10)$$

The partial correlation coefficients r_{12} define the correlation between independent parameters D and Q and can be defined by the expression, [18, 19]:

$$r_{12} \equiv r_{21} = \frac{\sum X_{1i} X_{2i}}{\sqrt{\left(\sum X_{1i}^2\right)\left(\sum X_{2i}^2\right)}} = \frac{X(1,2)}{\sqrt{X(1,1)X(2,2)}} \qquad (11)$$

Partial correlation coefficient $r_{i1\cdot 2}$

The partial correlation coefficient $r_{i1\cdot 2}$ defines the level of agreement between the dependent variable ξ_i and independent parameter D when the other independent parameter Q is constant.

The partial correlation coefficient $r_{i1\cdot 2}$ of the functional relationship (6) defines the probability of transmitting-reduction of the model (6) into the plain $\xi_i D$, when the other independent parameter Q is constant. The partial correlation coefficient can be defined by the expression [18]:

$$r_{i1\cdot 2} = \frac{r_{i1} - r_{i2} r_{12}}{\sqrt{\left(1 - r_{i2}^2\right)\left(1 - r_{12}^2\right)}} \qquad (12)$$

For functional relationship in the form $\xi_i = K D_1^a Q_2^b$ coefficients of the best approximate plane concerning the least square method of the corresponding regressive plane, can be obtained by regression analysis using experimental data for ξ_i.

The algorithm based program has been designed to determine a valve resistance coefficient, numerical partial coefficient correlation and multiple coefficient correlation as well as the qualitative evaluation of the model $\xi_i = K D_1^a Q_2^b$ accordance with experimental results of the research.

Presentation plan of the experimental results

For experimental purposes and in order to define the model of the valves similar resistance coefficient ξ_i of the working and valve dimensional characteristics (Q, D), presentation plan of the experiment is defined.

Presentation plan of the experimental results i.e. functional relationship in the form $\xi_i = K D_1^a Q_2^b$, is given in Table 1.

Table 1. Plan for experimental investigation of the functional relationship $\xi_i = K D_1^a Q_2^b$

D [mm]	Q [m³/h]	Valve resistance coefficient ξ_i			$\bar{\xi}$
		Measuring			
		1	2	3	
D_1	Q_1	ξ_3	ξ_{12}	ξ_{15}	$(\xi_3 + \xi_{12} + \xi_{15})/3$
	Q_2	ξ_5	ξ_{10}	ξ_6	$(\xi_5 + \xi_{10} + \xi_6)/3$
	Q_3	ξ_{14}	ξ_{16}	ξ_9	$(\xi_{14} + \xi_{16} + \xi_9)/3$
D_2	Q_1	ξ_{24}	ξ_{13}	ξ_{17}	$(\xi_{24} + \xi_{13} + \xi_{17})/3$
	Q_2	ξ_{22}	ξ_{23}	ξ_4	$(\xi_{22} + \xi_{23} + \xi_4)/3$
	Q_3	ξ_8	ξ_{26}	ξ_{11}	$(\xi_8 + \xi_{26} + \xi_{11})/3$
D_3	Q_1	ξ_{19}	ξ_{20}	ξ_{21}	$(\xi_{19} + \xi_{20} + \xi_{21})/3$
	Q_2	ξ_7	ξ_{18}	ξ_{13}	$(\xi_7 + \xi_{18} + \xi_{13})/3$
	Q_3	ξ_{25}	ξ_1	ξ_{27}	$(\xi_{25} + \xi_1 + \xi_{27})/3$

The number of experimental units in this case is:

$$N = abn \qquad (13)$$

Where:

$a = 3$ - level of the factor Q,

$b = 3$ - level of the factor D,

$n = 3$ - number of repeated readings.

The number of experimental units is: $N = abn = 27$.

Description of the experiment

The goal of the research is to define the methods of modelling the valve resistance coefficient depending on nominal diameter, and air flow for similar valves as well as qualitative evaluation of the model $\xi_i = K D_1^a Q_2^b$ accordance with the experimental results.

In general, valve resistance coefficient is in function of the six parameters, which can be expressed as follows [2, 4-18]:

$$\xi = f(D, Q, \varphi, \rho, t_v, \gamma, \alpha) \qquad (14)$$

among which the greatest influence is that of the nominal diameter of the valve and air flow.

Parameters $(\varphi, \rho, t_v, \gamma, \alpha)$ are constant.

Pressure crash $\Delta H` = \Delta H - \Delta H_1$ is proportional to dynamic pressure, [2, 4-10, 13-18]:

$$\Delta H - \Delta H_1 = \xi \frac{\rho v^2}{2} \qquad (15)$$

If the air flow v behind the valve is expressed in terms of the air flow Q and solved by ξ from equation (15). It results in:

$$\xi = \frac{\pi^2 D^4 (\Delta H - \Delta H_1)}{8 \rho Q^2} \qquad (16)$$

Where:

$\Delta H_1 [Pa]$ - level of overpressure that includes the moment of opening of the valve,

$D[m]$ - nominal diameter of the valve,

$\Delta H` [Pa]$ - pressure crash in the valve,

$\rho [kg/m^3]$ - air density,

$Q[m^3/h]$ - air flow volume through the valve,

$\varphi [\%]$ - air moisture,

$t_v [^\circ C]$ - air temperature,

$\gamma [^\circ]$ - valve fin rotation angle at air flow Q through the valve, and

$\alpha [^\circ]$ - fin rotational axis inclination angle with respect to the vertical plane.

For three similar valves with nominal diameters D_1, D_2 and D_3 at fixed air flows Q_1, Q_2 and Q_3 it is necessary to measure the adequate pressure crash for the valves.

Based on equation (16) the adequate values of the valve resistance coefficients are calculated.

This experiment is two-factorized.

The experiment is carried out according to the plan of the experiment, Table 1.

Numerical data for the valve resistance coefficient are inserted into the plan of the experiment, Table 1.

The experiment provides a data base of the similar valves resistance coefficients that could also be used for the valves resistance coefficient modelling and the model adequacy estimation, in accordance with the algorithms presented above.

Estimation of agreement between the model of valve resistance coefficient and experimental results

Estimation of agreement between the model of valve resistance coefficient of similar valves and experimental data for ξ_i is made on the bases of the numerical values of the multiple correlation coefficients $R_{i\cdot 12}$.

Estimation of agreement between the models in the plains $D\xi_i$ and $Q\xi_i$, respectively, and experimental data for ξ_i is made on the bases of the numerical values of the partial correlation characteristic coefficients $r_{i1\cdot 2}$ and $r_{i2\cdot 1}$.

Valve resistance models

In general, the form of the valve resistance model is:

$$\Delta H = \frac{8\rho}{\pi^2 D^4}\frac{Q^2}{3600^2}\xi + \Delta H_i \tag{17}$$

The value of the valve resistance ΔH_i that includes the moment of opening of the valve is defined experimentally.

At nominal air flow through the valve the resistance coefficient is optimum, ($\xi = \xi_{opt}$ for $Q = Q_{nom}$):

$$\xi_{opt} = KD^a Q_{nom}^b \tag{18}$$

Analytical expression of optimum resistance ΔH_{opt_i} to the air flow through the valves (models of optimum resistance of the valves) are derived by introducing optimum values of the resistance coefficients of the valves, $\xi = \xi_{opt_i}$, into equation (17):

$$\Delta H_{opt_i} = \frac{8\rho}{\pi^2 D^4}\frac{Q^2}{3600^2}\xi_{opt_i} + \Delta H_i \tag{19}$$

Where:

$\Delta H_{opt_i}[Pa]$ - optimum resistance to the air flow through the valves,

$D[mm]$ - nominal diameter of the valve,

$\rho[kg/m^3]$ - air density,

$Q[m^3/h]$ - air flow volume through the valve,

$\Delta H_i[Pa]$ - valve resistance at which the air flow through the valve is equal to zero i.e. valve resistance when the valve flops opening moment occurs,

ξ - value of resistance coefficient at nominal air flow through the valve, [28-30].

The problem of regulating the air flows through the similar valves has been defined by expressions (18) and (19).

Nominal air flows through the valves, according to [28-30], amounts to:

$Q_{nom} = 188[m^3/h]$ - for nominal diameter of the valve 100[mm],

$Q_{nom} = 375[m^3/h]$ - for nominal diameter of the valve 150[mm],

$Q_{nom} = 750[m^3/h]$ - for nominal diameter of the valve 200[mm].

Conclusion

Papers [2, 4-10, 15], have implemented the methods of mathematical statistics on defining the methods of similar valves aerodynamic characteristics modelling evaluation of the adequacy levels of the obtained models and experimental results.

In evaluating the obtained models, papers [2, 4-10, 15], were derived based on the Fisher's criterion, (comparison of dispersion relation coefficient with Fisher's criterion)

If the dispersion coefficient is less than Fisher's criterion, it can be concluded that the obtained models are adequate with the probability of 95[%] or 99[%].

If however the evaluation of the obtained models' adequacy, shows the dispersion coefficient exceeds the Fisher's criterion, this will be followed by the conclusion that the obtained models are in adequate with 95[%] or 99[%] probability.

When the evaluation of the model adequacy, based on the Fisher's criterion shows that the model is inadequate, in classical method theory of mathematical statistics it is concluded that such models are to be rejected.

Discarding the inadequate models without knowing the numerical compatibility of the obtained models with the data base of the experimental results is acceptable.

This paper has the objective to give the correct answer to this dilemma. In cases where the methods or mathematical statistics do not give a complete answer concerning model evaluation, the idea proposed in this study is that it is necessary to define methods of the analytical-qualitative assessment of the obtained model's level of agreement with the test results.

On the example of modelling the similar valves aerodynamic characteristics in the function of working and dimensional characteristics of the similar valves, the modelling methods of the valves' characteristics as well as hyper plane problems, qualitative evaluation of the level of accordance of the model $\xi_i = KD_1^a Q_2^b$ with the experimental results for ξ_i are defined.

The methods of the similar valves aerodynamic characteristics, as functions of working and geometry characteristics of similar valves have been defined along with the qualitative evaluation of the level of agreement of the model with the experimental results.

Analytical expressions of characteristic partial correlation coefficients and multiple correlation coefficients have been defined for the qualitative model evaluation.

Based on the algorithms, a program for obtaining the model of aerodynamic characteristics of similar valves, (valve resistance coefficient and valve resistance) and the qualitative evaluation of the obtained models accordance with the experimental results for ξ_i was realized.

The original contribution of this paper is in defining:

1. Method for modelling the resistance coefficient ξ_i of similar valves.
2. Method for model adequacy estimation.
3. Experimental results presentation plain and experiment description of the resistance coefficient of the similar valves.
4. Method of qualitative estimation of harmonization between the obtained model and experimental results.
5. Method of qualitative estimation of the agreement level of the models in the plains with the experimental results for T_{z_i}.

Using partial correlation characteristic coefficients $r_{i1\cdot 2}$ and $r_{i2\cdot 1}$, the probability of influence of the system $\xi_i = KD_1^a Q_2^b$ characteristic values (D,Q) on similar valves resistance coefficient ξ_i, when the other characteristic values of the system Q and D are presumed to be constant has been defined.

In other words, the probabilities of transmitting-reduction of models $\xi_i = KD_1^a Q_2^b$ into plain models are defined.

A singular contribution of this paper is in an original definition of the probability of three-dimensional model $\xi_i = KD_1^a Q_2^b$ transmitting-reduction into plain models and methods of qualitative estimation of the models.

In other words, these original contributions amount to:

1. Method of qualitative estimation of harmonization between the model and experimental results.
2. Method of qualitative estimation of the agreement level of the models in the plains with the experimental results for T_{z_i}.

The presentation plan of experimental results and description of the experiment have been given.

Analytical expressions of the valves resistance optimum ΔH_{opt_i} were obtained by introducing the optimal values of valves resistance coefficient for nominal air flow through the valves into general analytical expression of valve resistance.

The described modelling methods and model evaluation can be applied in other fields (hydraulics, pneumatics, automatic control, etc.), for the problems that can not be solved by direct implementation of the laws of physics, (see [31-32]), which, among other things, adds to the scientific dimension of the research.

The problem presented in this paper has been treated as a hyper plane problem.

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Prilog modeliranju karakteristika sličnih ventila i oceni modela

Definisane su metode modeliranja aerodinamičkih karakteristika ventila, kvalitativne ocene nivoa saglasnosti dobijenih modela i rezultata eksperimentalnih istraživanja.U slučaju da se pri oceni adekvatnosti modela na osnovu Fisherovog kriterijuma dođe do zaključka da model nije adekvatan verovatnoćom od 99%, (odnosno 95%) klasična teorija metoda matematičke statistike nalaže: da se modeli odbacuju. Postavlja se pitanje šta činiti, odbaciti model ili definisati metod kvalitativne ocene modela. Motiv za izradu ovoga rada je davanje pravog odgovora na postavljenu dilemu.Za slučajeve gde metode matematičke statistike ne daju potpun odgovor po pitanju ocene adekvatnosti modela autor ovoga rada došao na ideju da je potrebno definisati metode analitičke-kvalitativne ocene nivoa saglasnosti dobijenih modela i rezultata eksperimenta. Odgovor na postavljenu dilemu sadržan je u ovome radu.

Ključne reči: **objekti specijalne namene, ventilacija, ventil, aerodinamika, koeficijent otpora ventila, otpor ventila, metod modeliranja, eksperiment, plan eksperimenta, koeficijent korelacije, ocena modela.**

Приложение моделированию характеристик подобных клапанов и оценке моделей

Здесь определены методы моделирования аэродинамических характеристик клапанов, качественные оценки уровня соотносительности полученных моделей и результатов экспериментальных исследований. В случае, если при оценке адекватности модели на основе критерия Фишера сделаем вывод, что модель неадекватна вероятностью 95% (то есть 99%), классическая теория метода математической статистики приказывает: отбросить модели. Возникает вопрос - что делать? - отбросить модель или определить метод качественной оценки модели? Мотивировка для выработки этой темы - дать настоящий и полный ответ на поставленную дилемму. Для случаев, в которых методы математической статистики не дают полного ответа в связи с оценкой соответственности модели, автор этой работы придумал идею, что нужно (необходимо) определить методы аналитически-качественных оценок уровня соотносительности полученных моделей и результатов экспериментов. Ответ на поставленную дилемму находится в этой работе.

Ключевые слова: вентиляция, клапан, дроссельный клапан, аэродинамика, коэффициент сопротивления, метод моделирования, защита объекта.

Contribution à la modélisation des caractéristiques des soupapes similaires et à l'évaluation du modèle

Ce papier définit les méthodes de modélisation des caractéristiques aérodynamiques des soupapes, l'évaluation qualitative du niveau d'accord des modèles obtenus et les résultats des recherches expérimentales. Dans le cas où l' évaluation de l'adéquation du modèle, selon le critère de Fisher, démontre que le modèle n'est pas adéquat avec la probabilité de 95% (voire 99%), la théorie classique des méthodes de statistique mathématique ordonne de rejeter les modèles. On se pose la question que faire : rejeter le modèle ou définir la méthode de l'évaluation qualitative du modèle? C'est la résolution du dilemme posé qui a motivé l'élaboration de ce travail. Pour le cas où les méthodes de statistique mathématique ne donnent pas la réponse complète quant à l'évaluation de l'adéquation du modèle, l'auteur de ce travail a eu l'idée qu'il faut définir les méthodes de l'évaluation analytique qualitative du niveau d'accord des modèles obtenus et les résultats des recherches. La réponse au dilemme posé est contenue dans ce travail.

Mots clés: **ventilation, soupape, soupape antichoc, aérodynamique, coefficient de résistence, méthode de modélisation, protection**